

Assessment of the Yellowfin Sole Stock in the Bering Sea and Aleutian Islands

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Executive summary

Summary of changes in assessment inputs

Relative to last year's Bering Sea and Aleutian Islands (BSAI) SAFE report, the following substantive changes have been made to the BSAI Yellowfin Sole assessment. Several models are presented in this document that incorporate new data since the last full assessment in 2020.

Changes in the data

1. The 2020 fishery age composition was added.
2. The estimate of the total catch made through the end of 2020 was updated as reported by the NMFS Alaska Regional office. The catch through the end of 2021 was estimated based on available data to be 108,086 t. Catch for the 2022 and 2023 projections were assumed to be the mean of the past 5 years, 2017 - 2021, 126,929 t.
3. The 2021 NMFS survey biomass estimate and standard error was included. A VAST estimate of the EBS biomass estimate and standard error were used in Model 18.2a. The 2021 Northern Bering Sea biomass estimate and standard error were combined with the 2021 EBS survey VAST estimate in Model 18.2b.

Changes in the assessment methods

Three models are presented in this assessment. Model 18.2 is presented in full, and is the preferred model. Models 18.2a and 18.2b are presented to promote discussion on the use of VAST biomass estimates and incorporation of the Northern Bering Sea (NBS) survey.

1. Model 18.2 uses a fixed value for female natural mortality ($M=0.12$) and allows male natural mortality to be estimated within the model. This model was accepted by the BSAI Plan Team and the SSC in 2021. Model 18.2 is the authors' preferred model.
2. Model 18.2a is the same as Model 18.2 except it incorporates VAST biomass estimates and standard error for the Eastern Bering Sea survey region, 1982-2021.
3. Model 18.2c is the same as Model 18.2 except it incorporates VAST biomass estimates and standard error for the EBS and NBS, combined, 1982-2021. These estimates used all valid NBS survey data (1985, 1988, 1991, 2010, 2017, 2018, 2019, and 2021) and all valid EBS survey data estimates (1982-2021, except 2020).

Summary of Results

The accepted 2021 Model 18.2 includes survey mean bottom temperature across stations $< 100\text{m}$ as a covariate on survey catchability, as well as National Marine Fisheries Service Eastern Bering Sea survey start

date as an additional covariate within the model, based correlations documented in Nichol et al. (2019). Model 18.2 specifies female natural mortality to be fixed at 0.12 while allowing the model to estimate male natural mortality. This model is presented in this year's assessment and is the preferred model.

In the Eastern Bering Sea (EBS) bottom trawl survey performed in 2021, the EBS Yellowfin Sole biomass was estimated to be 19% lower than estimated by the 2019 EBS bottom trawl survey, at 1,622,910 t. Spawning biomass estimated by Model 18.2 was $1.73 * B_{MSY}$. Therefore, Yellowfin Sole continues to qualify for management under Tier 1a. The 1978-2015 age-1 recruitments and the corresponding spawning biomass estimates were used to fit the stock recruitment curve and determine the Tier 1 harvest recommendations. Tier 3 estimates were also conducted, which is typical for this assessment.

This assessment updates last year's assessment with total and spawning biomass estimates that are lower than the 2020 assessment. This is due to a long-term decline in the stock. However this year's ABC and OFL are higher than the 2020 assessment, due to revisiting calculations and assumptions for annual weight at age. Increased management quantities are the result of increased growth rate, which translates into a stock that is more resilient to harvest. More discussion on this topic can be found under "Parameters Estimated Outside the Assessment Model".

Catch of Yellowfin Sole as of October 1, 2021 in the Bering Sea and Aleutian Islands was 88,895 t. Over the past 5 years (2016 - 2020), 82.2% of the catch has taken place by this date. Therefore, the full year's estimate of catch in 2021 was extrapolated to be 108,157 t. This is lower than the average catch over the past ten years 140,888 t. Future catch for the next 10 years, 2022 - 2031 was estimated to be the mean of the catch from 2017-2020 and the extrapolated full year's catch for 2021, which resulted in an estimate of 126,929 t. Catches in 2021 were likely impacted by a 25% tariff on exports to China; therefore, the estimate for future catches is somewhat precautionary.

Yellowfin Sole female spawning biomass continues to be above B_{MSY} and the annual harvest remains below the ABC level. Management quantities are given in the following table for the 2020 accepted model (Model 18.2 - 2020) and the 2021 preferred model (Model 18.2 - 2021). The projected estimate of total biomass for 2022 was lower by 18% from the 2020 assessment of 3,025,430 t, to 2,479,370 t. The model projection of spawning biomass for 2022, assuming catch for 2021 as described above, was 857,101 t, 14% lower than the projected 2021 spawning biomass from the 2020 assessment of 996,044 t. The 2022 and 2023 ABCs using F_{ABC} from this assessment model were higher than last year's 2022 ABC of 344,140 t; 354,014 t and 326,235 t. The 2022 and 2023 OFLs estimated by model 18.2 were 377,071 t and 347,483 t.

The Risk Table indicates some uncertainty in the status of Yellowfin Sole in 2021 and an ecosystem risk level 2. Together, the most recent data available suggest concerns of model uncertainty, continuing high temperatures, and fish condition in the NBS. Therefore we recommend 2021 and 2022 ABCs that average the Tier 3 and Tier 1 ABCs, which results in 269,649 t for 2022 and 258,567 t for 2023. The Tier 3 reference points are more precautionary than Tier 1 because Tier 3 methodology does not assume a known spawning-recruitment relationship (Table 4.1).

| Quantity | As estimated or <i>specified</i> <i>last year for:</i> | | As estimated or <i>recommended</i> <i>this year for:</i> | |
|---------------------------------------|---|-------------|---|-------------|
| | 2021 | 2022 | 2022 | 2023 |
| M (natural mortality rate) | 0.12, 0.135 | 0.12, 0.135 | 0.12, 0.135 | 0.12, 0.135 |
| Tier | 1a | 1a | 1a | 1a |
| Projected total (age 6+) biomass (t) | 2,755,870 t | 3,025,430 t | 2,479,370 t | 2,284,820 t |
| Projected female spawning biomass (t) | 1,040,900 t | 996,044 t | 857,101 t | 727,101 t |
| B_0 | 1,528,700 t | 1,528,700 t | 1,489,190 t | 1,489,190 t |
| B_{MSY} | 559,704 t | 559,704 t | 495,904 t | 495,904 t |
| F_{OFL} | 0.124 | 0.124 | 0.152 | 0.152 |
| $maxF_{ABC}$ | 0.114 | 0.114 | 0.143 | 0.143 |
| F_{ABC} | 0.114 | 0.114 | 0.109 | 0.110 |
| OFL (t) | 341,571 t | 374,982 t | 377,071 t | 347,483 t |
| $maxABC$ | 313,477 t | 344,140 t | 354,014 t | 326,235 t |
| ABC (t) | 313,477 t | 344,140 t | 269,649 t | 258,567 t |
| Status | 2019 | 2020 | 2020 | 2021 |
| Overfishing | No | n/a | No | n/a |
| Overfished | n/a | No | n/a | No |
| Approaching overfished | n/a | No | n/a | No |

Projections were based on estimated catches of 126,929 t in 2021 and 126,929 t used in place of maximum ABC for 2022. This estimate was based on the mean of the past 5 years, 2017-2021, which includes an extrapolated catch of 108,157 t for 2021.

Responses to SSC and Plan Team Comments on Assessments in General

SSC November 2020

The SSC cautions against standardized model fitting (e.g., a single error distribution, set of covariates, number of knots), other than as a starting point. The species-specific biological distribution, and interaction of this distribution with covariates, may require differing error distributions to fit the data adequately. It is more important for each species to have a statistically rigorous model selection process resulting in good model fit and diagnostics than the simplicity of fitting the same approach to all species: unlike design-based estimators, the SSC suggests that one size does not fit all for VAST models. For each species, assessment documents should describe why the particular error distributions, covariates, and number of knots were chosen for that individual species.

Authors' response: Noted.

SSC November 2020

In general, ...the SSC recommends the continued inclusion of community engagement and dependency indices at varying scales in ESPs, ESRs, and SAFEs. For ESPs specifically, changes in patterns of community engagement and dependency at the stock level have the potential to inform not only stock assessments and analyses that support fishery management, but they may also function as early indicators of larger ecosystem changes.

Authors' response: Noted.

September/October 2021 SSC meeting

Please incorporate the 14-point list about risk tables.

Responses to SSC and Plan Team Comments Specific to this Assessment

SSC November 2020

We also agree that no adjustment to the maximum ABC is necessary at this time, based on the risk table. However, the SSC suggests that the authors and BSAI GPT consider a level 2 designation for the assessment

category in the risk table, given the strong retrospective bias in the model.

Authors' response

Retrospective bias, measured by Mohn's Rho for Model 18.2 (2020) was -0.185 and Rho for Model 18.1 (2020) was -0.184. In the current assessment, the mean weight at age based on survey data was revisited, which improved retrospective bias. Legacy weight at age was based on standards that did not match survey weight at age that had shifted (heavier) in recent years. Recalibration of survey weight at age is described in the section Parameters Estimated Outside the Assessment Model. The Mohn's Rho for Model 18.2 (2021) was closer to zero than past assessments. Therefore, we propose a level 1 designation for the assessment category in the risk table.

SSC November 2020

The SSC remains concerned about the large retrospective pattern and supports the PT recommendation to investigate decreased female natural mortality and weight at age.

Authors' response:

In the current assessment, Mohn's rho shifted closer to zero. Further investigation into decreased female natural mortality should be a point of future study.

SSC November 2020

The SSC commends the authors for including temperature-dependent growth, validated by otolith chronologies, into the model as noted on p. 8 of the assessment. However, details of the implementation are not documented and the list of parameters does not show any parameters related to temperature-dependent growth. The SSC requests a clarification and, as appropriate, additional documentation of how temperature-dependent growth is implemented in the model.

Authors' response:

There is some evidence of temperature-dependent growth by Yellowfin sole (YFS) (Yeung et al. 2021). It appears that YFS remain in the shallow nearshore nursery areas through at least their first 2 years post-settlement. They begin to disperse offshore age 3-5 and by 5-8 years they follow adult migratory patterns. The trend in growth related to temperature is observed at approximately the time the juveniles move offshore, based on model estimates. There is also evidence that Yellowfin Sole have been growing larger in part of a trend over the past 5 decades (Figure 4.1, Figure 4.2). However, there is no strong evidence thus far that Yellowfin sole have shifted distribution in response to climate changes, although research is ongoing. Research on this topic includes beam trawl studies to better sample YFS throughout their distribution. Some tolerance to temperatures may be explained by observations that Yellowfin sole settle later in summer, when the influence of the cold pool is weaker and nearshore bottom temperature is relatively stable and high (Yeung and Cooper 2019). Therefore, an investigation of temperature-mediated growth is warranted as a covariate in the model. Currently, weight at age is incorporated in the model based on survey weight at age data. It should also be noted that the trend in increasing length at age (and weight at age) may not continue if metabolic needs exceed prey availability as ocean temperatures continue to increase (e.g. Yeung et al 2021), as climate models predict.

SSC November 2020

The SSC appreciates the discussion of YFS biomass trends in the NBS, including trends in the ADF&G survey in Norton Sound, as well as the inclusion of a model that uses VAST estimates of the combined EBS + NBS survey biomass time series (Model 18.4). Both models 18.3 and 18.4 provided good fits to the survey biomass estimates and reasonable estimates of total and spawning biomass. We note that the biomass in the NBS increased from 311,000 t in 2010 to 520,000 t in 2019 based on the NBS bottom trawl survey. Similarly, YFS catch per unit effort in the ADF&G trawl survey in Norton Sound has shown an increasing trend over time since the late 1970s with peak catches in 2019. The design-based estimates of survey biomass for the EBS and NBS suggest that just over 20% of the portion of the stock that is sampled by the survey occurred in the NBS during the summer of 2019. Therefore, and in anticipation of annual surveys in the NBS and

potential further increases in YFS biomass in the NBS, the SSC encourages the authors to bring forward a model in the next assessment cycle, such as Model 18.4, that includes the NBS survey biomass estimates.

Authors' response:

In the current assessment, Model 18.2b uses a VAST biomass estimate of Yellowfin Sole biomass in the Eastern Bering Sea and Northern Bering Sea.

SSC November 2020

The SSC was concerned about some of the posterior distributions from the MCMC analysis, specifically the bimodality in log(Recruitment) for Model 18.2. The SSC requests that the authors provide standard diagnostics for assessing MCMC convergence and parameter correlations. If the bimodality in log(Recruitment) is a feature of Model 18.2, the SSC recommends that the authors examine if the issue is related to the separation of sexes in the model.

Authors' response:

With the reanalysis of survey weight at age, MCMC distributions no longer appear bimodal, and have improved over MCMC posteriors from the 2020 assessment.

SSC November 2020

The SSC recommends further investigation of previously noted issues as time allows, including possible further adjustments to estimating separate natural mortality for males and females, explorations of the sex ratio relative to the timing of annual spawning migrations as an alternative explanation for a high proportion of females, a potential link between wave height and catchability, and a single selectivity curve for both sexes. We note that the latter is supported by survey selectivity estimates that are virtually indistinguishable in Model 18.2 (Fig. 4.17) and by time-varying fishery selectivities that are very similar between males and females since the early 1980s, but diverge widely and inconsistently in some earlier years (Fig. 4.18).

Author's response:

Noted. These suggestions were not possible to complete in the current assessment due to time constraints but are on the list for future assessments.

SSC November 2020

With regards to estimating natural mortality, we note that the author suggested that the data provide more information on female than male M, hence we support the PT suggestion to fix male M at the estimated value from Model 18.2 and to estimate female M in the model as one possible approach to modeling sex-specific values. However, other options could be explored and the SSC does not intend to be prescriptive but encourages further examinations of sex-specific mortality and how to implement it.

Author's response:

Noted. These were not possible in the current assessment but are on the list for future assessments.

Introduction

Yellowfin Sole (*Limanda aspera*) are one of the most abundant flatfish species in the eastern Bering Sea (EBS) and currently is the target of the largest flatfish fishery in the world. Yellowfin Sole are distributed in North American waters from off British Columbia, Canada, (approx. lat. 49°N) to the Chukchi Sea (approx. lat. 70°N) and south along the Asian coast off the South Korean coast in the Sea of Japan (approximately lat. 35°N). Their abundance in the Aleutian Islands region is considered low to negligible.

Adults exhibit a benthic lifestyle and occupy separate spawning areas in winter and feeding distributions in summer on the eastern Bering Sea shelf (Figure 4.3). Adults begin a migration from over-wintering grounds near the shelf margins (>100m) onto the inner shelf (15-75m) in April or early May each year for spawning and feeding. Adults migrate back offshore in fall and winter as a response to ice cover/cold water of the inner and central shelf water in winter (Bakkala 1979). Young Yellowfin Sole remain in the shallow nearshore

nursery areas throughout their first few years of life. They begin to disperse offshore age 3-5, and by 5-8 years they follow adult migratory patterns (Bakkala 1979).

Year-class strength of flatfishes is thought to be determined during the first few years of life between the pelagic egg and benthic settlement (van der Veer et al., 2015). Temperature in the early life stages can affect egg size, larval duration, size at settlement, as well as the size of suitable nursery habitat (Yeung and Cooper 2019). It has been hypothesized that colder bottom temperatures delay migration and spawning in Yellowfin Sole. As a result, mature individuals may reside in nearshore nursery grounds during months in which the NMFS survey occurs, which likely decreases survey biomass estimates during cold years (Nichol et al., 2019; Yeung and Cooper 2019).

YFS may be less sensitive to temperature due to their settlement timing, relative to Northern Rock Sole, which seems to be sensitive to temperature. YFS settle later in summer, when the influence of the cold pool is weaker and nearshore bottom temperature is relatively stable and high (Yeung and Yang, 2018). In contrast, YFS migrate across the shelf to spawn near their nursery habitat, rather than relying on currents for larval transport to nursery habitat (Nichol and Acuna, 2001); therefore, their larvae may be less susceptible to variable currents (Yeung and Cooper 2019).

There appear to be several distinct stocks, although the genetic basis remains to be determined. The stocks are referred to as the Unimak group, the Pribilof-west group, and the Pribilof-east group (Figure 4.3). Yellowfin Sole are managed as a single stock in the BSAI management area as there is presently no direct evidence of stock structure.

Fishery

Yellowfin Sole has been targeted with bottom trawls on the Bering Sea shelf since the fishery began in 1954. It was overexploited by foreign fisheries in 1959-62 when catches averaged 404,000 t annually (Figure 4.4, top panel). Catches declined to an annual average of 117,800 t from 1963-1971 and further declined to an annual average of 50,700 t from 1972-1977. The lower yield in this latter period was partially due to the discontinuation of the Union of Soviet Socialist Republics (U.S.S.R.) fishery. In the early 1980s, after the stock condition had improved, catches again increased reaching a peak of over 227,000 t in 1985. Catch of Yellowfin Sole takes place primarily in the eastern Bering Sea, with low to negligible levels in the eastern Aleutian Islands.

During the 1980s, there was also a major transition in the characteristics of the fishery. Yellowfin Sole were traditionally taken exclusively by foreign fisheries and these fisheries continued to dominate through 1984. However, U.S. fisheries developed rapidly during the 1980s in the form of joint ventures, and during the last half of the decade began to dominate and then take all of the catch as the foreign fisheries were phased out of the Eastern Bering Sea. Since 1990, only domestic harvesting and processing has occurred.

The management of the Yellowfin Sole fishery changed significantly in 2008 with the implementation of Amendment 80 to the BSAI Fisheries Management Plan. The Amendment directly allocated fishery resources among BSAI trawl harvesters in consideration of their historic harvest patterns and future harvest needs to improve retention and utilization of fishery resources by the non-AFA (American Fisheries Act) trawl catcher/processor fleet. This was accomplished by extending the groundfish retention standards to all H&G (headed and gutted, fish are processed with heads and viscera removed) vessels and also by providing the ability to form cooperatives within the newly formed Amendment 80 sector. In addition, Amendment 80 also mandated additional monitoring requirements which included observer coverage on all hauls, motion-compensating scales for weighing samples, flow scales to obtain accurate catch weight estimates for the entire catch, no mixing of hauls and no on-deck sorting. The partitioning of TAC (total allowable catch) and PSC (prohibited species catch) among cooperatives has significantly changed the way the annual catch has accumulated (Figure 4.4, lower panel) and the rate of target catch per bycatch ton. There is now a more even and slow attainment of the annual catch relative to the pre-Amendment 80 fishing behavior.

In 2010, following a comprehensive assessment process, the Yellowfin Sole fishery was certified under the Marine Stewardship Council environmental standard for sustainable and well-managed fisheries. The certification also applies to all the major flatfish fisheries in the BSAI and GOA.

In 2011, federally permitted vessels using non-pelagic trawl gear whose harvest resulted in flatfish retained catch that was greater than any other retained fishery category were required to use modified trawl gear. The modifications required the use of elevating devices to raise the section of the trawl warps between the doors and the trawl wing tips by 2.5 inches off the seafloor. The purpose of the management action was to reduce damage of non-target animals, particularly those that form habitat structure or support other fisheries while not substantially reducing flatfish catch rates or causing gear handling problems (Rose et al. 2010).

Yellowfin Sole are typically headed and gutted, frozen at sea, and then shipped primarily to China and South Korea. Reprocessed Yellowfin Sole from China may also be sold to Japan, US, and Europe as fillets, among other countries (AFSC 2016). The 1997 catch of 181,389 t (retained and discarded) was the largest since the fishery became completely domestic, but decreased from 1998–2010, averaging 94,004 t (Table 4.2, Table 4.3). From 2011–2014 the catch increased, averaging 155,000 t. The 2013 catch totaled approximately 165,000 t (73% of the ABC), and was the highest annual catch since prior to 1990. Catches have declined since 2013 and the average catch over the past ten years was 140,888 t. The full year's estimate of catch in 2021 was 108,157 t.

Yellowfin sole accounted for 65% of the retained flatfish catch in 2020 caught in the Eastern Bering Sea by catcher/processors in the Amendment 80 Fleet. The first-wholesale value of Yellowfin Sole showed a 23% decrease to \$0.60/pound between 2019 and 2020. Export quantities of Yellowfin Sole increased in 2020 from 2019 (Appendix B, Fissel 2020). In 2021 25% tariffs were imposed on Yellowfin Sole exports to China, which may have played a role in the decreased catch in 2021.

As of late October 2021, the fishing season is ongoing. To estimate the total 2021 catch for the stock assessment model, the average proportion of the 2016–2020 cumulative catch attained by the end of October was applied to the 2021 catch amount at the same time period and resulted in a 2021 catch estimate of 108,157 t, 31.43% of the ABC.

Length distributions of Yellowfin Sole throughout NMFS areas 509, 513, 514, 516, 521, and 524 ranged from 20–50 cm, with a higher proportion of large fish in areas 513 and 514 in the eastern and southeastern and Bering Sea and 521 further offshore (Figure 4.5). Catch proportions of Yellowfin Sole by month and area are shown in Figure 4.6, and were highest in areas 509, 513, and 514 in 2021. The highest proportion of the catch was taken in February through May. Although catches in July are typically low relative to other months, the catch in July 2021 was almost negligible. Maps of the locations where Yellowfin Sole were caught in 2021, by month (through October 1), are shown in Figure 4.7. The average age of Yellowfin Sole in the 2019 catch was estimated at 13.16 and 12.8 years for females and males, respectively. Age data for the current year is not yet available, and no survey was conducted in 2020.

The time-series of catch in Table 4.2 also includes Yellowfin Sole that were discarded in domestic fisheries from 1987 to the present. Annual discard estimates were calculated from at-sea sampling (Table 4.3). The rate of discard has ranged from a low of 2% of the total catch in 2019 through 2021 to a high of 29% in 1992. The trend has been toward fuller retention of the catch in recent years, and with the advent of the Amendment 80 harvest practices, discarding is at its lowest level since these estimates have become available. Historically, discarding primarily occurred in the Yellowfin Sole directed fishery, with lesser amounts in the Pacific cod, Pollock, rock sole, flathead sole, and “other flatfish” fisheries (Table 4.4).

Data

The data used in this assessment include estimates of total catch, bottom trawl survey biomass estimates and their attendant 95% confidence intervals, catch-at-age from the fishery, and population age composition estimates from the bottom trawl survey. Weight-at-age and proportion mature-at-age are also available from studies conducted during the bottom trawl surveys. Estimates of fishery weight-at-age was based on catch-at-age methodology used in the Walleye Pollock assessment (Ianelli et al. 2019), following Kimura (1989) and modified by Dorn (1992).

| Data source | Year |
|---------------|-------------|
| Fishery catch | 1954 - 2021 |

| Data source | Year |
|---|--------------------------------|
| Fishery age composition | 1964 - 2020 |
| Fishery weight-at-age | Catch-at-age methodology |
| Survey biomass and standard error | 1982 - 2021 (not 2020) |
| Bottom temperature | 1982 - 2021 |
| Survey age composition | 1979 - 2019 |
| Annual length-at-age and weight-at-age from surveys | 1979 - 2019 |
| Age at maturity | Combined 1992 and 2012 samples |

Fishery

Age Determination

Yellowfin Sole ages have been determined at the AFSC by using the break and burn method on otoliths collected in surveys and from fisheries since 1979. In 2016 the age determination methods for Yellowfin Sole were validated using the bomb-produced uptake measurement of ^{14}C method (Kastelle et al. 2016). The number of otoliths read from the fishery has averaged 740 per year (Table 4.5). Trends for males and female ages from the fishery indicate that 2010 year class is the dominant cohort (Figure 4.8).

Catch

This assessment uses fishery catch data from 1954-2021 (Table 4.2), and fishery catch-at-age (proportions) from 1964-2020 (Table 4.6, 1975-2020). Removals from sources other than those that are included in the Alaska Region's official estimate of catch (e.g., removals due to scientific surveys, subsistence fishing, recreational fishing, fisheries managed under other FMPs) are presented in Appendix A, Table A1. Catch per unit effort calculated from fishery trawl data, based on the catch in kg and duration of the tow does not indicate a strong upward or downward trend through the time series, 1996-2021 for vessels >125 feet (Figure 4.9). Vessels <125 feet appear to have increased CPUE through time.

Numbers at age

The proportion of length at age from the fishery was applied to the length frequencies from the aged sample from the fishery, providing proportions at age from the fishery. The fishery age composition has always been primarily composed of fish older than 9 years with a large amount of 20+ fish, although the proportion has declined from 90% over age 7 to 70% over age 7 since the 1970's (Table 4.6).

Weight-at-age

The fishery weight-at-age composition was based on the catch-at-age methodology of Kimura (1989) and modified by Dorn (1992), as implemented in the 2019 Walleye Pollock stock assessment (Ianelli et al. 2019). Length-stratified age data were used to construct age-length keys for each stratum and sex. These keys are then applied to randomly sampled catch length frequency data. The stratum-specific age composition estimates were then weighted by the catch within each stratum to arrive at an overall age composition for each year. The three strata were the EBS trimesters of the year (January-April, May-August, and September-December). This method was used to derive the age compositions from 1991–2019 (the period for which all the necessary information was readily available). The catch-at-age estimation method uses a two-stage bootstrap resampling of the data. Observed tows were first selected with replacement, followed by resampling actual lengths and age specimens given that set of tows. This method allows an objective way to specify the effective sample size for fitting fishery age composition data within the assessment model. Estimates of stratum-specific fishery mean weights-at-age are a product of this analysis and these were used as input data to the model (Figure 4.10).

Maturity-at-age

Maturity information collected from Yellowfin Sole females during the 1992 and 1993 eastern Bering Sea trawl surveys have been used in this assessment for the past 20 years (Table 4.7). Nichol (1995) estimated the age of 50% maturity at 10.5 years based on the histological examination of 639 ovaries. Maturity has

recently been re-evaluated from a histological analysis of ovaries collected in 2012 (Table 4.7). Results were very similar to the earlier study with only a 2% difference in estimates of Yellowfin Sole female spawning biomass (TenBrink and Wilderbuer 2015). In addition, the SSC requested that the assessment use a maturity schedule that uses estimates derived from both the 1992 and the 2012 collections (Table 4.7). For Yellowfin Sole sexual maturity occurs well after the age of entry into the fishery. Yellowfin Sole females are 82% selected to the fishery by age 10 whereas they have been found to be only 40% mature at this age.

Survey

Length and Weight-at-Age

Sex-specific size at age used in the model is based on the average length-at-age and weight-at-length relationships from the time-series of survey observations over all years since 1971. The survey age data indicates that the dominant age class in 2021 are 11 year olds, spawned in 2010 (Figure 4.11).

Applications of dendrochronology (tree-ring techniques) have been used to develop biochronologies from the otolith growth increments of northern rock sole (*Lepidopsetta polyxystra*), Yellowfin Sole and Alaska plaice (*Pleuronectes quadrituberculatus*) in the eastern Bering Sea. These techniques ensure that all growth increments are assigned the correct calendar year, allowing for estimation of somatic growth by age and year for chronologies that span approximately 25 years (Matta et al. 2010). The analysis indicated that age 5 Yellowfin Sole somatic growth exhibits annual variability and has a strong positive correlation with May bottom water temperature in the Bering Sea (Figure 4.12).

The relationship between temperature and growth was further explored by reanalyzing Yellowfin Sole growth by age and year. Length-weight data collected when obtaining otolith (age) samples in RACE surveys (n=7,000 from 1987, 1994 and 1999-2009) also indicate that weight-at-age exhibits annual variability and is highly correlated with summer bottom water temperature observations with a lag of 2-3 years for the temperature effect to be seen (shown for age 5 fish in Figure 4.13). These empirical data indicate good somatic growth correspondence with annual bottom temperature anomalies. These observations were then extended back to 1979 using survey population length-at-age estimates (since weight-at-age is a power function of the length-at-age, Clark et al. 1999, Walters and Wilderbuer 2000).

The use of annual observed population mean weight-at-age (time-varying) from the trawl survey allows for time-varying (year effect on growth) in the age-structured stock assessment model.

Survey Biomass Estimates and Population Age Composition Estimates

Indices of relative abundance available from AFSC surveys showed high NMFS surveys biomass estimates in the 1980s (Table 4.8. High levels of biomass in the late 1970s have been documented through Japanese commercial pair trawl data and catch-at-age modeling in past assessments (Bakkala and Wilderbuer 1990).

Average survey CPUE for Yellowfin Sole has fluctuated from approximately 30-60 kg/hectare over the eastern Bering Sea time survey from 1982-2021 (Figure 4.14). In 2021, survey CPUE was the third lowest in the time series, since the year 2000, at 32.93 kg/hectare. Catch is typically taken throughout the Bering Sea shelf, as far north as 65°N and small amounts are taken in the Aleutian Islands (Figure 4.15). Biomass estimates for Yellowfin Sole from the annual bottom trawl survey on the eastern Bering Sea shelf showed a doubling of survey biomass between 1975 and 1979 with a further increase to over 3.3 million t in 1981 (Table 4.9 and Figure 4.16). Total survey abundance estimates fluctuated from 1983 to 1990 with biomass ranging from as high as 3.5 million t in 1983 to as low as 1.9 million t in 1986. Biomass estimates since 1990 indicate an even trend at high levels of abundance for Yellowfin Sole, with the exception of the results from the 1999 and 2000 summer surveys, which were at lower levels. Surveys from 2001-2005 estimated an increase each year but the estimates since 2006 indicate a stable level with some annual variability. However, the 2012 estimate is a 19% decrease from 2011 and the 2013 and 2014 surveys have estimated a 17% increase over 2012. Similarly, there was a 24% decrease from 2014 to 2015 followed by a 48% increase from 2015 to 2016, the highest biomass estimate since 1984. Fluctuations of the magnitude shown between 1980 and 1990, 1998 and 1999, 2008 and 2009, 2011 and 2012, 2014 and 2015, and 2015 and 2016 are unreasonable considering the elements of slow growth and long life span of Yellowfin Sole combined with low to moderate exploitation rate, characteristics which should produce more gradual changes in abundance (Table 4.8). The 2021 survey estimate for Yellowfin

Sole in the Biomass estimates from the eastern Bering Sea are the third lowest from the entire time series. Biomass estimates from the northern Bering Sea have shown an increase in Yellowfin Sole biomass from 310,617 t in 2010 to 520,029 t in 2019, and a subsequent decline to 496,038 t in 2021 (Table 4.10).

Experiments examining the bridle efficiency of the Bering Sea survey trawl indicate that Yellowfin Sole are herded into the trawl path from an area between the wing tips of the net and the point where the bridles contact the seafloor (Somerton and Munro 2001). The herding experiments suggest that the survey trawl vulnerability (a component of catchability) is greater than 1.0. The likelihood profile of q from the model indicated a small variance with a narrow range of likely values with a low probability of q being equal to the value of 1.0 in a past assessment (Wilderbuer and Nichol 2003).

Variability of Yellowfin Sole survey biomass estimates (Figure 4.16) is in part due to the availability of Yellowfin Sole to the survey area (Nichol 1998, Nichol et al. 2019). Yellowfin Sole are known to undergo annual migrations from wintering areas off the shelf-slope break to near shore waters where they spawn throughout the spring and summer months (Nichol 1995; Wakabayashi 1989; Wilderbuer et al. 1992). Exploratory survey sampling in coastal waters of the eastern Bering Sea during early summer indicate that Yellowfin Sole concentrations can be greater in these shallower areas not covered by the standard AFSC survey than in the survey proper. Commercial bottom trawlers have commonly found high concentrations of Yellowfin Sole in areas such as near Togiak Bay (Low and Narita 1990) and in more recent years from Kuskokwim Bay to just south of Nunivak Island. The coastal areas are sufficiently large enough to offer a substantial refuge for Yellowfin Sole from the current survey.

Over the past 18 years, survey biomass estimates for Yellowfin Sole have shown a positive correlation with shelf bottom temperatures (Nichol, 1998); estimates have generally been lower during cold years. The 1999 survey, which was conducted in exceptionally cold waters, indicated a decline in biomass that was unrealistic. The bottom temperatures during the 2000 survey were much warmer than in 1999, and the biomass increased, but still did not approach estimates from earlier years. Average bottom temperature and biomass both increased again during the period 2001 – 2003, with the 2003 value the highest temperature and biomass observed over the 22 year time series up to that time. Given that both the 1999 and 2000 surveys were conducted two weeks earlier than previous surveys, it is possible that the time difference may also have also affected the availability of Yellowfin Sole to the survey. If, for example, the timing of peak Yellowfin Sole spawning in nearshore waters corresponded to the time of the survey, a greater proportion of the population would be unavailable to the standard survey area. This pattern was observed again in 2009 and 2012 when the temperatures and the bottom trawl survey point estimates were lower. Summer shelf bottom temperatures in 2012 were the 2nd coldest recorded by the survey and the time-series and resulted in a 19% decline from 2011. Temperatures in the Bering Sea have been higher than the mean since 2013 (Figure 4.13), and the 2016 estimate of biomass was the highest in 32 years and 48% higher than the 2015 estimate. The 2017 survey estimate of 2,787,700 t was 3% lower than 2016, and the 2018 estimate of 1,892,925 was down 32% from 2017, followed by a 6% increase in 2021. We propose several possible reasons why survey biomass estimates are lower during years when bottom temperatures are low. First, catchability may be lower because Yellowfin Sole may be less active when cold. Less active fish may be less susceptible to herding and more likely to escape under the foot rope of survey gear. Secondly, bottom temperatures may influence the timing of the inshore spawning migrations of Yellowfin Sole and therefore affect their availability to the survey area (Nichol et al. 2019). Because Yellowfin Sole spawning grounds include nearshore areas outside the survey area, availability of fish within the survey area can vary with the timing of this migration and the timing of the survey. In the case of 2016, a very warm year in the Bering Sea, it appears that a higher portion of the adult biomass was distributed on the shelf (outside of the spawning areas) relative to the average of all previous survey years, indicating earlier spawning migration. Third, Yellowfin Sole growth appears to be correlated with temperature, as can be seen with greater length anomalies of 5 year old males in females in warm years and smaller lengths in cold years (Figure 4.13).

Yellowfin Sole population numbers-at-age estimated from the annual bottom trawl surveys are shown in Table 4.11 and their occurrence in trawl survey hauls and associated collections of lengths and age structures since 1982 are shown in Table 4.5. Their total tonnage caught in the resource assessment surveys since 1982 are listed in Table 4.12 and also in an appendix table with IPHC survey catches (Table A1).

Northern Bering Sea survey

Trawl survey sampling was extended to the northern Bering Sea in 2010, 2017, 2018, 2019, and 2021. The trawl surveys conducted in 2010, 2017, 2019, and 2021 occupied the same areas with similar sampling densities. The 2018 survey was a reduced effort and only sampled a subset of the northern Bering Sea. Stations in 2018 were 30 nautical miles apart (instead of 20 nm) and excluded Norton Sound and inshore areas north of Nunivak Island. For comparison among years, 2018 biomass estimates were derived by truncating the areal coverage of the 2010 and 2017 surveys to include only the area covered in 2018 that was common to all three surveys, and this was treated as a single stratum (Figure 4.17). This truncated area was 158,286 square kilometers (compared to 200,207 square kilometers in 2010 and 2017). There was an increase in the biomass estimate of Yellowfin Sole in the northern Bering Sea since 2010; the estimate in 2010 was 310,617 t and the estimate in 2019 was 520,029 t. The estimate declined in 2021 to 496,038 t. Since bottom trawl fishing is presently prohibited in the northern Bering Sea, the biomass from this area has typically not been included in the stock assessment model, although Model 18.2b does incorporate EBS+NBS biomass estimates. Large shifts in the abundance of Yellowfin Sole into the Bering Sea have not been observed (Figure 4.17), but the spatial distribution will continue to be monitored as shifts may occur under future climate change. A time series based on an ADF&G survey in Norton Sound confirms that the biomass of Yellowfin Sole has generally increased since 1980. The mean CPUE/km² of Yellowfin Sole in Norton Sound has increased from a mean CPUE of 201 over the first five survey years (1976, 1979, 1982, 1985, and 1988) to a mean CPUE of 411 over the last five survey years (2017, 2018, 2019, 2020, and 2021) (Figure 4.18).

VAST estimates of biomass

We incorporated vector-autoregressive spatio-temporal (VAST) biomass estimates into two new models; Model 18.2a incorporated VAST estimates from the EBS from 1982-2021, and Model 18.2b incorporated VAST estimates from the NBS and the EBS from 1982-2021 (Thorson 2019). Abundance indices for the EBS+NBS region were fit using a temporal smoother on epsilon and a cold pool effect. The EBS-only dataset did not use the temporal smoother on epsilon to avoid extra complexity of covariance among years, and also provided consistency with previous EBS-only indices. When fitting spatially balanced survey data, it is conventional to avoid specifying any temporal correlation for intercepts or spatio-temporal variation (Thorson et al. 2015); this minimizes covariance in the estimated index among years, and is done for all spatio-temporal indices in the eastern Bering Sea and Gulf of Alaska. However, for spatially unbalanced survey data (e.g., when combining the EBS and NBS, and lacking NBS data in many years), it is appropriate to specify a temporal correlation for the spatio-temporal component (O’Leary et al. 2020). This allows hotspots in density to be propagated forward and backwards in time in the NBS (e.g., a Brownian bridge in log-density between surveys in 2010 and 2017). The spatially varying response to cold-pool extent further refines this interpolation, and provides information about the rate of density increases in the NBS as informed by the annual cold-pool index (Thorson et al. 2020).

The VAST model fit survey numbers per unit area from all grid cells and corner stations in the 83-112 bottom trawl survey of the EBS, 1982-2021, as well as 83-112 samples available in the NBS in 1982, 1985, 1988, 1991, 2010, 2017-2019, and 2021. NBS samples prior to 2010 did not follow the 30 nautical mile sampling grid that was used in 2010, 2017, 2019, and 2021, and the 2018 sampling followed a coarsened grid as well.

The distribution of positive catch rates was specified using a gamma distribution; expected encounter probability and expected positive catch rates (catch given an encounter) were calculated from two linear predictors using a Poisson-link delta model (Thorson 2018). We extrapolated density to the entire EBS and NBS in each year, using extrapolation grids that are available within FishStatsUtils when integrating densities. The extrapolation-grids were composed of a total of 51,769 cells where each cell represented an area of 13.720 km², 3705m (2nmi) x 3705m (2nmi). This results in 36,690 extrapolation-grid cells for the eastern Bering Sea and 15,079 in the northern Bering Sea. We used bilinear interpolation to interpolate densities from 250 “knots” to these extrapolation-grid cells; knots were distributed spatially in proportion to the distribution of extrapolation-grid cells (i.e., having an approximately even distribution across space). We estimated “geometric anisotropy” (the tendency for correlations to decline faster in some cardinal directions than others), and including a spatial and spatio-temporal term for both linear predictors. To improve interpolation of density “hotspots” between unsampled years, we specified that the spatio-temporal term was autocorrelated

across years (where the magnitude of autocorrelation was estimated as a fixed effect for each linear predictor). However, we did not include any temporal correlation for intercepts, which we treated as fixed effects for each linear predictor and year. Finally, we used epsilon bias-correction to correct for retransformation bias (Thorson and Kristensen 2016). Only estimates with the spatio-temporal term were included.

Analytic Approach

General Model Structure

The abundance, mortality, recruitment and selectivity of Yellowfin Sole were assessed with a stock assessment model using the AD Model Builder language (Fournier et al. 2012; Ianelli and Fournier 1998). The conceptual model is a separable catch-age analysis that uses survey estimates of biomass and age composition as auxiliary information (Fournier and Archibald 1982). The assessment model simulates the dynamics of the population and compares the expected values of the population characteristics to the characteristics observed from surveys and fishery sampling programs. This was accomplished by the simultaneous estimation of the parameters in the model using the maximum likelihood estimation procedure. The fit of the simulated values to the observable characteristics was optimized by maximizing a log(likelihood) function given some distributional assumptions about the observed data.

The model includes ages one through 20+. In the 20+ group, fish older than twenty are allowed to accumulate into an age category that includes fish of age twenty and older (20+). Since the sex-specific weight-at-age for Yellowfin Sole diverges after age of maturity (about age 10 for 40% of the stock), with females growing larger than males, the current assessment model is coded to accommodate the sex-specific aspects of the population dynamics of Yellowfin Sole. The model allows for the input of sex-specific estimates of fishery and survey age composition and weight-at-age and provides sex-specific estimates of population numbers, fishing mortality, selectivity, fishery and survey age composition and allows for the estimation of sex-specific natural mortality and catchability. The model retains the utility to fit combined sex data inputs.

The suite of parameters estimated by the model are classified by three likelihood components:

| Data component | Distributional assumption |
|---|---------------------------|
| Trawl fishery catch-at-age | Multinomial |
| Trawl survey population age composition | Multinomial |
| Trawl survey biomass estimates and S.E. | Log-normal |

The likelihood components may be weighted by an emphasis factor; however, equal emphasis was placed on fitting each likelihood component in the Yellowfin Sole assessment except for the catch. The AD Model Builder software fits the data components using automatic differentiation (Griewank and Corliss 1991) software developed as a set of libraries (AUTODIFF C++ library).

Sharp increases in trawl survey abundance estimates for most species of Bering Sea flatfish between 1981 and 1982 indicate that the 83-112 trawl was more efficient for capturing these species than the 400-mesh eastern trawl used in 1975, and 1979-81. Allowing the model to tune to these early survey estimates would underestimate the true pre-1982 biomass, thus exaggerating the degree to which biomass increased during that period. Although this underestimate would have little effect on the estimate of current Yellowfin Sole biomass, it would affect the spawner and recruitment estimates for the time-series. Hence, the pre-1982 survey biomass estimates were omitted from the analysis.

Total mortality Z in the model was modeled as the sum of fishing mortality F and natural mortality M , such that total mortality in year t at age a is $Z_{t,a} = F_{t,a} + M$.

Fishing mortality at each year and age, $F_{t,a}$, was the product of age-specific fishing gear selectivity s_a and the median year-effect of fishing mortality μ^F , with normally distributed error,

$$F_{t,a} = s_a \mu^F e^{\epsilon_t^F}, \epsilon_t^F \sim N(0, \sigma_F^2),$$

where ϵ_t^F is the residual year-effect of fishing mortality and σ_F is the standard deviation of fishing mortality. Age-specific fishing selectivity s_a was calculated using the logistic equation

$$s_a = \frac{1}{1 + e^{(-\alpha + age\beta)}}.$$

Catch in year t for age a fish $C_{t,a}$ was calculated:

$$C_{t,a} = \frac{F_{t,a}}{Z_{t,a}}(1 - e^{Z_{t,a}})N_{t,a},$$

where $N_{t,a}$ is the number of fish at time t , age a . Total catch in each year C_t was the sum of catch over all ages, $C_t = \sum_a C_{t,a}$, and the proportion at age in catch was $P_{t,a} = \frac{C_{t,a}}{C_t}$.

Recruitment from 1956-1975 was modeled as $N_{t,1} = R_t = R_0 e^{\tau_t}$, $\tau_t \sim N(0, \sigma_R^2)$, where R_0 is the geometric mean of the modeled age 1 recruitment from 1956-1975, and σ_R is the standard deviation of recruitment.

Recruitment from 1978-2021 was determined using the Ricker stock recruitment curve,

$$R = \alpha S e^{-\beta S},$$

where S is the spawning stock biomass. Parameters α and β were estimated by fitting spawning biomass and recruitment during the period 1978-2015, and are shown from Model 18.2 from the 2020 assessment (Figure 4.19) and Model 18.2 from the current assessment (Figure 4.20).

The number of fish in year $t+1$ at age a was the number of fish in the previous year subjected to natural and fishing mortality,

$$N_{t+1,a+1} = N_{t,a} e^{-Z_{t,a}}.$$

The “plus group” included all fish age 20 and older included fish surviving from age 19 as well as those age 20 and higher,

$$N_{t+1,A} = N_{t,a} e^{-Z_{t,A-1}} + N_{t,A} e^{-Z_{t,A}}.$$

Spawning biomass was calculated as the product of weight-at-age and the number of mature females at each age,

$$S_t = \sum N_{t,a} W_{t,a} \phi_a,$$

where ϕ_a is the proportion of mature females at age a and $W_{a,t}$ is the mean body weight in kg of fish age a in year t . Survey biomass was assumed to be the product of catchability q , survey selectivity s_a , and the biomass,

$$Biomass_{survey,t} = q \sum N_{t,a} W_{t,a} s_a.$$

A Markov chain Monte Carlo (MCMC) was performed in ADMB to capture variability in F_{MSY} , B_{MSY} , recruitment, female spawning biomass, and total (age 1+) biomass for Model 18.2. The MCMC was run with 1,000,000 iterations, and thinning every 200.

The model of Yellowfin Sole population dynamics was evaluated with respect to the observations of the time-series of survey and fishery age compositions and the survey biomass trend since 1982.

Description of Alternative Models

In this assessment we considered Model 18.2 used in the 2020 assessment updated with 2021 data. This model used a fixed value for female natural mortality ($M=0.12$) and allowed male natural mortality to be estimated within the model. Model 18.2 is the preferred model.

In addition, two models were included that used VAST estimates of biomass rather than standard design-based estimates of biomass. Model 18.2a used VAST biomass and standard error estimates for the eastern Bering Sea area. Model 18.2b used VAST estimates of biomass and standard error for the eastern and northern portions of the Bering Sea.

Parameters Estimated Outside the Assessment Model

Weight at age

Prior to 2021, the procedure for estimating the weight-at-age was as follows. Length-at-age estimates were estimated from the von Bertalanffy growth curve and converted to weight using a power function.

Parameters of the von Bertalanffy growth curve were estimated for Yellowfin Sole, by sex, from the trawl survey database::

| Sex | L_{inf} | K | t_0 | n |
|---------|-----------|-------|-------|-----|
| Males | 34.03 | 0.161 | 0.515 | 656 |
| Females | 38.03 | 0.137 | 0.297 | 709 |

A sex-specific length-weight relationship was also calculated from the survey database using the power function, $Weight(g) = a * Length(cm)^b$, where a and b are parameters estimated to provide the best fit to the data. This relationship between weight and length were applied to the annual trawl survey estimates of population length at age, by sex, to calculate the weight at each age. Since the resulting estimates of annual weight-at-age were highly variable for fish older than 11 years, ages 11-20 were smoothed using a five-year average smoothing method for 1982-2020. The estimated weight at age for the years 1954-2018 are shown in (Figure 4.21), and compared with the weight at age estimate from the 2019 survey (the most recent EBS survey with YFS ages). It became apparent that legacy weights at age were different enough from the 2019 estimate that the legacy weight at age and methodology required re-evaluation.

For 2021, weight at age from the entire time series were evaluated as follows. Survey weights at age were available from 1984 through 2019 (19,074 records). Weight-at-age was calculated for all ages 1-19 as well as the age 20 plus group (all ages 20 and over). There were some gaps due to years in which no fish of a particular age had been collected. Where possible, these gaps were filled with survey length at age data converted to weight at age. Between 1971 through 2019, there were lengths associated with aged Yellowfin Sole for more years than weights. Lengths at age were converted to weights at age and used to fill gaps using a sex-specific length-weight relationship based on all available current data. The relationship between weight and length was calculated using the power function, $Weight(g) = a * Length(cm)^b$, where a and b are parameters estimated to provide the best fit to the data. The parameter estimates and the number of individual data points are shown below.

| Sex | a | b | n |
|---------|--------|-------|--------|
| Males | 0.0091 | 3.068 | 10,663 |
| Females | 0.0059 | 3.205 | 13,702 |

Finally, annual age categories for which no length-at-age or weight-at-age were available were filled by calculating weight at age (using the power relationship described above) from a mean overall length at age for males and females from 1971-2019 data.

The mean weight at age from first 10 years (1971-1980) was used to fill in years 1954-1970. It was important to select years from the beginning of the time series, as it appears that length at age appears to be increasing in Yellowfin Sole (Figure 4.1 and Figure 4.2).

The mean weight at age from 2015-2019 was used as an estimate for weight at age in 2020 and 2021, as there was no survey in 2020 and the 2021 ages have not yet been processed. The five most recent years of age data were used for 2020 and 2021 in consideration of the increase in average size at age (Figure 4.22, Table 4.13).

