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. Despite no new survey data, several models are presented in this document that incorporate new data since the last full assessment in 2019.

Changes in the data

1. The 2019 fishery age composition was added.
2. The 2019 survey age composition was added.
3. The estimate of the total catch made through the end of 2019 was updated as reported by the NMFS Alaska Regional office. The catch through the end of 2020 was estimated based on available data. Catch of 139,283 t was assumed for the 2021 and 2022 projections.
4. Due to COVID-19, the 2020 NMFS Eastern Bering Sea (EBS) shelf bottom-trawl survey was not conducted. Therefore, there is no survey biomass estimate from 2020.
5. Fishery weight-at-age was calculated based on methodology in the document.

Changes in the assessment methods

Four models are presented in this assessment. Models 18.1 and 18.2 are presented in full, and Model 18.2 is the preferred model. Models 18.3 and 18.4 are presented to promote discussion on the use of VAST biomass estimates and incorporation of the Northern Bering Sea (NBS) survey.

1. Last year's accepted model is referred to as Model 18.1. This model has not changed and uses the same natural mortality for males and females, M=0.12.
2. A second model is presented (Model 18.2) that 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 reviewed by the BSAI Plan Team in September, 2020. Model 18.2 is the authors' preferred model.
3. Model 18.3 is the same as Model 18.2 except it incorporates VAST biomass estimates and standard errors for the Eastern Bering Sea survey region, 1982-2019.
4. Model 18.4 is the same as Model 18.2 except it incorporates VAST biomass estimates and standard errors for the EBS and NBS, 1982-2019.

Summary of Results

The accepted 2019 Model 18.1 included the survey mean bottom temperature across stations < 100m as a covariate on survey catchability, as in previous years, but added survey start date as an additional covariate within the model, based on a recent study by Nichol et al. (2019). Model 18.2 retains these features. Model 18.2 retains female natural mortality fixed at 0.12 while allowing the model to estimate male natural mortality.

In the most recent Eastern Bering Sea (EBS) bottom trawl survey performed in 2019, the Yellowfin Sole biomass in the Eastern Bering Sea was estimated to be 6% higher than in 2018 at 2,006,510 t. Spawning biomass estimated by Model 18.2 remained high at 1.86 * B_{MSY}. Therefore, Yellowfin Sole continues to qualify for management under Tier 1a. The 1978-2014 age-1 recruitments and the corresponding spawning biomass estimates were used to fit the stock recruitment curve and determine the Tier 1 harvest recommendations.

This assessment updates last year's assessment with results and management quantities that are higher than the 2019 assessment. Model 18.2 estimated male natural mortality to be higher than female natural mortality, 0.135, which increased biomass estimates.

Catch as of October 13, 2020 was 128,092 t. Over the past 5 years (2015 - 2019), 93.6% of the catch has taken place by this date. Therefore, the full year's estimate of catch in 2020 was 136,821 t. This is lower than the average catch over the past ten years 139,271 t. Future catch for the next 10 years, 2021 - 2030 was estimated as the mean of the past 10 years catch.

Yellowfin Sole continue to be above B_{MSY} and the annual harvest remains below the ABC level. Management quantities are given in the following table for the 2019 accepted model (Model 18.1) and the 2020 preferred model (Model 18.2). The projected estimate of total biomass for 2021 was higher by 11% from the 2019 assessment of 2,486,700 t, to 2,755,870 t. The model projection of spawning biomass for 2021, assuming catch for 2020 as described above, was 1,040,900 t, 23% higher than the projected 2020 spawning biomass from the 2019 assessment of 847,101 t. The 2021 and 2022 ABCs using F_{ABC} from this assessment model were higher than the 2019 ABC of 278,370 t; 313,477 t and 344,140 t. The 2021 and 2022 OFLs estimated by model 18.2 were 341,571 t and 374,982 t.

Quantity	As estimated or *specified last* year for: 2020	2021	As estimated or *recommended this* year for: 2021	2022
M (natural mortality rate)	0.12	0.12	0.12, 0.135	0.12, 0.135
Tier	1a	1a	1a	1a
Projected total (age 6+) biomass (t)	2,486,700 t	2,733,340 t	2,755,870 t	3,025,430 t
Projected female spawning biomass (t)	847,101 t	809,813 t	1,040,900 t	996,044 t
$B_{100\%}$	1,275,940 t	1,275,940 t	1,528,700 t	1,528,700 t
$B_{MSY\%}$	477,288 t	477,288 t	559,704 t	559,704 t
F_{OFL}	0.123	0.123	0.124	0.124
$maxF_{ABC}$	0.112	0.112	0.114	0.114
F_{ABC}	0.112	0.112	0.114	0.114
OFL	306,410 t	336,801 t	341,571 t	374,982 t
$maxABC$	278,370 t	305,980 t	313,477 t	344,140 t
ABC	278,370 t	305,980 t	313,477 t	344,140 t
Status	2018	2019	2019	2020
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 136,821 t in 2020 and 139,271 t used in place of maximum ABC for 2021.

Responses to SSC and Plan Team Comments on Assessments in General

SSC December 2018

The SSC requests that all authors fill out the risk table in 2019.

SSC December 2019 . . . risk tables only need to be produced for groundfish assessments that are in 'full' year in the cycle. The SSC requests the the GPTs, as time allows, update the risk tables for the 2020 full assessments.

Plan Team November 2019 The Teams recommended that authors continue to fill out the risk tables for full assessments. The Teams recommended that adjustment of ABC in response to levels of concern should be left to the discretion of the author, the Team(s), and/or the SSC, but should not be mandated by the inclusion of a >1 level in any particular category. The Teams request clarification and guidance from the SSC regarding the previously noted issues associated with completing the risk table, along with any issues noted by the assessment authors.

Authors' response: We have included a risk table in this assessment. We did not recommend adjustment of ABC in response to the risk table.

Responses to SSC and Plan Team Comments Specific to this Assessment

Plan Team September 2020

A Team member noted that the SSC had commented that if M is estimated in the model at a value higher than 0.12, and if the best estimate of the value averaged across both sexes is 0.12, then female M has to be less than 0.12, by about the same amount as the male M exceeds 0.12 (depending on the sex ratio).

The Team requested that both models [18.1 and 18.2] be included for consideration in November.

The Team recommends that, if the authors have time this year or else in the future, they should consider estimating male M freely but with female M adjusted so that the average across sexes is equal to 0.12

(e.g., $M_{female} = (0.12 - (1 - P_{female})xM_{male})/P_{female}$, where P_{female} is the proportion of the population that is female).

Authors' response: We have included Model 18.1 and 18.2 in this assessment. Further changes to female vs. male natural mortality will be explored in future models.

SSC October 2020

The SSC agrees that sex-linked mortality is biologically plausible and concurs with the BSAI-GPT's and authors' recommendation to bring forward Model 18.2 (in addition to the 18.1 base model) for consideration in the next assessment.

Authors' response: We have included Model 18.1 and 18.2 in this assessment.

The SSC notes a couple of long-term development issues with this assessment. A question remains about the timing of the trawl survey relative to the availability of male and female fish, and whether the sex-ratio observed at the time of the survey is influenced by the timing of annual spawning migrations to adjacent inshore areas. Thus, it is questionable that a freely estimated male M is really reflecting the population sex ratio better. For future assessments, the SSC requests the authors consider developing a prior on male M using the literature values and/or fixing the male M based on the literature value. Additionally, the SSC requests the authors investigate whether recent work by Somerton et al. (2018) on wave height, as it relates to gear efficiency, is informative to the parameterization of catchability.

Authors' response: This will be investigated in future assessments.

The SSC recommends consideration of including the Northern Bering Sea (NBS) in the modeled area even for species that have low density there now but could increase under shifting environmental conditions. This would avoid another change in the survey analysis paradigm required to extend the modeled area, as has been the case with recent extensions to include the NBS for pollock, Pacific cod and yellowfin sole.

Authors' response: Two models, 18.3 and 18.4 in the current assessment incorporate VAST estimates, one for the Eastern Bering Sea (EBS) (18.3) and one for the EBS+NBS (18.4).

SSC December 2019

The SSC appreciates the authors' work on Model 18.2 and looks forward to reviewing a model with sex-specific natural mortality in next year's cycle. The SSC requested the authors clarify and justify why natural mortality M is estimated in the model for males, rather than for females or both sexes, and whether the value previously used for both sexes combined, M=0.12, is appropriate for a single sex.

Authors' response:

- *Allowing the model to freely estimate M was a first step towards examining sex-specific M for Yellowfin Sole.*
- *Sex-specific natural mortality is a common feature for flatfish, e.g. Arrowtooth Flounder (Nichol et al. 1998, Wilderbuer and Turnock 2009).*
- *There has consistently been a high proportion of females reported in this species, therefore the data provides more information on female M.*
- *Literature values suggest that Female M ranges from 0.10 to 0.33, while Male M ranges from 0.16 to 0.51 (Wilderbuer and Turnock 2009).*
- *We acknowledge that other parameterizations may provide a better fit to the data, but the assumptions in Model 18.2 were made based on the best available information. Future model configurations will to continue to explore split sex natural mortality for Yellowfin Sole.*

The SSC appreciates the authors' initial response concerning the variability in the proportion of the Yellowfin Sole stock that occurs in the Northern Bering Sea. As described in the 2018 SSC minutes, the SSC suggests the application of the VAST model to estimate the proportion of Yellowfin Sole in the NBS over time, as well as an examination of other available data sources, in particular the ADF&G survey in Norton Sound that has been conducted triennially since 1978 and annually since 2017. The SSC continues to encourage the authors to consider approaches for including the substantial biomass of NBS Yellowfin Sole in the model, with the expectation that NBS surveys will be conducted regularly in the future.

Authors' response: Two models in the current assessment incorporate VAST estimates, one for the EBS (18.3) and one for the EBS+NBS (18.4). Data from the ADF&G survey is presented in this assessment.

The SSC suggests the authors consider estimating a single selectivity curve for both sexes since the sex-specific selectivities are so similar.

Authors' response: This will be considered in a future assessment. For this assessment, we are attempting to keep the number of models to a minimum to reduce the time required for review under full teleworking.

The SSC requests the authors include an explanation of why the model fit to the survey and the model estimated biomass trends diverge, including what model-estimated process explains the change, whether the process is biologically plausible, and whether this model estimated process could potentially explain the retrospective pattern.

Authors' response: This will be investigated in future analyses.

The SSC acknowledges the past work that has been done to resolve the retrospective pattern and recognizes that the models with the best fit are different than those that with the best retrospective pattern. However, the SSC remains concerned about the large retrospective pattern and requests the authors continue to investigate this as they are able.

Authors' response: This will continue to be investigated.

The SSC requests that the authors use the model numbering convention in future assessments.

Authors' response: We will follow naming conventions and will retain the names initiated in 2019 for clarity.

The SSC recommends the authors revisit the fixed values of natural mortality, as the document states the data from which these values are based are from the 1990s.

Authors' response: This will be investigated in future analyses.

The SSC also noted a number of editorial matters which we were grateful to receive and note that they were corrected for the posted final version.

Authors' response: Noted.

Introduction

Yellowfin Sole (*Limanda aspera*) is 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 inhabit the EBS shelf and abundance in the Aleutian Islands region is negligible.

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). Adults exhibit a benthic lifestyle and occupy separate spawning areas in winter and feeding distributions in summer on the eastern Bering Sea shelf (Figure 4.1). From over-wintering grounds near the shelf margins, adults begin a migration onto the inner shelf in April or early May each year for spawning and feeding. There appears 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 4.1). 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 have been targeted with bottom trawls on the Bering Sea shelf since the fishery began in 1954. They were overexploited by foreign fisheries in 1959-62 when catches averaged 404,000 t annually (Figure 4.2, 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 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 4.2, 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 4.1, Table 4.2). 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 139,271 t. The full year's estimate of catch in 2020 was 136,821 t.

Yellowfin sole accounted for 64% of the retained flatfish catch in 2019 caught in the Eastern Bering Sea by catcher/processors in the Amendment 80 Fleet. The first-wholesale value of Yellowfin Sole showed a 4% decrease to $0.78/pound. Export quantities of Yellowfin Sole increased in 2019 from 2018 and the share of exports to China decreased despite rising export prices (Appendix B, Fissel 2020).

As of late October 2020, the fishing season is ongoing. To estimate the total 2020 catch for the stock assessment model, the average proportion of the 2015-2019 cumulative catch attained by the end of October was applied to the 2020 catch amount at the same time period and resulted in a 2020 catch estimate of 136,821 t, 49.15% of the ABC.

Length distributions of Yellowfin Sole throughout NMFS areas 509, 513, 514, 516, 517, and 524 ranged from 20-50 cm, with a higher proportion of large fish in areas 509 and 517 in the southeastern Bering Sea (Figure 4.3). Catch proportions of Yellowfin Sole by month and area are shown in Figure 4.4. The primary fishing areas for Yellowfin Sole in 2020 through the end of September were NMFS Areas 513 and 514, and the highest proportion of the catch was taken in February, March, and April. Although catches in July are typically low relative to other months, the catch in July 2020 was almost negligible. Maps of the locations where Yellowfin Sole were caught in 2020, by month (through mid-September), are shown in Figure 4.5. The average age of Yellowfin Sole in the 2019 catch is estimated at 13.46 and 13 years for females and males, respectively.

The time-series of catch in Table 4.1 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 4.2). The rate of discard has ranged from a low of 2% of the total catch in 2019 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 4.3).

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 - 2020
Fishery age composition	1964 - 2019
Fishery weight-at-age	Catch-at-age methodology
Survey biomass and standard error	1982 - 2019
Bottom temperature	1982 - 2019
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 4.4).

Catch

This assessment uses fishery catch data from 1954-2020 (Table 4.1), and fishery catch-at-age (proportions) from 1964-2019 (Table 4.5, 1975-2019). 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.

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 4.5.

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.

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 4.6). 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 4.6). 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 4.6). 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, time-invariant growth 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 1982. 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 estimated for Yellowfin Sole, by sex, from the trawl survey database as follows:

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 (Figure 4.6).

Sex	a	b	n
Males	0.00854	3.081	2,701
Females	0.0054	3.227	3,662

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 (Figure 4.6). 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 weight-at-age for the final year (2020) was assumed to be the same as for 2019, as no survey was conducted in 2020 (Table 4.7).

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 Yellowfin Sole somatic growth exhibits annual variability and has a strong positive correlation with May bottom water temperature in the Bering Sea (Figure 4.7).

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 4.8). 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).

We used the annual observed population mean weight-at-age (time-varying) from the trawl survey to incorporate time-varying (year effect on growth) and temperature-dependent growth functions into the age-structured stock assessment model. These empirical data indicate good somatic growth correspondence with annual bottom temperature anomalies (Figure 4.8).
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 1982-2019 (Figure 4.9). 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 4.10). 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 4.11). 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). 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 (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 4.11) 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 4.8), 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 2020.

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 (Figure 4.12). 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 4.8).

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 4.4. 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, and 2019. The trawl surveys conducted in 2010, 2017, and 2019 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 (2010, 2017, 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 4.13). This truncated area was 158,286 square kilometers (compared to 200,207 square kilometers in 2010 and 2017). There has been 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. 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 18.4 presented this year did incorporate EBS+NBS biomass estimates. Large shifts in the abundance of Yellowfin Sole into the Bering Sea have not been observed (Figure 4.13), 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 is increasing there. 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 390 over the last five survey years (2014, 2017, 2018, 2019, and 2020) (Figure 4.14).

VAST estimates of biomass

We incorporated vector-autoregressive spatio-temporal (VAST) biomass estimates into two new models; Model 18.3 incorporated VAST estimates from the EBS from 1982-2019, and Model 18.4 incorporated VAST estimates from the NBS and the EBS from 1982-2019 (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, 1982-2019, as well as 83-112 samples available in the NBS in 1982, 1985, 1988, 1991, 2010, and 2017-2019. NBS samples prior to 2010 did not follow the 30 nautical mile sampling grid that was used in 2010, 2017, and 2019, 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 3705 (2nmi) x 3705 (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).

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. Fish older than twenty are allowed to accumulate into a plus group 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 total log likelihood is the sum of the likelihoods for each data component (Table 4.13). 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 1978-2020 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 1978-2014, and are shown from Model 18.1 (Figure 4.15) and Model 18.2 (Figure 4.16).

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. The MCMC was run with 1,000,000 iterations, and thinning every 200. An MCMC was run for Models 18.2 and 18.1.

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 18.1 used in the 2019 assessment updated with 2020 data. Model 18.1 used the same natural mortality for males and females, M=0.12. A second model was considered in this assessment (Model 18.2) that 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 18.3 used VAST biomass and standard error estimates for the eastern Bering Sea area. Model 18.4 used VAST estimates of biomass and standard error for the eastern and northern portions of the Bering Sea.

Parameters Estimated Outside the Assessment Model

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 natural mortality value of 0.12 is used for both sexes in Model 18.1 and fixed female natural mortality at M=0.12 and male natural mortality estimated by the model is used in Model 18.2.

Yellowfin Sole maturity schedules were estimated from in-situ observations from two studies as discussed in the "Data" section (Table 4.6).

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 507 parameters estimated by Model 18.1 and 508 by Models 18.2, 18.3, and 18.4. The number of key parameters are presented below:

Fishing mortality	Selectivity	Survey catchability	Year-class strength	Spawner-recruit	M	Total
68	317	4	115	2	2 (or 1)	508 (or 507)

The increase in the number of parameters estimated in this assessment compared to last year (7) 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, male natural mortality, 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 4.17).

Time-varying fishing selectivity curves were estimated because there have been annual changes in management, vessel participation and possibly gear selectivity (Figure 4.18). 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 2020 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).

In Model 18.1, a revised survey catchability model was introduced (in 2018), which included survey start date (expressed as deviation in days (- and +) from the average survey start date of June 4th). This feature was retained in Model 18.2, and its interaction with annual bottom water temperature was 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 1978-2014 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, two models were examined in full (Model 18.1 and 18.2), and two additional exploratory models were examined, Model 18.3 and 18.4. Model 18.1 was the accepted model in the 2018 and 2019 Yellowfin Sole stock assessments. Model 18.2 fixed female natural mortality at M=0.12 as in previous years, but allowed the model to freely estimate male natural mortality. The model estimated male natural mortality to be higher than female natural mortality, 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).

Models 18.1 and 18.2 differ for some parameter estimates. The trend in survey catchability was similar with Model 18.1 and Model 18.2, but catchability was lower with Model 18.2 (Figure 4.19). The sex ratio estimate changed slightly with Model 18.2. The proportion female was estimated to be slightly lower in Model 18.1 than Model 18.2, as higher male natural mortality increased the estimated number of males in the population (Figure 4.20). Overall, the total negative log likelihod was lower for Model 18.2, and provided a better fit to the survey and fishery ages, as well as an improvement to the fit to survey catchability, with the total negative log likelihood reduced from 1,449 in Model 18.1 to 1,386 in Model 18.2 (Table 4.13, Figure 4.21, Figure 4.22, Figure 4.23, Figure 4.24).

Table 4.15 indicates that the ABC from Model 18.2 for 2021 would be 35,106 t higher than Model 18.1. This is due to the higher biomass estimate resulting from an increased value of male natural mortality in Model 18.2. Model 18.2 also provided a slightly better fit to survey biomass, but this effect was primarily noticeable during the years 1988-1995. Overall Model 18.2 provided very little change in the fit to survey biomass (Figure 4.25). Models 18.3 and 18.4 fit their corresponding estimates of survey biomass fairly well, but there was some discontinuity in the fit for 2015, that was consistent among models.

Posterior distributions of several key parameters in the model capture variability in posterior distributions of parameter estimates and differences between Model 18.2 and Model 18.1 (Figure 4.26). Model 18.2 resulted in higher estimates for B_{MSY}, total and age 6 biomass and female spawning biomass and recruitment, but similar values to Model 18.1 for F_{MSY}. The posterior distribution for female spawning biomass is above the Model 18.2 estimate for B_{MSY} (Figure 4.26).

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 1977-2014 spawner-recruit data in the model. The resulting stock recruitment curves are very similar for Model 18.1 and 18.2 (Figure 4.15 and Figure 4.16).

Model 18.2 is the preferred model for estimating the Yellowfin Sole stock size and management quantities for the 2021 fishing season. However, two other models were considered for an exploratory analysis of VAST biomass estimates and inclusion of the Bering Sea survey. Model 18.3 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 4.27). Model 18.2 provided consistently higher estimates than Model 18.3. Model 18.4 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 2020 to include current values of catch, fishery and survey age compositions from 2019. 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. These changes produced Model 18.2 ABC and OFL estimates for 2021 higher than the 2019 assessment (Model 18.1) projections for 2020, 313,477 t and 344,140 t. Model 18.2 produced slightly higher estimates for ABC and OFL than Model 18.1 due to the estimate of higher male natural mortality (Table 4.15). Reference points for Model 18.3 were very similar to Model 18.2. Reference points for Model 18.4 were the highest of all models, because it included biomass estimates for the EBS+NBS. The model results indicate the stock has been in a slowly declining condition since 1994 (Figure 4.28). The five past years in the Bering Sea have had bottom temperature anomalies above the mean. The temperature-dependent q adjustment for 2020 was 0.89.

Fishing Mortality and Selectivity

The full-selection fishing mortality, F, has averaged 0.0656 over the period 2014-2019 (Table 4.16). Model estimated selectivities, Figure 4.17 and Figure 4.18 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 q at an average value of 0.77 for the period 1982-2020 which resulted in the model estimate of the 2020 age 2+ total biomass at 3,283 million t (Table 4.9). 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 4.28). 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 80% of the peak 1985 level. The female spawning biomass has also declined since the peak in 1994, with a 2020 estimate of 1,086 million 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 slightly increasing trend in female spawning biomass through 2033 if the fishing mortality rate continues at the same level as the average of the past 5 years (Figure 4.29).

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 4.30). 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 1998 has been average, and the 2016 year-class appeared to be one of the lowest on record (Figure 4.30).

Retrospective Analysis

A within-model retrospective analysis was included for the recommended assessment model (Model 18.2) and Model 18.1. 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 4.31). Mohn's rho did not change significantly for Model 18.2; it was -0.185 for Model 18.2 and -0.184 for Model 18.1. 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 4.31). Retrospective plots did not change significantly betweeen models 18.1 and 18.2 (Figure 4.31). The difference in female spawning biomass was negative for most recent years, except for the most recent (Figure 4.32), and very similar among models. It is notable that there was very little difference in the retrospective pattern for the current year vs. 2019 and 2018. This is an improvement in the retrospective pattern than seen in previous years. The Mohn's rho appears to exceed the rule of thumb guideline of 0.20 for long-lived stocks proposed by Hurtado-Ferro at al. (2015), which includes flatfish. The rule of thumb is 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 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.

Risk Table

Assessment related considerations

The BSAI Yellowfin Sole assessment is based on surveys conducted annually on the EBS shelf from 1982-2019, 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 current assessment model was less than desirable and has been the subject of some concern for the assessment. 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.

The level of uncertainty due to lack of survey data for 2020 was assessed in Bryan et al. 2020. The BSAI yellowfin sole and EBS snow crab models exhibit a negative bias that becomes more negative when the most recent survey data were not included in the assessment model (-.209 to -.0.237). Bias in recruitment was greater for EBS Pacific cod, tanner crab and snow crab and less for BSAI yellowfin, northern rock sole, flathead sole, and Greenland turbot when the most recent survey data was missing from the assessment model (additional σ^2 with no recent survey was 0.001). Based on this analysis, level of uncertainty in the Yellowfin Sole stock is lower than for other species. Regardless, this is the first year that new survey data was not available for Yellowfin Sole, and although uncertainty is expected to increase without survey data, it is relatively low in comparison to other species and does not pose an assessment concern for this one year.

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 all look about average according to the 2018 stock assessment. The present biomass is estimated at 80% of the peak 1985 level and female spawning biomass is at 996,044 t, while B_{MSY} is estimated at 559,704 t. Projections indicate that the FSB will remain well-above the B_{MSY} level through 2033 (Figure 4.29). Population dynamics are not a concern for this assessment.

Environmental/ecosystem considerations

Following two years of physical oceanographic perturbations, the eastern Bering Sea experienced a return to near-normal climatic conditions in 2020. Summer bottom temperatures and spatial extent of the cold pool were average based on the ROMS hindcast model and observations from the 2020 Dyson cruise. However, summer sea surface temperatures through August were above average in the southern and northern Bering Sea, similar to those observed in 2019 (Siddon 2020).

Yellowfin Sole (YFS) demonstrate earlier migration to spawning grounds and spawning events in warm years, also somatic growth increases in warmer temperatures. In 2019, fish condition (as measured by length-weight residuals [updated method]) was positive in the southeastern Bering Sea (SEBS) and NBS and continued upward trends since 2017 in both areas (Rohan and Lahman 2020). The mean length of the groundfish community increased in 2019 and was buoyed by prominent species including Yellowfin Sole, which had above average mean length (Whitehouse 2020).

The 2019 distribution of age-classes showed older/larger fish over the southern shelf and younger/smaller fish over the northern shelf (L. Britt, pers comm). This indicates favorable growth and survival of juvenile YFS in the NBS. A proposed thermal window (Yeung et al. In Prep.) 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.

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 NOAA AFSC bottom trawl survey. The biomass of motile epifauna (e.g., brittle stars, urchins, sand dollars) remained above the long-term mean in 2019, although decreased 10% from 2018. This suggests sufficient prey availability for YFS over the southern Bering Sea shelf (Whitehouse 2019).

Predators of YFS include Pacific cod and Pacific halibut. In 2019, the abundance and biomass of Pacific cod increased across the eastern Bering Sea, especially in abundance indicating successful recruitment of early age classes (L. Britt, Sept. GPT presentation). This dramatic increase of predators over the shelf suggests potential increased risk of predation, although size, spatial, and/or temporal mismatches may exist and provide refuge for YFS.

Competitors for YFS prey resources in the northern Bering Sea may include gray whales (e.g., benthic amphipods). Since January 2019, a total of 213 gray whale strandings have been reported, with 49 of those within Alaska. An Unusual Mortality Event was declared for gray whales in 2019 (see K. Savage 'Noteworthy' in the 2019 Eastern Bering Sea Ecosystem Status Report for more information). Gray whale life history includes annual migrations of up to 20,000 km from summer feeding grounds in the northern Bering and Chukchi seas to southern Baja California to mate and calve. Preliminary findings in several of the whales shows evidence of emaciation; benthic prey (primarily amphipods) in the Bering, Chukchi, and Beaufort seas are a main prey source. The 2019 strandings may reflect 2018 conditions (prior to their migration) of poor feeding or competition for limited prey resources and/or indicate thresholds in the carrying capacity of the northern Bering Sea ecosystem.

Together, the most recent data available suggest there are no apparent ecosystem concerns–level 1. The main points are summarized below:

- Summer bottom temperatures and spatial extent of the cold pool were average, indicating a cooler thermal experience for YFS, which may be adapted to colder temperatures, than in recent years.
- In 2019, YFS condition (weighted length-weight residuals) was positive in the SEBS and NBS and continued upward trends since 2017;
- The mean size of the groundfish community increased in 2019 buoyed by species including YFS, which had above average mean length;
- YFS abundance and biomass remained below the long-term mean over the southern shelf;
- YFS abundance and biomass increased between 2017 and 2019 over the northern shelf;
- Indirect measurements of prey availability suggest sufficient prey availability for YFS over the southern Bering Sea shelf;
- Increase of predators over the eastern Bering Sea shelf indicates increased risk of predation, although size, spatial, and/or temporal mismatches may exist and provide refuge for YFS;
- 2019 gray whale Unusual Mortality Event reflects poor feeding conditions in the northern Bering Sea during 2018.

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	Overall
Level 1: Only minor, low level of concern	Level 1: Stock trends are typical for the stock and expected given stock dynamics; recent recruitment is within the normal range.	Level 1: Stock trends are typical for the stock and expected given stock dynamics; recent recruitment is within the normal range.	Level 1: No apparent environmental/ecosystem concerns	Level 1: Normal.

No changes are recommended to the ABC, based on this risk table assessment.

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 2020 numbers at age from the stock assessment model are projected to 2020 given the 2019 catch and then a 2020 catch of 139,271 t was applied to the projected 2020 population biomass to obtain the 2021 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 2021 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 2021 biomass estimate.

