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 $<$ 100m 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 *specified last* year for: 2021	2022	As estimated or *recommended this* year for: 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 14C 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/km^2 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 km^2, 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 where 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,

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

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 $P_{t,a} = \dfrac{C_{t,a}}{C_t}$.

Recruitment from 1956-1975 was modeled as $N_{t,1} = R_t = R_0 e^{\tau_t}, \tau_t \backsim N(0, \sigma_R^2)$, 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 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,

$$S^f_{a,t} = [1 + e^{\eta_t(a-\varphi_t)}]^{-1}, \tag{1}$$

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:

$$q = e^{-\alpha+\beta T}, \tag{2}$$

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:

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

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:

$$R = \alpha S e^{-\beta S}, \tag{4}$$

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, 0.95. 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 1988 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 at 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 $\leq$ 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 ($\leq$ 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 *specified last* year for: 2021	2022	As estimated or *recommended this* year for: 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.

		Domestic				
Year	Foreign	JVP	DAP	Aleutian Islands	Bering Sea	Total
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).

	Nichol (1995)	TenBrink and Wilderbuer (2015)	Total
Age	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	2,745,060
1955	2,379,370	1,999,760	2,831,030	2,244,950	1,882,290	2,677,490	2,408,180	2,690,380
1956	2,320,060	1,967,510	2,735,780	2,198,900	1,859,310	2,600,510	2,339,630	2,619,240
1957	2,266,300	1,945,330	2,640,220	2,153,360	1,840,490	2,519,400	2,272,320	2,543,510
1958	2,220,480	1,934,240	2,549,080	2,136,280	1,859,300	2,454,530	2,213,600	2,470,440
1959	2,177,220	1,930,160	2,455,900	2,132,960	1,906,140	2,386,770	2,156,690	2,389,760
1960	2,003,890	1,806,910	2,222,350	2,012,340	1,849,180	2,189,890	1,973,720	2,165,640
1961	1,555,590	1,421,720	1,702,060	1,637,170	1,543,530	1,736,500	1,524,930	1,657,170
1962	1,069,860	1,007,380	1,136,220	1,199,170	1,146,280	1,254,500	1,045,980	1,103,260
1963	757,854	728,526	788,362	887,952	839,583	939,108	745,908	764,333
1964	804,634	772,068	838,573	911,499	866,169	959,200	808,078	798,382
1965	804,179	767,988	842,074	892,030	851,247	934,767	813,882	785,547
1966	858,369	820,252	898,258	932,953	892,498	975,242	872,192	837,021
1967	856,728	817,776	897,536	914,946	875,023	956,691	869,279	833,077
1968	786,394	748,814	825,860	838,641	799,568	879,622	795,621	769,225
1969	818,403	778,145	860,745	879,883	836,550	925,462	827,331	806,949
1970	777,343	734,340	822,863	866,260	817,714	917,687	786,818	774,186
1971	1,000,410	938,184	1,066,760	954,861	896,886	1,016,580	1,014,970	1,003,050
1972	1,535,130	1,429,830	1,648,180	1,058,690	988,791	1,133,540	1,563,260	1,550,590
1973	1,320,370	1,237,070	1,409,270	1,353,890	1,267,840	1,445,780	1,341,970	1,333,960
1974	1,187,980	1,110,060	1,271,360	1,647,840	1,544,370	1,758,250	1,209,010	1,201,140
1975	1,481,560	1,385,940	1,583,760	2,050,800	1,925,290	2,184,480	1,507,390	1,501,050
1976	1,574,480	1,478,740	1,676,430	2,409,330	2,264,070	2,563,900	1,599,430	1,595,820
1977	1,693,610	1,593,460	1,800,060	2,768,530	2,604,430	2,942,970	1,716,920	1,715,900
1978	2,188,460	2,064,830	2,319,510	3,108,590	2,926,830	3,301,650	2,212,180	2,217,180
1979	2,452,690	2,309,570	2,604,670	3,304,210	3,107,960	3,512,850	2,477,760	2,486,660
1980	2,820,290	2,656,980	2,993,640	3,517,060	3,307,890	3,739,460	2,843,770	2,859,840
1981	3,107,690	2,929,500	3,296,720	3,707,350	3,487,360	3,941,220	3,124,640	3,151,090
1982	3,583,020	3,378,420	3,800,010	3,840,390	3,614,180	4,080,760	3,590,080	3,633,290
1983	3,422,280	3,223,350	3,633,480	3,814,550	3,587,200	4,056,300	3,426,010	3,471,330
1984	3,794,790	3,576,310	4,026,630	4,081,170	3,838,180	4,339,560	3,778,470	3,850,760
1985	3,841,940	3,615,260	4,082,830	4,104,890	3,854,550	4,371,490	3,814,220	3,900,660
1986	3,490,780	3,276,460	3,719,110	3,798,830	3,556,460	4,057,720	3,447,340	3,547,510
1987	3,486,120	3,264,690	3,722,570	3,780,260	3,531,070	4,047,040	3,425,270	3,545,800
1988	3,186,490	2,977,000	3,410,720	3,675,670	3,427,740	3,941,550	3,120,020	3,245,300
1989	3,429,240	3,200,190	3,674,680	3,762,820	3,502,760	4,042,190	3,335,870	3,500,620
1990	3,396,500	3,164,850	3,645,090	3,611,280	3,356,600	3,885,290	3,294,160	3,472,940
1991	3,511,060	3,274,590	3,764,610	3,739,510	3,477,640	4,021,110	3,398,600	3,596,260
1992	3,544,780	3,307,550	3,799,030	3,974,950	3,698,850	4,271,670	3,424,340	3,638,990
1993	3,714,790	3,466,950	3,980,360	4,049,530	3,766,880	4,353,400	3,580,480	3,823,790
1994	3,603,400	3,366,280	3,857,230	4,097,340	3,811,770	4,404,300	3,470,860	3,722,660
1995	3,464,870	3,228,420	3,718,630	3,834,710	3,560,820	4,129,660	3,333,160	3,585,300
1996	3,369,040	3,137,960	3,617,140	3,728,610	3,459,850	4,018,240	3,239,470	3,499,260
1997	3,346,800	3,115,750	3,594,980	3,763,620	3,491,160	4,057,340	3,218,420	3,489,230
1998	3,034,700	2,818,830	3,267,100	3,438,880	3,181,270	3,717,350	2,916,030	3,178,830
1999	2,773,290	2,569,220	2,993,580	3,206,790	2,961,350	3,472,580	2,662,080	2,911,420
2000	2,858,580	2,654,960	3,077,810	3,250,520	3,004,660	3,516,490	2,754,190	3,014,720
2001	2,867,690	2,660,120	3,091,460	3,148,860	2,909,040	3,408,440	2,762,300	3,031,430

2002	2,919,490	2,712,400	3,142,390	3,183,720	2,943,740	3,443,270	2,822,550	3,096,830
2003	3,201,970	2,978,780	3,441,890	3,416,780	3,163,620	3,690,190	3,108,690	3,408,510
2004	3,338,370	3,108,340	3,585,410	3,653,900	3,386,690	3,942,200	3,253,850	3,564,560
2005	3,392,440	3,160,460	3,641,450	3,764,640	3,491,140	4,059,570	3,319,870	3,631,220
2006	3,441,730	3,204,400	3,696,630	3,745,810	3,472,350	4,040,800	3,376,470	3,694,430
2007	3,254,230	3,030,490	3,494,490	3,747,670	3,471,700	4,045,570	3,207,840	3,505,050
2008	3,125,180	2,906,260	3,360,590	3,585,080	3,315,670	3,876,380	3,089,150	3,379,170
2009	3,115,290	2,890,380	3,357,690	3,365,630	3,104,790	3,648,380	3,089,730	3,385,130
2010	3,241,480	3,003,340	3,498,490	3,398,180	3,131,750	3,687,270	3,224,770	3,536,280
2011	3,168,560	2,933,460	3,422,510	3,398,460	3,127,330	3,693,100	3,171,280	3,474,200
2012	2,992,180	2,761,710	3,241,890	3,339,860	3,065,280	3,639,030	3,005,570	3,301,110
2013	2,856,540	2,628,850	3,103,950	3,242,770	2,967,160	3,543,990	2,881,490	3,172,020
2014	2,800,240	2,566,800	3,054,910	2,979,390	2,715,320	3,269,150	2,833,810	3,134,400
2015	2,831,740	2,584,730	3,102,350	2,964,580	2,690,840	3,266,160	2,873,980	3,193,240
2016	2,864,840	2,606,650	3,148,620	3,093,610	2,797,760	3,420,760	2,906,420	3,249,410
2017	2,881,920	2,609,850	3,182,360	3,013,720	2,710,700	3,350,610	2,916,150	3,287,230
2018	2,699,330	2,433,780	2,993,840	3,116,980	2,783,110	3,490,900	2,718,990	3,086,880
2019	2,876,830	2,576,650	3,211,990	3,234,230	2,851,490	3,668,350	2,871,340	3,287,350
2020	2,685,450	2,383,820	3,025,240	3,283,680	2,849,560	3,783,930	2,663,710	3,071,230
2021	2,666,770	2,333,390	3,047,790				2,618,900	3,039,800

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	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	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.

	Model 18.2 (2021)		Model 18.2 (2020)	
Quantity	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

	Model 18.2a		Model 18.2b	
Quantity	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	1,571,830	1,571,830
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 (HCI) and lower (LCI) 95% confidence intervals from the 2020 and 2021 stock assessments, including Model 18.2 (2020), 18.2 (2021), and 18.2a.

	Model 18.2 (2020)			Model 18.2 (2021)			Model 18.2a	
FSB (t)	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 Maximum ABC harvest permissible			
Year	FSB	Catch	F
2021	853,521	108,157	0.067
2022	816,003	126,929	0.079
2023	780,284	190,898	0.117
2024	754,840	195,438	0.117
2025	753,650	199,579	0.117
2026	770,517	199,536	0.117
2027	779,543	196,533	0.117
2028	777,665	194,344	0.117
2029	769,052	192,101	0.117
2030	761,685	190,156	0.116
2031	756,555	187,643	0.115
2032	753,630	186,026	0.114
2033	758,207	186,588	0.113
2034	762,508	187,564	0.113

Scenario 3 Harvest at average F over past 5 years			
Year	FSB	Catch	F
2021	853,521	108,157	0.067
2022	816,003	126,929	0.079
2023	791,108	121,085	0.073
2024	795,197	128,374	0.073
2025	821,149	135,166	0.073
2026	865,188	138,317	0.073
2027	900,500	139,559	0.073
2028	921,420	140,768	0.073
2029	931,171	141,322	0.073
2030	938,422	142,284	0.073
2031	944,306	143,223	0.073
2032	949,240	144,299	0.073
2033	961,584	145,794	0.073
2034	972,069	147,350	0.073

Scenario 4, Maximum Tier 3 ABC harvest permissible set at F60			
Year	FSB	Catch	F
2021	853,521	108,157	0.067
2022	822,325	88,713	0.055
2023	812,660	96,846	0.057
2024	826,710	103,624	0.057
2025	862,140	109,995	0.057
2026	916,207	113,468	0.057
2027	961,599	115,353	0.057
2028	991,578	117,089	0.057
2029	1,008,918	118,142	0.057
2030	1,022,571	119,430	0.057
2031	1,033,858	120,628	0.057
2032	1,043,354	121,889	0.057
2033	1,060,562	123,476	0.057
2034	1,075,267	125,098	0.057

Scenario 5 No fishing			
Year	FSB	Catch	F
2021	853,521	108,157	0.067
2022	836,695	0	0.000
2023	868,962	0	0.000
2024	925,259	0	0.000
2025	1,003,660	0	0.000
2026	1,104,923	0	0.000
2027	1,199,953	0	0.000
2028	1,277,558	0	0.000
2029	1,338,018	0	0.000
2030	1,390,702	0	0.000
2031	1,437,279	0	0.000
2032	1,478,640	0	0.000
2033	1,529,274	0	0.000
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	0	10,395	118	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	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	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	0	1	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	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	0
O. Flatfish	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	0	0
Other Rockfish	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	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	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	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	22,306	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	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	4	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	6	0	3	0
Sculpin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,804	1,940	1,920	1,259	1,082	948	1,308	1,246	1,534	1,451	0
Shark	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	3	1	4	2	2	1
Sharpchin/N. RF	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	0
SR/RE/Sharpchin/N. RF	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	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	1	0	1	0	1	0	0	0	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	3	0	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.Sculpins	238	823	1,057	1,058	2,269	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Large.Sculpins...Bigmouth.Sculpin	0	0	0	0	0	47	26	0	0	0	0	0	0	0	0	0	0	0	0
Large.Sculpins...Great.Sculpin	0	0	0	0	0	1,203	1,346	0	0	0	0	0	0	0	0	0	0	0	0
Large.Sculpins...Myoxocephalus.Unidentified	0	0	0	0	0	129	4	0	0	0	0	0	0	0	0	0	0	0	0
Large.Sculpins...Plain.Sculpin	0	0	0	0	0	1,273	914	0	0	0	0	0	0	0	0	0	0	0	0
Large.Sculpins...Red.Irish.Lord	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Large.Sculpins...Warty.Sculpin	0	0	0	0	0	68	49	0	0	0	0	0	0	0	0	0	0	0	0
Large.Sculpins...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.Sculpins	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	0	1	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	Low exploitation rate	Natural fluctuation	No concern
Fishery contribution to discards and offal production	Stable trend	Improving, but data limited	Possible concern
Fishery effects on age-at-maturity and fecundity	Unknown		Possible concern

Figures

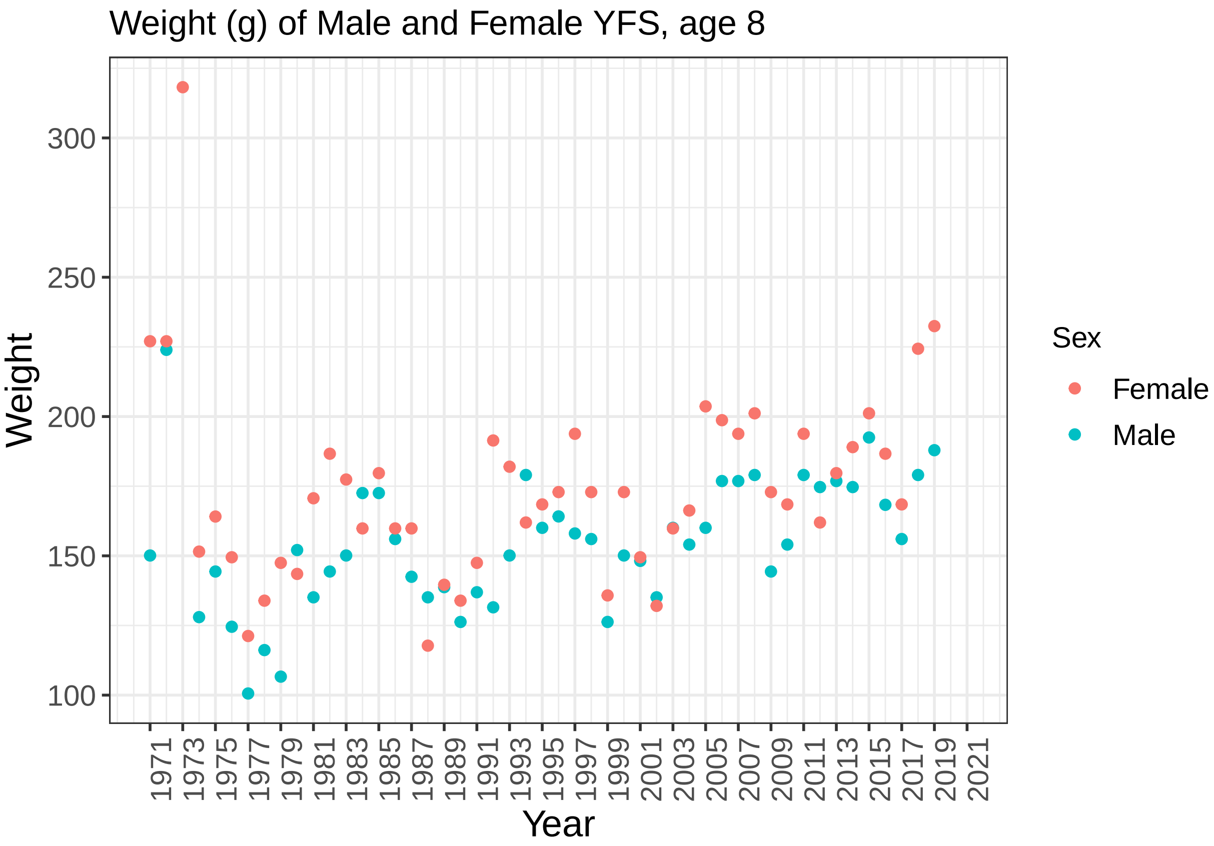


Figure 4.1: Mean weight at age (g) for Yellowfin Sole Age 8 females and males from the Eastern Bering Sea survey, 1971-2019. High values early in the time series are likely outliers.

