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 BSAI SAFE report, the following substantive changes have been made in the BSAI Yellowfin Sole assessment.

Changes in the data

1. The 2019 NMFS eastern Bering Sea shelf bottom-trawl survey biomass estimates and standard error were included.
2. The 2018 fishery age composition was added.
3. The 2018 survey age composition was included.
4. Estimates of the retained and discarded portions of the 2018 catch were added.
5. The estimate of the total catch made through the end of 2020 was used. Catch of 150,000 t was assumed for the 2020 and 2021 projections.

Changes in the assessment methods

Two models were considered in this assessment.

1. The model used in the 2018 assessment, and updated with 2019 data is referred to as Model 18.1a. Model 18.1a used the same natural mortality for males and females, M=0.12. Last year's model is referred to as Model 18.1.

2. A second model is presented (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.

Summary of Results

In 2019 a new model was introduced based on the 2018 Model 18.1 that retains female natural mortality fixed at 0.12 while allowing the model to estimate male natural mortality. This model is referred to as Model 18.2. Model 18.1 (and Model 18.1a) 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. (2018). Model 18.2 retains these features.

An unexpected 32% decrease in the NMFS eastern Bering Sea survey biomass was observed in 2018. In 2019 the survey biomass was 6% higher than in 2018 at 2,006,510 t. Spawning biomass estimated by Model 18.2 remained high at 1.94 * B_{MSY}. Therefore, Yellowfin Sole continues to qualify for management under Tier 1a. Similar to recent years, the 1978-2013 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 2018 assessment. This is due to a higher 2019 survey biomass point estimate, 6% higher than the

2018 estimate. Secondarily, the model estimated male natural mortality slightly higher than female natural mortality, 0.135, which increased biomass estimates.

Catch as of October 28, 2019 was 109,620 t. Over the past 5 years (2014 - 2018), 92.4% of the catch has taken place by this date. Therefore, the full year's estimate of catch in 2019 was 118,642 t. Future catch for the next 10 years, 2020 - 2029 was estimated as the mean of the past 10 years catch, 137,230 t.

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 2018 base model (Model 18.1a) and the 2019 preferred model (Model 18.2). The projected estimate of total biomass for 2020 was higher by 17% from the 2018 assessment of 2,331,500 t, to 2,726,370 t. The model projection of spawning biomass for 2020, assuming catch for 2019 as described above, was 1,051,050 t, 132% of the projected 2020 spawning biomass from the 2018 assessment of 796,600 t. The 2020 and 2021 ABCs using F_{ABC} from this assessment model were higher than the 2018 ABC of 249,100 t; 296,060 t and 296,793 t. The 2020 and 2021 OFLs estimated in this assessment were 321,794 t and 322,591 t.

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2019	2020	2020	2021
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)	2,388,000 t	2,331,500 t	2,726,370 t	2,733,120 t
Projected female spawning biomass (t)	827,900 t	796,600 t	1,051,050 t	1,005,310 t
$B_{100\%}$	1,236,000 t	1,236,000 t	1,501,510 t	1,501,510 t
$B_{MSY\%}$	451,600 t	451,600 t	542,791 t	542,791 t
F_{OFL}	0.118	0.118	0.118	0.118
$maxF_{ABC}$	0.107	0.107	0.109	0.109
F_{ABC}	0.107	0.107	0.109	0.109
OFL	281,800 t	275,100 t	321,794 t	322,591 t
$maxABC$	255,100 t	249,100 t	296,060 t	296,793 t
ABC	255,100 t	249,100 t	296,060 t	296,793 t
Status	2017	2018	2018	2019
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 118,642 t in 2019 and 137,230 used in place of maximum ABC for 2020.

Responses to SSC and Plan Team Comments on Assessments in General

SSC December 2017

1.The SSC reminds authors of the need to balance the desire to improve model fit with increased risk of model misspecification.

Authors' response

Noted.