The geometric mean of the 2021 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 2021 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 2021 harvest (now the 1978-2014 time-series) recommendation (Model 18.2), the $F_{ABC} = F_{Hmean} =$ 0.114. The estimate of age 6+ total biomass for 2021 is 2,755,870 t. The calculations outlined above give a Tier 1 ABC harvest recommendation of 313,477 t and an OFL of 341,571 t for 2021. This results in an 8 % (28,094 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 fishing mortality values, ABC fishing mortality values and their corresponding yields are given as follows:

Harvest level	F value	2021 Yield
Tier 1 $F_{OFL} = F_{MSY}$	0.124	341,571 t
Tier 1 $F_{ABC} = F_{harmonic_mean}$	0.114	313,477 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 2020 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2021 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2020. 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 2021, 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 2019 recommended in the assessment to the max F_{ABC} for 2021. (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 2015 - 2019 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 expected to be above its MSY level in 2016 and above its MSY level in 2030 under this scenario, then the stock is not overfished.)
- Scenario 7: In 2021 and 2022, F is set equal to max F_{ABC}, and in all subsequent years, F is set equal to FOFL. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is 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 4.29). 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 4.33). The ABC and OFL for 2021 and 2022 assuming average catch rates are shown in the following table.

Year	Catch	FSB	Geom. mean 6+ biomass	ABC	OFL
2021	139,271	1,040,900	2,755,870	313,477	341,571
2022	139,271	996,044	3,025,430	344,140	374,982

Based on the 2020 assessment Model 18.2, an F=0.16348 would have produced a 2019 catch equal to the 2019 OFL.

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
Herring	2
Red King crab	5

Prohibited species	Yellowfin Sole fishery % of total bycatch
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: Foreign and domestic catch (t) of Yellowfin Sole 1954-2020. Foreign catches are designated as joint venture processing (JVP) and domestic annual processing (DAP). Domestic catch since 1991 is subdivided into catch from the Aleutian Islands and the Bering Sea. Catch for 2020 was downloaded November 15, 2020.

		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			145,382	3.6	145,382	145,386
1993			105,810		105,810	105,810
1994			140,050	0.2	140,050	140,050
1995			124,746	5.6	124,746	124,752
1996			129,659	0.4	129,659	129,659
1997			182,813	1.2	182,813	182,814
1998			101,150	4.7	101,150	101,155

1999	69,221	12.8	69,221	69,234
2000	84,058	12.5	84,058	84,071
2001	63,564	14.5	63,564	63,579
2002	74,957	28.5	74,957	74,986
2003	79,806	0.4	79,806	79,806
2004	75,502	8.8	75,502	75,511
2005	94,383	1.8	94,383	94,385
2006	99,156	3.8	99,156	99,160
2007	120,962	2.4	120,962	120,964
2008	148,893	0.5	148,893	148,894
2009	107,512	1.1	107,512	107,513
2010	118,624	0.2	118,624	118,624
2011	151,157	1.1	151,157	151,158
2012	147,186	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	135,348	0.2	135,324	135,324
2017	132,265	0.6	132,219	132,220
2018	131,541	4.5	131,491	131,496
2019	128,061	4.6	128,046	128,051
2020	118,917	11.0	128,081	128,092

Table 4.2: Estimates of retained and discarded (t) Yellowfin Sole caught in Bering Sea fisheries from 1991 through October 12th, 2020, and the proportion discarded.

Year	Retained (t)	Discarded (t)	Proportion discarded
1991	88,967	28,337	0.24
1992	102,542	42,843	0.29
1993	76,798	29,012	0.27
1994	104,918	35,132	0.25
1995	96,770	27,982	0.22
1996	101,324	28,335	0.22
1997	150,745	32,069	0.18
1998	80,267	20,888	0.21
1999	56,604	12,629	0.18
2000	69,971	14,100	0.17
2001	54,918	8,661	0.14
2002	63,625	11,361	0.15
2003	68,832	10,974	0.14
2004	62,746	12,765	0.17
2005	85,311	9,074	0.1
2006	90,592	8,568	0.09
2007	109,004	11,960	0.1
2008	141,235	7,659	0.05
2009	100,642	6,871	0.06
2010	113,244	5,380	0.05
2011	146,418	4,740	0.03
2012	142,132	5,056	0.03
2013	158,781	6,163	0.04
2014	152,167	4,606	0.03
2015	123,065	3,871	0.03
2016	131,203	4,121	0.03
2017	128,665	3,554	0.03
2018	127,331	4,164	0.03
2019	125,113	2,937	0.02
2020	117,144	1,773	0.01

Table 4.3: Discarded and retained catch of non-CDQ Yellowfin Sole, by fishery, in 2019. 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
Other Species	HAL	1	0
Pacific Cod	HAL	722	27
Alaska Plaice	NPT	0	1
Atka Mackerel	NPT	0	0
Greenland Turbot	NPT	0	0
Halibut	NPT	37	302
Kamchatka Flounder	NPT	4	296
Other Species	NPT	284	9,645
Pacific Cod	NPT	0	0
Pollock - bottom	NPT	0	0
Pollock - midwater	NPT	1,233	109,195
Atka Mackerel	POT	543	15
Yellowfin Sole	POT	0	35

Table 4.4: 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

Table 4.5: Yellowfin Sole fishery catch-at-age (proportions), 1975-2019 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	0.1114	0.2793	0.2636	0.1141	0.0609	0.0316	0.0249	0.0299	0.0096	0.0085	0.0052	0.9390
1976	0.0950	0.1574	0.2546	0.2016	0.0876	0.0481	0.0254	0.0201	0.0242	0.0078	0.0069	0.9287
1977	0.1744	0.1949	0.1554	0.1353	0.0728	0.0265	0.0137	0.0071	0.0056	0.0067	0.0021	0.7945
1978	0.0931	0.2040	0.2266	0.1654	0.1327	0.0677	0.0240	0.0122	0.0063	0.0049	0.0059	0.9428
1979	0.0604	0.1424	0.2189	0.1932	0.1277	0.0990	0.0500	0.0176	0.0089	0.0046	0.0036	0.9263
1980	0.0621	0.0693	0.1310	0.1881	0.1696	0.1167	0.0934	0.0480	0.0171	0.0087	0.0045	0.9085
1981	0.0761	0.0985	0.0935	0.1445	0.1730	0.1371	0.0874	0.0670	0.0337	0.0119	0.0060	0.9287
1982	0.0584	0.1349	0.1355	0.0987	0.1258	0.1347	0.1009	0.0626	0.0474	0.0237	0.0083	0.9309
1983	0.0936	0.1009	0.1599	0.1247	0.0803	0.0973	0.1022	0.0760	0.0470	0.0355	0.0178	0.9352
1984	0.0348	0.0949	0.0994	0.1572	0.1232	0.0796	0.0965	0.1015	0.0755	0.0467	0.0353	0.9446
1985	0.0199	0.0565	0.1189	0.1021	0.1466	0.1108	0.0707	0.0854	0.0897	0.0667	0.0413	0.9086
1986	0.0517	0.0525	0.0984	0.1387	0.0947	0.1229	0.0894	0.0563	0.0676	0.0709	0.0527	0.8958
1987	0.0173	0.0480	0.0415	0.0831	0.1301	0.0944	0.1258	0.0924	0.0584	0.0703	0.0737	0.8350
1988	0.0494	0.0438	0.1045	0.0631	0.0908	0.1177	0.0785	0.1013	0.0735	0.0463	0.0556	0.8245
1989	0.0049	0.0782	0.0609	0.1189	0.0622	0.0844	0.1076	0.0714	0.0920	0.0668	0.0420	0.7893
1990	0.0389	0.0228	0.2244	0.0913	0.1103	0.0468	0.0594	0.0743	0.0491	0.0632	0.0458	0.8263
1991	0.0174	0.1018	0.0366	0.2402	0.0807	0.0923	0.0387	0.0492	0.0615	0.0406	0.0523	0.8113
1992	0.0159	0.0401	0.1734	0.0445	0.2309	0.0690	0.0752	0.0310	0.0391	0.0488	0.0322	0.8001
1993	0.0217	0.0249	0.0458	0.1637	0.0397	0.2089	0.0642	0.0715	0.0299	0.0380	0.0476	0.7559
1994	0.0376	0.0551	0.0559	0.0759	0.1997	0.0387	0.1772	0.0505	0.0540	0.0221	0.0278	0.7945
1995	0.0491	0.0900	0.0817	0.0586	0.0682	0.1703	0.0325	0.1481	0.0421	0.0451	0.0185	0.8042
1996	0.0257	0.0776	0.0966	0.0741	0.0514	0.0601	0.1515	0.0290	0.1328	0.0378	0.0405	0.7771
1997	0.0273	0.0373	0.0958	0.1032	0.0721	0.0476	0.0544	0.1356	0.0259	0.1182	0.0336	0.7510
1998	0.0754	0.0525	0.0563	0.1127	0.1014	0.0640	0.0401	0.0448	0.1105	0.0210	0.0957	0.7744
1999	0.0108	0.0442	0.0402	0.0533	0.1185	0.1105	0.0703	0.0442	0.0493	0.1217	0.0231	0.6861
2000	0.0097	0.0277	0.0927	0.0615	0.0605	0.1130	0.0982	0.0609	0.0380	0.0423	0.1043	0.7088
2001	0.0210	0.0424	0.0784	0.1537	0.0666	0.0520	0.0886	0.0745	0.0457	0.0284	0.0316	0.6829
2002	0.0248	0.0254	0.0511	0.0880	0.1589	0.0655	0.0501	0.0845	0.0708	0.0434	0.0270	0.6895
2003	0.0186	0.0930	0.0630	0.0773	0.0913	0.1373	0.0529	0.0396	0.0664	0.0555	0.0340	0.7289
2004	0.0182	0.0442	0.1589	0.0762	0.0745	0.0793	0.1147	0.0436	0.0325	0.0544	0.0455	0.7420
2005	0.0303	0.0404	0.0663	0.1746	0.0704	0.0643	0.0671	0.0965	0.0367	0.0273	0.0457	0.7196
2006	0.1106	0.0911	0.0700	0.0747	0.1505	0.0528	0.0451	0.0457	0.0649	0.0245	0.0182	0.7481
2007	0.0279	0.0746	0.0731	0.0664	0.0774	0.1618	0.0576	0.0495	0.0502	0.0714	0.0270	0.7369
2008	0.0417	0.0559	0.1133	0.0840	0.0638	0.0682	0.1377	0.0483	0.0413	0.0418	0.0594	0.7554
2009	0.0326	0.0766	0.0799	0.1243	0.0796	0.0570	0.0598	0.1197	0.0419	0.0358	0.0363	0.7435
2010	0.0565	0.0668	0.0956	0.0758	0.1085	0.0686	0.0491	0.0515	0.1033	0.0362	0.0309	0.7428
2011	0.0237	0.1012	0.0935	0.1049	0.0716	0.0959	0.0590	0.0419	0.0438	0.0877	0.0307	0.7539
2012	0.0295	0.0475	0.1449	0.1007	0.0967	0.0620	0.0812	0.0497	0.0352	0.0367	0.0735	0.7576
2013	0.0143	0.0341	0.0603	0.1683	0.1046	0.0942	0.0588	0.0762	0.0464	0.0328	0.0343	0.7243
2014	0.0150	0.0445	0.0709	0.0781	0.1647	0.0928	0.0814	0.0505	0.0653	0.0398	0.0281	0.7311
2015	0.0149	0.0278	0.0592	0.0733	0.0732	0.1532	0.0873	0.0772	0.0481	0.0623	0.0379	0.7144
2016	0.0336	0.0503	0.0709	0.1017	0.0861	0.0676	0.1264	0.0689	0.0600	0.0371	0.0480	0.7506
2017	0.0219	0.1160	0.1140	0.0994	0.0995	0.0697	0.0504	0.0915	0.0493	0.0427	0.0264	0.7808
2018	0.0075	0.0308	0.1378	0.1180	0.0959	0.0936	0.0651	0.0470	0.0852	0.0459	0.0398	0.7666
2019	0.0231	0.0166	0.0514	0.1701	0.1183	0.0868	0.0814	0.0557	0.0400	0.0725	0.0390	0.7549

Year	7	8	9	10	11	12	13	14	15	16	17+	Total male proportion over age 7
1975	0.2026	0.3633	0.2192	0.0645	0.0349	0.0112	0.0064	0.0080	0.0016	0.0010	0.0005	0.9132
1976	0.0978	0.1722	0.2952	0.2220	0.0756	0.0433	0.0142	0.0081	0.0102	0.0021	0.0012	0.9419
1977	0.1009	0.2247	0.2450	0.2262	0.1114	0.0313	0.0168	0.0054	0.0031	0.0038	0.0008	0.9694
1978	0.0862	0.1920	0.2291	0.1769	0.1481	0.0720	0.0202	0.0109	0.0035	0.0020	0.0025	0.9434
1979	0.0615	0.1486	0.2299	0.1991	0.1278	0.0986	0.0464	0.0129	0.0069	0.0022	0.0013	0.9352
1980	0.0510	0.0552	0.1088	0.1735	0.1770	0.1357	0.1202	0.0620	0.0182	0.0101	0.0033	0.9150
1981	0.0766	0.0933	0.0880	0.1406	0.1754	0.1414	0.0894	0.0691	0.0326	0.0091	0.0048	0.9203
1982	0.0792	0.1546	0.1363	0.0928	0.1149	0.1213	0.0886	0.0532	0.0399	0.0185	0.0051	0.9044
1983	0.1028	0.1057	0.1618	0.1242	0.0795	0.0962	0.1007	0.0734	0.0439	0.0330	0.0153	0.9365
1984	0.0446	0.1195	0.1107	0.1590	0.1189	0.0755	0.0911	0.0953	0.0694	0.0416	0.0312	0.9568
1985	0.0306	0.0849	0.1455	0.1056	0.1394	0.1019	0.0643	0.0774	0.0809	0.0589	0.0353	0.9247
1986	0.0657	0.0623	0.1034	0.1372	0.0921	0.1192	0.0867	0.0546	0.0658	0.0688	0.0501	0.9059
1987	0.0264	0.0999	0.0700	0.0999	0.1276	0.0849	0.1098	0.0798	0.0503	0.0606	0.0633	0.8725
1988	0.0642	0.0679	0.1366	0.0658	0.0855	0.1072	0.0712	0.0920	0.0668	0.0421	0.0507	0.8500
1989	0.0050	0.0931	0.0757	0.1321	0.0622	0.0808	0.1016	0.0675	0.0872	0.0634	0.0399	0.8085
1990	0.0802	0.0410	0.2851	0.0888	0.0937	0.0378	0.0473	0.0590	0.0391	0.0505	0.0367	0.8592
1991	0.0233	0.1715	0.0517	0.2644	0.0751	0.0776	0.0311	0.0390	0.0486	0.0322	0.0416	0.8561
1992	0.0224	0.0579	0.2174	0.0478	0.2271	0.0638	0.0657	0.0264	0.0330	0.0412	0.0273	0.8300
1993	0.0266	0.0302	0.0534	0.1806	0.0417	0.2114	0.0621	0.0657	0.0267	0.0336	0.0421	0.7741
1994	0.0519	0.0720	0.0648	0.0802	0.1995	0.0376	0.1700	0.0470	0.0483	0.0194	0.0242	0.8149
1995	0.0625	0.1084	0.0905	0.0614	0.0689	0.1671	0.0313	0.1411	0.0390	0.0401	0.0161	0.8264
1996	0.0392	0.1055	0.1142	0.0785	0.0508	0.0566	0.1373	0.0257	0.1162	0.0322	0.0330	0.7892
1997	0.0327	0.0461	0.1144	0.1156	0.0764	0.0485	0.0537	0.1297	0.0243	0.1096	0.0303	0.7813
1998	0.0424	0.0469	0.0642	0.1340	0.1183	0.0730	0.0450	0.0492	0.1184	0.0221	0.0998	0.8133
1999	0.0091	0.0358	0.0331	0.0479	0.1183	0.1177	0.0768	0.0484	0.0534	0.1288	0.0241	0.6934
2000	0.0095	0.0284	0.0995	0.0676	0.0657	0.1199	0.1022	0.0626	0.0385	0.0421	0.1013	0.7373
2001	0.0084	0.0184	0.0435	0.1197	0.0683	0.0616	0.1106	0.0943	0.0579	0.0357	0.0391	0.6575
2002	0.0212	0.0302	0.0706	0.1119	0.1792	0.0683	0.0496	0.0808	0.0663	0.0401	0.0246	0.7428
2003	0.0218	0.1405	0.0885	0.0899	0.0945	0.1345	0.0499	0.0360	0.0586	0.0481	0.0291	0.7914
2004	0.0184	0.0480	0.1771	0.0833	0.0795	0.0833	0.1191	0.0443	0.0320	0.0521	0.0427	0.7798
2005	0.0378	0.0544	0.0849	0.2007	0.0741	0.0643	0.0654	0.0924	0.0343	0.0247	0.0403	0.7733
2006	0.1135	0.1043	0.0785	0.0818	0.1615	0.0558	0.0473	0.0477	0.0674	0.0250	0.0180	0.8008
2007	0.0448	0.1152	0.0939	0.0725	0.0769	0.1527	0.0528	0.0448	0.0452	0.0638	0.0236	0.7862
2008	0.0530	0.0696	0.1292	0.0890	0.0650	0.0678	0.1342	0.0464	0.0394	0.0397	0.0560	0.7893
2009	0.0335	0.0722	0.0781	0.1279	0.0840	0.0605	0.0629	0.1243	0.0430	0.0365	0.0368	0.7597
2010	0.0914	0.1050	0.1213	0.0804	0.1038	0.0625	0.0438	0.0451	0.0890	0.0307	0.0261	0.7991
2011	0.0360	0.1410	0.1107	0.1099	0.0703	0.0903	0.0544	0.0381	0.0392	0.0774	0.0267	0.7940
2012	0.0479	0.0738	0.1812	0.1061	0.0939	0.0579	0.0735	0.0441	0.0309	0.0318	0.0627	0.8038
2013	0.0229	0.0491	0.0731	0.1792	0.1055	0.0936	0.0577	0.0734	0.0440	0.0308	0.0317	0.7610
2014	0.0265	0.0738	0.0942	0.0846	0.1622	0.0883	0.0767	0.0471	0.0597	0.0358	0.0251	0.7740
2015	0.0201	0.0401	0.0832	0.0907	0.0793	0.1533	0.0841	0.0733	0.0450	0.0572	0.0343	0.7606
2016	0.0376	0.0612	0.0870	0.1162	0.0907	0.0676	0.1233	0.0664	0.0575	0.0353	0.0448	0.7876
2017	0.0160	0.0871	0.0981	0.0993	0.1081	0.0778	0.0567	0.1029	0.0554	0.0480	0.0295	0.7789
2018	0.0082	0.0393	0.1760	0.1370	0.1011	0.0920	0.0610	0.0430	0.0770	0.0412	0.0356	0.8114
2019	0.0274	0.0218	0.0658	0.1983	0.1274	0.0883	0.0789	0.0521	0.0366	0.0656	0.0351	0.7973

Table 4.6: 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 4.7: Mean unsmoothed weight-at-age (grams) for Yellowfin Sole, based on survey data, females presented first, followed by males, 1964-2019.

Year	Age (Females)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1964	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481	590
1965	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481	590
1966	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481	590
1967	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481	590
1968	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481	590
1969	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481	590
1970	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481	590
1971	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481	590
1972	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481	590
1973	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481	590
1974	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481	590
1975	8	20	31	55	84	124	165	217	266	301	341	374	407	428	443	480	483	499	590	590
1976	8	20	31	55	84	124	165	217	266	301	341	374	407	428	443	480	483	499	590	590
1977	8	20	31	55	84	124	165	217	266	301	341	374	407	428	443	480	483	499	590	590
1978	8	20	31	55	84	124	165	217	266	301	341	374	407	428	443	480	483	499	590	590
1979	8	20	31	55	84	124	165	217	266	301	341	374	407	428	443	480	483	499	590	590
1980	8	20	31	55	84	124	165	217	266	301	341	374	407	428	443	480	483	499	590	590
1981	8	20	31	55	84	124	165	217	266	301	341	374	407	428	443	480	483	499	590	590
1982	8	20	42	75	98	139	176	214	233	235	331	359	393	410	436	482	470	476	586	590
1983	10	14	26	60	103	162	185	201	243	255	318	350	391	419	455	503	489	503	605	590
1984	14	26	33	57	110	156	177	222	246	294	318	342	375	418	453	498	492	536	617	590
1985	11	16	28	46	77	177	202	251	286	302	314	341	367	417	450	502	520	556	623	590
1986	14	27	23	41	71	103	173	239	284	338	314	336	366	401	439	490	511	547	628	590
1987	10	14	20	47	55	127	179	256	317	324	331	351	375	411	443	475	519	557	619	590
1988	9	12	16	34	66	85	159	237	286	307	351	364	377	393	418	446	490	528	597	590
1989	12	21	33	67	71	112	133	197	279	339	364	384	402	400	422	445	506	490	570	590
1990	11	17	24	38	65	99	126	197	243	321	389	400	411	405	430	436	475	475	559	590
1991	11	16	23	58	56	100	142	156	238	310	394	421	420	429	446	450	486	481	557	590
1992	12	21	29	55	85	121	177	176	283	305	377	417	430	456	454	464	498	485	562	590
1993	15	28	35	64	93	155	165	232	244	301	368	411	438	469	470	477	506	496	563	590
1994	20	46	53	86	87	125	155	235	276	284	355	405	418	470	472	482	486	504	571	590
1995	12	20	28	60	84	123	160	217	284	332	333	403	412	463	470	478	515	495	575	590
1996	11	16	36	51	108	137	167	202	222	311	322	379	403	448	461	487	509	503	567	590
1997	16	34	33	72	85	157	200	236	260	292	336	383	397	439	457	488	492	514	577	590
1998	10	14	36	51	90	104	177	237	278	279	333	383	391	430	439	478	479	513	576	590
1999	9	12	18	37	67	103	131	239	284	296	331	374	398	417	429	474	484	506	593	590
2000	11	16	33	33	91	81	158	175	237	306	325	360	401	422	423	485	462	506	603	590
2001	6	6	32	41	57	83	148	179	255	305	333	367	410	425	420	463	464	506	611	590
2002	11	18	27	48	65	87	120	224	243	261	330	362	404	413	419	455	479	501	608	590
2003	9	12	31	53	86	124	156	213	289	303	335	369	406	412	425	439	485	486	599	590
2004	9	18	43	63	101	168	172	245	299	346	346	381	426	441	432	439	478	490	592	590
2005	14	26	44	78	114	152	213	238	277	337	353	386	434	445	454	444	464	501	590	590
2006	9	13	40	82	125	153	204	245	319	314	357	385	451	454	465	533	465	504	609	590
2007	11	16	36	66	115	173	198	244	316	311	362	388	459	465	471	542	462	529	620	590
2008	13	24	28	54	98	129	199	226	286	320	364	383	463	472	478	575	481	548	639	590
2009	6	9	18	45	69	127	163	239	306	322	363	385	442	446	483	630	496	546	654	590
2010	8	20	31	55	84	124	165	217	266	301	362	380	436	439	465	622	505	538	646	590
2011	8	18	25	56	80	126	188	205	327	332	361	387	412	435	455	522	507	539	626	590
2012	8	12	26	49	81	144	169	256	313	341	358	404	421	437	458	512	514	522	616	590
2013	8	12	21	35	92	125	182	261	305	364	369	413	425	442	454	507	507	518	608	590
2014	6	8	11	18	34	74	145	203	260	305	370	403	430	441	457	464	496	536	582	590
2015	6	8	11	16	39	53	122	210	273	360	387	414	433	448	462	475	513	541	564	590
2016	6	8	32	50	66	74	112	186	338	372	397	416	449	455	479	499	518	535	560	590
2017	6	9	18	56	65	155	129	156	250	357	402	413	454	459	487	512	521	542	551	590
2018	6	9	24	44	85	102	143	221	226	345	404	417	449	460	503	518	529	543	557	590
2019	6	9	24	44	85	102	143	221	226	345	413	433	456	471	512	521	540	535	571	590

Year	Age (Males)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1964	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1965	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1966	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1967	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1968	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1969	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1970	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1971	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1972	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1973	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1974	0	4	15	34	60	91	125	160	195	230	263	294	322	348	372	393	412	429	444	481
1975	4	14	18	32	54	85	120	156	193	225	253	280	303	324	330	344	355	366	390	423
1976	4	14	18	32	54	85	120	156	193	225	253	280	303	324	330	344	355	366	390	423
1977	4	14	18	32	54	85	120	156	193	225	253	280	303	324	330	344	355	366	390	423
1978	4	14	18	32	54	85	120	156	193	225	253	280	303	324	330	344	355	366	390	423
1979	4	14	18	32	54	85	120	156	193	225	253	280	303	324	330	344	355	366	390	423
1980	4	14	18	32	54	85	120	156	193	225	253	280	303	324	330	344	355	366	390	423
1981	4	14	18	32	54	85	120	156	193	225	253	280	303	324	330	344	355	366	390	423
1982	4	11	25	50	83	112	133	142	158	182	242	266	286	309	345	352	361	384	418	420
1983	4	5	5	23	57	95	156	156	155	176	233	256	271	295	331	341	344	385	414	417
1984	4	10	20	31	57	121	150	181	202	193	223	242	259	281	316	325	330	394	394	406
1985	4	11	23	32	51	84	148	186	214	227	218	236	254	269	307	317	340	399	423	399
1986	4	9	18	27	34	61	98	176	217	233	215	225	248	257	293	313	322	389	405	389
1987	4	8	14	17	27	53	97	157	211	226	228	236	266	269	267	294	306	358	364	386
1988	4	7	10	18	45	75	76	138	207	242	238	252	281	278	283	297	314	347	355	381
1989	4	7	10	27	47	72	142	130	179	244	252	279	300	298	295	305	336	325	370	377
1990	4	9	16	22	44	64	98	120	175	197	261	295	312	309	305	301	324	318	332	377
1991	4	9	17	29	51	75	100	132	180	212	266	302	323	328	319	308	341	315	378	379
1992	4	9	17	28	53	86	97	125	174	208	262	302	322	368	345	329	349	328	394	373
1993	4	9	18	45	56	93	135	145	206	209	257	294	339	369	347	341	362	335	397	372
1994	4	23	32	53	76	92	116	182	198	207	255	291	334	367	353	362	355	369	394	387
1995	4	10	19	32	59	88	110	154	177	207	250	278	333	361	349	380	359	375	406	399
1996	4	10	19	32	54	107	134	163	184	215	241	277	324	349	347	374	355	398	365	410
1997	4	8	14	37	64	75	149	174	185	239	240	274	315	308	335	362	363	400	353	427
1998	4	10	20	27	49	79	113	156	208	207	244	274	296	308	324	356	354	401	354	429
1999	4	6	7	18	37	63	95	123	170	171	241	263	287	292	324	340	362	375	355	434
2000	4	10	20	36	32	64	88	133	161	284	238	265	280	285	318	331	359	368	349	421
2001	4	9	16	27	38	51	91	152	161	198	247	260	280	285	314	330	361	356	370	421
2002	4	9	18	21	57	59	81	134	188	204	249	260	282	286	305	331	351	343	374	415
2003	4	11	22	39	53	83	109	161	179	251	247	269	277	319	313	333	346	340	375	418
2004	4	7	20	40	64	94	157	157	213	266	265	275	282	337	315	334	344	353	393	417
2005	4	11	24	44	77	110	136	170	201	262	274	287	295	347	323	338	349	352	388	427
2006	4	10	19	36	71	124	139	180	207	237	267	302	305	364	341	363	354	348	379	418
2007	4	10	19	36	63	107	140	181	208	248	277	309	313	370	356	363	358	361	390	421
2008	4	8	13	29	50	91	113	181	194	252	280	306	322	350	363	369	371	368	403	436
2009	4	7	11	20	39	74	112	133	194	273	267	305	332	343	367	365	375	359	392	439
2010	4	14	18	32	54	85	120	156	193	225	262	294	320	346	367	364	371	363	400	437
2011	4	14	17	25	47	81	134	164	174	305	272	297	312	339	356	344	375	369	399	439
2012	4	14	12	27	48	83	126	181	214	249	268	299	309	339	350	352	380	372	394	433
2013	4	14	13	21	40	72	122	179	227	259	272	306	302	342	348	354	387	376	384	417
2014	4	8	11	44	34	75	150	195	246	296	280	308	298	333	349	367	386	397	393	405
2015	4	8	11	44	34	75	150	195	246	296	300	324	306	336	355	370	393	427	424	420
2016	4	8	43	57	63	82	116	171	253	319	308	324	323	341	369	380	400	433	421	440
2017	4	9	26	58	76	94	103	149	207	291	316	336	338	343	380	376	424	433	421	460
2018	4	9	32	47	86	88	154	174	216	286	323	346	357	349	388	371	419	430	457	480
2019	4	9	32	47	86	88	154	174	216	286	324	357	365	376	392	364	415	409	480	500

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

Table 4.9: Model estimates of Yellowfin Sole age 2+ total biomass (t) from the 2019 and 2020 stock assessments, Model 18.1, Model 18.1, and 18.2.