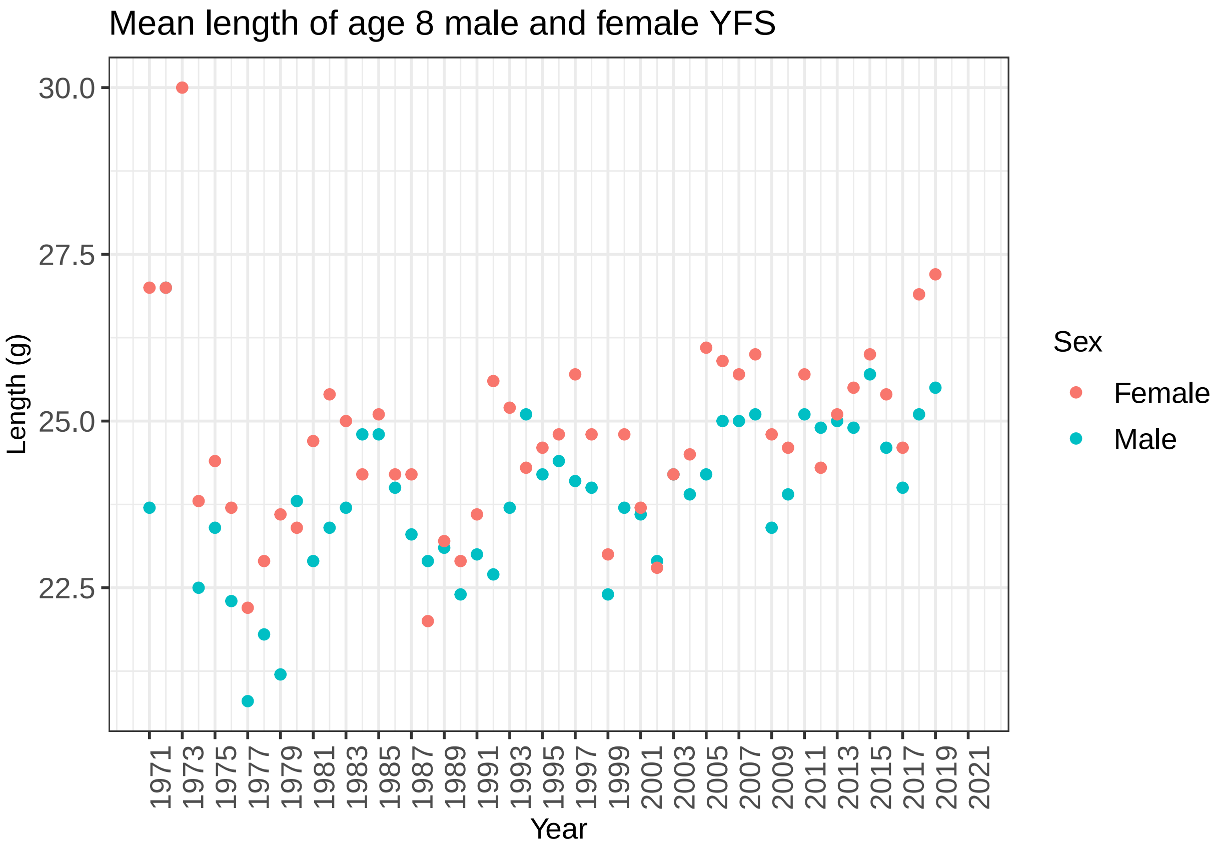


Figure 4.2: Mean length at age (cm) for Yellowfin Sole Age 8 females and males from the Eastern Bering Sea survey, 1971-2019.

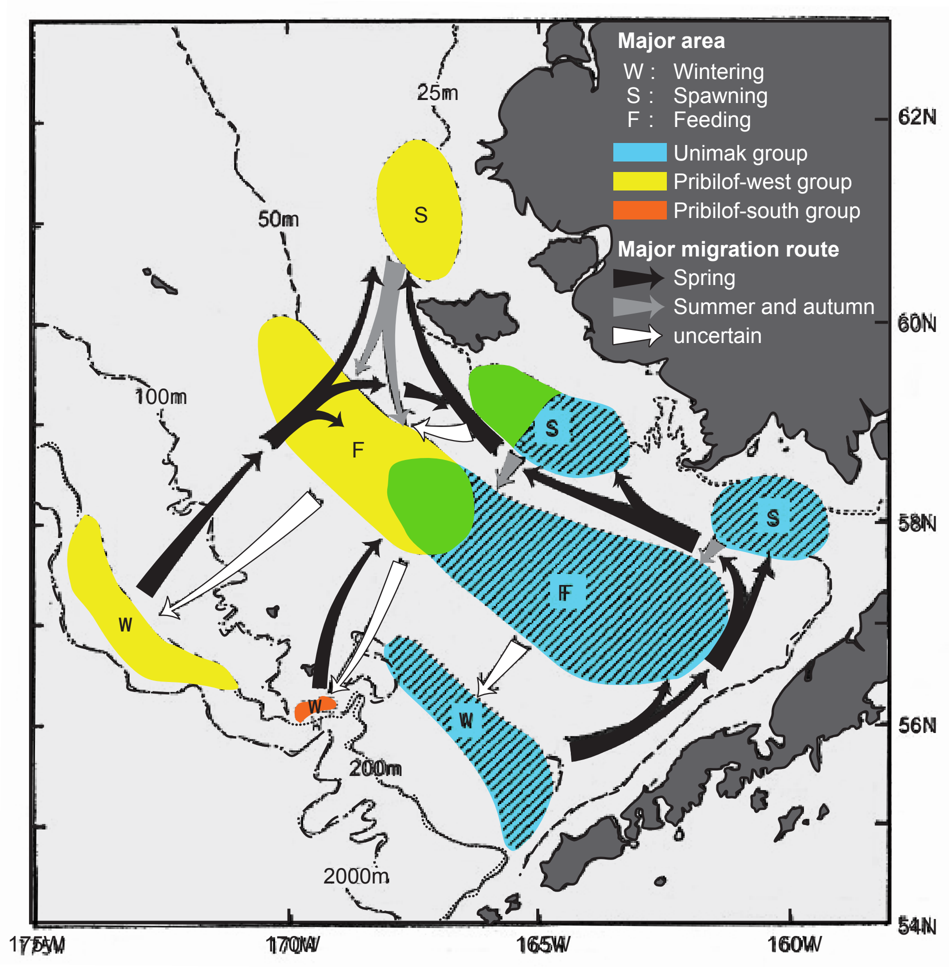


Figure 4.3: Distribution of wintering, spawning, and feeding areas for Yellowfin Sole in the Bering Sea, and observed regional grouping. Migration routes from wintering to feeding take place in spring, and the dates that Yellowfin Sole return to their wintering areas are unknown.

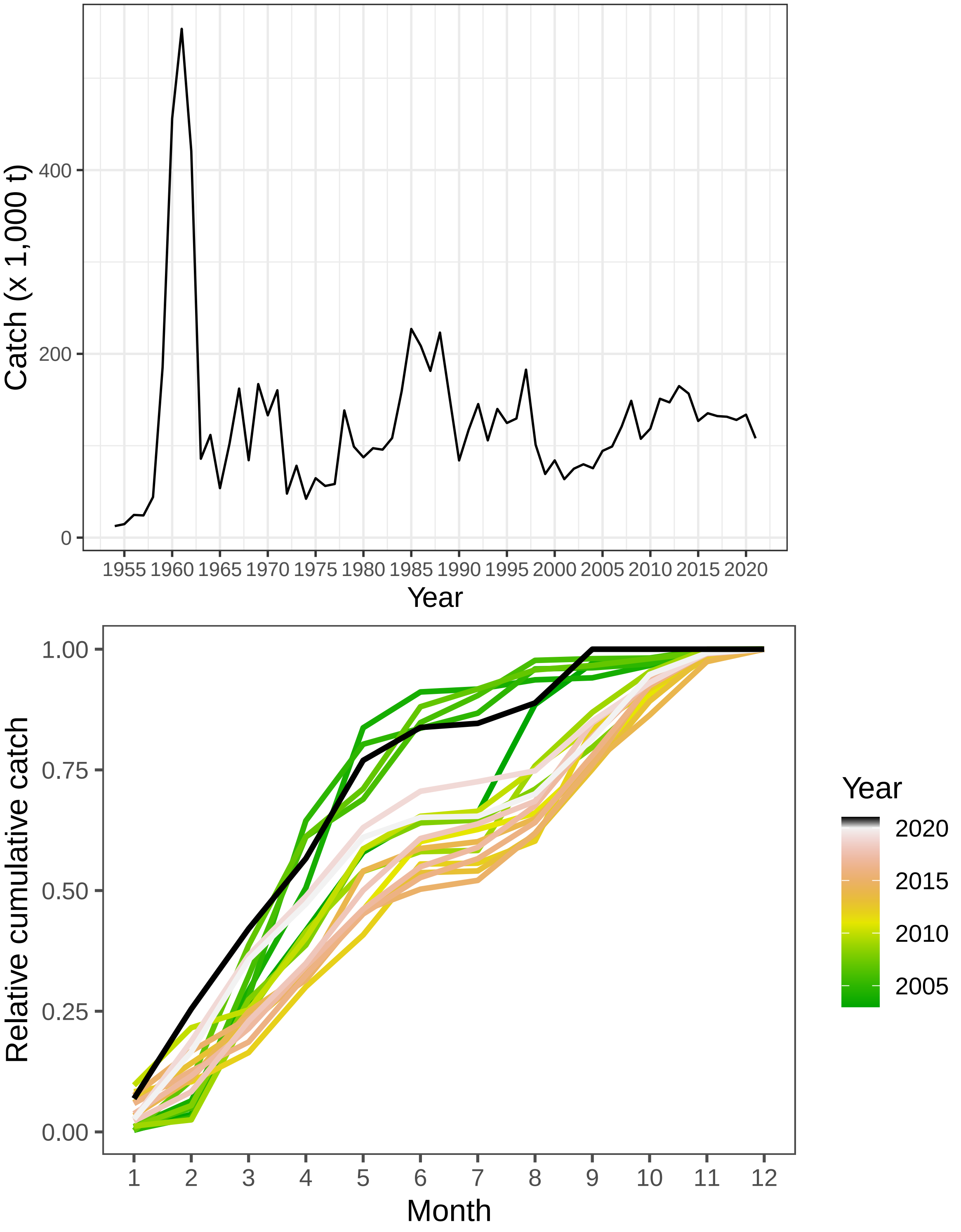


Figure 4.4: Yellowfin Sole annual total catch (1,000s t) in the Eastern Bering Sea from 1954-2021 (upper panel). Yellowfin Sole annual cumulative catch by month and year (non CDQ) 2003-October 1, 2021 (lower panel).

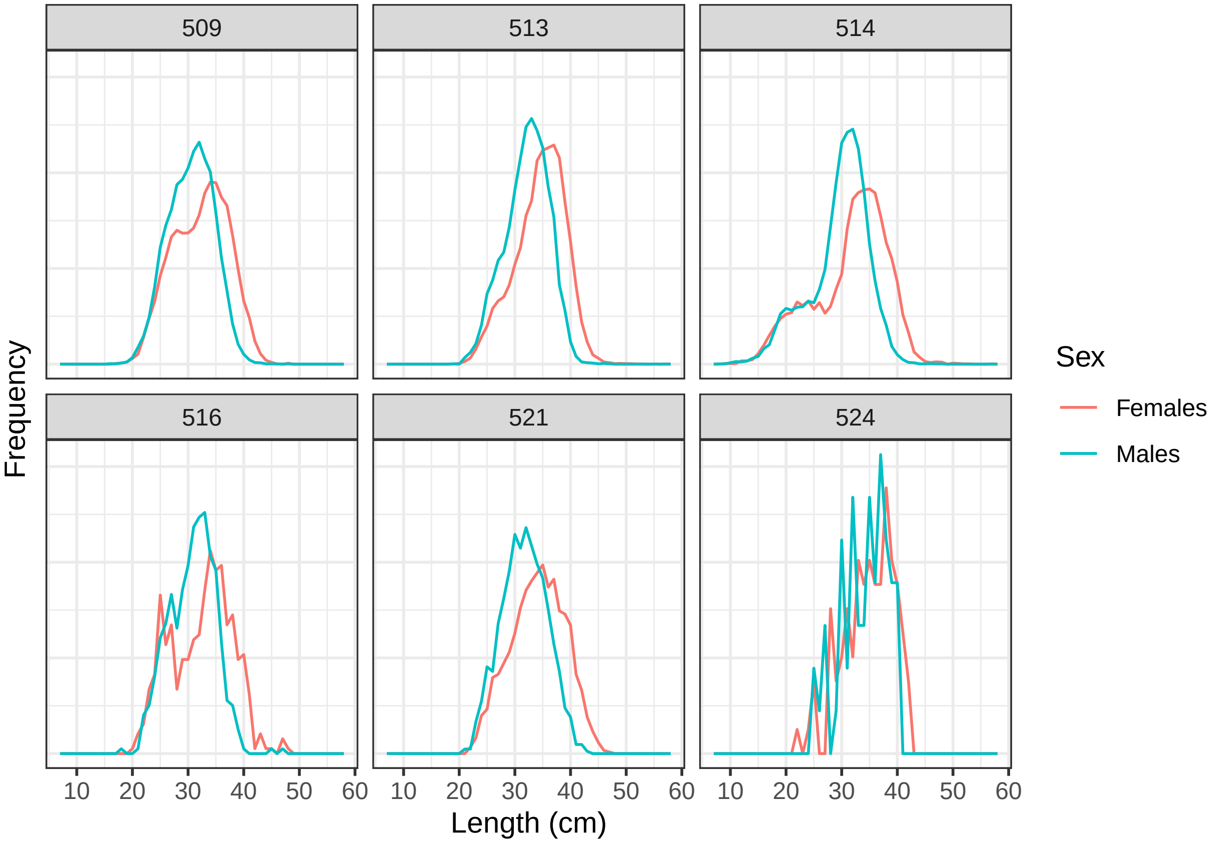


Figure 4.5: Size composition of the Yellowfin Sole catch in 2021 (through October 6) caught by trawl gear, by subarea and total, for the primary areas where Yellowfin Sole are caught, 509, 513, 514, 516, 521, and 524.

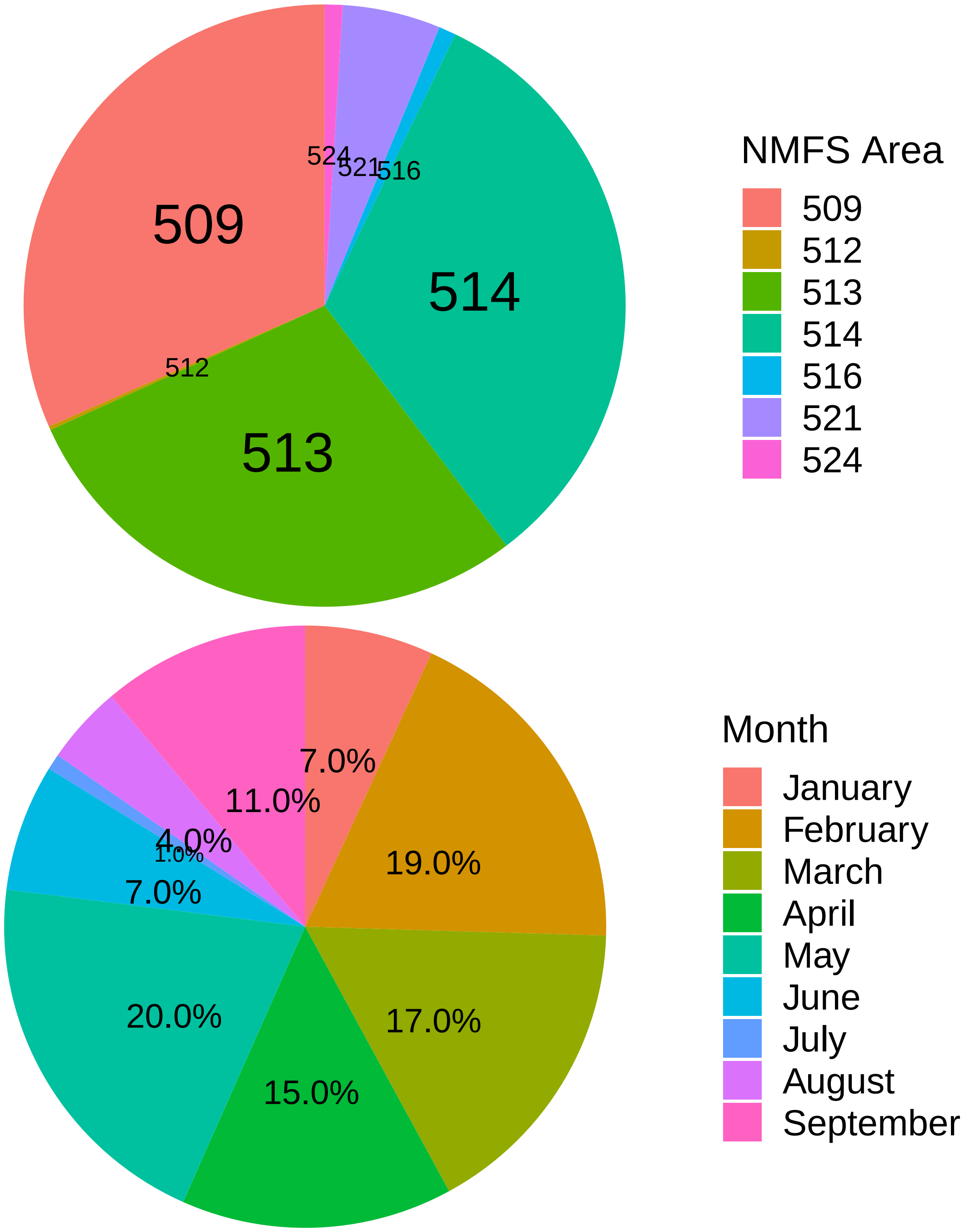


Figure 4.6: Yellowfin Sole catch proportion by area in which catch through October 1, 2021 was greater than 100 t (upper panel) and by month (lower panel) in the Eastern Bering Sea in 2021, through October 1.