Natural mortality

Natural mortality (M) was initially estimated by a least squares analysis where catch at age data were fitted to Japanese pair trawl effort data while varying the catchability coefficient (q) and M simultaneously. The best

fit to the data (the point where the residual variance was minimized) occurred at a value of $M=0.12$ (Bakkala and Wespestad 1984). This was also the value which provided the best fit to the observable population characteristics when M was profiled over a range of values in the stock assessment model using data up to 1992. Since then, natural mortality has been estimated as a free parameter in some of the stock assessment model runs which have been evaluated the past five years. A fixed female natural mortality at $M=0.12$ and male natural mortality estimated by the model is used in Model 18.2.

Maturity

Yellowfin Sole maturity schedules were estimated from in-situ observations from two studies as discussed in the “Data” section (Table 4.7).

Parameter Estimates

A list of selected parameters estimated inside the model are shown in Table 4.14.

Parameters Estimated Inside the Assessment Model

There were 514 parameters estimated by Model 18.2, 18.2a, and 18.2b, and last year’s model had 508. The number of key parameters are presented below:

| Fishing mortality | Selectivity | Survey catchability | Year-class strength | Spawner-recruit | M | Total |
|-------------------|-------------|---------------------|---------------------|-----------------|-----|-------|
| 69 | 321 | | 4 | 116 | 2 | 2 514 |

The increase in the number of parameters estimated in this assessment compared to last year (6) can be accounted for by the input of another year of fishery data and the entry of another year-class into the observed population, four more sex-specific fishery selectivity parameters, and an additional catchability parameter. The population simulation specifies the numbers-at-age in the beginning year of the simulation, the number of recruits in each subsequent year, and the survival rate for each cohort as it moves through the population over time.

Selectivity

Fishery and survey selectivity was modeled separately for males and females using the two parameter formulation of the logistic function. The model was run with an asymptotic selectivity curve for the older fish in the fishery and survey, but still allowed to estimate the shape of the logistic curve for young fish. The oldest year-classes in the surveys and fisheries were truncated at 20 and allowed to accumulate into the 20+ age category. A single selectivity curve, for both males and females, was fit for all years of survey data (Figure 4.23).

Time-varying fishing selectivity curves were estimated because there have been annual changes in management, vessel participation and possibly gear selectivity (Figure 4.24). A logistic equation was used to model fishery selectivity and is a function of time-varying parameters specifying the age and slope at 50% selection, φ_t and η_t , respectively. The fishing selectivity (S^f) for age a and year t is modeled as,

$$S_{a,t}^f = [1 + e^{\eta_t(a - \varphi_t)}]^{-1}, \quad (1)$$

where φ_t and η_t are time-varying and partitioned (for estimation) into parameters representing the mean and a vector of deviations (log-scale) conditioned to sum to zero. The deviations are constrained by a lognormal prior with a variance that was iteratively estimated. The process of iterating was to first set the variance to a high value to estimate the deviations. The next step was to compare the variability of model estimates. The variance of the model estimates were then rounded up slightly and fixed for subsequent runs. The 2021 values were fixed as the average of the 3 most recent years.

Fishing Mortality

The fishing mortality rates (F) for each age and year are calculated to approximate the catch weight by solving for F while still allowing for observation error in catch measurement. A large emphasis (300) was placed on the catch likelihood component to force the model to closely match the observed catch.

Survey Catchability

Past assessments have examined the relationship between estimates of survey biomass and bottom water temperature. To better understand how water temperature may affect the catchability of Yellowfin Sole to the survey trawl, catchability was estimated for each year in the stock assessment model as:

$$q = e^{-\alpha + \beta T}, \quad (2)$$

where q is catchability, T is the average annual bottom water temperature anomaly at survey stations less than 100 m, and α and β are parameters estimated by the model. The catchability equation has two parts. The $e^{-\alpha}$ term is a constant or time-independent estimate of q . The second term, $e^{\beta T}$ is a time-varying (annual) q which responds to metabolic aspects of herding or distribution (availability) which can vary annually with bottom water temperature. The result of incorporating bottom temperature to estimate annual q has resulted in an improved fit to the survey (described in the 2018 BSAI Yellowfin Sole assessment).

The survey catchability model includes survey start date (expressed as deviation in days (- and +) from the average survey start date of June 4th). This feature has been used since 2018, and its interaction with annual bottom water temperature is added to the catchability equation as:

$$q = e^{-\alpha + \beta T + \gamma S + \mu T:S}, \quad (3)$$

where T =survey bottom temperature (averaged per year for all stations <100 m), S =survey start date, and $T : S$ =interaction of T and S . Earlier survey start dates usually encounter colder water and since the timing of the survey start date is positively correlated with bottom water temperature, improvement in fitting the survey biomass estimates can be gained by estimating two new parameters (μ and γ). Akaike information criterion (AIC) were used to determine if the additional variables (S and $T : S$) improved the regression fit. The improvement in fit was more than offset by the additional two parameters (Nichol et al. 2019).

Spawner-Recruit Estimation

Annual recruitment estimates from 1978-2015 were constrained to fit a Ricker (1958) form of the stock recruitment relationship as follows:

$$R = \alpha S e^{-\beta S}, \quad (4)$$

where R is age 1 recruitment, S is female spawning biomass in metric tons the previous year, and α and β are parameters estimated by the model. This stock recruitment curve expresses a peak level of recruitment at an intermediate stock abundance and density dependence at higher stock sizes. The spawner-recruit fitting is estimated in a later phase after initial estimates of survival, numbers-at-age and selectivity are obtained.

Results

Model Evaluation

For this assessment, Model 18.2 and two additional exploratory models were examined, Model 18.2a and 18.2b. Model 18.2 was the accepted model in the 2020 Yellowfin Sole stock assessment. The model estimated male natural mortality 0.134961 to be higher than female natural mortality 0.12, which is in common with known life history parameters of other Alaska flatfish. In Arrowtooth Flounder, higher natural mortality

is assumed for males and is consistent with their skewed sex ratio (Wilderbuer and Turnock 2009). Higher natural mortality for male flatfish has been assumed to flatfish from other regions as well (Maunder and Wong 2011).

Model 18.2 and the 2020 Model 18.2 provided similar parameter estimates for survey catchability. The 2020 Model 18.2 (Figure 4.25), indicates a shift towards lower survey catchability in 2021, corresponding with lower bottom temperatures than in 2020 (Figure 4.13). Overall, selectivity was shifted slightly higher for Model 18.2 in the current assessment. The proportion female was estimated to be similar in the 2020 and the current model since 1970 (Figure 4.26).

Models 18.2, 18.2a, and 18.2b used different assumptions for the estimates of biomass (design-based vs. VAST); therefore, their likelihoods could not be compared. Model 18.2 provided a good fit the survey age composition (Figure 4.27) and fishery age composition (Figure 4.28).

Overall Model 18.2 provided a good fit to survey biomass (Figure 4.29). Discrepancies between the survey biomass and the model fit can be attributed to the higher than average water temperatures that reduce estimates of survey catchability, as well as larger confidence intervals on design based estimates of biomass compared with VAST. Models 18.2a and 18.2b fit their corresponding estimates of survey biomass fairly well. There was some discontinuity in the fit for 2016 that was consistent among all three models, that corresponded with the second largest temperature anomaly on record, after 2019 (Figure 4.30).

Posterior distributions of several key parameters in the model capture variability in posterior distributions of parameter estimates for Model 18.2 (Figure 4.31). Model 18.2 resulted in smooth posteriors for B_{MSY} , total and age 6 biomass and female spawning biomass and recruitment. The posterior distribution for female spawning biomass is above the Model 18.2 estimate for B_{MSY} (Figure 4.31).

Given the uncertainty of the productivity of Yellowfin Sole at low spawning stock sizes, and because the AFSC policy for reference point time-series selection is to use the post 1977 regime shift values unless there is a compelling reason to do otherwise, the productivity of Yellowfin Sole in this assessment was estimated by fitting the 1977-2015 spawner-recruit data in the model. The resulting stock recruitment curve shows average recruitment for the years 2016-2021 (2016 and 2017 are slightly above average) based on Model 18.2 (Figure 4.20, and recruitment estimates are similar to last year's model Figure 4.19).

Model 18.2 is the preferred model for estimating the Yellowfin Sole stock size and management quantities for the 2022 fishing season because models 18.2a and 18.2b do not incorporate VAST age compositions. Also, there are no weight at age estimates from the NBS survey included in Models 18.2a or 18.2b. However, Models 18.2a and 18.2b were considered for an exploratory analysis of VAST biomass estimates and inclusion of the Bering Sea survey. Model 18.2a provided similar estimates of total (age 2+) and spawning biomass as Model 18.2; both of which used biomass estimates from the EBS and similar model parameterization (Figure 4.32). Model 18.2 provided consistently higher estimates than Model 18.2a. Model 18.2b yielded the highest estimates of total and spawning biomass, which is reasonable, as biomass estimates were based on the standard EBS region plus the northern Bering Sea. Reference points resulting from all models, as well as the 2019 accepted model are shown in (Table 4.15).

Time Series Results

The data was updated in 2021 to include current values of catch, fishery and survey age compositions from 2020. The latest year of data was included in fishery weight-at-age. The preferred model (18.2) also incorporates a model estimate of male natural mortality, which increases estimates of biomass. Models 18.2 and 18.2a produced lower estimates for ABC and OFL than Model 18.2b due to the inclusion of the NBS in the biomass estimate for Model 18.2b (Table 4.15). Reference points for Model 18.2a were very similar to Model 18.2. The model results indicate the stock has been in a slowly declining condition since 1994 (Figure 4.33). The five past years in the Bering Sea have had bottom temperature anomalies above the mean. The temperature-dependent q adjustment for 2021 was 0.86.

Fishing Mortality and Selectivity

The full-selection fishing mortality, F , has averaged 0.0729 over the 5 years, 2016-2021 (Table 4.16). Model

estimated selectivities, Figure 4.23 and Figure 4.24 indicate that both sexes of Yellowfin Sole are 50% selected by the fishery at about age 9 and nearly fully selected by age 13, with annual variability. Based on results from the stock assessment model, annual average exploitation rates of Yellowfin Sole since 1977 ranged from 3% to 7% of the total biomass, and have averaged approximately 4%.

Abundance Trends

Model 18.2 estimated catchability q at an average value of 0.82 for the period 1982-2021 which resulted in a model estimate of the 2021 age 2+ total biomass at 2.666 million t (Table 4.9). In comparison, catchability increased for Model 18.2a, which was estimated at 0.89 and increased further for Model 18.2b, 0.8. Model results indicate that Yellowfin Sole total biomass (age 2+) was at low levels during most of the 1960s and early 1970s (700,000-1,000,000 t) after a period of high exploitation (Table 4.9, Figure 4.33). Sustained above average recruitment from 1967-1976 combined with light exploitation resulted in a biomass increase to a peak of approximately 3.6 million t by 1985. The population biomass has since been in a slow decline as the strong 1981 and 1983 year-classes have passed through the population, with only the 1991, 1995 and 2003 year-classes at levels observed during the 1970s. The present biomass is estimated at 69% of the peak 1985 level. The female spawning biomass has also declined since the peak in 1994, with a 2021 estimate of 941,735 t (Table 4.17).

Allowing q to be correlated with annual bottom temperature and survey start date provides a better fit to the bottom trawl survey estimates than using a q fixed at the average value (Fig. 4.18, Wilderbuer et al. 2018). Both the trawl survey and the stock assessment model indicate that the Yellowfin Sole resource (total biomass) increased during the 1970s and early 1980s to a peak level during the mid-1980s. The Yellowfin Sole population biomass slowly decreased over the 23 years since the mid-1990s as the majority of year-classes during those years were below average strength. Average to above average recruitment from 2006 to 2009 is expected to maintain the abundance of Yellowfin Sole at a level above B_{MSY} in the near future. The stock assessment projection model indicates a generally stable trend in female spawning biomass through 2034 if the fishing mortality rate continues at the same level as the average of the past 5 years (Figure 4.34).

Recruitment Trends

The primary reason for the sustained increase in abundance of Yellowfin Sole during the 1970s and early 1980s was the recruitment of a series of stronger than average year-classes spawned in 1967-76 (Table 4.18 and Figure 4.35). The 1981 year-class was the strongest observed (and estimated) during the time series, followed by the 1983 year-class. Survey age composition estimates and the assessment model also estimate that the 1987 and 1988 year-classes were average and the 1986 and 1989 year-classes were above average. Recruitment since 1990 has been below the long-term average in most years, and the 2016 year-class appeared to be one of the lowest on record (Figure 4.35). Recruitment for years subsequent to 2016 may be less reliable given the fit to the stock recruitment curve and lack of survey data to confirm recruitment estimates.

Retrospective Analysis

A within-model retrospective analysis was included for the recommended assessment model (Model 18.2). In this analysis, retrospective female spawning biomass was calculated by sequentially dropping data one year at a time and then comparing the peeled estimate to the reference stock assessment model used in the assessment (Figure 4.36). Mohn's rho for Model 18.2 was -0.118. This was an improvement over past assessment models. Retrospective bias, measured by Mohn's Rho for model 18.2 (2020) was -0.185 and Rho for %>% (2020) was -0.184.

A similar retrospective pattern was observed as in recent years, in which earlier retrospective years indicated a lower level of spawning biomass than the current year's data (Figure 4.36). The difference in female spawning biomass was negative for most recent years, except for the most recent (Figure 4.37), and very similar among models. This is an improvement in the retrospective pattern than seen in previous years. The Mohn's rho does not exceed the rule of thumb guideline for long-lived stocks proposed by Hurtado-Ferro et al. (2015), which includes flatfish, that values of Mohn's rho higher than 0.20 or lower than -0.15 may be an indication of a retrospective pattern.

In the 2017 assessment it was demonstrated that low values of Mohn's rho and desirable retrospective patterns

of female spawning biomass were obtainable if lower values of M and q were used relative to the base model. The Plan Team and SSC requested a plot of the model-estimated female spawning biomass trajectory that reduced the retrospective pattern using M fixed at 0.09 and $q=1.0$ on top of the estimated female spawning biomass trajectory with confidence interval from the assessment.

The retrospective technique may not always be the best tool for model selection, at least for BSAI Yellowfin Sole as there is tension between model fit and good retrospective pattern over the range of parameterization examined. In 2017 the Plan Team recommended that the assessment continue to explore the retrospective patterns in relation to M and q by profiling over a range of combinations of M and q and recording the resulting values of Mohn's rho and also total likelihood. Profiling over M and q was performed in the 2018 assessment. The best retrospective patterns did not occur at corresponding best model fit values

Risk Table

Assessment related considerations

The BSAI Yellowfin Sole assessment is based on surveys conducted annually on the EBS shelf from 1982-2021, continually except for 2020 due to the COVID-19 pandemic. Fish ages, derived from otoliths collected during the surveys and the fishery to calculate annual estimates of population and fishery age composition, have been validated. The assessment model exhibits good fits to all compositional and abundance data and converges to a single minima in the likelihood surface. Recruitment estimates track strong year-classes that are consistent with the data.

The retrospective pattern from the assessment model has typically been less than desirable and has been the subject of some concern for the assessment. However, in the current assessment, reanalysis of survey weights at age resulted in a Mohn's rho value that is still negative, but closer to zero. Peculiar to the Yellowfin Sole assessment, in comparison to the northern rock sole and Alaska plaice assessments (that have preferable patterns), is the large amount of variability in the annual survey biomass assessments for this stock due to the temperature-influenced availability to the survey. This large variability in the annual estimates can contribute to undesirable patterns since the earlier years are not fitting the same highly variable information as the current year.

We propose a level 1 designation for the assessment category in the risk table, given the improvement to the retrospective pattern.

Population dynamics considerations

Stock assessment model results indicate that Yellowfin Sole total biomass (age 2+) was at low levels during most of the 1960s and early 1970s (700,000-1,000,000 t) after a period of high exploitation. Sustained above average recruitment from 1967-76 combined with light exploitation resulted in a biomass increase to a peak of 3.6 million t by 1985. The population biomass has since been in a slow decline as the strong 1981 and 1983 year-classes have passed through the population, with only the 1991, 1995 and 2003 year-classes at levels observed during the 1970s, although the 2006-2010 year-classes appear average according to the 2018 stock assessment. The current model for 2021 estimates B_{MSY} at 495,904 t. Projections indicate that the FSB will remain well-above the B_{MSY} level through 2033 (Figure 4.34). However, the stock continues to decline and the 2021 NMFS survey biomass estimate was the third lowest in the survey history since 1982 and the number of fish is also declining, despite a gradual increase in size at age.

We propose a level 2 designation for the population dynamics category in the risk table.

Environmental/ecosystem considerations

Environmental processes: Beginning in approximately 2014, the eastern Bering Sea (EBS) entered a warm phase of unprecedented duration. The EBS remains in this warm phase, though to a lesser degree compared to the extreme years of 2018 and 2019. Through summer 2021, satellite observations of SST exceeded one standard deviation above the long term average for much of the past year. Sea ice formation in fall of 2020

was delayed due to residual warmth in the system, which has become the ‘new normal’ in this protracted warm phase. While the areal extent of sea ice was closer to the pre-2014 levels than at any point in the last 7 years, ice thickness differed between the northern (thicker ice) and southern (thinner/no ice) shelves due to opposing prevailing winds. The summer 2021 cold pool remained significantly reduced in area, and its southern boundary was shifted northwestward (Siddon, 2021). Summer bottom temperatures varied spatially over the shelf. Near-average conditions were present over the SEBS, while the NBS had a very warm inner domain (i.e., Norton Sound) and a small cold pool over the middle domain to the southwest of St. Lawrence Island (Rohan and Barnett, 2021).

Yellowfin sole (YFS) demonstrate earlier migration to spawning grounds and spawning events in warm years, also somatic growth increases in warmer temperatures. In 2021, fish condition (as measured by weighted length-weight residuals) was neutral in the SEBS and negative in the NBS, with both regions showing declines from positive residuals observed in 2019 (Rohan and Prohaska, 2021).

In 2021, the center of gravity for the population continued to shift northward, as has been the case for the past several years, and shifted eastward in 2021 relative to 2019, though the center of gravity is still west of its long-term average. Between 2019 and 2021, the mean distribution across the groundfish community as a whole shifted back to the southeast again, after several years during which the overall center of gravity had shifted northward (see Mueter and Britt, 2021). A proposed thermal window (Yeung et al., 2021) suggests continued warming over the EBS shelf may result in temperatures above the thermal physiological maximum of YFS. Such high temperatures in juvenile habitats (i.e., inner domain) could negatively affect production of YFS, which may be adapted to colder temperatures.

Multiple ecosystem ‘red flags’ occurred in the NBS this year: crab population declines, salmon run failures in the Arctic-Yukon-Kuskokwim region, and seabird die-offs combined with low colony attendance and poor reproductive success. Whether a single or suite of mechanisms can be identified to explain these coincident events, the common thread in these collapses is the marine environment in the NBS. Concerns about the food web dynamics and carrying capacity in the NBS have existed since 2018, highlighted by the gray whale Unusual Mortality Event and short-tailed shearwater mass mortality event.

The dominant prey of YFS are polychaete worms, miscellaneous worms, clams, and benthic amphipods. Direct measurements of infaunal abundance trends are not available; however, abundance trends of motile epifauna that also consume infauna (i.e., indirect measurements) are quantified from the bottom trawl survey. The biomass of motile epifauna peaked in 2017 and remains above their long term mean in 2021. Trends in motile epifauna biomass indicate benthic productivity, which suggests that sufficient prey may have been available for YFS over the southern Bering Sea shelf. Brittle stars, sea stars, and other echinoderms account for 50% of this guild and these groups are well above their long term means. Crab within this functional group, including hermit crabs, king crabs, tanner crab, and snow crab are all below their long term means. (Whitehouse, 2021).

Predators of YFS include Pacific cod and Pacific halibut, which are included in the apex predator guild. In 2021, the biomass of apex predators was below their long term mean. The trend in the apex predator guild is largely driven by Pacific cod, whose recent (2016-2021) mean biomass was below their long term mean. In addition to a decrease in overall biomass, the spatial distribution of Pacific cod may provide a potential refuge from predation in the inner domain. Conversely, the spatial distribution of the relative abundance of Pacific halibut overlaps with that of YFS and may represent increased predation pressure.

Competitors for YFS prey resources include other benthic foragers, like northern rock sole and flathead sole. The trend in biomass of the benthic foragers guild has been declining since approximately 2010 and is at the lowest level over the times series (Whitehouse, 2021). Trends in benthic forager biomass indirectly indicate availability of infauna (i.e., prey of these species), suggesting a reduction in prey competition.

Summary for Environmental/Ecosystem considerations: * Near-average bottom temperatures were present over the SEBS, while the NBS had a very warm inner domain that may have exceeded the thermal physiological maximum of YFS. A small cold pool over the middle domain to the southwest of St. Lawrence Island may provide thermal refuge for YFS. * In 2021, fish condition was neutral in the SEBS and negative in the NBS, with both regions showing declines from positive residuals observed in 2019. * The center of gravity

for the population shifted northeastward, especially into Norton Sound, where bottom water temperatures may have exceeded the thermal tolerance of Yellowfin sole. * Concerns about the food web dynamics and carrying capacity in the NBS have existed since 2018 and may reflect poor feeding conditions in the northern Bering Sea. * Sufficient prey may have been available for YFS over the southern shelf based on trends in motile epifauna. Predation pressure may be mixed; a decrease in Pacific cod biomass and potential refuge from predation in the inner domain may be countered by the spatial overlap with Pacific halibut in the inner domain of the SEBS. * Trends in benthic forager biomass over the SEBS suggest a reduction in prey competition.

Together, the most recent data available suggest concerns of thermal exposure and fish conditions in the NBS support an ecosystem risk level 2.

Fishery performance considerations

Recent surveys of the northern Bering sea have not indicated a large shift in the spatial distribution of the eastern Bering Sea stock of Yellowfin Sole. If the stock moves northward out of the eastern Bering Sea under climate change into untrawlable areas in the northern Bering sea, then fisheries would be unable to target the stock in the untrawlable zone. A NOAA Coastal and Oceans Climate Applications proposal will be submitted examine the implications to the fishery and the region of the northern Bering Sea if the stock of Yellowfin Sole shifts northward. At the current time, fishery CPUE is not showing a contrasting pattern from the stock biomass trend, unusual spatial pattern of fishing, or changes in the percent of TAC taken, changes in the duration of fishery openings.

Several other fishery performance considerations are as follows:

- Landings of benthic foragers (including YFS) remained relatively stable through 2018.
- Landings of benthic forager flatfish may be larger than salmon, but salmon ex-vessel value is higher because it commands a higher price.
- Revenues from benthic forager flatfish (including YFS) decreased from 2012-2015 as a result of decreased prices; since 2015 price increases have increased value while landings have remained stable.

| Assessment consideration | Population dynamics | Environmental ecosystem | Fishery performance |
|--|---|--|---------------------|
| Level 1: There has been an improvement to the retrospective pattern. | Level 2: Stock trends are declining at a slow but steady pace; survey estimate in 2021 was the third lowest since 1982. | Level 2: Recent data suggest concerns of thermal exposure and fish conditions in the NBS | Level 1: Normal. |

We recommend a reduction in ABC, based on this risk table assessment. Therefore we recommend 2021 and 2022 ABCs that average the Tier 3 and Tier 1 ABCs, which results in 269,649 t for 2022 and 258,567 t for 2023. The Tier 3 reference points are more precautionary than Tier 1 because Tier 3 methodology does not assume a known spawning-recruitment relationship (Table 4.1).

Harvest Recommendations

Scenario Projections and Two-Year Ahead Overfishing Level

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. The 2021 numbers at age from the stock assessment model are projected to 2021 given the 2020 catch and then a 2021 catch of 140,888 t was applied to the projected 2021 population biomass to obtain the 2022 OFL.

The SSC determined in December 2006 that Yellowfin Sole would be managed under the Tier 1 harvest guidelines, and therefore future harvest recommendations would be based on maximum sustainable yield

MSY and the associated fishing effort F_{MSY} values calculated from a spawner-recruit relationship. MSY is an equilibrium concept and its value is dependent on both the spawner-recruit estimates which are assumed to represent the equilibrium stock size-recruitment relationship and the model used to fit the estimates. In the Yellowfin Sole stock assessment model, a Ricker form of the stock-recruit relationship was fit to various combinations of these data and estimates of F_{MSY} and B_{MSY} were calculated, assuming that the fit to the stock-recruitment data represents the long-term productivity of the stock (details provided in Wilderbuer et al. 2018). The 2022 ABC is calculated using Tier 1 methodology. The Tier 1 harvest level is calculated as the product of the harmonic mean of F_{MSY} and the geometric mean of the 2022 biomass estimate.

The geometric mean of the 2022 biomass estimate, B_{gm} , is estimated using the equation $B_{gm} = e^{\ln(B) - (cv^2/2)}$, where B is the point estimate of the 2022 biomass from the stock assessment model and cv^2 is the coefficient of variation of the point estimate (a proxy for sigma). The harmonic mean of F_{MSY} , F_{har} is estimated as $F_{har} = e^{\ln(F_{MSY} - (\ln(sd^2)/2))}$, where F_{MSY} is the peak mode of the F_{MSY} distribution and sd^2 is the square of the standard deviation of the F_{MSY} distribution.

In 2006 the SSC selected the 1978-2001 data set for the Tier 1 harvest recommendation. Using this approach for the 2022 harvest (now the 1978-2015 time-series) recommendation (Model 18.2), the $F_{ABC} = F_{Hmean} = 0.143$. The estimate of age 6+ total biomass for 2022 is 2,479,370 t. The calculations outlined above give a Tier 1 ABC harvest recommendation of 354,014 t and an OFL of 377,071 t for 2022. This results in an 6 % (23,057 t) buffer between ABC and OFL.

The stock assessment analysis must also consider harvest limits, usually described as overfishing fishing mortality levels with corresponding yield amounts. Amendment 56 to the BSAI FMP sets the Tier 1 harvest limit at the F_{MSY} fishing mortality value. The overfishing limit mortality values, ABC fishing mortality values and their corresponding yields are given as follows:

| Harvest level | F value | 2022 Yield |
|-------------------------------------|---------|------------|
| Tier 1 $F_{OFL} = F_{MSY}$ | 0.152 | 377,071 t |
| Tier 1 $F_{ABC} = F_{harmonicmean}$ | 0.143 | 354,014 t |

A complete record of catch, ABC, and OFL since 1980 is available in Table 4.19.

Status Determination

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), which was implemented in 1977.

For each scenario, the projections begin with the vector of 2021 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2022 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2021. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1,000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2022, are as follows (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 2021 recommended in the assessment to the max F_{ABC} for 2022. (Rationale: When F_{ABC} is set at a value below max F_{ABC} , it is often set at the value recommended in the stock assessment.)
- Scenario 3: In all future years, F is set equal to the 2016 - 2020 average F . (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC} .)
- Scenario 4: In all future years, F is set equal to $F_{60\%}$. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)
- Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

- Scenario 6: In all future years, F is set equal to F_{OFL} . (Rationale: This scenario determines whether a stock is overfished. If the stock is 1) above its MSY level in 2021 or 2) above 1/2 of its MSY level in 2021 and expected to be above its MSY level in 2031 under this scenario, then the stock is not overfished.)
- Scenario 7: In 2022, 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 1) above its MSY level in 2023 or 2) above 1/2 of its MSY level in 2023 and expected to be above its MSY level in 2033 under this scenario, then the stock is not approaching an overfished condition.)

Simulation results shown in Table 4.20 indicate that Yellowfin Sole are not currently overfished and are not approaching an overfished condition. If fishing continues at the same fishing mortality as in the past 5 years, the stock is projected to remain well above B_{MSY} (Figure 4.34). A phase plane figure of the estimated time-series of Yellowfin Sole female spawning biomass (FSB) relative to the harvest control rule indicates that the stock is above B_{MSY} , has been consistently fished below F_{MSY} for decades, and that projections of female spawning biomass are also expected to be above B_{MSY} (Figure 4.38). The ABC and OFL for 2022

and 2023 assuming average catch rates are shown in the following table.

| Year | Catch | FSB | Geom. mean 6+ biomass | ABC | OFL |
|------|---------|---------|-----------------------|---------|---------|
| 2022 | 126,929 | 857,101 | 2,479,370 | 354,014 | 377,071 |
| 2023 | 126,929 | 727,101 | 2,284,820 | 326,235 | 347,483 |

Based on the 2021 assessment Model 18.2, an F=0.19464 would have produced a 2020 catch equal to the 2020 OFL, 341,571 t.

Ecosystem Considerations

Ecosystem Effects on the Stock

Prey availability/abundance trends

Yellowfin Sole diet by life stage varies as follows: Larvae consume plankton and algae, early juveniles consume zooplankton, late juvenile stage and adults prey includes bivalves, polychaetes, amphipods, mollusks, euphausids, shrimps, brittle stars, sculpins and miscellaneous crustaceans. Information is not available to assess the abundance trends of the benthic infauna of the Bering Sea shelf. The original description of infaunal distribution and abundance by Haflinger (1981) resulted from sampling conducted in 1975 and 1976 and has not been re-sampled since. The large populations of flatfish which have occupied the middle shelf of the Bering Sea over the past twenty-five years for summertime feeding do not appear food-limited. These populations have fluctuated due to the variability in recruitment success which suggests that the primary infaunal food source has been at an adequate level to sustain the Yellowfin Sole resource.

Predator population trends

As juveniles, it is well-documented from studies in other parts of the world that flatfish are prey for shrimp species in near shore areas. This has not been reported for Bering Sea yellowfn sole due to a lack of juvenile sampling and collections in near shore areas, but is thought to occur. As late juveniles they have been found in stomachs of Pacific cod and Pacific halibut; mostly small Yellowfin Sole ranging from 7 to 25 cm standard length..

Past, present and projected future population trends of these predator species can be found in their respective SAFE chapters in this volume and also from Annual reports compiled by the International Pacific Halibut Commission. Encounters between Yellowfin Sole and their predators may be limited since their distributions do not completely overlap in space and time.

Changes in habitat quality

Changes in the physical environment which may affect Yellowfin Sole distribution patterns, recruitment success and migration timing patterns are catalogued in the Ecosystem Considerations Report of this SAFE report. Habitat quality may be enhanced during years of favorable cross-shelf advection (juvenile survival) and warmer bottom water temperatures with reduced ice cover (higher metabolism with more active feeding).

Fishery Effects on the Ecosystem

1. The Yellowfin Sole target fishery contribution to the total bycatch of other target species is shown for 1992-2019 in Table 4.21, and bycatch of the Other Species group (Octopus,Shark, Skate, Squid, and Sculpin) are presented in Table 4.22. The catch of non-target species from 2003-2019 is shown in Table 4.23. The Yellowfin Sole target fishery contribution to the total bycatch of prohibited species is summarized for 2015 as follows:

| Prohibited species | Yellowfin Sole fishery % of total bycatch |
|--------------------|---|
| Halibut mortality | 30 |

| Prohibited species | Yellowfin Sole fishery % of total bycatch |
|--------------------|---|
| Herring | 2 |
| Red King crab | 5 |
| C. bairdi | 25.5 |
| Other Tanner crab | 78.2 |
| Salmon | <1 |

2. Relative to the predator needs in space and time, the Yellowfin Sole target fishery has a low selectivity for fish 7-25 cm and therefore has minimal overlap with removals from predation.
3. The target fishery is not perceived to have an effect on the amount of large size target fish in the population due to its history of light to moderate exploitation (6%) over the past 30 years. Population age composition data indicate a large 20+ age group.
4. Yellowfin Sole fishery discards are presented in the Catch History section.
5. It is unknown what effect the fishery has had on Yellowfin Sole maturity-at-age and fecundity, but based on two maturity studies conducted 20 years apart, it is expected to be minimal.
6. Analysis of the benthic disturbance from the Yellowfin Sole fishery is available in the Preliminary draft of the Essential Fish Habitat Environmental Impact Statement and summarized in Table 4.24.

Data Gaps and Research Priorities

Genetic studies are needed to confirm the assumption that Yellowfin Sole consist of a single stock throughout the Bering Sea. Additional studies of maturity at age throughout the range of Yellowfin Sole (including the northern Bering Sea) are also warranted.

In addition, research is needed to study the spatial variation in juvenile flatfish growth and condition in relation to habitat quality in the Bering Sea. The bottom trawl used in the Bering Sea surveys is not efficient in retaining animals of size ≤ 14 cm (Kotwicki et al. 2017). In recent studies where the 83-112 bottom trawl and the 3-m plumb staff beam trawl were fished consecutively at a survey station, the catch per unit effort (CPUE, number/hectare) of juvenile Yellowfin Sole (≤ 16 cm) estimated from the bottom trawl can be lower than the CPUE from the beam trawl by as high as an order of magnitude, or erroneously indicate absence (Yeung, unpubl. data). As a result of the low catch of small fish in the surveys, there is high uncertainty at the left tail of the age-length curve. The age-at-length from otolith analysis of juveniles collected with the beam trawl (n=84) was consistently older by 1-3 years than the estimated age using the survey-derived age-length key (Matta and Yeung, unpubl. data), suggesting that currently the age of juveniles may have been underestimated. Juvenile Yellowfin Sole are known historically to be concentrated in shallow, nearshore habitats near Kuskokwim and Togiak Bays in the EBS that are out of bottom-trawl survey range, just as the NBS surveys now showed them in high abundance in habitat of such type in Norton Sound in the NBS. Long-term, systematic survey of the nearshore with appropriate sampling gear will improve the assessment of the density and distribution of juvenile Yellowfin Sole, and the understanding of the linkages between environmental drivers, habitat quality and usage, and biomass production. Norton Sound and Kuskokwim-Togiak Bays should be focal areas of investigation for their potential importance as nurseries. These coastal areas are of high anthropogenic and environmental sensitivity, and are experiencing anomalously high water temperatures because of climate change that are likely to impact fish growth and condition. To fully assess Yellowfin Sole stock production, the level of connectivity between the EBS and NBS populations will need to be addressed with tools such as tagging, genomics, biomarkers and otolith microchemistry.

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Tables

Table 4.1: Tier 3 reference points for this year's Yellowfin Sole assessment model 18.2.

| Quantity | As estimated or <i>specified</i> <i>last year for:</i> | | As estimated or <i>recommended</i> <i>this year for:</i> | |
|---------------------------------------|---|-------------|---|-------------|
| | 2021 | 2022 | 2022 | 2023 |
| M (natural mortality rate) | 0.12, 0.135 | 0.12, 0.135 | 0.12, 0.135 | 0.12, 0.135 |
| Tier | 1a | 1a | 3a | 3a |
| Projected total (age 1+) biomass (t) | 2,755,870 t | 3,025,430 t | 3,282,396 t | 3,301,360 t |
| Projected female spawning biomass (t) | 1,040,900 t | 996,044 t | 816,003 t | 780,284 t |
| $B_{100\%}$ (B_0 for Tier 1a) | 1,528,700 t | 1,528,700 t | 1,890,560 t | 1,890,560 t |
| $B_{40\%}$ | - | - | 756,223 t | 756,223 t |
| $B_{35\%}$ (B_{MSY} for Tier 1a) | 559,704 t | 559,704 t | 661,695 t | 661,695 t |
| F_{OFL} | 0.124 | 0.124 | 0.14 | 0.14 |
| $maxF_{ABC}$ | 0.114 | 0.114 | 0.117 | 0.117 |
| F_{ABC} | 0.114 | 0.114 | 0.117 | 0.117 |
| OFL (t) | 341,571 t | 374,982 t | 220,127 t | 226,860 t |
| $maxABC$ | 313,477 t | 344,140 t | 185,284 t | 190,898 t |
| ABC (t) | 313,477 t | 344,140 t | 185,284 t | 190,898 t |
| Status | 2019 | 2020 | 2020 | 2021 |
| Overfishing | No | n/a | No | n/a |
| Overfished | n/a | No | n/a | No |
| Approaching overfished | n/a | No | n/a | No |

Projections were based on estimated catches of 108,157 t in 2021 and 126,929 t used in place of maximum ABC for 2022.

Table 4.2: Foreign and domestic catch (t) of Yellowfin Sole 1954-2021. Foreign catches are designated as joint venture processing (JVP), and non-foreign catches as domestic annual processing (DAP). Domestic catch since 1991 is subdivided into catch from the Aleutian Islands and the Bering Sea. Catch for 2021 was downloaded October 13, 2021.

| Year | Foreign | Domestic | | | | Total |
|------|---------|----------|---------|------------------|------------|---------|
| | | JVP | DAP | Aleutian Islands | Bering Sea | |
| 1954 | 12,562 | | | | | 12,562 |
| 1955 | 14,690 | | | | | 14,690 |
| 1956 | 24,697 | | | | | 24,697 |
| 1957 | 24,145 | | | | | 24,145 |
| 1958 | 44,153 | | | | | 44,153 |
| 1959 | 185,321 | | | | | 185,321 |
| 1960 | 456,103 | | | | | 456,103 |
| 1961 | 553,742 | | | | | 553,742 |
| 1962 | 420,703 | | | | | 420,703 |
| 1963 | 85,810 | | | | | 85,810 |
| 1964 | 111,777 | | | | | 111,777 |
| 1965 | 53,810 | | | | | 53,810 |
| 1966 | 102,353 | | | | | 102,353 |
| 1967 | 162,228 | | | | | 162,228 |
| 1968 | 84,189 | | | | | 84,189 |
| 1969 | 167,134 | | | | | 167,134 |
| 1970 | 133,079 | | | | | 133,079 |
| 1971 | 160,399 | | | | | 160,399 |
| 1972 | 47,856 | | | | | 47,856 |
| 1973 | 78,240 | | | | | 78,240 |
| 1974 | 42,235 | | | | | 42,235 |
| 1975 | 64,690 | | | | | 64,690 |
| 1976 | 56,221 | | | | | 56,221 |
| 1977 | 58,373 | | | | | 58,373 |
| 1978 | 138,433 | | | | | 138,433 |
| 1979 | 99,019 | | | | | 99,019 |
| 1980 | 77,768 | 9,623 | | | | 87,391 |
| 1981 | 81,255 | 16,046 | | | | 97,301 |
| 1982 | 78,331 | 17,381 | | | | 95,712 |
| 1983 | 85,874 | 22,511 | | | | 108,385 |
| 1984 | 126,762 | 32,764 | | | | 159,526 |
| 1985 | 100,706 | 126,401 | | | | 227,107 |
| 1986 | 57,197 | 151,400 | | | | 208,597 |
| 1987 | 1,811 | 179,613 | 4 | | | 181,428 |
| 1988 | | 213,323 | 9,833 | | | 223,156 |
| 1989 | | 151,501 | 1,664 | | | 153,165 |
| 1990 | | 69,677 | 14,293 | | | 83,970 |
| 1991 | | | 117,303 | | 117,303 | 117,303 |
| 1992 | | | 145,386 | 3.6 | 145,382 | 145,386 |
| 1993 | | | 105,810 | | 105,810 | 105,810 |
| 1994 | | | 140,050 | 0.2 | 140,050 | 140,050 |
| 1995 | | | 124,752 | 5.6 | 124,746 | 124,752 |
| 1996 | | | 129,659 | 0.4 | 129,659 | 129,659 |
| 1997 | | | 182,814 | 1.2 | 182,813 | 182,814 |
| 1998 | | | 101,155 | 4.7 | 101,150 | 101,155 |
| 1999 | | | 69,234 | 12.8 | 69,221 | 69,234 |

| | | | | |
|------|---------|------|---------|---------|
| 2000 | 84,071 | 12.5 | 84,058 | 84,071 |
| 2001 | 63,579 | 14.5 | 63,564 | 63,579 |
| 2002 | 74,986 | 28.5 | 74,957 | 74,986 |
| 2003 | 79,806 | 0.4 | 79,806 | 79,806 |
| 2004 | 75,511 | 8.8 | 75,502 | 75,511 |
| 2005 | 94,385 | 1.8 | 94,383 | 94,385 |
| 2006 | 99,160 | 3.8 | 99,156 | 99,160 |
| 2007 | 120,964 | 2.4 | 120,962 | 120,964 |
| 2008 | 148,894 | 0.5 | 148,893 | 148,894 |
| 2009 | 107,513 | 1.1 | 107,512 | 107,513 |
| 2010 | 118,624 | 0.2 | 118,624 | 118,624 |
| 2011 | 151,158 | 1.1 | 151,157 | 151,158 |
| 2012 | 147,187 | 1.1 | 147,186 | 147,187 |
| 2013 | 164,944 | 0.3 | 164,944 | 164,944 |
| 2014 | 156,772 | 0.3 | 156,772 | 156,772 |
| 2015 | 126,937 | 0.0 | 126,937 | 126,937 |
| 2016 | 135,324 | 0.2 | 135,324 | 135,324 |
| 2017 | 132,220 | 0.6 | 132,219 | 132,220 |
| 2018 | 131,496 | 4.5 | 131,491 | 131,496 |
| 2019 | 128,051 | 4.6 | 129,061 | 128,051 |
| 2020 | 133,800 | 11.1 | 133,789 | 133,800 |
| 2021 | 88,895 | 53.9 | 88,841 | 88,895 |

Table 4.3: Estimates of retained and discarded (t) Yellowfin Sole caught in Bering Sea fisheries from 1991 through October 12th, 2021, and the proportion discarded.

| Year | Retained (t) | Discarded (t) | Proportion discarded |
|------|--------------|---------------|----------------------|
| 1991 | 88,967 | 28,337 | 0.24 |
| 1992 | 102,542 | 42,840 | 0.29 |
| 1993 | 76,798 | 29,012 | 0.27 |
| 1994 | 104,918 | 35,132 | 0.25 |
| 1995 | 96,767 | 27,980 | 0.22 |
| 1996 | 101,324 | 28,335 | 0.22 |
| 1997 | 150,745 | 32,068 | 0.18 |
| 1998 | 80,263 | 20,887 | 0.21 |
| 1999 | 56,604 | 12,617 | 0.18 |
| 2000 | 69,971 | 14,087 | 0.17 |
| 2001 | 54,918 | 8,646 | 0.14 |
| 2002 | 63,625 | 11,332 | 0.15 |
| 2003 | 68,832 | 10,974 | 0.14 |
| 2004 | 62,746 | 12,756 | 0.17 |
| 2005 | 85,311 | 9,072 | 0.1 |
| 2006 | 90,592 | 8,564 | 0.09 |
| 2007 | 109,004 | 11,958 | 0.1 |
| 2008 | 141,235 | 7,659 | 0.05 |
| 2009 | 100,642 | 6,870 | 0.06 |
| 2010 | 113,244 | 5,379 | 0.05 |
| 2011 | 146,418 | 4,739 | 0.03 |
| 2012 | 142,132 | 5,054 | 0.03 |
| 2013 | 158,781 | 6,163 | 0.04 |
| 2014 | 152,167 | 4,605 | 0.03 |
| 2015 | 123,065 | 3,871 | 0.03 |
| 2016 | 131,202 | 4,121 | 0.03 |
| 2017 | 128,665 | 3,554 | 0.03 |
| 2018 | 127,331 | 4,160 | 0.03 |
| 2019 | 126,111 | 2,951 | 0.02 |
| 2020 | 131,774 | 2,014 | 0.02 |
| 2021 | 87,227 | 1,614 | 0.02 |

Table 4.4: Discarded and retained catch of non-CDQ Yellowfin Sole, by fishery, in 2020. Gear types include longline (HAL), bottom trawl (NPT), pot (POT), and pelagic trawl (PTR). Catch was non-zero for all target-gear combinations shown, but may appear as zero as results were rounded to the nearest metric ton (t). Source: NMFS AKRO BLEND/Catch Accounting System.

| Trip target name | Gear type | Discarded (t) | Retained (t) |
|---------------------|-----------|---------------|--------------|
| Halibut | HAL | 0 | 0 |
| Pacific Cod | HAL | 443 | 26 |
| Alaska Plaice | NPT | 1 | 60 |
| Arrowtooth Flounder | NPT | 0 | 0 |
| Atka Mackerel | NPT | 10 | 819 |
| Flathead Sole | NPT | 0 | 0 |
| Halibut | NPT | 0 | 0 |
| Other Flatfish | NPT | 0 | 0 |
| Other Species | NPT | 6 | 141 |
| Pacific Cod | NPT | 6 | 507 |
| Pollock - midwater | NPT | 126 | 10,098 |
| Rock Sole | NPT | 0 | 0 |
| Rockfish | NPT | 1,074 | 119,471 |
| Flathead Sole | POT | 0 | 0 |
| Other Flatfish | POT | 185 | 12 |
| Pollock - midwater | POT | 0 | 0 |
| Alaska Plaice | PTR | 0 | 1 |
| Other Flatfish | PTR | 70 | 405 |
| Other Species | PTR | 92 | 124 |
| Pollock - midwater | PTR | 0 | 2 |

Table 4.5: Occurrence of Yellowfin Sole in the eastern Bering Sea trawl survey and collections of length and age structures and the number of otoliths aged from the survey. The final column represents the number of otoliths read in each year from the fishery.

| Year | Total hauls | Hauls with length | Number of lengths | Hauls with otoliths | Hauls with ages | N. ages (survey) | N. ages (fishery) |
|------|-------------|-------------------|-------------------|---------------------|-----------------|------------------|-------------------|
| 1982 | 334 | 246 | 37023 | 35 | 35 | 744 | 2432 |
| 1983 | 353 | 256 | 33924 | 37 | 37 | 709 | 1178 |
| 1984 | 355 | 271 | 33894 | 56 | 56 | 796 | 338 |
| 1985 | 357 | 261 | 33824 | 44 | 43 | 802 | 840 |
| 1986 | 354 | 249 | 30470 | 34 | 34 | 739 | 1503 |
| 1987 | 357 | 224 | 31241 | 16 | 16 | 798 | 1071 |
| 1988 | 373 | 254 | 27138 | 14 | 14 | 543 | 1361 |
| 1989 | 374 | 236 | 29672 | 24 | 24 | 740 | 1462 |
| 1990 | 371 | 251 | 30257 | 28 | 28 | 792 | 1220 |
| 1991 | 372 | 248 | 27986 | 26 | 26 | 742 | 935 |
| 1992 | 356 | 229 | 23628 | 16 | 16 | 606 | 1203 |
| 1993 | 375 | 242 | 26651 | 20 | 20 | 549 | 1020 |
| 1994 | 375 | 269 | 24448 | 14 | 14 | 522 | 573 |
| 1995 | 376 | 254 | 22116 | 20 | 20 | 647 | 554 |
| 1996 | 375 | 247 | 27505 | 16 | 16 | 721 | 314 |
| 1997 | 376 | 262 | 26034 | 11 | 11 | 466 | 397 |
| 1998 | 375 | 310 | 34509 | 15 | 15 | 570 | 426 |
| 1999 | 373 | 276 | 28431 | 31 | 31 | 770 | 487 |
| 2000 | 372 | 255 | 24880 | 20 | 20 | 511 | 583 |
| 2001 | 375 | 251 | 26558 | 25 | 25 | 593 | 491 |
| 2002 | 375 | 246 | 26309 | 32 | 32 | 723 | 486 |
| 2003 | 376 | 241 | 27135 | 37 | 37 | 695 | 590 |
| 2004 | 375 | 251 | 26103 | 26 | 26 | 712 | 483 |
| 2005 | 373 | 251 | 24658 | 34 | 34 | 635 | 494 |
| 2006 | 376 | 246 | 28470 | 39 | 39 | 426 | 490 |
| 2007 | 376 | 247 | 24790 | 66 | 66 | 772 | 496 |
| 2008 | 375 | 238 | 25848 | 65 | 65 | 830 | 542 |
| 2009 | 376 | 235 | 22018 | 70 | 70 | 752 | 515 |
| 2010 | 376 | 228 | 20619 | 77 | 77 | 827 | 535 |
| 2011 | 376 | 228 | 21665 | 65 | 64 | 753 | 525 |
| 2012 | 376 | 242 | 23519 | 72 | 72 | 973 | 504 |
| 2013 | 376 | 232 | 23261 | 70 | 70 | 803 | 670 |
| 2014 | 376 | 219 | 20229 | 52 | 52 | 790 | 502 |
| 2015 | 376 | 223 | 20830 | 73 | 73 | 875 | 622 |
| 2016 | 376 | 242 | 26674 | 69 | 69 | 876 | 495 |
| 2017 | 376 | 258 | 25767 | 78 | 78 | 886 | 595 |
| 2018 | 376 | 255 | 1830 | 68 | 68 | 720 | 608 |
| 2019 | 376 | 270 | 25669 | 67 | 67 | 836 | 589 |
| 2020 | | | | | | | 660 |
| 2021 | 376 | 234 | 18757 | 201 | | 1030 | |