	Model 18.2 (2020)			Model 18.1 (2020)			Model 18.1 (2019)
	Biomass (t)	LCI	HCI	Biomass (t)	LCI	HCI	Biomass (t)
1954	2,286,480	1,902,960	2,747,310	2,148,670	1,806,100	2,556,210	2,144,750
1955	2,244,950	1,882,290	2,677,490	2,124,920	1,799,680	2,508,940	2,121,150
1956	2,198,900	1,859,310	2,600,510	2,097,070	1,791,370	2,454,950	2,093,480
1957	2,153,360	1,840,490	2,519,400	2,069,620	1,787,200	2,396,670	2,066,230
1958	2,136,280	1,859,300	2,454,530	2,069,880	1,819,660	2,354,520	2,066,780
1959	2,132,960	1,906,140	2,386,770	2,082,870	1,878,090	2,309,980	2,080,230
1960	2,012,340	1,849,180	2,189,890	1,977,480	1,829,980	2,136,870	1,975,550
1961	1,637,170	1,543,530	1,736,500	1,615,710	1,529,200	1,707,120	1,614,830
1962	1,199,170	1,146,280	1,254,500	1,186,380	1,131,260	1,244,190	1,187,020
1963	887,952	839,583	939,108	875,000	825,009	928,019	876,083
1964	911,499	866,169	959,200	896,472	850,162	945,305	897,522
1965	892,030	851,247	934,767	875,128	833,909	918,385	876,729
1966	932,953	892,498	975,242	913,938	874,017	955,683	915,086
1967	914,946	875,023	956,691	893,599	855,205	933,717	893,987
1968	838,641	799,568	879,622	813,045	776,713	851,077	812,292
1969	879,883	836,550	925,462	845,506	806,348	886,566	843,211
1970	866,260	817,714	917,687	817,343	775,214	861,761	813,113
1971	954,861	896,886	1,016,580	882,954	834,348	934,392	876,828
1972	1,058,690	988,791	1,133,540	957,096	900,262	1,017,520	949,354
1973	1,353,890	1,267,840	1,445,780	1,215,860	1,147,060	1,288,790	1,200,300
1974	1,647,840	1,544,370	1,758,250	1,471,250	1,389,450	1,557,880	1,452,940
1975	2,050,800	1,925,290	2,184,480	1,838,520	1,740,070	1,942,540	1,814,240
1976	2,409,330	2,264,070	2,563,900	2,155,740	2,042,470	2,275,300	2,127,170
1977	2,768,530	2,604,430	2,942,970	2,476,840	2,349,320	2,611,290	2,444,030
1978	3,108,590	2,926,830	3,301,650	2,782,730	2,641,820	2,931,150	2,745,610
1979	3,304,210	3,107,960	3,512,850	2,952,660	2,800,700	3,112,870	2,911,750
1980	3,517,060	3,307,890	3,739,460	3,144,310	2,982,320	3,315,100	3,099,850
1981	3,707,350	3,487,360	3,941,220	3,319,080	3,148,540	3,498,850	3,271,190
1982	3,840,390	3,614,180	4,080,760	3,439,660	3,264,840	3,623,840	3,388,970
1983	3,814,550	3,587,200	4,056,300	3,419,430	3,243,240	3,605,190	3,367,930
1984	4,081,170	3,838,180	4,339,560	3,656,660	3,468,930	3,854,550	3,599,760
1985	4,104,890	3,854,550	4,371,490	3,672,420	3,478,780	3,876,850	3,612,850
1986	3,798,830	3,556,460	4,057,720	3,384,260	3,196,650	3,582,880	3,325,520
1987	3,780,260	3,531,070	4,047,040	3,350,980	3,158,700	3,554,960	3,289,470
1988	3,675,670	3,427,740	3,941,550	3,257,480	3,065,340	3,461,660	3,194,590
1989	3,762,820	3,502,760	4,042,190	3,325,790	3,124,260	3,540,320	3,257,340
1990	3,611,280	3,356,600	3,885,290	3,191,020	2,992,930	3,402,210	3,122,590
1991	3,739,510	3,477,640	4,021,110	3,313,930	3,109,500	3,531,810	3,245,140
1992	3,974,950	3,698,850	4,271,670	3,523,020	3,307,680	3,752,390	3,458,920
1993	4,049,530	3,766,880	4,353,400	3,592,320	3,371,330	3,827,800	3,496,970
1994	4,097,340	3,811,770	4,404,300	3,641,190	3,417,220	3,879,840	3,542,840
1995	3,834,710	3,560,820	4,129,660	3,408,480	3,192,530	3,639,030	3,312,770
1996	3,728,610	3,459,850	4,018,240	3,316,600	3,104,000	3,543,750	3,229,850
1997	3,763,620	3,491,160	4,057,340	3,343,580	3,128,140	3,573,850	3,248,810
1998	3,438,880	3,181,270	3,717,350	3,049,080	2,844,730	3,268,100	2,970,390
1999	3,206,790	2,961,350	3,472,580	2,841,640	2,646,260	3,051,450	2,782,050
2000	3,250,520	3,004,660	3,516,490	2,884,760	2,688,970	3,094,810	2,832,140
2001	3,148,860	2,909,040	3,408,440	2,798,910	2,607,130	3,004,790	2,755,720

2002	3,183,720	2,943,740	3,443,270	2,835,350	2,643,190	3,041,470	2,797,500
2003	3,416,780	3,163,620	3,690,190	3,050,820	2,847,800	3,268,300	3,014,610
2004	3,653,900	3,386,690	3,942,200	3,266,740	3,052,420	3,496,110	3,226,680
2005	3,764,640	3,491,140	4,059,570	3,374,880	3,154,770	3,610,340	3,331,470
2006	3,745,810	3,472,350	4,040,800	3,360,680	3,140,170	3,596,680	3,304,740
2007	3,747,670	3,471,700	4,045,570	3,367,390	3,143,980	3,606,670	3,300,160
2008	3,585,080	3,315,670	3,876,380	3,223,940	3,004,760	3,459,100	3,149,710
2009	3,365,630	3,104,790	3,648,380	3,026,220	2,813,060	3,255,530	2,966,710
2010	3,398,180	3,131,750	3,687,270	3,056,460	2,838,200	3,291,500	2,996,190
2011	3,398,460	3,127,330	3,693,100	3,059,560	2,836,510	3,300,150	3,002,560
2012	3,339,860	3,065,280	3,639,030	3,003,730	2,777,110	3,248,850	2,952,060
2013	3,242,770	2,967,160	3,543,990	2,913,400	2,685,060	3,161,160	2,867,420
2014	2,979,390	2,715,320	3,269,150	2,683,290	2,462,380	2,924,020	2,642,960
2015	2,964,580	2,690,840	3,266,160	2,670,070	2,439,520	2,922,410	2,636,060
2016	3,093,610	2,797,760	3,420,760	2,784,380	2,533,980	3,059,530	2,760,450
2017	3,013,720	2,710,700	3,350,610	2,712,490	2,454,200	2,997,960	2,679,370
2018	3,116,980	2,783,110	3,490,900	2,807,760	2,520,690	3,127,520	2,757,730
2019	3,234,230	2,851,490	3,668,350	2,913,730	2,581,300	3,288,970	2,797,800
2020	3,283,680	2,849,560	3,783,930	2,958,850	2,578,150	3,395,760	-

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

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). Data come from the 'plusnw' extended survey area. Females are presented first, followed by males.

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)
1977	60
1978	71
1979	147
1980	92
1981	74
1982	158
1983	254
1984	218
1985	105
1986	68
1987	92
1988	138
1989	148
1990	129
1991	118
1992	60
1993	95
1994	91
1995	95
1996	72
1997	76
1998	79
1999	61
2000	72
2001	75
2002	76
2003	78
2004	114
2005	94
2006	74
2007	74
2008	69
2009	60
2010	119
2011	101
2012	83
2013	75
2014	83
2015	65
2016	98
2017	112
2018	73
2019	85

Table 4.13: Comparison of likelihood values for survey and fishery age, selectivity, survey biomass, recruitment, catchability, and total likelihood for Models 18.1 and 18.2.

Likelihood component	Model 18.1	Model 18.2
Survey age	604.51	575.56
Fishery age	658.01	620.17
Selectivity	61.41	61.16
Survey biomass	93.23	96.41
Recruitment	28.88	29.67
Catchability	0.0084	0.007
Total	1446.05	1382.98

Table 4.14: Parameter values and their 95% confidence intervals, estimated within the preferred stock assessment model, Model 18.2.

Name	Value	Standard Deviation	Name	Value	Standard Deviation
male natural mortality	1.3469e-01	1.3113e-03	TotBiom	2050.8	64.771
alpha (q-temp model)	-2.6698e-01	4.0101e-02	TotBiom	2409.3	74.926
beta (q-temp model)	5.9633e-02	1.2970e-02	TotBiom	2768.5	84.603
beta (survey start date)	1.1568e-02	2.9984e-03	TotBiom	3108.6	93.669
beta (start date/temp interaction)	-1.0737e-02	2.8669e-03	TotBiom	3304.2	101.180
mean log recruitment	1.0403e+00	9.3764e-02	TotBiom	3517.1	107.850
log_avg_fmort	-2.4704e+00	7.9867e-02	TotBiom	3707.3	113.420
sel_slope_fsh_f	1.1963e+00	7.8199e-02	TotBiom	3840.4	116.600
sel50_fsh_f	8.6780e+00	2.3877e-01	TotBiom	3814.5	117.230
sel_slope_fsh_m	1.4005e+00	9.7291e-02	TotBiom	4081.2	125.300
sel50_fsh_m	8.0154e+00	2.2630e-01	TotBiom	4104.9	129.180
sel_slope_srv	1.5421e+00	8.1202e-02	TotBiom	3798.8	125.260
sel50_srv	5.0747e+00	6.7669e-02	TotBiom	3780.3	128.930
sel_slope_srv_m	1.0082e-02	7.0867e-02	TotBiom	3675.7	128.390
sel50_srv_m	-2.1704e-03	1.6511e-02	TotBiom	3762.8	134.780
R_logalpha	-4.4363e+00	4.6851e-01	TotBiom	3611.3	132.100
R_logbeta	-6.6098e+00	2.8382e-01	TotBiom	3739.5	135.790
msy	4.6886e+02	1.6619e+02	TotBiom	3975.0	143.130
Fmsy	1.8873e-01	7.8768e-02	TotBiom	4049.5	146.550
logFmsy	-1.6674e+00	4.1735e-01	TotBiom	4097.3	148.050
Fmsyr	1.1874e-01	3.4786e-02	TotBiom	3834.7	142.130
logFmsyr	-2.1308e+00	2.9297e-01	TotBiom	3728.6	139.520
Bmsy	5.5970e+02	8.5099e+01	TotBiom	3763.6	141.460
Bmsyr	3.9488e+03	3.6801e+02	TotBiom	3438.9	133.930
TotBiom	2.2865e+03	2.1035e+02	TotBiom	3206.8	127.720
TotBiom	2.2450e+03	1.9816e+02	TotBiom	3250.5	127.870
TotBiom	2.1989e+03	1.8476e+02	TotBiom	3148.9	124.770
TotBiom	2.1534e+03	1.6929e+02	TotBiom	3183.7	124.800
TotBiom	2.1363e+03	1.4851e+02	TotBiom	3416.8	131.560
TotBiom	2.1330e+03	1.2000e+02	TotBiom	3653.9	138.790
TotBiom	2.0123e+03	8.5115e+01	TotBiom	3764.6	142.020
TotBiom	1.6372e+03	4.8224e+01	TotBiom	3745.8	142.030
TotBiom	1.1992e+03	2.7049e+01	TotBiom	3747.7	143.380
TotBiom	8.8795e+02	2.4873e+01	TotBiom	3585.1	140.090
TotBiom	9.1150e+02	2.3252e+01	TotBiom	3365.6	135.800
TotBiom	8.9203e+02	2.0875e+01	TotBiom	3398.2	138.780
TotBiom	9.3295e+02	2.0682e+01	TotBiom	3398.5	141.340
TotBiom	9.1495e+02	2.0413e+01	TotBiom	3339.9	143.330
TotBiom	8.3864e+02	2.0009e+01	TotBiom	3242.8	144.090
TotBiom	8.7988e+02	2.2222e+01	TotBiom	2979.4	138.340
TotBiom	8.6626e+02	2.4985e+01	TotBiom	2964.6	143.690
TotBiom	9.5486e+02	2.9912e+01	TotBiom	3093.6	155.590
TotBiom	1.0587e+03	3.6169e+01	TotBiom	3013.7	159.790
TotBiom	1.3539e+03	4.4466e+01	TotBiom	3117.0	176.710
TotBiom	1.6478e+03	5.3447e+01	TotBiom	3234.2	203.880

Table 4.15: Comparison of reference points for Model 18.2, 18.1 (2020), and Model 18.1 (2019) (upper panel), and Models 18.3 and 18.4 (lower panel). Values are in metric tons (t). Female, then male natural mortality is listed for each year and model.

	Model 18.2 (2020)		Model 18.1 (2020)		Model 18.1 (2019)	
Quantity	2021	2022	2021	2022	2020	2021
M (natural mortality rate)	0.12, 0.135	0.12, 0.135	0.12, 0.12	0.12, 0.12	0.12, 0.12	0.12, 0.12
Tier	1a	1a	1a	1a	1a	1a
Projected total (age 6+) biomass (t)	2,755,870	3,025,430	2,486,700	2,733,340	2,466,130	2,472,760
Projected female spawning biomass (t)	1,040,900	996,044	847,101	809,813	859,256	820,588
$B_{100\%}$	1,528,700	1,528,700	1,292,750	1,292,750	1,274,470	1,274,470
$B_{MSY\%}$	559,704	559,704	477,288	477,288	467,194	467,194
F_{OFL}	0.124	0.124	0.123	0.123	0.117	0.117
$maxF_{ABC}$	0.114	0.114	0.112	0.112	0.106	0.106
F_{ABC}	0.114	0.114	0.112	0.112	0.106	0.106
OFL	341,571	374,982	306,410	336,801	289,512	290,290
$maxABC$	313,477	344,140	278,370	305,980	262,632	263,337
ABC	313,477	344,140	278,370	305,980	262,632	263,337
Status	2019	2020	2019	2020	2019	2020
Overfishing	No	n/a	No	n/a	No	n/a
Overfished	n/a	No	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No	n/a	No

	Model 18.3		Model 18.4	
Quantity	2021	2022	2021	2022
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)	2,623,500	2,858,590	3,218,080	3,526,600
Projected female spawning biomass (t)	1,005,830	957,179	1,239,380	1,192,870
$B_{100\%}$	1,480,750	1,480,750	1,672,060	1,672,060
$B_{MSY\%}$	551,169	551,169	609,176	609,176
F_{OFL}	0.118	0.118	0.125	0.125
$maxF_{ABC}$	0.107	0.107	0.116	0.116
F_{ABC}	0.107	0.107	0.116	0.116
OFL	310,309	338,115	403,664	442,363
$maxABC$	280,409	305,536	374,641	410,557
ABC	280,409	305,536	374,641	410,557
Status	2019	2020	2019	2020
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 18.1 were based on estimated catches of 118,642 t in 2020, and projections for Model 18.2 were based on 139,271 t used in place of maximum ABC for 2021. Projections for Models 18.3 and 18.4 were based on estimated catches of 139,271 used in place of maximum ABC for 2021.

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

	Model 18.2		Model 18.1	
	Full selection F	Catch/Total Biomass	Full selection F	Catch/Total Biomass
1954	0.007	0.005	0.007	0.006
1955	0.008	0.007	0.009	0.007
1956	0.015	0.011	0.015	0.012
1957	0.015	0.011	0.016	0.012
1958	0.030	0.021	0.031	0.021
1959	0.141	0.087	0.145	0.089
1960	0.488	0.227	0.500	0.231
1961	1.365	0.338	1.398	0.343
1962	5.061	0.351	4.912	0.355
1963	0.353	0.097	0.355	0.098
1964	0.319	0.123	0.318	0.125
1965	0.248	0.060	0.251	0.061
1966	0.468	0.110	0.472	0.112
1967	0.619	0.177	0.622	0.182
1968	0.553	0.100	0.569	0.104
1969	0.674	0.190	0.678	0.198
1970	0.747	0.154	0.742	0.163
1971	0.610	0.168	0.623	0.182
1972	0.316	0.045	0.329	0.050
1973	0.419	0.058	0.448	0.064
1974	0.131	0.026	0.148	0.029
1975	0.116	0.032	0.127	0.035
1976	0.112	0.023	0.122	0.026
1977	0.052	0.021	0.056	0.024
1978	0.101	0.045	0.111	0.050
1979	0.058	0.030	0.065	0.034
1980	0.065	0.025	0.072	0.028
1981	0.051	0.026	0.057	0.029
1982	0.039	0.025	0.043	0.028
1983	0.040	0.028	0.044	0.032
1984	0.062	0.039	0.068	0.044
1985	0.091	0.055	0.101	0.062
1986	0.083	0.055	0.093	0.062
1987	0.081	0.048	0.091	0.054
1988	0.102	0.061	0.115	0.069
1989	0.076	0.041	0.086	0.046
1990	0.035	0.023	0.039	0.026
1991	0.042	0.031	0.047	0.035
1992	0.052	0.037	0.058	0.041
1993	0.045	0.026	0.051	0.029
1994	0.055	0.034	0.061	0.038
1995	0.050	0.033	0.056	0.037
1996	0.049	0.035	0.054	0.039
1997	0.081	0.049	0.090	0.055
1998	0.050	0.029	0.056	0.033
1999	0.037	0.022	0.042	0.024
2000	0.046	0.026	0.051	0.029
2001	0.034	0.020	0.038	0.023

2002	0.038	0.024	0.041	0.026
2003	0.034	0.023	0.037	0.026
2004	0.030	0.021	0.034	0.023
2005	0.036	0.025	0.040	0.028
2006	0.035	0.026	0.038	0.030
2007	0.048	0.032	0.053	0.036
2008	0.064	0.042	0.070	0.046
2009	0.043	0.032	0.048	0.036
2010	0.049	0.035	0.053	0.039
2011	0.063	0.044	0.069	0.049
2012	0.062	0.044	0.067	0.049
2013	0.074	0.051	0.081	0.057
2014	0.073	0.053	0.080	0.058
2015	0.064	0.043	0.070	0.048
2016	0.069	0.044	0.076	0.049
2017	0.063	0.044	0.070	0.049
2018	0.062	0.042	0.068	0.047
2019	0.063	0.040	0.069	0.044
2020	0.062	0.037	0.069	0.041

Table 4.17: Model estimates of Yellowfin Sole female spawning biomass (FSB) in metric tons (t) and upper (HCI) and lower (LCI) 95% confidence intervals from the 2019 and 2020 stock assessments, including Model 18.1, 18.1 and 18.2.

	Model 18.2			Model 18.1 (2020)			Model 18.1 (2019)
	FSB (t)	LCI	HCI	FSB (t)	LCI	HCI	Biomass (t)
1954	884,722	662,312	1,181,820	831,646	624,508	1,107,490	830,061
1955	892,774	677,305	1,176,790	838,885	638,509	1,102,140	837,274
1956	884,073	678,827	1,151,380	830,324	639,793	1,077,590	828,710
1957	861,259	668,151	1,110,180	808,451	629,565	1,038,170	806,853
1958	827,415	647,414	1,057,460	776,270	609,926	987,980	774,705
1959	755,336	591,812	964,044	707,612	557,218	898,598	706,084
1960	575,442	436,328	758,910	536,489	410,174	701,705	534,891
1961	286,991	174,537	471,900	265,612	164,992	427,594	263,547
1962	99,655	64,235	154,604	97,766	65,711	145,458	97,363
1963	118,327	99,567	140,623	117,462	98,944	139,447	117,318
1964	138,213	119,492	159,866	136,839	118,654	157,811	136,803
1965	162,997	141,023	188,396	160,947	139,592	185,569	161,105
1966	195,037	165,507	229,835	191,834	163,422	225,186	192,229
1967	202,923	171,114	240,644	198,895	168,293	235,063	199,639
1968	197,797	169,571	230,720	193,494	166,218	225,245	194,542
1969	184,560	161,193	211,314	179,973	156,945	206,380	181,248
1970	136,760	118,764	157,484	132,030	114,530	152,203	133,445
1971	112,496	97,942	129,211	107,178	93,346	123,059	108,156
1972	91,698	77,441	108,579	85,747	72,710	101,120	85,842
1973	93,427	77,819	112,164	85,610	71,639	102,307	81,685
1974	103,335	86,334	123,684	93,785	78,818	111,592	88,806
1975	157,584	134,541	184,572	146,665	126,680	169,802	139,355
1976	224,580	196,405	256,797	208,115	183,873	235,553	199,288
1977	329,159	293,494	369,158	301,983	271,754	335,576	291,616
1978	465,287	420,855	514,409	420,333	383,707	460,455	408,412
1979	609,933	555,769	669,375	540,734	497,465	587,766	527,471
1980	773,293	708,550	843,951	674,926	624,665	729,232	660,172
1981	927,400	852,463	1,008,920	799,029	742,128	860,294	782,548
1982	1,016,570	936,367	1,103,630	868,826	808,914	933,175	851,469
1983	1,144,750	1,056,750	1,240,070	973,478	908,725	1,042,850	954,690
1984	1,247,780	1,153,600	1,349,660	1,056,060	987,701	1,129,160	1,035,829
1985	1,314,650	1,214,260	1,423,330	1,105,990	1,033,850	1,183,160	1,084,490
1986	1,310,280	1,207,110	1,422,270	1,094,120	1,020,480	1,173,070	1,072,050
1987	1,313,610	1,206,710	1,429,990	1,089,120	1,013,090	1,170,860	1,066,240
1988	1,252,240	1,146,550	1,367,680	1,031,550	956,500	1,112,500	1,008,740
1989	1,227,990	1,120,610	1,345,670	1,005,360	929,165	1,087,810	981,913
1990	1,243,850	1,134,790	1,363,380	1,016,970	939,717	1,100,570	993,327
1991	1,339,640	1,225,040	1,464,960	1,097,840	1,016,920	1,185,210	1,075,230
1992	1,442,100	1,321,270	1,573,990	1,183,890	1,098,840	1,275,540	1,158,770
1993	1,497,570	1,372,310	1,634,260	1,229,250	1,141,100	1,324,210	1,194,730
1994	1,503,800	1,378,000	1,641,090	1,233,760	1,145,280	1,329,080	1,198,140
1995	1,504,890	1,377,830	1,643,670	1,233,100	1,143,680	1,329,520	1,197,610
1996	1,423,790	1,301,550	1,557,530	1,164,220	1,078,100	1,257,220	1,130,820
1997	1,382,480	1,261,910	1,514,560	1,128,500	1,043,500	1,220,430	1,094,570
1998	1,299,720	1,183,340	1,427,540	1,057,830	975,673	1,146,910	1,030,180
1999	1,283,210	1,167,570	1,410,300	1,044,110	962,317	1,132,860	1,022,290
2000	1,262,580	1,148,180	1,388,380	1,027,120	946,034	1,115,150	1,009,240

2001	1,252,550	1,139,250	1,377,120	1,019,640	939,208	1,106,960	1,005,440
2002	1,246,590	1,134,110	1,370,220	1,015,380	935,424	1,102,170	1,004,020
2003	1,254,250	1,142,210	1,377,290	1,023,540	943,804	1,110,010	1,013,490
2004	1,290,820	1,177,190	1,415,420	1,056,100	975,133	1,143,780	1,045,190
2005	1,312,030	1,197,690	1,437,270	1,075,540	993,964	1,163,820	1,061,950
2006	1,343,430	1,227,030	1,470,860	1,103,030	1,019,810	1,193,030	1,083,390
2007	1,356,430	1,238,770	1,485,260	1,114,710	1,030,390	1,205,930	1,089,200
2008	1,329,770	1,212,720	1,458,120	1,092,390	1,008,210	1,183,590	1,064,870
2009	1,284,240	1,168,990	1,410,860	1,053,950	970,796	1,144,230	1,029,109
2010	1,255,370	1,141,460	1,380,650	1,030,310	947,857	1,119,940	1,004,290
2011	1,225,310	1,112,820	1,349,160	1,006,290	924,578	1,095,220	980,926
2012	1,201,050	1,088,680	1,325,020	986,459	904,470	1,075,880	962,024
2013	1,185,240	1,071,790	1,310,710	973,272	890,059	1,064,270	949,339
2014	1,132,950	1,020,240	1,258,100	927,967	844,837	1,019,280	903,492
2015	1,120,640	1,005,550	1,248,920	916,683	831,228	1,010,920	890,681
2016	1,117,570	999,623	1,249,430	913,577	825,415	1,011,160	886,357
2017	1,088,840	969,985	1,222,270	888,630	799,193	988,076	861,995
2018	1,086,590	964,287	1,224,400	886,212	793,482	989,779	858,392
2019	1,100,300	972,439	1,244,970	897,576	799,764	1,007,350	869,838
2020	1,086,650	955,134	1,236,260	885,645	784,157	1,000,270	-

Table 4.18: Model estimates of age 1 recruitment (in billions of fish), 1954-2019, with 95% lower and upper confidence intervals (LCI, HCI) for Model 18.1 and 18.2.