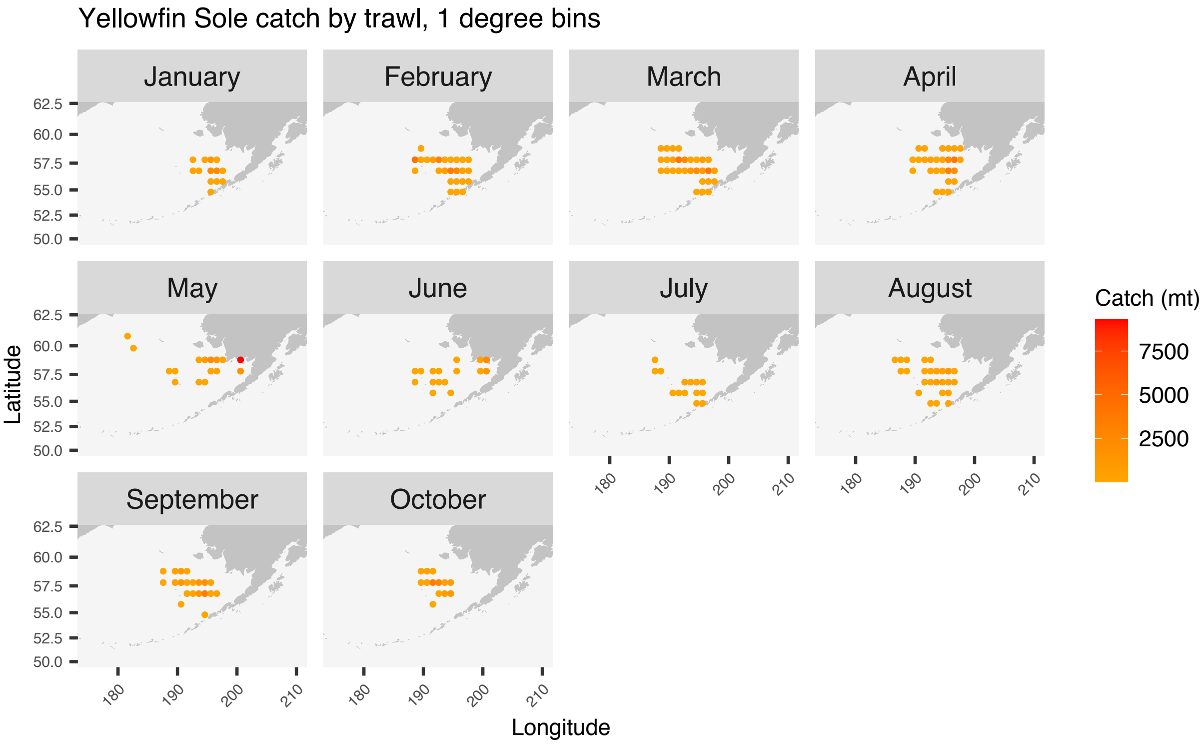


Figure 4.7: Catch of Yellowfin Sole in the BSAI in 2021 by month (through October), reported by observers. Circles represent presence of Yellowfin Sole the catch by the following gear types: non-pelagic trawl, pair trawl, or pelagic trawl.

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

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 includng 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.

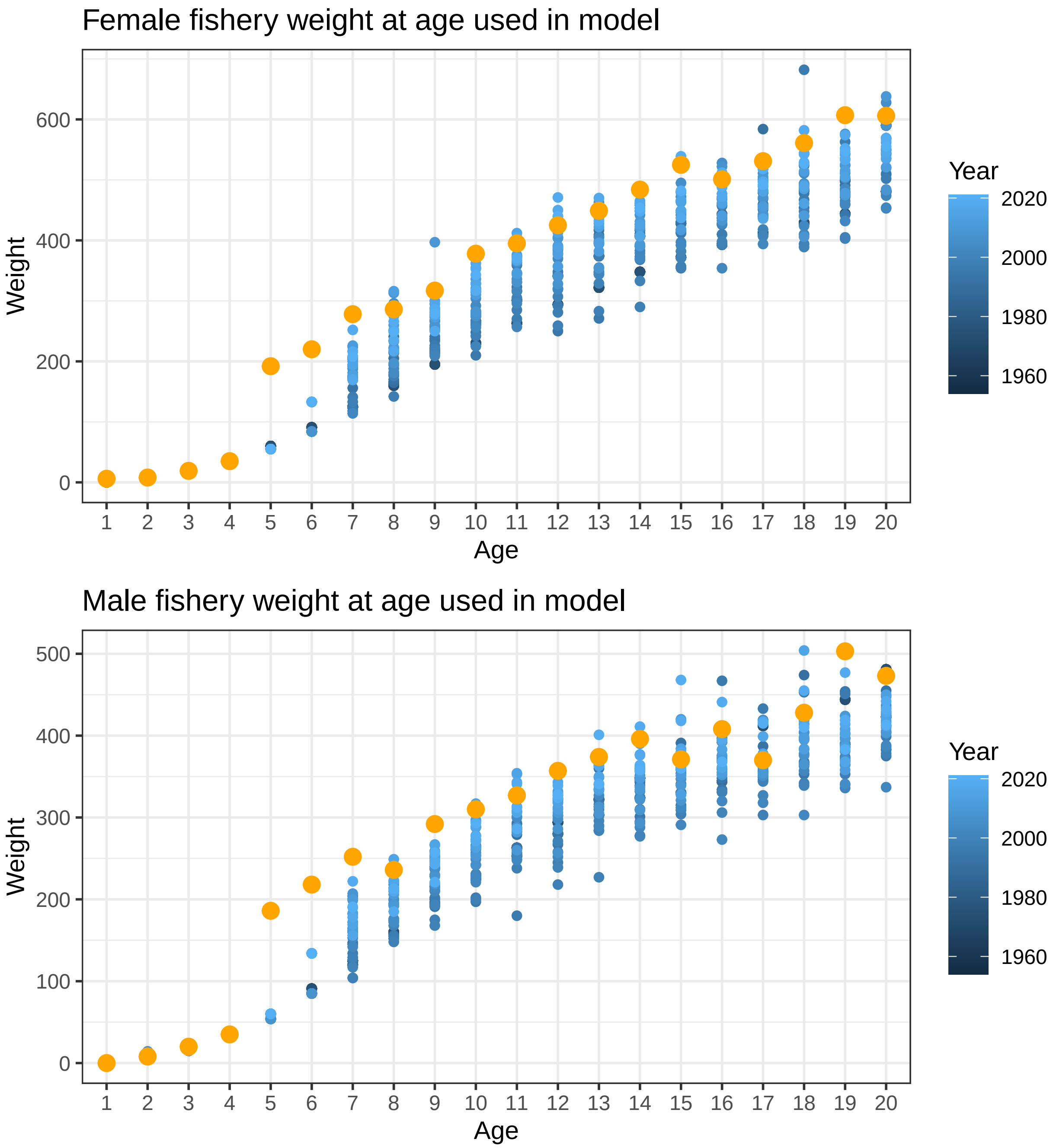


Figure 4.10: Empirical estimates of weight (g) at age for Yellowfin Sole females and males, based on fishery data 1954-2021, and used in this year's Model 18.2. Yellow dots indicate estimates for 2021, which are based on 2020, the most recent set of aged data.

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

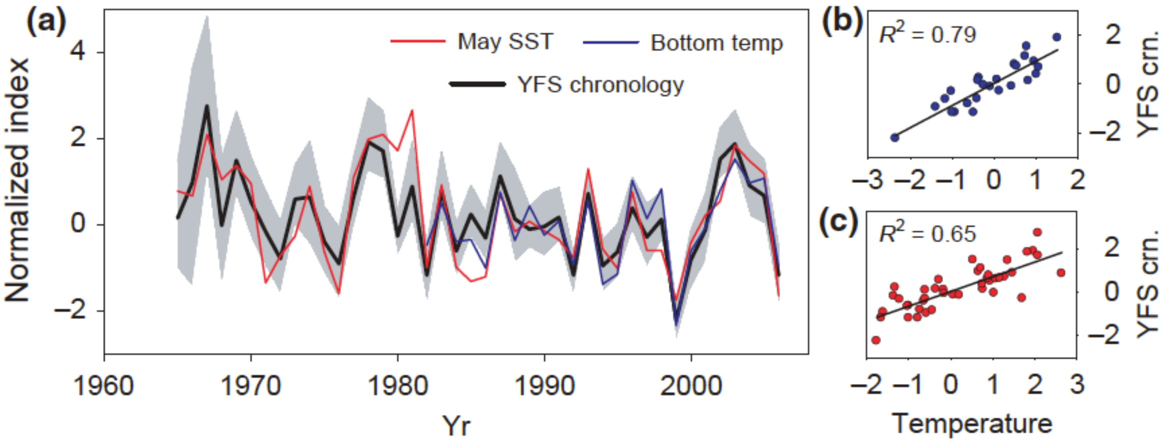


Figure 4.12: Master chronology for Yellowfin Sole and time series of mean summer bottom temperature and May sea surface temperature for the southeastern Bering Sea (Panel A). All data were normalized to a mean of 0 and standard deviation of 1. Correlations of chronologies with bottom temperature and 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.

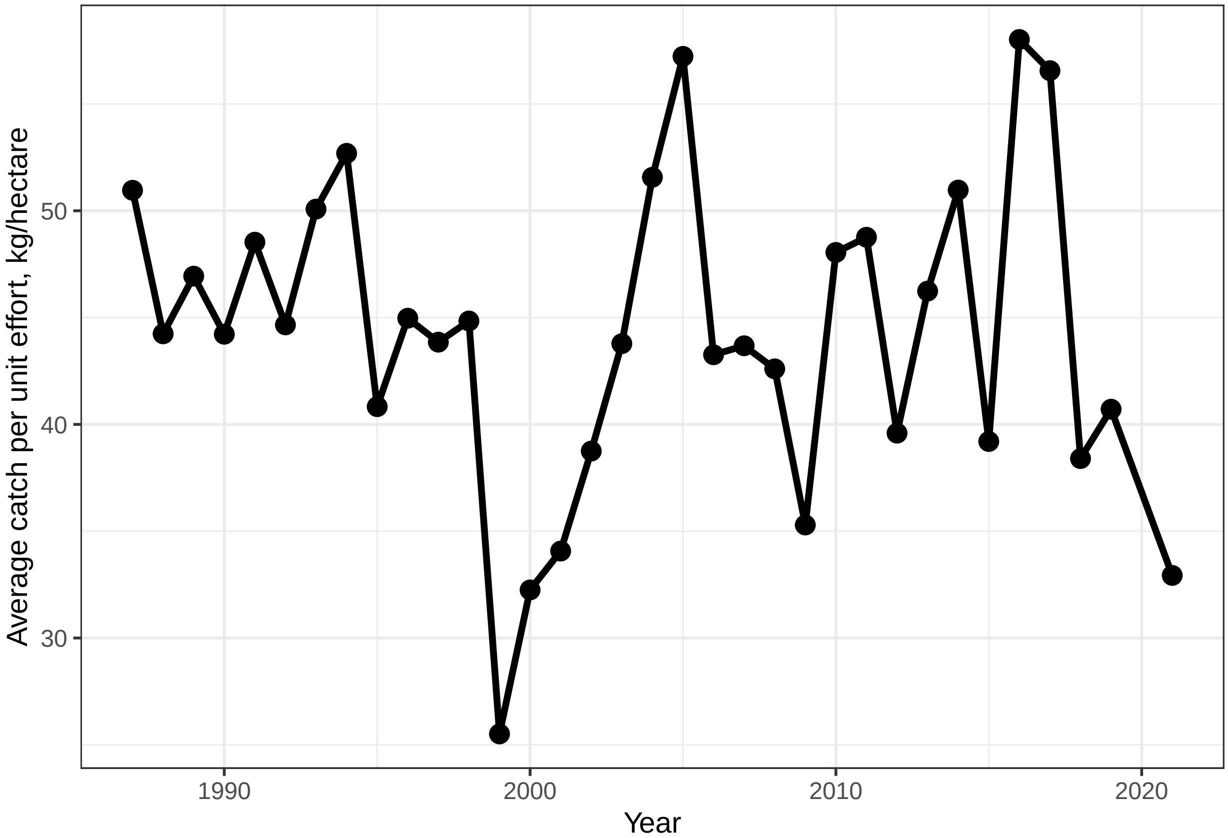


Figure 4.14: Average catch per unit effort on NMFS eastern Bering Sea surveys, 1982-2021, in kg/hectare.

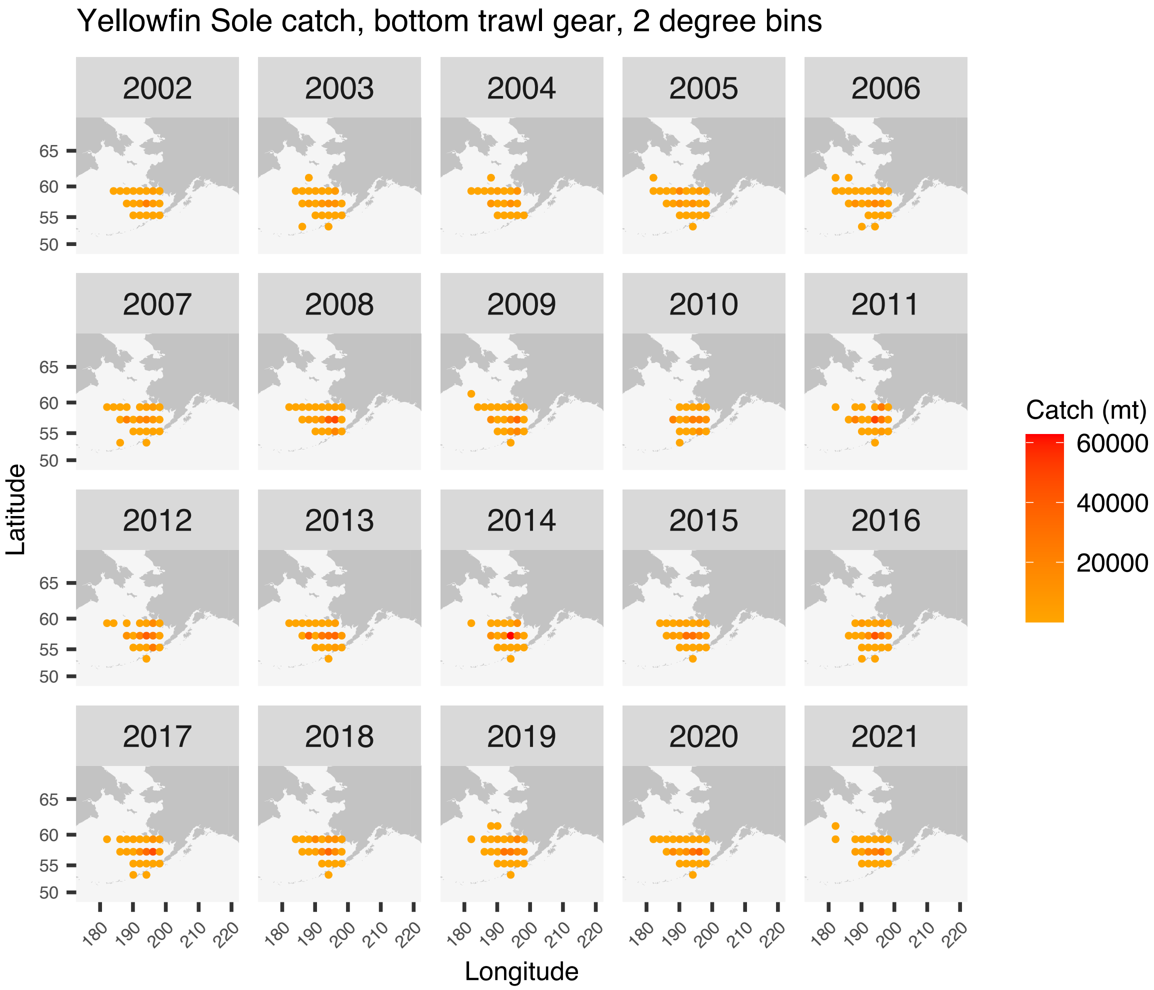


Figure 4.15: Catch of Yellowfin Sole by trawl gear in the BSAI, 2002-2021, by year, reported by observers. Gear types include pelagic and non-pelagic trawl. Colored circles represent catch of Yellowfin Sole, with darker shades of red representing higher catch.