SSC December 2018

1. The SSC requests that all authors fill out the risk table in 2019, and that the PTs provide comment on the author's results in any cases where a reduction to the ABC may be warranted (concern levels 2-4).

Authors' response

A risk table was included in this assessent.

Responses to SSC and Plan Team Comments Specific to this Assessment

SSC December 2018

1. The SSC encourages further exploration of the way mortality is handled in the model, for example through the use of sex-specific or time-varying mortality and the authors noted that they may be able to explore this more fully in 2019.

Authors' response

In the current assessment, a model was explored that used a fixed value for female natural mortality, and allowed male natural mortality to be estimated by within the model (Model 18.2).

2. Given recent changes in the distribution of other species, the SSC encourages authors to explore variability over time in the proportion of the stock that occurs in the Northern Bering Sea. While the model may account for this portion of the stock through the catchability parameter this assumes that the fraction of the biomass occurring in the NBS has not changed substantially. There is little evidence for a change in the NBS biomass within the area that was surveyed in all three years, but this does not account for the possibly large fraction of Yellowfin Sole in nearshore areas that were not surveyed in 2018. The SSC suggests a few avenues to explore possible changes in distribution of Yellowfin Sole, including a comparison of the full NBS survey area between 2010 and 2017, the application of the VAST model to estimate the proportion of Yellowfin Sole in the NBS over time, and 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 encourages the authors to consider approaches for including the substantial biomass of NBS Yellowfin Sole in the model, with the expectations that NBS surveys will be conducted regularly in the future.

Authors' response

The distribution of Yellowfin Sole in the eastern Bering Sea is shown in Figure 4.1, based on results from the four most recent NBS surveys. There does not appear to be a large shift in distribution since 2010. The biomass estimate of Yellowfin Sole in the NBS in 2010 was 310,617 t (95% CI: 215,238-405,997) and it increased to 520,029 t (95% CI: 398,122-641,936) in 2019. This is compared to a survey estimate of 2,006,510 t in the eastern Bering Sea in 2019. The distribution of Yellowfin Sole will continue to be monitored and approaches for including the substantial biomass of Yellowfin Sole in the NBS will be considered in future assessments. The size distribution of Yellowfin Sole from the eastern Bering Sea shelf survey vs. the northern Bering sea survey was compared for the most full survey years in the northern Bering Sea, 2017 and 2019 Figure 4.2.

Introduction

The 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. They inhabit the EBS shelf and are considered one stock. 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 (about lat. 70°N) and south along the Asian coast off the South Korean coast in the Sea of Japan (to about 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 4.3). 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 4.3). The directed fishery historically occurred from winter through autumn, and NMFS research surveys take place during summer months (Wilderbuer et al. 1992). Yellowfin Sole are managed as a single stock in the BSAI management area as there is presently no direct evidence of stock structure.

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.

Data source	Year
Fishery catch	1954 - 2019
Fishery age composition	1964 - 2018
Fishery weight-at-age	Avg. weight at age from 2008-2018 used for 2008-2019
Survey biomass and standard error	1982 - 2019
bottom temperature	1982 - 2019
Survey age composition	1979 - 2018
Annual length-at-age and weight-at-age from surveys	1979 - 2018
Age at maturity	Combined 1992 and 2012 samples

Fishery Catch and Catch-at-Age

This assessment uses fishery catch data from 1954-2019 (Table 4.1), and fishery catch-at-age (proportions) from 1964-2018 (Table 4.2, 1975-2018). 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.

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).

Length and Weight-at-Age

Past assessments of Yellowfin Sole have used sex-specific, time-invariant growth based on the average length-at-age and weight-at-length relationships from the time-series of survey observations summed over all years since 1982. These weight-at-age estimates were estimated from the von Bertalanffy growth curve.

Parameters of the von Bertalanffy growth curve have been 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	0.112	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 4.4).

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

These estimates of weight at length were applied to the annual trawl survey estimates of population length at age, by sex, to calculate the weight at each age (Figure 4.4). 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 1982-2019.

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 4.5).