Year	Model 18.1			Model 18.2		
	Recruitment	LCI	HCI	Recruitment	LCI	HCI
1954	2.037	1.469	2.605	1.877	0.957	2.797
1955	1.661	1.243	2.079	2.057	1.481	2.634
1956	1.430	1.023	1.837	1.674	1.254	2.094
1957	5.331	3.490	7.172	1.446	1.048	1.844
1958	3.526	1.759	5.292	5.454	3.607	7.302
1959	2.257	1.423	3.091	3.670	1.637	5.703
1960	1.882	1.459	2.305	2.362	1.417	3.307
1961	1.028	0.824	1.232	1.977	1.535	2.419
1962	1.920	1.659	2.181	1.088	0.875	1.301
1963	0.996	0.810	1.182	2.063	1.783	2.343
1964	0.923	0.748	1.098	1.076	0.874	1.279
1965	1.197	0.992	1.403	0.999	0.807	1.190
1966	1.225	1.004	1.446	1.310	1.083	1.537
1967	2.572	2.224	2.920	1.359	1.110	1.609
1968	3.932	3.479	4.385	2.907	2.494	3.319
1969	4.029	3.560	4.498	4.532	3.983	5.081
1970	5.316	4.770	5.862	4.690	4.121	5.259
1971	5.913	5.340	6.486	6.200	5.530	6.871
1972	4.652	4.159	5.146	6.898	6.190	7.607
1973	3.225	2.832	3.618	5.427	4.822	6.031
1974	4.338	3.890	4.787	3.758	3.283	4.234
1975	5.095	4.617	5.574	5.046	4.498	5.595
1976	3.352	2.977	3.727	5.913	5.324	6.503
1977	4.221	3.796	4.647	3.879	3.426	4.331
1978	2.767	2.433	3.101	4.875	4.357	5.393
1979	1.770	1.509	2.031	3.193	2.793	3.593
1980	3.426	3.057	3.796	2.044	1.735	2.354
1981	2.560	2.245	2.874	3.971	3.521	4.421
1982	7.423	6.833	8.013	2.983	2.602	3.365
1983	1.375	1.149	1.601	8.682	7.925	9.438
1984	6.153	5.633	6.674	1.608	1.338	1.878
1985	2.132	1.853	2.412	7.192	6.532	7.852
1986	1.641	1.401	1.881	2.492	2.153	2.830
1987	2.248	1.968	2.529	1.916	1.627	2.204
1988	3.089	2.754	3.423	2.621	2.281	2.961
1989	3.093	2.759	3.426	3.599	3.189	4.010
1990	1.545	1.319	1.771	3.604	3.195	4.014
1991	1.733	1.491	1.975	1.801	1.530	2.072
1992	3.841	3.452	4.229	2.026	1.734	2.318
1993	2.287	2.000	2.574	4.499	4.015	4.983
1994	1.926	1.665	2.187	2.683	2.332	3.034
1995	1.934	1.672	2.197	2.258	1.941	2.576
1996	4.764	4.314	5.215	2.264	1.946	2.582
1997	2.060	1.788	2.331	5.566	5.002	6.129
1998	1.712	1.470	1.955	2.401	2.073	2.729
1999	2.100	1.832	2.368	1.990	1.700	2.281
2000	2.948	2.622	3.274	2.430	2.108	2.752
2001	1.912	1.658	2.167	3.405	3.010	3.801

2002	2.578	2.270	2.886	2.209	1.904	2.513
2003	2.481	2.175	2.788	2.979	2.607	3.350
2004	3.824	3.414	4.235	2.868	2.499	3.237
2005	1.730	1.472	1.989	4.423	3.921	4.925
2006	1.959	1.667	2.250	2.005	1.696	2.313
2007	2.367	2.020	2.713	2.272	1.923	2.621
2008	2.161	1.818	2.503	2.746	2.331	3.161
2009	2.638	2.225	3.051	2.507	2.098	2.915
2010	3.719	3.142	4.297	3.059	2.566	3.552
2011	1.319	1.000	1.638	4.305	3.620	4.991
2012	0.645	0.415	0.875	1.522	1.151	1.893
2013	1.724	1.246	2.202	0.743	0.477	1.009
2014	1.814	1.221	2.408	1.990	1.433	2.547
2015	3.115	1.965	4.265	2.100	1.408	2.792
2016	4.696	2.387	7.006	3.617	2.275	4.960
2017	6.649	1.763	11.536	5.428	2.752	8.104
2018	2.257	-0.670	5.185	7.563	2.000	13.126
2019	2.460	-0.945	5.865	2.563	-0.756	5.882
2020	2.487	-0.989	5.963	2.797	-1.073	6.668

Table 4.19: Yellowfin Sole total allowable catch (TAC), overfishing limit (OFL), and acceptable biological catch (ABC) levels, 1980-2020. Data is in metric tons. Estimates for 2020 are calculated using Model 18.2, and the 2020 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	153,170
1990	207,650	278,900	n/a	80,584
1991	135,000	250,600	n/a	95,000
1992	235,000	372,000	452,000	159,038
1993	220,000	238,000	275,000	106,101
1994	150,325	230,000	269,000	144,544
1995	190,000	277,000	319,000	124,740
1996	200,000	278,000	342,000	129,659
1997	230,000	233,000	339,000	181,389
1998	220,000	220,000	314,000	101,201
1999	207,980	212,000	308,000	67,320
2000	123,262	191,000	226,000	83,850
2001	113,000	176,000	209,000	63,395
2002	86,000	115,000	136,000	72,999
2003	83,750	114,000	136,000	74,418
2004	86,075	114,000	135,000	69,046
2005	90,686	124,000	148,000	94,683
2006	95,701	121,000	144,000	99,068
2007	136,000	225,000	240,000	121,029
2008	225,000	248,000	265,000	148,894
2009	210,000	210,000	224,000	107,528
2010	219,000	219,000	234,000	118,624
2011	196,000	239,000	262,000	151,164
2012	202,000	203,000	222,000	147,183
2013	198,000	206,000	220,000	164,944
2014	184,000	239,800	259,700	156,778
2015	149,000	248,800	266,400	126,933
2016	144,000	211,700	228,100	130,500
2017	154,000	260,800	287,000	132,297
2018	154,000	277,500	306,700	131,543
2019	154,000	263,200	290,000	128,061
2020		296,060	321,794	127,020

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
2020	1,035,490	139,283	0.072
2021	993,883	139,283	0.075
2022	929,581	211,825	0.117
2023	872,590	216,500	0.117
2024	862,044	231,219	0.117
2025	887,339	242,687	0.117
2026	937,948	245,417	0.117
2027	972,307	238,982	0.117
2028	968,635	230,386	0.117
2029	932,046	221,810	0.117
2030	901,275	216,085	0.117
2031	877,483	211,742	0.117
2032	856,801	208,136	0.117
2033	842,065	204,621	0.116

Scenario 3 Harvest at average F over past 5 years			
Year	FSB	Catch	F
2020	1,035,490	139,278	0.072
2021	995,391	130,826	0.070
2022	949,454	119,382	0.064
2023	933,871	126,823	0.064
2024	960,553	139,613	0.064
2025	1,022,240	150,683	0.064
2026	1,111,970	156,803	0.064
2027	1,186,500	157,104	0.064
2028	1,216,640	155,195	0.064
2029	1,202,720	152,403	0.064
2030	1,189,080	150,762	0.064
2031	1,178,230	149,478	0.064
2032	1,166,340	148,509	0.064
2033	1,158,440	147,812	0.064

Scenario 4, Maximum Tier 3 ABC harvest permissible set at F60			
Year	FSB	Catch	F
2020	1,035,490	139,278	0.072
2021	999,711	106,494	0.057
2022	963,573	107,431	0.057
2023	952,987	114,543	0.057
2024	984,381	126,408	0.057
2025	1,050,820	136,780	0.057
2026	1,145,930	142,774	0.057
2027	1,226,310	143,536	0.057
2028	1,261,590	142,224	0.057
2029	1,251,320	140,026	0.057
2030	1,240,640	138,804	0.057
2031	1,232,180	137,849	0.057
2032	1,222,080	137,140	0.057
2033	1,215,720	136,652	0.057

Scenario 5 No fishing			
Year	FSB	Catch	F
2020	1,035,490	139,278	0.072
2021	1,018,240	0	0.000
2022	1,034,550	0	0.000
2023	1,072,780	0	0.000
2024	1,152,950	0	0.000
2025	1,270,730	0	0.000
2026	1,424,190	0	0.000
2027	1,568,840	0	0.000
2028	1,664,260	0	0.000
2029	1,702,260	0	0.000
2030	1,734,080	0	0.000
2031	1,763,040	0	0.000
2032	1,784,480	0	0.000
2033	1,807,010	0	0.000

Alternative 6, Determination of whether Yellowfin Sole are currently overfished			
Year	FSB	Catch	F
2020	1,035,490	139,278	0.0717795
2021	973,260	252,589	0.1399950
2022	868,877	238,342	0.1399990
2023	803,182	241,802	0.1399990
2024	785,672	257,424	0.1399990
2025	804,502	269,045	0.1399990
2026	847,300	270,224	0.1399990
2027	873,111	260,996	0.1399990
2028	863,223	249,933	0.1399990
2029	824,294	239,467	0.1399990
2030	792,769	231,555	0.1392770
2031	770,105	222,033	0.1360160
2032	753,154	214,750	0.1329730
2033	743,131	210,525	0.1311600

Scenario 7, Determination of whether stock is approaching an overfished condition			
Year	FSB	Catch	F
2020	1,035,490	139,278	0.0717795
2021	980,558	212,971	0.1168430
2022	894,244	204,706	0.1168540
2023	836,128	249,843	0.1399990
2024	813,722	264,120	0.1399990
2025	827,982	274,495	0.1399990
2026	866,662	274,589	0.1399990
2027	888,892	264,458	0.1399990
2028	875,847	252,644	0.1399990
2029	834,244	241,579	0.1399990
2030	800,486	233,701	0.1396320
2031	775,837	224,096	0.1366200
2032	757,230	216,275	0.1334690
2033	745,959	211,557	0.1315070

Table 4.21: Incidental catch of FMP Groundfish in the Yellowfin Sole fishery. Source: NMFS AKRO Blend/Catch Accounting System; 1991-present.

Year	Arrowtooth Fl.	Atka Mackerel	AK Plaice	Kamchatka Fl.	Other Flatfish	Flathead Sole	Flounder	Greenland Turbot	NA
1992	366	1	0	0	7,990	0	16,826	0	0
1993	1,017	0	0	0	3,847	0	9,620	4	0
1994	1,595	0	0	0	3,983	0	12,422	4	0
1995	345	0	0	0	2,904	3,929	0	67	12,239
1996	819	0	0	0	2,565	3,165	0	8	10,962
1997	386	0	0	0	4,754	3,896	0	4	17,222
1998	2,382	0	0	0	3,570	5,323	0	103	9,182
1999	1,631	32	0	0	2,765	2,309	0	69	11,449
2000	1,998	0	0	0	3,641	2,644	0	23	10,286
2001	1,845	0	0	0	3,969	3,231	0	32	6,844
2002	997	0	10,395	0	4,946	2,190	0	2	519
2003	1,132	16	8,513	0	213	2,856	0	3	0
2004	263	0	5,835	0	433	1,076	0	0	0
2005	645	110	8,711	0	653	1,247	0	6	0
2006	350	17	13,972	0	877	2,025	0	8	0
2007	213	0	16,357	0	2,850	1,735	0	0	0
2008	1,969	0	13,511	0	1,235	5,579	0	0	0
2009	1,851	0	10,631	0	241	3,497	0	3	0
2010	1,619	0	12,044	0	977	2,695	0	1	0
2011	2,331	0	18,305	91	1,585	3,229	0	5	0
2012	987	0	13,594	122	1,206	2,095	0	5	0
2013	2,042	0	15,978	148	388	4,179	0	35	0
2014	2,216	0	14,372	498	2,886	3,998	0	56	0
2015	1,685	0	11,681	427	1,041	3,337	0	42	0
2016	3,249	0	8,163	284	1,135	4,103	0	7	0
2017	1,262	0	12,782	164	1,734	3,106	0	8	0
2018	3,075	0	15,340	218	3,282	3,966	0	26	0
2019	3,177	0	12,850	228	1,439	4,128	0	6	0
2020	1,324	0	15,901	84	2,174	2,702	0	12	0

Year	Northern RF	Shortraker	Other RF	Pacific Cod	Pollock	Rock Sole	Sablefish	Sharpchin/Northern RF	SR/RE/Sharpchin/N. RF	Pacific Ocean Perch
1992	0	0	0	8,700	13,100	14,646	0	0	0	0
1993	0	0	0	8,723	15,253	7,300	0	0	0	4
1994	0	0	0	16,415	33,200	8,096	0	0	0	0
1995	0	0	3	13,181	27,041	7,486	0	0	0	0
1996	0	0	22	8,684	22,254	12,903	0	0	0	0
1997	0	0	12	12,825	24,100	16,693	0	0	0	0
1998	0	0	1	10,233	15,339	9,826	0	0	1	1
1999	0	0	3	4,383	8,701	10,774	4	0	15	12
2000	0	0	3	5,192	13,425	7,345	0	0	0	1
2001	0	0	0	6,531	16,502	5,810	0	1	0	0
2002	0	0	0	6,259	14,489	10,664	0	0	0	1
2003	0	0	0	4,634	11,578	8,314	0	0	0	10
2004	0	0	2	3,574	10,383	9,972	0	0	0	0
2005	3	0	0	3,769	10,312	10,090	1	0	0	15
2006	0	0	0	2,545	5,966	7,971	0	0	0	0
2007	0	0	0	2,519	4,020	8,241	0	0	0	0
2008	0	0	0	5,767	9,827	10,468	0	0	0	0
2009	0	0	0	10,716	7,036	8,978	0	0	0	0
2010	0	0	0	11,117	5,179	9,624	0	0	0	0
2011	0	0	0	16,204	8,673	9,694	0	0	0	0
2012	0	0	0	19,380	11,197	9,179	0	0	0	0
2013	0	0	0	24,339	20,171	7,688	0	0	0	16
2014	0	0	0	15,218	24,712	7,030	0	0	0	0
2015	0	0	0	12,168	21,281	9,772	0	0	0	0
2016	0	0	0	11,985	22,306	7,948	0	0	0	2
2017	0	0	0	14,648	23,414	12,196	0	0	0	0
2018	0	0	0	12,582	28,235	9,362	6	0	0	0
2019	0	0	0	11,682	23,051	9,073	0	0	0	0
2020	0	1	0	10,983	28,549	10,760	3	0	0	63

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.

	BSAI Skate	BSAI Squid	Octopus	Other	Other Species	Shark	Squid
1992	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	4
1995	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	10
1997	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	1
1999	0	0	0	26	0	0	0
2000	0	0	0	3	0	0	0
2001	0	0	0	21	0	0	0
2002	0	0	0	1,042	0	0	0
2003	0	1	0	0	1,529	0	0
2004	0	0	0	0	598	0	0
2005	0	0	0	0	944	0	0
2006	0	0	0	0	1,133	0	0
2007	0	0	0	0	1,410	0	0
2008	0	0	0	0	1,303	0	0
2009	0	0	0	0	1,785	0	0
2010	0	0	0	0	1,913	0	0
2011	2,107	0	1	0	0	1	0
2012	2,234	0	1	0	0	0	0
2013	2,683	0	0	0	0	0	0
2014	1,970	0	0	0	0	0	0
2015	1,072	0	0	0	0	1	0
2016	1,294	0	0	0	0	3	0
2017	1,931	0	0	0	0	1	0
2018	2,561	0	0	0	0	4	0
2019	3,493	0	0	0	0	2	0
2020	1,436	0	0	0	0	2	0

Table 4.23: Catch (t) of BSAI non-target and ecosystem species in the Yellowfin Sole directed fishery from 1992-2020 estimated from a combination of regional office reported catch and observer sampling of the catch. Source: NMFS AKRO Catch Accounting System, Nontarget Estimates; available for 2003 and later.

X	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Benthic.urochordata	1,671	1,701	674	520	114	347	204	155	133	147	197	116	260	225	319	207	188	68
Birds...Gull	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Birds...Murre	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Birds...Northern.Fulmar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Birds...Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Birds...Other.Alcid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Birds...Shearwaters	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Birds...Unidentified	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalves	1	1	1	0	0	1	1	1	1	0	1	0	1	0	0	0	1	0
Brittle.star.unidentified	34	32	28	19	7	18	5	4	14	13	5	11	11	6	2	2	4	2
Capelin	0	4	0	0	0	0	0	1	3	2	0	1	1	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
Eelpouts	19	12	7	4	2	5	5	5	29	14	51	69	30	56	8	26	21	7
Eulachon	0	0	0	0	5	0	0	0	0	0	0	0	0	3	0	0	0	0
Giant.Grenadier	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0
Greenlings	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Grenadier...Rattail.Grenadier.Unidentified	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gunnels	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hermit.crab.unidentified	87	51	83	26	35	36	15	17	15	10	6	8	4	2	2	0	2	2
Invertebrate.unidentified	556	625	421	177	40	70	30	25	65	121	25	44	6	7	11	3	1	0
Large.Sculpins	238	823	1,057	1,058	2,269	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
Large.Sculpins...Great.Sculpin	0	0	0	0	0	1,203	1,346	0	0	0	0	0	0	0	0	0	0	0
Large.Sculpins...Hemilepidotus.Unidentified	0	0	0	0	0	0	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
Large.Sculpins...Plain.Sculpin	0	0	0	0	0	1,273	914	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
Large.Sculpins...Warty.Sculpin	0	0	0	0	0	68	49	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
Misc.crabs	14	21	11	10	28	14	11	12	20	19	39	20	22	13	15	5	5	6
Misc.crustaceans	0	0	0	2	1	0	1	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	23
Misc.inverts..worms.etc.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other.osmerids	4	4	0	0	35	9	0	2	2	4	1	9	4	5	2	0	12	4
Other.Sculpins	1,157	131	105	68	195	38	74	0	0	0	0	0	0	0	0	0	0	0
Pacific.Sand.lance	0	0	0	0	0	0	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
Pandalid.shrimp	0	0	0	0	0	0	0	0	2	0	2	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
Scypho.jellies	111	298	115	46	42	145	223	152	307	179	463	804	381	67	93	161	676	114
Sea.anemone.unidentified	6	6	2	4	8	24	25	20	14	6	23	5	4	1	2	2	4	5
Sea.pens.whips	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	1,808	1,336
Snails	118	191	69	141	95	139	57	57	74	34	46	33	36	24	24	13	22	21
Sponge.unidentified	11	6	12	3	0	6	69	16	15	14	16	1	2	1	2	5	2	1
Squid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
State.managed.Rockfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stichaeidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf.smelt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
urchins.dollars.cucumbers	2	0	2	0	3	4	7	1	0	0	0	0	0	0	2	0	3	4

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

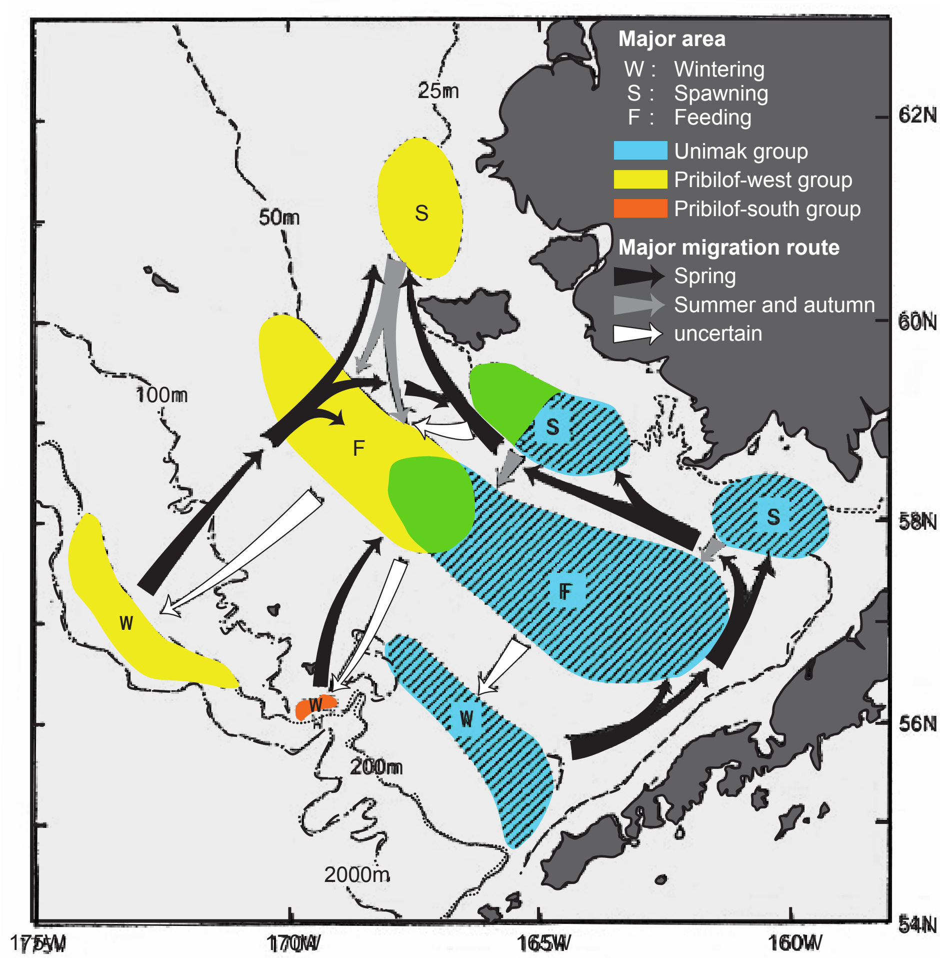


Figure 4.1: Distribution of wintering, spawning, and feeding areas for Yellowfin Sole in the Bering Sea, and observed regional grouping. Migration routes from wintering to feeding take place in spring, and the dates that Yellowfin Sole return to their wintering areas are unknown.

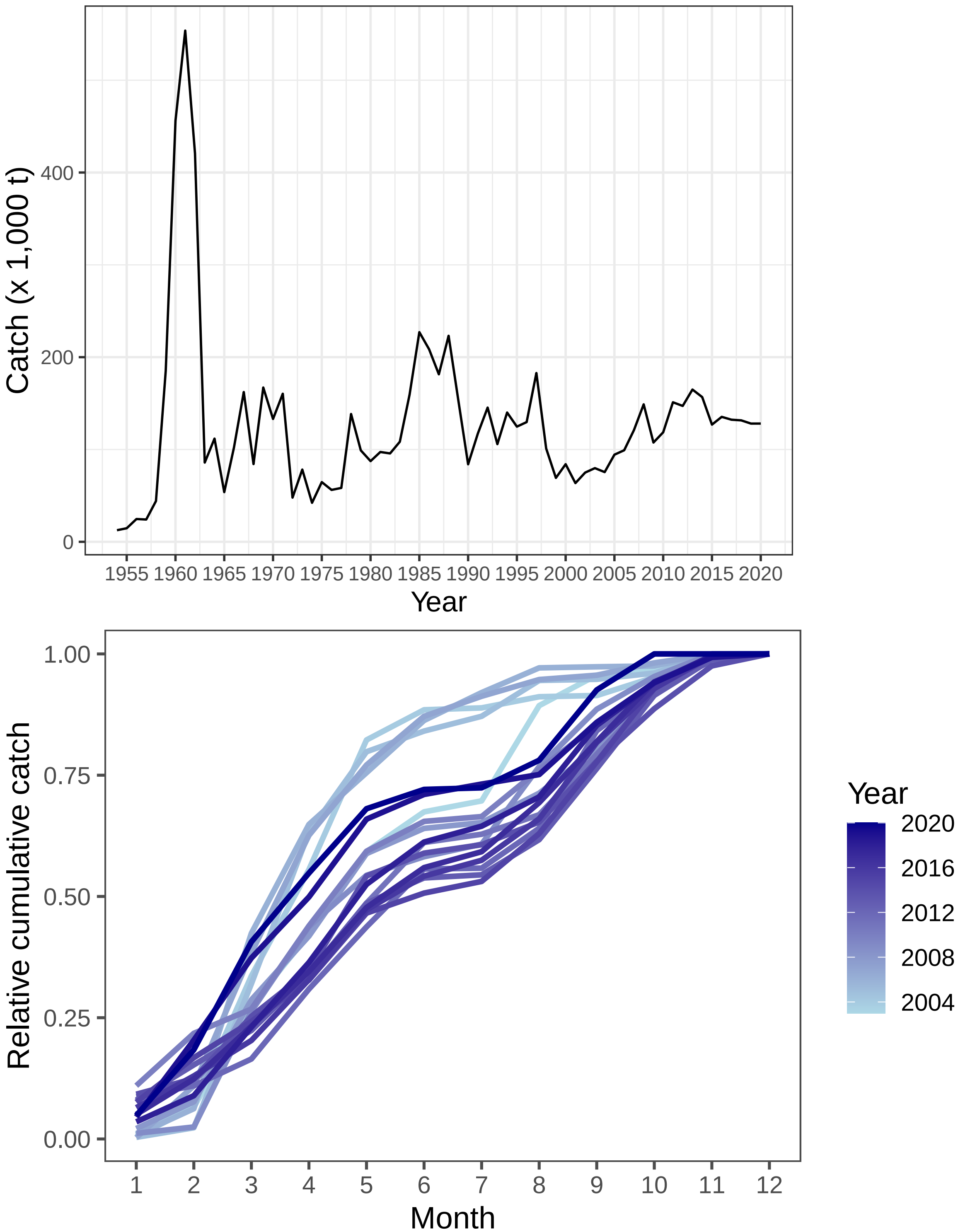


Figure 4.2: Yellowfin Sole annual total catch (1,000s t) in the Eastern Bering Sea from 1954-2020 (upper panel). Yellowfin Sole annual cumulative catch by month and year (non CDQ) 2003-November 15, 2020 (lower panel).

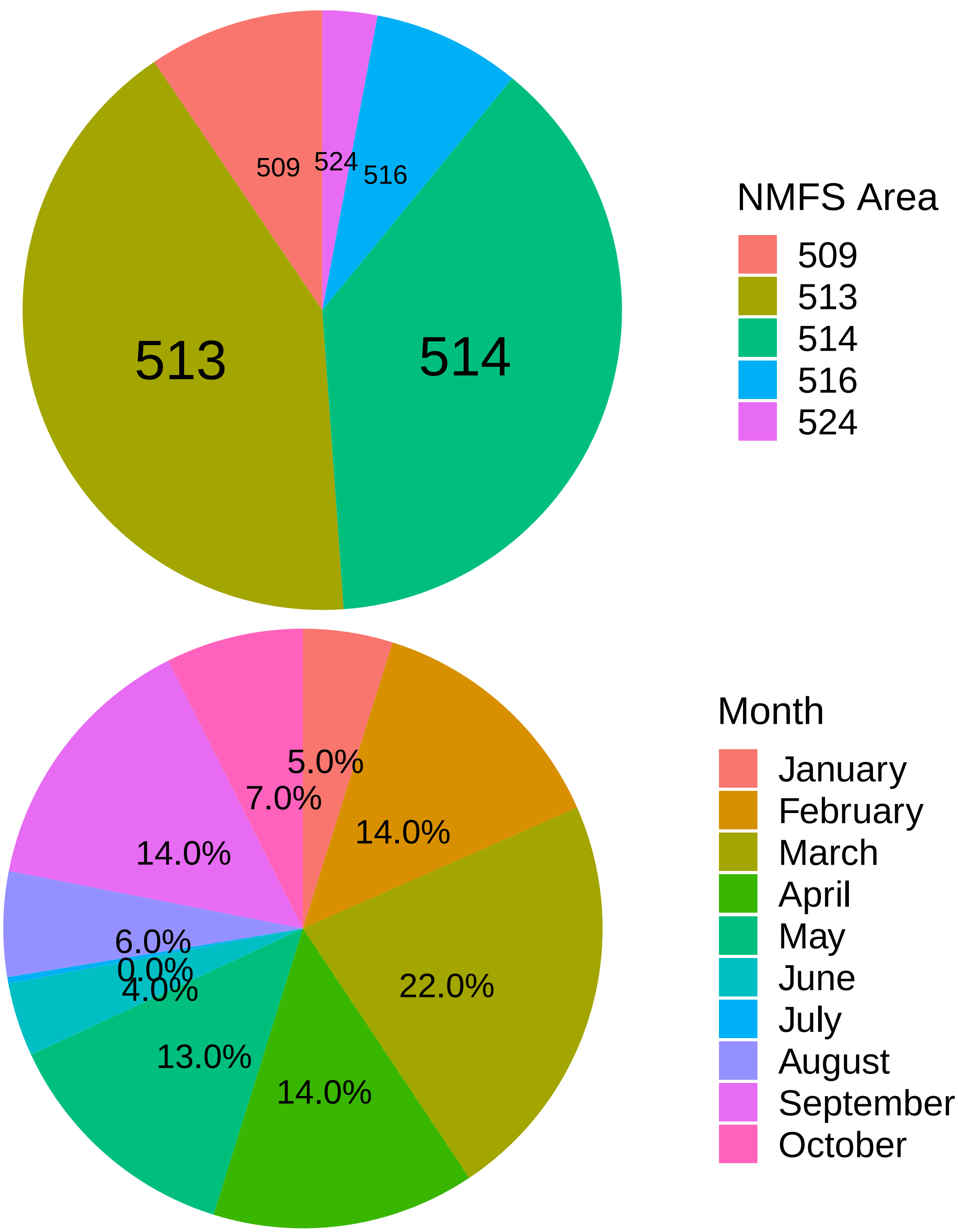


Figure 4.4: Yellowfin Sole catch proportion by area (upper panel) and by month (lower panel) in the Eastern Bering Sea in 2020.