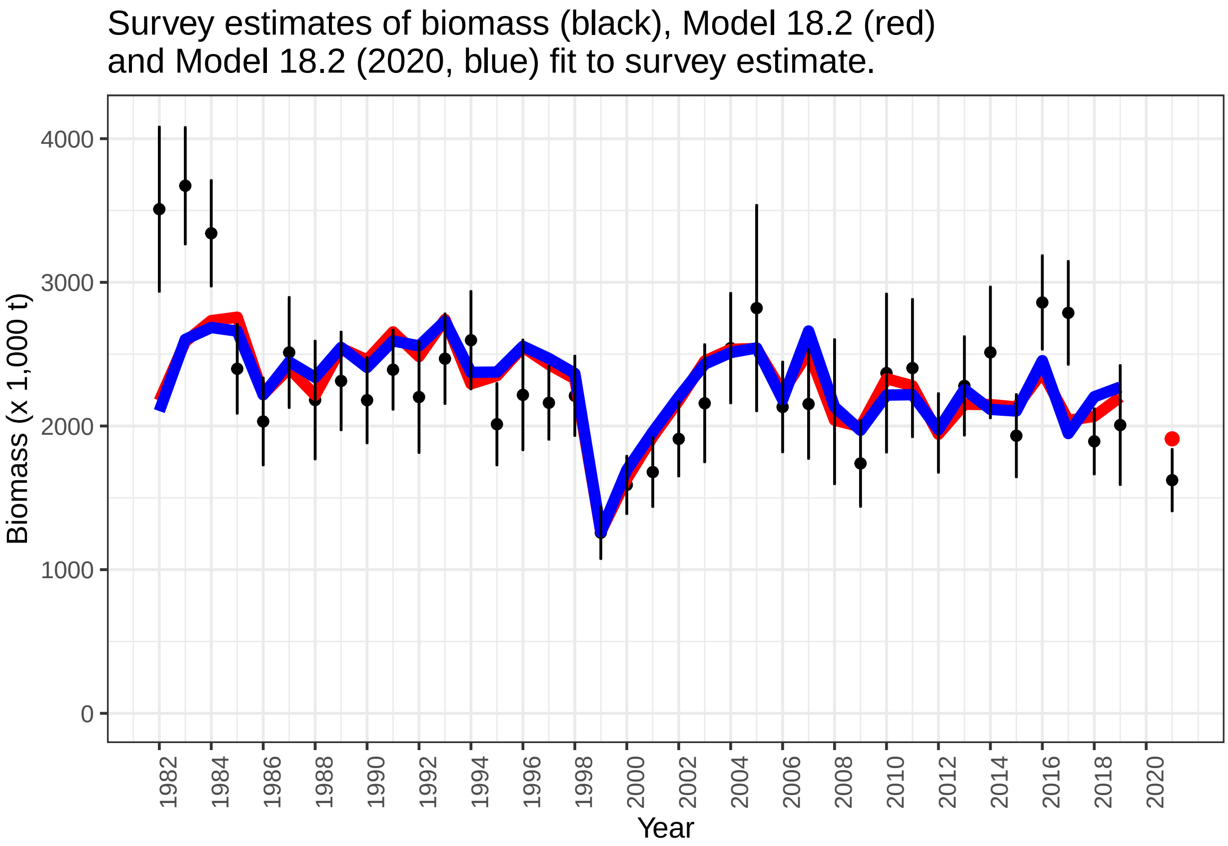


Figure 4.16: Annual eastern Bering Sea bottom trawl survey biomass point estimates and 95% confidence intervals for Yellowfin Sole, 1982-2021, with Model 18.2 fit to the data (red line), Model 18.2 (2000) fit to data (blue line).

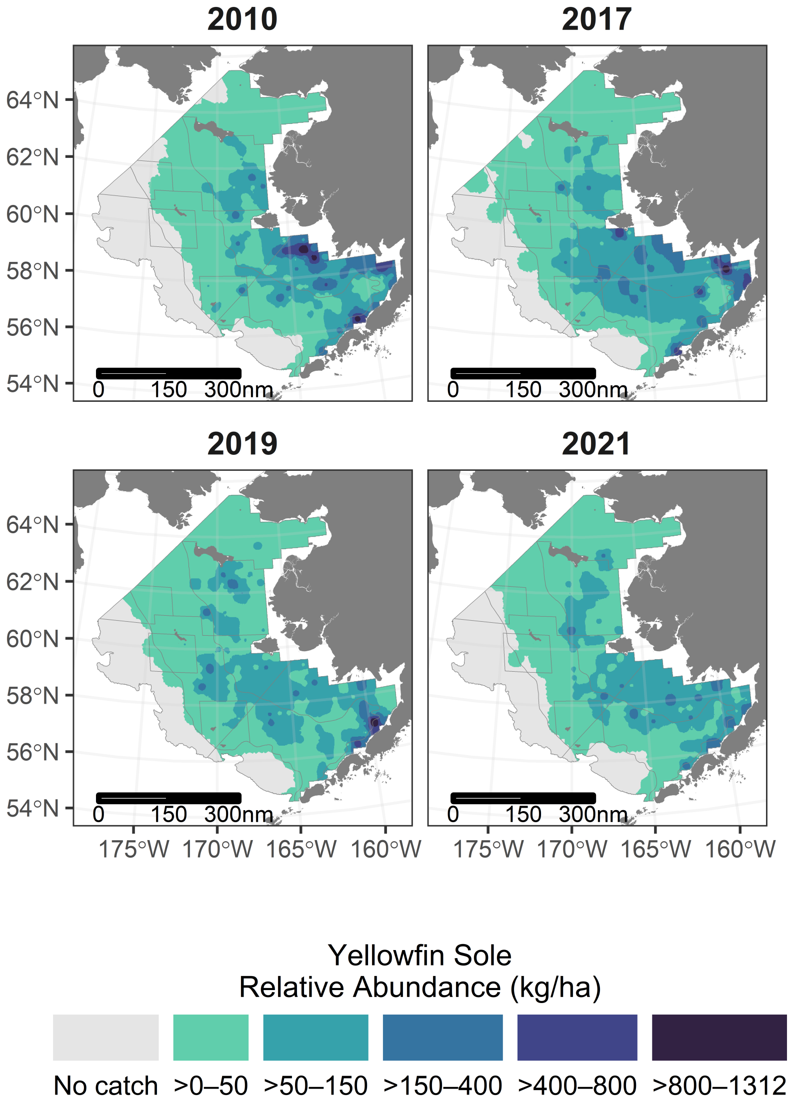


Figure 4.17: Distribution of Yellowfin Sole in the eastern and northern Bering sea based on surveys conducted in 2010, 2017, 2019, and 2021.

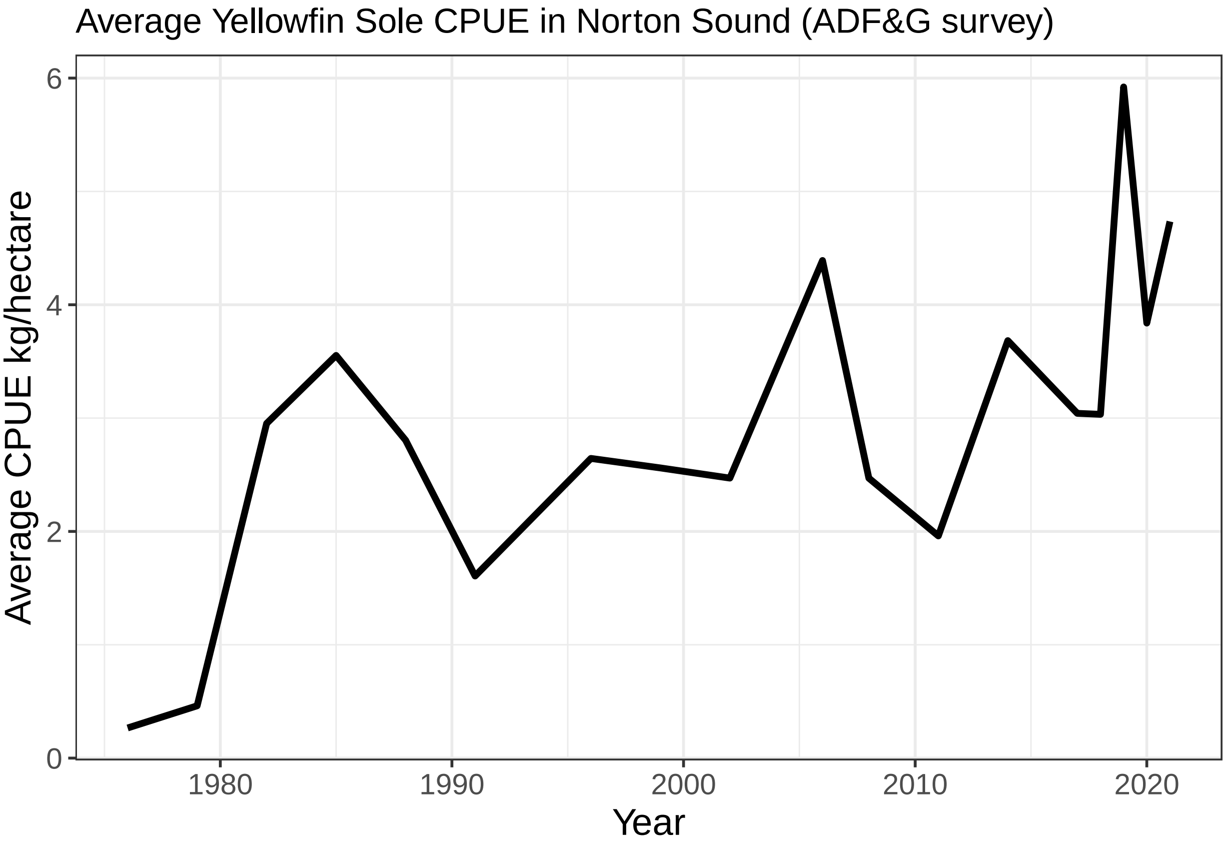


Figure 4.18: Average catch per unit effort (CPUE) of Yellowfin Sole in Norton Sound, based on ADF&G survey time series, 1976 - 2021.

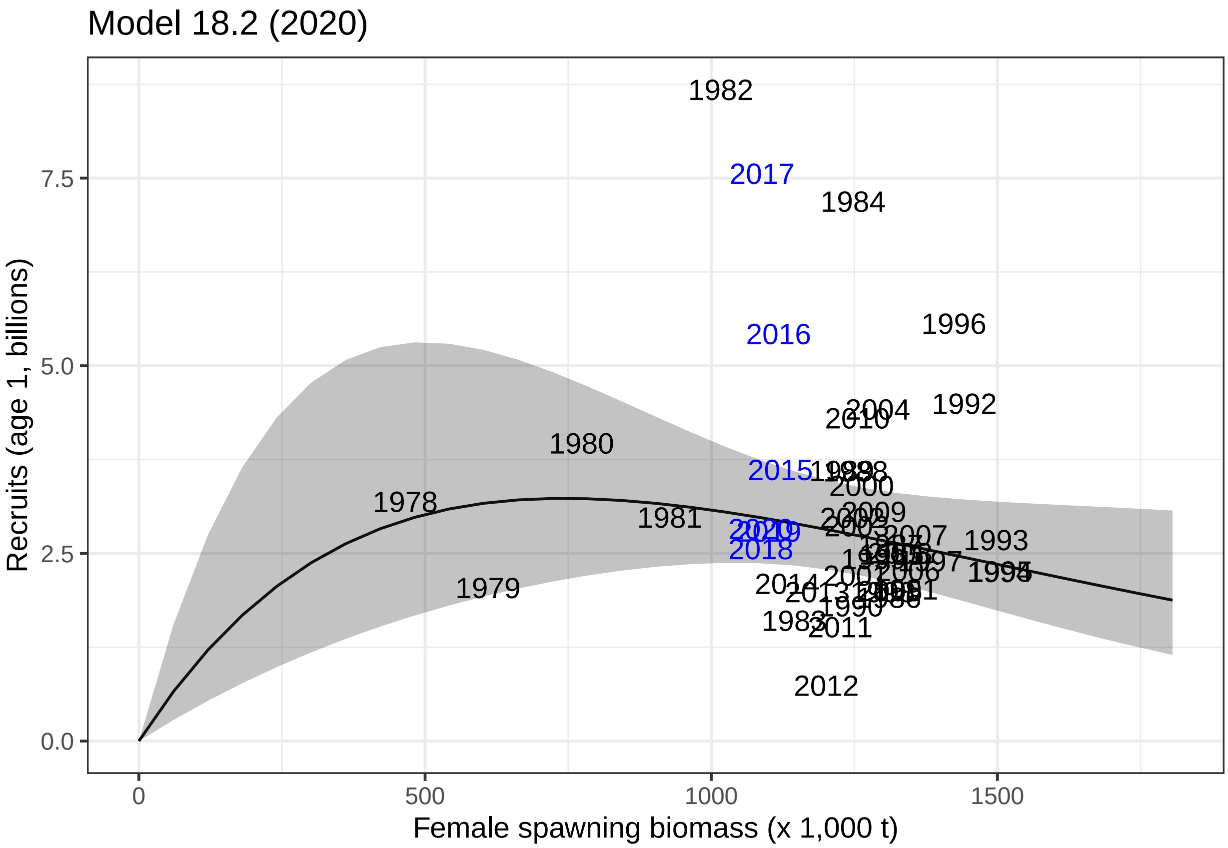


Figure 4.19: Ricker stock recruitment curve for Model 18.2 (2020) with 95% confidence intervals (shaded region) fit to female spawning biomass and recruitment data from 1978-2014. Years in black indicate data used to fit the model, years in blue were not used to fit the model.