Table 4.6: Yellowfin Sole fishery catch-at-age (proportions), 1975-2020 female first then male, ages 7-17+.

| Year | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17+ | Total female proportion over age 7 |
|------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|------------------------------------|
| 1975 | 0.1112 | 0.2795 | 0.2636 | 0.1140 | 0.0608 | 0.0316 | 0.0250 | 0.0300 | 0.0096 | 0.0085 | 0.0052 | 0.9390 |
| 1976 | 0.0951 | 0.1572 | 0.2548 | 0.2016 | 0.0875 | 0.0480 | 0.0254 | 0.0201 | 0.0243 | 0.0078 | 0.0069 | 0.9287 |
| 1977 | 0.1748 | 0.1953 | 0.1551 | 0.1354 | 0.0728 | 0.0265 | 0.0136 | 0.0070 | 0.0056 | 0.0067 | 0.0021 | 0.7949 |
| 1978 | 0.0935 | 0.2043 | 0.2262 | 0.1647 | 0.1328 | 0.0679 | 0.0241 | 0.0122 | 0.0063 | 0.0049 | 0.0059 | 0.9428 |
| 1979 | 0.0609 | 0.1422 | 0.2180 | 0.1926 | 0.1274 | 0.0995 | 0.0504 | 0.0178 | 0.0090 | 0.0046 | 0.0036 | 0.9260 |
| 1980 | 0.0632 | 0.0704 | 0.1316 | 0.1880 | 0.1689 | 0.1158 | 0.0929 | 0.0478 | 0.0170 | 0.0087 | 0.0045 | 0.9088 |
| 1981 | 0.0765 | 0.0997 | 0.0938 | 0.1434 | 0.1717 | 0.1367 | 0.0873 | 0.0674 | 0.0340 | 0.0120 | 0.0061 | 0.9286 |
| 1982 | 0.0586 | 0.1348 | 0.1356 | 0.0982 | 0.1245 | 0.1340 | 0.1011 | 0.0630 | 0.0481 | 0.0242 | 0.0085 | 0.9306 |
| 1983 | 0.0940 | 0.1009 | 0.1589 | 0.1245 | 0.0799 | 0.0965 | 0.1020 | 0.0764 | 0.0475 | 0.0362 | 0.0182 | 0.9350 |
| 1984 | 0.0347 | 0.0948 | 0.0991 | 0.1562 | 0.1231 | 0.0793 | 0.0959 | 0.1014 | 0.0760 | 0.0472 | 0.0360 | 0.9437 |
| 1985 | 0.0198 | 0.0561 | 0.1183 | 0.1017 | 0.1457 | 0.1109 | 0.0706 | 0.0851 | 0.0899 | 0.0674 | 0.0419 | 0.9074 |
| 1986 | 0.0518 | 0.0524 | 0.0977 | 0.1379 | 0.0942 | 0.1222 | 0.0896 | 0.0563 | 0.0675 | 0.0712 | 0.0533 | 0.8941 |
| 1987 | 0.0173 | 0.0483 | 0.0415 | 0.0826 | 0.1295 | 0.0939 | 0.1250 | 0.0925 | 0.0583 | 0.0701 | 0.0739 | 0.8329 |
| 1988 | 0.0491 | 0.0438 | 0.1050 | 0.0630 | 0.0900 | 0.1169 | 0.0781 | 0.1008 | 0.0737 | 0.0463 | 0.0555 | 0.8222 |
| 1989 | 0.0049 | 0.0779 | 0.0608 | 0.1193 | 0.0621 | 0.0838 | 0.1069 | 0.0711 | 0.0916 | 0.0670 | 0.0421 | 0.7875 |
| 1990 | 0.0388 | 0.0227 | 0.2247 | 0.0921 | 0.1113 | 0.0467 | 0.0588 | 0.0735 | 0.0486 | 0.0626 | 0.0457 | 0.8255 |
| 1991 | 0.0173 | 0.1013 | 0.0365 | 0.2415 | 0.0815 | 0.0931 | 0.0386 | 0.0485 | 0.0608 | 0.0402 | 0.0517 | 0.8110 |
| 1992 | 0.0158 | 0.0399 | 0.1736 | 0.0447 | 0.2331 | 0.0696 | 0.0757 | 0.0308 | 0.0385 | 0.0480 | 0.0318 | 0.8015 |
| 1993 | 0.0216 | 0.0248 | 0.0455 | 0.1637 | 0.0398 | 0.2107 | 0.0648 | 0.0720 | 0.0297 | 0.0374 | 0.0470 | 0.7570 |
| 1994 | 0.0376 | 0.0551 | 0.0561 | 0.0761 | 0.2009 | 0.0389 | 0.1785 | 0.0507 | 0.0541 | 0.0219 | 0.0272 | 0.7971 |
| 1995 | 0.0491 | 0.0900 | 0.0819 | 0.0588 | 0.0684 | 0.1714 | 0.0327 | 0.1491 | 0.0423 | 0.0451 | 0.0182 | 0.8070 |
| 1996 | 0.0257 | 0.0777 | 0.0968 | 0.0743 | 0.0516 | 0.0603 | 0.1523 | 0.0292 | 0.1336 | 0.0380 | 0.0405 | 0.7800 |
| 1997 | 0.0273 | 0.0373 | 0.0959 | 0.1035 | 0.0723 | 0.0478 | 0.0545 | 0.1364 | 0.0260 | 0.1189 | 0.0338 | 0.7537 |
| 1998 | 0.0755 | 0.0525 | 0.0564 | 0.1129 | 0.1018 | 0.0642 | 0.0403 | 0.0449 | 0.1110 | 0.0211 | 0.0962 | 0.7768 |
| 1999 | 0.0107 | 0.0442 | 0.0402 | 0.0533 | 0.1187 | 0.1109 | 0.0706 | 0.0444 | 0.0494 | 0.1223 | 0.0232 | 0.6879 |
| 2000 | 0.0097 | 0.0276 | 0.0928 | 0.0617 | 0.0606 | 0.1133 | 0.0985 | 0.0611 | 0.0381 | 0.0424 | 0.1047 | 0.7105 |
| 2001 | 0.0211 | 0.0425 | 0.0783 | 0.1541 | 0.0667 | 0.0521 | 0.0888 | 0.0747 | 0.0458 | 0.0285 | 0.0316 | 0.6842 |
| 2002 | 0.0247 | 0.0254 | 0.0513 | 0.0879 | 0.1594 | 0.0657 | 0.0501 | 0.0847 | 0.0710 | 0.0435 | 0.0270 | 0.6907 |
| 2003 | 0.0186 | 0.0929 | 0.0630 | 0.0772 | 0.0910 | 0.1377 | 0.0531 | 0.0397 | 0.0666 | 0.0557 | 0.0341 | 0.7296 |
| 2004 | 0.0182 | 0.0442 | 0.1588 | 0.0762 | 0.0743 | 0.0790 | 0.1150 | 0.0438 | 0.0326 | 0.0546 | 0.0457 | 0.7424 |
| 2005 | 0.0304 | 0.0404 | 0.0663 | 0.1742 | 0.0704 | 0.0642 | 0.0668 | 0.0968 | 0.0368 | 0.0274 | 0.0459 | 0.7196 |
| 2006 | 0.1103 | 0.0904 | 0.0695 | 0.0743 | 0.1500 | 0.0528 | 0.0452 | 0.0457 | 0.0654 | 0.0248 | 0.0184 | 0.7468 |
| 2007 | 0.0280 | 0.0748 | 0.0731 | 0.0661 | 0.0770 | 0.1611 | 0.0576 | 0.0495 | 0.0502 | 0.0719 | 0.0272 | 0.7365 |
| 2008 | 0.0418 | 0.0559 | 0.1129 | 0.0835 | 0.0633 | 0.0679 | 0.1373 | 0.0484 | 0.0414 | 0.0419 | 0.0600 | 0.7543 |
| 2009 | 0.0327 | 0.0767 | 0.0795 | 0.1233 | 0.0791 | 0.0567 | 0.0596 | 0.1196 | 0.0421 | 0.0360 | 0.0364 | 0.7417 |
| 2010 | 0.0566 | 0.0672 | 0.0956 | 0.0753 | 0.1077 | 0.0681 | 0.0488 | 0.0513 | 0.1032 | 0.0363 | 0.0310 | 0.7411 |
| 2011 | 0.0244 | 0.1018 | 0.0936 | 0.1043 | 0.0710 | 0.0950 | 0.0586 | 0.0416 | 0.0436 | 0.0876 | 0.0308 | 0.7523 |
| 2012 | 0.0299 | 0.0491 | 0.1450 | 0.1002 | 0.0959 | 0.0614 | 0.0806 | 0.0494 | 0.0350 | 0.0366 | 0.0736 | 0.7567 |
| 2013 | 0.0140 | 0.0346 | 0.0616 | 0.1660 | 0.1034 | 0.0935 | 0.0585 | 0.0760 | 0.0464 | 0.0328 | 0.0344 | 0.7212 |
| 2014 | 0.0151 | 0.0446 | 0.0716 | 0.0786 | 0.1614 | 0.0917 | 0.0809 | 0.0503 | 0.0653 | 0.0398 | 0.0282 | 0.7275 |
| 2015 | 0.0151 | 0.0284 | 0.0596 | 0.0742 | 0.0739 | 0.1505 | 0.0862 | 0.0765 | 0.0477 | 0.0620 | 0.0379 | 0.7120 |
| 2016 | 0.0333 | 0.0517 | 0.0730 | 0.1007 | 0.0854 | 0.0675 | 0.1238 | 0.0682 | 0.0597 | 0.0370 | 0.0481 | 0.7484 |
| 2017 | 0.0231 | 0.1174 | 0.1134 | 0.0969 | 0.0951 | 0.0684 | 0.0507 | 0.0909 | 0.0496 | 0.0433 | 0.0269 | 0.7757 |
| 2018 | 0.0074 | 0.0325 | 0.1377 | 0.1161 | 0.0932 | 0.0896 | 0.0641 | 0.0474 | 0.0850 | 0.0464 | 0.0405 | 0.7599 |
| 2019 | 0.0225 | 0.0164 | 0.0537 | 0.1680 | 0.1158 | 0.0844 | 0.0781 | 0.0551 | 0.0406 | 0.0726 | 0.0396 | 0.7468 |
| 2020 | 0.0404 | 0.0633 | 0.0313 | 0.0686 | 0.1656 | 0.1006 | 0.0696 | 0.0631 | 0.0442 | 0.0324 | 0.0580 | 0.7371 |

| Year | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17+ | Total male proportion over age 7 |
|------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|----------------------------------|
| 1975 | 0.2028 | 0.3634 | 0.2190 | 0.0645 | 0.0348 | 0.0112 | 0.0064 | 0.0081 | 0.0016 | 0.0010 | 0.0005 | 0.9133 |
| 1976 | 0.0979 | 0.1723 | 0.2957 | 0.2218 | 0.0754 | 0.0432 | 0.0142 | 0.0081 | 0.0103 | 0.0021 | 0.0013 | 0.9423 |
| 1977 | 0.1015 | 0.2259 | 0.2442 | 0.2256 | 0.1111 | 0.0313 | 0.0167 | 0.0054 | 0.0031 | 0.0038 | 0.0008 | 0.9694 |
| 1978 | 0.0863 | 0.1927 | 0.2294 | 0.1763 | 0.1481 | 0.0720 | 0.0203 | 0.0109 | 0.0035 | 0.0020 | 0.0025 | 0.9440 |
| 1979 | 0.0620 | 0.1488 | 0.2293 | 0.1985 | 0.1274 | 0.0990 | 0.0467 | 0.0130 | 0.0069 | 0.0022 | 0.0013 | 0.9351 |
| 1980 | 0.0513 | 0.0555 | 0.1089 | 0.1739 | 0.1773 | 0.1354 | 0.1200 | 0.0618 | 0.0181 | 0.0100 | 0.0033 | 0.9155 |
| 1981 | 0.0768 | 0.0943 | 0.0885 | 0.1401 | 0.1746 | 0.1410 | 0.0893 | 0.0694 | 0.0328 | 0.0091 | 0.0049 | 0.9208 |
| 1982 | 0.0797 | 0.1545 | 0.1365 | 0.0923 | 0.1139 | 0.1208 | 0.0888 | 0.0535 | 0.0405 | 0.0189 | 0.0052 | 0.9046 |
| 1983 | 0.1033 | 0.1058 | 0.1608 | 0.1241 | 0.0792 | 0.0955 | 0.1005 | 0.0737 | 0.0443 | 0.0335 | 0.0156 | 0.9363 |
| 1984 | 0.0446 | 0.1195 | 0.1104 | 0.1579 | 0.1190 | 0.0753 | 0.0907 | 0.0953 | 0.0699 | 0.0420 | 0.0318 | 0.9564 |
| 1985 | 0.0306 | 0.0844 | 0.1447 | 0.1051 | 0.1386 | 0.1021 | 0.0643 | 0.0772 | 0.0812 | 0.0595 | 0.0358 | 0.9235 |
| 1986 | 0.0660 | 0.0623 | 0.1026 | 0.1363 | 0.0917 | 0.1186 | 0.0870 | 0.0547 | 0.0657 | 0.0690 | 0.0506 | 0.9045 |
| 1987 | 0.0264 | 0.1005 | 0.0699 | 0.0991 | 0.1267 | 0.0845 | 0.1092 | 0.0800 | 0.0503 | 0.0604 | 0.0635 | 0.8705 |
| 1988 | 0.0641 | 0.0682 | 0.1378 | 0.0658 | 0.0847 | 0.1064 | 0.0708 | 0.0914 | 0.0670 | 0.0421 | 0.0506 | 0.8489 |
| 1989 | 0.0049 | 0.0930 | 0.0760 | 0.1331 | 0.0621 | 0.0801 | 0.1008 | 0.0671 | 0.0867 | 0.0635 | 0.0399 | 0.8072 |
| 1990 | 0.0799 | 0.0409 | 0.2874 | 0.0898 | 0.0943 | 0.0375 | 0.0466 | 0.0581 | 0.0386 | 0.0499 | 0.0365 | 0.8595 |
| 1991 | 0.0231 | 0.1715 | 0.0520 | 0.2672 | 0.0758 | 0.0779 | 0.0308 | 0.0382 | 0.0477 | 0.0317 | 0.0409 | 0.8568 |
| 1992 | 0.0223 | 0.0578 | 0.2185 | 0.0481 | 0.2291 | 0.0642 | 0.0659 | 0.0261 | 0.0323 | 0.0404 | 0.0268 | 0.8315 |
| 1993 | 0.0266 | 0.0300 | 0.0532 | 0.1810 | 0.0418 | 0.2133 | 0.0626 | 0.0660 | 0.0265 | 0.0330 | 0.0414 | 0.7754 |
| 1994 | 0.0521 | 0.0724 | 0.0652 | 0.0805 | 0.2007 | 0.0377 | 0.1710 | 0.0472 | 0.0482 | 0.0190 | 0.0236 | 0.8176 |
| 1995 | 0.0628 | 0.1090 | 0.0909 | 0.0617 | 0.0691 | 0.1678 | 0.0313 | 0.1417 | 0.0391 | 0.0399 | 0.0158 | 0.8291 |
| 1996 | 0.0394 | 0.1060 | 0.1147 | 0.0788 | 0.0510 | 0.0567 | 0.1379 | 0.0258 | 0.1166 | 0.0322 | 0.0329 | 0.7920 |
| 1997 | 0.0329 | 0.0464 | 0.1150 | 0.1161 | 0.0767 | 0.0487 | 0.0537 | 0.1301 | 0.0243 | 0.1099 | 0.0303 | 0.7841 |
| 1998 | 0.0426 | 0.0472 | 0.0645 | 0.1345 | 0.1187 | 0.0732 | 0.0451 | 0.0492 | 0.1187 | 0.0221 | 0.1000 | 0.8158 |
| 1999 | 0.0091 | 0.0360 | 0.0333 | 0.0481 | 0.1188 | 0.1182 | 0.0771 | 0.0486 | 0.0535 | 0.1293 | 0.0241 | 0.6961 |
| 2000 | 0.0095 | 0.0284 | 0.1003 | 0.0681 | 0.0659 | 0.1203 | 0.1025 | 0.0627 | 0.0386 | 0.0421 | 0.1015 | 0.7399 |
| 2001 | 0.0084 | 0.0185 | 0.0436 | 0.1206 | 0.0687 | 0.0618 | 0.1109 | 0.0945 | 0.0580 | 0.0357 | 0.0390 | 0.6597 |
| 2002 | 0.0212 | 0.0305 | 0.0711 | 0.1120 | 0.1799 | 0.0685 | 0.0496 | 0.0809 | 0.0664 | 0.0401 | 0.0246 | 0.7448 |
| 2003 | 0.0218 | 0.1409 | 0.0887 | 0.0897 | 0.0942 | 0.1349 | 0.0501 | 0.0361 | 0.0588 | 0.0482 | 0.0291 | 0.7925 |
| 2004 | 0.0184 | 0.0483 | 0.1778 | 0.0835 | 0.0793 | 0.0831 | 0.1194 | 0.0444 | 0.0320 | 0.0521 | 0.0428 | 0.7811 |
| 2005 | 0.0381 | 0.0549 | 0.0851 | 0.2003 | 0.0740 | 0.0641 | 0.0652 | 0.0928 | 0.0344 | 0.0248 | 0.0404 | 0.7741 |
| 2006 | 0.1135 | 0.1036 | 0.0779 | 0.0814 | 0.1612 | 0.0559 | 0.0474 | 0.0479 | 0.0680 | 0.0252 | 0.0181 | 0.8001 |
| 2007 | 0.0452 | 0.1154 | 0.0935 | 0.0720 | 0.0764 | 0.1521 | 0.0529 | 0.0449 | 0.0453 | 0.0643 | 0.0238 | 0.7858 |
| 2008 | 0.0537 | 0.0700 | 0.1289 | 0.0885 | 0.0645 | 0.0675 | 0.1337 | 0.0464 | 0.0394 | 0.0398 | 0.0565 | 0.7889 |
| 2009 | 0.0338 | 0.0732 | 0.0784 | 0.1274 | 0.0834 | 0.0600 | 0.0625 | 0.1239 | 0.0430 | 0.0365 | 0.0368 | 0.7589 |
| 2010 | 0.0927 | 0.1060 | 0.1209 | 0.0796 | 0.1029 | 0.0620 | 0.0435 | 0.0449 | 0.0888 | 0.0308 | 0.0261 | 0.7982 |
| 2011 | 0.0376 | 0.1428 | 0.1105 | 0.1090 | 0.0696 | 0.0894 | 0.0539 | 0.0378 | 0.0390 | 0.0772 | 0.0268 | 0.7936 |
| 2012 | 0.0494 | 0.0755 | 0.1783 | 0.1047 | 0.0931 | 0.0576 | 0.0733 | 0.0441 | 0.0309 | 0.0319 | 0.0630 | 0.8018 |
| 2013 | 0.0233 | 0.0508 | 0.0748 | 0.1762 | 0.1039 | 0.0927 | 0.0574 | 0.0731 | 0.0439 | 0.0308 | 0.0318 | 0.7587 |
| 2014 | 0.0275 | 0.0763 | 0.0956 | 0.0846 | 0.1581 | 0.0868 | 0.0760 | 0.0468 | 0.0596 | 0.0358 | 0.0251 | 0.7722 |
| 2015 | 0.0200 | 0.0427 | 0.0878 | 0.0934 | 0.0798 | 0.1492 | 0.0822 | 0.0721 | 0.0444 | 0.0565 | 0.0340 | 0.7621 |
| 2016 | 0.0380 | 0.0641 | 0.0897 | 0.1135 | 0.0886 | 0.0670 | 0.1206 | 0.0657 | 0.0575 | 0.0354 | 0.0450 | 0.7851 |
| 2017 | 0.0167 | 0.0900 | 0.1012 | 0.0993 | 0.1038 | 0.0758 | 0.0563 | 0.1011 | 0.0551 | 0.0481 | 0.0296 | 0.7770 |
| 2018 | 0.0081 | 0.0416 | 0.1764 | 0.1351 | 0.0983 | 0.0876 | 0.0598 | 0.0433 | 0.0770 | 0.0418 | 0.0365 | 0.8055 |
| 2019 | 0.0268 | 0.0218 | 0.0691 | 0.1965 | 0.1251 | 0.0858 | 0.0753 | 0.0512 | 0.0370 | 0.0658 | 0.0357 | 0.7901 |
| 2020 | 0.0442 | 0.0695 | 0.0341 | 0.0736 | 0.1755 | 0.1053 | 0.0709 | 0.0619 | 0.0420 | 0.0304 | 0.0540 | 0.7614 |

Table 4.7: Female Yellowfin Sole proportion mature at age from Nichol (1995) and TenBrink and Wilderbuer (2015).

| Age | Nichol (1995) | TenBrink and Wilderbuer (2015) | Total |
|-----|--------------------|--------------------------------|----------|
| | 1992, 1993 samples | 2012 samples | Combined |
| 1 | 0.000 | 0.00 | 0.00 |
| 2 | 0.000 | 0.00 | 0.00 |
| 3 | 0.001 | 0.00 | 0.00 |
| 4 | 0.004 | 0.00 | 0.00 |
| 5 | 0.008 | 0.00 | 0.00 |
| 6 | 0.020 | 0.01 | 0.01 |
| 7 | 0.046 | 0.03 | 0.04 |
| 8 | 0.104 | 0.09 | 0.10 |
| 9 | 0.217 | 0.21 | 0.21 |
| 10 | 0.397 | 0.43 | 0.41 |
| 11 | 0.612 | 0.68 | 0.65 |
| 12 | 0.790 | 0.86 | 0.83 |
| 13 | 0.899 | 0.94 | 0.92 |
| 14 | 0.955 | 0.98 | 0.97 |
| 15 | 0.981 | 0.99 | 0.99 |
| 16 | 0.992 | 1.00 | 1.00 |
| 17 | 0.997 | 1.00 | 1.00 |
| 18 | 1.000 | 1.00 | 1.00 |
| 19 | 1.000 | 1.00 | 1.00 |
| 20 | 1.000 | 1.00 | 1.00 |

Table 4.8: Yellowfin Sole biomass estimates (t) from the annual Bering Sea shelf bottom trawl survey, with upper and lower 95% confidence intervals, based on Model 18.2. Note that this survey was not conducted in 2020.

| Year | Biomass (t) | Lower confidence interval | Upper confidence interval |
|------|-------------|---------------------------|---------------------------|
| 1982 | 3,509,130 | 3,508,559 | 3,509,700 |
| 1983 | 3,672,420 | 3,672,015 | 3,672,824 |
| 1984 | 3,341,320 | 3,340,953 | 3,341,686 |
| 1985 | 2,398,080 | 2,397,771 | 2,398,388 |
| 1986 | 2,031,600 | 2,031,298 | 2,031,901 |
| 1987 | 2,511,840 | 2,511,457 | 2,512,222 |
| 1988 | 2,180,750 | 2,180,341 | 2,181,158 |
| 1989 | 2,313,620 | 2,313,280 | 2,313,959 |
| 1990 | 2,179,610 | 2,179,314 | 2,179,905 |
| 1991 | 2,391,860 | 2,391,585 | 2,392,134 |
| 1992 | 2,201,520 | 2,201,135 | 2,201,904 |
| 1993 | 2,468,430 | 2,468,119 | 2,468,740 |
| 1994 | 2,597,190 | 2,596,851 | 2,597,528 |
| 1995 | 2,012,400 | 2,012,117 | 2,012,682 |
| 1996 | 2,216,500 | 2,216,118 | 2,216,881 |
| 1997 | 2,161,400 | 2,161,147 | 2,161,652 |
| 1998 | 2,210,180 | 2,209,904 | 2,210,455 |
| 1999 | 1,257,180 | 1,257,000 | 1,257,359 |
| 2000 | 1,589,780 | 1,589,581 | 1,589,978 |
| 2001 | 1,679,520 | 1,679,280 | 1,679,759 |
| 2002 | 1,910,070 | 1,909,812 | 1,910,327 |
| 2003 | 2,158,130 | 2,157,723 | 2,158,536 |
| 2004 | 2,542,070 | 2,541,689 | 2,542,450 |
| 2005 | 2,820,840 | 2,820,125 | 2,821,554 |
| 2006 | 2,132,480 | 2,132,168 | 2,132,791 |
| 2007 | 2,153,090 | 2,152,712 | 2,153,467 |
| 2008 | 2,099,670 | 2,099,169 | 2,100,170 |
| 2009 | 1,739,430 | 1,739,132 | 1,739,727 |
| 2010 | 2,368,260 | 2,367,710 | 2,368,809 |
| 2011 | 2,403,220 | 2,402,743 | 2,403,696 |
| 2012 | 1,951,410 | 1,951,137 | 1,951,682 |
| 2013 | 2,279,020 | 2,278,678 | 2,279,361 |
| 2014 | 2,512,260 | 2,511,805 | 2,512,714 |
| 2015 | 1,932,350 | 1,932,064 | 1,932,635 |
| 2016 | 2,859,810 | 2,859,485 | 2,860,134 |
| 2017 | 2,787,520 | 2,787,162 | 2,787,877 |
| 2018 | 1,892,920 | 1,892,693 | 1,893,146 |
| 2019 | 2,006,510 | 2,006,096 | 2,006,923 |
| 2021 | 1,622,910 | 1,622,697 | 1,623,122 |

Table 4.9: Model estimates of Yellowfin Sole age 2+ total biomass (t) from the 2020 and 2021 stock assessments, Model 18.2, Model 18.2a, and 18.2b.

| Model | 18.2 (2021) | | | 18.2 (2020) | | | 18.2a (2021) | 18.2b (2021) |
|-------|-------------|-----------|-----------|-------------|-----------|-----------|--------------|--------------|
| | Biomass (t) | LCI | HCI | Biomass (t) | LCI | HCI | Biomass (t) | Biomass (t) |
| 1954 | 2,426,690 | 2,021,580 | 2,912,990 | 2,286,480 | 1,902,960 | 2,747,310 | 2,461,240 | 2,184,110 |
| 1955 | 2,379,370 | 1,999,760 | 2,831,030 | 2,244,950 | 1,882,290 | 2,677,490 | 2,408,180 | 2,099,490 |
| 1956 | 2,320,060 | 1,967,510 | 2,735,780 | 2,198,900 | 1,859,310 | 2,600,510 | 2,339,630 | 2,017,180 |
| 1957 | 2,266,300 | 1,945,330 | 2,640,220 | 2,153,360 | 1,840,490 | 2,519,400 | 2,272,320 | 1,935,570 |
| 1958 | 2,220,480 | 1,934,240 | 2,549,080 | 2,136,280 | 1,859,300 | 2,454,530 | 2,213,600 | 1,879,620 |
| 1959 | 2,177,220 | 1,930,160 | 2,455,900 | 2,132,960 | 1,906,140 | 2,386,770 | 2,156,690 | 1,844,200 |
| 1960 | 2,003,890 | 1,806,910 | 2,222,350 | 2,012,340 | 1,849,180 | 2,189,890 | 1,973,720 | 1,715,360 |
| 1961 | 1,555,590 | 1,421,720 | 1,702,060 | 1,637,170 | 1,543,530 | 1,736,500 | 1,524,930 | 1,369,860 |
| 1962 | 1,069,860 | 1,007,380 | 1,136,220 | 1,199,170 | 1,146,280 | 1,254,500 | 1,045,980 | 980,018 |
| 1963 | 757,854 | 728,526 | 788,362 | 887,952 | 839,583 | 939,108 | 745,908 | 691,580 |
| 1964 | 804,634 | 772,068 | 838,573 | 911,499 | 866,169 | 959,200 | 808,078 | 735,416 |
| 1965 | 804,179 | 767,988 | 842,074 | 892,030 | 851,247 | 934,767 | 813,882 | 731,678 |
| 1966 | 858,369 | 820,252 | 898,258 | 932,953 | 892,498 | 975,242 | 872,192 | 778,998 |
| 1967 | 856,728 | 817,776 | 897,536 | 914,946 | 875,023 | 956,691 | 869,279 | 765,288 |
| 1968 | 786,394 | 748,814 | 825,860 | 838,641 | 799,568 | 879,622 | 795,621 | 686,844 |
| 1969 | 818,403 | 778,145 | 860,745 | 879,883 | 836,550 | 925,462 | 827,331 | 710,449 |
| 1970 | 777,343 | 734,340 | 822,863 | 866,260 | 817,714 | 917,687 | 786,818 | 686,871 |
| 1971 | 1,000,410 | 938,184 | 1,066,760 | 954,861 | 896,886 | 1,016,580 | 1,014,970 | 759,948 |
| 1972 | 1,535,130 | 1,429,830 | 1,648,180 | 1,058,690 | 988,791 | 1,133,540 | 1,563,260 | 878,845 |
| 1973 | 1,320,370 | 1,237,070 | 1,409,270 | 1,353,890 | 1,267,840 | 1,445,780 | 1,341,970 | 1,172,910 |
| 1974 | 1,187,980 | 1,110,060 | 1,271,360 | 1,647,840 | 1,544,370 | 1,758,250 | 1,209,010 | 1,444,580 |
| 1975 | 1,481,560 | 1,385,940 | 1,583,760 | 2,050,800 | 1,925,290 | 2,184,480 | 1,507,390 | 1,752,210 |
| 1976 | 1,574,480 | 1,478,740 | 1,676,430 | 2,409,330 | 2,264,070 | 2,563,900 | 1,599,430 | 2,015,720 |
| 1977 | 1,693,610 | 1,593,460 | 1,800,060 | 2,768,530 | 2,604,430 | 2,942,970 | 1,716,920 | 2,268,880 |
| 1978 | 2,188,460 | 2,064,830 | 2,319,510 | 3,108,590 | 2,926,830 | 3,301,650 | 2,212,180 | 2,526,800 |
| 1979 | 2,452,690 | 2,309,570 | 2,604,670 | 3,304,210 | 3,107,960 | 3,512,850 | 2,477,760 | 2,743,840 |
| 1980 | 2,820,290 | 2,656,980 | 2,993,640 | 3,517,060 | 3,307,890 | 3,739,460 | 2,843,770 | 3,072,270 |
| 1981 | 3,107,690 | 2,929,500 | 3,296,720 | 3,707,350 | 3,487,360 | 3,941,220 | 3,124,640 | 3,441,370 |
| 1982 | 3,583,020 | 3,378,420 | 3,800,010 | 3,840,390 | 3,614,180 | 4,080,760 | 3,590,080 | 3,659,320 |
| 1983 | 3,422,280 | 3,223,350 | 3,633,480 | 3,814,550 | 3,587,200 | 4,056,300 | 3,426,010 | 3,735,240 |
| 1984 | 3,794,790 | 3,576,310 | 4,026,630 | 4,081,170 | 3,838,180 | 4,339,560 | 3,778,470 | 3,865,870 |
| 1985 | 3,841,940 | 3,615,260 | 4,082,830 | 4,104,890 | 3,854,550 | 4,371,490 | 3,814,220 | 3,858,040 |
| 1986 | 3,490,780 | 3,276,460 | 3,719,110 | 3,798,830 | 3,556,460 | 4,057,720 | 3,447,340 | 3,744,080 |
| 1987 | 3,486,120 | 3,264,690 | 3,722,570 | 3,780,260 | 3,531,070 | 4,047,040 | 3,425,270 | 3,741,350 |
| 1988 | 3,186,490 | 2,977,000 | 3,410,720 | 3,675,670 | 3,427,740 | 3,941,550 | 3,120,020 | 3,716,050 |
| 1989 | 3,429,240 | 3,200,190 | 3,674,680 | 3,762,820 | 3,502,760 | 4,042,190 | 3,335,870 | 3,616,930 |
| 1990 | 3,396,500 | 3,164,850 | 3,645,090 | 3,611,280 | 3,356,600 | 3,885,290 | 3,294,160 | 3,567,080 |
| 1991 | 3,511,060 | 3,274,590 | 3,764,610 | 3,739,510 | 3,477,640 | 4,021,110 | 3,398,600 | 3,555,260 |
| 1992 | 3,544,780 | 3,307,550 | 3,799,030 | 3,974,950 | 3,698,850 | 4,271,670 | 3,424,340 | 3,489,780 |
| 1993 | 3,714,790 | 3,466,950 | 3,980,360 | 4,049,530 | 3,766,880 | 4,353,400 | 3,580,480 | 3,654,240 |
| 1994 | 3,603,400 | 3,366,280 | 3,857,230 | 4,097,340 | 3,811,770 | 4,404,300 | 3,470,860 | 3,595,400 |
| 1995 | 3,464,870 | 3,228,420 | 3,718,630 | 3,834,710 | 3,560,820 | 4,129,660 | 3,333,160 | 3,424,630 |
| 1996 | 3,369,040 | 3,137,960 | 3,617,140 | 3,728,610 | 3,459,850 | 4,018,240 | 3,239,470 | 3,431,050 |
| 1997 | 3,346,800 | 3,115,750 | 3,594,980 | 3,763,620 | 3,491,160 | 4,057,340 | 3,218,420 | 3,377,860 |
| 1998 | 3,034,700 | 2,818,830 | 3,267,100 | 3,438,880 | 3,181,270 | 3,717,350 | 2,916,030 | 3,189,890 |
| 1999 | 2,773,290 | 2,569,220 | 2,993,580 | 3,206,790 | 2,961,350 | 3,472,580 | 2,662,080 | 3,036,680 |
| 2000 | 2,858,580 | 2,654,960 | 3,077,810 | 3,250,520 | 3,004,660 | 3,516,490 | 2,754,190 | 3,094,320 |
| 2001 | 2,867,690 | 2,660,120 | 3,091,460 | 3,148,860 | 2,909,040 | 3,408,440 | 2,762,300 | 3,057,060 |

| | | | | | | | | |
|------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 2002 | 2,919,490 | 2,712,400 | 3,142,390 | 3,183,720 | 2,943,740 | 3,443,270 | 2,822,550 | 3,180,170 |
| 2003 | 3,201,970 | 2,978,780 | 3,441,890 | 3,416,780 | 3,163,620 | 3,690,190 | 3,108,690 | 3,310,750 |
| 2004 | 3,338,370 | 3,108,340 | 3,585,410 | 3,653,900 | 3,386,690 | 3,942,200 | 3,253,850 | 3,272,020 |
| 2005 | 3,392,440 | 3,160,460 | 3,641,450 | 3,764,640 | 3,491,140 | 4,059,570 | 3,319,870 | 3,437,570 |
| 2006 | 3,441,730 | 3,204,400 | 3,696,630 | 3,745,810 | 3,472,350 | 4,040,800 | 3,376,470 | 3,444,750 |
| 2007 | 3,254,230 | 3,030,490 | 3,494,490 | 3,747,670 | 3,471,700 | 4,045,570 | 3,207,840 | 3,406,260 |
| 2008 | 3,125,180 | 2,906,260 | 3,360,590 | 3,585,080 | 3,315,670 | 3,876,380 | 3,089,150 | 3,327,810 |
| 2009 | 3,115,290 | 2,890,380 | 3,357,690 | 3,365,630 | 3,104,790 | 3,648,380 | 3,089,730 | 3,212,000 |
| 2010 | 3,241,480 | 3,003,340 | 3,498,490 | 3,398,180 | 3,131,750 | 3,687,270 | 3,224,770 | 3,199,840 |
| 2011 | 3,168,560 | 2,933,460 | 3,422,510 | 3,398,460 | 3,127,330 | 3,693,100 | 3,171,280 | 3,229,850 |
| 2012 | 2,992,180 | 2,761,710 | 3,241,890 | 3,339,860 | 3,065,280 | 3,639,030 | 3,005,570 | 3,087,160 |
| 2013 | 2,856,540 | 2,628,850 | 3,103,950 | 3,242,770 | 2,967,160 | 3,543,990 | 2,881,490 | 3,149,590 |
| 2014 | 2,800,240 | 2,566,800 | 3,054,910 | 2,979,390 | 2,715,320 | 3,269,150 | 2,833,810 | 3,140,230 |
| 2015 | 2,831,740 | 2,584,730 | 3,102,350 | 2,964,580 | 2,690,840 | 3,266,160 | 2,873,980 | 3,062,190 |
| 2016 | 2,864,840 | 2,606,650 | 3,148,620 | 3,093,610 | 2,797,760 | 3,420,760 | 2,906,420 | 3,087,060 |
| 2017 | 2,881,920 | 2,609,850 | 3,182,360 | 3,013,720 | 2,710,700 | 3,350,610 | 2,916,150 | 2,965,060 |
| 2018 | 2,699,330 | 2,433,780 | 2,993,840 | 3,116,980 | 2,783,110 | 3,490,900 | 2,718,990 | 2,786,840 |
| 2019 | 2,876,830 | 2,576,650 | 3,211,990 | 3,234,230 | 2,851,490 | 3,668,350 | 2,871,340 | 2,675,810 |
| 2020 | 2,685,450 | 2,383,820 | 3,025,240 | 3,283,680 | 2,849,560 | 3,783,930 | 2,663,710 | 2,596,950 |
| 2021 | 2,666,770 | 2,333,390 | 3,047,790 | | | | 2,618,900 | 2,531,970 |

Table 4.10: Yellowfin Sole biomass estimates (t) from the northern Bering Sea survey, with upper and lower 95% confidence intervals, as well as number of hauls, hauls with Yellowfin Sole, and hauls in which length data was obtained.

| Year | Biomass (t) | LCI | HCI | Haul count | Hauls with catch | Number count | Length count |
|------|-------------|---------|---------|------------|------------------|--------------|--------------|
| 2010 | 310,617 | 215,238 | 405,997 | 108 | 88 | 88 | 88 |
| 2017 | 368,156 | 254,797 | 481,515 | 110 | 98 | 98 | 97 |
| 2018 | 373,373 | 240,861 | 505,885 | 49 | 49 | 49 | 49 |
| 2019 | 520,029 | 398,122 | 641,936 | 144 | 141 | 141 | 140 |
| 2021 | 496,038 | 394,385 | 394,385 | 144 | 138 | 138 | 137 |

Table 4.11: Yellowfin Sole population numbers-at-age (millions) estimated from the annual EBS bottom trawl surveys, 1987-2019 (Current year data is not yet available and there was no survey in 2020). Data in years 1987 or later come from the ‘plusnw’ extended survey area. Females are presented first, followed by males. Continued on next page.

| Year | Age (Females) | | | | | | | | | | | | | | | |
|------|---------------|-----|-----|-------|-------|-------|-------|-------|-------|-------|-------|-----|-----|-----|-----|-----|
| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17+ |
| 1982 | 37 | 183 | 349 | 1,215 | 1,488 | 1,425 | 1,621 | 844 | 829 | 832 | 704 | 409 | 246 | 159 | 50 | 33 |
| 1983 | 0 | 4 | 56 | 149 | 729 | 1,377 | 823 | 1,039 | 913 | 735 | 1,128 | 846 | 287 | 156 | 58 | 26 |
| 1984 | 0 | 52 | 277 | 264 | 427 | 744 | 841 | 1,111 | 1,079 | 941 | 541 | 583 | 480 | 239 | 173 | 75 |
| 1985 | 0 | 3 | 104 | 438 | 578 | 396 | 616 | 892 | 430 | 506 | 532 | 375 | 290 | 313 | 200 | 76 |
| 1986 | 0 | 7 | 23 | 218 | 349 | 666 | 278 | 573 | 519 | 377 | 283 | 317 | 195 | 250 | 136 | 153 |
| 1987 | 0 | 0 | 68 | 116 | 781 | 443 | 816 | 250 | 362 | 576 | 341 | 431 | 232 | 259 | 237 | 173 |
| 1988 | 0 | 0 | 6 | 341 | 64 | 1,354 | 497 | 495 | 163 | 213 | 315 | 186 | 323 | 245 | 196 | 151 |
| 1989 | 0 | 0 | 14 | 97 | 715 | 233 | 1,333 | 592 | 446 | 74 | 179 | 307 | 234 | 238 | 183 | 82 |
| 1990 | 0 | 0 | 69 | 101 | 324 | 1,065 | 192 | 1,257 | 408 | 481 | 101 | 71 | 107 | 78 | 230 | 126 |
| 1991 | 0 | 9 | 126 | 247 | 122 | 404 | 894 | 150 | 1,261 | 212 | 524 | 62 | 127 | 86 | 122 | 163 |
| 1992 | 0 | 18 | 238 | 461 | 495 | 202 | 273 | 895 | 90 | 789 | 72 | 295 | 123 | 130 | 162 | 103 |
| 1993 | 0 | 24 | 99 | 357 | 635 | 434 | 268 | 224 | 1,315 | 78 | 867 | 156 | 165 | 68 | 67 | 91 |
| 1994 | 0 | 53 | 94 | 221 | 515 | 900 | 552 | 479 | 283 | 1,164 | 0 | 513 | 43 | 272 | 141 | 41 |
| 1995 | 0 | 18 | 152 | 288 | 181 | 890 | 628 | 275 | 135 | 24 | 634 | 20 | 561 | 104 | 80 | 96 |
| 1996 | 0 | 15 | 149 | 787 | 278 | 269 | 419 | 498 | 198 | 140 | 146 | 579 | 112 | 613 | 44 | 28 |
| 1997 | 0 | 17 | 323 | 502 | 724 | 255 | 238 | 504 | 227 | 113 | 176 | 183 | 499 | 43 | 313 | 75 |
| 1998 | 0 | 9 | 78 | 451 | 399 | 853 | 246 | 192 | 350 | 390 | 349 | 160 | 166 | 250 | 63 | 396 |
| 1999 | 0 | 3 | 61 | 188 | 166 | 177 | 697 | 99 | 103 | 236 | 182 | 179 | 69 | 98 | 168 | 101 |
| 2000 | 0 | 11 | 54 | 247 | 208 | 304 | 445 | 540 | 190 | 198 | 238 | 220 | 65 | 117 | 145 | 109 |
| 2001 | 0 | 1 | 65 | 219 | 474 | 223 | 361 | 369 | 581 | 331 | 73 | 171 | 137 | 113 | 169 | 99 |
| 2002 | 0 | 15 | 118 | 162 | 242 | 733 | 326 | 273 | 216 | 432 | 208 | 85 | 289 | 109 | 143 | 136 |
| 2003 | 0 | 15 | 113 | 234 | 241 | 276 | 1,104 | 217 | 268 | 275 | 241 | 98 | 110 | 162 | 160 | 82 |
| 2004 | 10 | 33 | 195 | 438 | 568 | 414 | 217 | 970 | 222 | 212 | 220 | 221 | 107 | 19 | 168 | 186 |
| 2005 | 0 | 52 | 166 | 194 | 600 | 431 | 212 | 485 | 831 | 195 | 143 | 190 | 323 | 169 | 53 | 183 |
| 2006 | 8 | 67 | 301 | 375 | 276 | 633 | 470 | 176 | 325 | 737 | 132 | 132 | 70 | 156 | 175 | 1 |
| 2007 | 0 | 37 | 514 | 348 | 375 | 276 | 503 | 307 | 123 | 226 | 503 | 119 | 137 | 126 | 104 | 76 |
| 2008 | 0 | 23 | 114 | 735 | 620 | 545 | 359 | 355 | 198 | 116 | 259 | 349 | 152 | 79 | 85 | 118 |
| 2009 | 5 | 37 | 203 | 203 | 1,186 | 608 | 487 | 259 | 210 | 218 | 129 | 138 | 196 | 88 | 43 | 1 |
| 2010 | 0 | 32 | 327 | 386 | 438 | 895 | 554 | 516 | 329 | 335 | 154 | 166 | 135 | 172 | 99 | 49 |
| 2011 | 0 | 14 | 243 | 539 | 706 | 463 | 769 | 410 | 456 | 204 | 226 | 148 | 141 | 144 | 186 | 98 |
| 2012 | 9 | 49 | 229 | 394 | 504 | 293 | 243 | 753 | 255 | 334 | 106 | 156 | 36 | 150 | 128 | 149 |
| 2013 | 0 | 4 | 88 | 268 | 421 | 532 | 259 | 223 | 404 | 408 | 348 | 121 | 134 | 132 | 132 | 94 |
| 2014 | 0 | 0 | 36 | 420 | 383 | 248 | 419 | 231 | 228 | 522 | 340 | 160 | 144 | 228 | 34 | 122 |
| 2015 | 0 | 22 | 3 | 167 | 466 | 349 | 307 | 287 | 249 | 149 | 282 | 258 | 134 | 99 | 80 | 67 |
| 2016 | 0 | 32 | 71 | 45 | 163 | 743 | 565 | 403 | 363 | 300 | 143 | 244 | 229 | 140 | 162 | 169 |
| 2017 | 16 | 78 | 381 | 378 | 121 | 317 | 1,001 | 481 | 335 | 377 | 228 | 148 | 202 | 200 | 148 | 117 |
| 2018 | 0 | 49 | 181 | 265 | 182 | 99 | 257 | 609 | 319 | 245 | 58 | 75 | 48 | 141 | 101 | 106 |
| 2019 | 1 | 123 | 208 | 306 | 155 | 240 | 78 | 209 | 544 | 357 | 129 | 159 | 124 | 122 | 71 | 44 |

| Year | Age (Males) | | | | | | | | | | | | | | | |
|------|-------------|-----|-----|-------|-------|-------|-------|-------|-------|-----|-----|-----|-----|-----|-----|-----|
| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17+ |
| 1982 | 88 | 193 | 429 | 1,783 | 1,783 | 1,059 | 1,673 | 643 | 774 | 463 | 471 | 482 | 302 | 7 | 23 | 7 |
| 1983 | 0 | 0 | 63 | 176 | 701 | 1,685 | 787 | 1,021 | 660 | 684 | 706 | 553 | 416 | 537 | 75 | 44 |
| 1984 | 0 | 67 | 246 | 323 | 496 | 734 | 829 | 612 | 787 | 718 | 357 | 378 | 201 | 315 | 121 | 55 |
| 1985 | 0 | 41 | 171 | 416 | 553 | 259 | 644 | 522 | 397 | 446 | 357 | 221 | 257 | 155 | 110 | 16 |
| 1986 | 0 | 12 | 47 | 108 | 373 | 651 | 261 | 326 | 283 | 335 | 211 | 204 | 115 | 210 | 81 | 136 |
| 1987 | 0 | 4 | 39 | 103 | 813 | 453 | 650 | 427 | 314 | 264 | 201 | 140 | 101 | 135 | 176 | 209 |
| 1988 | 0 | 1 | 9 | 410 | 45 | 1,079 | 503 | 403 | 77 | 170 | 25 | 161 | 305 | 172 | 25 | 105 |
| 1989 | 0 | 2 | 23 | 180 | 783 | 176 | 1,301 | 511 | 355 | 134 | 49 | 103 | 53 | 203 | 35 | 38 |
| 1990 | 0 | 10 | 47 | 120 | 316 | 888 | 194 | 1,143 | 317 | 263 | 39 | 64 | 66 | 23 | 54 | 72 |
| 1991 | 0 | 0 | 102 | 353 | 139 | 274 | 1,043 | 67 | 1,135 | 328 | 243 | 74 | 64 | 60 | 52 | 91 |
| 1992 | 0 | 0 | 140 | 425 | 538 | 250 | 214 | 773 | 109 | 869 | 184 | 204 | 11 | 12 | 59 | 37 |
| 1993 | 0 | 20 | 52 | 233 | 646 | 393 | 278 | 246 | 1,096 | 69 | 842 | 52 | 53 | 50 | 0 | 48 |
| 1994 | 4 | 21 | 70 | 165 | 424 | 947 | 652 | 305 | 189 | 817 | 25 | 618 | 45 | 131 | 11 | 36 |
| 1995 | 0 | 0 | 168 | 119 | 270 | 667 | 565 | 94 | 179 | 75 | 477 | 13 | 602 | 49 | 24 | 77 |
| 1996 | 0 | 73 | 92 | 815 | 236 | 219 | 411 | 332 | 319 | 136 | 134 | 385 | 58 | 433 | 120 | 91 |
| 1997 | 0 | 9 | 214 | 425 | 797 | 180 | 183 | 445 | 244 | 194 | 213 | 108 | 514 | 78 | 264 | 30 |
| 1998 | 0 | 45 | 66 | 332 | 541 | 791 | 150 | 213 | 192 | 256 | 326 | 131 | 148 | 180 | 106 | 251 |
| 1999 | 0 | 5 | 95 | 134 | 214 | 232 | 550 | 140 | 90 | 297 | 258 | 71 | 51 | 27 | 114 | 33 |
| 2000 | 0 | 0 | 35 | 218 | 259 | 143 | 511 | 585 | 78 | 215 | 133 | 76 | 92 | 78 | 66 | 152 |
| 2001 | 0 | 0 | 80 | 129 | 598 | 307 | 339 | 321 | 509 | 189 | 79 | 143 | 59 | 66 | 128 | 54 |
| 2002 | 0 | 55 | 70 | 151 | 295 | 721 | 301 | 314 | 247 | 418 | 183 | 114 | 208 | 152 | 125 | 19 |
| 2003 | 0 | 23 | 92 | 172 | 248 | 242 | 1,038 | 229 | 351 | 51 | 275 | 167 | 9 | 69 | 55 | 103 |
| 2004 | 4 | 63 | 115 | 473 | 451 | 200 | 397 | 997 | 264 | 82 | 196 | 224 | 103 | 47 | 250 | 104 |
| 2005 | 0 | 48 | 166 | 186 | 473 | 475 | 203 | 287 | 971 | 122 | 141 | 121 | 132 | 69 | 92 | 127 |
| 2006 | 0 | 100 | 172 | 347 | 331 | 504 | 393 | 287 | 297 | 383 | 116 | 154 | 89 | 38 | 11 | 54 |
| 2007 | 0 | 57 | 480 | 351 | 405 | 283 | 545 | 209 | 165 | 251 | 338 | 100 | 133 | 71 | 59 | 123 |
| 2008 | 0 | 10 | 99 | 661 | 462 | 483 | 344 | 452 | 225 | 144 | 184 | 329 | 62 | 65 | 34 | 103 |
| 2009 | 0 | 64 | 144 | 290 | 952 | 464 | 544 | 247 | 249 | 216 | 78 | 31 | 195 | 29 | 28 | 50 |
| 2010 | 0 | 77 | 199 | 418 | 370 | 1,032 | 462 | 509 | 171 | 188 | 159 | 52 | 116 | 151 | 78 | 53 |
| 2011 | 0 | 6 | 149 | 384 | 482 | 357 | 791 | 398 | 224 | 176 | 77 | 80 | 136 | 102 | 156 | 96 |
| 2012 | 0 | 69 | 273 | 352 | 345 | 275 | 239 | 426 | 297 | 179 | 98 | 67 | 90 | 34 | 100 | 59 |
| 2013 | 0 | 6 | 91 | 365 | 383 | 481 | 210 | 267 | 444 | 199 | 200 | 33 | 88 | 99 | 117 | 18 |
| 2014 | 0 | 0 | 8 | 365 | 396 | 285 | 338 | 310 | 250 | 399 | 206 | 192 | 19 | 191 | 94 | 107 |
| 2015 | 0 | 28 | 35 | 130 | 426 | 332 | 301 | 312 | 317 | 47 | 179 | 130 | 80 | 0 | 79 | 110 |
| 2016 | 0 | 43 | 84 | 20 | 141 | 704 | 544 | 401 | 366 | 125 | 117 | 226 | 180 | 88 | 35 | 91 |
| 2017 | 9 | 120 | 231 | 396 | 106 | 260 | 880 | 498 | 310 | 275 | 194 | 107 | 215 | 155 | 37 | 12 |
| 2018 | 0 | 39 | 173 | 187 | 228 | 72 | 229 | 529 | 245 | 171 | 101 | 80 | 72 | 82 | 73 | 31 |
| 2019 | 0 | 135 | 251 | 237 | 103 | 266 | 104 | 147 | 488 | 269 | 129 | 154 | 83 | 68 | 53 | 94 |