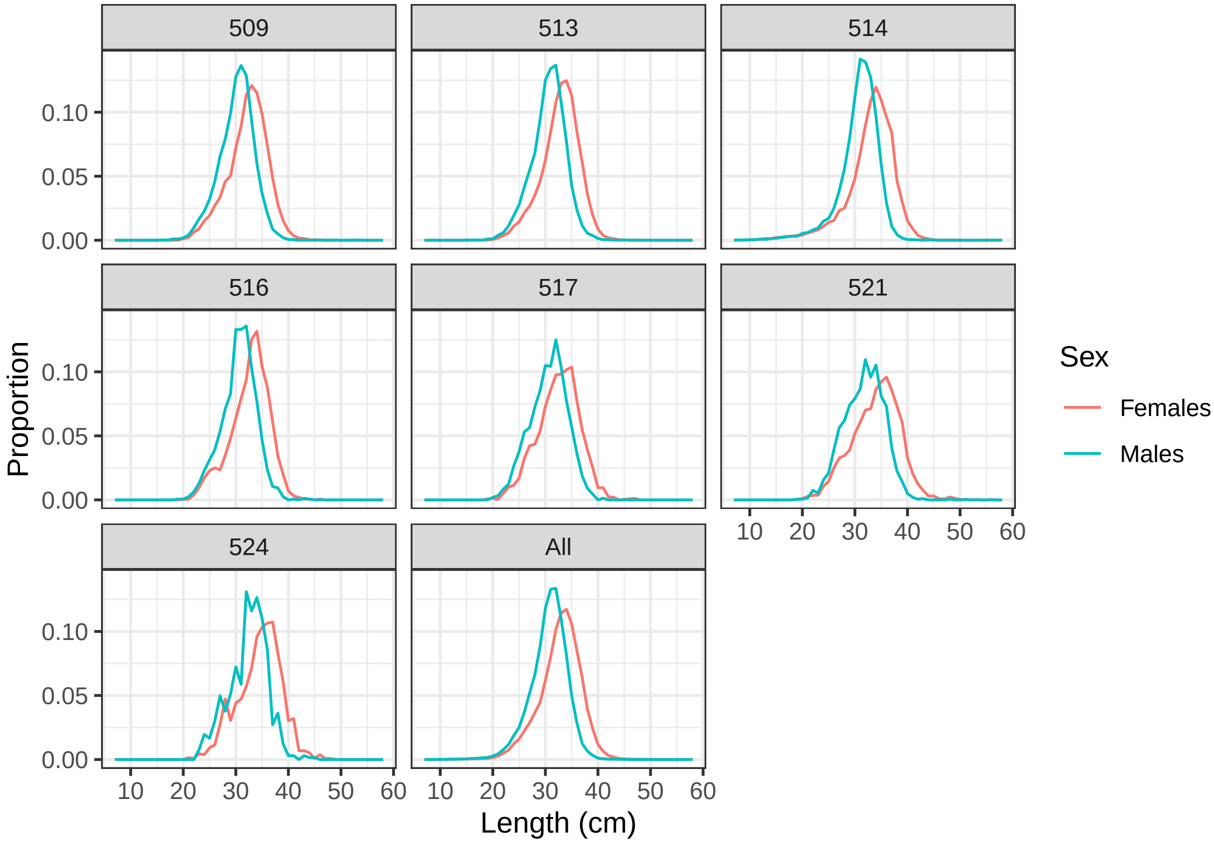


Figure 4.3: Size composition of the Yellowfin Sole catch in 2020 (through October 1) caught by trawl gear, by subarea and total, for the primary areas where Yellowfin Sole are caught, 509, 513, 514, 516, 517, 521, and 524.

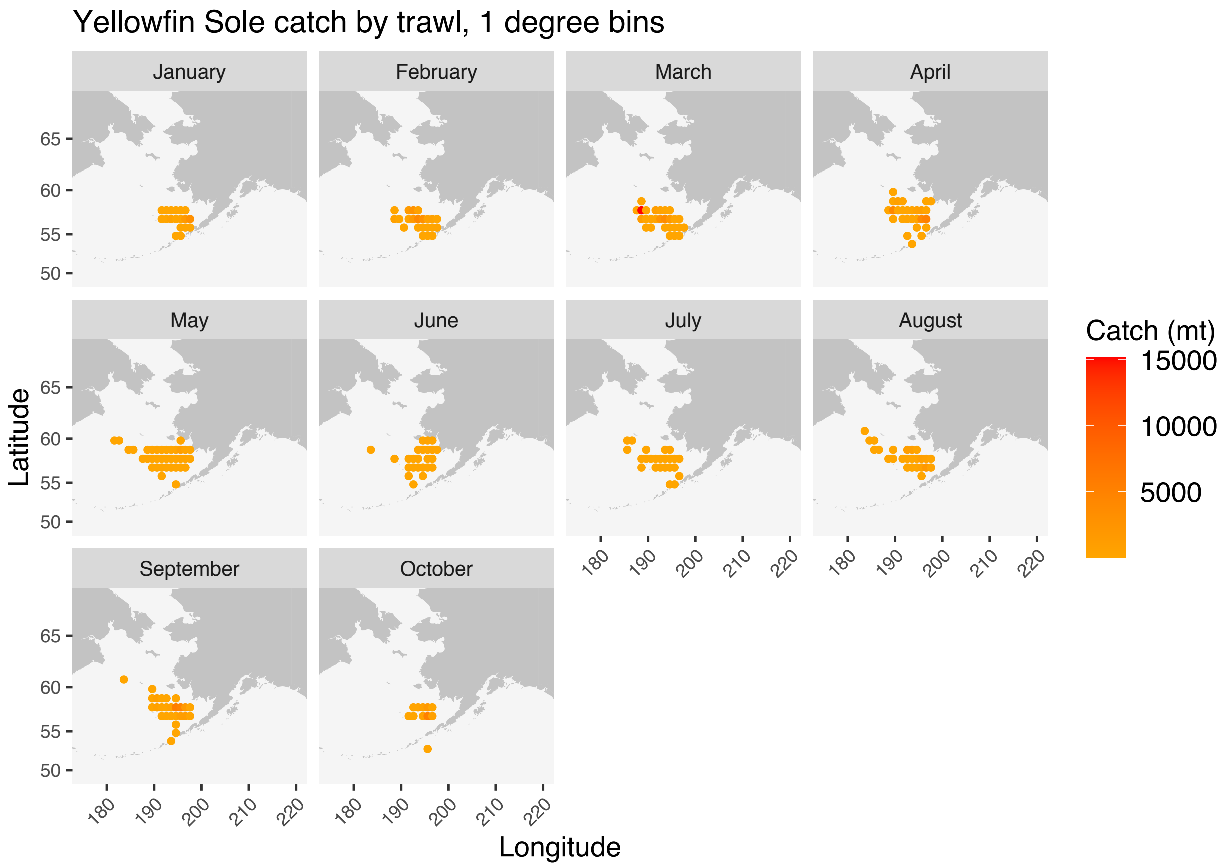


Figure 4.5: Catch of Yellowfin Sole in the BSAI in 2020 by month, reported by observers. Circles represent presence of Yellowfin Sole the catch by the following gear types: non-pelagic trawl, pair trawl, or pelagic trawl.

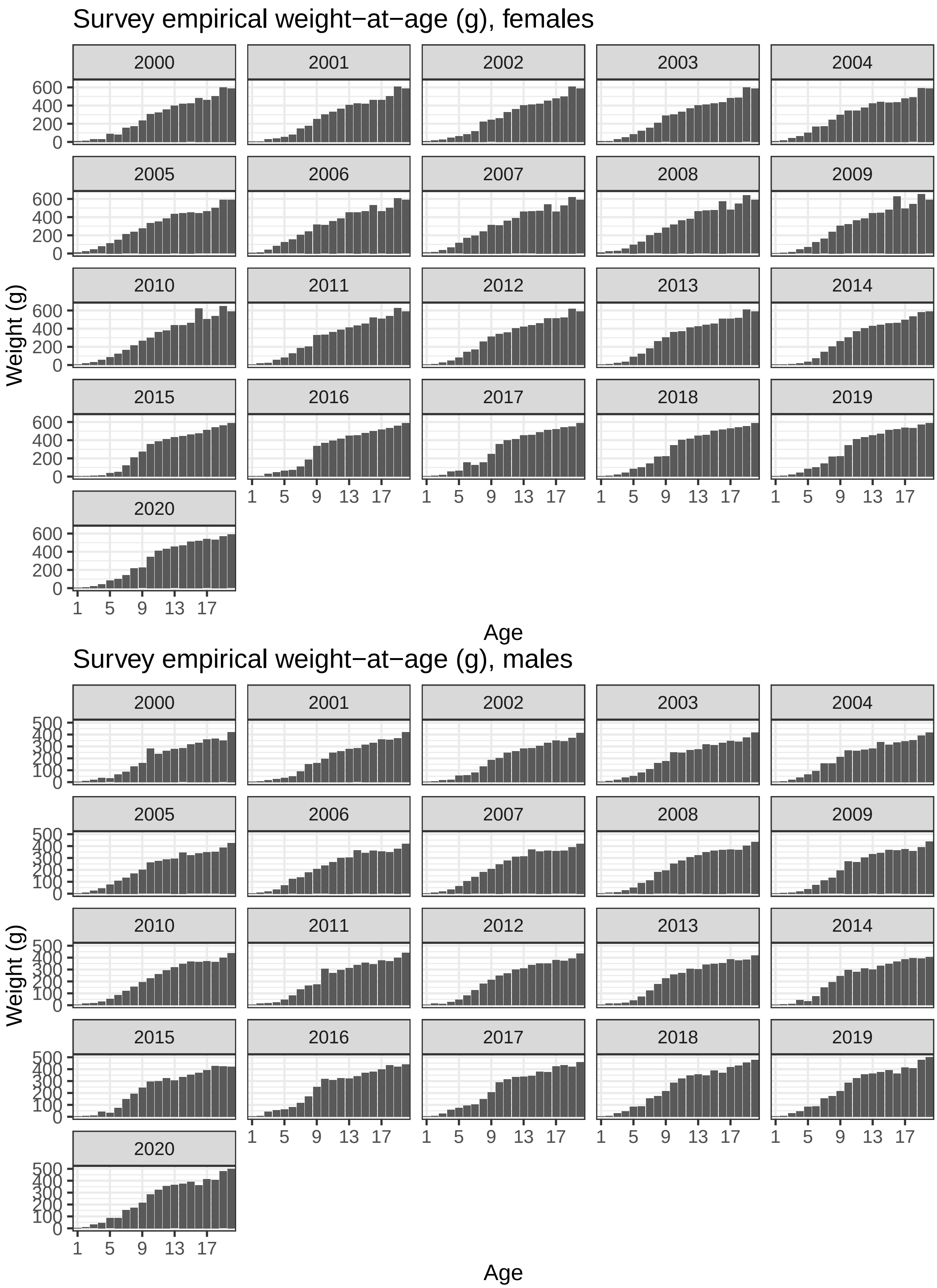


Figure 4.6: Empirical estimates of weight (g) at age for Yellowfin Sole females and males, 2000-2020.

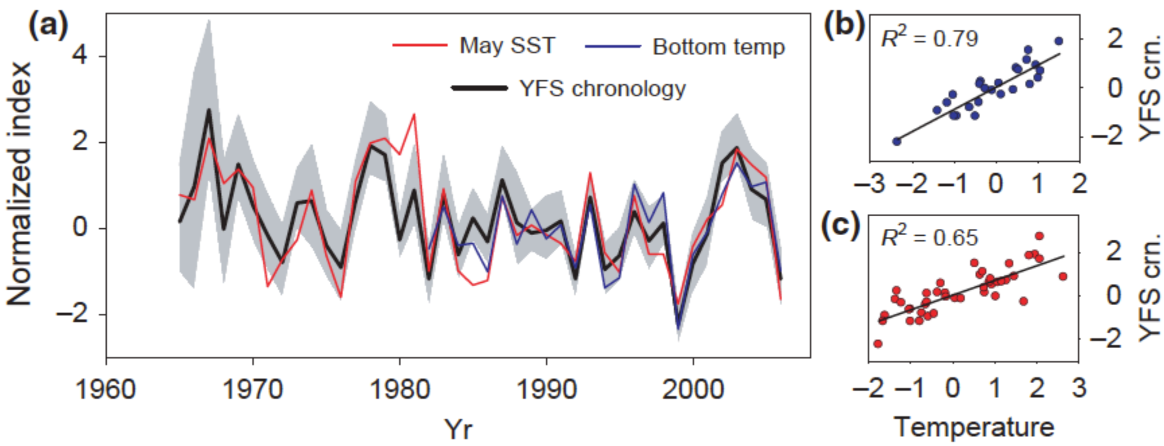


Figure 4.7: Master chronology for Yellowfin Sole and time series of mean summer bottom temperature and May sea surface temperature for the southeastern Bering Sea (Panel A). All data were normalized to a mean of 0 and standard deviation of 1. Correlations of chronologies with bottom temperature and sea surface temperature are shown in panels B and C, respectively (Matta et al. 2010).

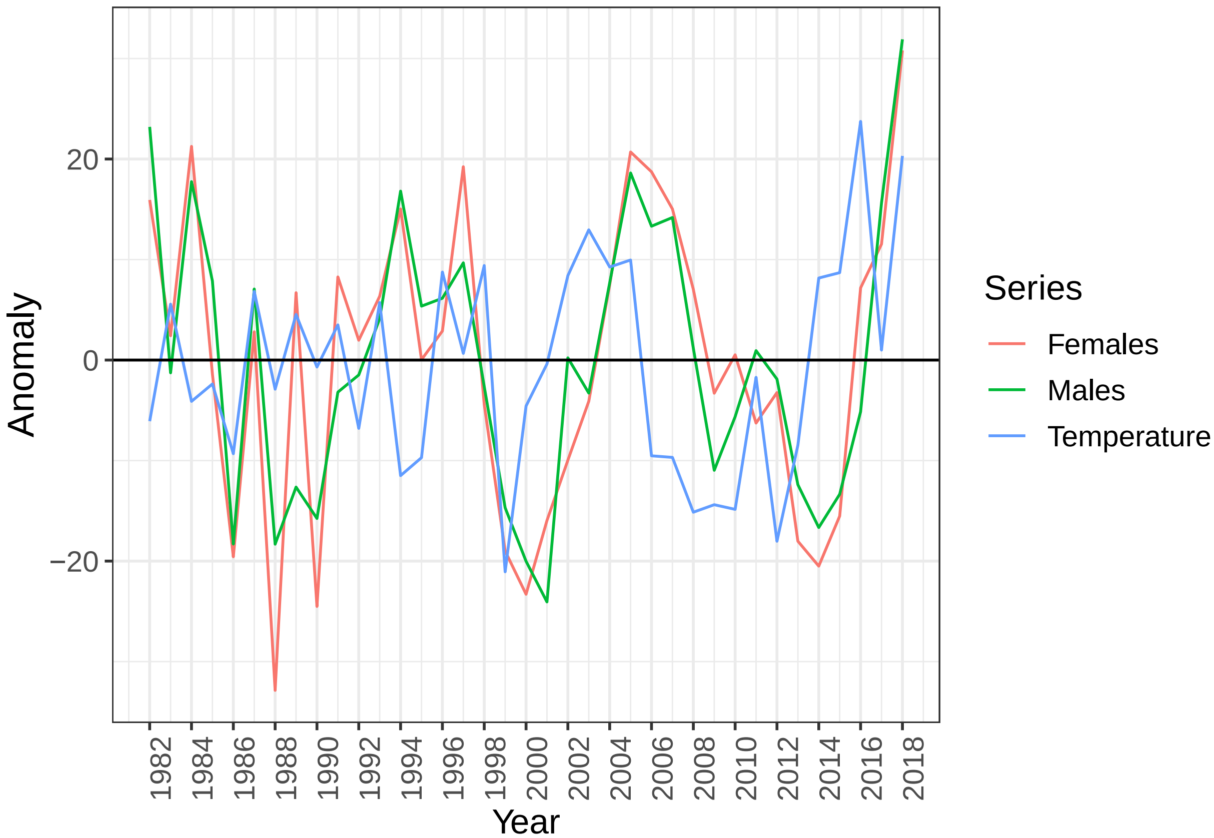


Figure 4.8: Yellowfin Sole length-at-age anomalies, for 5-year old males and females, and bottom temperature anomalies (Model 18.2). Correspondence in these residuals is apparent with a 2-3 year lag effect from the mid-1990s to 2019. Late 1980s and early 1990s pattern may be a density-dependent response 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.

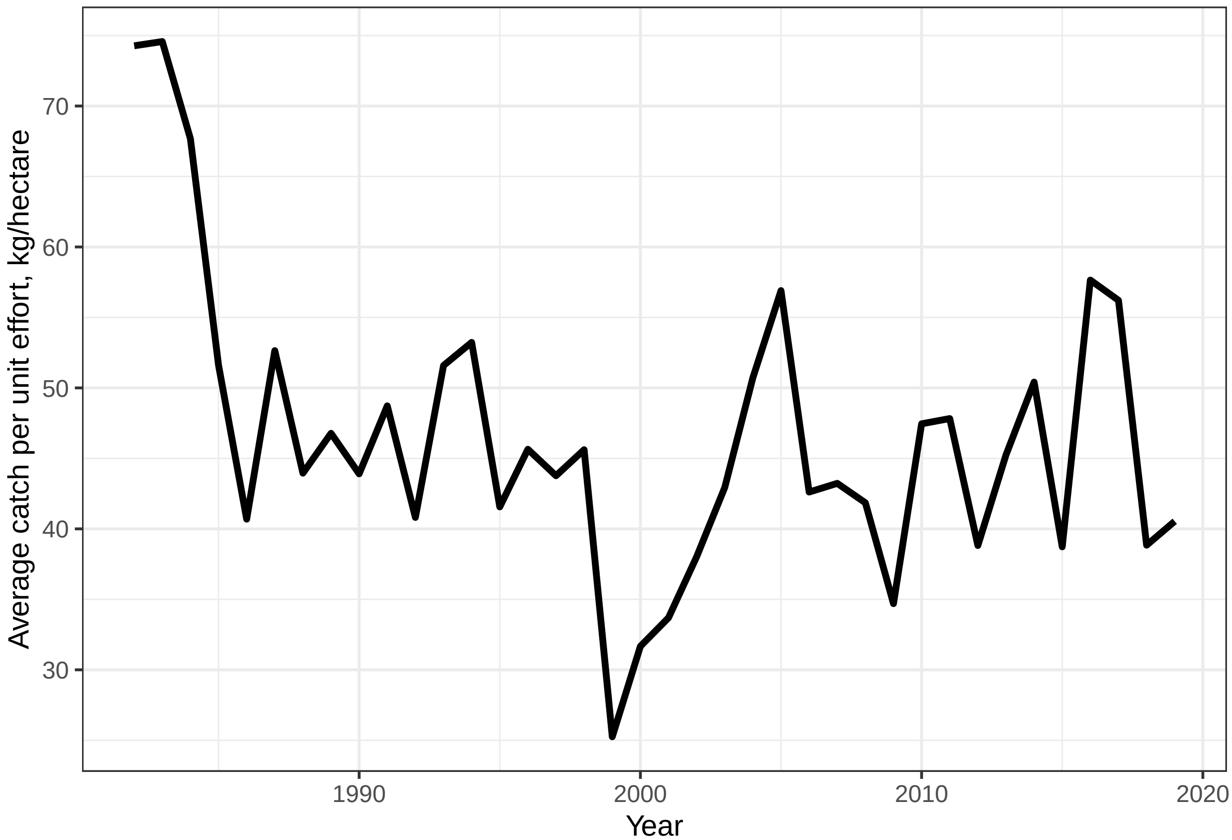


Figure 4.9: Average catch per unit effort on NMFS eastern Bering Sea surveys, 1982-2019, in kg/hectare.

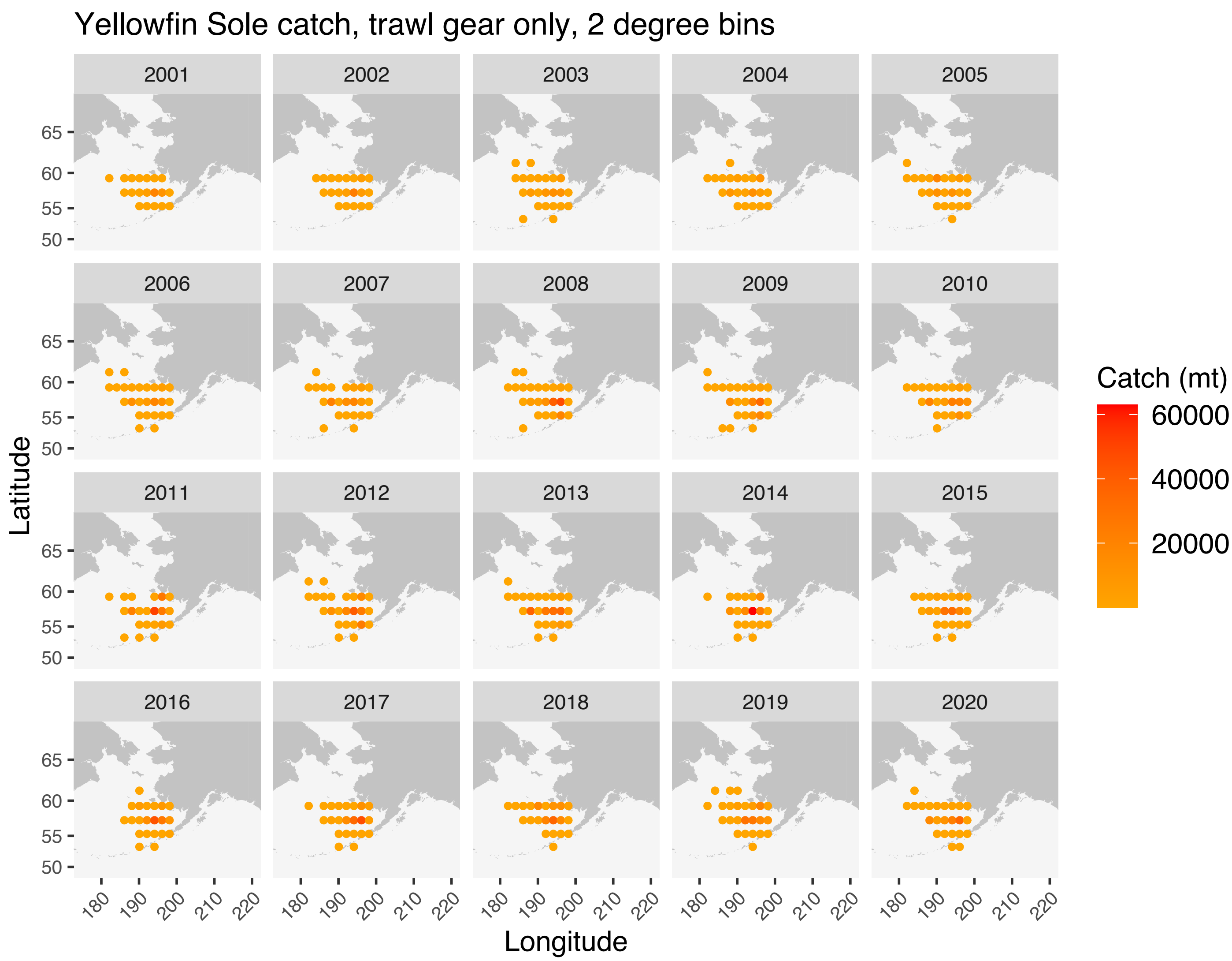


Figure 4.10: Catch of Yellowfin Sole by trawl gear in the BSAI, 2001-2020, by year, reported by observers. Gear types include pelagic and non-pelagic trawl. Colored circles represent catch of Yellowfin Sole, with darker shades of red representing higher catch.

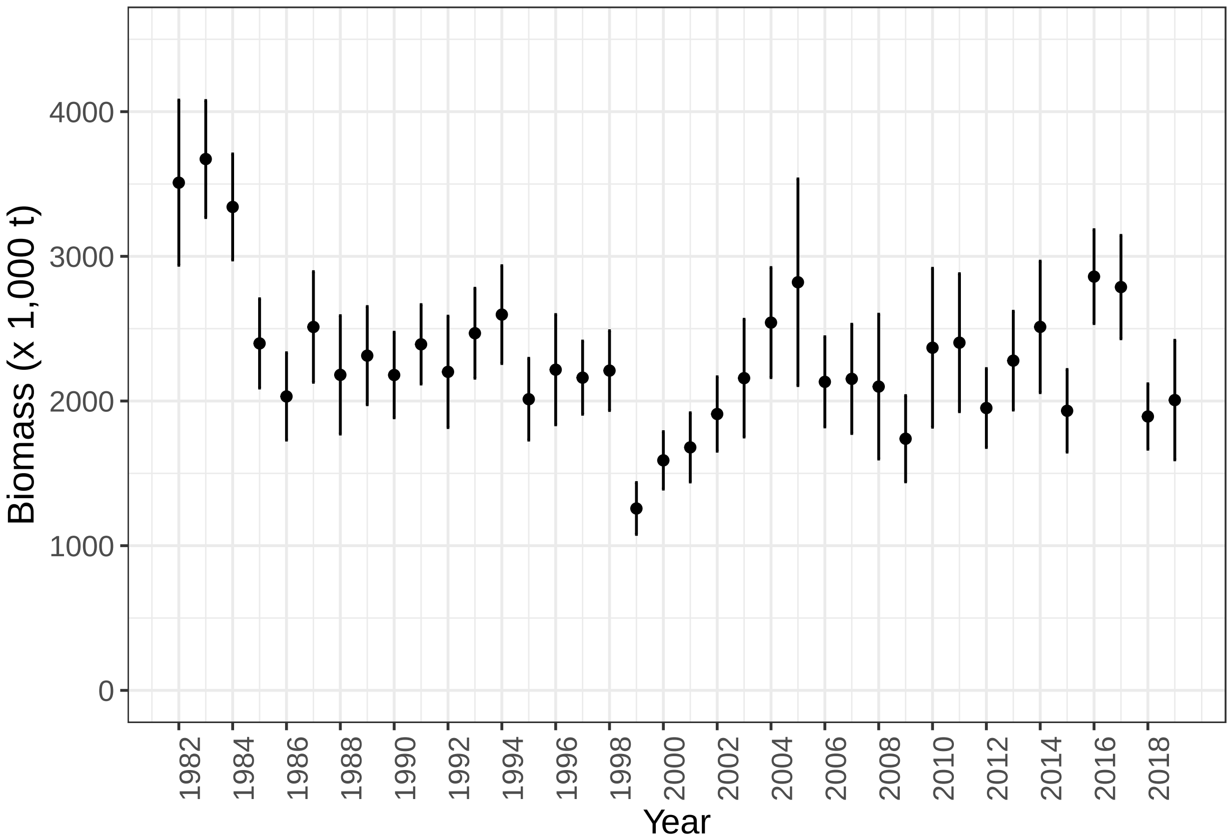


Figure 4.11: Annual eastern Bering Sea bottom trawl survey biomass point estimates and 95% confidence intervals for Yellowfin Sole, 1982-2020, Model 18.2.

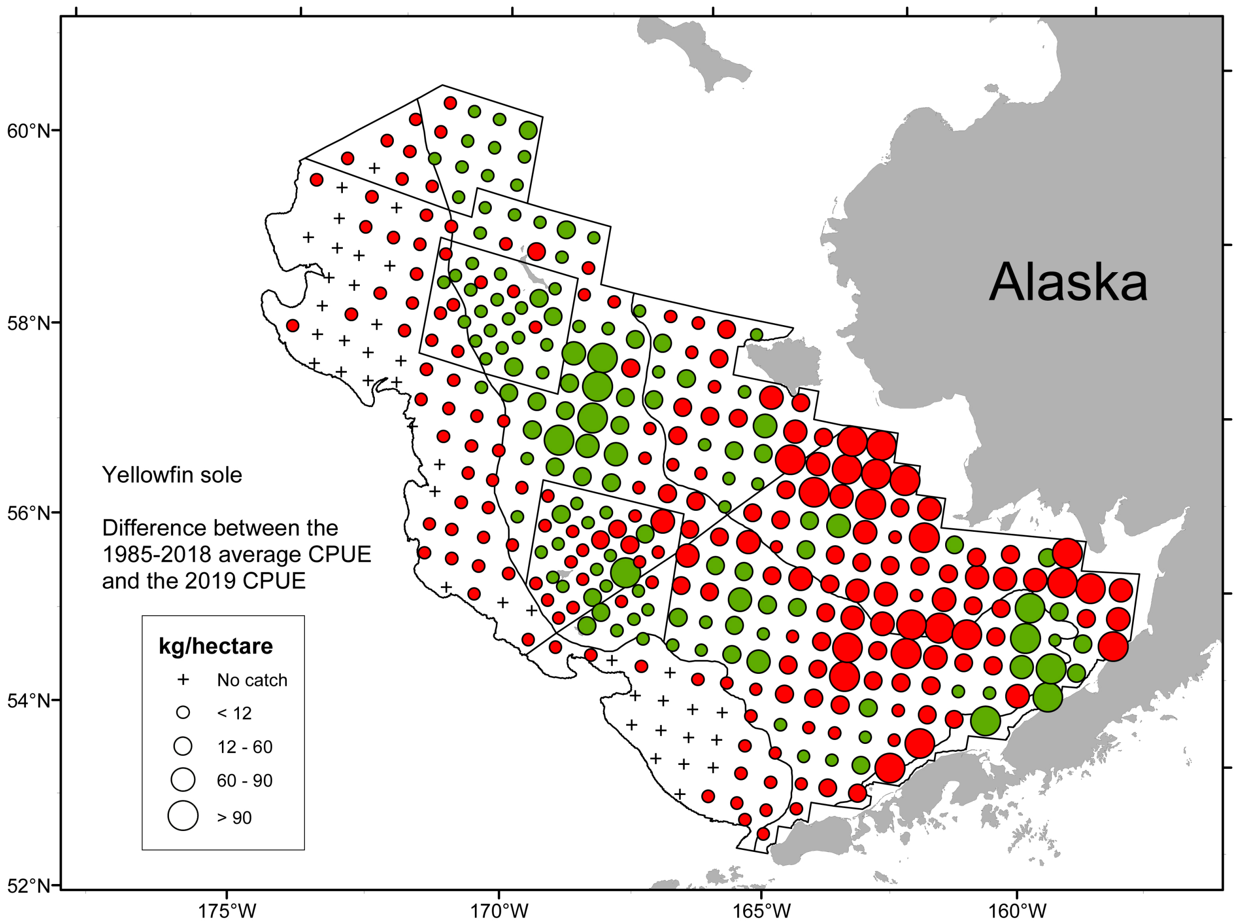


Figure 4.12: Difference between the 1985-2018 average trawl survey CPUE for yellowfin sole and the 2019 survey CPUE. Green circles indicate that the magnitude of the catch was greater in 2019 than the long-term average, red circles indicate the catch was greater in the longterm average than in 2019.