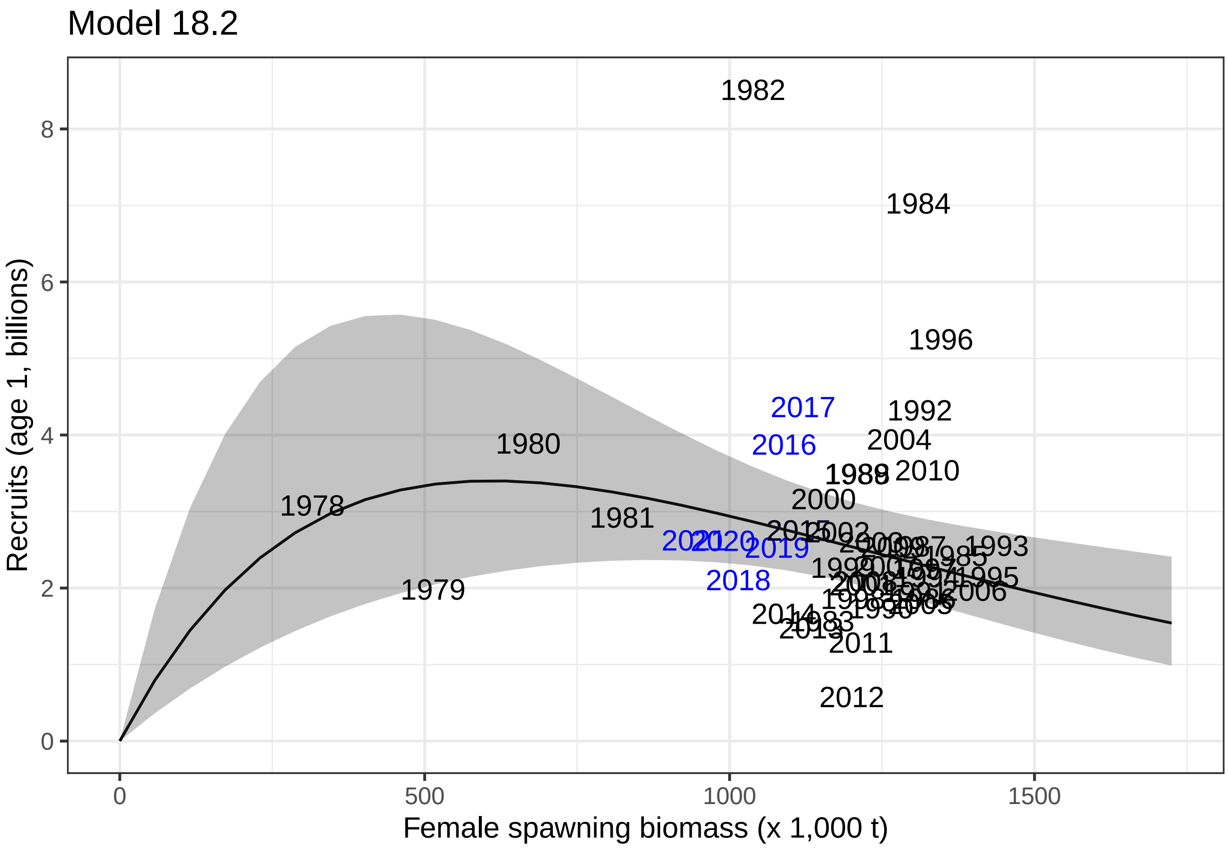
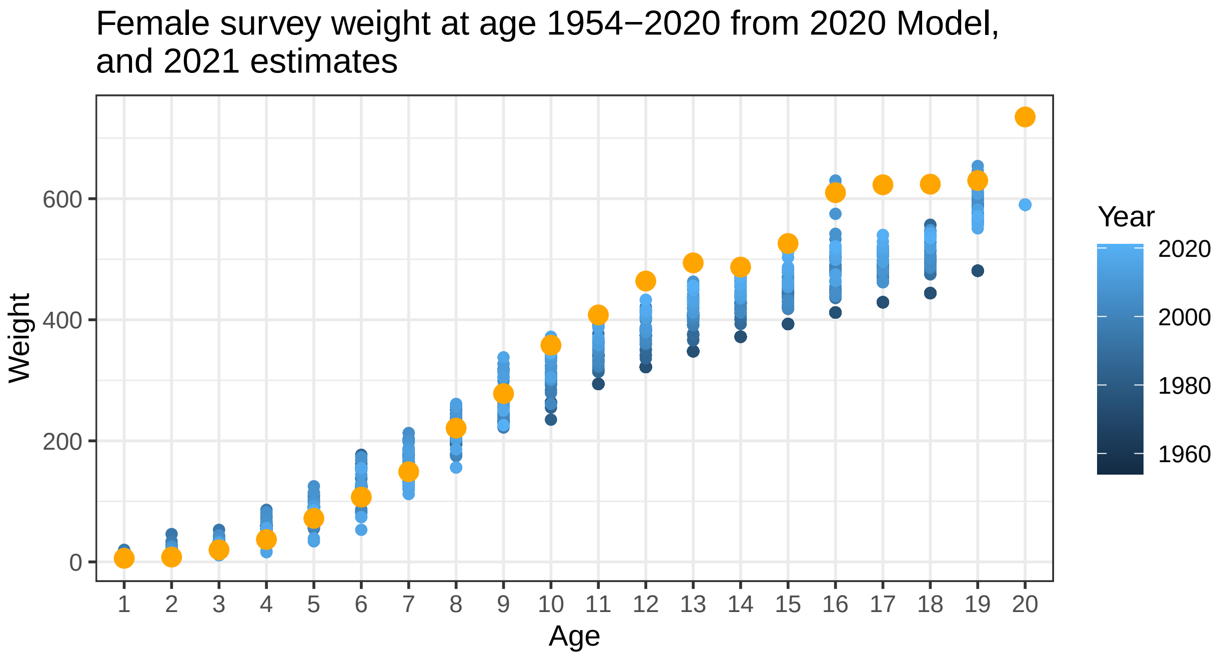


Figure 4.20: Ricker stock recruitment curve for Model 18.2 with 95% confidence intervals (shaded region) fit to female spawning biomass and recruitment data from 1978-2014. Years in black indicate data used to fit the model, years in blue were not used to fit the model.


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

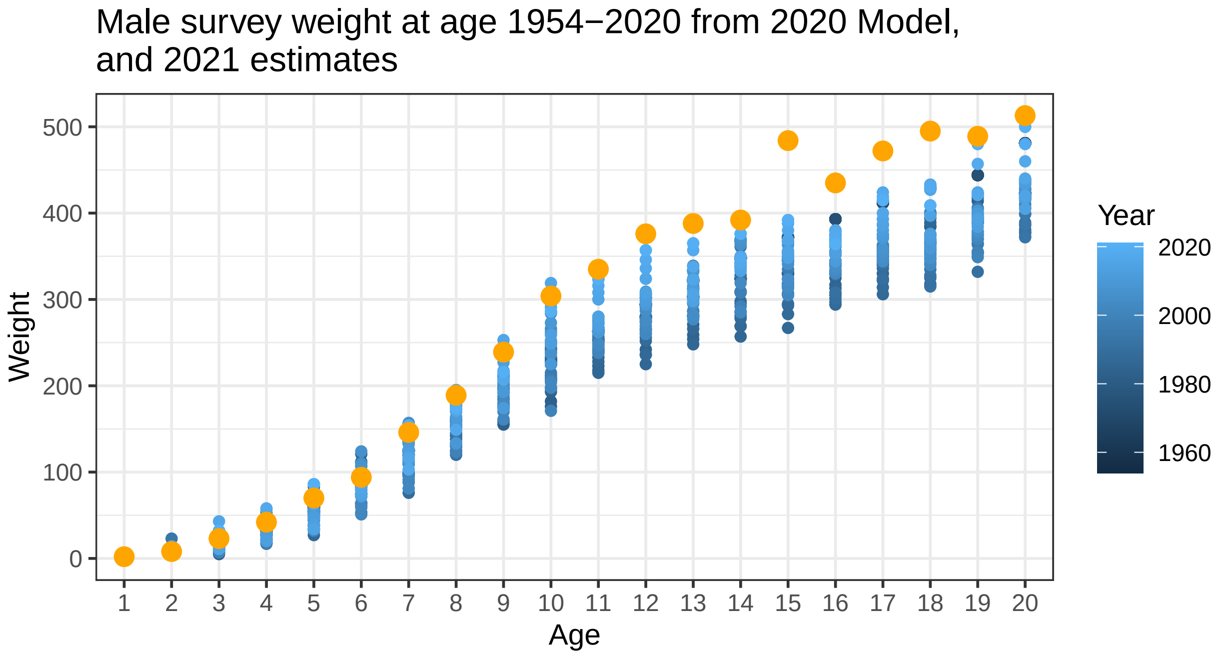
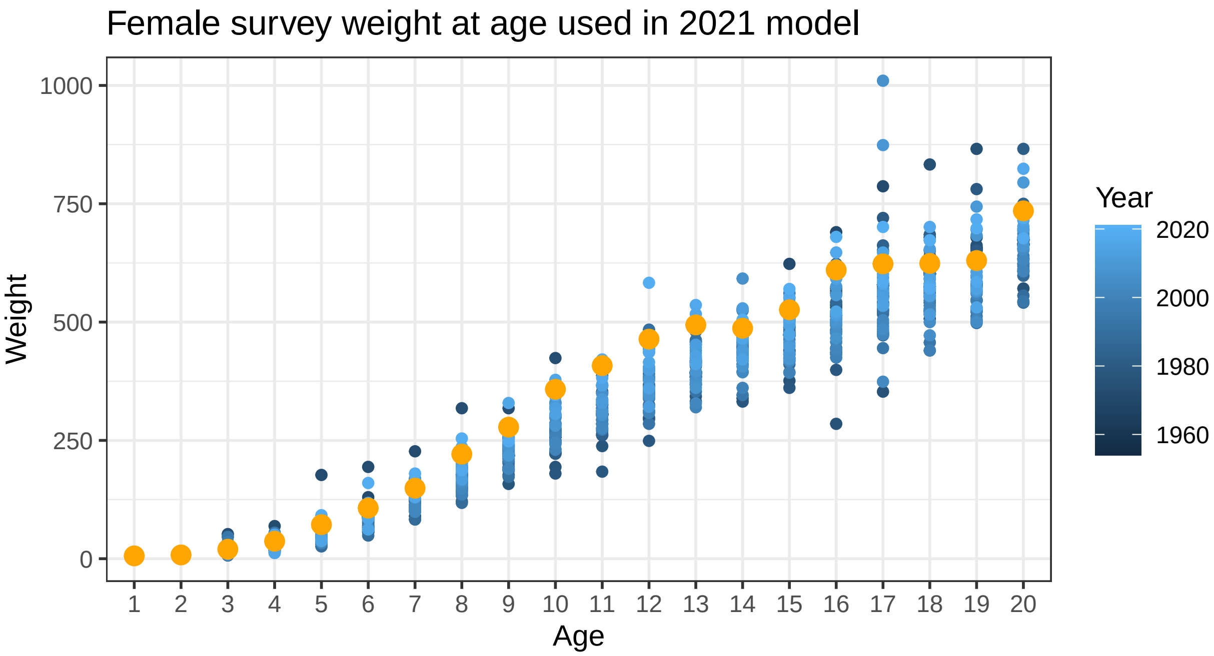

Male survey weight at age 1954−2020 from 2020 Model, and 2021 estimates

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.



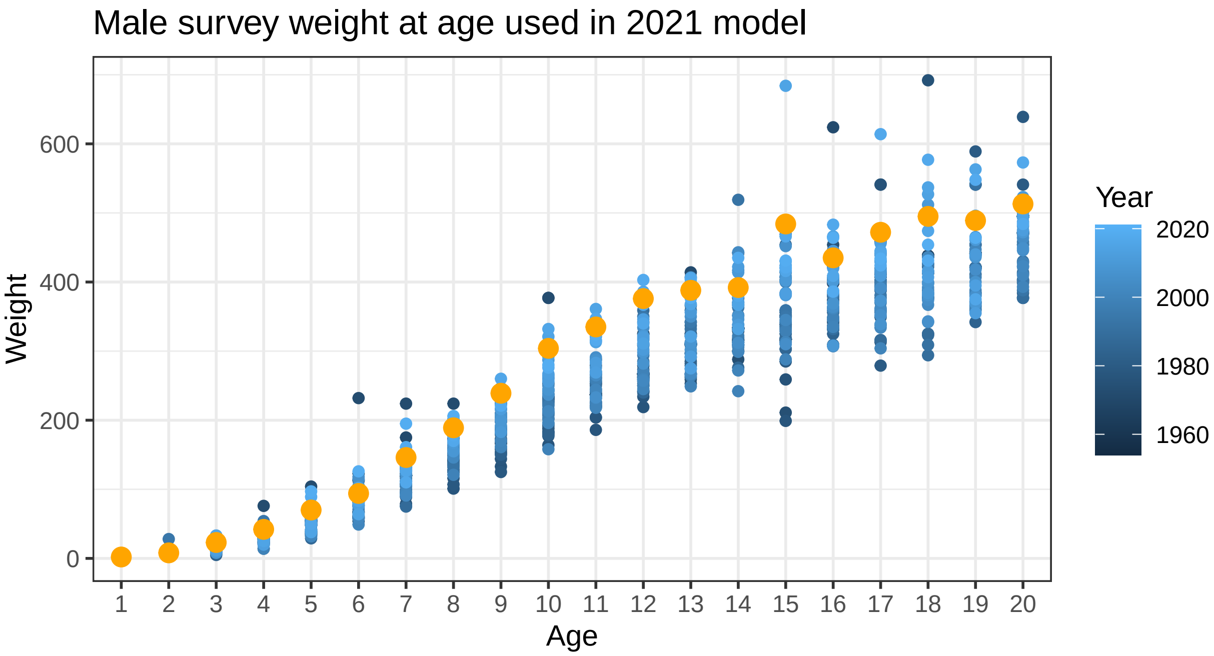


Figure 4.22: Mean weight at age (g) for Yellowfin Sole females and males from the Eastern Bering Sea survey, 1954-2021 used in Model 18.2. Estimates for 2021 are highlighted in yellow.

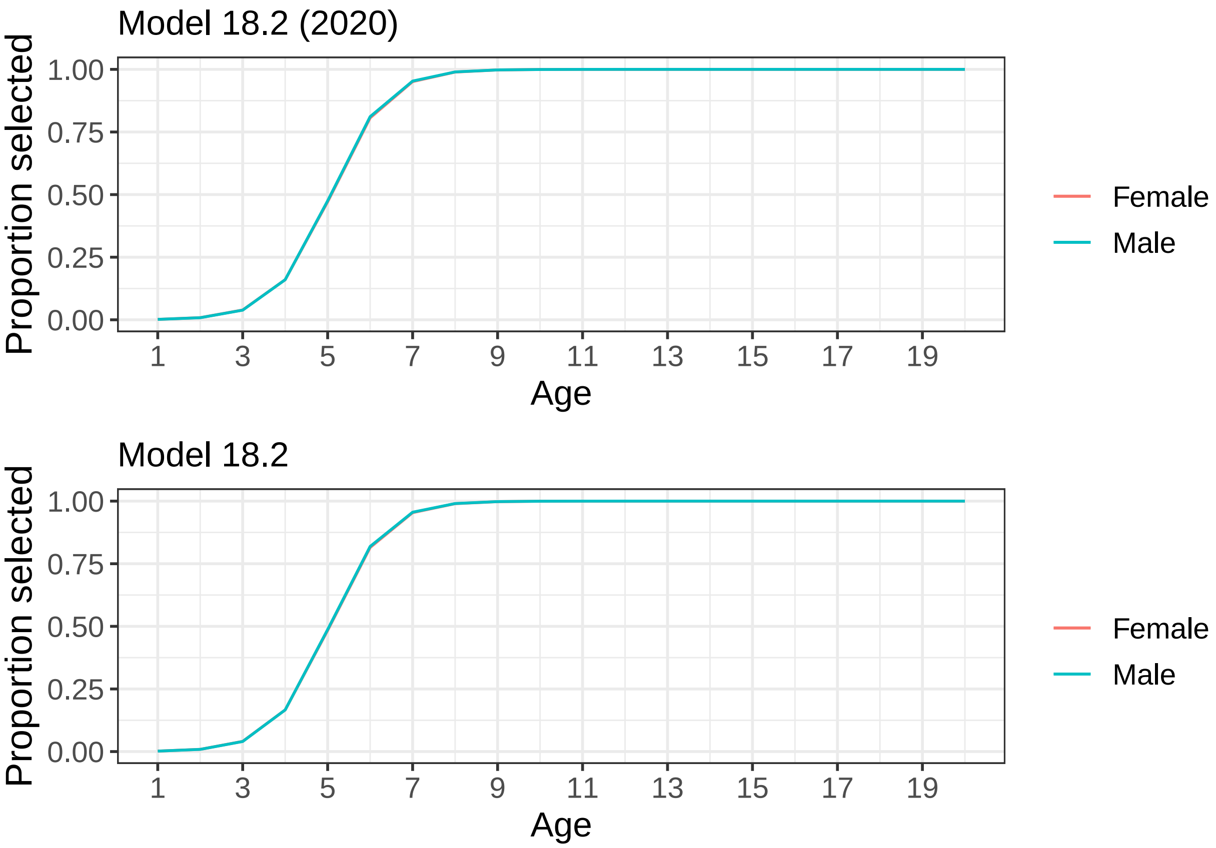


Figure 4.23: Estimate of survey selectivity for males and females, Model 18.2 (2020 assessment) upper panel, Model 18.2 (current assessment) lower panel.