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 4.6). 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).

In order to incorporate time-varying (year effect on growth) and temperature-dependent growth functions into the age-structured stock assessment model we used the annual observed population mean weight-at-age (time-varying) from the trawl survey. These empirical data indicate good somatic growth correspondence with annual bottom temperature anomalies from 1982-2019 (Figure 4.6). Fishery weight at age data awere averaged across years for each age to provide updated estimates for the fishery.

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 4.3). 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 4.3). 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 4.3). 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.

Fishery

Yellowfin Sole have annually been caught with bottom trawls on the Bering Sea shelf since the fishery began in 1954 and were overexploited by foreign fisheries in 1959-62 when catches averaged 404,000 t annually (Figure 4.7, top panel). As a result of reduced stock abundance, catches declined to an annual average of 117,800 t from 1963-71 and further declined to an annual average of 50,700 t from 1972-77. The lower yield in this latter period was partially due to the discontinuation of the 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 (Figure 4.7).

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 EBS. 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 in order to improve retention and utilization of fishery resources by the non-AFA trawl catcher/processor fleet. This was accomplished by extending the groundfish retention standards to all H&G 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 and PSC (prohibited species catch) among cooperatives has significantly changed the way the annual catch has accumulated (Fig 4.1, bottom 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.

Yellowfin Sole are usually 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 first wholesale value of Alaska Yellowfin Sole totaled $97.8 million in 2014. From 2016 to 2017 the first wholesale price of all Bering Sea flatfish fisheries increased 16% to $192.9 million t and Yellowfin Sole price increased 19% year over year. 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. The total annual catch (t) since 1954 is shown in Table 4.1. Note that the MFCMA was implemented in 1977.

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).

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).

The 1997 catch of 181,389 t (retained and discards) was the largest since the fishery became completely domestic, but decreased from 1998–2010, averaging 94,004 t (Table 4.4). From 2011-2014 the catch increased, averaging 155,000 t. The 2013 catch totaled 165,000 t (73% of the ABC), and was the highest annual catch since prior to 1990. For 2019, the catch distribution has been spread out from January through May with the majority coming from four BSAI management areas (509, 513, 514, 517).

As of late October 2019, the fishing season is ongoing. In order to estimate the total 2019 catch for the stock assessment model, the average proportion of the 2011-2018 cumulative catch attained by the end of October was applied to the 2019 catch amount at the same time period and resulted in a 2019 catch estimate of 154,200 t (52.08% 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 4.8). Catch proportions of Yellowfin Sole by month and area are shown in Figure 4.9. The primary fishing areas for Yellowfin Sole in 2019 through the end of September were NMFS Areas 513 and 514, and the highest proportion of the catch was taken in February and March. Maps of the locations where Yellowfin Sole were caught in 2019, by month (through mid-September), are shown in Figure 4.10. The average age of Yellowfin Sole in the 2018 catch is estimated at 13.37 and 12.83 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 4.4). 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 4.5).

Survey

Weight at age

Average weight at age is calculated for Yellowfin Sole based on the weight of aged fish from the NMFS eastern Bering Sea survey. The weight at age for the final year (2019) was assumed to be the same as for 2018, as the 2019 age data is not yet available (Table 4.6).

Survey Biomass Estimates and Population Age Composition Estimates

Indices of relative abundance available from AFSC surveys showed a major increase in the abundance of Yellowfin Sole during the late 1970s, increasing from 21 kg/ha in 1975 to 51 kg/ha in 1981 (Fig. 4.2 in Bakkala and Wilderbuer 1990, Table 4.7). These increases have also been documented through Japanese commercial pair trawl data and catch-at-age modeling in past assessments (Bakkala and Wilderbuer 1990).

Survey CPUE for Yellowfin Sole has fluctuated from approximately 1 million to 2.5 million kg/km^2 over the eastern Bering Sea time survey from 1982-2019 (Figure 4.11). 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 4.12). Biomass estimates for Yellowfin Sole from the annual bottom trawl survey on the eastern Bering Sea shelf show a doubling of survey biomass between 1975 and 1979 with a further increase to over 3.3 million t in 1981 (Table 4.8, Table 4.9 and Figure 4.13). 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 4.7).