Table 4.12: Total tonnage of Yellowfin Sole caught in resource assessment surveys in the eastern Bering Sea from 1977-2019.

| Year | Research catch (t) |
|------|--------------------|
| 2016 | 98 |
| 2017 | 112 |
| 2018 | 73 |
| 2019 | 85 |

Table 4.13: Mean unsmoothed weight-at-age (grams) for Yellowfin Sole, based on survey data, females presented first, followed by males, 1964-2021, except 2020.

| Year | Age (Females) | | | | | | | | | | | | | | | | | | | |
|------|---------------|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| 1964 | 6 | 7 | 17 | 34 | 62 | 89 | 130 | 178 | 218 | 259 | 305 | 348 | 393 | 437 | 473 | 514 | 579 | 602 | 655 | 664 |
| 1965 | 6 | 7 | 17 | 34 | 62 | 89 | 130 | 178 | 218 | 259 | 305 | 348 | 393 | 437 | 473 | 514 | 579 | 602 | 655 | 664 |
| 1966 | 6 | 7 | 17 | 34 | 62 | 89 | 130 | 178 | 218 | 259 | 305 | 348 | 393 | 437 | 473 | 514 | 579 | 602 | 655 | 664 |
| 1967 | 6 | 7 | 17 | 34 | 62 | 89 | 130 | 178 | 218 | 259 | 305 | 348 | 393 | 437 | 473 | 514 | 579 | 602 | 655 | 664 |
| 1968 | 6 | 7 | 17 | 34 | 62 | 89 | 130 | 178 | 218 | 259 | 305 | 348 | 393 | 437 | 473 | 514 | 579 | 602 | 655 | 664 |
| 1969 | 6 | 7 | 17 | 34 | 62 | 89 | 130 | 178 | 218 | 259 | 305 | 348 | 393 | 437 | 473 | 514 | 579 | 602 | 655 | 664 |
| 1970 | 6 | 7 | 17 | 34 | 62 | 89 | 130 | 178 | 218 | 259 | 305 | 348 | 393 | 437 | 473 | 514 | 579 | 602 | 655 | 664 |
| 1971 | 6 | 7 | 15 | 42 | 65 | 130 | 156 | 227 | 258 | 270 | 305 | 475 | 489 | 526 | 623 | 690 | 787 | 679 | 679 | 674 |
| 1972 | 6 | 7 | 15 | 69 | 177 | 194 | 227 | 227 | 255 | 285 | 399 | 360 | 384 | 447 | 477 | 571 | 554 | 575 | 583 | 674 |
| 1973 | 6 | 7 | 52 | 47 | 50 | 69 | 132 | 318 | 318 | 424 | 387 | 399 | 415 | 498 | 440 | 623 | 554 | 575 | 583 | 674 |
| 1974 | 6 | 7 | 15 | 26 | 41 | 56 | 144 | 152 | 222 | 264 | 350 | 380 | 415 | 458 | 507 | 536 | 612 | 833 | 866 | 674 |
| 1975 | 6 | 5 | 12 | 19 | 38 | 71 | 121 | 164 | 227 | 302 | 353 | 353 | 391 | 424 | 489 | 480 | 561 | 640 | 662 | 674 |
| 1976 | 6 | 3 | 7 | 26 | 39 | 66 | 90 | 149 | 177 | 224 | 285 | 322 | 332 | 339 | 376 | 285 | 353 | 507 | 583 | 571 |
| 1977 | 6 | 4 | 12 | 30 | 42 | 56 | 83 | 121 | 158 | 194 | 238 | 298 | 372 | 432 | 440 | 522 | 554 | 575 | 583 | 674 |
| 1978 | 6 | 7 | 15 | 17 | 68 | 84 | 123 | 134 | 189 | 180 | 184 | 249 | 391 | 332 | 361 | 399 | 475 | 575 | 583 | 674 |
| 1979 | 6 | 13 | 16 | 29 | 51 | 88 | 109 | 147 | 191 | 224 | 261 | 350 | 343 | 471 | 480 | 436 | 720 | 522 | 781 | 674 |
| 1980 | 6 | 7 | 13 | 29 | 54 | 77 | 114 | 144 | 187 | 222 | 285 | 295 | 395 | 440 | 536 | 597 | 623 | 541 | 651 | 679 |
| 1981 | 6 | 7 | 7 | 26 | 59 | 95 | 147 | 171 | 206 | 222 | 261 | 325 | 407 | 419 | 503 | 541 | 522 | 556 | 546 | 634 |
| 1982 | 6 | 6 | 19 | 37 | 69 | 97 | 142 | 187 | 241 | 264 | 270 | 343 | 424 | 475 | 471 | 531 | 651 | 561 | 522 | 866 |
| 1983 | 6 | 2 | 15 | 24 | 54 | 85 | 147 | 177 | 194 | 249 | 264 | 311 | 368 | 458 | 531 | 602 | 662 | 685 | 583 | 738 |
| 1984 | 6 | 7 | 28 | 41 | 62 | 95 | 125 | 160 | 216 | 249 | 325 | 384 | 384 | 432 | 536 | 561 | 618 | 623 | 696 | 750 |
| 1985 | 6 | 7 | 17 | 22 | 51 | 80 | 154 | 180 | 238 | 285 | 325 | 339 | 419 | 432 | 489 | 566 | 634 | 651 | 623 | 679 |
| 1986 | 6 | 7 | 28 | 23 | 35 | 75 | 105 | 160 | 222 | 270 | 365 | 365 | 387 | 475 | 436 | 512 | 536 | 517 | 640 | 656 |
| 1987 | 6 | 7 | 15 | 21 | 51 | 60 | 122 | 169 | 234 | 329 | 313 | 444 | 418 | 462 | 394 | 542 | 472 | 525 | 577 | 598 |
| 1988 | 6 | 3 | 8 | 13 | 26 | 49 | 83 | 118 | 216 | 273 | 302 | 368 | 458 | 449 | 411 | 445 | 517 | 566 | 546 | 541 |
| 1989 | 6 | 7 | 15 | 31 | 59 | 66 | 114 | 140 | 204 | 276 | 332 | 399 | 458 | 471 | 484 | 503 | 475 | 607 | 498 | 556 |
| 1990 | 6 | 7 | 15 | 23 | 31 | 62 | 101 | 134 | 201 | 246 | 325 | 484 | 480 | 453 | 475 | 493 | 526 | 571 | 581 | 612 |
| 1991 | 6 | 7 | 17 | 21 | 60 | 58 | 101 | 147 | 173 | 244 | 318 | 391 | 462 | 466 | 541 | 522 | 541 | 591 | 503 | 607 |
| 1992 | 6 | 7 | 22 | 30 | 54 | 81 | 121 | 191 | 187 | 285 | 311 | 285 | 353 | 445 | 561 | 498 | 526 | 581 | 512 | 618 |
| 1993 | 6 | 7 | 28 | 36 | 58 | 87 | 168 | 182 | 246 | 273 | 305 | 361 | 384 | 480 | 489 | 618 | 541 | 546 | 629 | 623 |
| 1994 | 6 | 6 | 46 | 55 | 65 | 93 | 131 | 154 | 253 | 269 | 294 | 360 | 409 | 346 | 463 | 497 | 445 | 457 | 524 | 544 |
| 1995 | 6 | 7 | 20 | 26 | 52 | 85 | 127 | 168 | 230 | 298 | 336 | 353 | 453 | 424 | 432 | 484 | 480 | 673 | 566 | 634 |
| 1996 | 6 | 7 | 17 | 42 | 55 | 94 | 128 | 173 | 211 | 230 | 318 | 339 | 368 | 440 | 432 | 503 | 571 | 571 | 576 | 623 |
| 1997 | 6 | 7 | 35 | 32 | 72 | 84 | 152 | 194 | 232 | 261 | 292 | 399 | 384 | 411 | 498 | 480 | 561 | 440 | 546 | 640 |
| 1998 | 6 | 7 | 14 | 25 | 48 | 103 | 113 | 173 | 216 | 261 | 273 | 311 | 391 | 436 | 424 | 432 | 498 | 440 | 576 | 607 |
| 1999 | 6 | 7 | 10 | 17 | 33 | 63 | 106 | 136 | 220 | 260 | 276 | 312 | 320 | 361 | 393 | 425 | 474 | 535 | 525 | 687 |
| 2000 | 6 | 7 | 14 | 33 | 36 | 99 | 110 | 192 | 211 | 231 | 294 | 308 | 378 | 395 | 419 | 458 | 491 | 522 | 505 | 609 |
| 2001 | 6 | 4 | 8 | 31 | 39 | 62 | 99 | 148 | 190 | 242 | 284 | 383 | 392 | 436 | 424 | 442 | 474 | 528 | 530 | 663 |
| 2002 | 6 | 7 | 19 | 27 | 45 | 66 | 105 | 156 | 229 | 246 | 276 | 343 | 328 | 394 | 451 | 480 | 504 | 552 | 560 | 631 |
| 2003 | 6 | 7 | 14 | 29 | 56 | 87 | 127 | 171 | 224 | 299 | 313 | 357 | 413 | 454 | 417 | 505 | 374 | 600 | 575 | 652 |
| 2004 | 4 | 8 | 14 | 38 | 64 | 101 | 163 | 162 | 243 | 300 | 328 | 359 | 440 | 524 | 551 | 476 | 485 | 500 | 500 | 654 |
| 2005 | 6 | 4 | 21 | 40 | 72 | 114 | 156 | 217 | 236 | 284 | 349 | 356 | 377 | 464 | 509 | 505 | 612 | 472 | 620 | 693 |
| 2006 | 6 | 6 | 16 | 36 | 76 | 114 | 149 | 206 | 236 | 303 | 308 | 360 | 368 | 592 | 493 | 495 | 1010 | 568 | 618 | 740 |
| 2007 | 6 | 7 | 16 | 38 | 70 | 113 | 170 | 196 | 239 | 330 | 304 | 351 | 361 | 406 | 456 | 466 | 558 | 568 | 683 | 662 |
| 2008 | 6 | 7 | 24 | 31 | 57 | 106 | 140 | 203 | 239 | 281 | 309 | 345 | 395 | 432 | 422 | 501 | 567 | 555 | 594 | 660 |
| 2009 | 6 | 6 | 10 | 22 | 51 | 88 | 142 | 182 | 248 | 321 | 334 | 377 | 434 | 429 | 433 | 575 | 874 | 556 | 565 | 697 |
| 2010 | 6 | 2 | 16 | 25 | 57 | 84 | 136 | 186 | 218 | 343 | 337 | 403 | 446 | 460 | 517 | 557 | 594 | 620 | 744 | 795 |
| 2011 | 6 | 7 | 12 | 30 | 49 | 110 | 145 | 210 | 264 | 318 | 329 | 405 | 419 | 441 | 448 | 621 | 534 | 516 | 623 | 696 |
| 2012 | 6 | 6 | 11 | 27 | 53 | 91 | 146 | 167 | 258 | 317 | 367 | 321 | 452 | 529 | 502 | 514 | 562 | 654 | 598 | 730 |
| 2013 | 6 | 7 | 12 | 21 | 40 | 102 | 131 | 195 | 275 | 318 | 366 | 399 | 415 | 474 | 473 | 518 | 550 | 555 | 606 | 702 |
| 2014 | 6 | 7 | 15 | 16 | 37 | 85 | 145 | 201 | 252 | 306 | 368 | 360 | 428 | 421 | 495 | 592 | 536 | 577 | 570 | 715 |
| 2015 | 6 | 7 | 15 | 12 | 40 | 62 | 130 | 215 | 262 | 355 | 418 | 437 | 411 | 484 | 474 | 596 | 647 | 593 | 531 | 731 |
| 2016 | 6 | 12 | 25 | 37 | 69 | 86 | 130 | 211 | 329 | 378 | 417 | 415 | 517 | 465 | 509 | 522 | 581 | 580 | 618 | 723 |
| 2017 | 4 | 9 | 19 | 51 | 69 | 118 | 143 | 187 | 273 | 366 | 382 | 436 | 536 | 503 | 553 | 647 | 601 | 701 | 585 | 824 |
| 2018 | 6 | 7 | 22 | 39 | 88 | 111 | 163 | 236 | 248 | 346 | 421 | 447 | 504 | 478 | 526 | 606 | 586 | 571 | 717 | 677 |
| 2019 | 6 | 6 | 21 | 47 | 92 | 160 | 180 | 254 | 277 | 346 | 404 | 583 | 503 | 505 | 570 | 680 | 701 | 673 | 698 | 720 |
| 2021 | 6 | 8 | 20 | 37 | 72 | 107 | 149 | 221 | 278 | 358 | 408 | 464 | 494 | 487 | 526 | 610 | 623 | 624 | 630 | 735 |

| Year | Age (Males) | | | | | | | | | | | | | | | | | | | |
|------|-------------|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| 1964 | 2 | 8 | 16 | 34 | 54 | 96 | 120 | 140 | 168 | 232 | 237 | 267 | 310 | 333 | 317 | 399 | 409 | 438 | 441 | 495 |
| 1965 | 2 | 8 | 16 | 34 | 54 | 96 | 120 | 140 | 168 | 232 | 237 | 267 | 310 | 333 | 317 | 399 | 409 | 438 | 441 | 495 |
| 1966 | 2 | 8 | 16 | 34 | 54 | 96 | 120 | 140 | 168 | 232 | 237 | 267 | 310 | 333 | 317 | 399 | 409 | 438 | 441 | 495 |
| 1967 | 2 | 8 | 16 | 34 | 54 | 96 | 120 | 140 | 168 | 232 | 237 | 267 | 310 | 333 | 317 | 399 | 409 | 438 | 441 | 495 |
| 1968 | 2 | 8 | 16 | 34 | 54 | 96 | 120 | 140 | 168 | 232 | 237 | 267 | 310 | 333 | 317 | 399 | 409 | 438 | 441 | 495 |
| 1969 | 2 | 8 | 16 | 34 | 54 | 96 | 120 | 140 | 168 | 232 | 237 | 267 | 310 | 333 | 317 | 399 | 409 | 438 | 441 | 495 |
| 1970 | 2 | 8 | 16 | 34 | 54 | 96 | 120 | 140 | 168 | 232 | 237 | 267 | 310 | 333 | 317 | 399 | 409 | 438 | 441 | 495 |
| 1971 | 2 | 8 | 17 | 43 | 76 | 123 | 175 | 150 | 224 | 377 | 279 | 325 | 414 | 442 | 351 | 624 | 541 | 414 | 421 | 471 |
| 1972 | 2 | 8 | 17 | 76 | 104 | 232 | 224 | 184 | 377 | 253 | 250 | 309 | 332 | 351 | 380 | 391 | 414 | 421 | 471 | |
| 1973 | 2 | 8 | 17 | 48 | 48 | 83 | 139 | 149 | 184 | 227 | 253 | 325 | 377 | 332 | 351 | 380 | 391 | 414 | 421 | 471 |
| 1974 | 2 | 8 | 17 | 24 | 38 | 77 | 104 | 128 | 152 | 188 | 262 | 262 | 288 | 211 | 342 | 391 | 414 | 421 | 471 | |
| 1975 | 2 | 7 | 15 | 22 | 35 | 67 | 108 | 144 | 199 | 253 | 288 | 279 | 325 | 329 | 407 | 446 | 458 | 692 | 454 | 471 |
| 1976 | 1 | 5 | 11 | 23 | 48 | 66 | 95 | 125 | 158 | 181 | 204 | 259 | 253 | 377 | 259 | 454 | 541 | 414 | 421 | 471 |
| 1977 | 2 | 6 | 15 | 28 | 39 | 54 | 79 | 101 | 133 | 164 | 186 | 219 | 259 | 300 | 199 | 380 | 391 | 414 | 421 | 471 |
| 1978 | 2 | 8 | 14 | 22 | 55 | 113 | 89 | 116 | 144 | 177 | 204 | 234 | 325 | 300 | 403 | 309 | 391 | 414 | 421 | 471 |
| 1979 | 2 | 11 | 18 | 29 | 48 | 60 | 76 | 107 | 125 | 183 | 219 | 256 | 291 | 316 | 285 | 332 | 313 | 377 | 421 | 639 |
| 1980 | 2 | 6 | 15 | 30 | 51 | 86 | 111 | 152 | 173 | 192 | 226 | 264 | 285 | 316 | 349 | 342 | 279 | 414 | 589 | 541 |
| 1981 | 2 | 8 | 7 | 25 | 61 | 101 | 130 | 135 | 154 | 183 | 221 | 242 | 267 | 316 | 339 | 374 | 359 | 414 | 421 | 403 |
| 1982 | 4 | 10 | 24 | 40 | 77 | 113 | 137 | 144 | 170 | 195 | 219 | 262 | 267 | 309 | 454 | 403 | 395 | 414 | 541 | 471 |
| 1983 | 2 | 8 | 5 | 24 | 50 | 83 | 142 | 150 | 150 | 179 | 224 | 253 | 279 | 313 | 303 | 374 | 388 | 377 | 421 | 471 |
| 1984 | 2 | 8 | 22 | 35 | 59 | 101 | 123 | 173 | 216 | 202 | 221 | 242 | 282 | 313 | 313 | 325 | 349 | 414 | 342 | 377 |
| 1985 | 2 | 8 | 23 | 29 | 60 | 91 | 132 | 173 | 207 | 232 | 240 | 273 | 297 | 316 | 325 | 356 | 442 | 422 | 541 | 384 |
| 1986 | 2 | 8 | 19 | 29 | 36 | 60 | 96 | 156 | 199 | 229 | 237 | 240 | 297 | 276 | 303 | 346 | 316 | 325 | 366 | 377 |
| 1987 | 2 | 8 | 12 | 20 | 29 | 59 | 107 | 156 | 210 | 223 | 266 | 261 | 337 | 370 | 338 | 337 | 338 | 323 | 371 | 412 |
| 1988 | 2 | 8 | 10 | 14 | 36 | 62 | 75 | 135 | 183 | 237 | 250 | 309 | 322 | 319 | 356 | 309 | 316 | 325 | 384 | 399 |
| 1989 | 2 | 8 | 11 | 27 | 41 | 68 | 142 | 139 | 186 | 237 | 256 | 359 | 359 | 366 | 319 | 332 | 414 | 294 | 411 | 377 |
| 1990 | 2 | 8 | 16 | 23 | 38 | 58 | 96 | 126 | 179 | 211 | 267 | 342 | 366 | 352 | 359 | 332 | 377 | 377 | 370 | 403 |
| 1991 | 2 | 8 | 17 | 27 | 49 | 75 | 105 | 137 | 186 | 216 | 270 | 267 | 342 | 388 | 335 | 430 | 399 | 309 | 541 | 430 |
| 1992 | 2 | 8 | 17 | 27 | 50 | 81 | 99 | 132 | 183 | 209 | 245 | 262 | 332 | 519 | 414 | 422 | 403 | 399 | 454 | 414 |
| 1993 | 2 | 8 | 19 | 43 | 56 | 84 | 132 | 150 | 224 | 226 | 242 | 285 | 407 | 332 | 359 | 380 | 388 | 377 | 421 | 388 |
| 1994 | 2 | 28 | 25 | 54 | 66 | 84 | 112 | 184 | 198 | 207 | 261 | 350 | 322 | 363 | 350 | 406 | 402 | 488 | 361 | 401 |
| 1995 | 2 | 8 | 17 | 31 | 57 | 84 | 116 | 160 | 181 | 211 | 256 | 264 | 342 | 309 | 332 | 426 | 381 | 426 | 438 | 458 |
| 1996 | 2 | 8 | 19 | 35 | 58 | 98 | 128 | 164 | 190 | 221 | 226 | 294 | 313 | 309 | 342 | 349 | 356 | 426 | 384 | 454 |
| 1997 | 2 | 8 | 14 | 36 | 61 | 77 | 150 | 158 | 186 | 242 | 232 | 250 | 264 | 322 | 384 | 363 | 395 | 388 | 359 | 454 |
| 1998 | 2 | 8 | 15 | 25 | 49 | 88 | 126 | 156 | 204 | 202 | 259 | 259 | 309 | 306 | 329 | 359 | 370 | 384 | 407 | 422 |
| 1999 | 2 | 8 | 10 | 14 | 33 | 58 | 93 | 121 | 161 | 158 | 224 | 270 | 249 | 242 | 400 | 346 | 420 | 398 | 388 | 428 |
| 2000 | 2 | 8 | 33 | 30 | 34 | 71 | 105 | 157 | 162 | 244 | 218 | 245 | 266 | 272 | 288 | 335 | 304 | 342 | 364 | 393 |
| 2001 | 2 | 8 | 17 | 22 | 32 | 49 | 95 | 151 | 170 | 196 | 244 | 259 | 296 | 299 | 313 | 307 | 362 | 436 | 447 | 410 |
| 2002 | 2 | 8 | 17 | 22 | 53 | 58 | 91 | 146 | 204 | 213 | 232 | 257 | 274 | 309 | 345 | 362 | 334 | 383 | 440 | 423 |
| 2003 | 2 | 8 | 27 | 39 | 53 | 83 | 112 | 170 | 189 | 250 | 265 | 308 | 267 | 443 | 382 | 370 | 360 | 367 | 381 | 469 |
| 2004 | 2 | 8 | 14 | 36 | 59 | 95 | 150 | 158 | 207 | 260 | 321 | 311 | 311 | 368 | 469 | 384 | 414 | 392 | 465 | 464 |
| 2005 | 2 | 4 | 19 | 40 | 72 | 115 | 134 | 162 | 206 | 265 | 291 | 334 | 395 | 312 | 310 | 364 | 391 | 374 | 418 | 446 |
| 2006 | 2 | 8 | 18 | 32 | 67 | 118 | 144 | 183 | 207 | 237 | 233 | 318 | 350 | 417 | 452 | 438 | 352 | 343 | 380 | 449 |
| 2007 | 2 | 8 | 17 | 33 | 67 | 105 | 139 | 177 | 208 | 244 | 287 | 282 | 302 | 351 | 408 | 369 | 339 | 381 | 400 | 473 |
| 2008 | 2 | 8 | 8 | 27 | 50 | 95 | 121 | 181 | 192 | 244 | 270 | 298 | 312 | 346 | 384 | 405 | 373 | 399 | 436 | 481 |
| 2009 | 2 | 8 | 10 | 20 | 42 | 85 | 128 | 155 | 200 | 287 | 276 | 316 | 399 | 338 | 430 | 308 | 439 | 384 | 369 | 472 |
| 2010 | 2 | 8 | 13 | 24 | 48 | 80 | 141 | 167 | 183 | 302 | 315 | 322 | 356 | 414 | 402 | 401 | 417 | 512 | 461 | 501 |
| 2011 | 2 | 4 | 11 | 31 | 56 | 88 | 133 | 188 | 227 | 262 | 341 | 302 | 398 | 338 | 381 | 445 | 409 | 416 | 440 | 523 |
| 2012 | 2 | 8 | 12 | 27 | 53 | 88 | 126 | 183 | 216 | 256 | 283 | 320 | 292 | 422 | 420 | 387 | 431 | 414 | 355 | 475 |
| 2013 | 2 | 8 | 12 | 20 | 41 | 77 | 131 | 189 | 228 | 267 | 269 | 346 | 275 | 371 | 383 | 420 | 456 | 407 | 395 | 487 |
| 2014 | 2 | 8 | 17 | 30 | 39 | 86 | 154 | 188 | 243 | 292 | 313 | 311 | 321 | 332 | 424 | 466 | 429 | 527 | 492 | 495 |
| 2015 | 2 | 6 | 19 | 25 | 38 | 64 | 135 | 202 | 230 | 321 | 361 | 386 | 368 | 367 | 684 | 432 | 445 | 537 | 563 | 494 |
| 2016 | 2 | 8 | 33 | 46 | 50 | 83 | 127 | 190 | 260 | 332 | 327 | 340 | 406 | 394 | 416 | 409 | 443 | 474 | 375 | 505 |
| 2017 | 2 | 8 | 21 | 46 | 76 | 102 | 110 | 170 | 247 | 311 | 347 | 367 | 404 | 380 | 466 | 483 | 614 | 577 | 496 | 573 |
| 2018 | 2 | 8 | 23 | 45 | 89 | 95 | 161 | 178 | 221 | 276 | 316 | 403 | 384 | 435 | 421 | 386 | 424 | 431 | 548 | 484 |
| 2019 | 2 | 8 | 20 | 48 | 97 | 126 | 195 | 206 | 237 | 280 | 324 | 384 | 377 | 384 | 431 | 464 | 434 | 454 | 464 | 507 |
| 2021 | 2 | 8 | 23 | 42 | 70 | 94 | 146 | 189 | 239 | 304 | 335 | 376 | 388 | 392 | 484 | 435 | 472 | 495 | 489 | 513 |

Table 4.14: Parameter values and their 95% confidence intervals, Model 18.2.

| Name | Value | Standard Deviation | | Name | Value | Standard Deviation |
|------------------------------------|-------------|--------------------|--|---------|--------|--------------------|
| male natural mortality | 1.3496e-01 | 1.2966e-03 | | TotBiom | 1574.5 | 49.402 |
| alpha (q-temp model) | -2.0009e-01 | 3.8479e-02 | | TotBiom | 1693.6 | 51.632 |
| beta (q-temp model) | 5.6651e-02 | 1.2908e-02 | | TotBiom | 2188.5 | 63.647 |
| beta (survey start date) | 1.2320e-02 | 3.0108e-03 | | TotBiom | 2452.7 | 73.747 |
| beta (start date/temp interaction) | -8.0410e-03 | 2.8504e-03 | | TotBiom | 2820.3 | 84.134 |
| mean log recruitment | 9.6637e-01 | 9.2682e-02 | | TotBiom | 3107.7 | 91.771 |
| log_avg_fmort | -2.4396e+00 | 7.9014e-02 | | TotBiom | 3583.0 | 105.360 |
| sel_slope_fsh_f | 1.2004e+00 | 7.7956e-02 | | TotBiom | 3422.3 | 102.490 |
| sel50_fsh_f | 8.6421e+00 | 2.3574e-01 | | TotBiom | 3794.8 | 112.540 |
| sel_slope_fsh_m | 1.4076e+00 | 9.6947e-02 | | TotBiom | 3841.9 | 116.850 |
| sel50_fsh_m | 7.9864e+00 | 2.2327e-01 | | TotBiom | 3490.8 | 110.610 |
| sel_slope_srv | 1.5474e+00 | 8.2366e-02 | | TotBiom | 3486.1 | 114.420 |
| sel50_srv | 5.0418e+00 | 6.7492e-02 | | TotBiom | 3186.5 | 108.380 |
| sel_slope_srv_m | 8.8238e-03 | 7.2188e-02 | | TotBiom | 3429.2 | 118.560 |
| sel50_srv_m | -1.8961e-03 | 1.6679e-02 | | TotBiom | 3396.5 | 120.000 |
| R_logalpha | -4.1878e+00 | 4.2355e-01 | | TotBiom | 3511.1 | 122.440 |
| R_logbeta | -6.4120e+00 | 2.1914e-01 | | TotBiom | 3544.8 | 122.810 |
| q_srv | 7.4738e-01 | 3.1874e-02 | | TotBiom | 3714.8 | 128.290 |
| q_srv | 8.6645e-01 | 3.6266e-02 | | TotBiom | 3603.4 | 122.680 |
| q_srv | 8.8031e-01 | 3.8758e-02 | | TotBiom | 3464.9 | 122.490 |
| q_srv | 8.5234e-01 | 3.6343e-02 | | TotBiom | 3369.0 | 119.730 |
| q_srv | 9.5865e-01 | 5.6085e-02 | | TotBiom | 3346.8 | 119.740 |
| Bmsy | 4.9590e+02 | 6.9442e+01 | | TotBiom | 3034.7 | 112.010 |
| Bmsyr | 3.9453e+03 | 3.7816e+02 | | TotBiom | 2773.3 | 106.020 |
| TotBiom | 2.4267e+03 | 2.2208e+02 | | TotBiom | 2858.6 | 105.650 |
| TotBiom | 2.3794e+03 | 2.0716e+02 | | TotBiom | 2867.7 | 107.770 |
| TotBiom | 2.3201e+03 | 1.9152e+02 | | TotBiom | 2919.5 | 107.440 |
| TotBiom | 2.2663e+03 | 1.7330e+02 | | TotBiom | 3202.0 | 115.710 |
| TotBiom | 2.2205e+03 | 1.5341e+02 | | TotBiom | 3338.4 | 119.200 |
| TotBiom | 2.1772e+03 | 1.3124e+02 | | TotBiom | 3392.4 | 120.190 |
| TotBiom | 2.0039e+03 | 1.0375e+02 | | TotBiom | 3441.7 | 122.990 |
| TotBiom | 1.5556e+03 | 7.0026e+01 | | TotBiom | 3254.2 | 115.940 |
| TotBiom | 1.0699e+03 | 3.2197e+01 | | TotBiom | 3125.2 | 113.520 |
| TotBiom | 7.5785e+02 | 1.4957e+01 | | TotBiom | 3115.3 | 116.760 |
| TotBiom | 8.0463e+02 | 1.6623e+01 | | TotBiom | 3241.5 | 123.710 |
| TotBiom | 8.0418e+02 | 1.8517e+01 | | TotBiom | 3168.6 | 122.190 |
| TotBiom | 8.5837e+02 | 1.9497e+01 | | TotBiom | 2992.2 | 119.970 |
| TotBiom | 8.5673e+02 | 1.9935e+01 | | TotBiom | 2856.5 | 118.690 |
| TotBiom | 7.8639e+02 | 1.9257e+01 | | TotBiom | 2800.2 | 121.930 |
| TotBiom | 8.1840e+02 | 2.0645e+01 | | TotBiom | 2831.7 | 129.290 |
| TotBiom | 7.7734e+02 | 2.2123e+01 | | TotBiom | 2864.8 | 135.370 |
| TotBiom | 1.0004e+03 | 3.2130e+01 | | TotBiom | 2881.9 | 142.980 |
| TotBiom | 1.5351e+03 | 5.4559e+01 | | TotBiom | 2699.3 | 139.860 |
| TotBiom | 1.3204e+03 | 4.3030e+01 | | TotBiom | 2876.8 | 158.630 |
| TotBiom | 1.1880e+03 | 4.0307e+01 | | TotBiom | 2685.4 | 160.120 |
| TotBiom | 1.4816e+03 | 4.9432e+01 | | TotBiom | 2666.8 | 178.270 |

Table 4.15: Comparison of reference points for Model 18.2 (2021), 18.2 (2020), and Models 18.2a and 18.2b (lower panel). Values are in metric tons (t). Female, then male natural mortality is listed for each year and model.

| Quantity | Model 18.2 (2021) | | Model 18.2 (2020) | |
|---------------------------------------|-------------------|-------------|-------------------|-------------|
| | 2022 | 2023 | 2022 | 2023 |
| M (natural mortality rate) | 0.12, 0.135 | 0.12, 0.135 | 0.12, 0.13 | 0.12, 0.13 |
| Tier | 1a | 1a | 1a | 1a |
| Projected total (age 6+) biomass (t) | 2,479,370 | 2,284,820 | 2,755,870 | 3,025,430 |
| Projected female spawning biomass (t) | 857,101 | 727,101 | 1,040,900 | 996,044 |
| B_0 | 1,489,190 | 1,489,190 | 1,528,700 | 1,528,700 |
| B_{MSY} | 495,904 | 495,904 | 559,704 | 559,704 |
| F_{OFL} | 0.152 | 0.152 | 0.124 | 0.124 |
| $maxF_{ABC}$ | 0.143 | 0.143 | 0.114 | 0.114 |
| F_{ABC} | 0.143 | 0.143 | 0.114 | 0.114 |
| OFL | 377,071 | 347,483 | 341,571 | 374,982 |
| $maxABC$ | 354,014 | 326,235 | 313,477 | 344,140 |
| ABC | 354,014 | 326,235 | 313,477 | 344,140 |
| Status | 2020 | 2021 | 2020 | 2021 |
| Overfishing | No | n/a | No | n/a |
| Overfished | n/a | No | n/a | No |
| Approaching overfished | n/a | No | n/a | No |
| Quantity | Model 18.2a | | Model 18.2b | |
| | 2022 | 2023 | 2022 | 2023 |
| M (natural mortality rate) | 0.12, 0.135 | 0.12, 0.135 | 0.12, 0.135 | 0.12, 0.135 |
| Tier | 1a | 1a | 1a | 1a |
| Projected total (age 6+) biomass (t) | 2,415,980 | 2,421,800 | 2,834,050 | 2,851,460 |
| Projected female spawning biomass (t) | 914,506 | 871,852 | 1,073,970 | 1,034,310 |
| B_0 | 1,470,230 | 1,470,230 | 1,556,560 | 1,556,560 |
| B_{MSY} | 496,096 | 496,096 | 519,464 | 519,464 |
| F_{OFL} | 0.148 | 0.148 | 0.153 | 0.153 |
| $maxF_{ABC}$ | 0.138 | 0.138 | 0.144 | 0.144 |
| F_{ABC} | 0.138 | 0.138 | 0.144 | 0.144 |
| OFL | 357,556 | 358,416 | 434,529 | 437,198 |
| $maxABC$ | 333,560 | 334,363 | 409,089 | 411,602 |
| ABC | 333,560 | 334,363 | 409,089 | 411,602 |
| Status | 2020 | 2021 | 2020 | 2021 |
| Overfishing | No | n/a | No | n/a |
| Overfished | n/a | No | n/a | No |
| Approaching overfished | n/a | No | n/a | No |

Projections for Model 18.2 were based on estimated catches of 108,157 t in 2021, and projections for Model 18.2 were based on 126,929 t used in place of maximum ABC for 2022. Projections for Models 18.2a and 18.2b were based on estimated catches of 126,929 used in place of maximum ABC for 2022.

Table 4.16: Model estimates of Yellowfin Sole full selection fishing mortality (F) and exploitation rate (catch/total biomass).

| | Model 18.2 | | Model 18.2a | |
|------|------------------|---------------------|------------------|---------------------|
| | Full selection F | Catch/Total Biomass | Full selection F | Catch/Total Biomass |
| 1954 | 0.007 | 0.005 | 0.007 | 0.005 |
| 1955 | 0.008 | 0.006 | 0.008 | 0.006 |
| 1956 | 0.015 | 0.011 | 0.014 | 0.011 |
| 1957 | 0.015 | 0.011 | 0.015 | 0.011 |
| 1958 | 0.029 | 0.020 | 0.029 | 0.020 |
| 1959 | 0.139 | 0.085 | 0.137 | 0.086 |
| 1960 | 0.482 | 0.228 | 0.472 | 0.231 |
| 1961 | 1.332 | 0.356 | 1.310 | 0.363 |
| 1962 | 4.933 | 0.393 | 5.317 | 0.402 |
| 1963 | 0.353 | 0.113 | 5.663 | 0.115 |
| 1964 | 0.316 | 0.139 | 0.353 | 0.138 |
| 1965 | 0.249 | 0.067 | 0.238 | 0.066 |
| 1966 | 0.468 | 0.119 | 0.444 | 0.117 |
| 1967 | 0.618 | 0.189 | 0.588 | 0.187 |
| 1968 | 0.554 | 0.107 | 0.421 | 0.106 |
| 1969 | 0.673 | 0.204 | 0.674 | 0.202 |
| 1970 | 0.746 | 0.171 | 0.735 | 0.169 |
| 1971 | 0.608 | 0.160 | 0.601 | 0.158 |
| 1972 | 0.315 | 0.031 | 0.310 | 0.031 |
| 1973 | 0.416 | 0.059 | 0.410 | 0.058 |
| 1974 | 0.130 | 0.036 | 0.127 | 0.035 |
| 1975 | 0.115 | 0.044 | 0.112 | 0.043 |
| 1976 | 0.112 | 0.036 | 0.108 | 0.035 |
| 1977 | 0.051 | 0.034 | 0.050 | 0.034 |
| 1978 | 0.101 | 0.063 | 0.098 | 0.063 |
| 1979 | 0.059 | 0.040 | 0.057 | 0.040 |
| 1980 | 0.064 | 0.031 | 0.061 | 0.031 |
| 1981 | 0.051 | 0.031 | 0.050 | 0.031 |
| 1982 | 0.039 | 0.027 | 0.039 | 0.027 |
| 1983 | 0.040 | 0.032 | 0.040 | 0.032 |
| 1984 | 0.063 | 0.042 | 0.063 | 0.042 |
| 1985 | 0.093 | 0.059 | 0.095 | 0.060 |
| 1986 | 0.086 | 0.060 | 0.087 | 0.061 |
| 1987 | 0.084 | 0.052 | 0.085 | 0.053 |
| 1988 | 0.106 | 0.070 | 0.108 | 0.072 |
| 1989 | 0.079 | 0.045 | 0.081 | 0.046 |
| 1990 | 0.036 | 0.025 | 0.037 | 0.025 |
| 1991 | 0.043 | 0.033 | 0.045 | 0.035 |
| 1992 | 0.054 | 0.041 | 0.056 | 0.042 |
| 1993 | 0.047 | 0.028 | 0.049 | 0.030 |
| 1994 | 0.056 | 0.039 | 0.059 | 0.040 |
| 1995 | 0.052 | 0.036 | 0.054 | 0.037 |
| 1996 | 0.051 | 0.038 | 0.053 | 0.040 |
| 1997 | 0.084 | 0.055 | 0.087 | 0.057 |
| 1998 | 0.052 | 0.033 | 0.055 | 0.035 |
| 1999 | 0.039 | 0.025 | 0.041 | 0.026 |
| 2000 | 0.048 | 0.029 | 0.050 | 0.031 |
| 2001 | 0.035 | 0.022 | 0.037 | 0.023 |

| | | | | |
|------|-------|-------|-------|-------|
| 2002 | 0.039 | 0.026 | 0.041 | 0.027 |
| 2003 | 0.035 | 0.025 | 0.037 | 0.026 |
| 2004 | 0.032 | 0.023 | 0.033 | 0.023 |
| 2005 | 0.038 | 0.028 | 0.040 | 0.028 |
| 2006 | 0.037 | 0.029 | 0.038 | 0.029 |
| 2007 | 0.051 | 0.037 | 0.053 | 0.038 |
| 2008 | 0.069 | 0.048 | 0.070 | 0.048 |
| 2009 | 0.046 | 0.035 | 0.047 | 0.035 |
| 2010 | 0.052 | 0.037 | 0.053 | 0.037 |
| 2011 | 0.068 | 0.048 | 0.068 | 0.048 |
| 2012 | 0.067 | 0.049 | 0.067 | 0.049 |
| 2013 | 0.082 | 0.058 | 0.081 | 0.057 |
| 2014 | 0.081 | 0.056 | 0.080 | 0.055 |
| 2015 | 0.072 | 0.045 | 0.071 | 0.044 |
| 2016 | 0.079 | 0.047 | 0.077 | 0.047 |
| 2017 | 0.073 | 0.046 | 0.072 | 0.045 |
| 2018 | 0.074 | 0.049 | 0.073 | 0.048 |
| 2019 | 0.076 | 0.045 | 0.074 | 0.045 |
| 2020 | 0.082 | 0.050 | 0.080 | 0.050 |
| 2021 | 0.059 | 0.036 | 0.058 | 0.036 |

Table 4.17: Model estimates of Yellowfin Sole female spawning biomass (FSB) in the Eastern Bering Sea in metric tons (t) and upper (HCl) and lower (LCI) 95% confidence intervals from the 2020 and 2021 stock assessments, including Model 18.2 (2020), 18.2 (2021), and 18.2a.