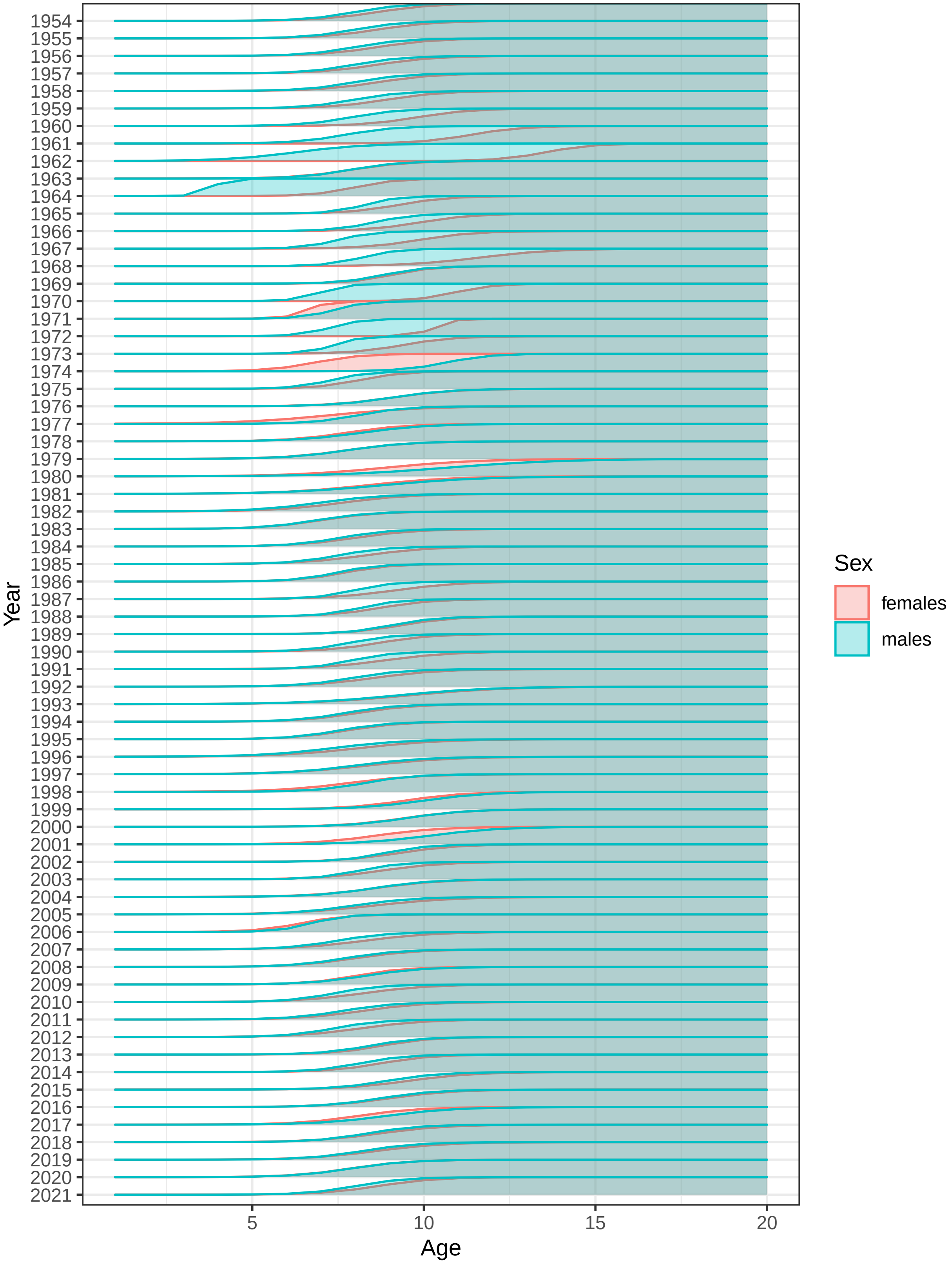


Figure 4.24: Estimate of fishery selectivity for males and females, 1954-2021, Model 18.2.

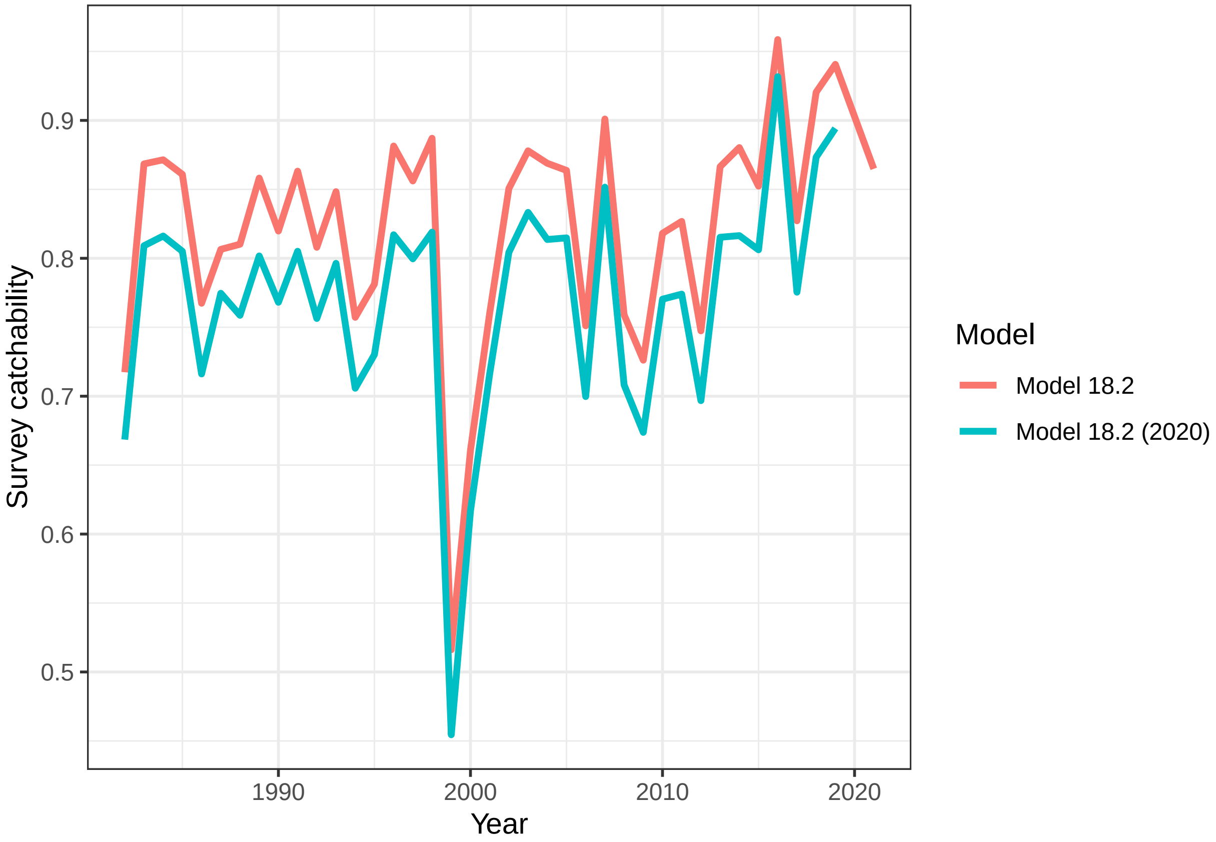


Figure 4.25: Survey catchability for Model 18.2 (2020) and 18.2 (2021), 1982-2020.

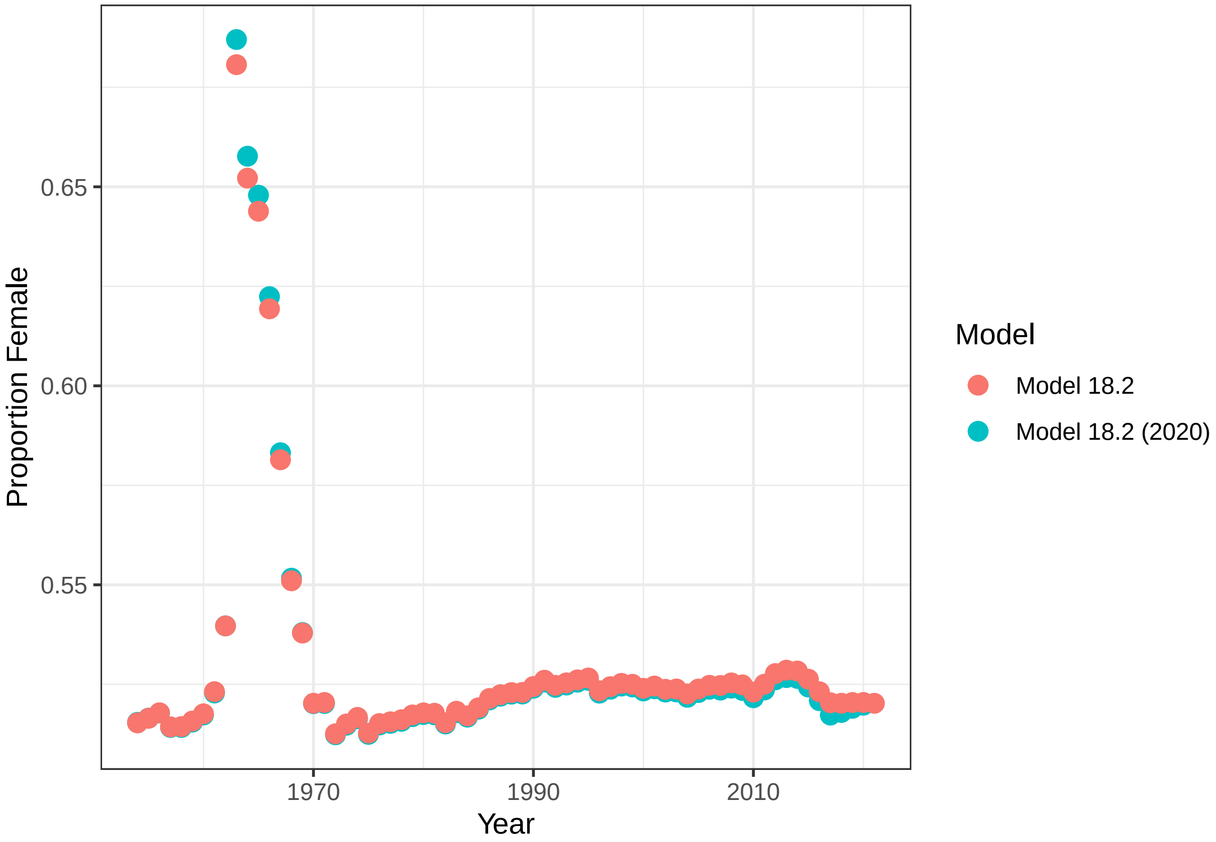


Figure 4.26: Model estimates of the proportion of female Yellowfin Sole in the population, 1982-2021.

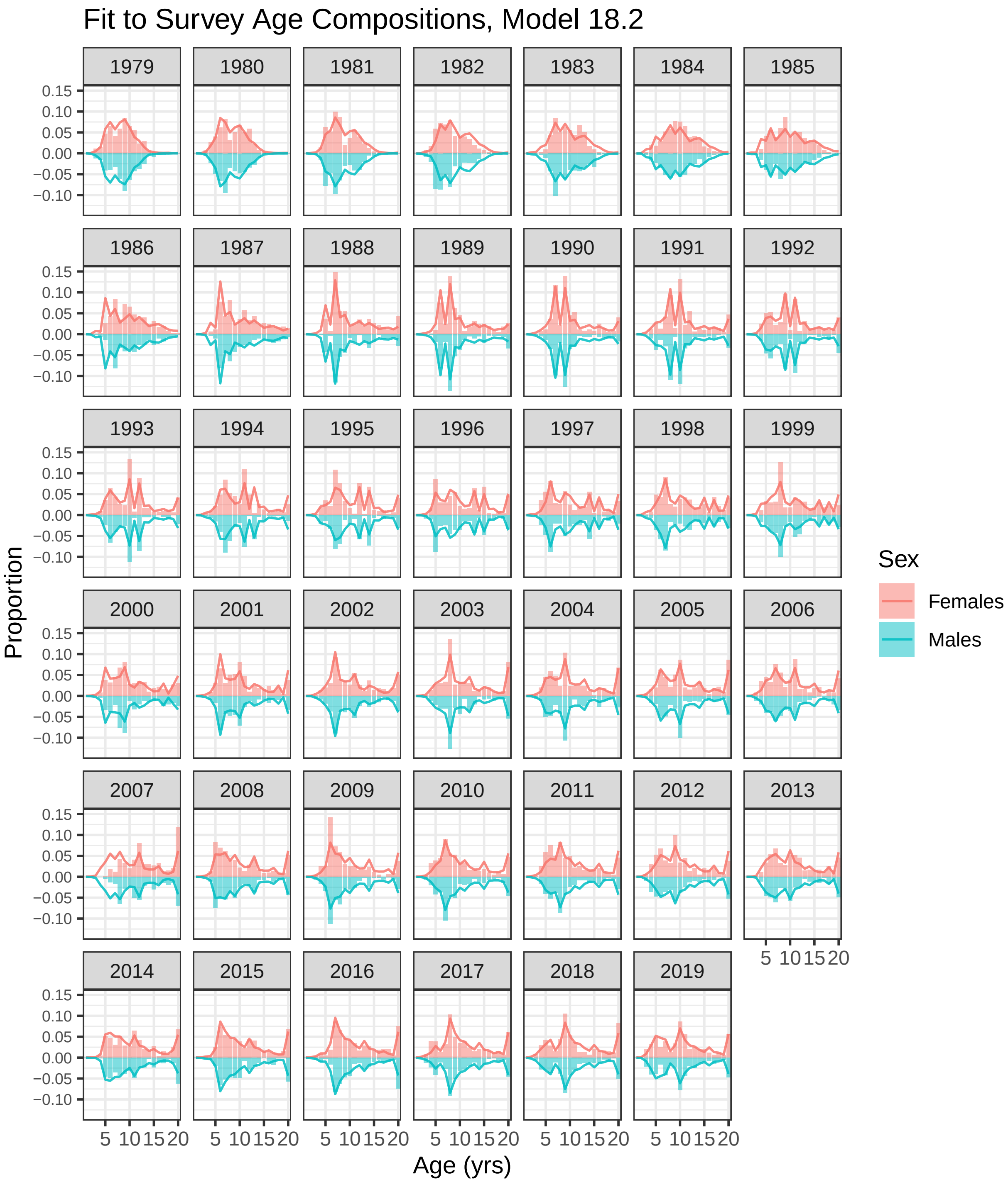


Figure 4.27: Model 18.2 fit to the time-series of survey age composition, by sex, 1979-2020.

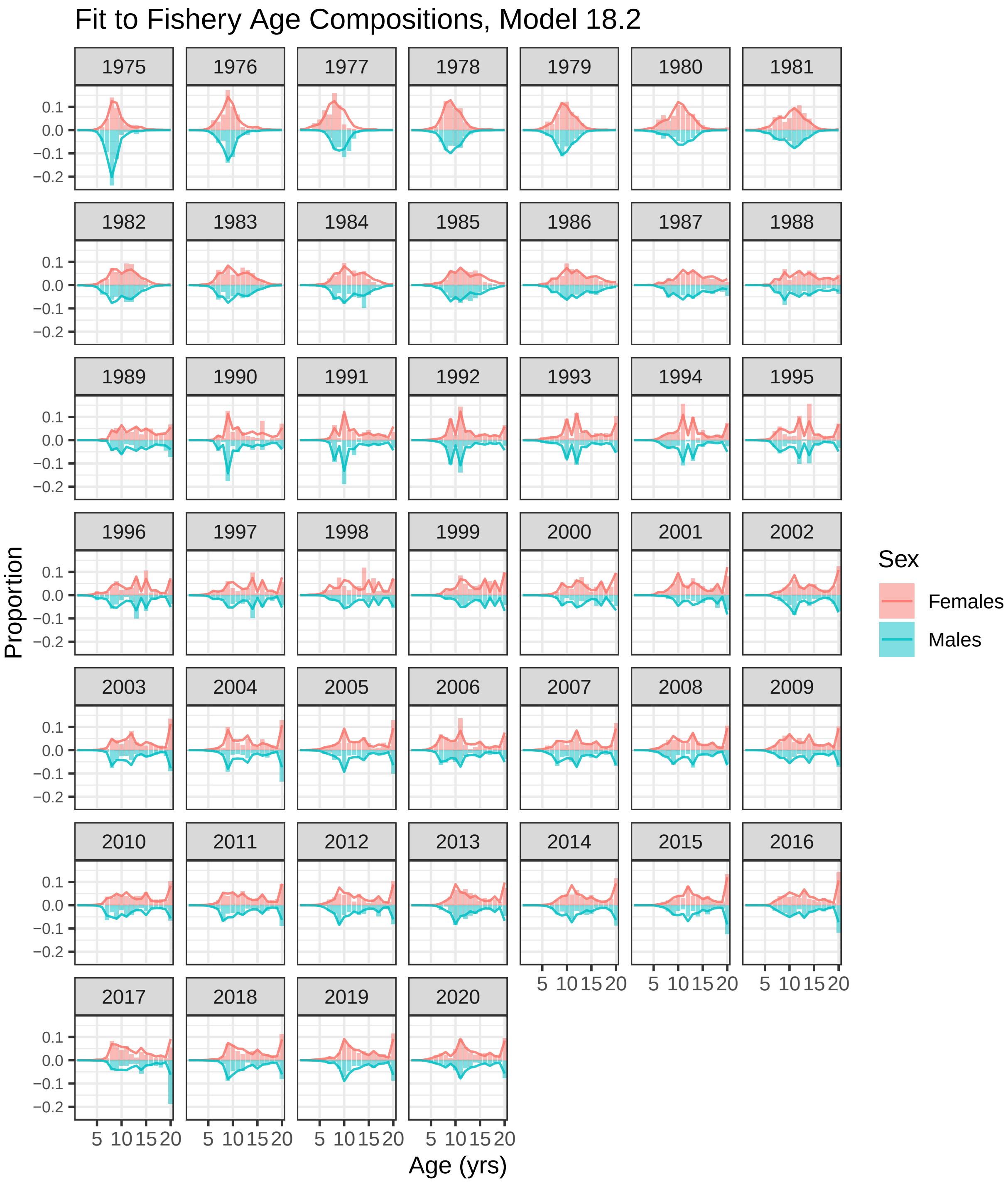
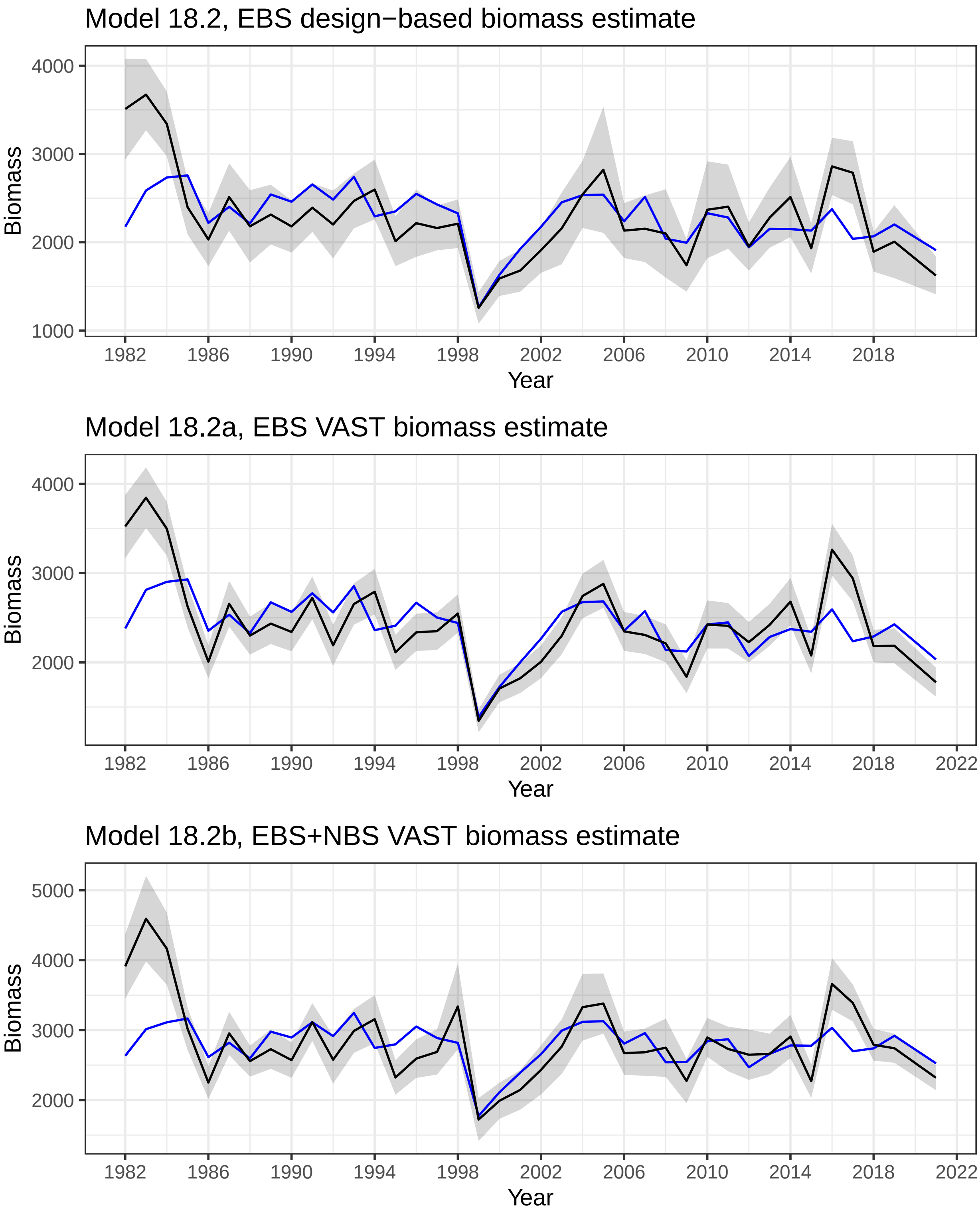