Variability of Yellowfin Sole survey biomass estimates (Figure 4.13) is in part due to the availability of Yellowfin Sole to the survey area (Nichol 1998). 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 4.6 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, but the 2018 estimate of 1,892,925 was down 32% from 2017, followed by a 6% increase in 2019.

We propose two 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 escapement under the footrope of survey gear may increase if fish are less active. 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. in review). 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 4.14). 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 4.6).

Yellowfin Sole population numbers-at-age estimated from the annual bottom trawl surveys are shown in Table 4.10 and their occurrence in trawl survey hauls and associated collections of lengths and age structures since 1982 are shown in Table 4.11. 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 4.1). 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 Yellowfin Sole fishing is presently prohibited in the northern Bering Sea, the biomass from this area is not included in the stock assessment model. Large shifts in the abundance of Yellowfin Sole into the Bering Sea have not been observed (Figure 4.1), but the spatial distribution will continue to be monitored as shifts may occur under future climate change.

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 starts at age one and fish older than twenty are allowed to accumulate into a plus group. 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 most likely 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 1978-2019 was determined using the Ricker stock recruitment curve,

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

Parameters α and β were estimated by fitting spawning biomass and recruitment during the period 1978-2013, and are shown from Model 18.1a (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 number of fish in a "plus group" which 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,

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

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

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 (Wilderbuer 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 18.1a 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 a previous section (Table 4.3).

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 452 parameters estimated by the model. The number of key parameters are presented below:

Fishing mortality	Selectivity	Survey catchability	Year-class strength	Spawner-recruit	M	Total
67	272	4	106	2	1	452

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 parameters.

Year Class Strengths

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 was 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 age category 20+ years. A single selectivity curve, for both males and females, was fit for all years of survey data.

Given that there have been annual changes in management, vessel participation and most likely gear selectivity, time-varying fishing selectivity curves were estimated. 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 (diffuse prior) of 0.5^2 and 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 2016 values were fixed as the average of the 3 most recent years. Survey selectivity curves are shown in Figure 4.17 and fishery selectiviyt in Figure 4.18

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 A past assessment (Wilderbuer and Nichol 2001) first 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 the current model, 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. In review).

Spawner-Recruit Estimation

Annual recruitment estimates from 1978-2013 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. 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

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.

For this assessment, two models were examined. The first was the same model used in the 2018 assessment, Model 18.1a. The second model, 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 trend in survey catchability was similar with Model 18.1a and Model 18.2, but the catchability was lower with Model 18.2 and estimates in some years were slightly over 1.0 (Figure 4.19).

The sex ratio, presented as the proportion female, was estimated to be slightly lower in Model 18.1a than Model 18.2 (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 1,424 in Model 18.1a to 1,356 in Model 18.2 (Table 4.13, figure_nums("srv_agecomp1",display="cite"), `figure_nums("srv_agecomp2",display="cite")`, figure_nums("fsh_agecomp1",display="cite"), `figure_nums("fsh_agecomp2",display="cite")`).

Table 4.15 indicates that the ABC values from Model 18.2 for 2020 would be 141,943 t higher than Model 18.2. 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 4.21).

It is important for the Tier 1 calculations to identify which subset of the stock recruitment data is used. Using the full time series to fit the spawner recruit curve estimates that the stock is most productive at a small stock size. Thus MSY and F_{MSY} are relatively high values and B_{MSY} is a lower value. If the stock was productive in the past at a small stock size because of non density-dependent factors (environment), then reducing the stock size to low levels could be detrimental to the long-term sustainability of the stock if the environment, and thus productivity, have changed from the earlier period. Since observations of Yellowfin Sole recruitment at low stock sizes are not available from multiple time periods, it is uncertain if future recruitment events at low stock conditions would be as productive as during the late 1960s-early 1970s.