| FSB (t) | Model 18.2 (2020) | | | Model 18.2 (2021) | | | Model 18.2a | |
|-----------|-------------------|-----------|-----------|-------------------|-----------|-----------|-------------|-----------|
| | LCI | HCI | FSB (t) | LCI | HCI | FSB (t) | LCI | HCI |
| 1,080,490 | 808,582 | 1,443,840 | 884,722 | 662,312 | 1,181,820 | 1,098,800 | 850,695 | 1,419,280 |
| 1,080,400 | 822,089 | 1,419,880 | 892,774 | 677,305 | 1,176,790 | 1,098,690 | 867,685 | 1,391,180 |
| 1,062,220 | 819,900 | 1,376,160 | 884,073 | 678,827 | 1,151,380 | 1,080,170 | 868,425 | 1,343,550 |
| 1,028,780 | 803,624 | 1,317,010 | 861,259 | 668,151 | 1,110,180 | 1,046,160 | 854,547 | 1,280,740 |
| 983,390 | 775,701 | 1,246,690 | 827,415 | 647,414 | 1,057,460 | 999,938 | 828,443 | 1,206,930 |
| 893,580 | 706,773 | 1,129,760 | 755,336 | 591,812 | 964,044 | 908,755 | 761,374 | 1,084,660 |
| 677,502 | 520,751 | 881,437 | 575,442 | 436,328 | 758,910 | 689,954 | 580,139 | 820,555 |
| 334,111 | 208,893 | 534,387 | 286,991 | 174,537 | 471,900 | 337,631 | 263,148 | 433,196 |
| 103,152 | 64,540 | 164,862 | 99,655 | 64,235 | 154,604 | 87,006 | 51,105 | 148,128 |
| 118,297 | 98,903 | 141,493 | 118,327 | 99,567 | 140,623 | 102,579 | 86,292 | 121,940 |
| 140,537 | 121,806 | 162,148 | 138,213 | 119,492 | 159,866 | 145,053 | 128,965 | 163,147 |
| 167,345 | 145,683 | 192,228 | 162,997 | 141,023 | 188,396 | 173,390 | 156,183 | 192,493 |
| 200,939 | 172,339 | 234,285 | 195,037 | 165,507 | 229,835 | 212,802 | 193,712 | 233,774 |
| 210,602 | 179,608 | 246,943 | 202,923 | 171,114 | 240,644 | 226,078 | 206,130 | 247,957 |
| 207,278 | 178,895 | 240,166 | 197,797 | 169,571 | 230,720 | 222,075 | 201,143 | 245,185 |
| 196,305 | 171,841 | 224,251 | 184,560 | 161,193 | 211,314 | 207,251 | 186,683 | 230,085 |
| 146,301 | 126,768 | 168,845 | 136,760 | 118,764 | 157,484 | 153,075 | 134,811 | 173,813 |
| 142,314 | 122,776 | 164,961 | 112,496 | 97,942 | 129,211 | 147,383 | 127,849 | 169,902 |
| 112,571 | 95,254 | 133,036 | 91,698 | 77,441 | 108,579 | 115,734 | 98,055 | 136,600 |
| 121,216 | 100,899 | 145,624 | 93,427 | 77,819 | 112,164 | 124,429 | 103,576 | 149,479 |
| 114,263 | 93,954 | 138,962 | 103,335 | 86,334 | 123,684 | 117,757 | 96,815 | 143,230 |
| 148,379 | 125,528 | 175,389 | 157,584 | 134,541 | 184,572 | 152,938 | 129,414 | 180,737 |
| 169,975 | 147,670 | 195,650 | 224,580 | 196,405 | 256,797 | 175,187 | 152,299 | 201,515 |
| 240,529 | 211,569 | 273,452 | 329,159 | 293,494 | 369,158 | 247,649 | 218,038 | 281,282 |
| 315,593 | 284,001 | 350,700 | 465,287 | 420,855 | 514,409 | 324,229 | 292,115 | 359,873 |
| 513,622 | 466,247 | 565,810 | 609,933 | 555,769 | 669,375 | 527,066 | 479,232 | 579,674 |
| 669,824 | 611,993 | 733,120 | 773,293 | 708,550 | 843,951 | 686,064 | 628,016 | 749,478 |
| 823,987 | 756,724 | 897,229 | 927,400 | 852,463 | 1,008,920 | 841,803 | 774,729 | 914,684 |
| 1,038,330 | 957,245 | 1,126,290 | 1,016,570 | 936,367 | 1,103,630 | 1,057,730 | 977,321 | 1,144,750 |
| 1,151,460 | 1,063,130 | 1,247,120 | 1,144,750 | 1,056,750 | 1,240,070 | 1,170,520 | 1,083,240 | 1,264,840 |
| 1,309,250 | 1,212,110 | 1,414,170 | 1,247,780 | 1,153,600 | 1,349,660 | 1,325,210 | 1,229,820 | 1,428,010 |
| 1,370,020 | 1,268,060 | 1,480,180 | 1,314,650 | 1,214,260 | 1,423,330 | 1,380,310 | 1,280,670 | 1,487,700 |
| 1,318,050 | 1,217,750 | 1,426,610 | 1,310,280 | 1,207,110 | 1,422,270 | 1,319,970 | 1,222,480 | 1,425,240 |
| 1,302,290 | 1,200,510 | 1,412,700 | 1,313,610 | 1,206,710 | 1,429,990 | 1,296,100 | 1,197,760 | 1,402,530 |
| 1,209,850 | 1,111,170 | 1,317,300 | 1,252,240 | 1,146,550 | 1,367,680 | 1,197,550 | 1,102,650 | 1,300,630 |
| 1,208,770 | 1,106,450 | 1,320,550 | 1,227,990 | 1,120,610 | 1,345,670 | 1,187,860 | 1,090,080 | 1,294,410 |
| 1,248,320 | 1,141,830 | 1,364,730 | 1,243,850 | 1,134,790 | 1,363,380 | 1,220,170 | 1,118,930 | 1,330,570 |
| 1,305,040 | 1,196,240 | 1,423,740 | 1,339,640 | 1,225,040 | 1,464,960 | 1,269,300 | 1,166,520 | 1,381,140 |
| 1,311,910 | 1,204,300 | 1,429,120 | 1,442,100 | 1,321,270 | 1,573,990 | 1,270,820 | 1,169,720 | 1,380,670 |
| 1,437,360 | 1,321,150 | 1,563,800 | 1,497,570 | 1,372,310 | 1,634,260 | 1,385,750 | 1,277,370 | 1,503,330 |
| 1,323,600 | 1,218,110 | 1,438,220 | 1,503,800 | 1,378,000 | 1,641,090 | 1,271,550 | 1,173,850 | 1,377,390 |
| 1,421,480 | 1,306,040 | 1,547,130 | 1,504,890 | 1,377,830 | 1,643,670 | 1,362,510 | 1,255,880 | 1,478,200 |
| 1,346,490 | 1,235,540 | 1,467,400 | 1,423,790 | 1,301,550 | 1,557,530 | 1,287,300 | 1,185,210 | 1,398,180 |
| 1,319,490 | 1,209,310 | 1,439,710 | 1,382,480 | 1,261,910 | 1,514,560 | 1,259,190 | 1,158,160 | 1,369,040 |
| 1,202,610 | 1,099,530 | 1,315,350 | 1,299,720 | 1,183,340 | 1,427,540 | 1,144,920 | 1,050,750 | 1,247,520 |
| 1,185,980 | 1,082,220 | 1,299,680 | 1,283,210 | 1,167,570 | 1,410,300 | 1,127,990 | 1,033,250 | 1,231,410 |
| 1,154,060 | 1,054,300 | 1,263,270 | 1,262,580 | 1,148,180 | 1,388,380 | 1,097,470 | 1,006,700 | 1,196,430 |

| | | | | | | | | |
|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 1,216,550 | 1,110,800 | 1,332,380 | 1,252,550 | 1,139,250 | 1,377,120 | 1,156,850 | 1,060,740 | 1,261,670 |
| 1,176,810 | 1,075,350 | 1,287,850 | 1,246,590 | 1,134,110 | 1,370,220 | 1,120,450 | 1,028,360 | 1,220,780 |
| 1,232,250 | 1,127,310 | 1,346,940 | 1,254,250 | 1,142,210 | 1,377,290 | 1,176,100 | 1,080,930 | 1,279,650 |
| 1,278,220 | 1,171,080 | 1,395,170 | 1,290,820 | 1,177,190 | 1,415,420 | 1,224,010 | 1,126,880 | 1,329,510 |
| 1,312,720 | 1,203,270 | 1,432,120 | 1,312,030 | 1,197,690 | 1,437,270 | 1,260,160 | 1,161,020 | 1,367,760 |
| 1,401,910 | 1,285,240 | 1,529,170 | 1,343,430 | 1,227,030 | 1,470,860 | 1,349,540 | 1,243,960 | 1,464,090 |
| 1,256,230 | 1,152,460 | 1,369,340 | 1,356,430 | 1,238,770 | 1,485,260 | 1,214,350 | 1,120,580 | 1,315,970 |
| 1,222,050 | 1,119,800 | 1,333,650 | 1,329,770 | 1,212,720 | 1,458,120 | 1,185,570 | 1,093,300 | 1,285,630 |
| 1,267,980 | 1,160,040 | 1,385,960 | 1,284,240 | 1,168,990 | 1,410,860 | 1,234,990 | 1,137,760 | 1,340,530 |
| 1,324,240 | 1,209,880 | 1,449,410 | 1,255,370 | 1,141,460 | 1,380,650 | 1,293,720 | 1,190,890 | 1,405,420 |
| 1,215,490 | 1,110,160 | 1,330,810 | 1,225,310 | 1,112,820 | 1,349,160 | 1,195,450 | 1,100,990 | 1,298,000 |
| 1,200,330 | 1,093,760 | 1,317,290 | 1,201,050 | 1,088,680 | 1,325,020 | 1,186,320 | 1,091,080 | 1,289,870 |
| 1,133,650 | 1,030,780 | 1,246,780 | 1,185,240 | 1,071,790 | 1,310,710 | 1,127,760 | 1,036,290 | 1,227,310 |
| 1,089,170 | 986,281 | 1,202,790 | 1,132,950 | 1,020,240 | 1,258,100 | 1,089,550 | 998,489 | 1,188,930 |
| 1,113,330 | 1,004,320 | 1,234,170 | 1,120,640 | 1,005,550 | 1,248,920 | 1,120,980 | 1,024,980 | 1,225,970 |
| 1,089,300 | 979,100 | 1,211,900 | 1,117,570 | 999,623 | 1,249,430 | 1,103,400 | 1,006,950 | 1,209,080 |
| 1,120,470 | 1,001,590 | 1,253,460 | 1,088,840 | 969,985 | 1,222,270 | 1,138,720 | 1,035,230 | 1,252,550 |
| 1,014,240 | 903,157 | 1,138,990 | 1,086,590 | 964,287 | 1,224,400 | 1,036,370 | 940,491 | 1,142,030 |
| 1,077,680 | 954,497 | 1,216,770 | 1,100,300 | 972,439 | 1,244,970 | 1,103,570 | 998,059 | 1,220,240 |
| 989,113 | 870,049 | 1,124,470 | 1,086,650 | 955,134 | 1,236,260 | 1,012,230 | 910,960 | 1,124,770 |
| 941,735 | 822,581 | 1,078,150 | | | | 962,314 | 861,588 | 1,074,810 |

Table 4.18: Model estimates of age 1 recruitment (in billions of fish), 1954–2021, with 95% lower and upper confidence intervals (LCI, HCI) for Model 18.2 (2021) and 18.2 (2020).

| Year | Model 18.2 (2021) | | | Model 18.2 (2020) | | |
|------|-------------------|-------|-------|-------------------|-------|-------|
| | Recruitment | LCI | HCI | Recruitment | LCI | HCI |
| 1954 | 2.051 | 1.477 | 2.626 | 1.877 | 0.957 | 2.797 |
| 1955 | 1.669 | 1.251 | 2.087 | 2.057 | 1.481 | 2.634 |
| 1956 | 1.440 | 1.040 | 1.839 | 1.674 | 1.254 | 2.094 |
| 1957 | 5.392 | 3.584 | 7.200 | 1.446 | 1.048 | 1.844 |
| 1958 | 3.590 | 1.782 | 5.398 | 5.454 | 3.607 | 7.302 |
| 1959 | 2.326 | 1.489 | 3.163 | 3.67 | 1.637 | 5.703 |
| 1960 | 1.965 | 1.546 | 2.383 | 2.362 | 1.417 | 3.307 |
| 1961 | 1.086 | 0.875 | 1.298 | 1.977 | 1.535 | 2.419 |
| 1962 | 2.065 | 1.785 | 2.345 | 1.088 | 0.875 | 1.301 |
| 1963 | 1.079 | 0.875 | 1.282 | 2.063 | 1.783 | 2.343 |
| 1964 | 1.000 | 0.808 | 1.192 | 1.076 | 0.874 | 1.279 |
| 1965 | 1.312 | 1.085 | 1.539 | 0.999 | 0.807 | 1.19 |
| 1966 | 1.364 | 1.114 | 1.614 | 1.31 | 1.083 | 1.537 |
| 1967 | 2.916 | 2.504 | 3.328 | 1.359 | 1.11 | 1.609 |
| 1968 | 4.539 | 3.994 | 5.083 | 2.907 | 2.494 | 3.319 |
| 1969 | 4.663 | 4.103 | 5.224 | 4.532 | 3.983 | 5.081 |
| 1970 | 6.144 | 5.488 | 6.800 | 4.69 | 4.121 | 5.259 |
| 1971 | 6.790 | 6.103 | 7.477 | 6.2 | 5.53 | 6.871 |
| 1972 | 5.309 | 4.725 | 5.893 | 6.898 | 6.19 | 7.607 |
| 1973 | 3.683 | 3.222 | 4.144 | 5.427 | 4.822 | 6.031 |
| 1974 | 4.951 | 4.420 | 5.482 | 3.758 | 3.283 | 4.234 |
| 1975 | 5.751 | 5.187 | 6.315 | 5.046 | 4.498 | 5.595 |
| 1976 | 3.771 | 3.336 | 4.206 | 5.913 | 5.324 | 6.503 |
| 1977 | 4.726 | 4.232 | 5.220 | 3.879 | 3.426 | 4.331 |
| 1978 | 3.084 | 2.703 | 3.465 | 4.875 | 4.357 | 5.393 |
| 1979 | 1.986 | 1.688 | 2.284 | 3.193 | 2.793 | 3.593 |
| 1980 | 3.894 | 3.460 | 4.328 | 2.044 | 1.735 | 2.354 |
| 1981 | 2.927 | 2.557 | 3.296 | 3.971 | 3.521 | 4.421 |
| 1982 | 8.516 | 7.796 | 9.236 | 2.983 | 2.602 | 3.365 |
| 1983 | 1.572 | 1.310 | 1.834 | 8.682 | 7.925 | 9.438 |
| 1984 | 7.031 | 6.404 | 7.659 | 1.608 | 1.338 | 1.878 |
| 1985 | 2.427 | 2.101 | 2.753 | 7.192 | 6.532 | 7.852 |
| 1986 | 1.866 | 1.588 | 2.144 | 2.492 | 2.153 | 2.83 |
| 1987 | 2.551 | 2.224 | 2.877 | 1.916 | 1.627 | 2.204 |
| 1988 | 3.498 | 3.107 | 3.888 | 2.621 | 2.281 | 2.961 |
| 1989 | 3.494 | 3.105 | 3.882 | 3.599 | 3.189 | 4.01 |
| 1990 | 1.741 | 1.482 | 1.999 | 3.604 | 3.195 | 4.014 |
| 1991 | 1.954 | 1.677 | 2.232 | 1.801 | 1.53 | 2.072 |
| 1992 | 4.327 | 3.875 | 4.779 | 2.026 | 1.734 | 2.318 |
| 1993 | 2.557 | 2.230 | 2.885 | 4.499 | 4.015 | 4.983 |
| 1994 | 2.149 | 1.852 | 2.446 | 2.683 | 2.332 | 3.034 |
| 1995 | 2.150 | 1.854 | 2.447 | 2.258 | 1.941 | 2.576 |
| 1996 | 5.255 | 4.743 | 5.767 | 2.264 | 1.946 | 2.582 |
| 1997 | 2.258 | 1.956 | 2.560 | 5.566 | 5.002 | 6.129 |
| 1998 | 1.864 | 1.597 | 2.131 | 2.401 | 2.073 | 2.729 |
| 1999 | 2.271 | 1.977 | 2.564 | 1.99 | 1.7 | 2.281 |
| 2000 | 3.168 | 2.813 | 3.523 | 2.43 | 2.108 | 2.752 |
| 2001 | 2.042 | 1.768 | 2.316 | 3.405 | 3.01 | 3.801 |

| | | | | | | |
|------|-------|--------|-------|-------|--------|--------|
| 2002 | 2.735 | 2.406 | 3.063 | 2.209 | 1.904 | 2.513 |
| 2003 | 2.602 | 2.280 | 2.924 | 2.979 | 2.607 | 3.35 |
| 2004 | 3.947 | 3.519 | 4.374 | 2.868 | 2.499 | 3.237 |
| 2005 | 1.798 | 1.532 | 2.064 | 4.423 | 3.921 | 4.925 |
| 2006 | 1.971 | 1.680 | 2.262 | 2.005 | 1.696 | 2.313 |
| 2007 | 2.288 | 1.953 | 2.622 | 2.272 | 1.923 | 2.621 |
| 2008 | 2.092 | 1.765 | 2.420 | 2.746 | 2.331 | 3.161 |
| 2009 | 2.540 | 2.151 | 2.929 | 2.507 | 2.098 | 2.915 |
| 2010 | 3.544 | 3.022 | 4.065 | 3.059 | 2.566 | 3.552 |
| 2011 | 1.292 | 1.008 | 1.576 | 4.305 | 3.62 | 4.991 |
| 2012 | 0.581 | 0.389 | 0.773 | 1.522 | 1.151 | 1.893 |
| 2013 | 1.479 | 1.090 | 1.868 | 0.743 | 0.477 | 1.009 |
| 2014 | 1.669 | 1.169 | 2.168 | 1.99 | 1.433 | 2.547 |
| 2015 | 2.758 | 1.872 | 3.643 | 2.1 | 1.408 | 2.792 |
| 2016 | 3.881 | 2.192 | 5.570 | 3.617 | 2.275 | 4.96 |
| 2017 | 4.371 | 1.360 | 7.382 | 5.428 | 2.752 | 8.104 |
| 2018 | 2.109 | -0.461 | 4.680 | 7.563 | 2 | 13.126 |
| 2019 | 2.534 | -0.913 | 5.980 | 2.563 | -0.756 | 5.882 |
| 2020 | 2.622 | -1.036 | 6.280 | 2.797 | -1.073 | 6.668 |
| 2021 | 2.628 | -1.045 | 6.301 | - | - | - |

Table 4.19: Yellowfin Sole total allowable catch (TAC), overfishing limit (OFL), and acceptable biological catch (ABC) levels, 1980-2021. Catch for the Bering Sea and Aleutian Islands was recorded through October 1, 2021. Data is in metric tons. Estimates for 2022 were calculated using Model 18.2, and the 2022 TAC has not yet been set.

| Year | TAC | ABC | OFL | Catch |
|------|---------|---------|---------|---------|
| 1980 | 117,000 | 169,000 | n/a | 87,391 |
| 1981 | 117,000 | 214,500 | n/a | 97,301 |
| 1982 | 117,000 | 214,500 | n/a | 95,712 |
| 1983 | 117,000 | 214,500 | n/a | 108,385 |
| 1984 | 230,000 | 310,000 | n/a | 159,526 |
| 1985 | 229,900 | 310,000 | n/a | 227,107 |
| 1986 | 209,500 | 230,000 | n/a | 208,597 |
| 1987 | 187,000 | 187,000 | n/a | 181,428 |
| 1988 | 254,000 | 254,000 | n/a | 223,156 |
| 1989 | 182,675 | 241,000 | n/a | 153,165 |
| 1990 | 207,650 | 278,900 | n/a | 83,970 |
| 1991 | 135,000 | 250,600 | n/a | 117,303 |
| 1992 | 235,000 | 372,000 | 452,000 | 145,386 |
| 1993 | 220,000 | 238,000 | 275,000 | 105,810 |
| 1994 | 150,325 | 230,000 | 269,000 | 140,050 |
| 1995 | 190,000 | 277,000 | 319,000 | 124,752 |
| 1996 | 200,000 | 278,000 | 342,000 | 129,659 |
| 1997 | 230,000 | 233,000 | 339,000 | 182,814 |
| 1998 | 220,000 | 220,000 | 314,000 | 101,155 |
| 1999 | 207,980 | 212,000 | 308,000 | 69,234 |
| 2000 | 123,262 | 191,000 | 226,000 | 84,071 |
| 2001 | 113,000 | 176,000 | 209,000 | 63,579 |
| 2002 | 86,000 | 115,000 | 136,000 | 74,986 |
| 2003 | 83,750 | 114,000 | 136,000 | 79,806 |
| 2004 | 86,075 | 114,000 | 135,000 | 75,511 |
| 2005 | 90,686 | 124,000 | 148,000 | 94,385 |
| 2006 | 95,701 | 121,000 | 144,000 | 99,160 |
| 2007 | 136,000 | 225,000 | 240,000 | 120,964 |
| 2008 | 225,000 | 248,000 | 265,000 | 148,894 |
| 2009 | 210,000 | 210,000 | 224,000 | 107,513 |
| 2010 | 219,000 | 219,000 | 234,000 | 118,624 |
| 2011 | 196,000 | 239,000 | 262,000 | 151,158 |
| 2012 | 202,000 | 203,000 | 222,000 | 147,187 |
| 2013 | 198,000 | 206,000 | 220,000 | 164,944 |
| 2014 | 184,000 | 239,800 | 259,700 | 156,772 |
| 2015 | 149,000 | 248,800 | 266,400 | 126,937 |
| 2016 | 144,000 | 211,700 | 228,100 | 135,324 |
| 2017 | 154,000 | 260,800 | 287,000 | 132,220 |
| 2018 | 154,000 | 277,500 | 306,700 | 131,496 |
| 2019 | 154,000 | 263,200 | 290,000 | 128,051 |
| 2020 | 150,700 | 260,918 | 287,307 | 133,800 |
| 2021 | 200,000 | 313,477 | 341,571 | 88,895 |
| 2022 | | 354,014 | 377,071 | |

Table 4.20: Projections of Yellowfin Sole female spawning biomass (FSB), future catch, and full selection fishing mortality rates (F) for seven future harvest scenarios. Estimates of FSB and catch are in metric tons (t). All estimates are based on Model 18.2.

| Scenarios 1 and 2 | | | | Scenario 3 | | | |
|---------------------------------|---------|---------|-------|--|---------|---------|-------|
| Maximum ABC harvest permissible | | | | Harvest at average F over past 5 years | | | |
| Year | FSB | Catch | F | Year | FSB | Catch | F |
| 2021 | 853,521 | 108,157 | 0.067 | 2021 | 853,521 | 108,157 | 0.067 |
| 2022 | 816,003 | 126,929 | 0.079 | 2022 | 816,003 | 126,929 | 0.079 |
| 2023 | 780,284 | 190,898 | 0.117 | 2023 | 791,108 | 121,085 | 0.073 |
| 2024 | 754,840 | 195,438 | 0.117 | 2024 | 795,197 | 128,374 | 0.073 |
| 2025 | 753,650 | 199,579 | 0.117 | 2025 | 821,149 | 135,166 | 0.073 |
| 2026 | 770,517 | 199,536 | 0.117 | 2026 | 865,188 | 138,317 | 0.073 |
| 2027 | 779,543 | 196,533 | 0.117 | 2027 | 900,500 | 139,559 | 0.073 |
| 2028 | 777,665 | 194,344 | 0.117 | 2028 | 921,420 | 140,768 | 0.073 |
| 2029 | 769,052 | 192,101 | 0.117 | 2029 | 931,171 | 141,322 | 0.073 |
| 2030 | 761,685 | 190,156 | 0.116 | 2030 | 938,422 | 142,284 | 0.073 |
| 2031 | 756,555 | 187,643 | 0.115 | 2031 | 944,306 | 143,223 | 0.073 |
| 2032 | 753,630 | 186,026 | 0.114 | 2032 | 949,240 | 144,299 | 0.073 |
| 2033 | 758,207 | 186,588 | 0.113 | 2033 | 961,584 | 145,794 | 0.073 |
| 2034 | 762,508 | 187,564 | 0.113 | 2034 | 972,069 | 147,350 | 0.073 |

| Scenario 4, Maximum Tier 3 ABC harvest permissible set at F60 | | | | Scenario 5 | | | |
|---|-----------|---------|-------|------------|-----------|---------|-------|
| | | | | No fishing | | | |
| Year | FSB | Catch | F | Year | FSB | Catch | F |
| 2021 | 853,521 | 108,157 | 0.067 | 2021 | 853,521 | 108,157 | 0.067 |
| 2022 | 822,325 | 88,713 | 0.055 | 2022 | 836,695 | 0 | 0.000 |
| 2023 | 812,660 | 96,846 | 0.057 | 2023 | 868,962 | 0 | 0.000 |
| 2024 | 826,710 | 103,624 | 0.057 | 2024 | 925,259 | 0 | 0.000 |
| 2025 | 862,140 | 109,995 | 0.057 | 2025 | 1,003,660 | 0 | 0.000 |
| 2026 | 916,207 | 113,468 | 0.057 | 2026 | 1,104,923 | 0 | 0.000 |
| 2027 | 961,599 | 115,353 | 0.057 | 2027 | 1,199,953 | 0 | 0.000 |
| 2028 | 991,578 | 117,089 | 0.057 | 2028 | 1,277,558 | 0 | 0.000 |
| 2029 | 1,008,918 | 118,142 | 0.057 | 2029 | 1,338,018 | 0 | 0.000 |
| 2030 | 1,022,571 | 119,430 | 0.057 | 2030 | 1,390,702 | 0 | 0.000 |
| 2031 | 1,033,858 | 120,628 | 0.057 | 2031 | 1,437,279 | 0 | 0.000 |
| 2032 | 1,043,354 | 121,889 | 0.057 | 2032 | 1,478,640 | 0 | 0.000 |
| 2033 | 1,060,562 | 123,476 | 0.057 | 2033 | 1,529,274 | 0 | 0.000 |
| 2034 | 1,075,267 | 125,098 | 0.057 | 2034 | 1,574,490 | 0 | 0.000 |

Alternative 6, Determination of whether Yellowfin Sole are currently overfished

| Year | FSB | Catch | F |
|------|---------|---------|-------|
| 2021 | 853,521 | 108,157 | 0.067 |
| 2022 | 800,229 | 220,127 | 0.140 |
| 2023 | 734,069 | 210,089 | 0.136 |
| 2024 | 703,671 | 205,320 | 0.130 |
| 2025 | 701,041 | 209,096 | 0.130 |
| 2026 | 715,684 | 212,394 | 0.132 |
| 2027 | 721,322 | 210,095 | 0.134 |
| 2028 | 716,706 | 205,753 | 0.133 |
| 2029 | 707,198 | 200,471 | 0.131 |
| 2030 | 700,376 | 197,788 | 0.129 |
| 2031 | 696,099 | 196,411 | 0.128 |
| 2032 | 693,669 | 195,820 | 0.128 |
| 2033 | 697,695 | 197,531 | 0.128 |
| 2034 | 701,081 | 199,144 | 0.128 |

Scenario 7, Determination of whether stock is approaching an overfished condition

| Year | FSB | Catch | F |
|------|---------|---------|-------|
| 2021 | 853,521 | 108,157 | 0.067 |
| 2022 | 806,186 | 185,284 | 0.117 |
| 2023 | 754,127 | 184,856 | 0.117 |
| 2024 | 728,095 | 218,733 | 0.135 |
| 2025 | 719,292 | 218,978 | 0.133 |
| 2026 | 728,962 | 219,382 | 0.135 |
| 2027 | 730,569 | 214,785 | 0.135 |
| 2028 | 722,841 | 208,760 | 0.134 |
| 2029 | 711,091 | 202,306 | 0.132 |
| 2030 | 702,741 | 198,863 | 0.130 |
| 2031 | 697,512 | 197,021 | 0.129 |
| 2032 | 694,499 | 196,157 | 0.128 |
| 2033 | 698,137 | 197,702 | 0.128 |
| 2034 | 701,284 | 199,213 | 0.128 |

Table 4.21: Incidental catch of FMP Groundfish in the Yellowfin Sole fishery. Source: NMFS AKRO Blend/Catch Accounting System; 1991-present. The following abbreviations are used: Fl. = flounder, Flathead = Flathead Sole, AK = Alaska, Atka = Atka Mackerel, RF = rockfish, POP = Pacific Ocean Perch, SR = Shortraker, RE = Rougheye, N. = Northern, G. Turbot = Greenland Turbot, O. = Other.

| Year | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|----------------|------|-------|-------|-------|-------|-------|-------|-------|-------|--------|-------|-------|-------|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-------|--------|--------|--------|--------|--------|
| Alaska Plaice | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10,395 | 118 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Arrowtooth Fl. | 366 | 1,017 | 1,595 | 345 | 819 | 386 | 2,382 | 1,631 | 1,998 | 1,845 | 997 | 1,132 | 263 | 645 | 350 | 213 | 1,969 | 1,851 | 1,619 | 2,331 | 987 | 2,042 | 2,216 | 1,685 | 3,249 | 1,262 | 3,075 | 3,219 | 2,015 | 1,198 |
| Atka Mackerel | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 32 | 0 | 0 | 0 | 16 | 0 | 110 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| AK Plaice | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8,395 | 5,835 | 8,711 | 13,972 | 16,357 | 13,511 | 10,631 | 12,044 | 18,305 | 13,594 | 15,978 | 14,372 | 11,681 | 8,163 | 12,782 | 15,330 | 12,953 | 16,595 | 11,422 |
| Kamchatka Fl. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 91 | 122 | 148 | 498 | 427 | 284 | 164 | 218 | 230 | 128 | 77 | |
| O. Flatfish | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 213 | 433 | 653 | 877 | 2,850 | 1,235 | 241 | 977 | 1,585 | 1,206 | 388 | 2,886 | 1,041 | 1,135 | 1,734 | 3,282 | 1,476 | 2,175 | 1,034 |
| Shortraker RF | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| Skate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2,107 | 2,234 | 2,683 | 1,970 | 1,072 | 1,294 | 1,931 | 2,560 | 3,508 | 2,480 | 2,791 | |
| Squid | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Flathead | 0 | 0 | 0 | 3,929 | 3,165 | 3,896 | 5,323 | 2,309 | 2,644 | 3,231 | 2,190 | 2,856 | 1,076 | 1,247 | 2,025 | 1,735 | 5,579 | 3,497 | 2,695 | 3,229 | 2,095 | 4,179 | 3,998 | 3,337 | 4,103 | 3,106 | 3,960 | 4,132 | 3,498 | 2,474 |

| Year | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|-----------------|--------|-------|--------|--------|--------|--------|--------|-------|--------|--------|-------|-------|-------|-------|-------|-------|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-------|
| Flounder | 16,826 | 9,620 | 12,422 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| G. Turbot | 0 | 4 | 4 | 67 | 8 | 4 | 103 | 69 | 23 | 32 | 2 | 3 | 0 | 6 | 8 | 0 | 0 | 3 | 1 | 5 | 5 | 35 | 56 | 42 | 7 | 8 | 26 | 6 | 12 | 2 |
| Non.TAC.Species | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 21 | 188 | 173 | 165 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Northern RF | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Octopus | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Other | 7,990 | 3,847 | 3,983 | 2,904 | 2,565 | 4,754 | 3,570 | 2,765 | 3,641 | 3,969 | 4,946 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| O. Flatfish | 0 | 0 | 0 | 0 | 12,239 | 10,962 | 17,222 | 9,182 | 11,449 | 10,286 | 6,844 | 519 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Other Rockfish | 0 | 0 | 0 | 0 | 3 | 22 | 12 | 1 | 3 | 3 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Other Species | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3,002 | 1,602 | 2,136 | 2,297 | 3,996 | 4,191 | 4,346 | 3,561 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Pacific Cod | 8,700 | 8,723 | 16,415 | 13,181 | 8,684 | 12,825 | 10,233 | 4,383 | 5,192 | 6,531 | 6,259 | 4,634 | 3,574 | 3,769 | 2,545 | 2,519 | 5,767 | 10,716 | 11,117 | 16,204 | 19,380 | 24,339 | 15,218 | 12,168 | 11,985 | 14,648 | 12,570 | 11,769 | 12,062 | 7,859 |

| Year | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | |
|-----------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-------|-------|--------|-------|-------|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-------|--|
| POP | 0 | 4 | 0 | 0 | 0 | 0 | 1 | 12 | 1 | 0 | 1 | 10 | 0 | 15 | 0 | 0 | 0 | 0 | 0 | 16 | 0 | 0 | 2 | 0 | 0 | 0 | 63 | 0 | | | |
| Pollock | 13,100 | 15,253 | 33,200 | 27,041 | 22,254 | 24,100 | 15,339 | 8,701 | 13,425 | 16,502 | 14,489 | 11,578 | 10,383 | 10,312 | 5,966 | 4,020 | 9,827 | 7,036 | 5,179 | 8,673 | 11,197 | 20,171 | 24,712 | 21,281 | 23,414 | 28,229 | 23,153 | 31,648 | 22,282 | | |
| Rex Sole | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| Rock Sole | 14,646 | 7,300 | 8,096 | 7,486 | 12,903 | 16,693 | 9,826 | 10,774 | 7,345 | 5,810 | 10,664 | 8,314 | 9,972 | 10,090 | 7,971 | 8,241 | 10,468 | 8,978 | 9,624 | 9,694 | 9,179 | 7,688 | 7,030 | 9,772 | 7,948 | 12,196 | 9,359 | 9,204 | 11,242 | 7,880 | |
| Sablefish | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | |
| Sculpin | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Shark | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Sharpchin/N. RF | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| SR/RE/Sharpchin/N. RF | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Squid | 0 | 0 | 4 | 0 | 10 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

Table 4.22: Bycatch of Other Species in the Yellowfin Sole directed fishery, which includes Octopus, Shark, Skate, Squid, and Sculpin. These species are included in the FMP but not available by species in the FMP Groundfish Incidental catch table. Bycatch reported in metric tons. Source: NMFS AKRO Catch Accounting System, Nontarget Estimates; available for 2003 and later.

| Year | BSAI.Skate | BSAI.Squid | Octopus | Other | Other.Species | Shark |
|------|------------|------------|---------|-------|---------------|-------|
| 1992 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1994 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1995 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1996 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1997 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1998 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1999 | 0 | 0 | 0 | 26 | 0 | 0 |
| 2000 | 0 | 0 | 0 | 3 | 0 | 0 |
| 2001 | 0 | 0 | 0 | 21 | 0 | 0 |
| 2002 | 0 | 0 | 0 | 1,042 | 0 | 0 |
| 2003 | 0 | 1 | 0 | 0 | 1,529 | 0 |
| 2004 | 0 | 0 | 0 | 0 | 598 | 0 |
| 2005 | 0 | 0 | 0 | 0 | 944 | 0 |
| 2006 | 0 | 0 | 0 | 0 | 1,133 | 0 |
| 2007 | 0 | 0 | 0 | 0 | 1,410 | 0 |
| 2008 | 0 | 0 | 0 | 0 | 1,303 | 0 |
| 2009 | 0 | 0 | 0 | 0 | 1,785 | 0 |
| 2010 | 0 | 0 | 0 | 0 | 1,913 | 0 |
| 2011 | 2,107 | 0 | 1 | 0 | 0 | 1 |
| 2012 | 2,234 | 0 | 1 | 0 | 0 | 0 |
| 2013 | 2,683 | 0 | 0 | 0 | 0 | 0 |
| 2014 | 1,970 | 0 | 0 | 0 | 0 | 0 |
| 2015 | 1,072 | 0 | 0 | 0 | 0 | 1 |
| 2016 | 1,294 | 0 | 0 | 0 | 0 | 3 |
| 2017 | 1,931 | 0 | 0 | 0 | 0 | 1 |
| 2018 | 2,560 | 0 | 0 | 0 | 0 | 4 |
| 2019 | 3,508 | 0 | 0 | 0 | 0 | 2 |
| 2020 | 2,480 | 0 | 0 | 0 | 0 | 2 |
| 2021 | 2,791 | 0 | 0 | 0 | 0 | 1 |

Table 4.23: Catch (t) of BSAI non-target and ecosystem species in the Yellowfin Sole fishery, 1992-2021. Source: NMFS AKRO CAS.

| Year | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|--|-------|-------|-------|-------|-------|-------|-------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Benthic.urochordata | 1,671 | 1,701 | 674 | 520 | 114 | 347 | 204 | 155 | 133 | 147 | 197 | 116 | 260 | 225 | 319 | 207 | 188 | 108 | 159 |
| Bivalves | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |
| Brittle.star.unidentified | 34 | 32 | 28 | 19 | 7 | 18 | 5 | 4 | 14 | 13 | 5 | 11 | 11 | 6 | 2 | 2 | 4 | 3 | 5 |
| Capelin | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Corals.Bryozoans...Corals.Bryozoans.Unidentified | 0 | 0 | 1 | 9 | 0 | 8 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Eelpouts | 19 | 12 | 7 | 4 | 2 | 5 | 5 | 5 | 29 | 14 | 51 | 69 | 30 | 56 | 8 | 26 | 21 | 16 | 21 |
| Eulachon | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| Giant.Grenadier | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 0 | 0 | 0 |
| Greenlings | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Hermit.crab.unidentified | 87 | 51 | 83 | 26 | 35 | 36 | 15 | 17 | 15 | 10 | 6 | 8 | 4 | 2 | 2 | 0 | 2 | 2 | 2 |
| Invertebrate.unidentified | 556 | 625 | 421 | 177 | 40 | 70 | 30 | 25 | 65 | 121 | 25 | 44 | 6 | 7 | 11 | 3 | 1 | 1 | 1 |
| Large.Scorpions | 238 | 823 | 1,057 | 1,058 | 2,269 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Large.Scorpions...Bigmouth.Scorpion | 0 | 0 | 0 | 0 | 0 | 47 | 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Large.Scorpions...Great.Scorpion | 0 | 0 | 0 | 0 | 0 | 1,203 | 1,346 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Large.Scorpions...Myoxocephalus.Unidentified | 0 | 0 | 0 | 0 | 0 | 129 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Large.Scorpions...Plain.Scorpion | 0 | 0 | 0 | 0 | 0 | 1,273 | 914 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Large.Scorpions...Red.Irish.Lord | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Large.Scorpions...Warty.Scorpion | 0 | 0 | 0 | 0 | 0 | 68 | 49 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Large.Scorpions...Yellow.Irish.Lord | 0 | 0 | 0 | 0 | 0 | 133 | 145 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Misc.crabs | 14 | 21 | 11 | 10 | 28 | 14 | 11 | 12 | 20 | 19 | 39 | 20 | 22 | 13 | 15 | 5 | 5 | 8 | 5 |
| Misc.crustaceans | 0 | 0 | 0 | 2 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Misc.fish | 95 | 91 | 66 | 42 | 71 | 66 | 48 | 29 | 39 | 54 | 46 | 26 | 36 | 30 | 42 | 25 | 30 | 30 | 54 |
| Other.osmerids | 4 | 4 | 0 | 0 | 35 | 9 | 0 | 2 | 2 | 4 | 1 | 9 | 4 | 5 | 2 | 0 | 12 | 4 | 1 |
| Other.Scorpions | 1,157 | 131 | 105 | 68 | 195 | 38 | 74 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pacific.Sandfish | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pandalid.shrimp | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Polychaete.unidentified | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| Saffron.Cod | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 31 | 1 | 42 | 3 | 0 | 0 | 0 | 2 | 0 | 0 |
| Sculpin | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,689 |
| Scypho.jellies | 111 | 298 | 115 | 46 | 42 | 145 | 223 | 152 | 307 | 179 | 463 | 804 | 381 | 67 | 93 | 161 | 677 | 334 | 337 |
| Sea.anemone.unidentified | 6 | 6 | 2 | 4 | 8 | 24 | 25 | 20 | 14 | 6 | 23 | 5 | 4 | 1 | 2 | 2 | 4 | 6 | 3 |
| Sea.pens.whips | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sea.star | 1,941 | 1,867 | 1,611 | 1,308 | 1,462 | 1,828 | 683 | 795 | 1,674 | 1,735 | 1,372 | 2,106 | 2,248 | 2,050 | 1,616 | 1,468 | 1,816 | 1,799 | 1,503 |
| Snails | 118 | 191 | 69 | 141 | 95 | 139 | 57 | 57 | 74 | 34 | 46 | 33 | 36 | 24 | 24 | 13 | 22 | 29 | 33 |
| Sponge.unidentified | 11 | 6 | 12 | 3 | 0 | 6 | 69 | 16 | 15 | 14 | 16 | 1 | 2 | 1 | 2 | 5 | 2 | 1 | 2 |
| Squid | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| urchins.dollars.cucumbers | 2 | 0 | 2 | 0 | 3 | 4 | 7 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 3 | 4 | 3 |

Table 4.24: Ecosystem indicators for Yellowfin Sole, interpretation and evaluation.

| Indicator | Observation | Interpretation | Evaluation |
|---|---|---|----------------------------------|
| Prey availability or abundance trends Benthic infauna | Stomach contents | Stable, data limited | Unknown |
| Predator population trends | | | |
| Fish (Pacific cod, halibut, skates) | Stable | Possible increases to YFS mortality | |
| Changes in habitat quality | | | |
| Temperature regime | Cold years yellowfin sole catchability and herding may decrease, timing of migration may be prolonged | Likely to affect surveyed stock | No concern (dealt with in model) |
| Winter-spring environmental conditions | Affects pre-recruit survival | Probably a number of factors | Causes natural variability |
| Yellowfin sole effects on ecosystem | | | |
| Indicator | Observation | Interpretation | Evaluation |
| Fishery contribution to bycatch | | | |
| Prohibited species | Stable, heavily monitored | Minor contribution to mortality | No concern |
| Forage (including herring, Atka mackerel, cod, and pollock) | Stable, heavily monitored | Bycatch levels small relative to forage biomass | No concern |
| HAPC biota | Low bycatch levels of (spp) | Bycatch levels small relative to HAPC biota | No concern |
| Marine mammals and birds | Very minor direct-take | Safe | No concern |
| Sensitive non-target species | Likely minor impact | Data limited, likely to be safe | No concern |
| Fishery concentration in space and time | Low exploitation rate | Little detrimental effect | No concern |
| Fishery effects on amount of large size target fish | | | |
| Fishery contribution to discards and offal production | Low exploitation rate | Natural fluctuation | No concern |
| Fishery effects on age-at-maturity and fecundity | Stable trend | Improving, but data limited | Possible concern |
| | Unknown | | Possible concern |

Figures

Weight (g) of Male and Female YFS, age 8

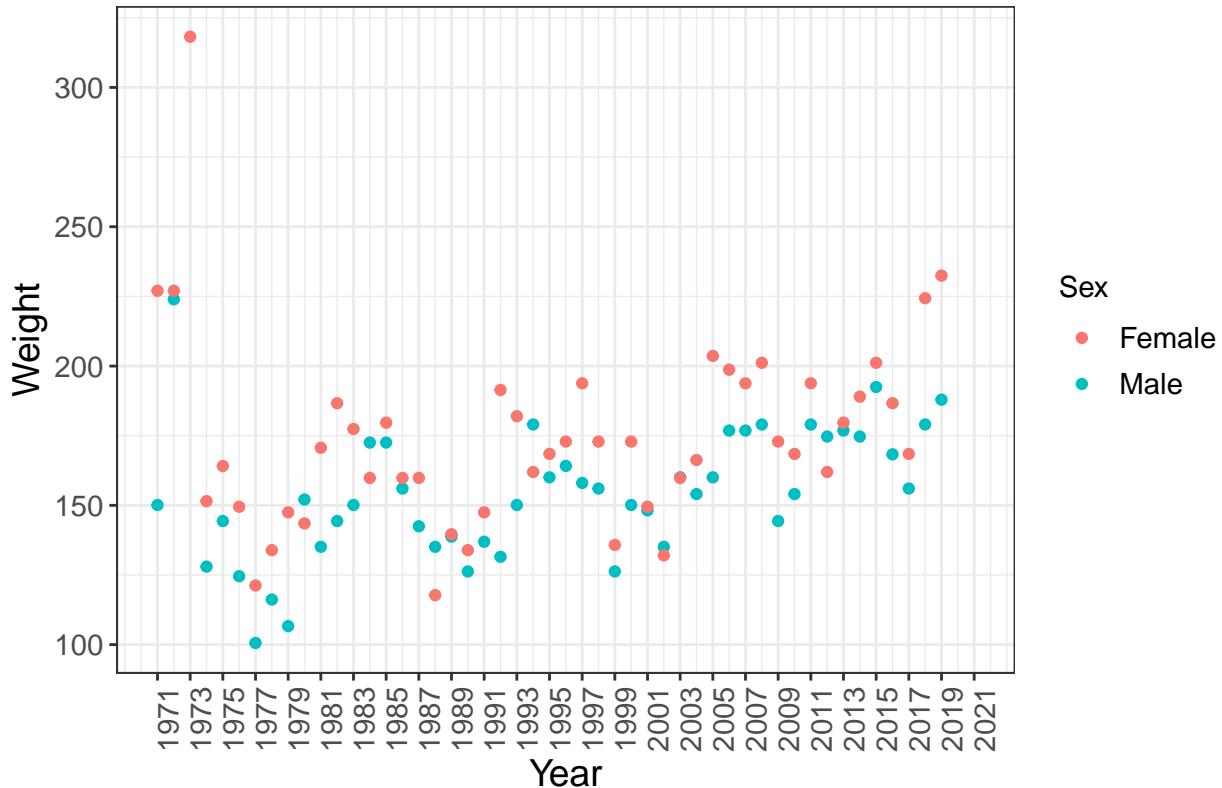


Figure 4.1: Mean weight at age (g) for Yellowfin Sole Age 8 females and males from the Eastern Bering Sea survey, 1971-2019. High values early in the time series are likely outliers.

Mean length of age 8 male and female YFS

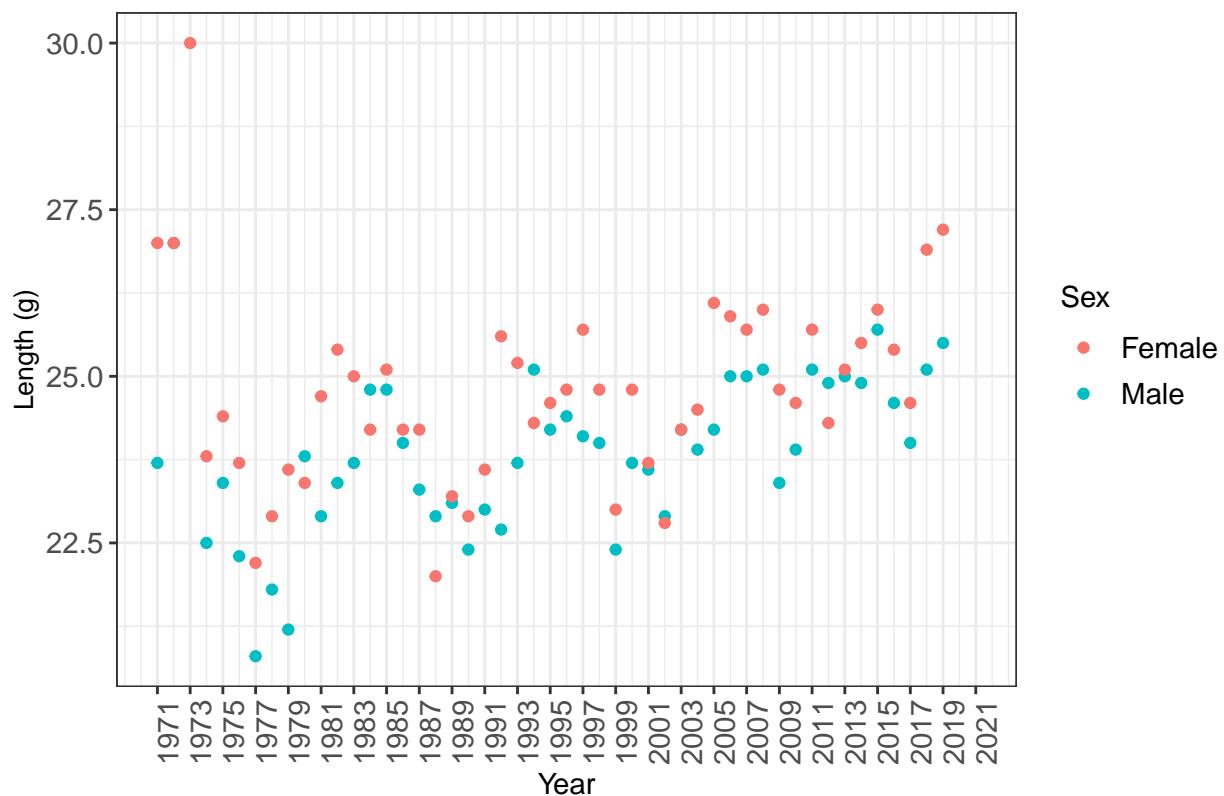


Figure 4.2: Mean length at age (cm) for Yellowfin Sole Age 8 females and males from the Eastern Bering Sea survey, 1971-2019.

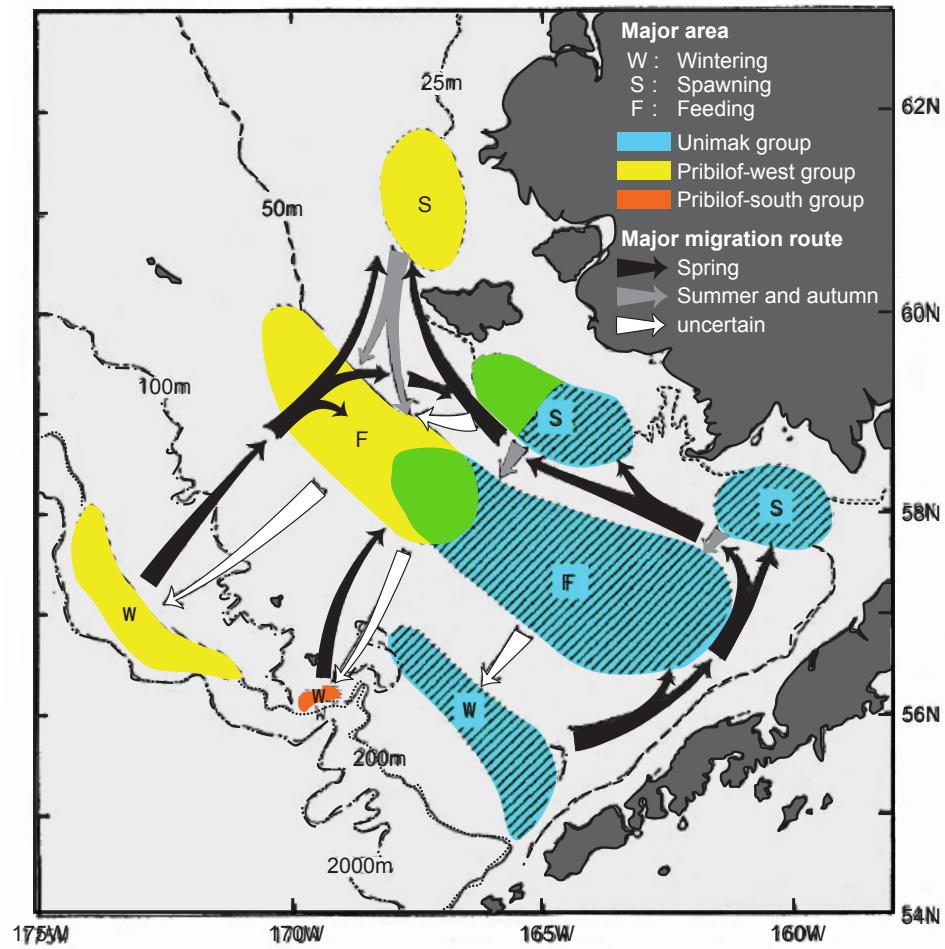


Figure 4.3: Distribution of wintering, spawning, and feeding areas for Yellowfin Sole in the Bering Sea, and observed regional grouping. Migration routes from wintering to feeding take place in spring, and the dates that Yellowfin Sole return to their wintering areas are unknown.