Figure 4.28: Model 18.2 fit to the time-series of fishery age composition, by sex, 1975-2020.



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.

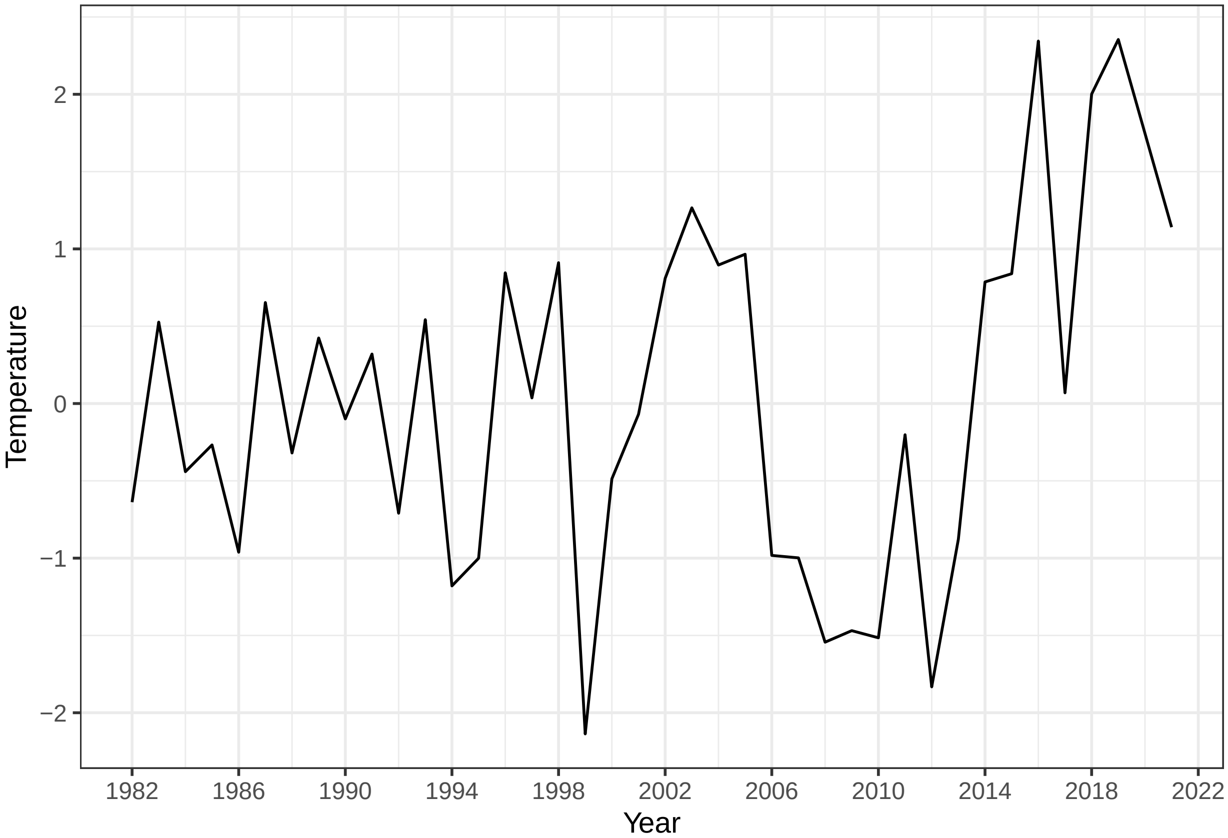


Figure 4.30: Bottom temperature anomalies from the NMFS survey, 1982-2021.

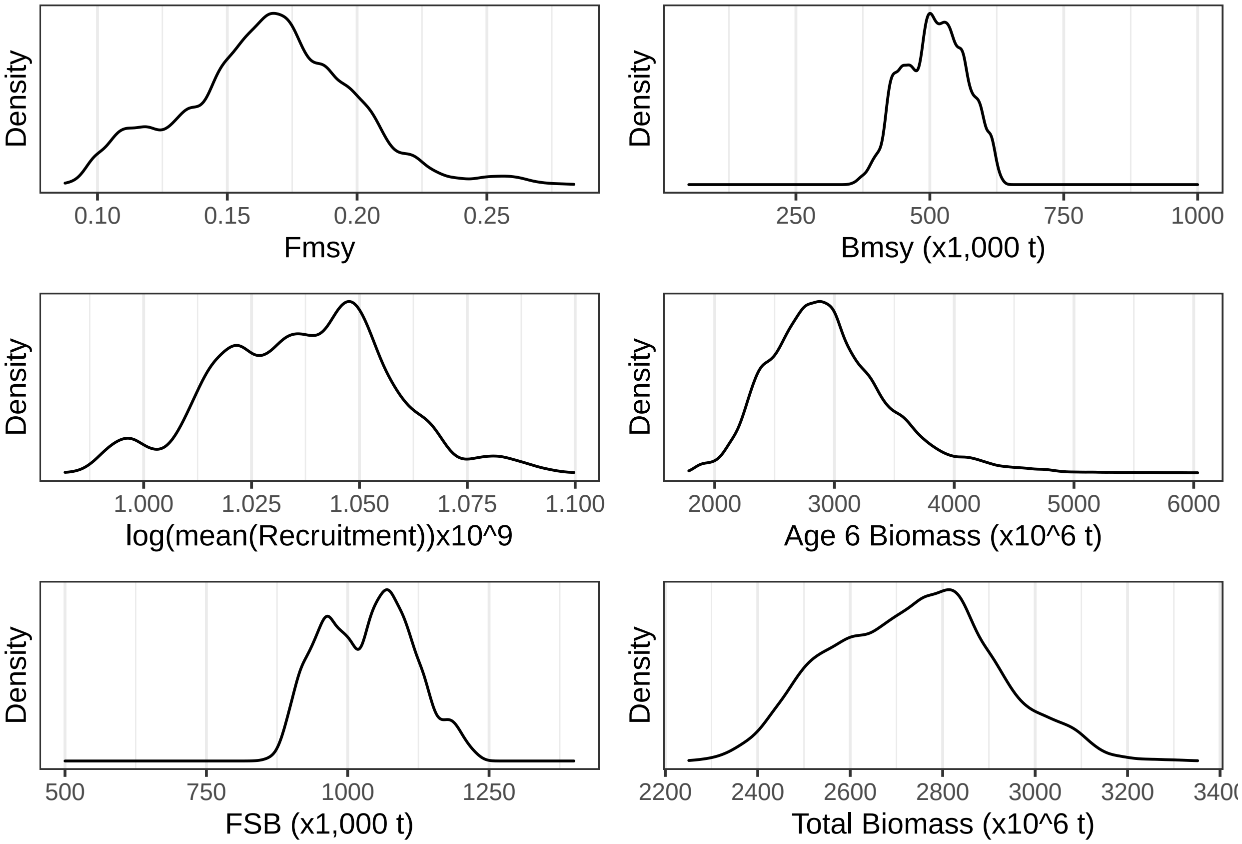


Figure 4.31: MCMC posterior distributions from Model 18.2, for Fmsy, Bmsy, log(mean(Recruitment)), Age 6 biomass, female spawning biomass (FSB) for 2021, and total biomass for 2021.

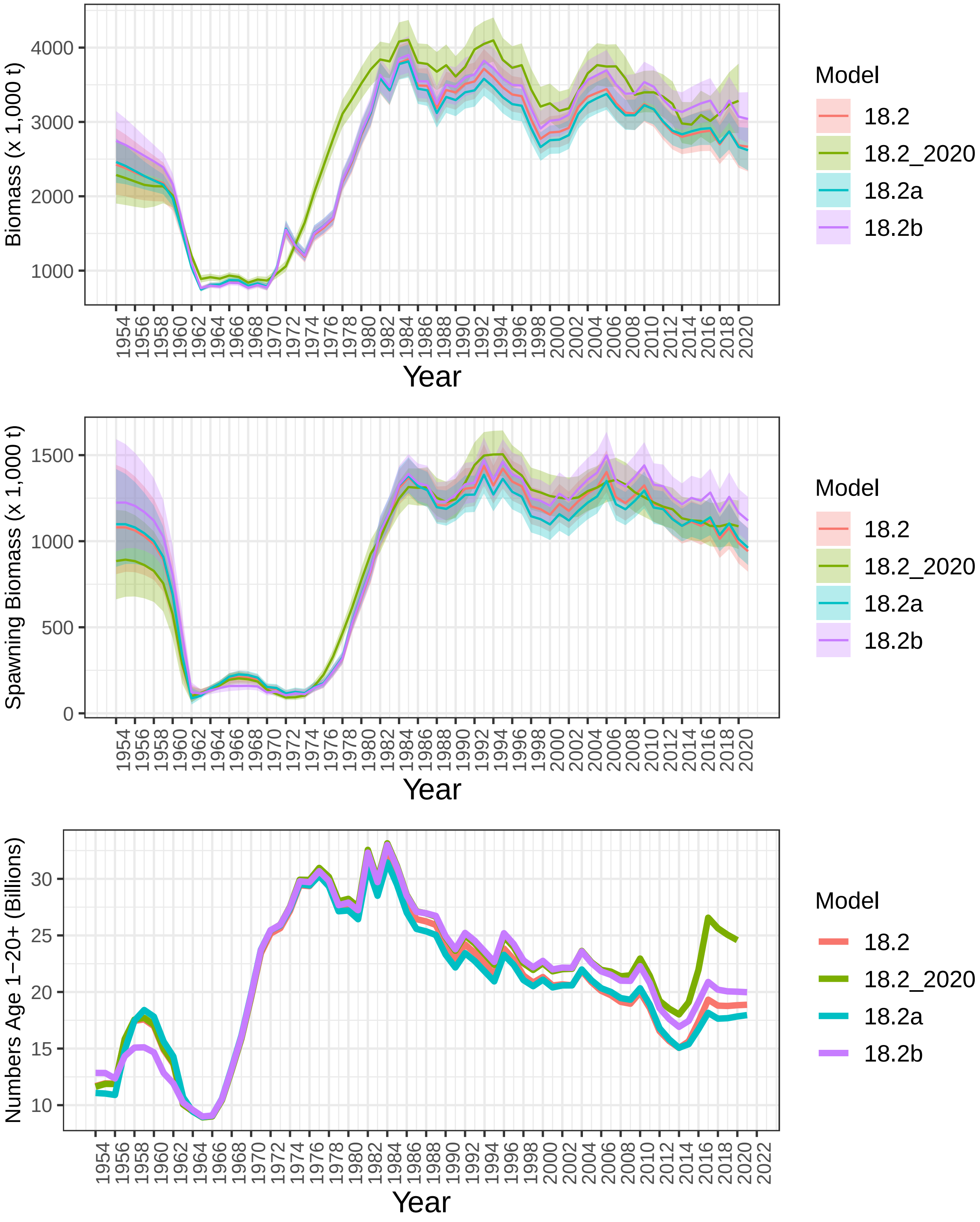


Figure 4.32: Total (age 2+) and spawning stock biomass for Yellowfin Sole, and total numbers, based on Models 18.2 (2020), 18.2, 18.2a, and 18.2b, from 1954-2021.

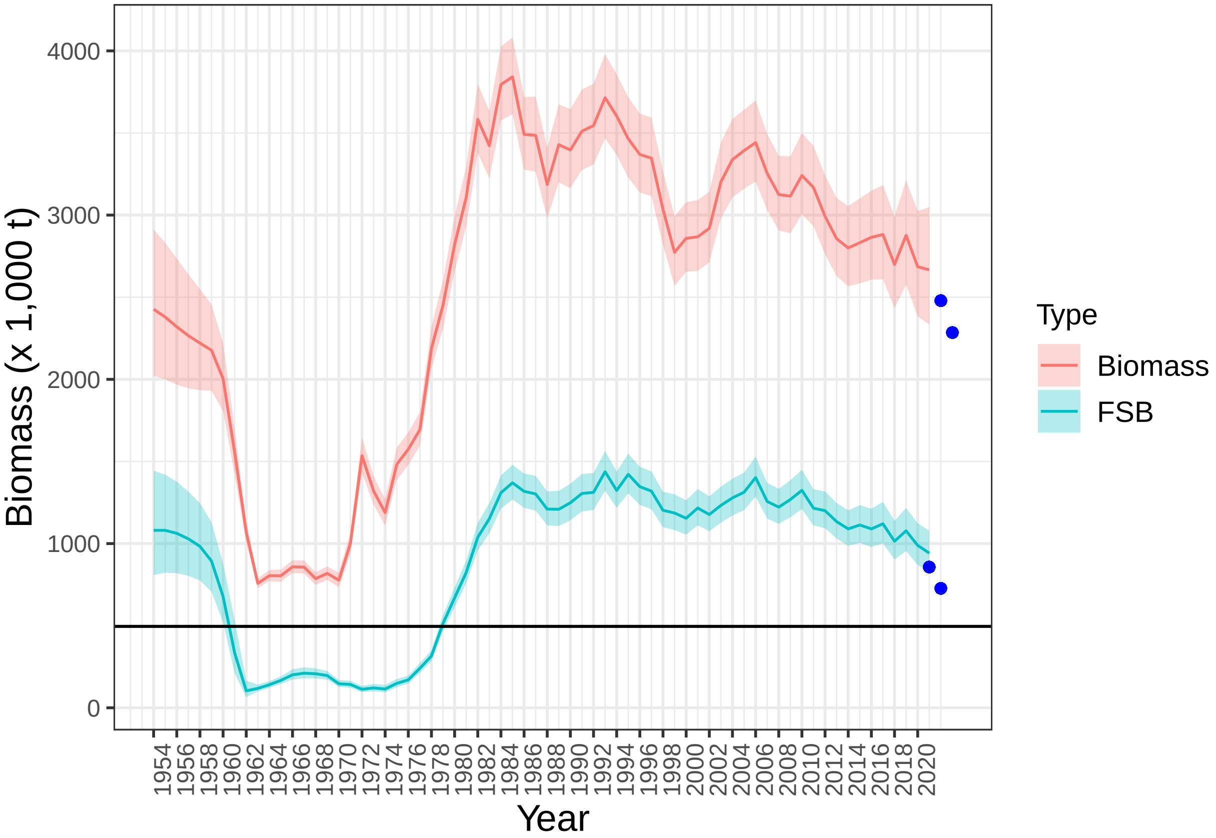


Figure 4.33: Model estimates of total (age 2+) and female spawning biomass with 95% confidence intervals, 1954-2021, Model 18.2. Dots indicate projections for 2022 and 2023.