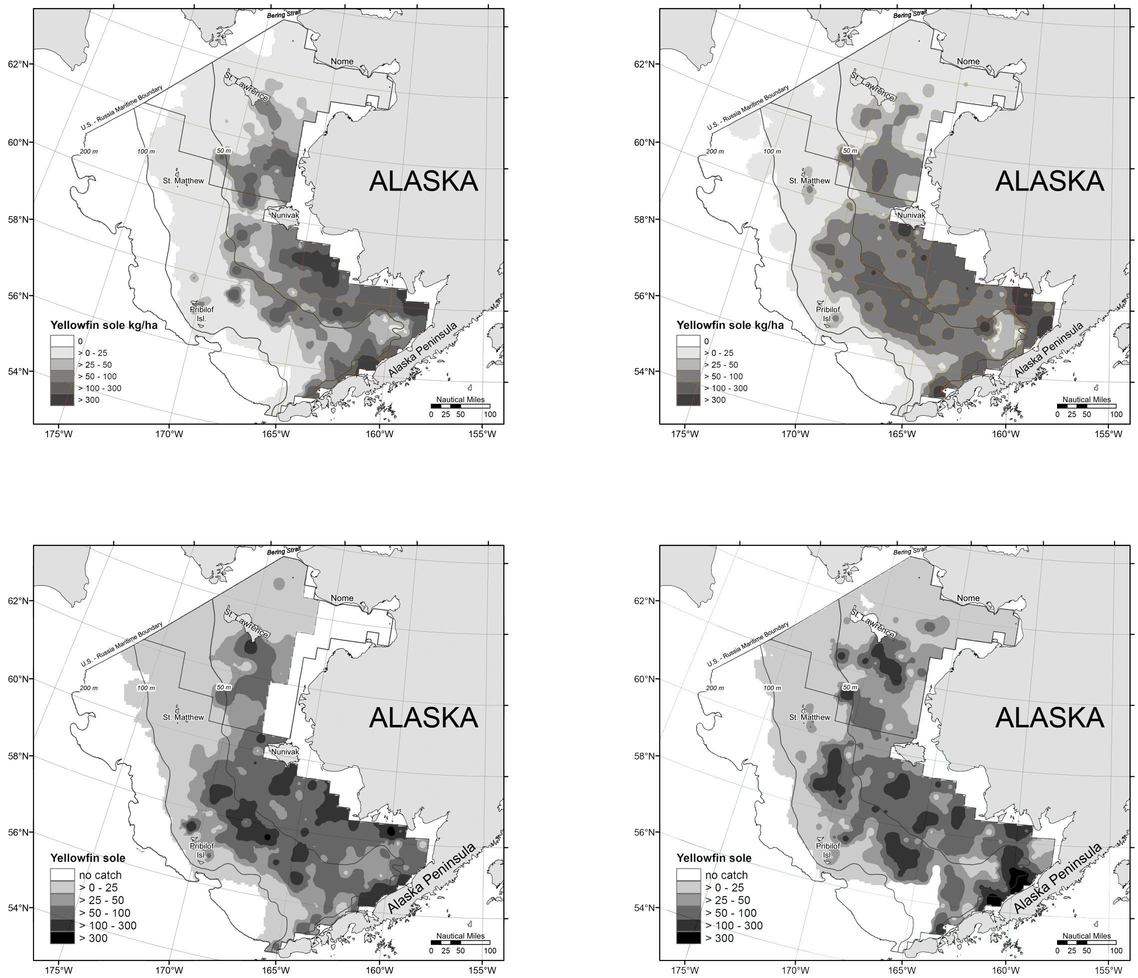


Figure 4.13: Distribution of Yellowfin Sole in the eastern and northern Bering sea based on surveys conducted in 2010 (upper left), 2017 (upper right), 2018 (lower left), and 2019 (lower right).

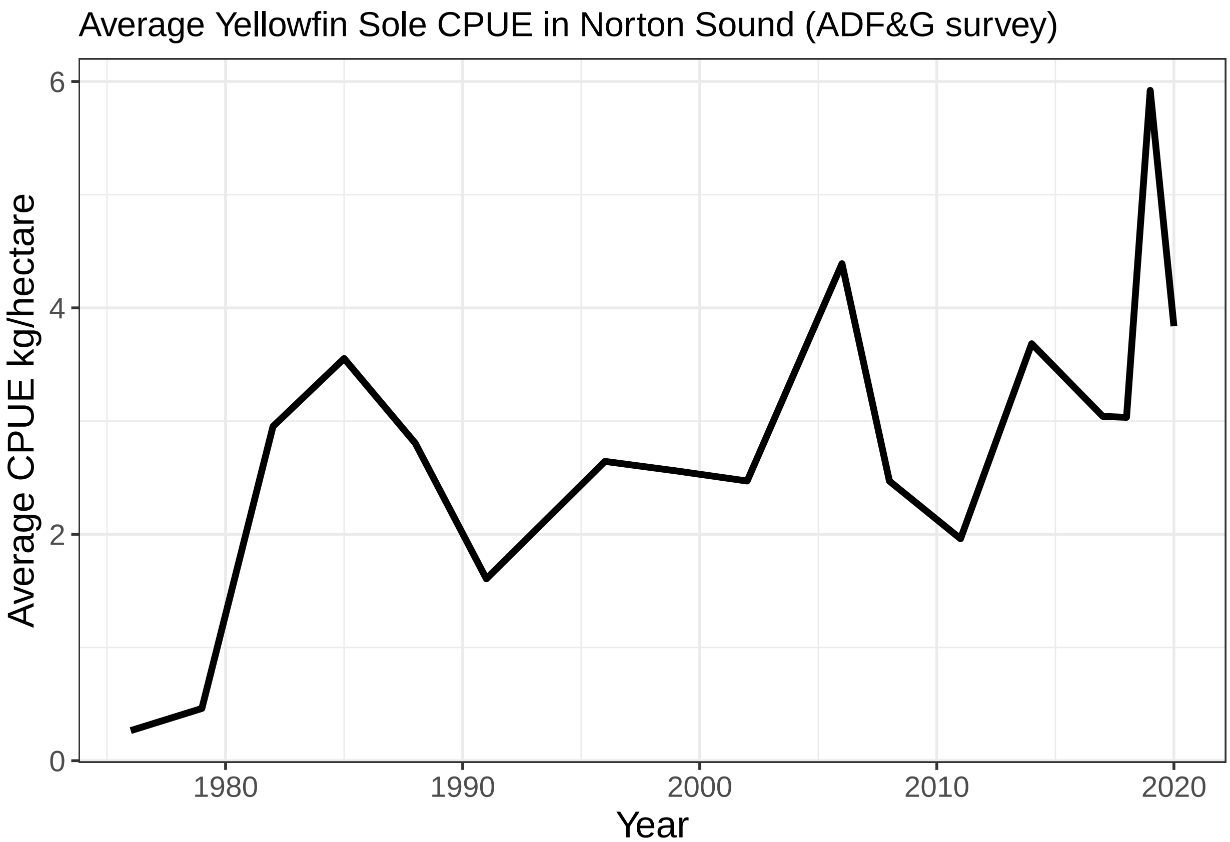


Figure 4.14: Average catch per unit effort (CPUE) of Yellowfin Sole in Norton Sound, based on an ADF&G survey time series.

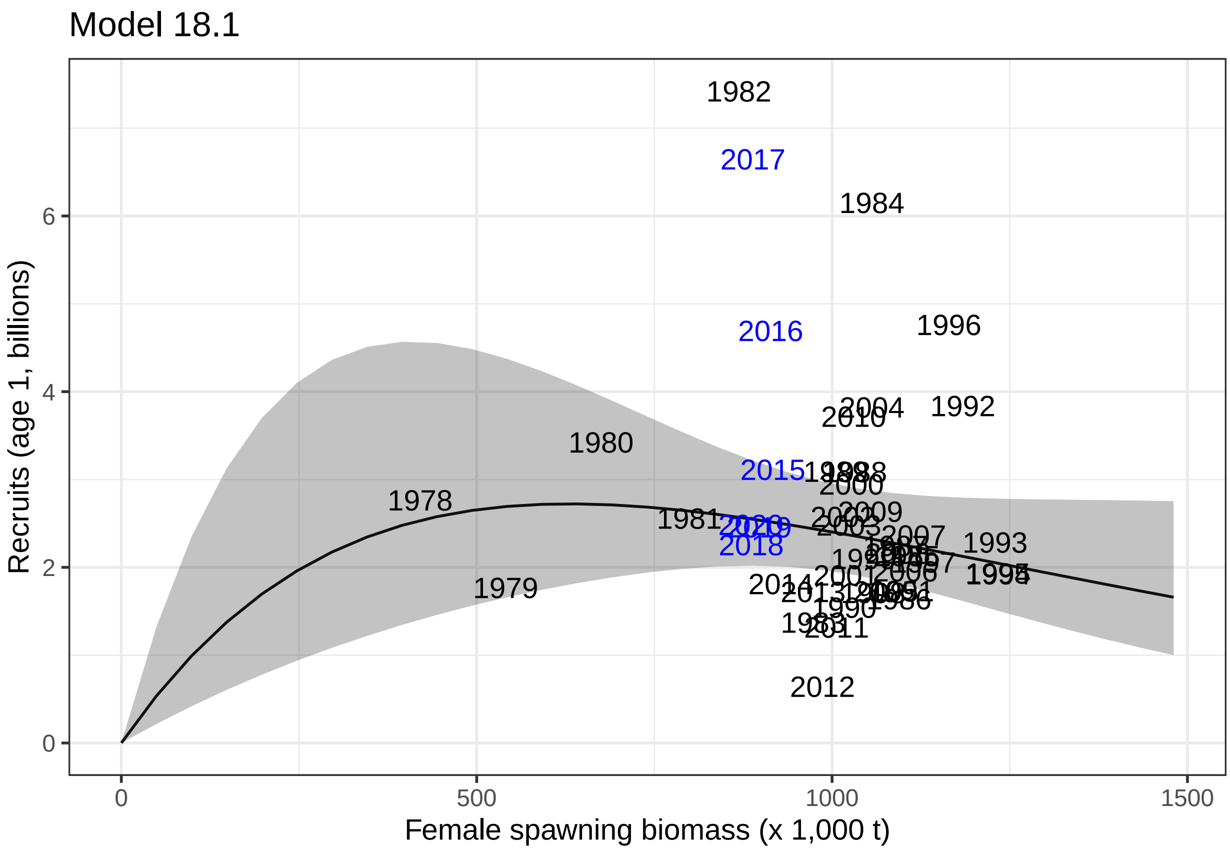


Figure 4.15: Ricker stock recruitment curve for Model 18.1 with 95% confidence intervals (shaded region) fit to female spawning biomass and recruitment data from 1978-2014. Years in black indicate data used to fit the model, years in blue were not used to fit the model.

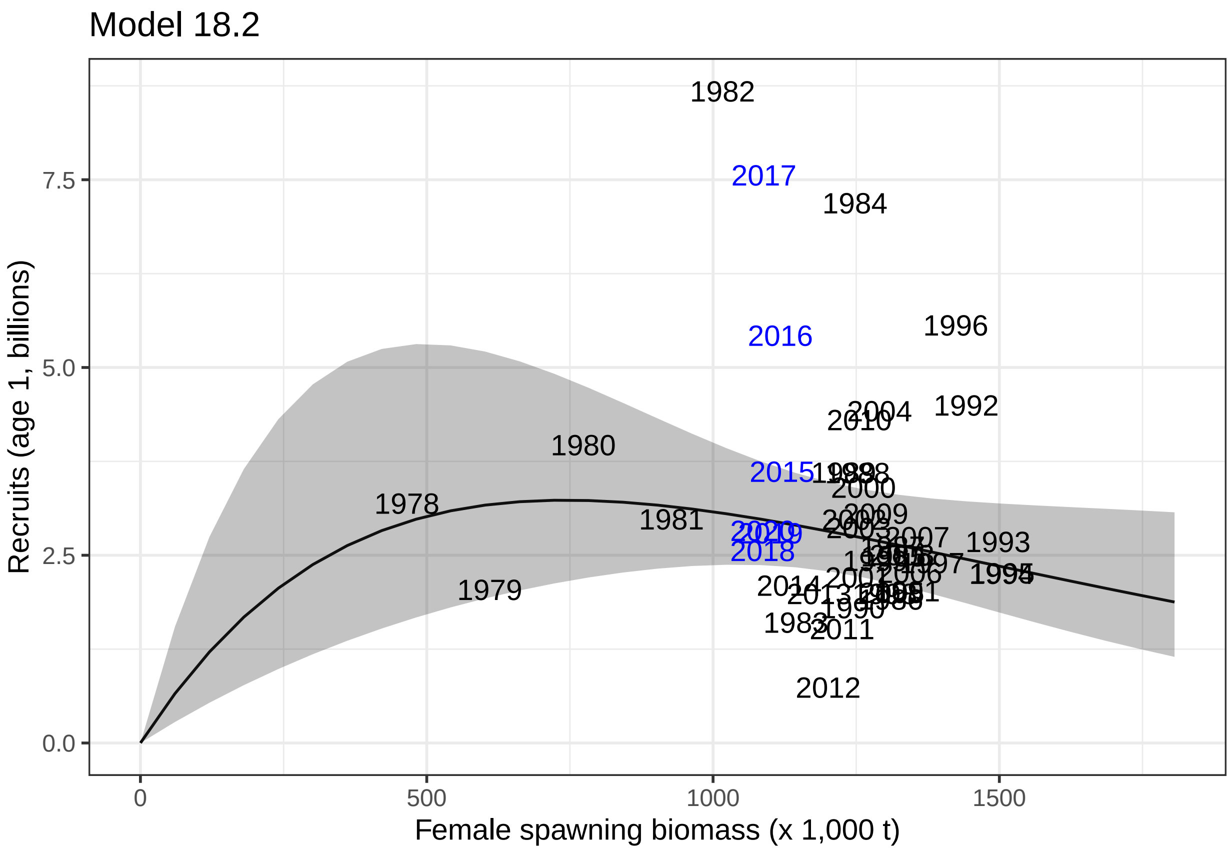


Figure 4.16: Ricker stock recruitment curve for Model 18.2 with 95% confidence intervals (shaded region) fit to female spawning biomass and recruitment data from 1978-2014. Years in black indicate data used to fit the model, years in blue were not used to fit the model.

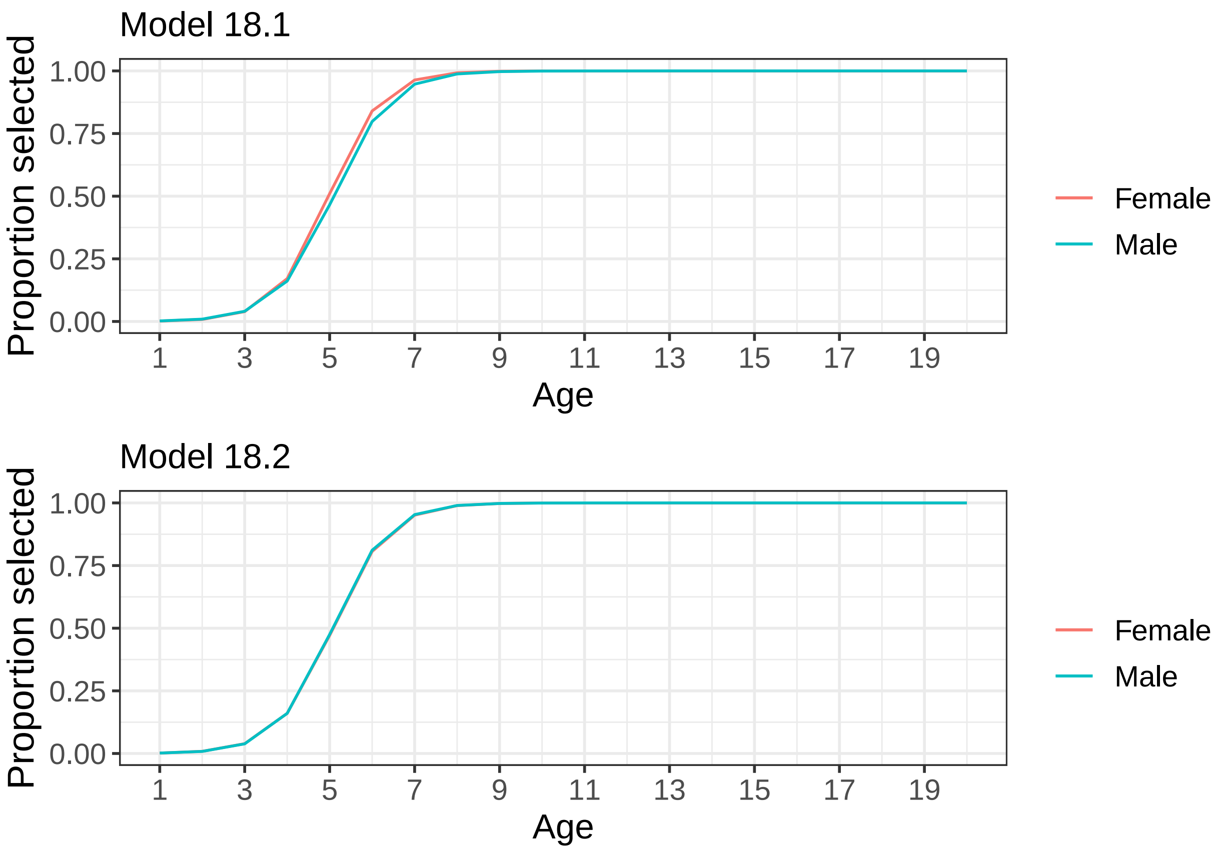


Figure 4.17: Estimate of survey selectivity for males and females, Model 18.1 upper panel, Model 18.2 lower panel.

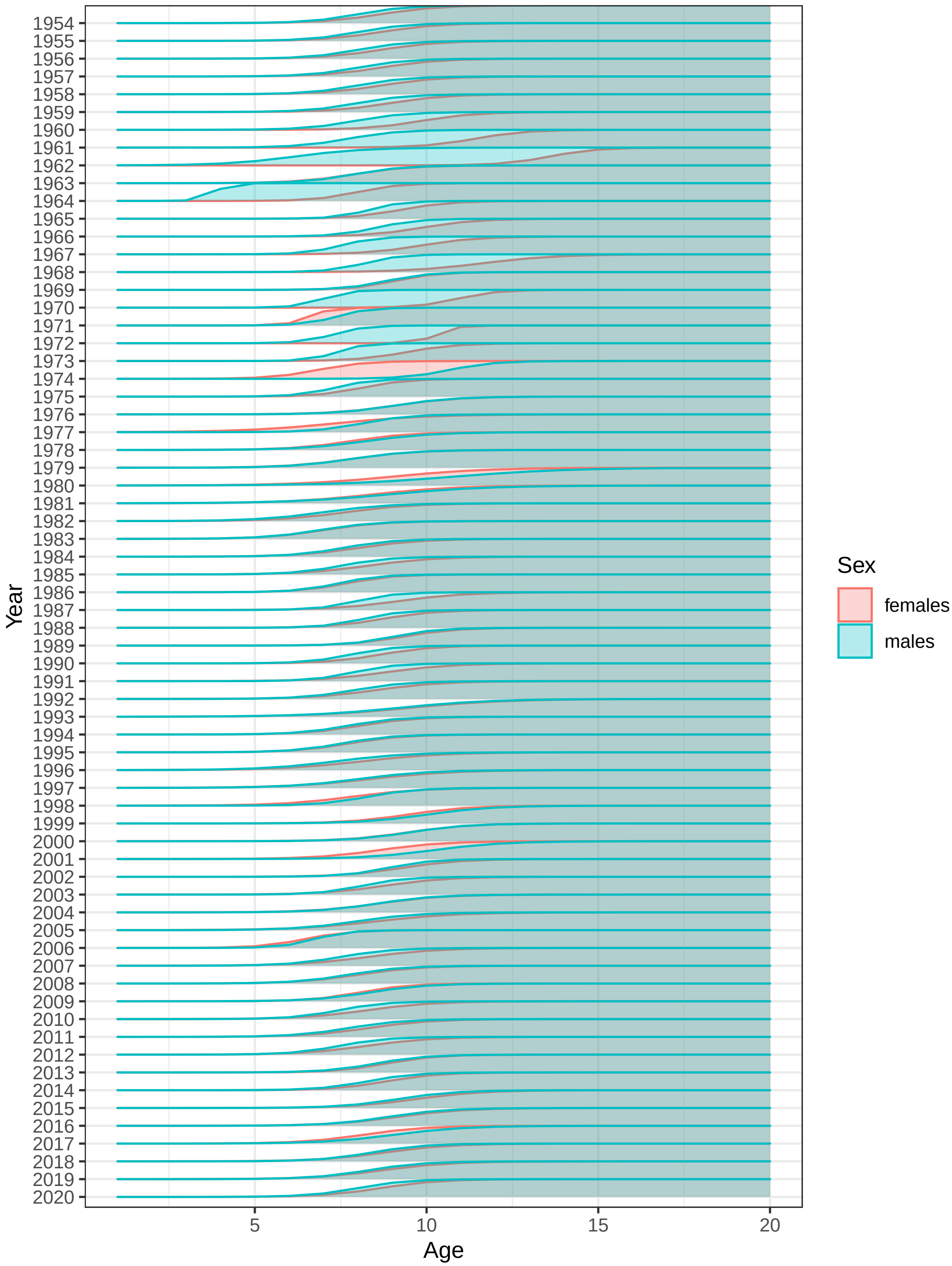


Figure 4.18: Estimate of fishery selectivity for males and females, 1954-2019, Model 18.2.

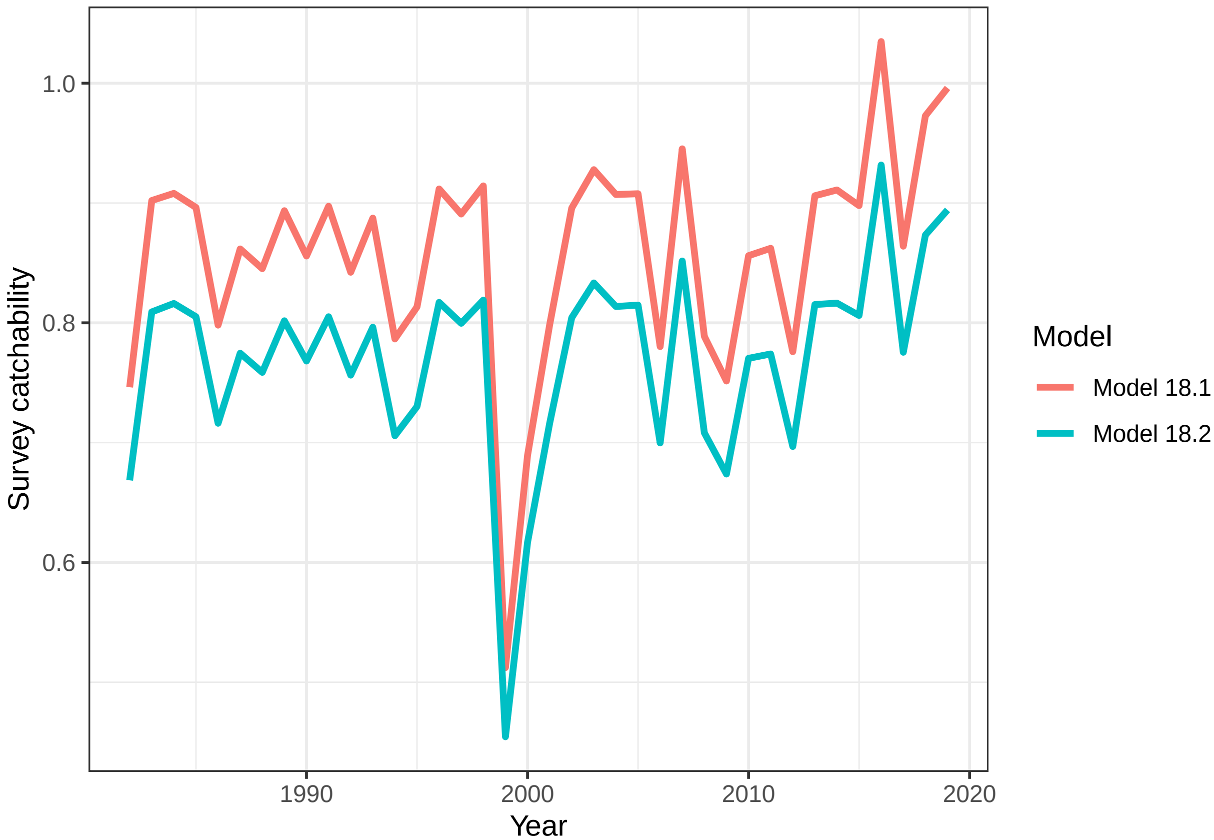


Figure 4.19: Survey catchability for Model 18.1 and 18.2, 1982-2019.

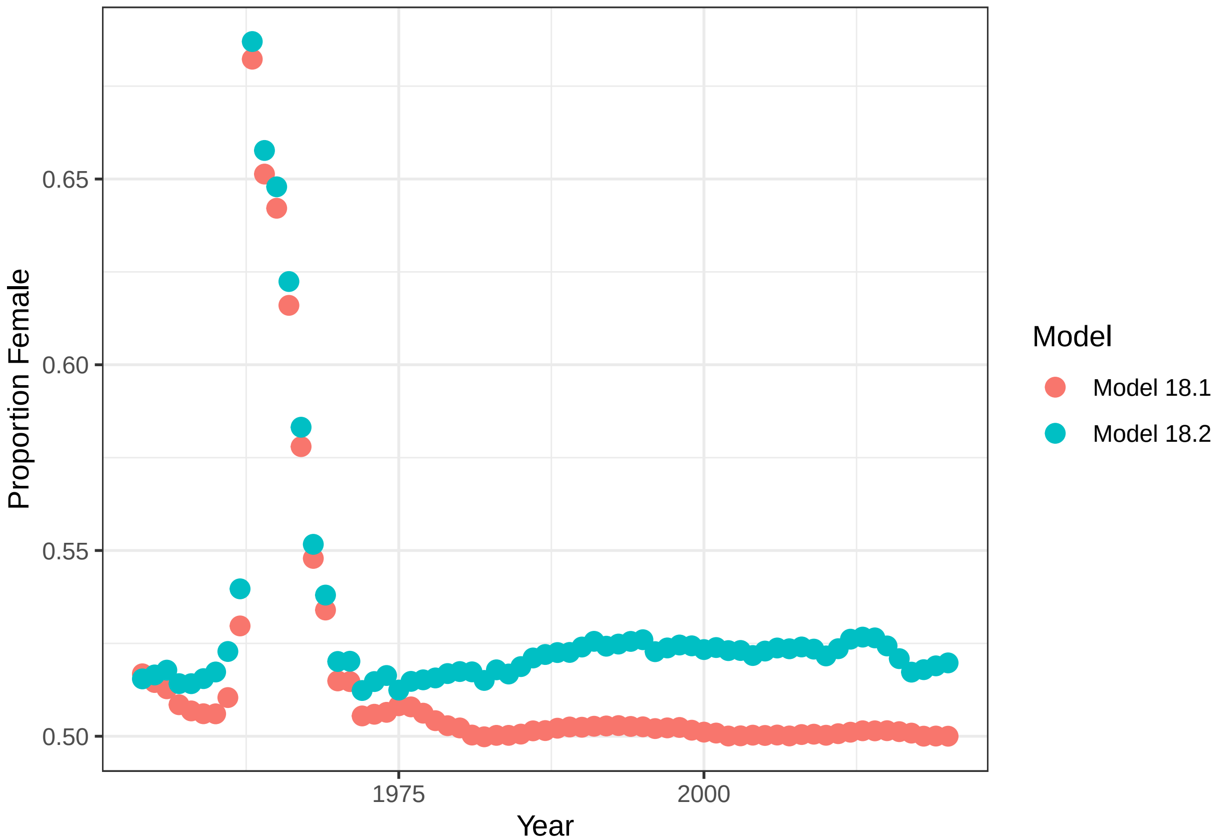


Figure 4.20: Model estimates of the proportion of female Yellowfin Sole in the population, 1982-2020.