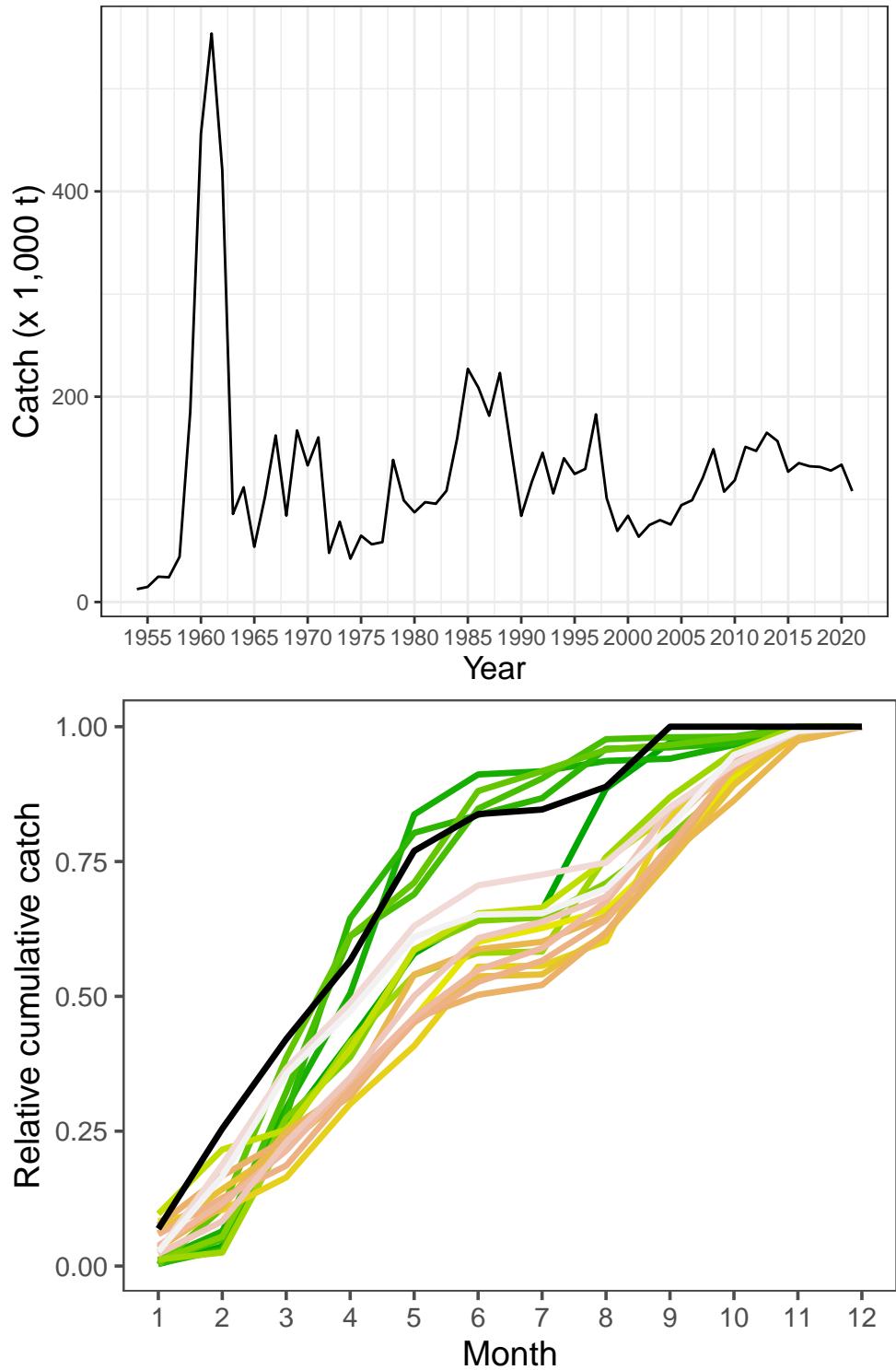


Figure 4.4: Yellowfin Sole annual total catch (1,000s t) in the Eastern Bering Sea from 1954-2021 (upper panel). Yellowfin Sole annual cumulative catch by month and year (non CDQ) 2003-October 1, 2021 (lower panel).

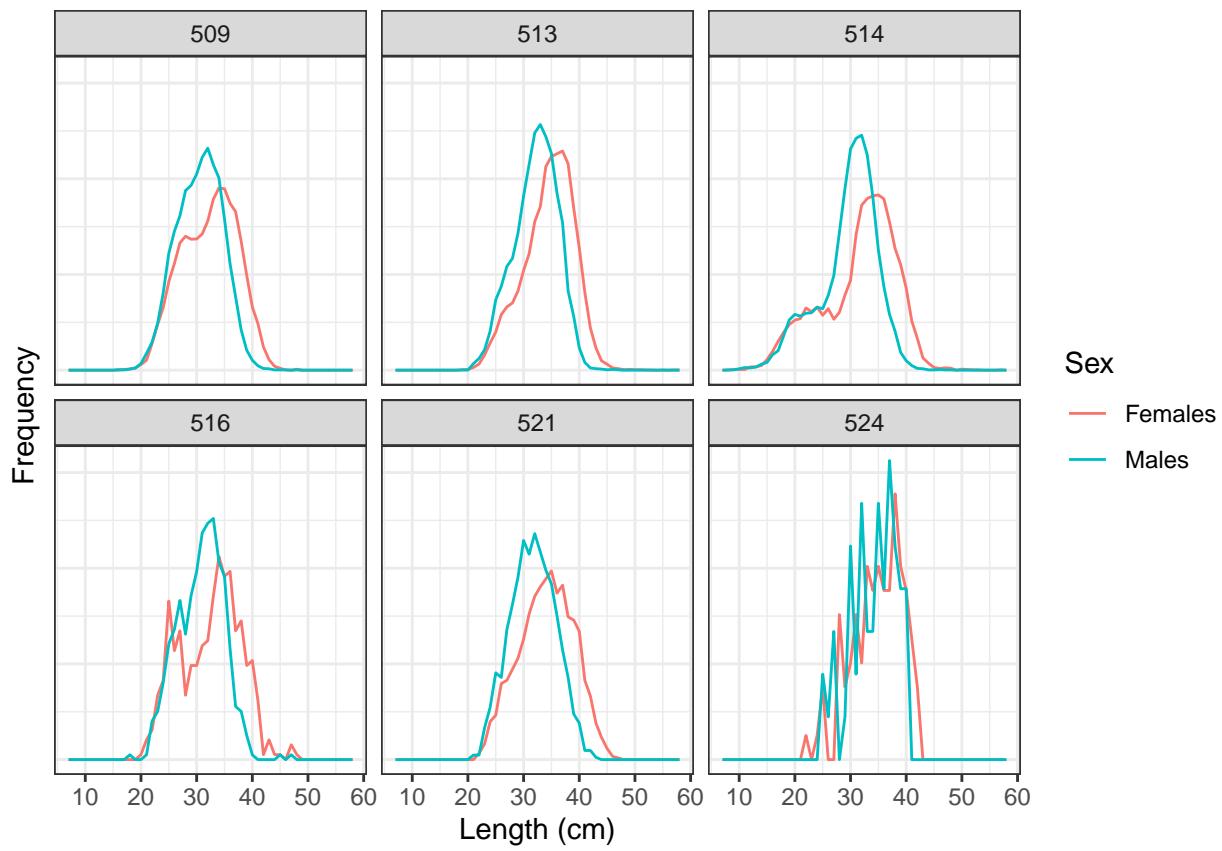


Figure 4.5: Size composition of the Yellowfin Sole catch in 2021 (through October 6) caught by trawl gear, by subarea and total, for the primary areas where Yellowfin Sole are caught, 509, 513, 514, 516, 521, and 524.

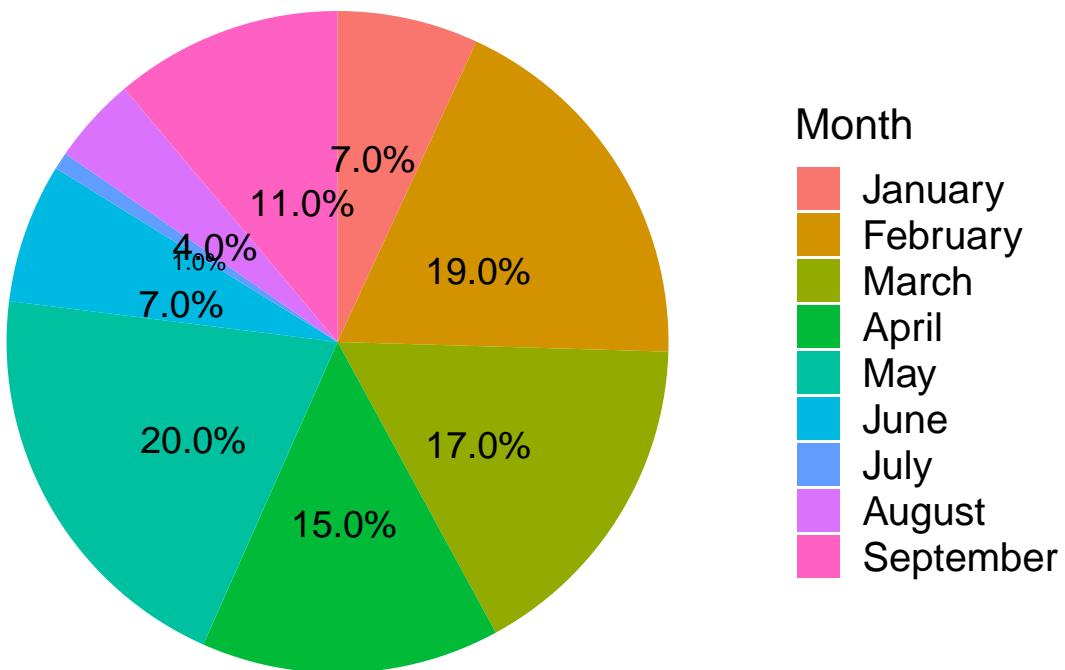
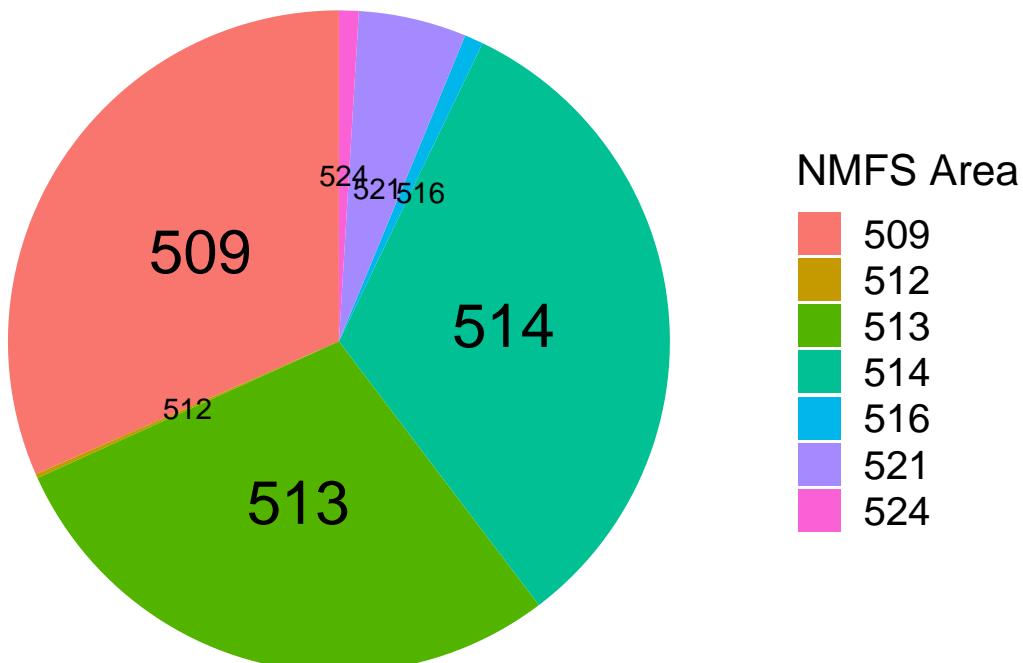


Figure 4.6: Yellowfin Sole catch proportion by area in which catch through October 1, 2021 was greater than 100 t (upper panel) and by month (lower panel) in the Eastern Bering Sea in 2021, through October 1.

Yellowfin Sole catch by trawl, 1 degree bins

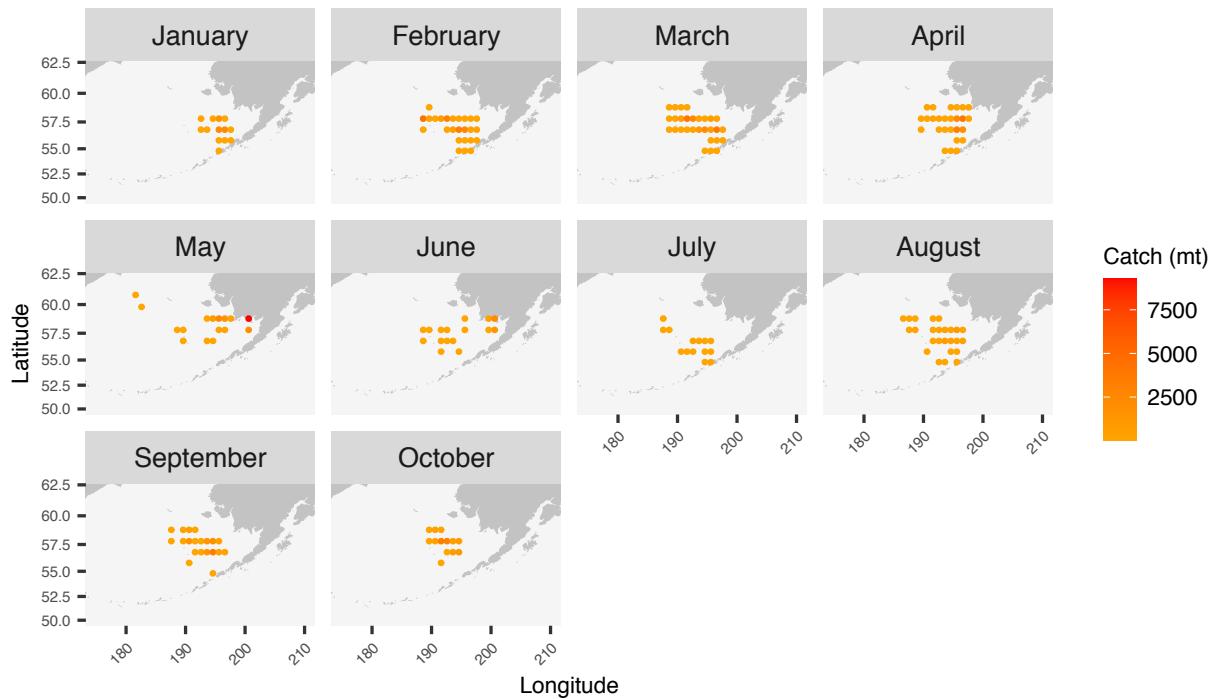
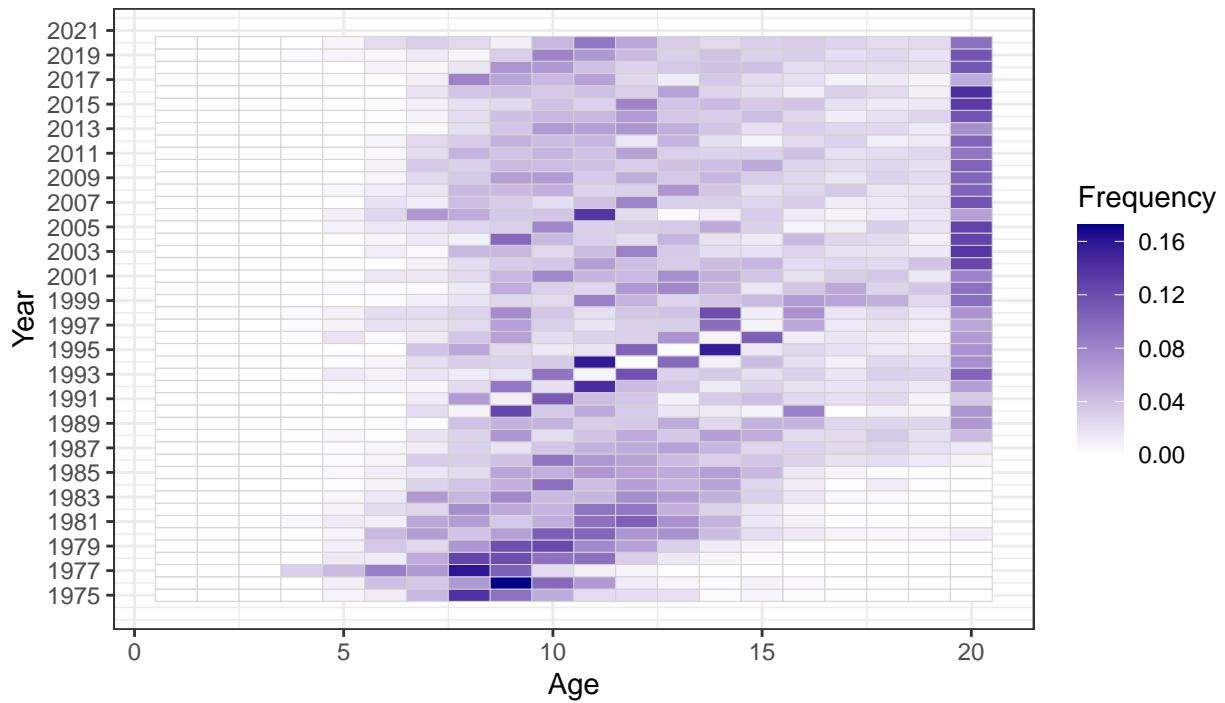


Figure 4.7: Catch of Yellowfin Sole in the BSAI in 2021 by month (through October), reported by observers. Circles represent presence of Yellowfin Sole the catch by the following gear types: non-pelagic trawl, pair trawl, or pelagic trawl.

YFS Ages – Fishery Females



YFS Ages – Fishery Males

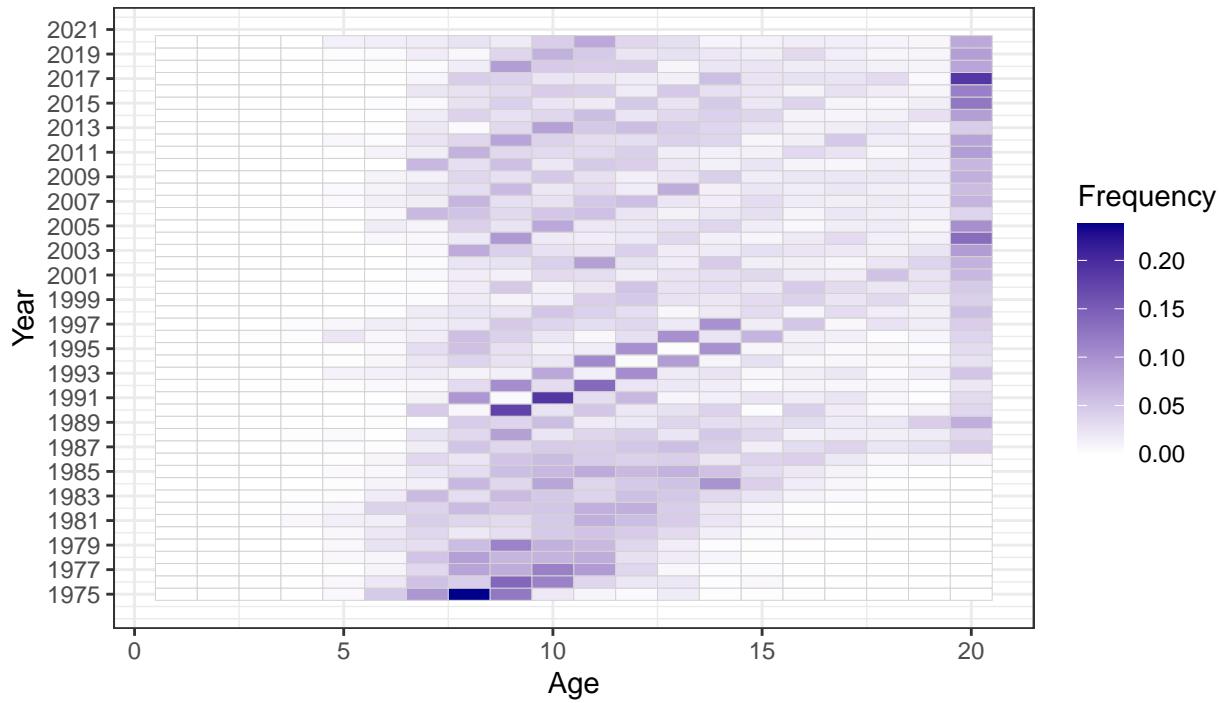
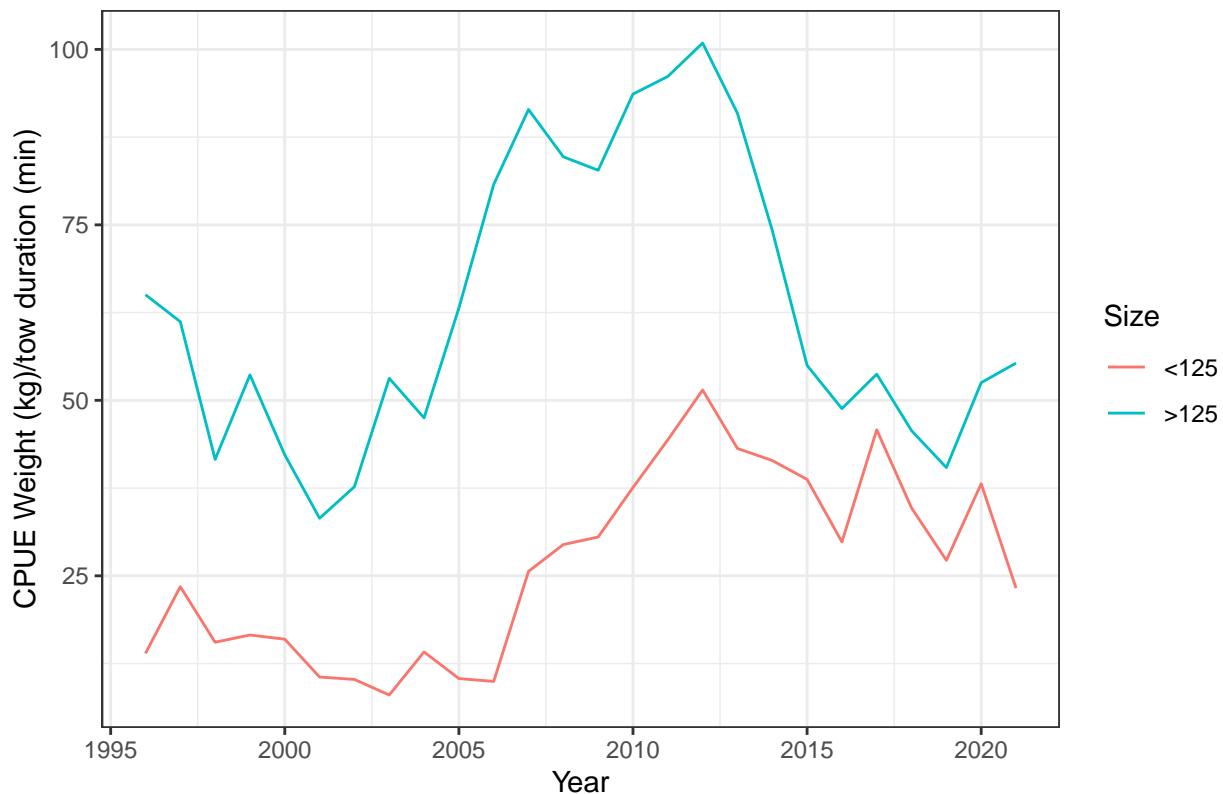


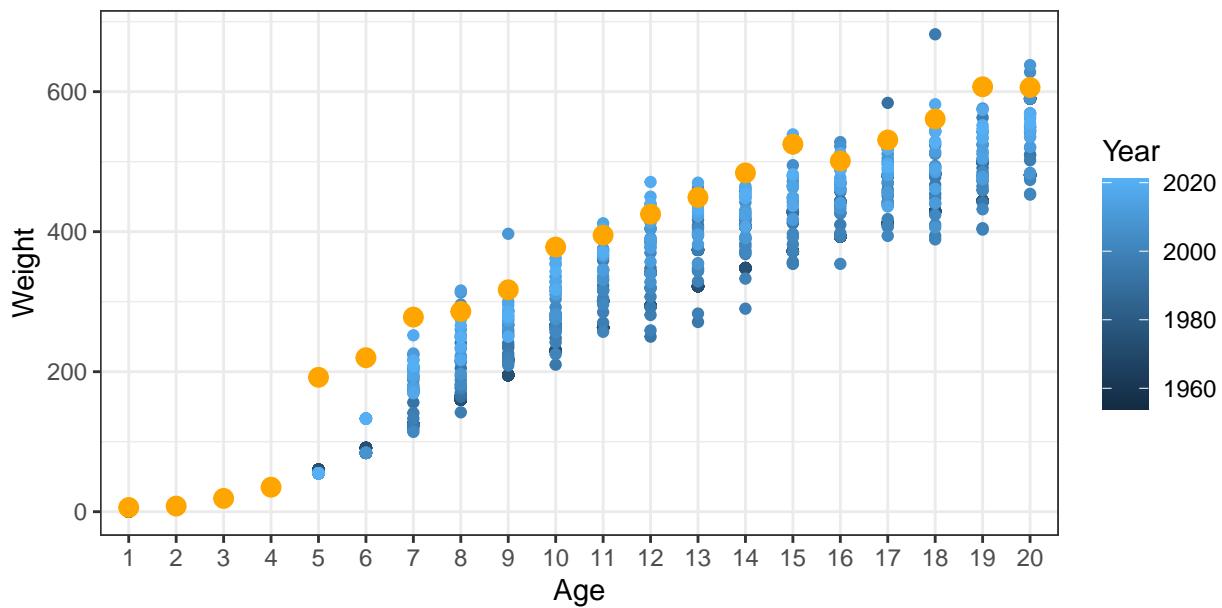
Figure 4.8: Age frequency of females and males from the Yellowfin Sole fishery, 1975 - 2020.

CPUE Weight/Duration for trawl gear, Vessel size cutoff 125 ft.



V15 V16 V17 V18 V19 V20 V21 0.8455060 0.0363572 0.9106990 -2.1368300 -0.4873220 -0.0693917 0.8094410
V22 V23 V24 V25 V26 V27 V28 1.2656400 0.8957810 0.9655420 -0.9824610 -0.9982580 -1.5435500 -1.4690900
V29 V30 V31 V32 V33 V34 V35 -1.5152200 -0.2018220 -1.8325600 -0.8771410 0.7862850 0.8395440 2.3441700
V36 V37 V38 V39 0.0691956 2.0012400 2.3544600 1.1404700 [1] 1996 1997 1998 1999 2000 2001 2002 2003
2004 2005 2006 2007 2008 2009 2010 [16] 2011 2012 2013 2014 2015 2016 2017 2018 2019 2021 Figure 4.9:
Catch per unit effort based on Yellowfin Sole fishery data, 1996-2021. CPUE weight (kg)/trawl duration (min) is shown for vessels greater and less than 125 ft, and only including self-made tows. Estimates of relative CPUE are complete through October 31, 2021. Results are limited to Catcher/Processor and Catcher vessels and tow duration >0 and <the 90% percentile of all the data (974 minutes). Source: NMFS/AKRO Catch Accounting System.

Female fishery weight at age used in model



Male fishery weight at age used in model

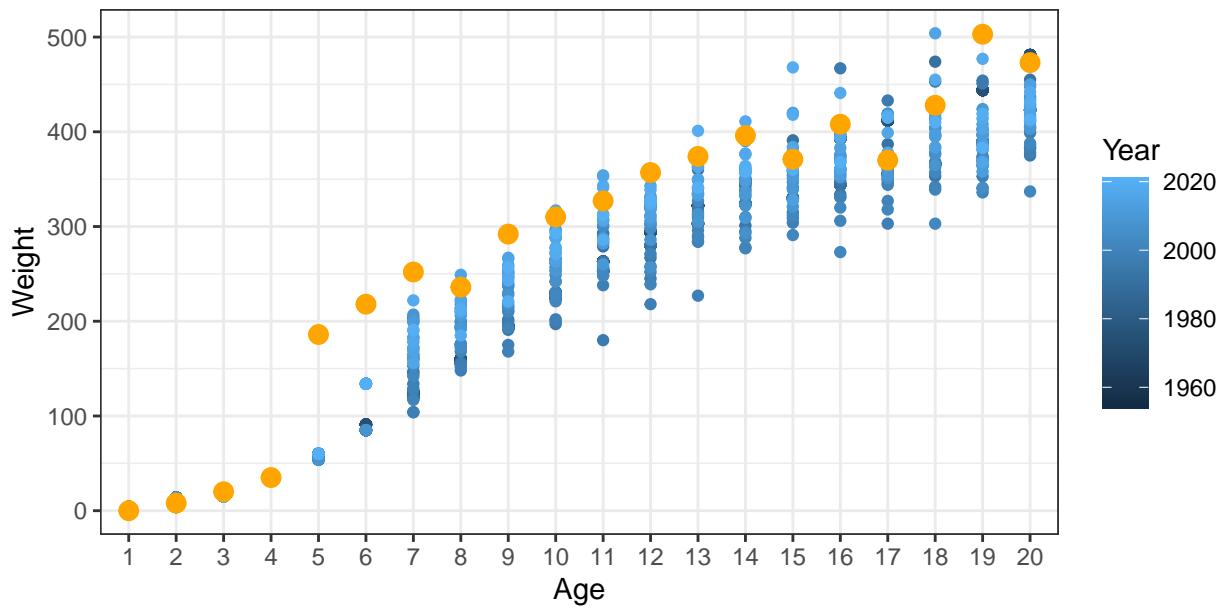
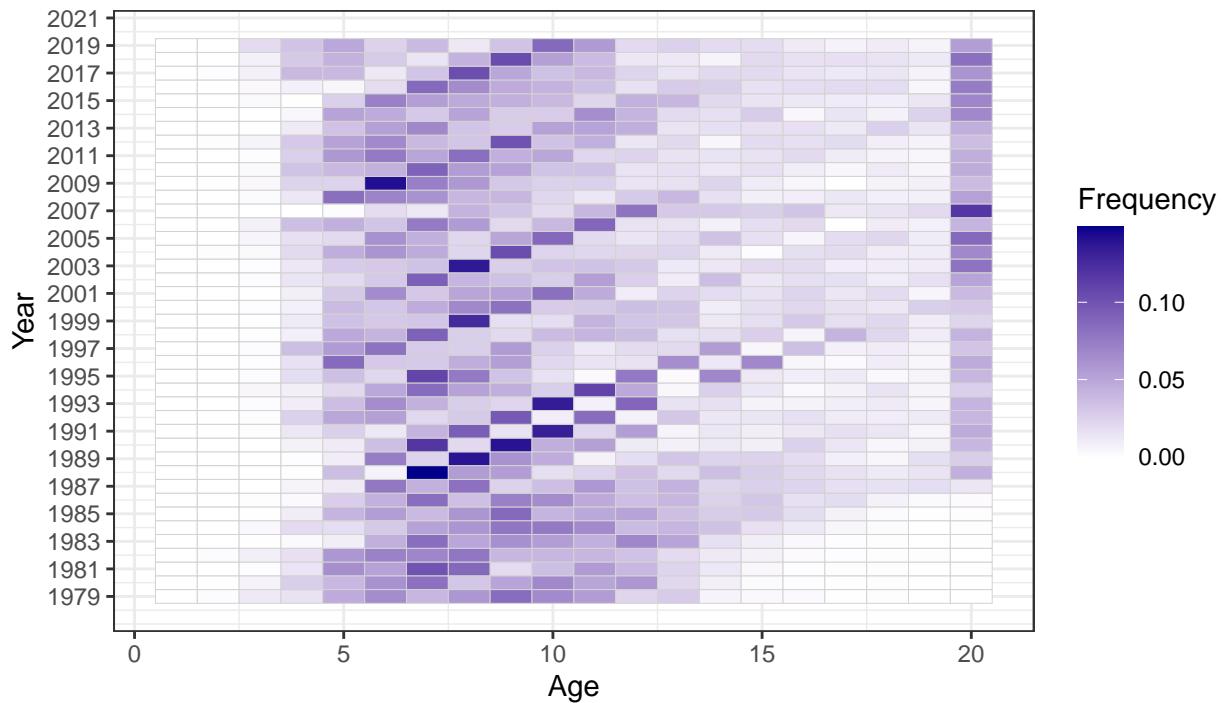


Figure 4.10: Empirical estimates of weight (g) at age for Yellowfin Sole females and males, based on fishery data 1954-2021, and used in this year's Model 18.2. Yellow dots indicate estimates for 2021, which are based on 2020, the most recent set of aged data.

YFS Ages – Survey Females



YFS Ages – Survey Males

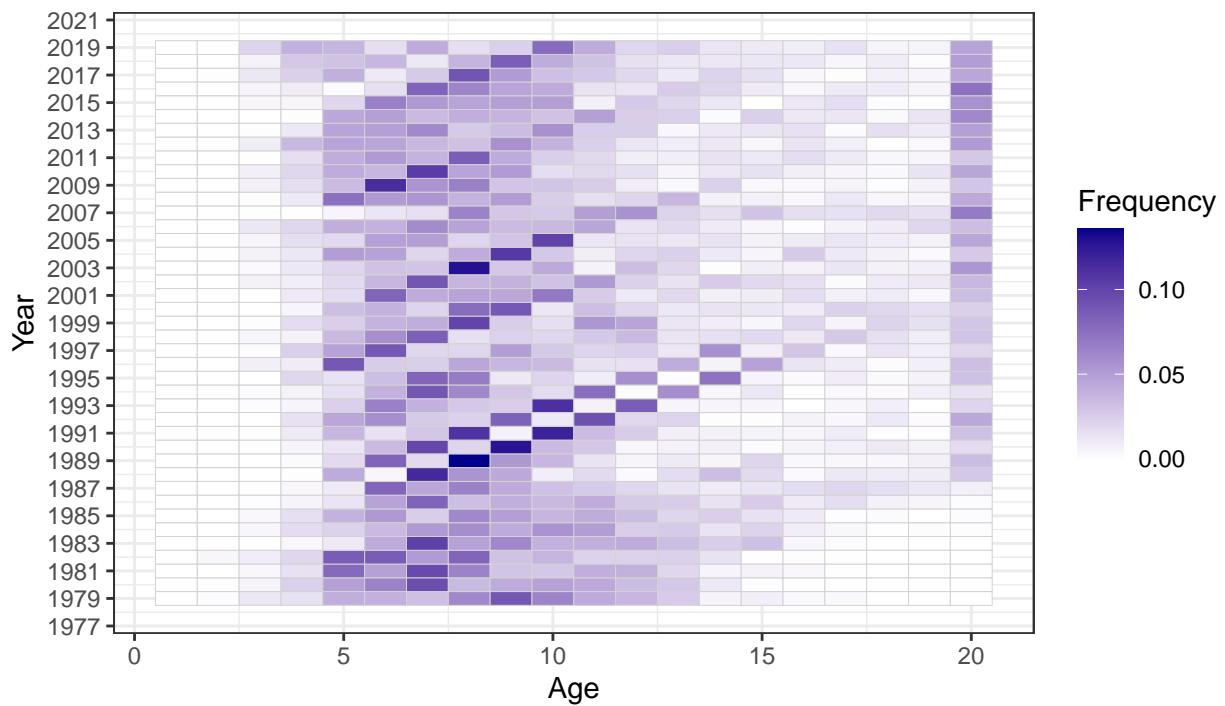


Figure 4.11: Age frequency of Yellowfin Sole females and males from the AFSC/NMFS research surveys, 1977–2020.

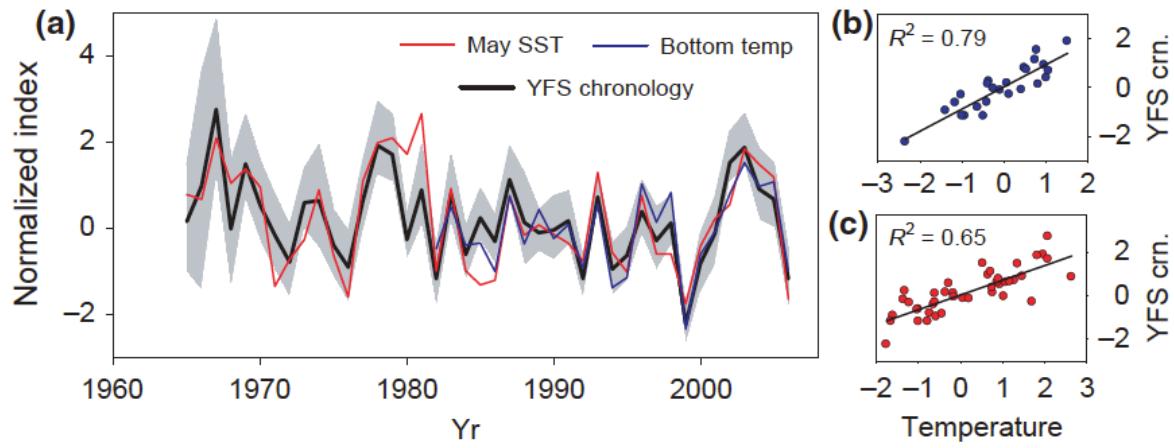


Figure 4.12: Master chronology for Yellowfin Sole and time series of mean summer bottom temperature and May sea surface temperature for the southeastern Bering Sea (Panel A). All data were normalized to a mean of 0 and standard deviation of 1. Correlations of chronologies with bottom temperature and sea surface temperature are shown in panels B and C, respectively (Matta et al. 2010).

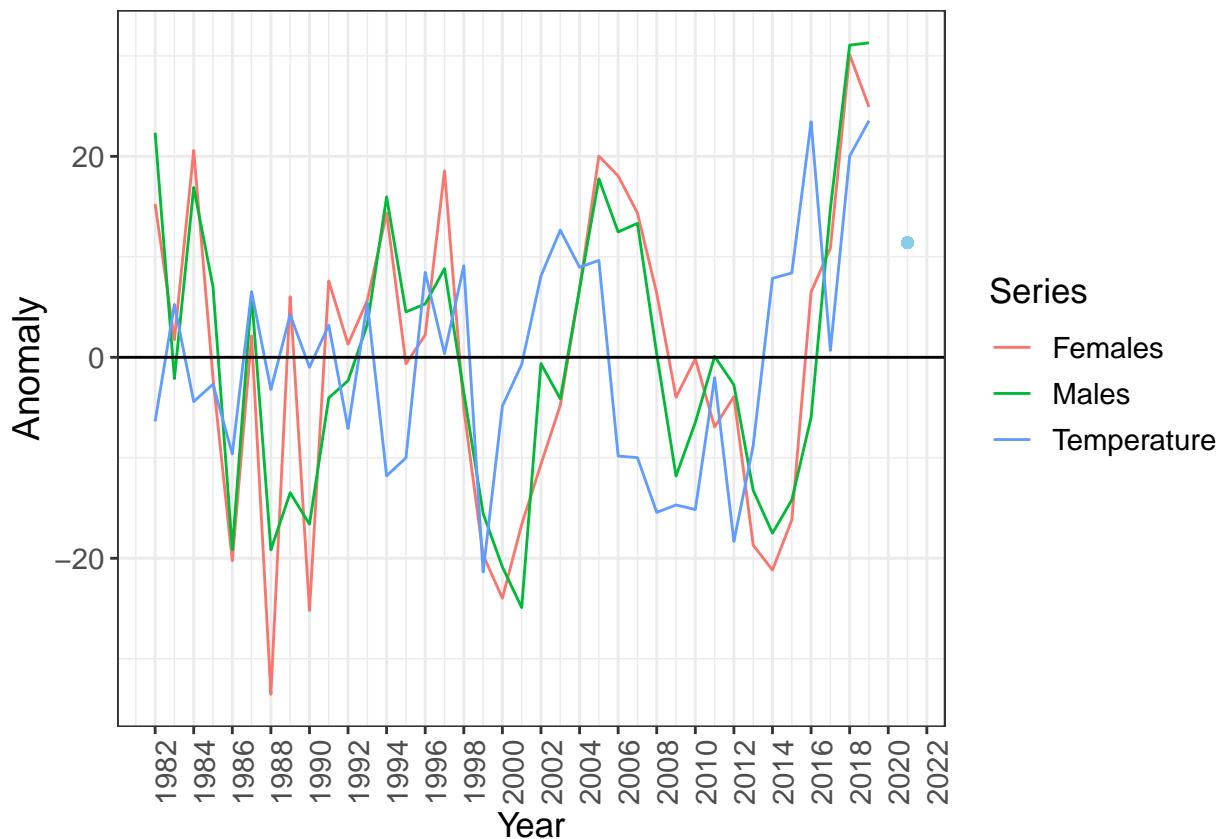


Figure 4.13: Yellowfin Sole length-at-age anomalies, for 5-year old males and females, and bottom temperature anomalies (Model 18.2). Correspondence in these residuals is apparent with a 2-3 year lag effect from the mid-1990s to 2019. Late 1980s and early 1990s pattern may be a density-dependent response in growth from the large 1981 and 1983 year-classes. Note: Bottom temperature anomalies were scaled up by a factor of 10 to demonstrate the pattern and match length anomalies. The blue point in 2021 shows the relative bottom temperature anomaly in that year, but age data is not yet available for 2021.

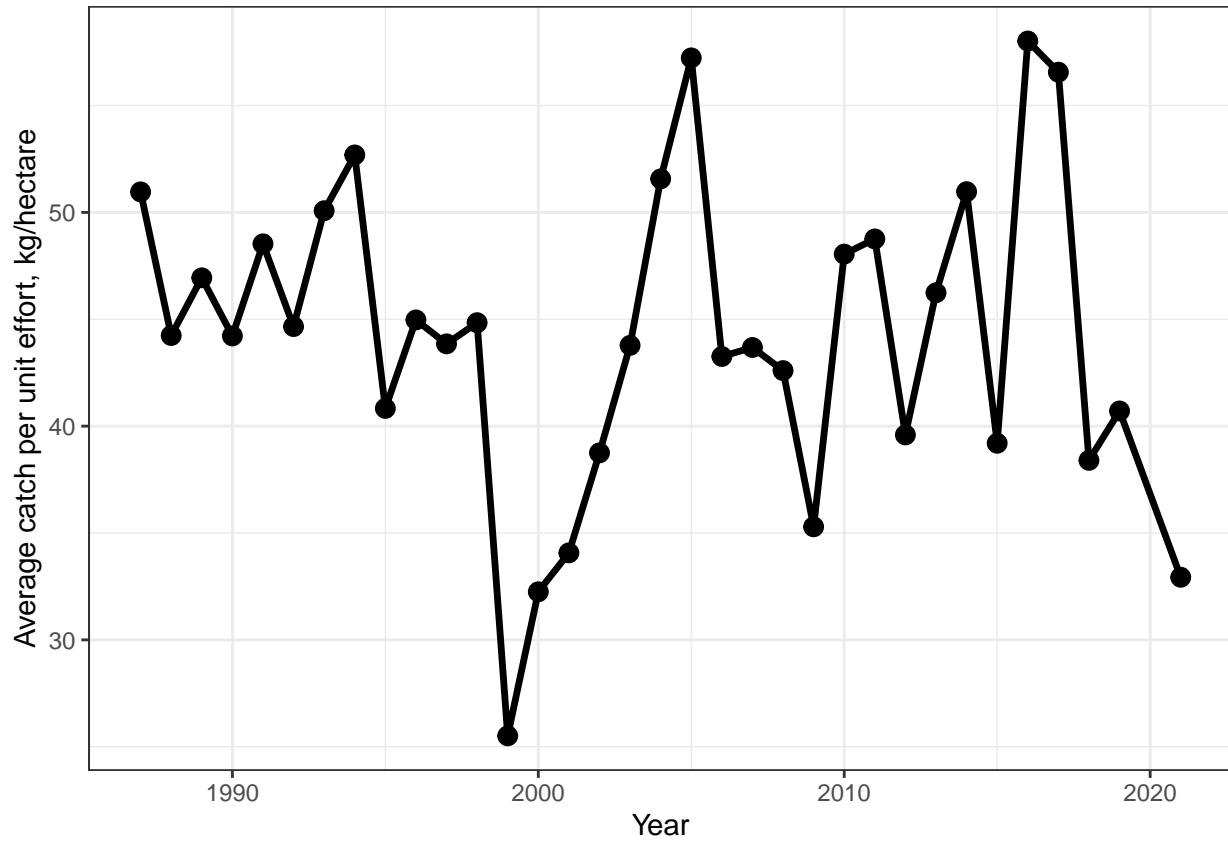


Figure 4.14: Average catch per unit effort on NMFS eastern Bering Sea surveys, 1982-2021, in kg/hectare.

Yellowfin Sole catch, bottom trawl gear, 2 degree bins

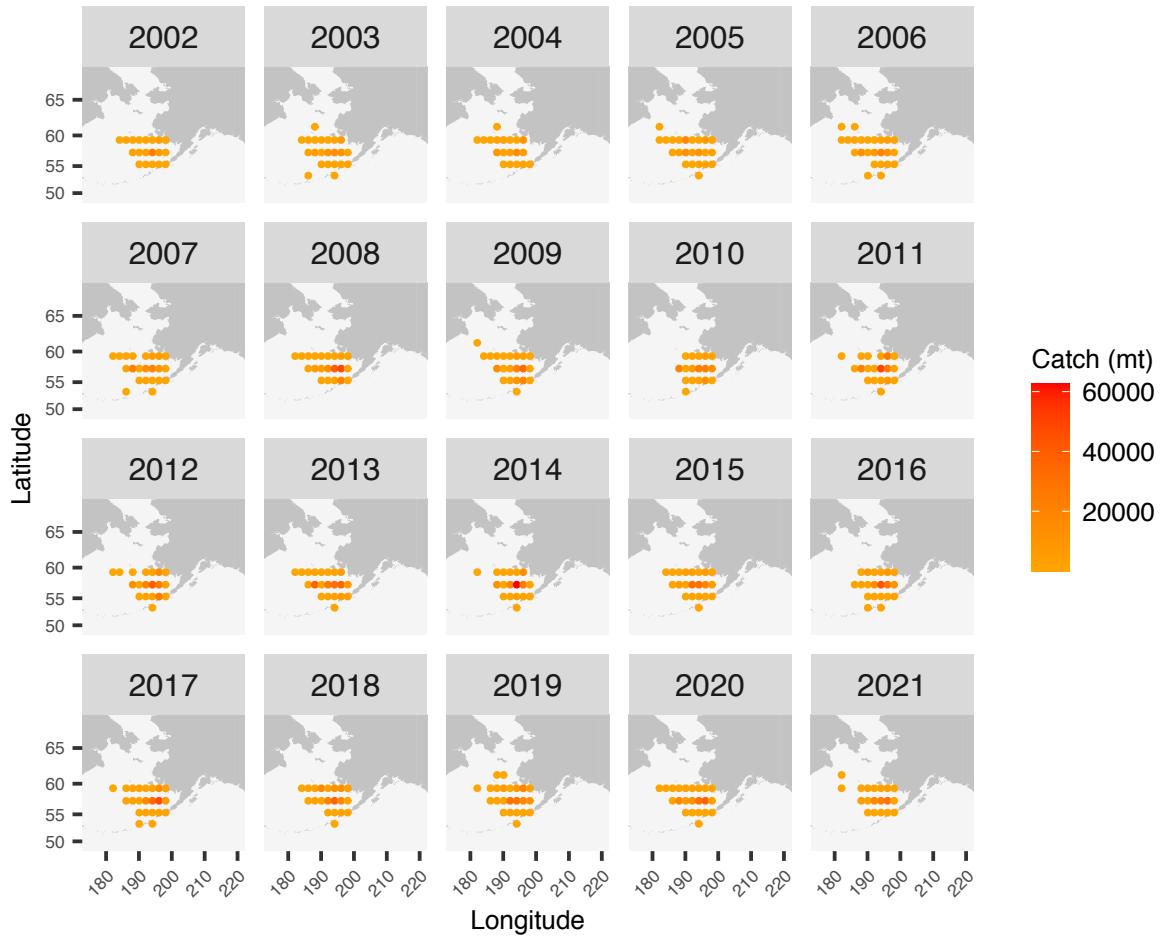


Figure 4.15: Catch of Yellowfin Sole by trawl gear in the BSAI, 2002-2021, by year, reported by observers. Gear types include pelagic and non-pelagic trawl. Colored circles represent catch of Yellowfin Sole, with darker shades of red representing higher catch.