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 1977-2013 spawner-recruit data in the model. The resulting stock rescruitment curves are very similar for Model 18.1a and 18.2 (Figure 4.15 and Figure 4.16).

Figure 4.22

Given these results, Model 18.2 is the preferred model for estimating the Yellowfin Sole stock size and management quantities for the 2020 fishing season.

Time Series Results

The data was updated in 2019 to include current values of catch, fishery and survey age compositions from 2018, and the 2019 survey biomass and standard error estimates. The fishery and survey weights-at-age were also changed in a small amount to include the latest year of data. These changes produced Model 18.1a ABC and OFL estimates for 2020 similar to the 2018 assessment (Model 18.1) projections for 2019, 296,060 t and 296,793 t. Model 18.2 produced slightly higher estimates for ABC and OFL than Model 18.1a due to the estimate of higher male natural mortality (Table 4.15).

The 2018 overall estimate (1982 – 2019) of trawl survey catchability decreased from Model 18.1a to Model 18.2. This resulted in slightly higher model estimates of population numbers at age and biomass for the time-series back to 1992 relative to last year's assessment and increased the estimated level of female spawning biomass. The model results indicate the stock has been in a slowly declining condition since 1994 (Figure 4.23). The five past years in the Bering Sea have had bottom temperature anomalies above the mean. The temperature-dependent q adjustment for 2019 was 0.91.

Fishing Mortality and Selectivity

The full-selection F has averaged round(mean(YFS2$F_m[61:65,18]),4) over the period 2014-2018 with a maximum of 0.11 in 1978 and a minimum of 0.04 in 2001 (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.

Abundance Trends

Model 18.2 estimated q at an average value of 0.79 for the period 1982-2019 which resultd in the model estimate of the 2019 age 2+ total biomass at 3,090,480 t (Table 4.8). Model results indicate that Yellowfin Sole total biomass (age 2+) was at low levels during most of the 1960s and early 1970s (700,000-1,000,000 t) after a period of high exploitation (Table 4.8, Figure 4.23). Sustained above average recruitment from 1967-1976 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. The present biomass is estimated at 77% of the peak 1985 level. The female spawning biomass has also declined since the peak in 1994, with a 2019 estimate of 1,062,990 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 2032 if the fishing mortality rate continues at the same level as the average of the past 5 years (Figure 4.24).

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 4.25). The 1981 year class was the strongest observed (and estimated) during the 47 year period analyzed and the 1983 year class was also very strong. Survey age composition estimates and the assessment model also estimate that the 1987 and 1988 year classes were average and the 1991 and 1995 year classes were above average. With the exception of these 4 year classes, recruitment from 15 of the following 19 years estimated from 1984-2005 (since the strong 1983 year-class) were below the 48 year average, which caused the population to gradually decline. The 2003 year-class has now been observed multiple times in the age compositions and is clearly a strong year class, similar to some of the strong recruitment mentioned above and have contributed to the reservoir of spawning fish in the current population. In addition, recruitment from 2006-2009 appear also to be average to above average.

Historical Exploitation Rates

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% (Figure 4.24).

Retrospective Analysis

A within-model retrospective analysis was included for the recommended assessment model (Model 18.2). In this analysis, retrospective female spawning biomass was calculated by sequentially dropping data one year at a time and then comparing the peeled estimate to the reference stock assessment model used in the assessment (Figure 4.26). Mohn's rho was -0.2185025 using this model. A similar retrospective pattern was observed as in similar yeaars, in which earlier retrospective years indicated a lower level of spawning biomass than the current year's data (Figure 4.26). The difference in female spawning biomass was negative for all years, except for the most recent, 2018 (Figure 4.27).

There is a large amount of variability in the annual survey biomass of Yellowfin Sole due to the temperature-influenced availability to the survey. This large variability can contribute to undesirable retrospective patterns since earlier years do not fit the same highly variable information as the current year. In particular, retrospective model runs are outside the confidence intervals of the assessment model spawning biomass trajectory for about a 17 year period from 1986-2019.