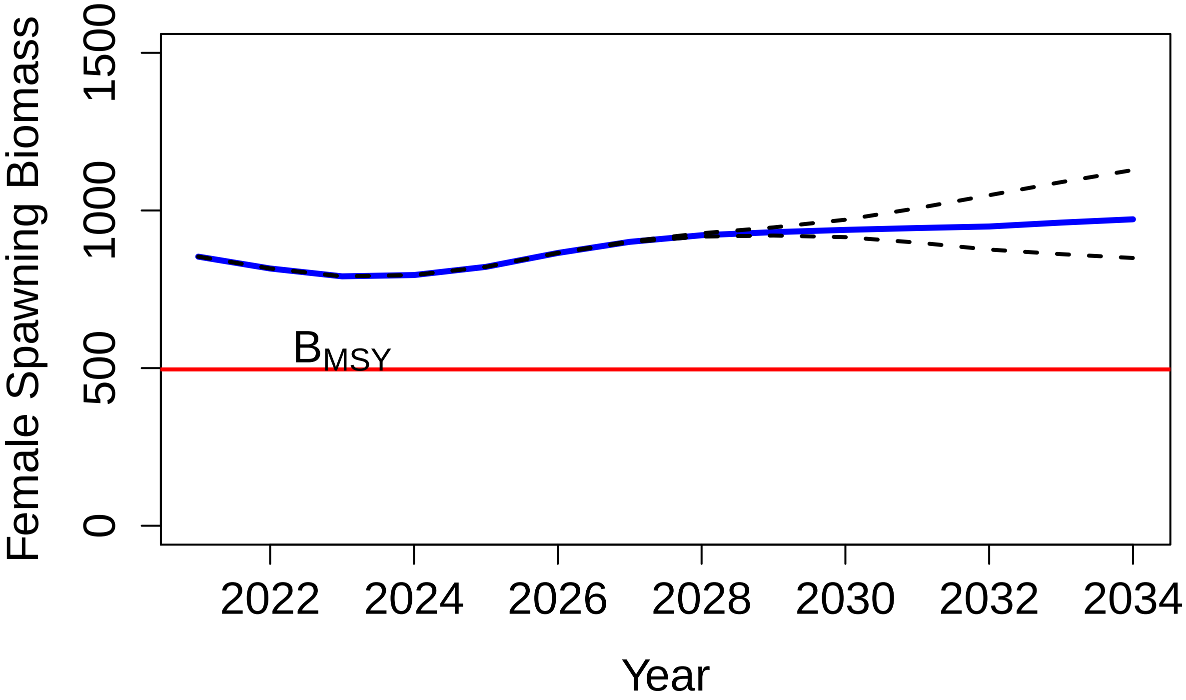


Figure 4.34: Projected female spawning biomass for 2021 to 2034 (blue line), with 5% and 95% confidence intervals, and fishing at the 5-year (2016-2020) average fishing mortality rate, F= 0.0769 , Model 18.2.

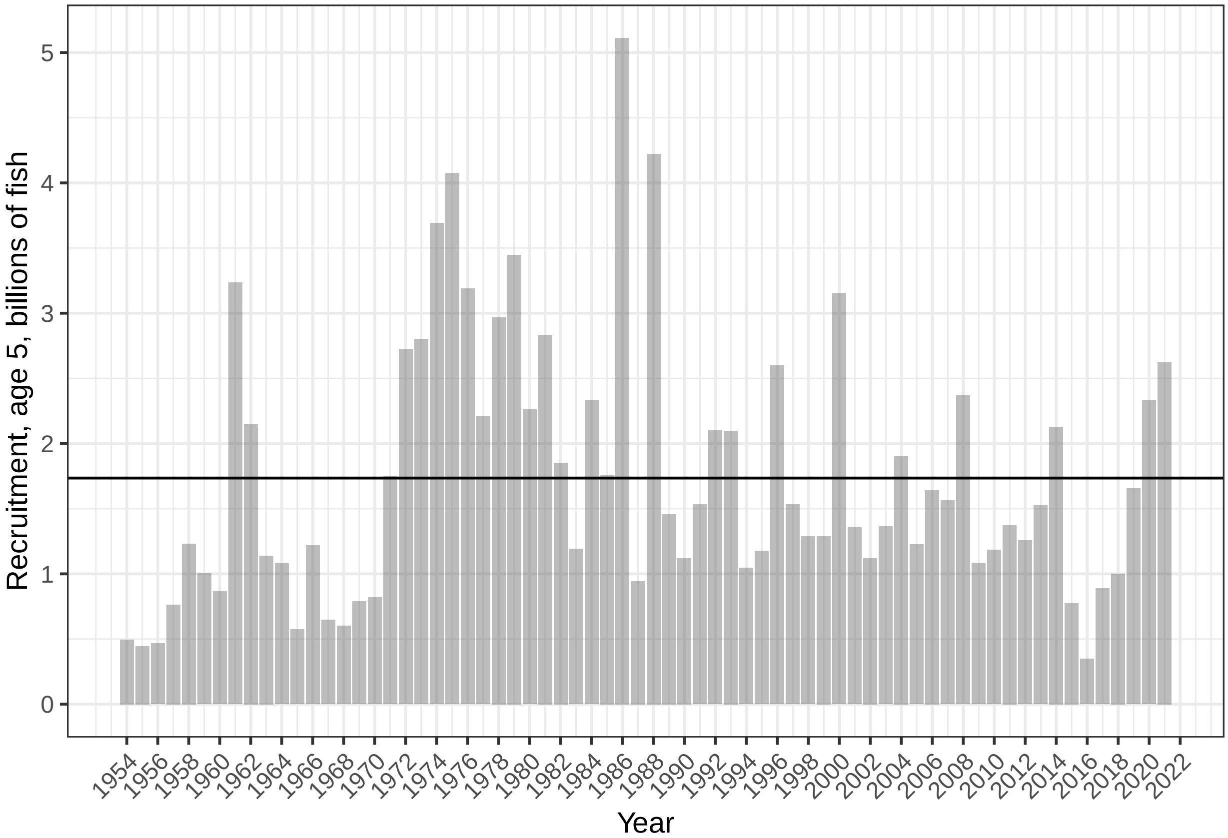


Figure 4.35: Year-class strength of age 5 Yellowfin Sole estimated by the stock assessment model. The horizontal line represents the average of the estimates from recruitment, 1954-2016, 1.78 billion, Model 18.2.

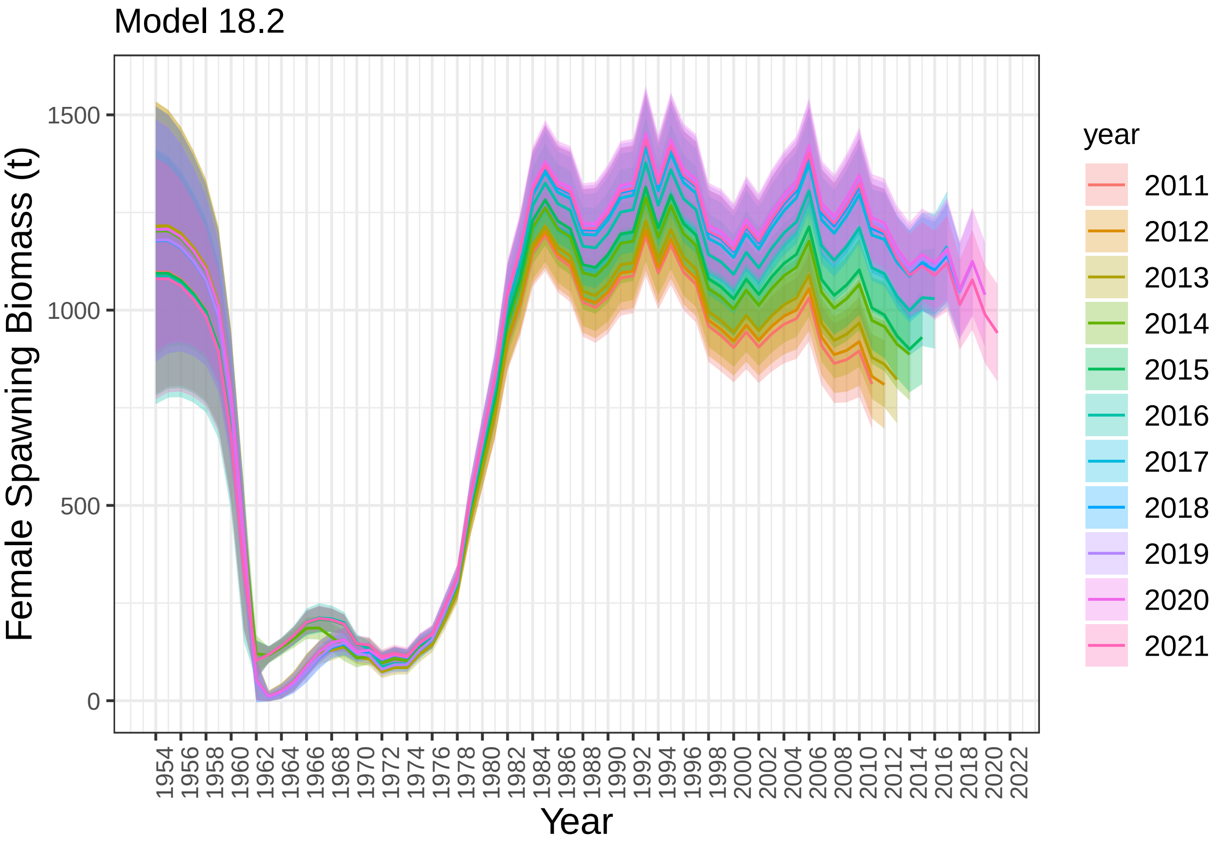


Figure 4.36: Retrospective plot of female spawning biomass for Model 18.2 (current year).

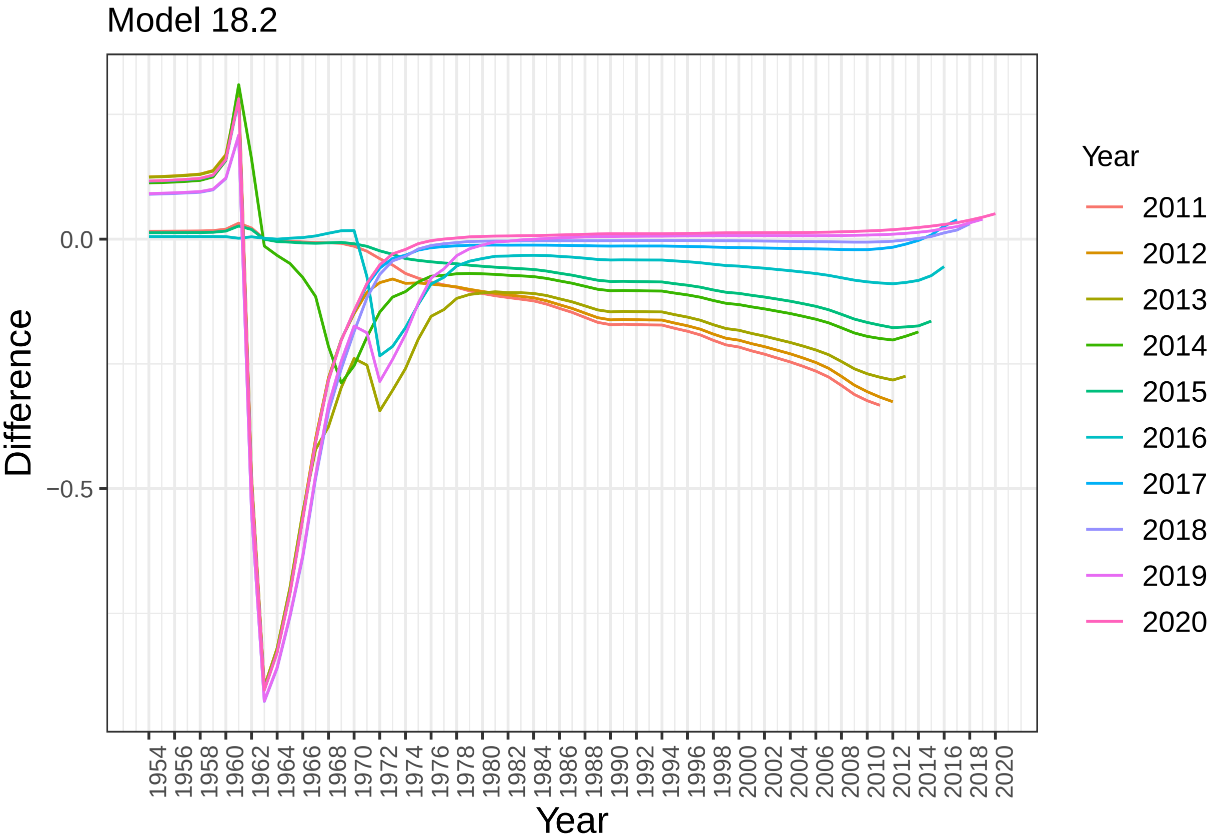


Figure 4.37: Relative differences spawning biomass between the 2021 model and the retrospective model run for years 2020 through 2011, Model 18.2.

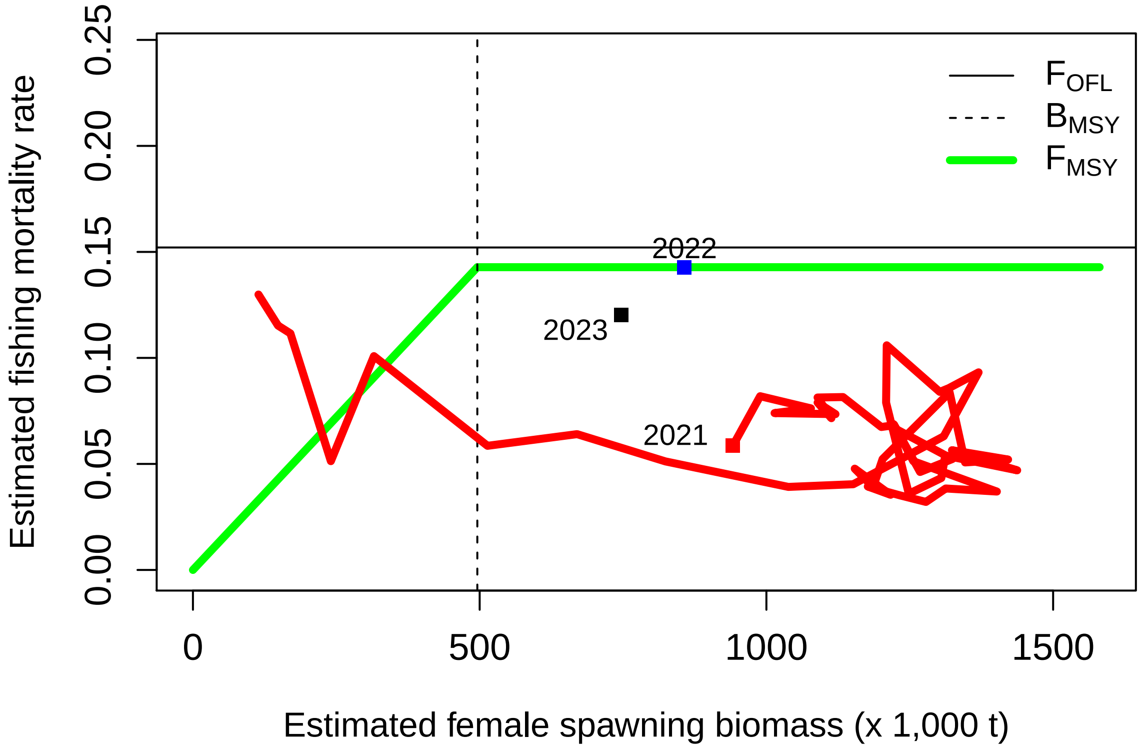


Figure 4.38: Fishing mortality rate and female spawning biomass from 1975 to 2021 compared to the F35% and F40% control rules, based on Model 18.2. Vertical line is B35%. Squares indicate estimates for 2021, 2022, and 2023.

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 begun 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.