Survey estimates of biomass (black), Model 18.2 (red) and Model 18.2 (2020, blue) fit to survey estimate.

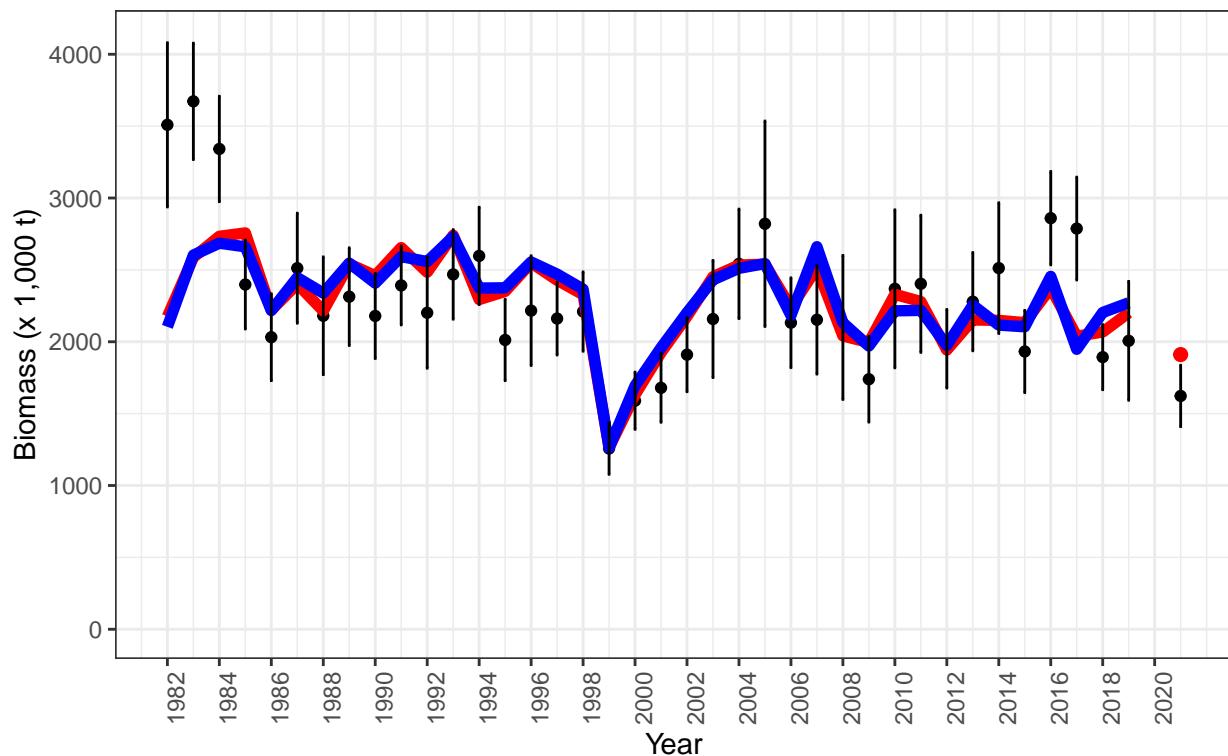


Figure 4.16: Annual eastern Bering Sea bottom trawl survey biomass point estimates and 95% confidence intervals for Yellowfin Sole, 1982-2021, with Model 18.2 fit to the data (red line), Model 18.2 (2000) fit to data (blue line).

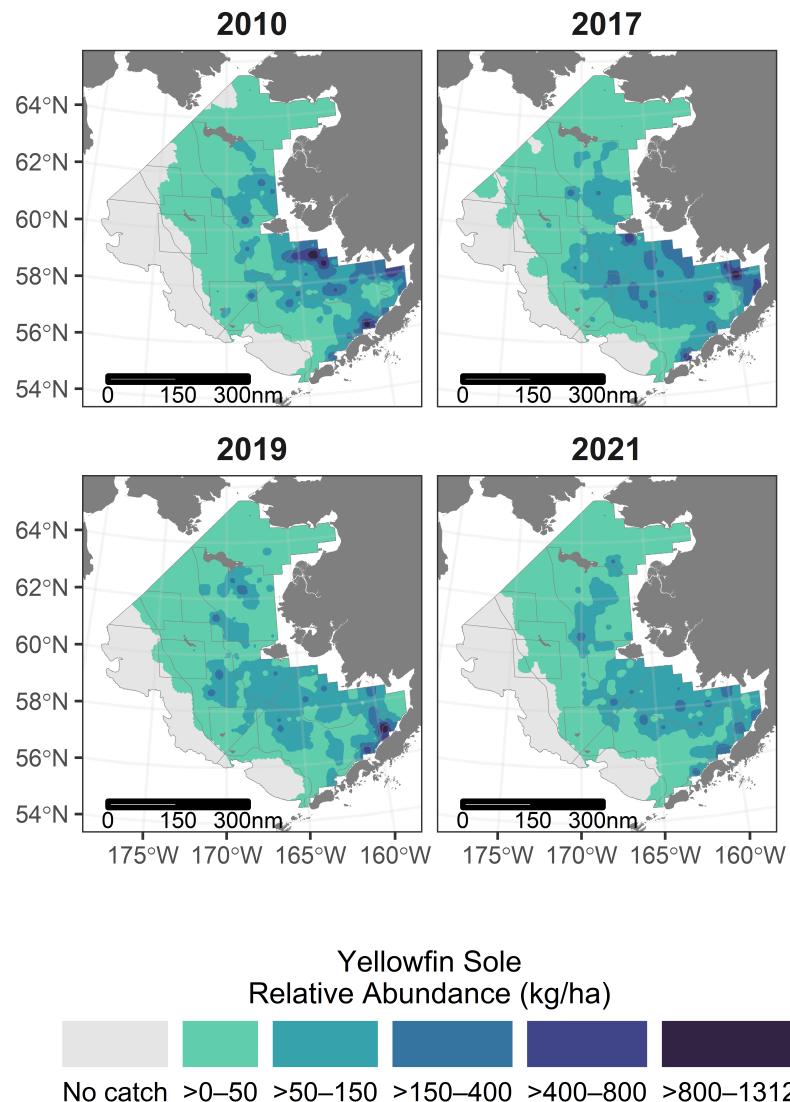


Figure 4.17: Distribution of Yellowfin Sole in the eastern and northern Bering sea based on surveys conducted in 2010, 2017, 2019, and 2021.

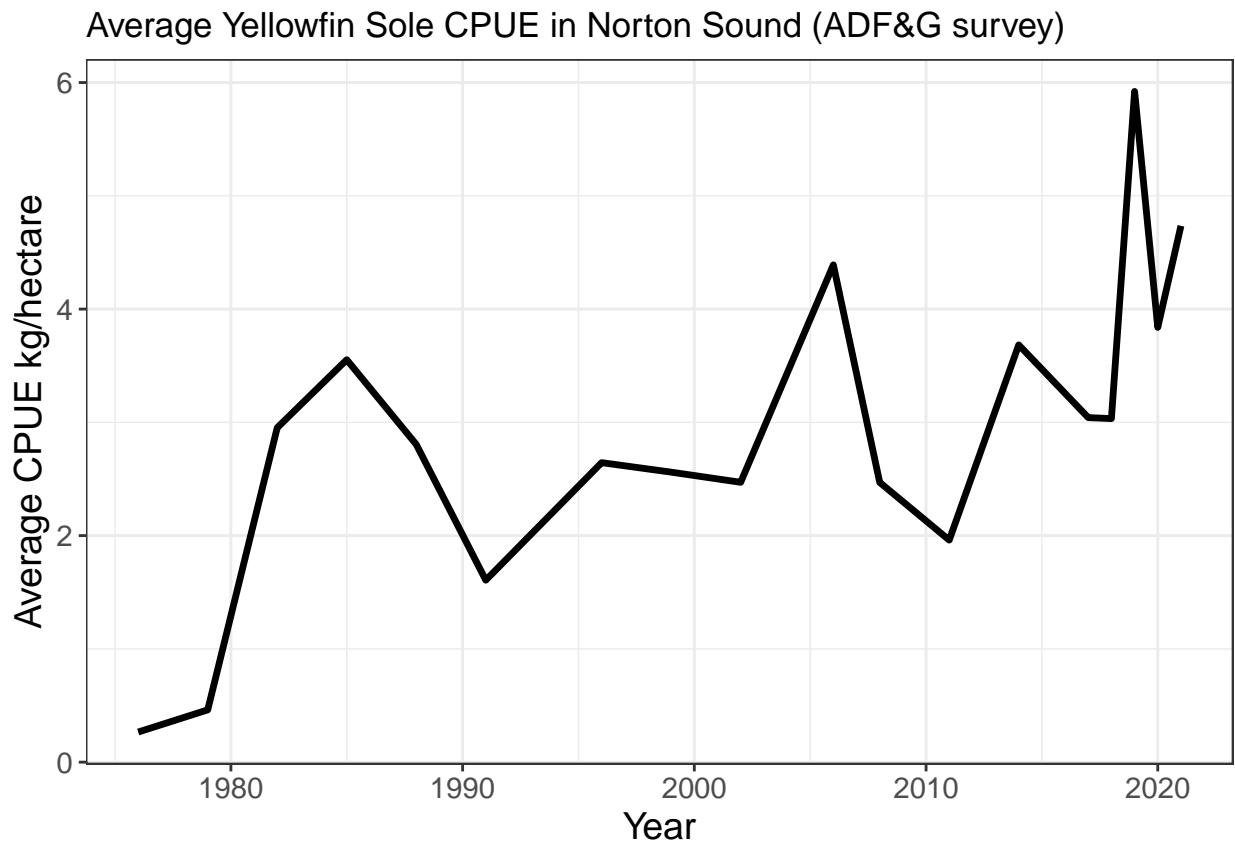


Figure 4.18: Average catch per unit effort (CPUE) of Yellowfin Sole in Norton Sound, based on ADF&G survey time series, 1976 - 2021.

Model 18.2 (2020)

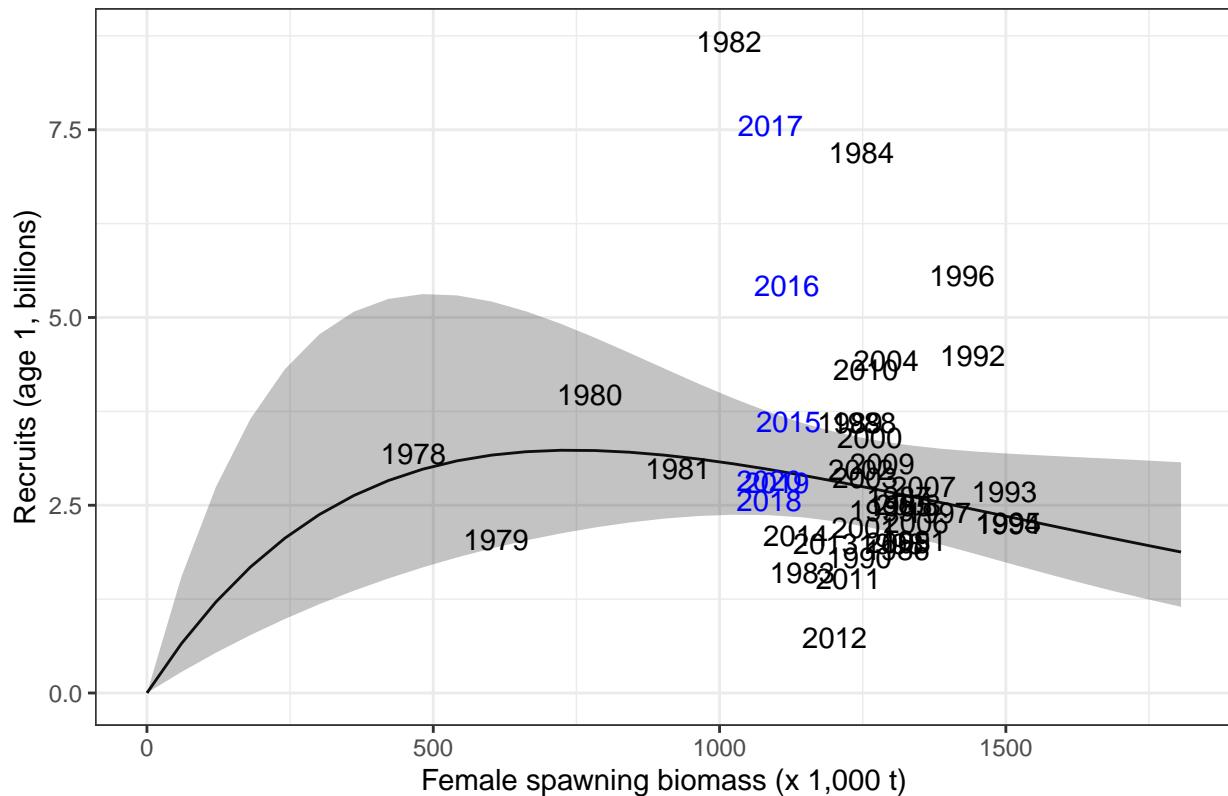


Figure 4.19: Ricker stock recruitment curve for Model 18.2 (2020) with 95% confidence intervals (shaded region) fit to female spawning biomass and recruitment data from 1978-2014. Years in black indicate data used to fit the model, years in blue were not used to fit the model.

Model 18.2

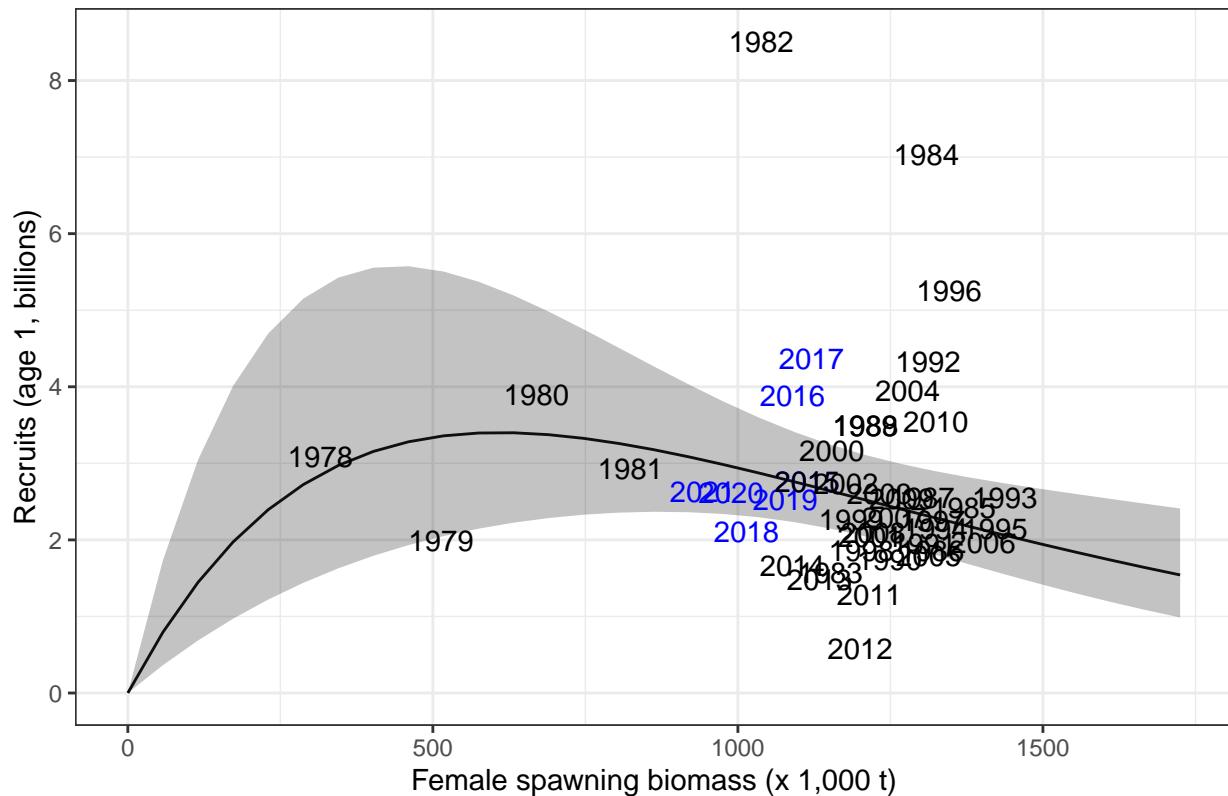
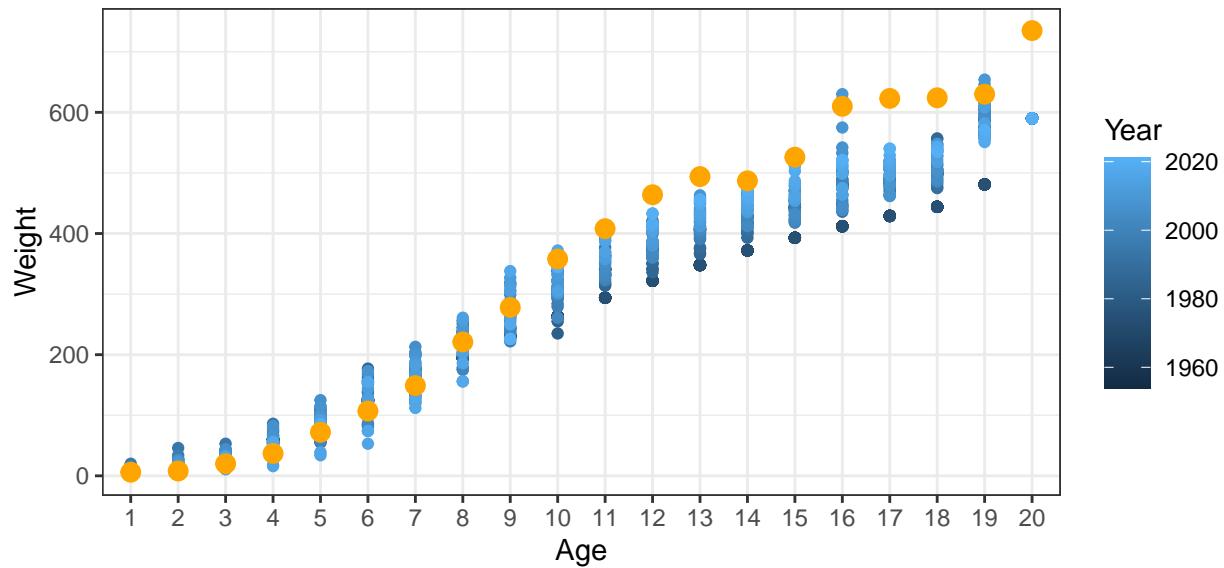


Figure 4.20: Ricker stock recruitment curve for Model 18.2 with 95% confidence intervals (shaded region) fit to female spawning biomass and recruitment data from 1978-2014. Years in black indicate data used to fit the model, years in blue were not used to fit the model.

Female survey weight at age 1954–2020 from 2020 Model, and 2021 estimates



Male survey weight at age 1954–2020 from 2020 Model, and 2021 estimates

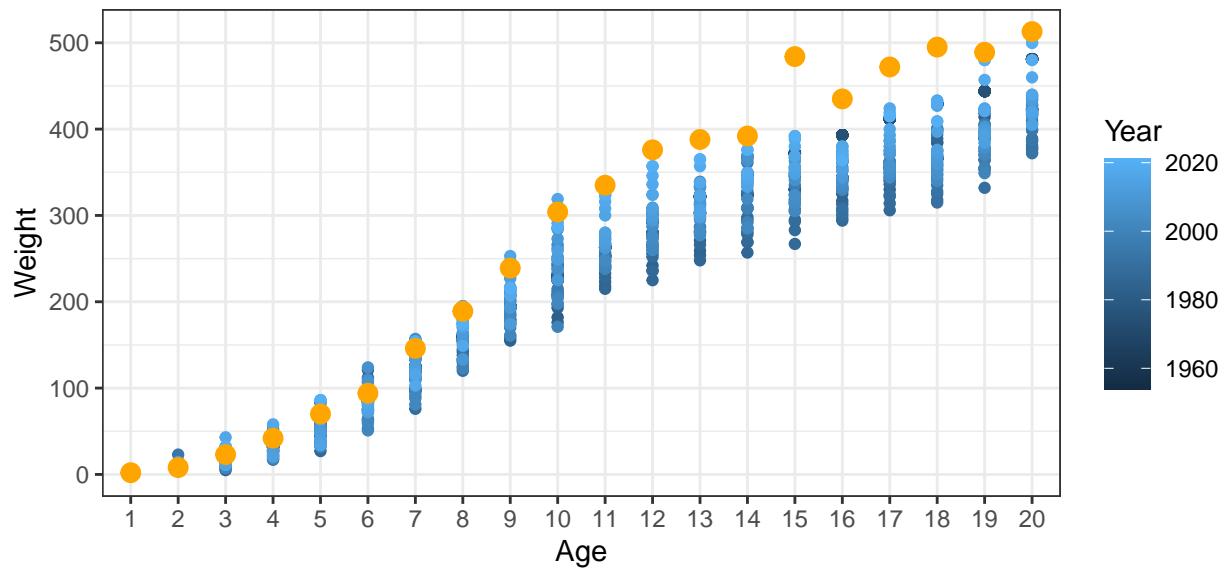
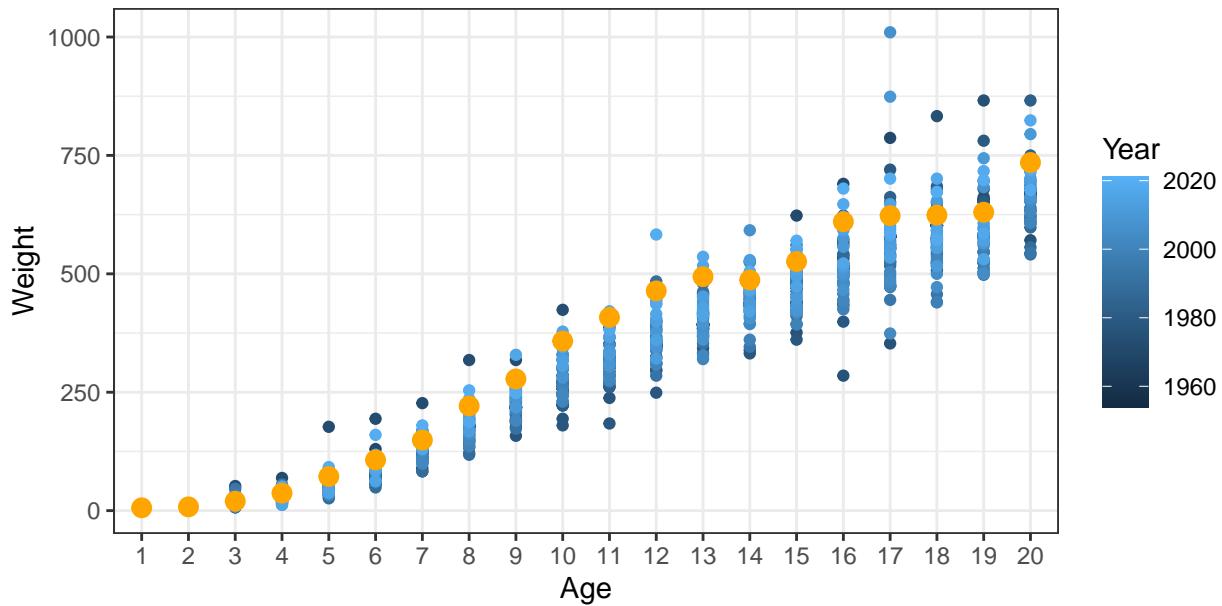


Figure 4.21: Mean weight at age (g) for Yellowfin Sole females and males from the Eastern Bering Sea survey, 1954-2019 used in Model 18.2 in 2020. Estimates for 2019 are highlighted in yellow and were added for comparison purposes.

Female survey weight at age used in 2021 model



Male survey weight at age used in 2021 model

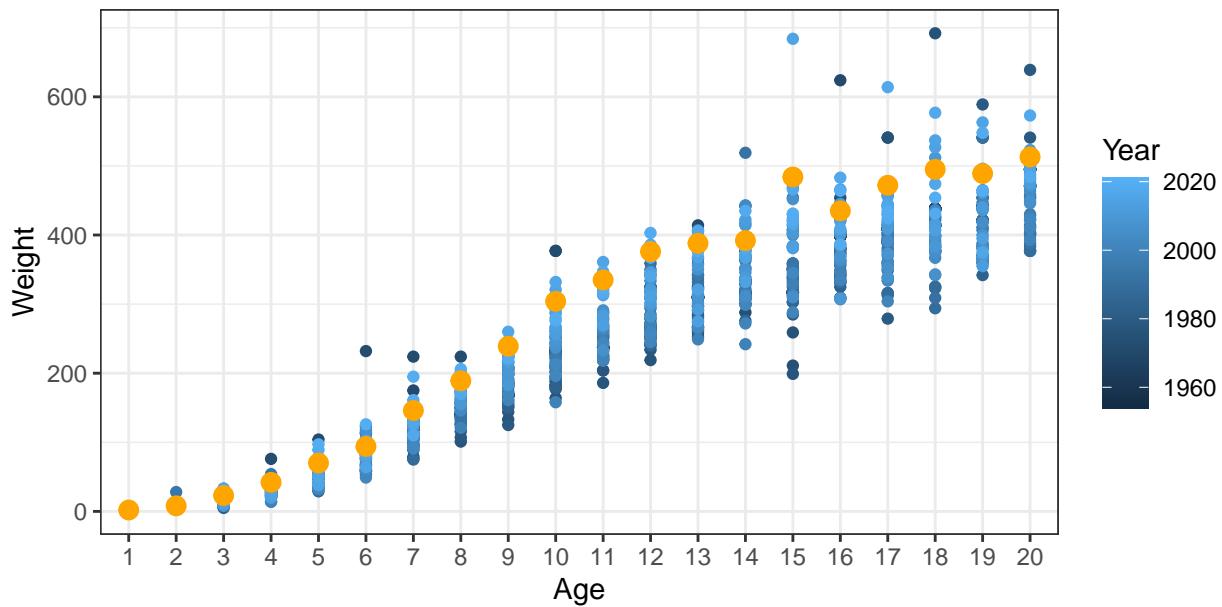


Figure 4.22: Mean weight at age (g) for Yellowfin Sole females and males from the Eastern Bering Sea survey, 1954-2021 used in Model 18.2. Estimates for 2021 are highlighted in yellow.

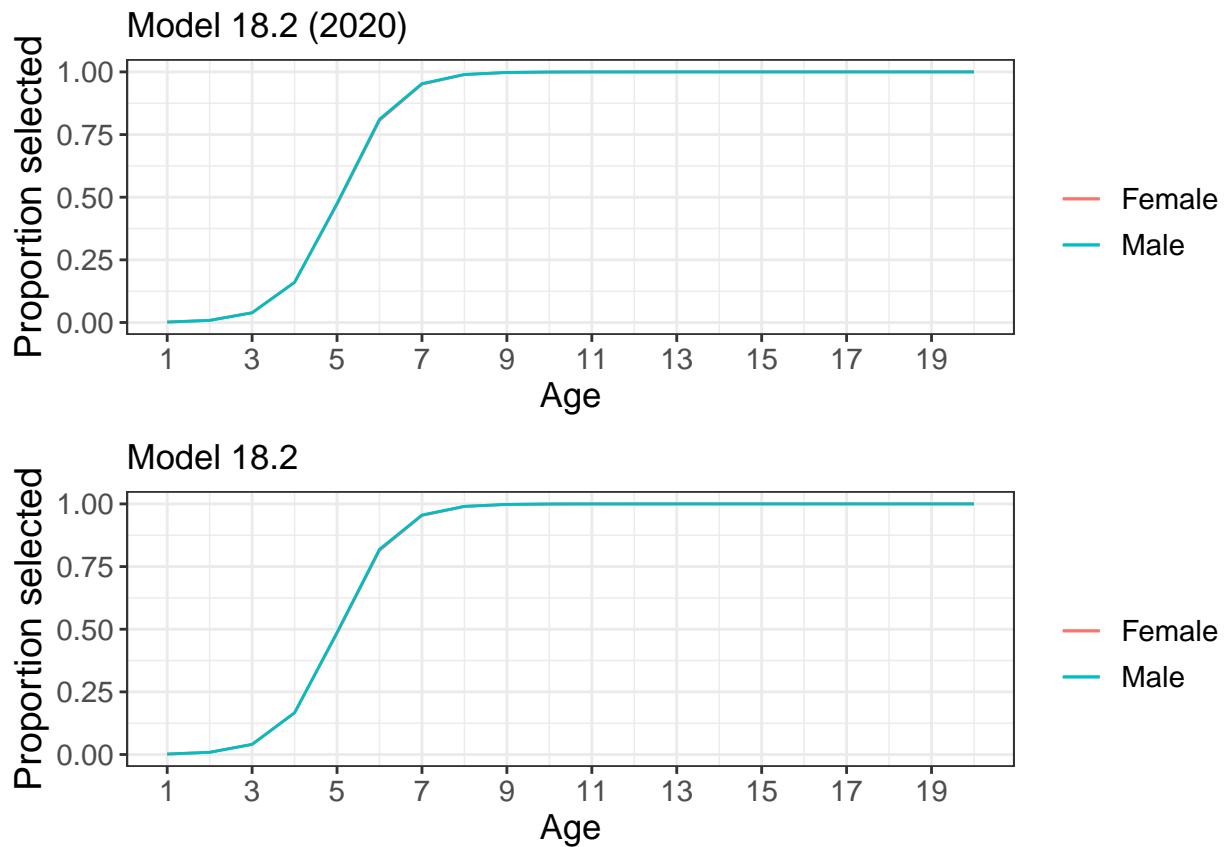


Figure 4.23: Estimate of survey selectivity for males and females, Model 18.2 (2020 assessment) upper panel, Model 18.2 (current assessment) lower panel.

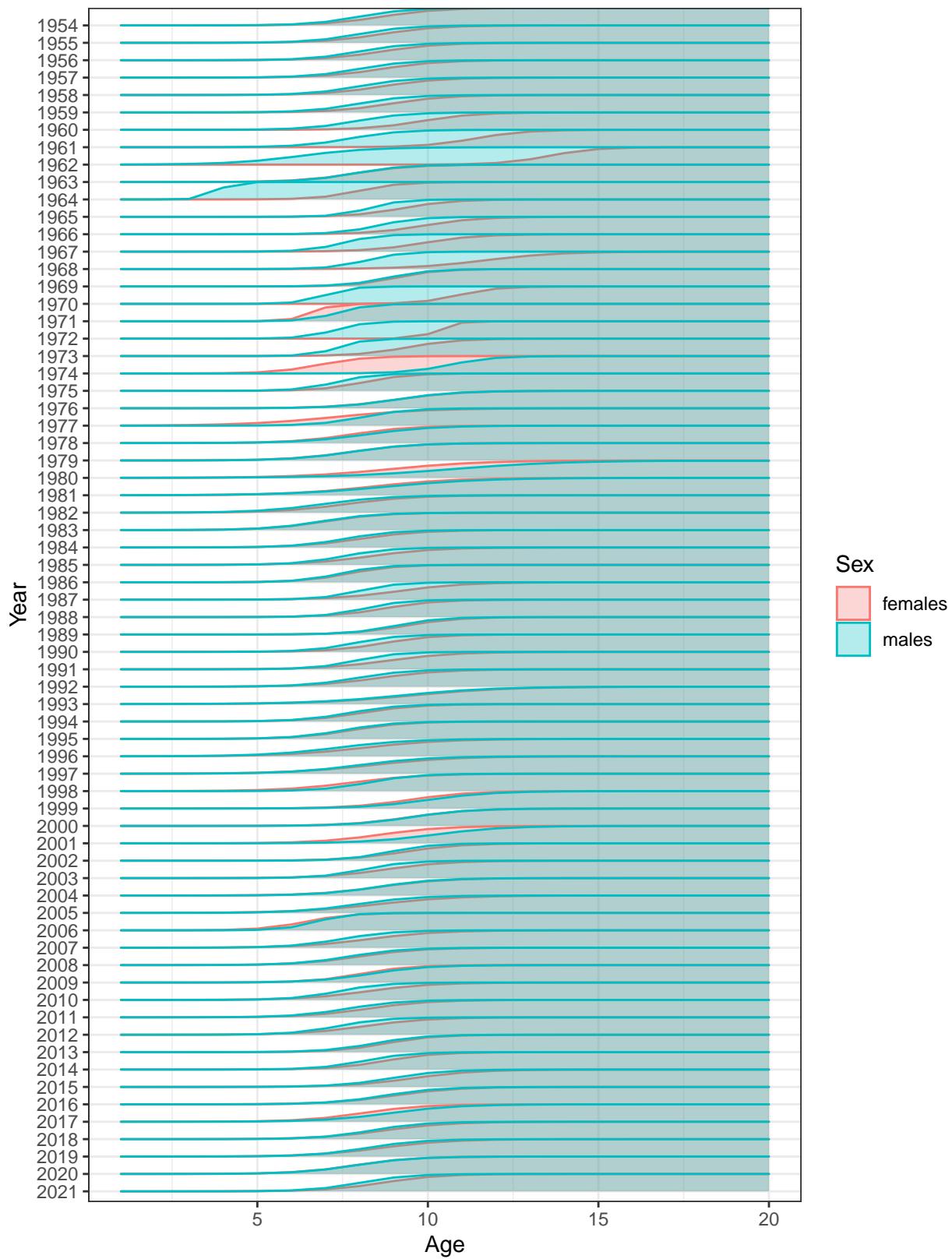


Figure 4.24: Estimate of fishery selectivity for males and females, 1954-2021, Model 18.2.

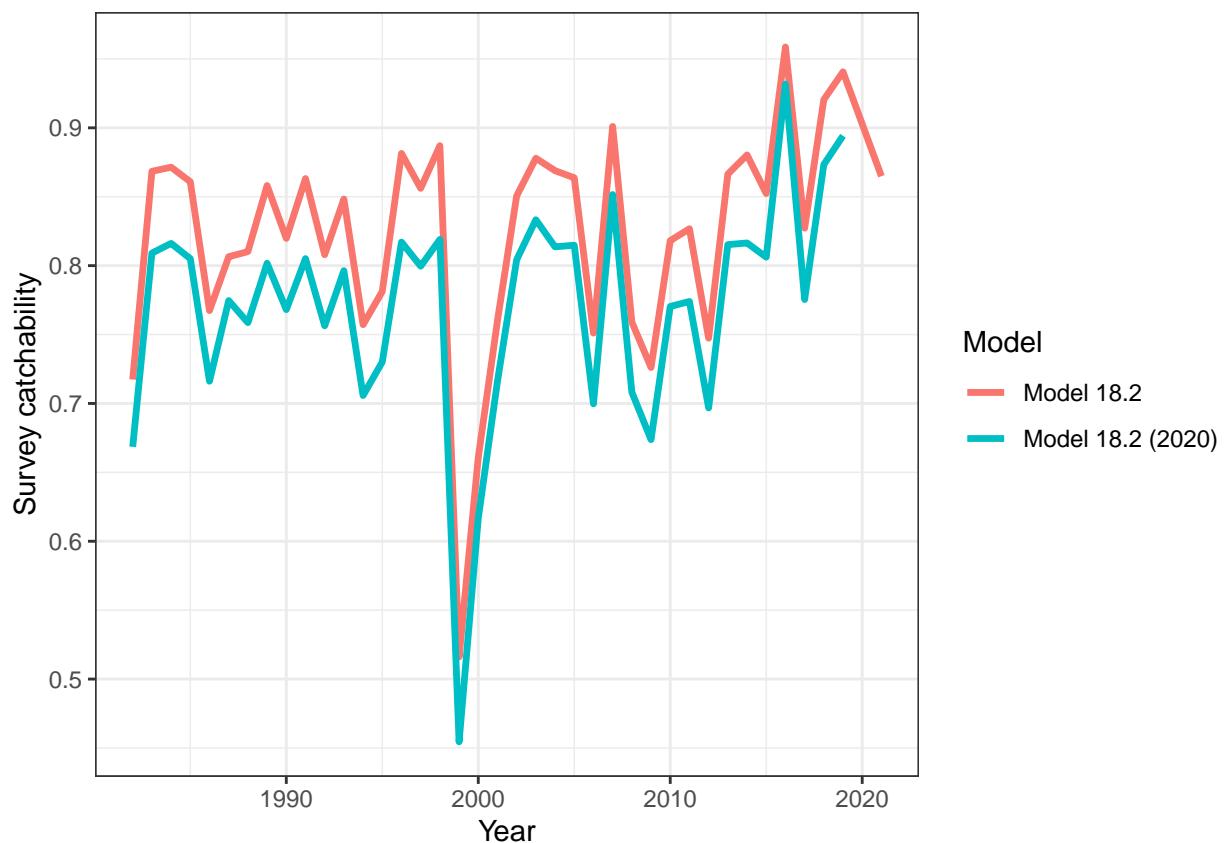


Figure 4.25: Survey catchability for Model 18.2 (2020) and 18.2 (2021), 1982-2020.

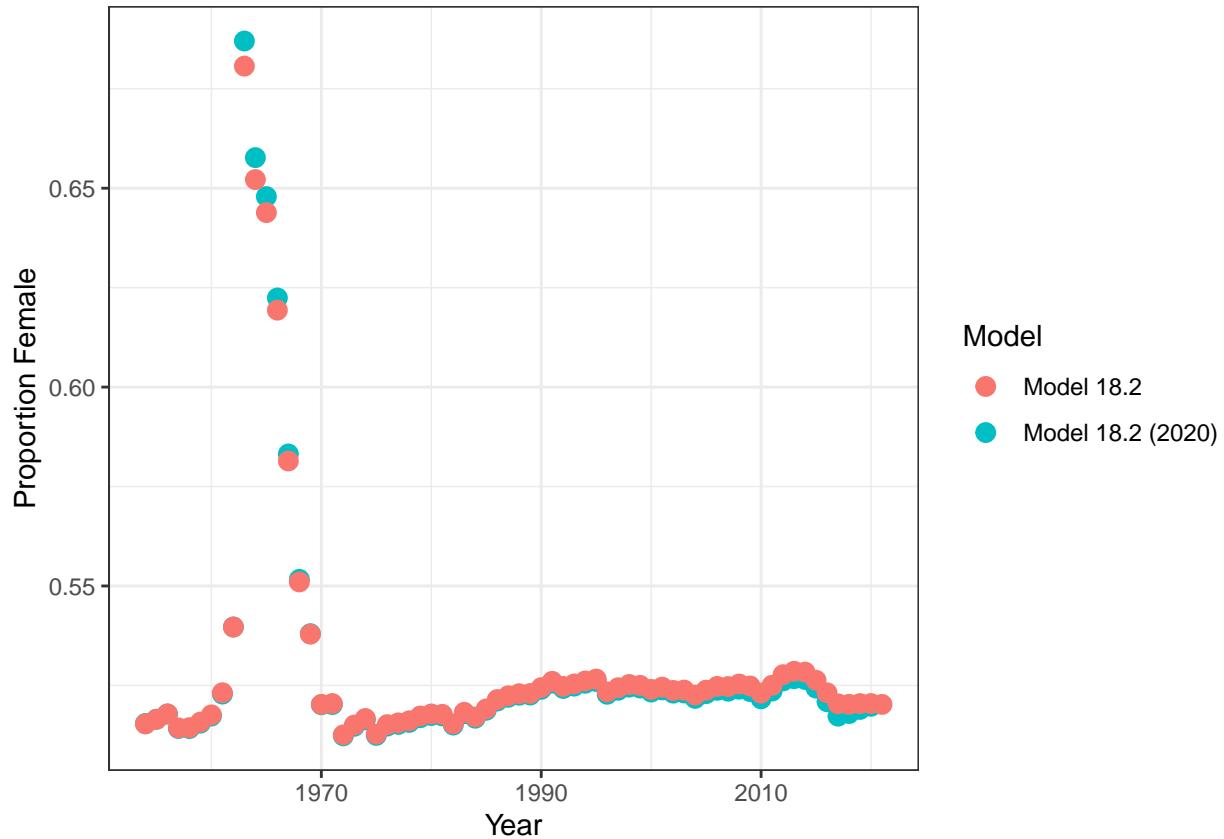


Figure 4.26: Model estimates of the proportion of female Yellowfin Sole in the population, 1982-2021.

Fit to Survey Age Compositions, Model 18.2

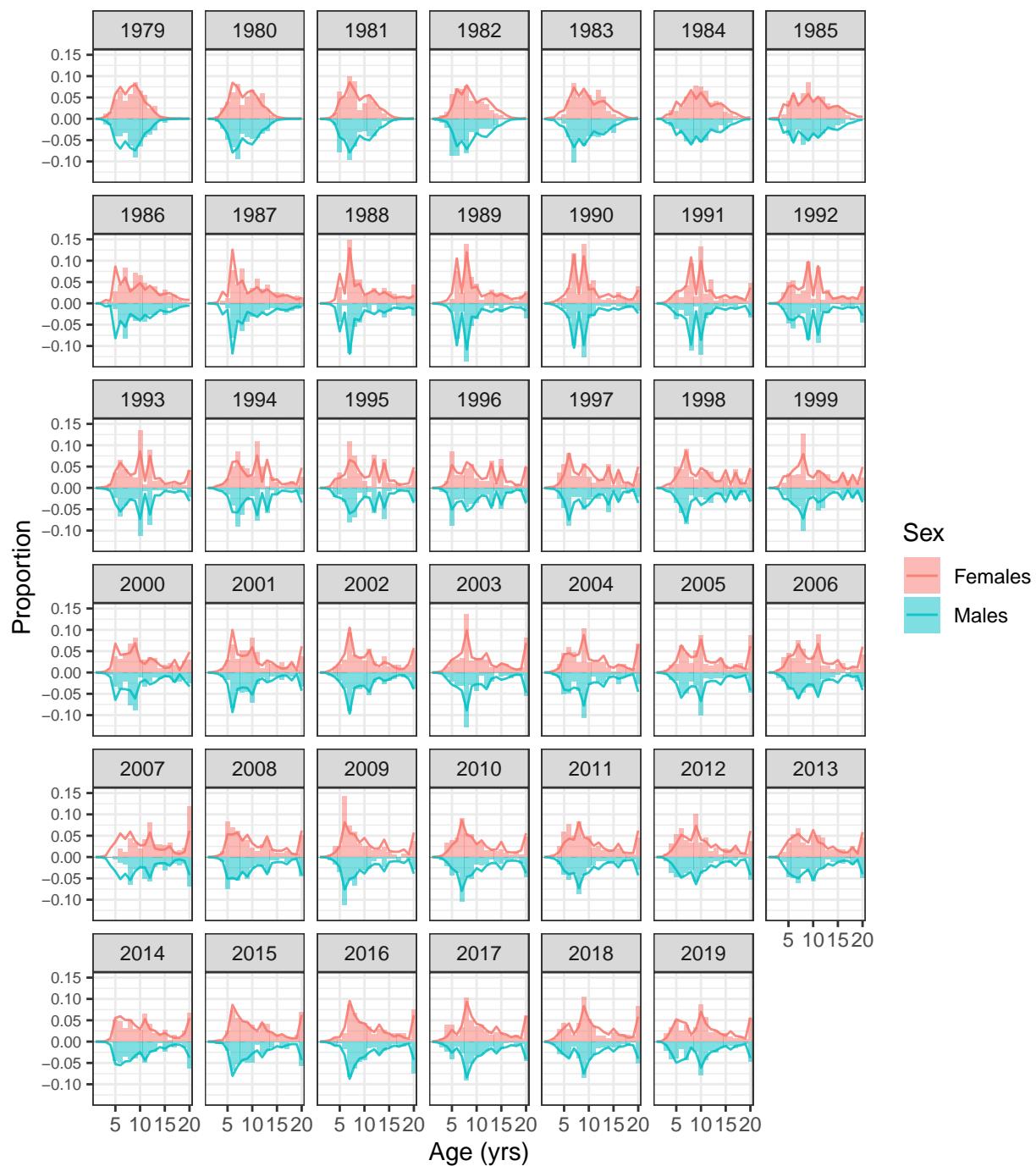


Figure 4.27: Model 18.2 fit to the time-series of survey age composition, by sex, 1979-2020.