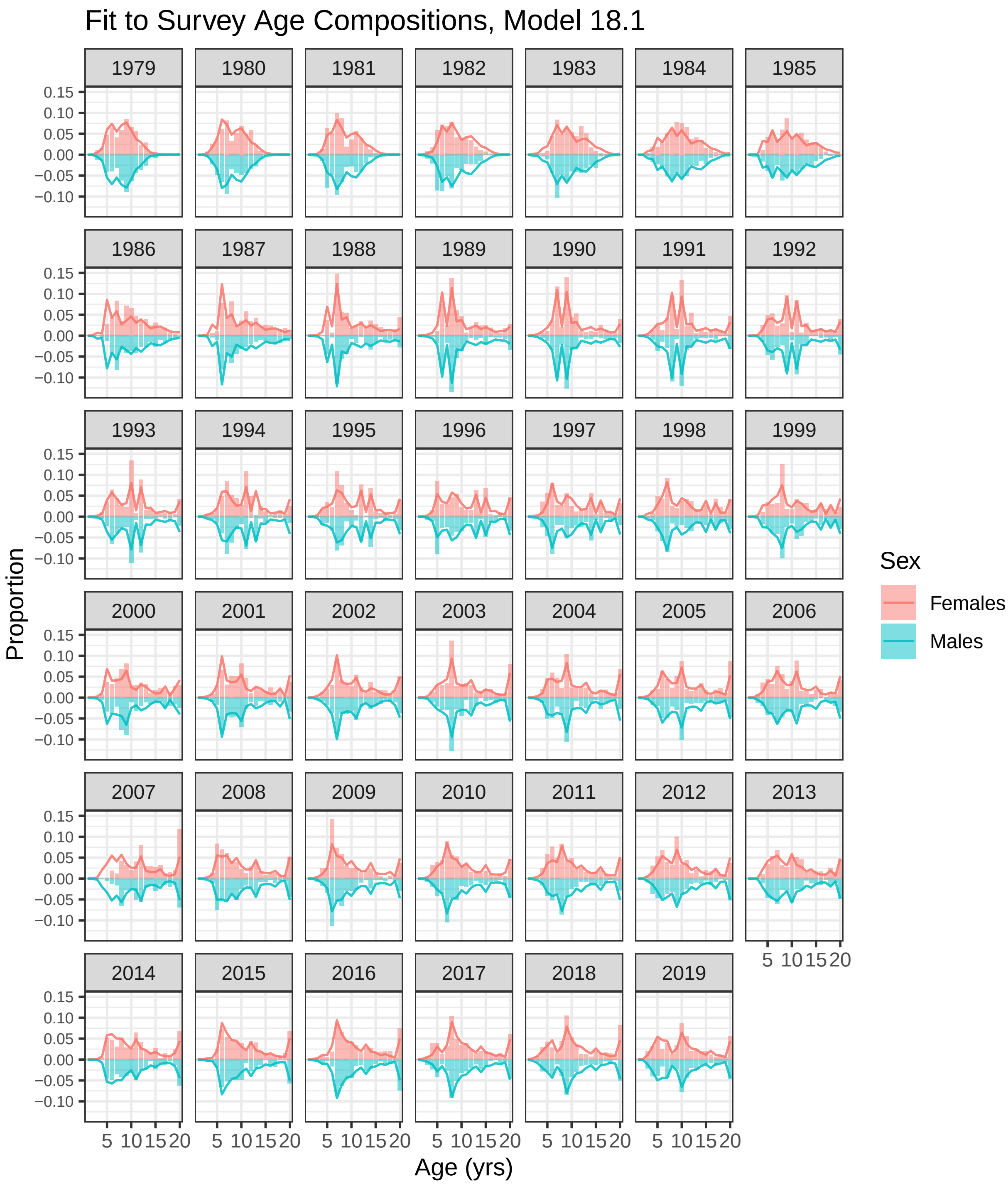


Figure 4.21: Model 18.1 fit to the time-series of survey age composition, by sex, 1979-2019.

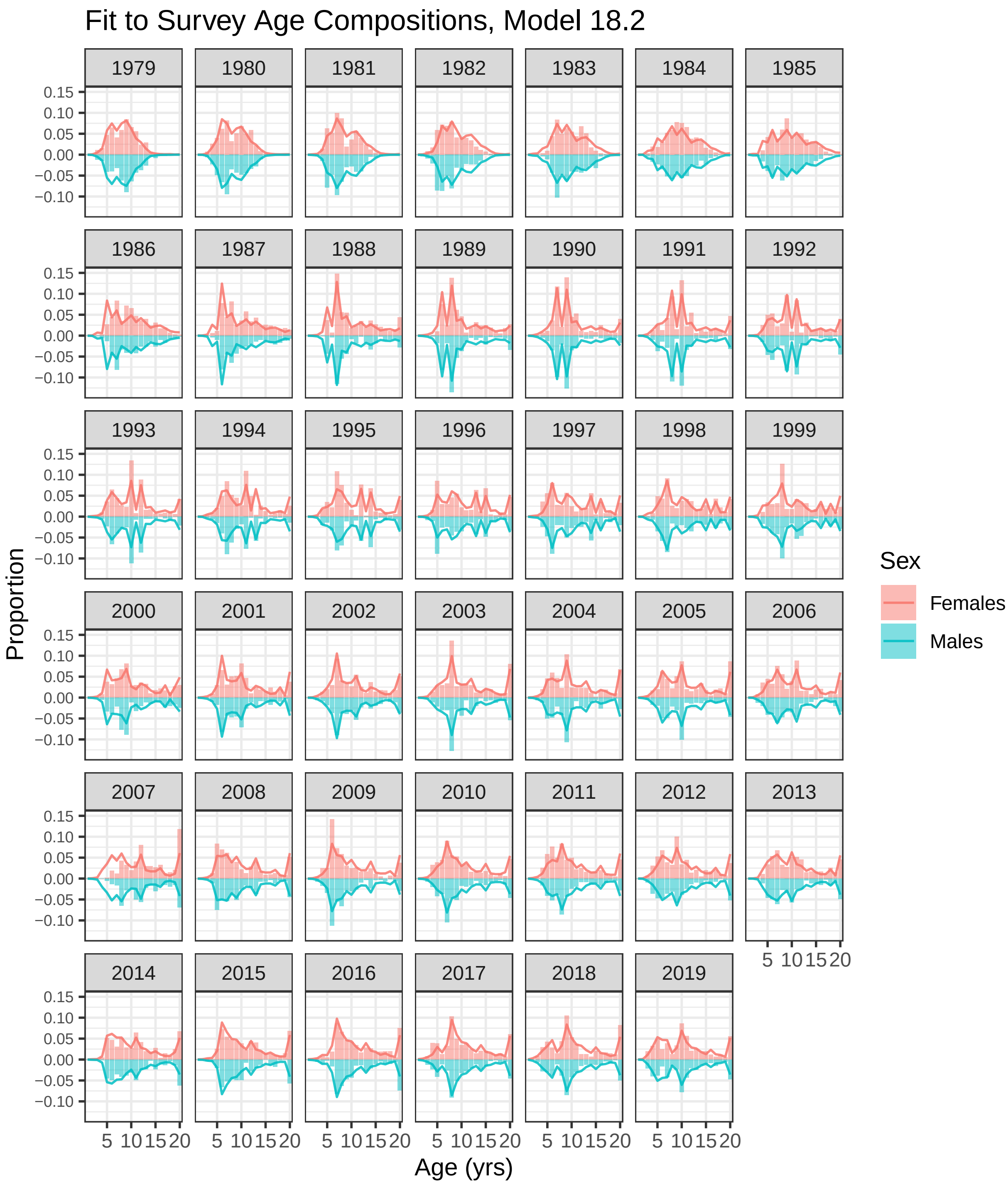


Figure 4.22: Model 18.2 fit to the time-series of survey age composition, by sex, 1979-2019.

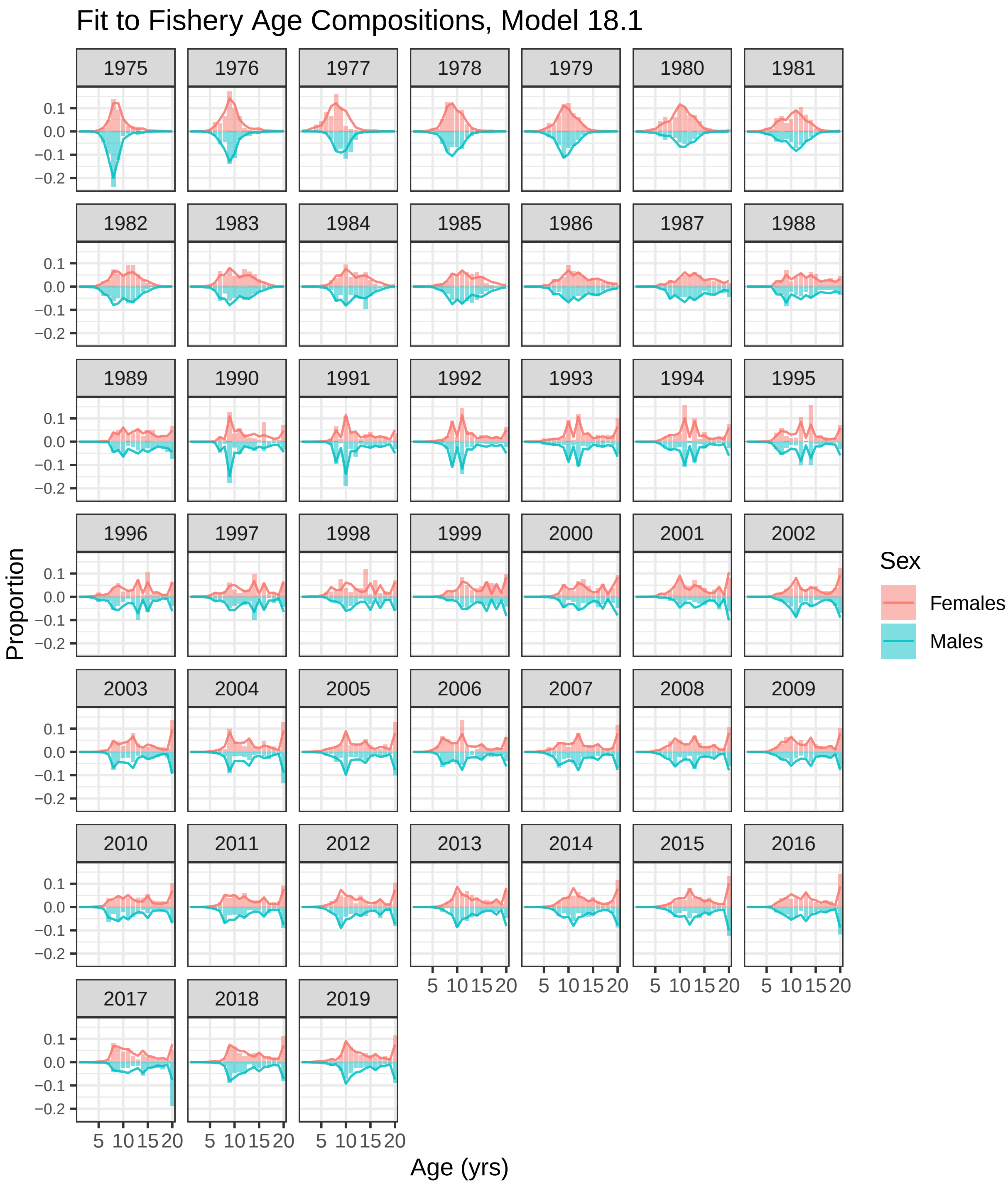


Figure 4.23: Model 18.1 fit to the time-series of fishery age composition, by sex, 1975-2019.

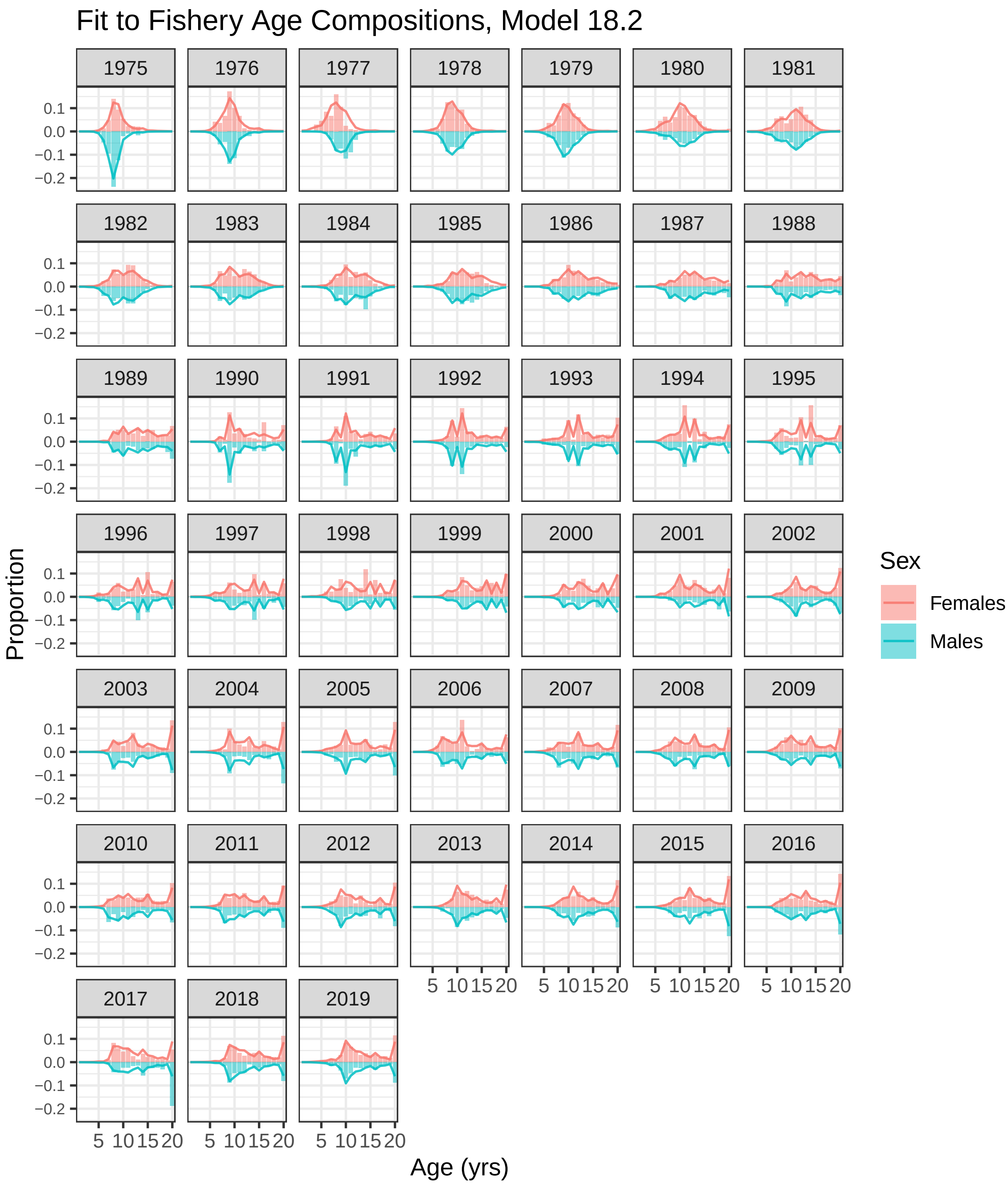


Figure 4.24: Model 18.2 fit to the time-series of fishery age composition, by sex, 1975-2019.

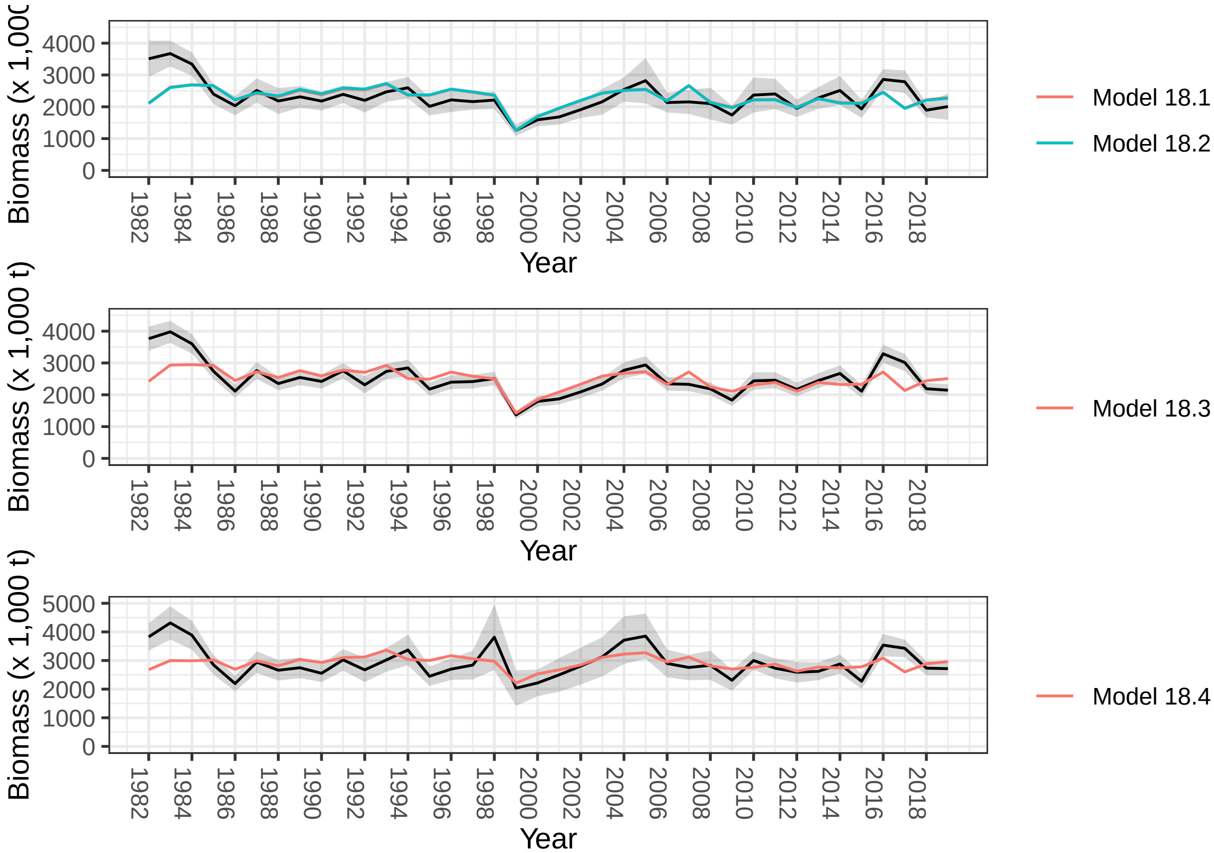


Figure 4.25: Model 18.1 and 18.2 (upper panel), Model 18.3 (middle panel), and Model 18.4 (lower panel) fit to NMFS eastern Bering Sea survey biomass estimates, from 1982-2019. Models 18.1, 18.2, and 18.3 incorporate estimates from the EBS only, while Model 18.4 used NBS+EBS estimates. Models 18.3 and 18.4 used VAST biomass and standard errror, while Models 18.1 and 18.2 used design-based biomass and error estimates.

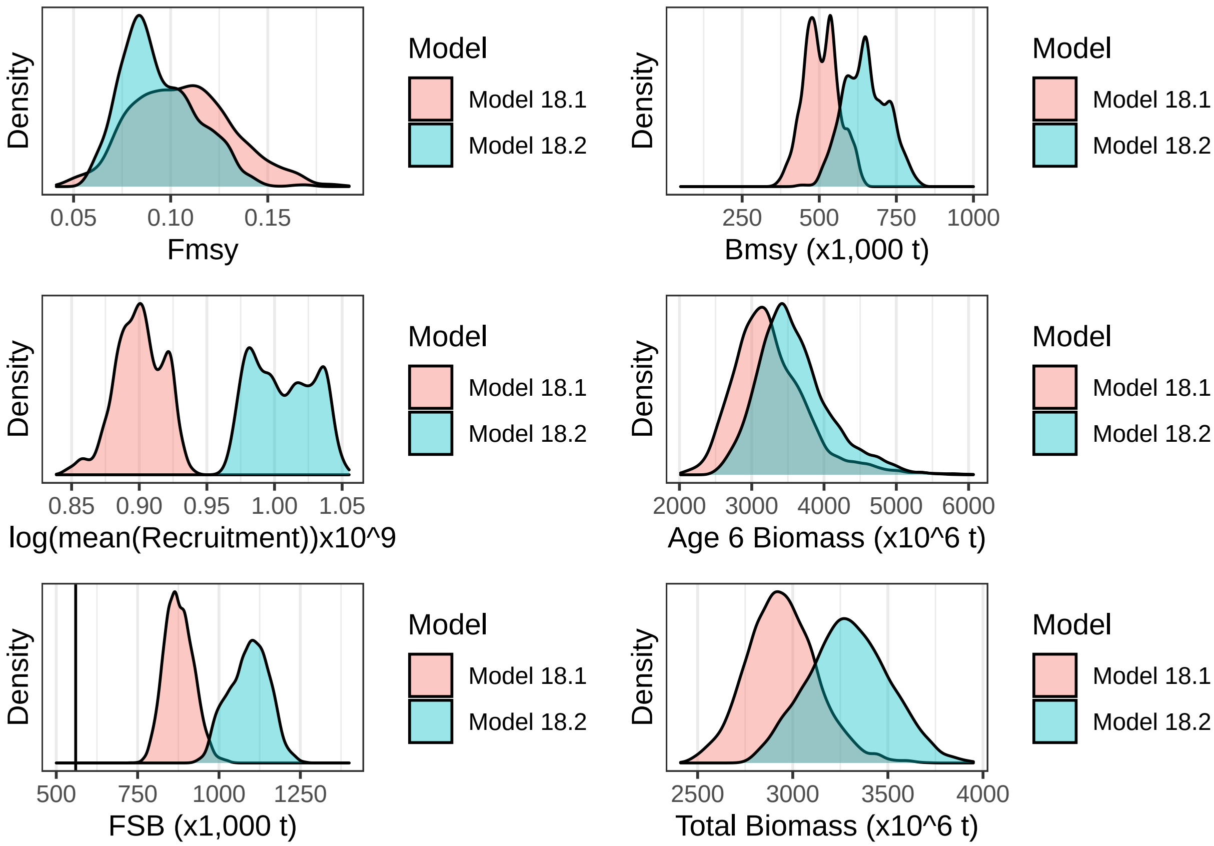


Figure 4.26: MCMC posterior distributions from Models 18.1 and 18.2, for Fmsy, Bmsy, log(mean(Recruitment)), Age 6 biomass, female spawning biomass (FSB) for 2020, and total biomass for 2020.

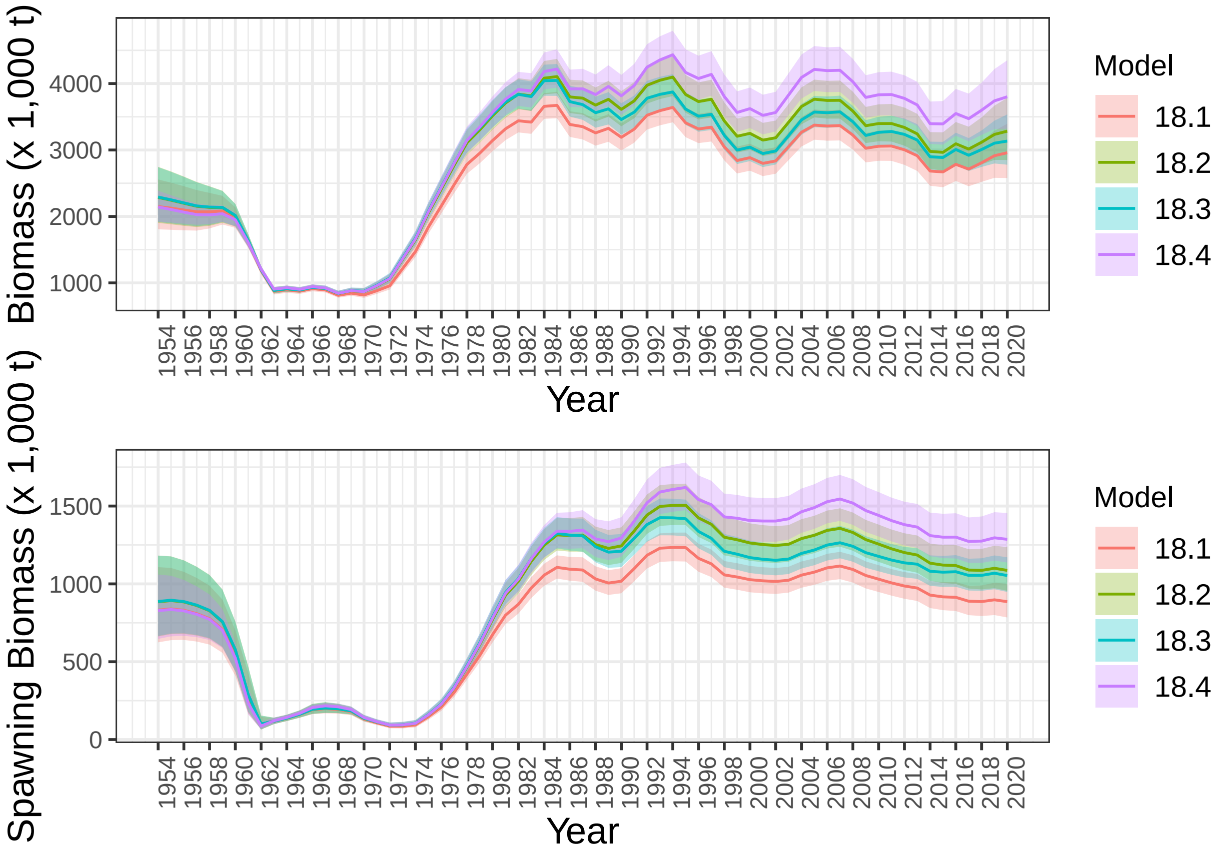


Figure 4.27: Total (age 2+) and spawning stock biomass for Yellowfin Sole, based on Models 18.1, 18.2, 18.3, and 18.4, from 1954-2020.