Fit to Fishery Age Compositions, Model 18.2

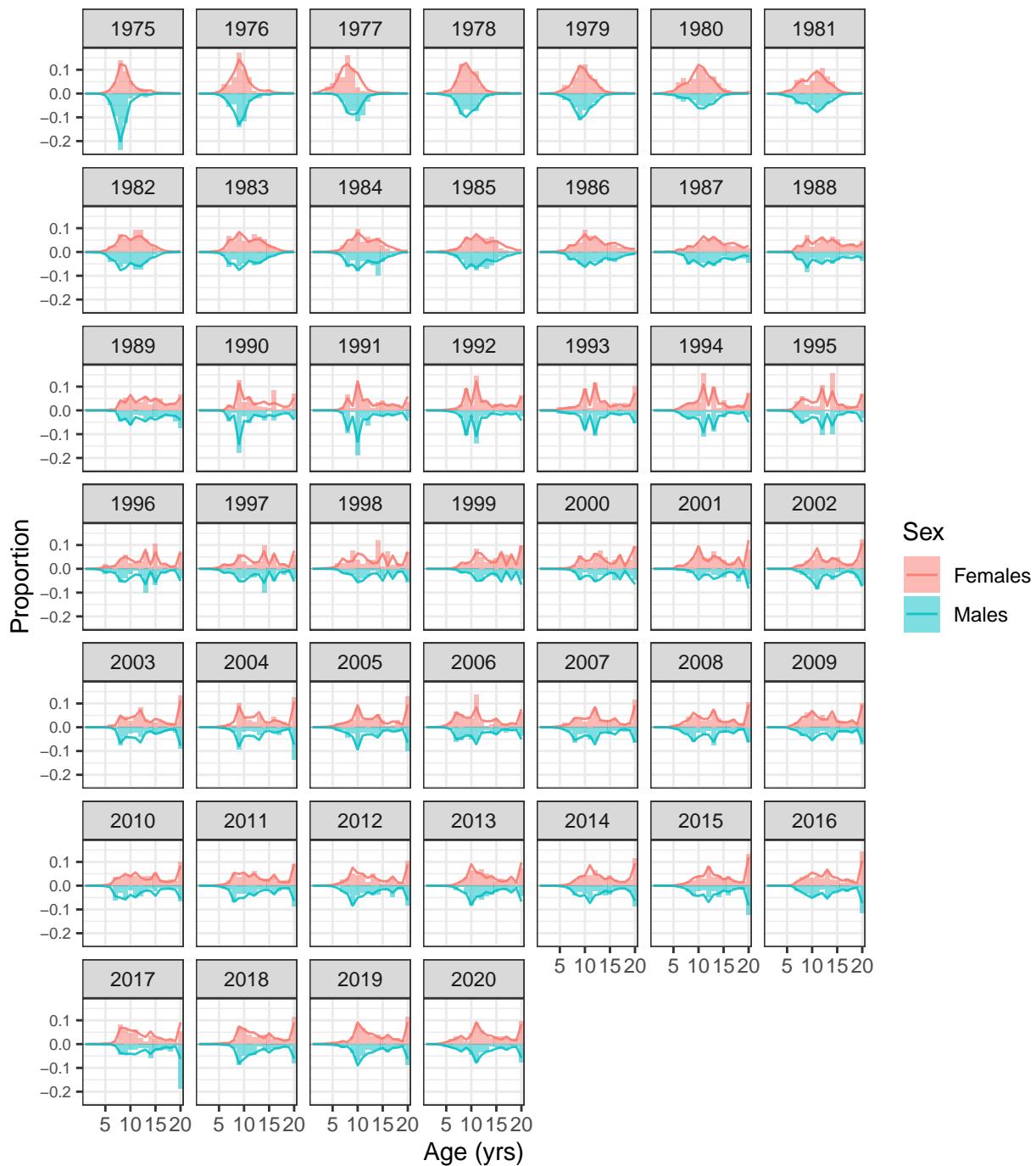
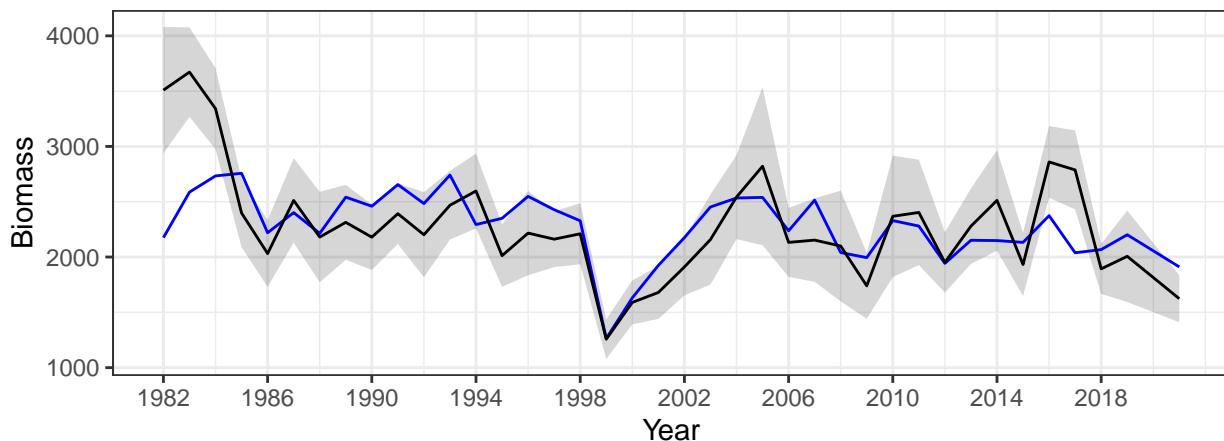
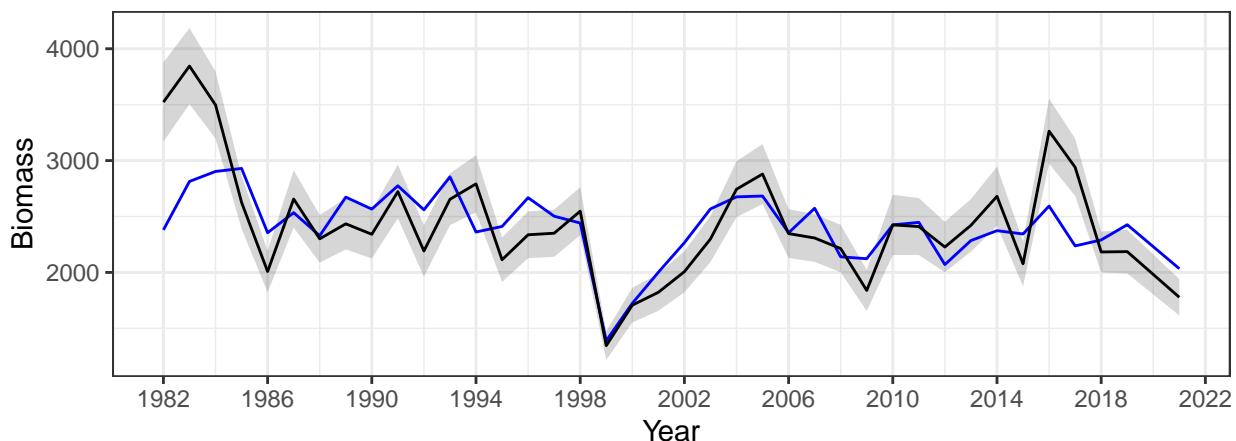


Figure 4.28: Model 18.2 fit to the time-series of fishery age composition, by sex, 1975-2020.

Model 18.2, EBS design-based biomass estimate



Model 18.2a, EBS VAST biomass estimate



Model 18.2b, EBS+NBS VAST biomass estimate

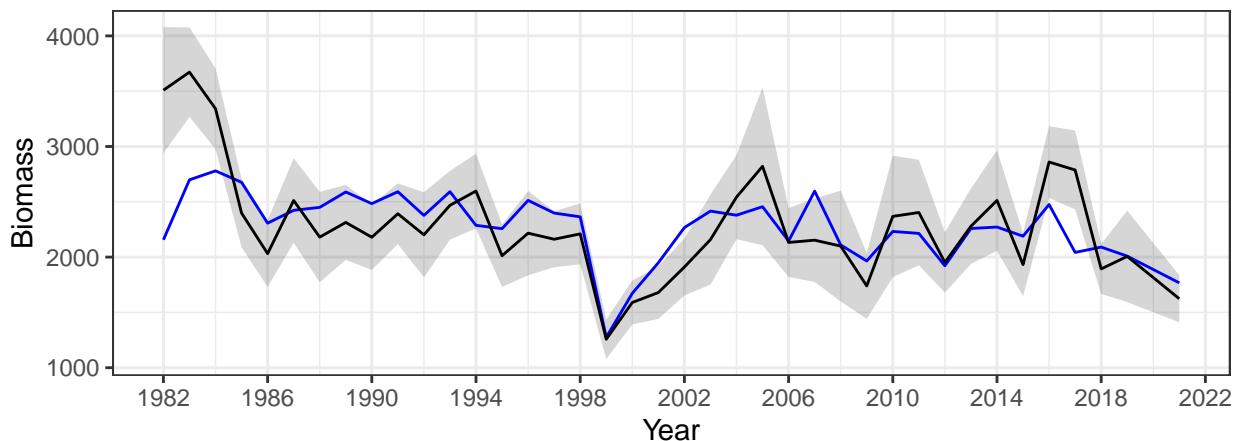


Figure 4.29: Model 18.2 (2021) (upper panel), Model 18.2a (middle panel), and Model 18.2b (lower panel) fit to NMFS eastern Bering Sea survey biomass estimates, from 1982-2021. Models 18.2 and 18.2a incorporate estimates from the EBS only, while Model 18.2b used NBS+EBS estimates. Models 18.2a and 18.2b used VAST biomass and standard error, while Model 18.2 used design-based biomass and error estimates. Blue lines are model estimates, grey represent survey estimates.

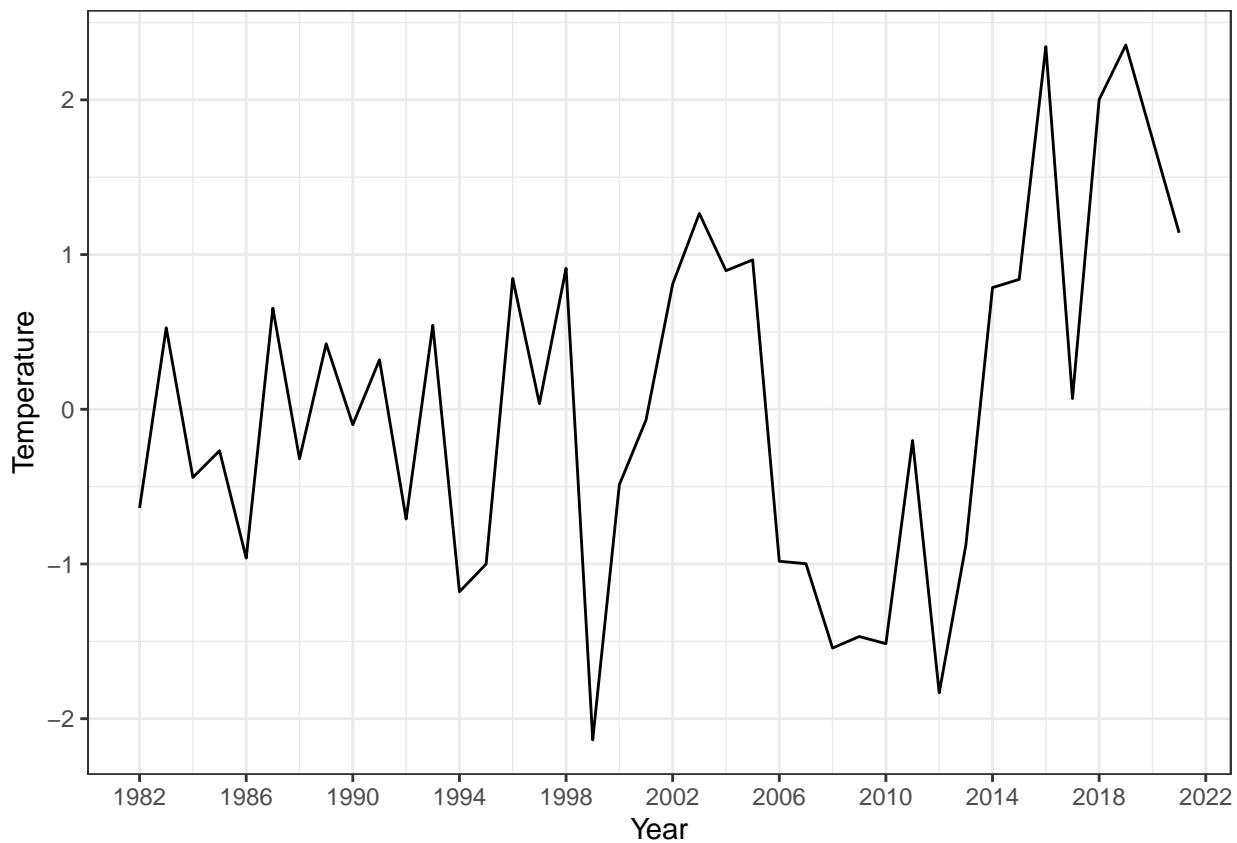


Figure 4.30: Bottom temperature anomalies from the NMFS survey, 1982-2021.

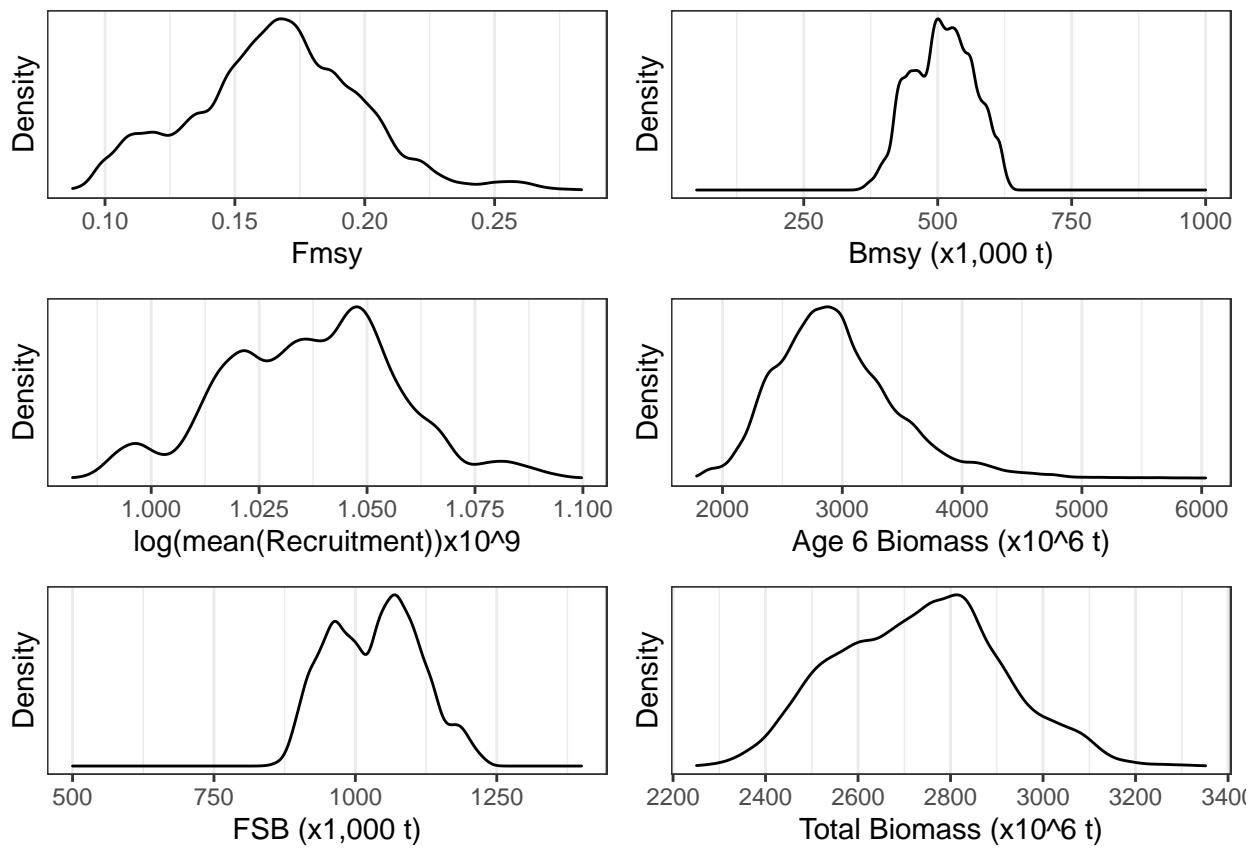


Figure 4.31: MCMC posterior distributions from Model 18.2, for F_{msy} , B_{msy} , $\log(\text{mean}(\text{Recruitment}))$, Age 6 biomass, female spawning biomass (FSB) for 2021, and total biomass for 2021.

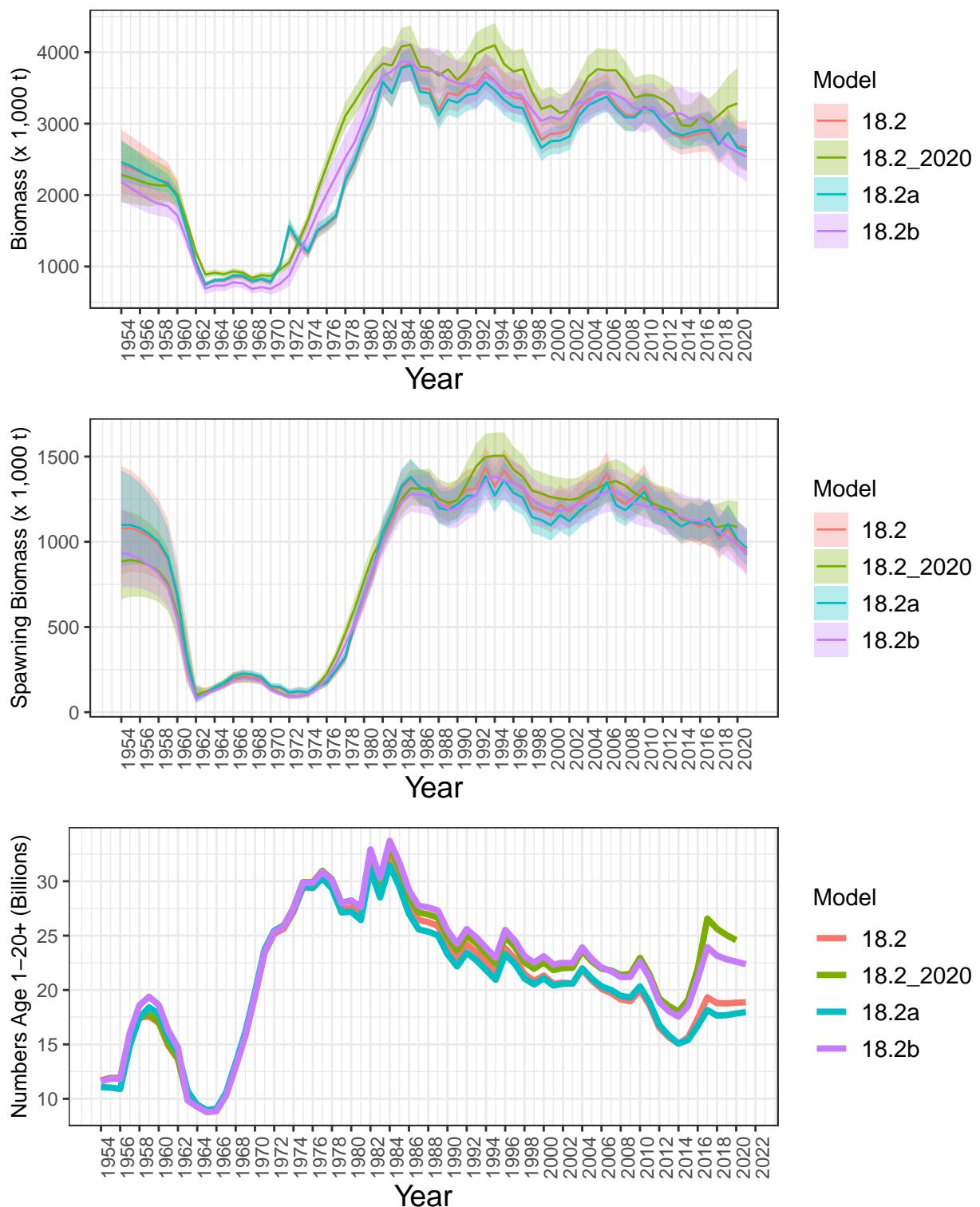


Figure 4.32: Total (age 2+) and spawning stock biomass for Yellowfin Sole, and total numbers, based on Models 18.2 (2020), 18.2, 18.2a, and 18.2b, from 1954-2021.

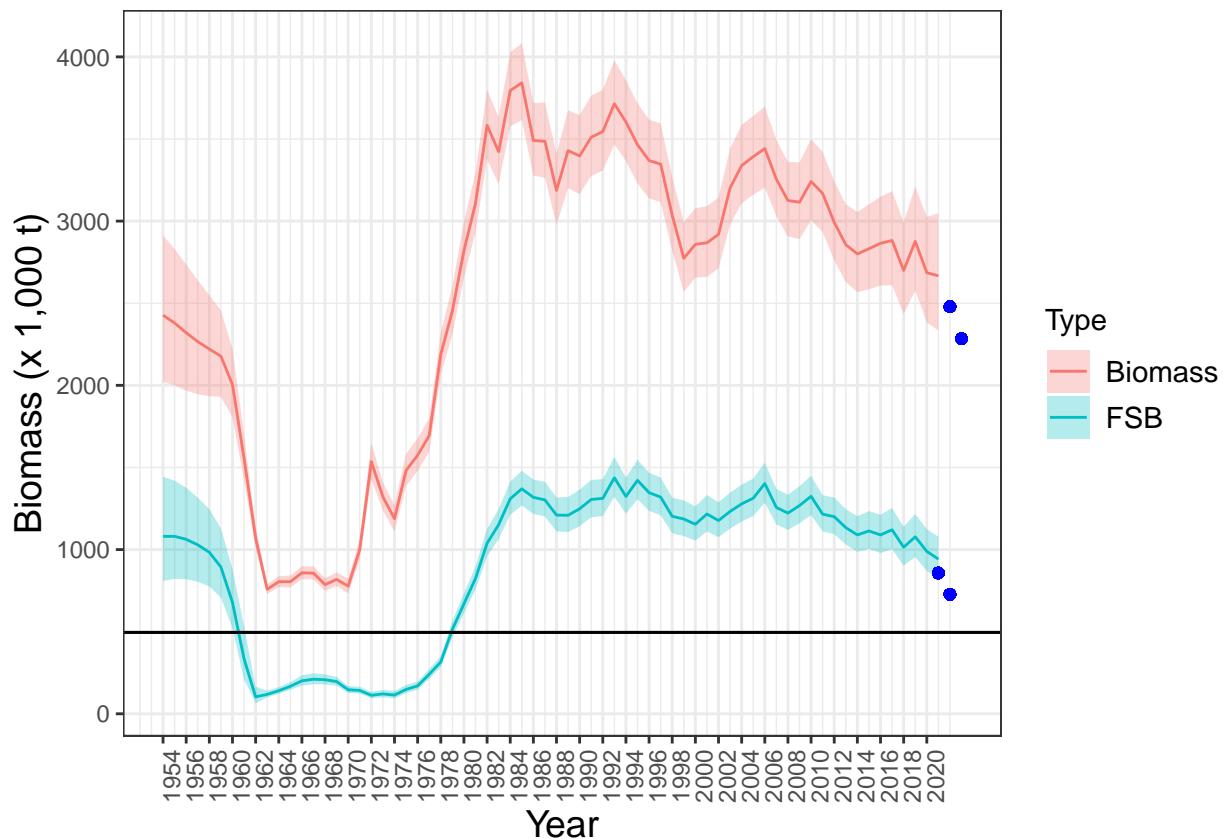


Figure 4.33: Model estimates of total (age 2+) and female spawning biomass with 95% confidence intervals, 1954-2021, Model 18.2. Dots indicate projections for 2022 and 2023.

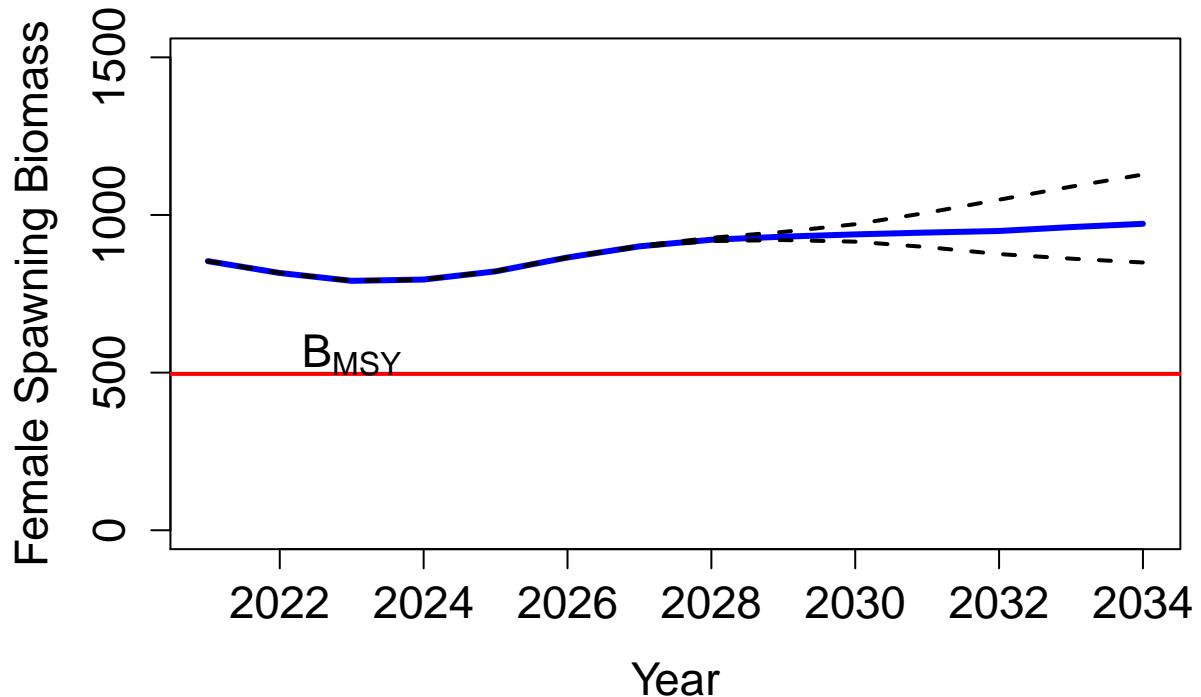


Figure 4.34: Projected female spawning biomass for 2021 to 2034 (blue line), with 5% and 95% confidence intervals, and fishing at the 5-year (2016-2020) average fishing mortality rate, $F = 0.0769$, Model 18.2.

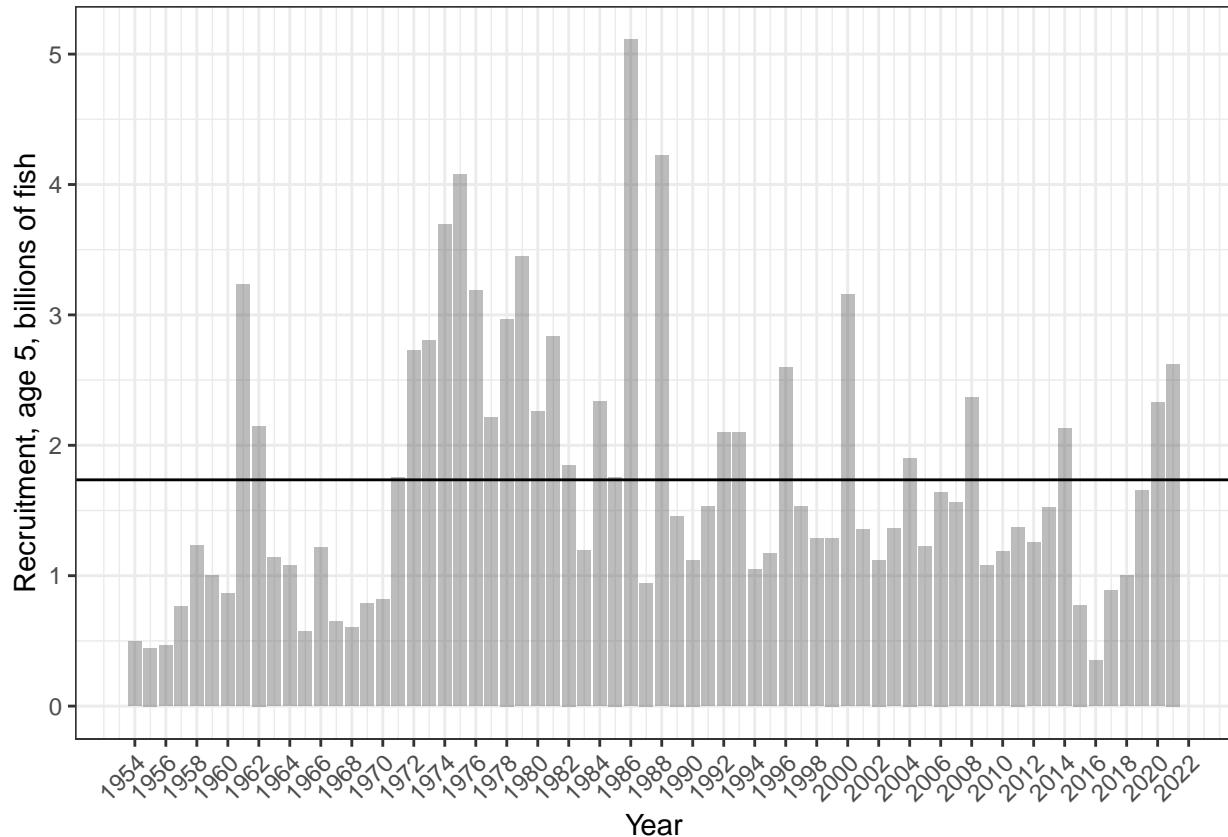


Figure 4.35: Year-class strength of age 5 Yellowfin Sole estimated by the stock assessment model. The horizontal line represents the average of the estimates from recruitment, 1954-2016, 1.78 billion, Model 18.2.

Model 18.2

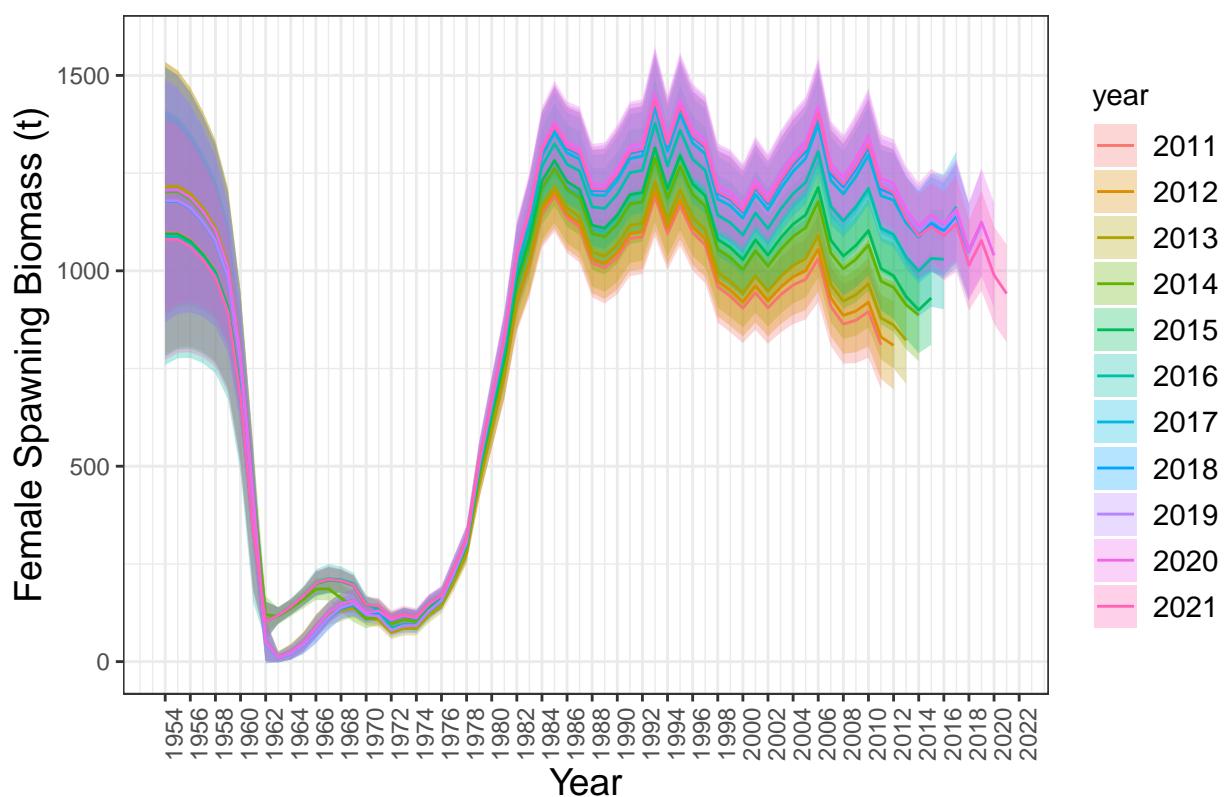


Figure 4.36: Retrospective plot of female spawning biomass for Model 18.2 (current year).

Model 18.2

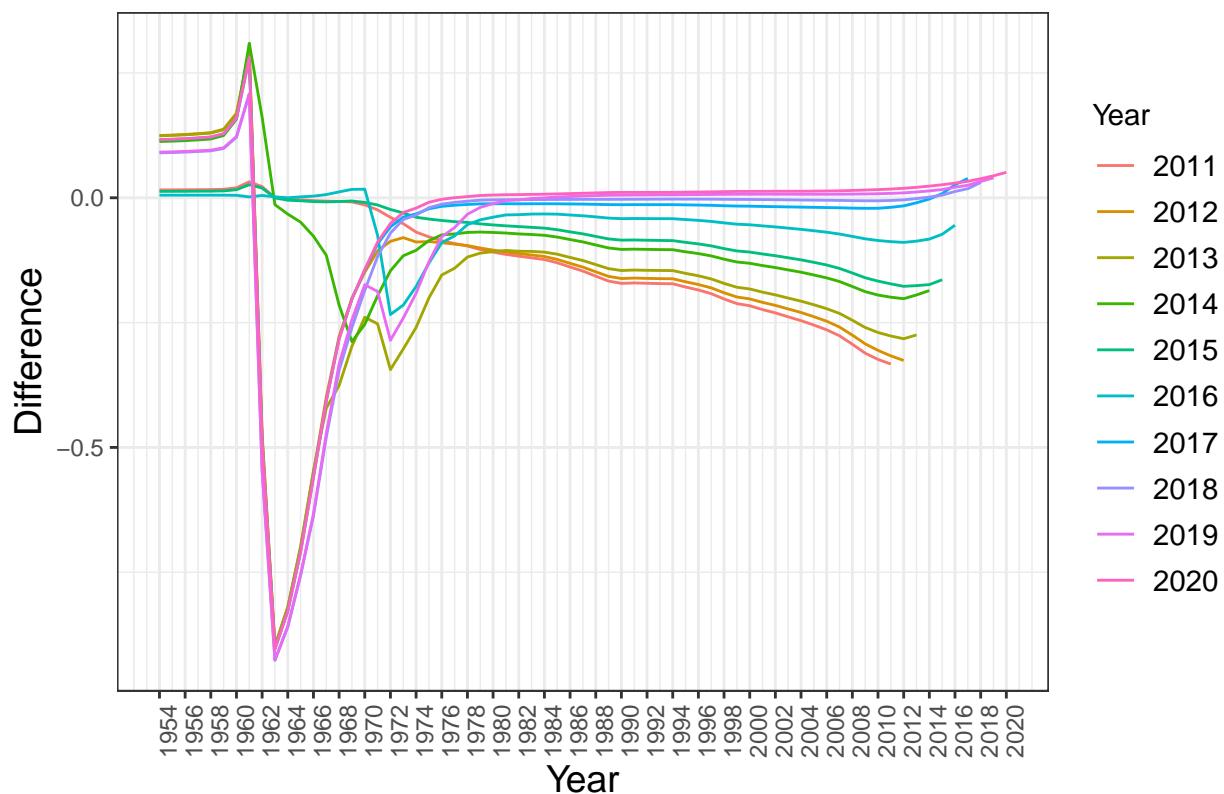


Figure 4.37: Relative differences spawning biomass between the 2021 model and the retrospective model run for years 2020 through 2011, Model 18.2.

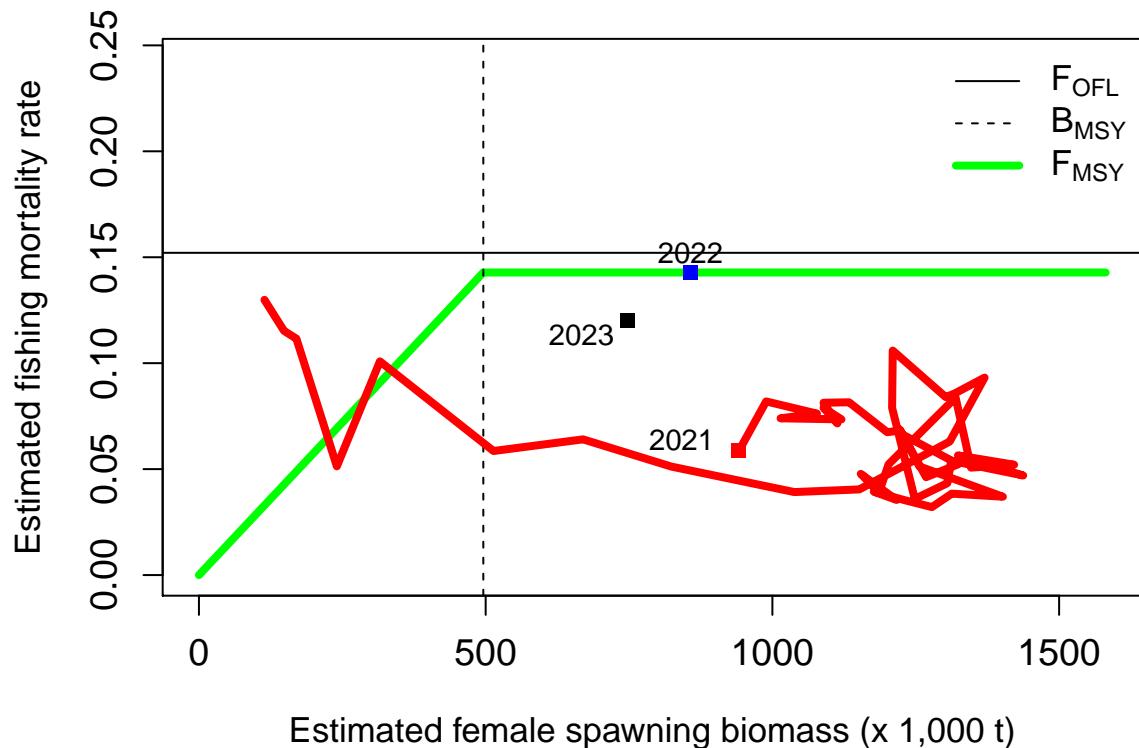


Figure 4.38: Fishing mortality rate and female spawning biomass from 1975 to 2021 compared to the F35% and F40% control rules, based on Model 18.2. Vertical line is B35%. Squares indicate estimates for 2021, 2022, and 2023.

Appendix A

Table A1. Removals (kg) of Yellowfin Sole from the Bering Sea from sources other than those that are included in the Alaska Region's official estimate of catch, 2006-2019. Source NMFS Alaska Region: Sourced by the AKR.V_NONCOMMERCIAL_FISHERY_CATCH table, October 23, 2021. Abbreviations: IPHC (International Pacific Halibut Commission), ADFG (Alaska Department of Fish and Game), NMFS (National Marine Fisheries Service).

| | ADFG | IPHC | NMFS |
|------|------|------|---------|
| 2006 | 0 | 0 | 1 |
| 2007 | 6 | 0 | 0 |
| 2010 | 38 | 1 | 118,577 |
| 2011 | 87 | 0 | 100,900 |
| 2012 | 13 | 0 | 83,390 |
| 2013 | 24 | 9 | 75,044 |
| 2014 | 2 | 0 | 82,574 |
| 2015 | 10 | 66 | 64,838 |
| 2016 | 61 | 15 | 97,795 |
| 2017 | 38 | 1 | 112,121 |
| 2018 | 55 | 1 | 72,451 |
| 2019 | 150 | 18 | 84,506 |

Appendix B

Flatfish (BSAI) Economic Performance Report for 2021 (Author: Ben Fissel)

BSAI FMP flatfish are predominantly caught in the Eastern Bering Sea by catcher/processors in the Amendment 80 Fleet. In 2020, total catch of FMP flatfish in the BSAI was 214 thousand t. Retained catch was 203.5 thousand t, which was a 3% increase over 2019 and was below the average catches between 2011-2015. The two most significant flatfish species in terms of market value and volume are yellowfin and rock sole. These two species accounted for 65% and 12%, respectively, of the retained flatfish catch. Flathead sole, arrowtooth flounder, and Kamchatka flounder are also caught in significant quantities accounting for approximately 5-10% of the retained flatfish. The remainder of the catch volume is comprised of other flatfish which includes Alaska plaice and Greenland turbot. First-wholesale value decreased 17% to \$175 million with a 20% decrease in prices.

COVID-19 had an unprecedented impact on fisheries in Alaska. Undoubtedly, one of the significant economic impacts experienced by the industry were the mitigation costs experienced by the fishing and processing industries to continue to supply national and global markets for seafood. Existing data collections do not adequately capture these costs, and as such, this report focuses on catch, revenues, and effort and changes occurring during the most recent year. BSAI flatfish catch levels relative to TAC were within a typical range suggesting that COVID-19 did not have a significant impact on catch levels. In contrast to changes in landings, however, there was a notable decrease in prices for many of the products with significant exports to China for reprocessing. This includes BSAI flatfish, which has significant end markets in North America and Europe in both foodservice and retail. The downward pressure on these prices is likely the result of COVID-19 related logistical difficulties in international shipping and inspections, as well as foodservice closures, and compounded the downward pressure on prices from tariffs. This downward pressure on fish product prices in the first-wholesale market coupled with cost pressure from COVID-19 mitigation efforts likely resulted in negative impacts on net revenues (Table B1).

In 2008, Amendment 80 to the BSAI FMP rationalized the non-pollock groundfish fisheries by instituting a catch-share system that annually allocates quota. The group of catcher processors managed under this system is referred to as the Amendment 80 Fleet. The species targeted by the Amendment 80 fleet include flatfish. Amendment 80 also mandated improved retention and utilization of fishery resources, which lowered discard and bycatch rates. Since 2008 total FMP flatfish catch has increased to an average of 265 thousand t over 2008-2012 from 184 thousand t in 2003-2007, and retention has increased from approximately 70% to more than 90%. In late 2014 flatfish harvest specification flexibility was implemented through Amendment 105 that allows Amendment 80 and CDQ entities to exchange harvest allocation between yellowfin sole, rock sole, and flathead sole. The Alaska flatfish undergo relatively low fishing pressure and harvests are routinely below their TAC and TACs are below the Allowable Biological Catches (ABC) because of the 2 million metric ton cap on Bering Sea groundfish catch. While the TAC is not typically a binding constraint on the fishery, industry may react to TAC changes. Since 2012 approximately 75-80% of the aggregate flatfish TACs have been caught and TACs are approximately 43-55% of the aggregate ABCs, though these proportions vary across individual species.

First-wholesale value in the BSAI flatfish fisheries decreased 17% to \$175million with a 23% decrease in yellowfin sole price, a 14% decrease in the rock sole price, a 25% decrease in the flathead sole price, and a 14% decrease in the arrowtooth flounder price. Prices for most flatfish were at a decadal high in 2018 and the decreases in 2020 brought the average 2020 price across species to a level that was approximately equal to the 2011-2015 average price. Flatfish are primarily processed into the headed-and-gutted (H&G) and whole fish product forms and changes in production largely reflect changes in catch. The export volume of yellowfin sole and rock sole is approximately 75-90% of the annual volume of processed products. Exports are primarily destined for China and South Korea, with China typically accounting approximately 80-85% of total exports. In 2019 China's share of exports dropped to 71% and South Korea's share of value increased from approximately 15% to 20% in 2019. A significant share of this product is re-processed into fillets and re-exported to North American and European markets. Flatfish can serve as a substitute for other higher priced whitefish products, and price changes for these other species can influence flatfish demand. Some rock sole is processed as H&G with roe, which is a higher priced product that is primarily destined for

Japanese markets. The Alaska flatfish fishery became MSC certified in 2010 and received the Responsible Fishery Management (RFM) certification in 2014. Certification provides access to some markets, particularly in Europe, and may enhance value. Some media reports have attributed the price increase in 2011 to the MSC certification and Asian markets where demand is expected to increase with growth in the middle class population. Reduced fishing opportunities in 2013-2014 for higher valued Atka mackerel may have diverted additional fishing effort towards flatfish increasing catch in these years. Increased supply and inventories from the additional catch put downward pressure on prices. As Atka mackerel fishing resumed more normal levels in 2015 and later, flatfish supply and inventories were reduced, prices began to rise. Atka mackerel catches were high in 2017 and 2018 which may have contributed to the reduced catch of flatfish despite high prices. Because of China's significance as a re-processor of flatfish products, the tariffs between the U.S. and China, which began in 2018, have put downward pressure on flatfish prices which has inhibited value growth in rockfish markets. Flatfish were among the species to receive relief under the USDA Seafood Tariff Relief Program in 2019-2020. Industry lacks immediate alternative reprocessing options to China on a large scale. Export quantities of flatfish increased in 2020 from 2019 and the share of exports to China was consistent with the average over the last decade (Table B2). The COVID-19 pandemic created supply chain logistical difficulties, particularly in China, which put downward pressure on prices. In addition, foodservice closures in major markets also likely impacted prices negatively for flatfish finished goods.

Table B1. BSAI flatfish catch and first-wholesale market data. Total and retained catch (thousand metric tons), number of vessels, first-wholesale production (thousand metric tons), value (million US\$), price (US\$ per pound), and head and gut share of production; 2010-2014 average and 2015-2019.

| | 2010-2015 Average | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|-------------------|----------|----------|----------|----------|----------|
| Total catch K mt | 273.92 | 225.1 | 210.9 | 211.9 | 208.3 | 213.8 |
| Retained catch K mt | 247.6 | 211.4 | 198.6 | 197.4 | 198.1 | 203.5 |
| Yellowfin sole share of retained | 56.19% | 62.05% | 64.77% | 64.50% | 63.66% | 64.70% |
| Rock sole share of retained | 22.32% | 20.46% | 17.09% | 13.75% | 12.31% | 12.13% |
| Flathead sole share of retained | 4.99% | 4.26% | 4.08% | 5.15% | 7.52% | 4.07% |
| Arrowtooth and Kamchatka flounder share of retained | 9.28% | 6.39% | 4.90% | 4.44% | 6.63% | 8.34% |
| Vessels # | 37.6 | 39 | 34 | 35 | 35 | 33 |
| Total flatfish first-wholesale production K mt | 147.8 | 123.9 | 116.9 | 115.1 | 116.2 | 121.3 |
| Total flatfish first-wholesale value M US\$ | \$206.70 | \$166.70 | \$192.40 | \$211.60 | \$209.80 | \$174.80 |
| Total flatfish first-wholesale price/lb US\$ | \$0.63 | \$0.61 | \$0.75 | \$0.83 | \$0.82 | \$0.65 |
| Yellowfin sole share of value | 52.41% | 56.51% | 57.59% | 64.56% | 61.39% | 61.67% |
| Yellowfin sole price/lb US\$ | \$0.56 | \$0.55 | \$0.65 | \$0.81 | \$0.78 | \$0.60 |
| Rock sole share of value | 22.81% | 20.40% | 15.75% | 13.75% | 11.63% | 12.01% |
| Rock sole price/lb US\$ | \$0.69 | \$0.62 | \$0.72 | \$0.89 | \$0.83 | \$0.72 |
| Flathead sole share of value | 5.18% | 4.68% | 4.16% | 5.62% | 7.29% | 3.38% |
| Flathead sole price/lb US\$ | \$0.80 | \$0.74 | \$0.85 | \$0.96 | \$0.85 | \$0.64 |
| Arrowtooth and Kamchatka flounder share of value | 10.06% | 8.22% | 8.63% | 4.54% | 6.77% | 9.44% |
| Arrowtooth and Kamchatka flounder price/lb US\$ | \$0.75 | \$0.84 | \$1.36 | \$1.00 | \$0.91 | \$0.79 |
| H&G share of value | 86.12% | 89.20% | 89.66% | 93.05% | 94.04% | 92.68% |

Source: NMFS Alaska Region Blend and Catch-accounting System estimates; NMFS Alaska Region At-sea Production Reports; and ADF&G Commercial Operators Annual Reports (COAR). Data compiled and provided by the Alaska Fisheries Information Network (AKFIN).

Table B2. Flatfish U.S. trade and global market data. Global production (thousand metric tons), U.S. share of global production, BSAI share of U.S. production. U.S. yellowfin sole and rock sole export volume (thousand metric tons), U.S. export value (million US dollars), U.S. export price (US dollars per pound), the share of U.S. export value from China, and the Euro/U.S. Dollar exchange rate; 2011-2015 average and 2016-2020.

| | 2010-2015 Average | 2016 | 2017 | 2018 | 2019 | 2020 |
|--|-------------------|----------|----------|----------|----------|----------|
| Global production of flounder, halibut, and sole K mt | 1,186 | 1,154 | 1,179 | 1,157 | 1,151 | - |
| US share global production | 27.91% | 22.88% | 22.72% | 22.54% | 21.56% | - |
| BSAI FMP flatfish share of U.S.1 | 76.03% | 78.66% | 78.91% | 76.15% | 79.55% | - |
| Export quantity of yellowfin sole and rock sole K mt | 70.7 | 87.0 | 94.8 | 81.4 | 72.0 | 76.7 |
| Export value of yellowfin sole and rock sole M US\$ | \$96.67 | \$118.07 | \$135.84 | \$115.26 | \$107.06 | \$118.42 |
| Export price/lb of yellowfin sole and rock sole US\$ | \$0.62 | \$0.62 | \$0.65 | \$0.64 | \$0.67 | \$0.70 |
| China's share of yellowfin sole and rock sole export value | 82.72% | 82.04% | 78.38% | 81.67% | 78.63% | 70.60% |
| Exchange rate, Euro/Dollar | 0.75 | 0.90 | 0.90 | 0.89 | 0.85 | 0.89 |

Source: FAO Fisheries & Aquaculture Dept. Statistics <http://www.fao.org/fishery/statistics/en>. NOAA Fisheries, Fisheries Statistics Division, Foreign Trade Division of the U.S. Census Bureau, <http://www.st.nmfs.noaa.gov/commercial-fisheries/foreign-trade/index>. U.S. Department of Agriculture <http://www.ers.usda.gov/data-products/agricultural-exchange-rate-data-set.aspx>. 1 - The BSAI FMP share of U.S. production is calculated as the BSAI retained catch divided by the FAO's U.S. production of flounder, halibut and sole.