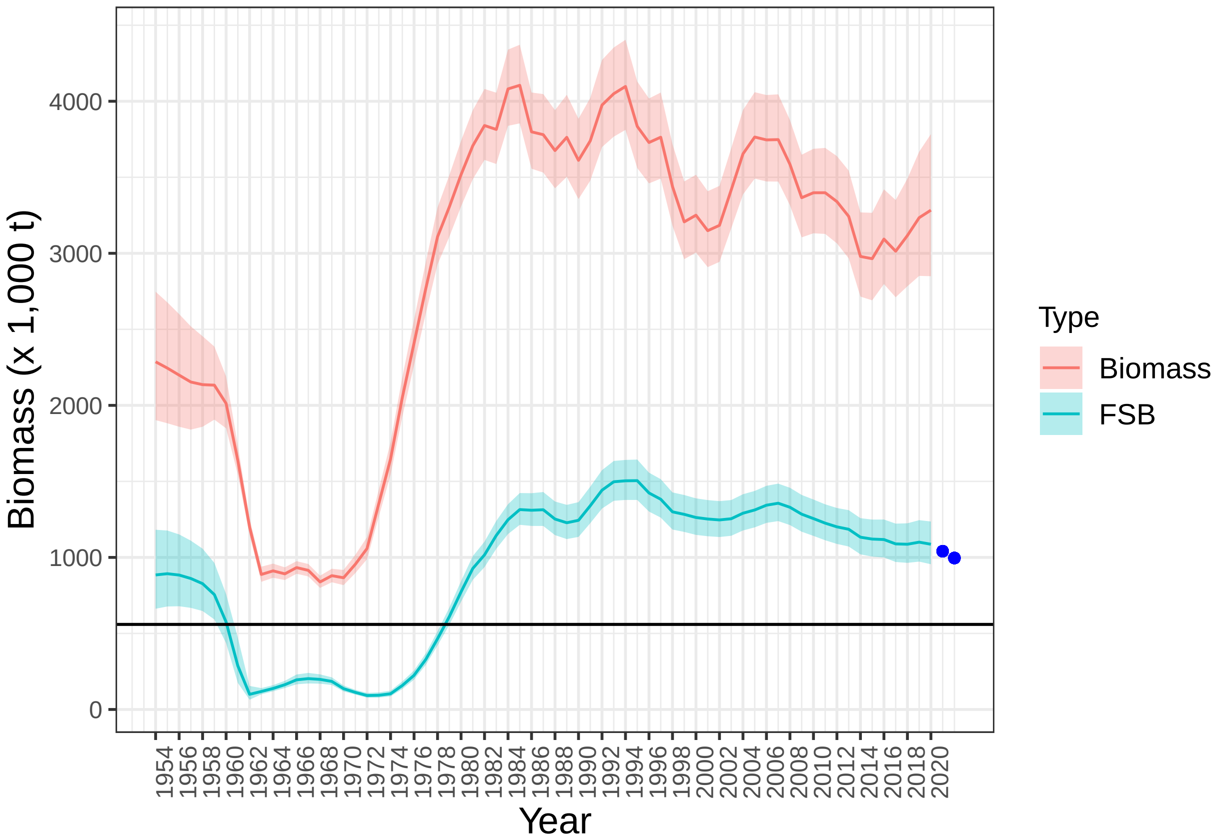


Figure 4.28: Model estimates of total (age 2+) and female spawning biomass with 95% confidence intervals, 1954-2020, Model 18.2. Dots indicate female spawning biomass projection model estimates for 2021 and 2022.

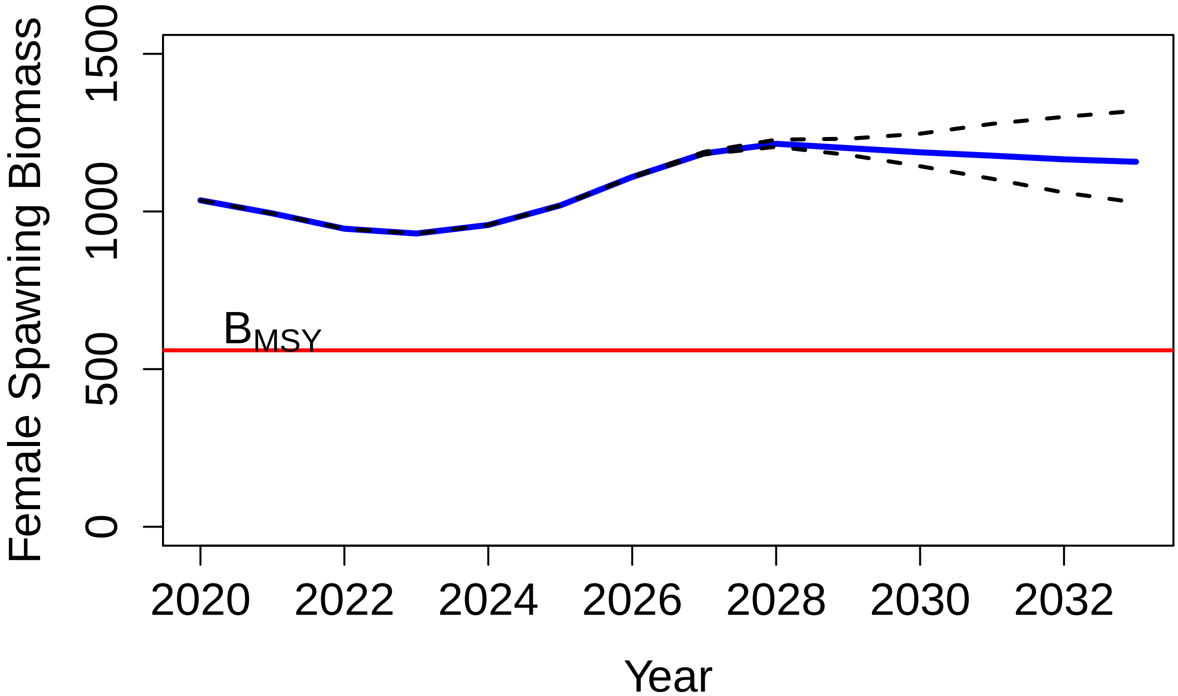


Figure 4.29: Projected female spawning biomass for 2020 to 2033 (blue line), with 5% and 95% confidence intervals, and fishing at the 5-year (2015-2019) average fishing mortality rate, F= 0.0641 , Model 18.2.

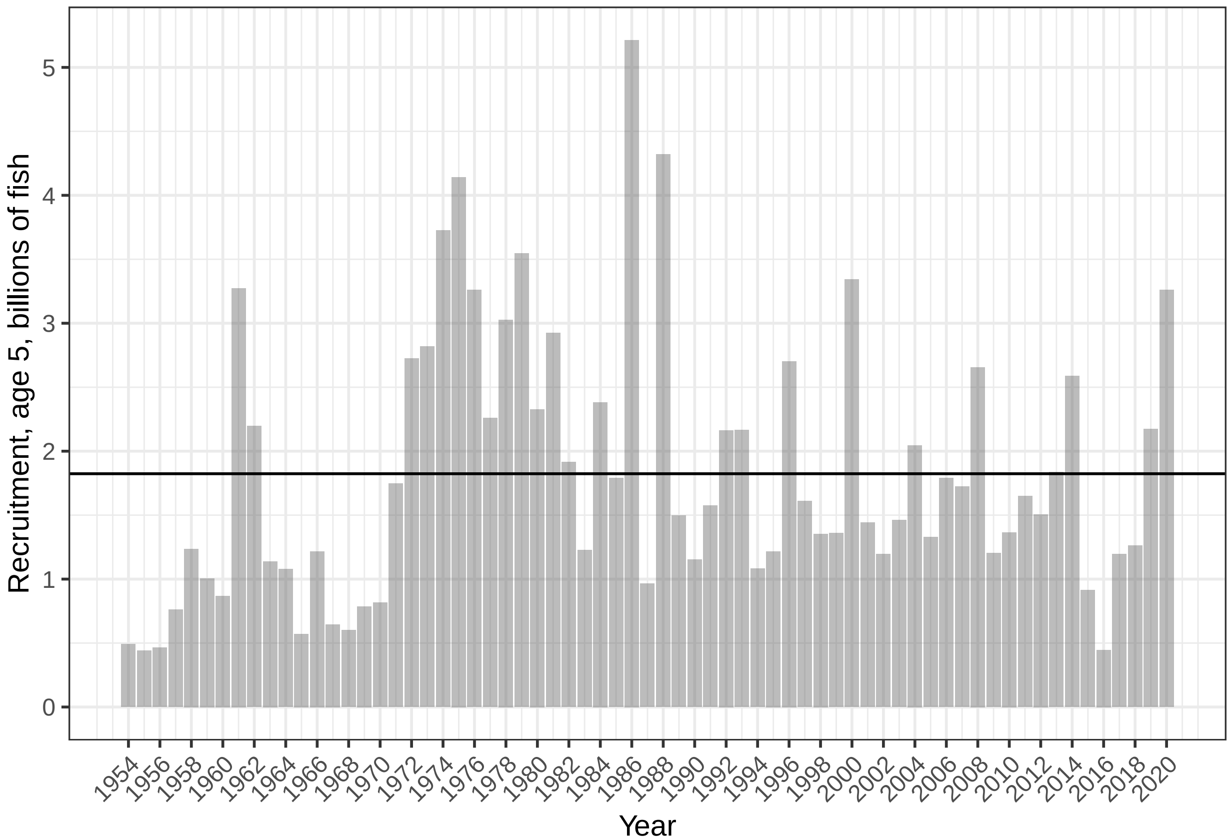
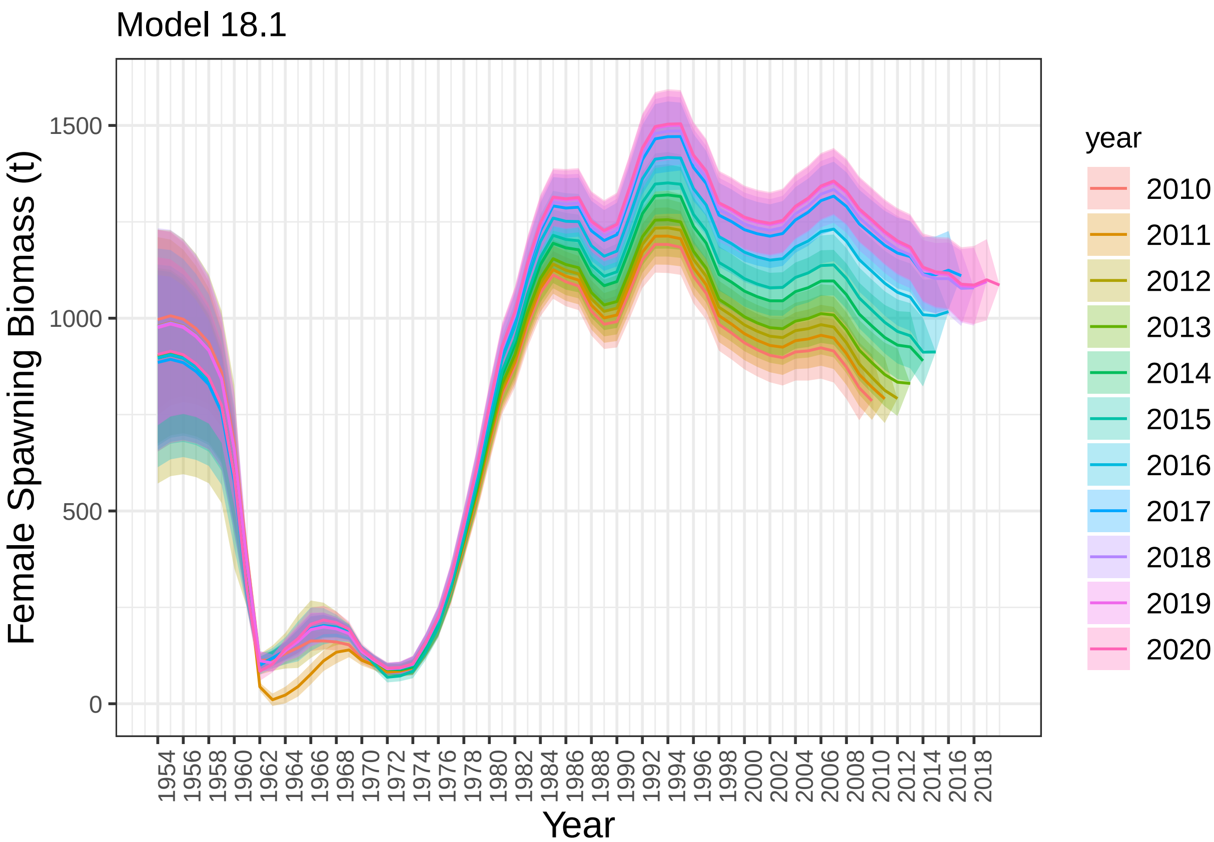


Figure 4.30: Year-class strength of age 5 Yellowfin Sole estimated by the stock assessment model. The horizontal line represents the average of the estimates from 67 years of recruitment, 1954-2020, 1.791 billion, Model 18.2.



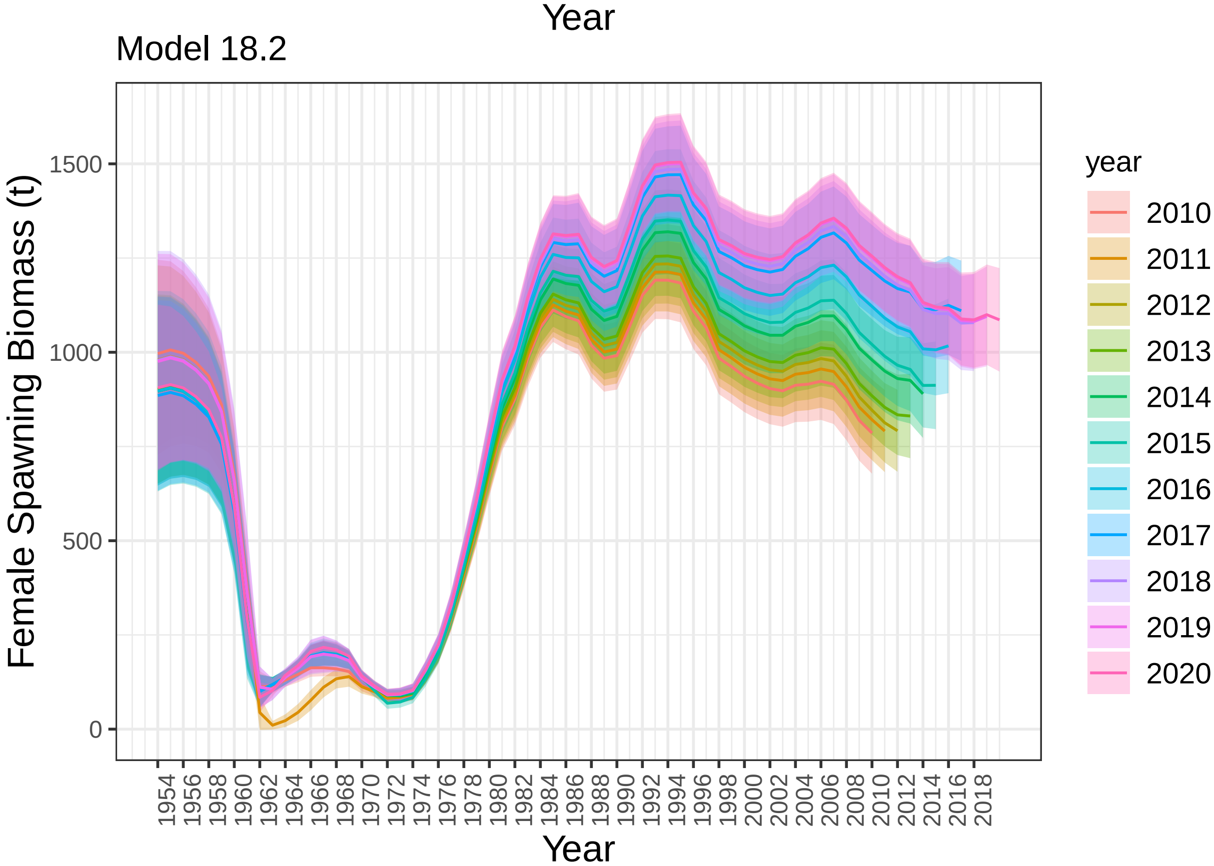
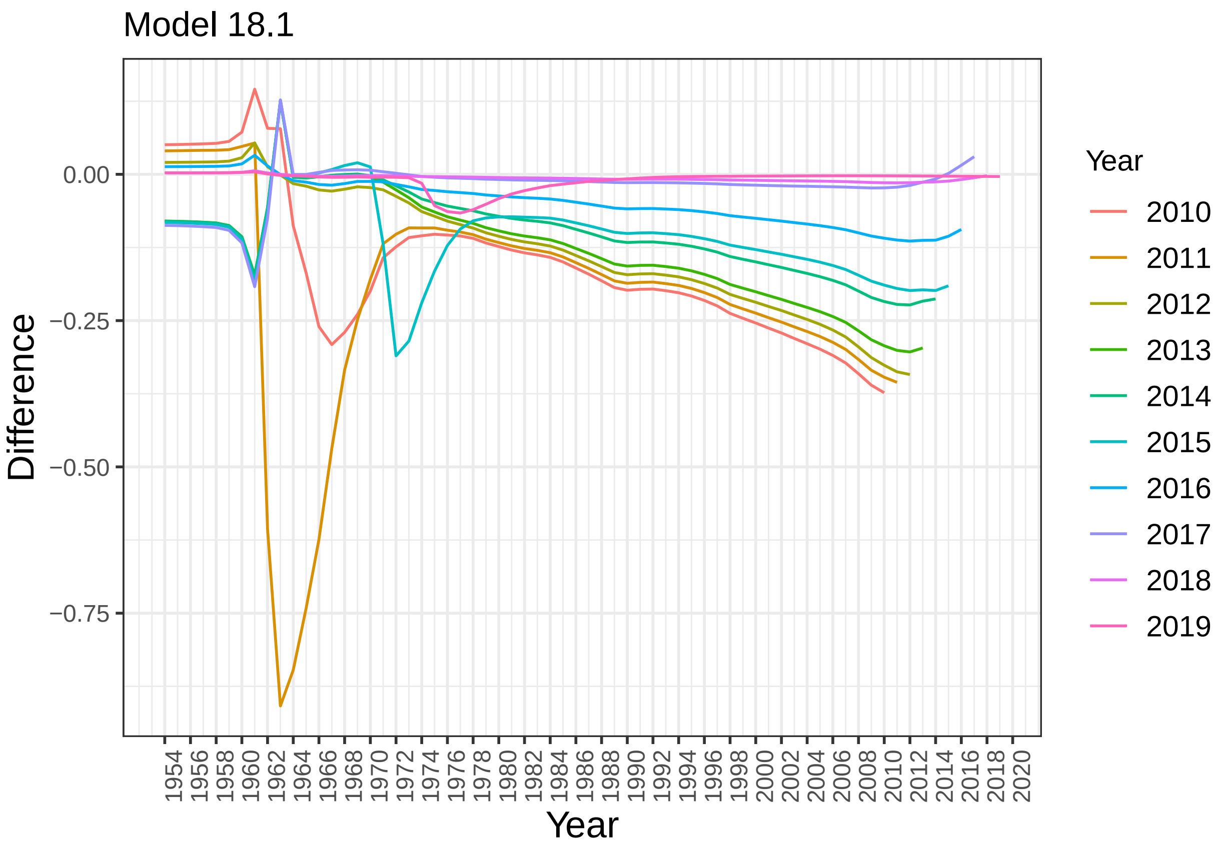


Figure 4.31: Retrospective plot of female spawning biomass for Model 18.1 (upper panel) and Model 18.2 (lower panel).



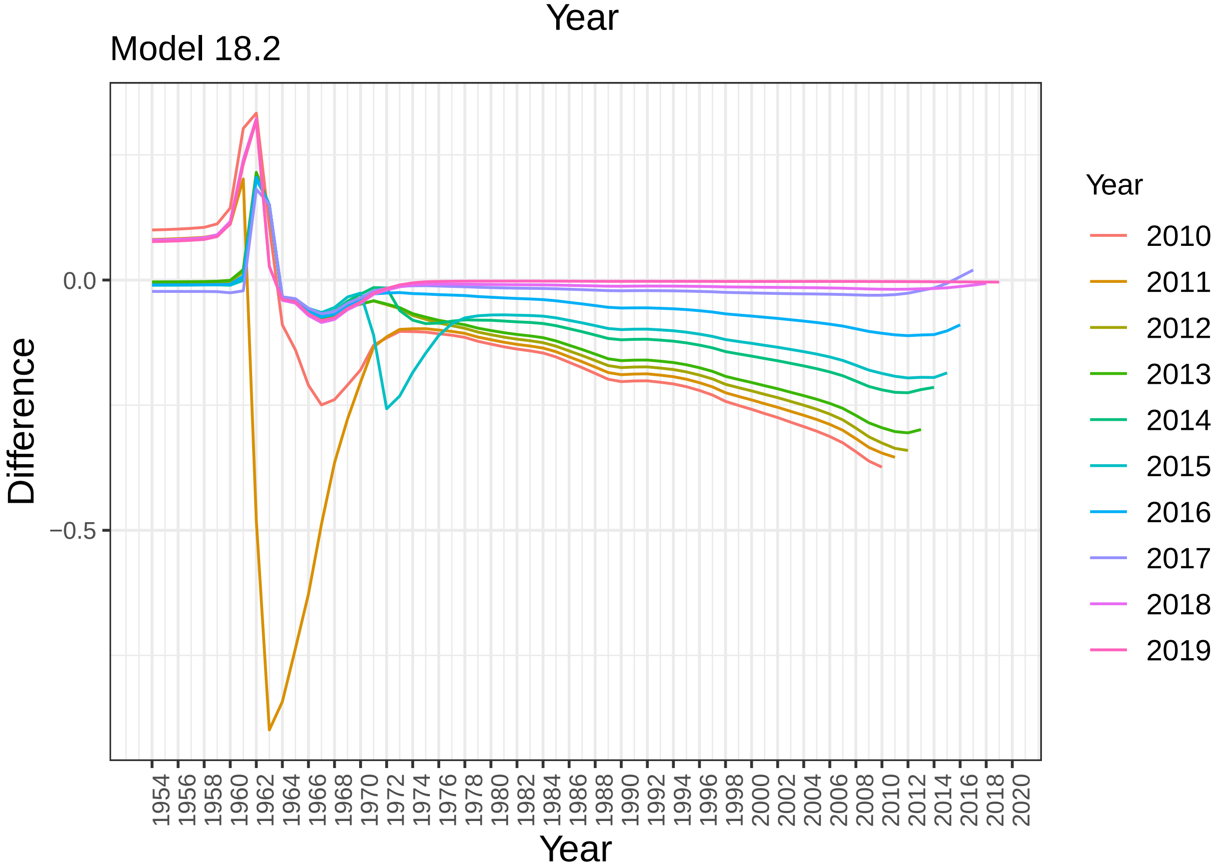


Figure 4.32: Relative differences spawning biomass between the 2020 model and the retrospective model run for years 2019 through 2010, Models 18.1 and 18.2.

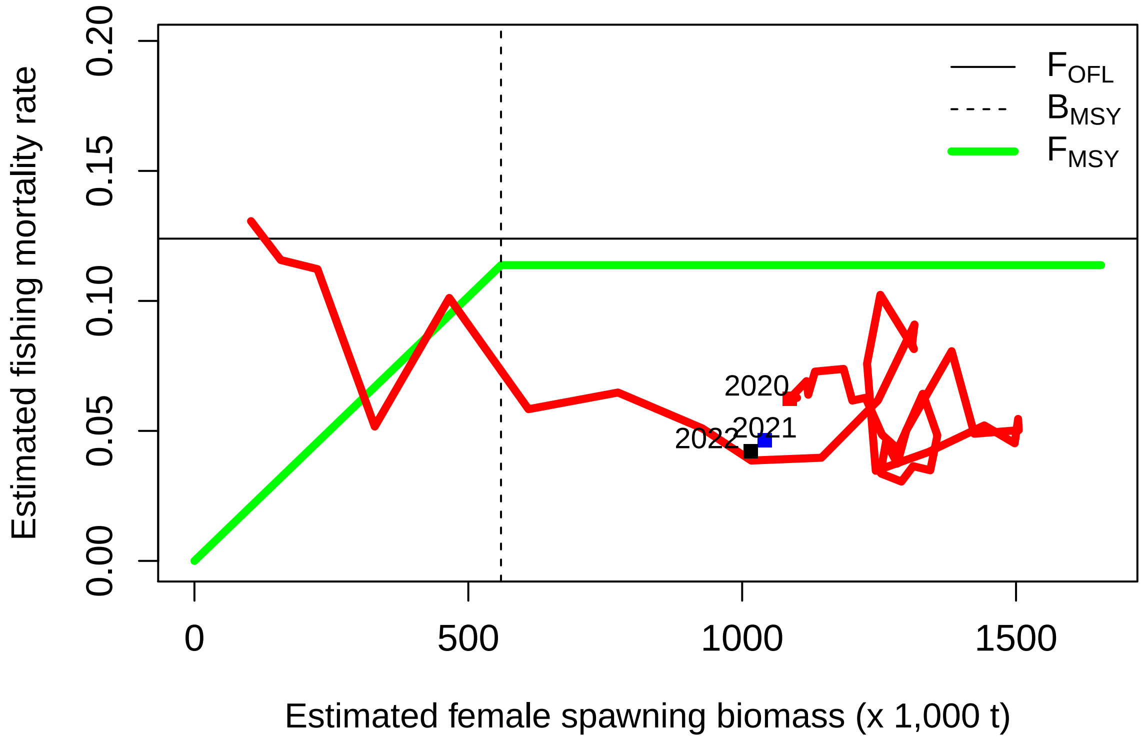


Figure 4.33: Fishing mortality rate and female spawning biomass from 1975 to 2020 compared to the F35% and F40% control rules, based on Model 18.2. Vertical line is B35%. Squares indicate estimates for 2020, 2021, and 2022.

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, 1990-2020. Source NMFS Alaska Region: Sourced by the AKR.V_NONCOMMERCIAL_FISHERY_CATCH table, October 23, 2020. Abbreviations: IPHC (International Pacific Halibut Commission), ADFG (Alaska Department of Fish and Gam), 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 2019 (Author: Ben Fissel)

BSAI FMP flatfish are predominantly caught in the Eastern Bering Sea by catcher/processors in the Amendment 80 Fleet. In 2019, total catch of FMP flatfish in the BSAI was 207 thousand t. Retained catch was 197 thousand t, which was a slight decrease (<1%) and was below the average catches between 2010-2014. The two most significant flatfish species in terms of market value and volume are yellowfin and rock sole. These two species accounted for 64% 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 1% to $210 million with a marginal decrease in prices. 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 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 1% to $209.8 million with a 4% decrease in yellowfin sole price, a 6% decrease in the rock sole price, an 11% decrease in the flathead sole price, and an 8% decrease in the arrowtooth flounder price. Prices for most flatfish were at a decadal high in 2018 and the marginal decreases in 2019 left prices at a high level relative to prices over the last decade. 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 which is primarily destined f or 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 have put downward pressure on flatfish prices and may inhibit value growth in some flatfish markets. Industry lacks immediate alternative reprocessing options to China. Export quantities of yellowfin sole and rock sole increased in 2019 from 2018 and the share of exports to China decreased despite rising export prices (Table 2).

Table 1. 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.

	2010-2014 Average	2015	2016	2017	2018	2019
Total catch K mt	280.7	219.2	225.2	211.1	212.1	207.1
Retained catch K mt	251.7	207.8	211.4	198.6	197.4	196.8
Yellowfin sole share of retained	54.47%	59.24%	62.05%	64.77%	64.50%	63.57%
Rock sole share of retained	22.41%	21.34%	20.46%	17.09%	13.75%	12.34%
Flathead sole share of retained	5.56%	4.85%	4.26%	4.08%	5.15%	7.56%
Arrowtooth and Kamchatka flounder share of retained	10.01%	6.76%	6.39%	4.90%	4.44%	6.64%
Vessels #	39	34	39	34	35	35
Total flatfish first-wholesale production K mt	150	121.6	123.9	116.9	115.1	116.2
Total flatfish first-wholesale value M US$	$211.84	$143.20	$166.70	$192.40	$211.60	$209.80
Total flatfish first-wholesale price/lb US$	$0.64	$0.53	$0.61	$0.75	$0.83	$0.82
Yellowfin sole share of value	51.20%	54.75%	56.51%	57.59%	64.56%	61.39%
Yellowfin sole price/lb US$	$0.57	$0.48	$0.55	$0.65	$0.81	$0.78
Rock sole share of value	23.01%	21.16%	20.40%	15.75%	13.75%	11.63%
Rock sole price/lb US$	$0.70	$0.55	$0.62	$0.72	$0.89	$0.83
Flathead sole share of value	5.69%	5.03%	4.68%	4.16%	5.62%	7.29%
Flathead sole price/lb US$	$0.79	$0.64	$0.74	$0.85	$0.96	$0.85
ATF and KF share of value	10.87%	8.31%	8.22%	8.63%	4.54%	6.77%
ATF and KF price/lb US$	$0.75	$0.71	$0.84	$1.36	$1.00	$0.91
H&G share of value	85.70%	90.57%	89.20%	89.66%	93.05%	94.04%

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 2. 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 $), U.S. export price (US$ per pound), the share of U.S. export value from China, and the Euro/U.S. Dollar exchange rate; 2010-2014 average and 2015-2019.

	2010-2014 Average	2015	2016	2017	2018	2019
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.