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.

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. This was accomplished using data through 2018 and yielded the following results.

Profiling over M and q was also 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 assessment table

Assessment related considerations

The BSAI Yellowfin Sole assessment is based on surveys conducted annually on the EBS shelf from 1982-2018 (no skipped years). 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 nice 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.

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. However, the best retrospective patterns do not occur at the corresponding values of best overall model fit of M and q (which occur at higher levels of M and q). 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.

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 78% of the peak 1985 level and is at twice the level of BMSY. Projections indicate that the FSB will remain well-above the BMSY level through 2032 (Figure 4.24). Population dynamics are not a concern for this assessment.

Environmental/ecosystem considerations

It is unknown how particular environmental factors affect the sustainability of Yellowfin Sole. It has been demonstrated that the migration to spawning grounds and subsequent spawning occurs sooner in warm years. Somatic growth has also been shown to increase in warmer temperatures. The prey field for this species consists primarily of polycheate worms and clam siphons, species whose distribution and abundance patterns relative to a changing environment are unknown. It is also unknown what effect environmental variability has on the distribution of Yellowfin Sole predators. Given the high level of sustained abundance of this species, there is a low level of concern for a variable environment, at least for the levels observed over the past 40 years.

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.

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.

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 2019 numbers at age from the stock assessment model are projected to 2019 given the 2018 catch and then a 2019 catch of 150,000 t is applied to the projected 2019 population biomass to obtain the 2020 OFL.

The SSC has determined that Yellowfin Sole qualify as a Tier 1 stock and therefore the 2020 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 2020 biomass estimate.

The geometric mean of the 2020 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 2020 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 2020 harvest (now the 1978-2013 time-series) recommendation (Model 18.2), the $F_{ABC} = F_{harmonic_mean}$ = 0.109. The estimate of age 6+ total biomass for 2020 is 2,726,370 t. The calculations outlined above give a Tier 1 ABC harvest recommendation of 296,060 t and an OFL of 321,794 t for 2020. This results in an 8 % (25,734 t) buffer between ABC and OFL. The ABC value is % lower than last year, primarily due to the 32% decline in the survey estimate from 2018 to 2019.

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	2020 Yield
Tier 1 $F_{OFL} = F_{MSY}$	0.118	289,900 t
Tier 1 $F_{ABC} = F_{harmonic_mean}$	0.109	263,200 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 1977 Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2019 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2020 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2019. 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 2020, 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 FABC value for 2019 recommended in the assessment to the max F_{ABC} for 2020. (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 2014-2019 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, the upper bound on F_{ABC} is set at F60%. (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 2020 and 2021, 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 2032 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. A phase plane figure of the estimated time-series of Yellowfin Sole female spawning biomass (FSB) relative to the harvest control rule is shown in Figure 4.28.

Year	Catch	FSB	Geom. mean 6+ biomass	ABC	OFL
2020	137,230	1,051,050	2,726,370	296,060	321,794

Year	Catch	FSB	Geom. mean 6+ biomass	ABC	OFL
2021	137,230	1,005,310	2,733,120	296,793	322,591

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
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 datch (t) of Yellowfin Sole 1954-2019. Foreign catches are designated as joint venture processing (JVP) and domestic annual processing (DAP). Catch for 2019 was downloaded October 28, 2019.

		Domestic		
Year	Foreign	JVP	DAP	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			115,842	115,842
1992			149,569	149,569
1993			106,101	106,101
1994			144,544	144,544
1995			124,740	124,740
1996			129,659	129,659
1997			181,389	181,389
1998			101,201	101,201

1999	67,320	67,320
2000	83,850	83,850
2001	63,395	63,395
2002	73,000	73,000
2003	74,418	74,418
2004	69,046	69,046
2005	94,383	94,383
2006	99,068	99,068
2007	121,029	121,029
2008	148,894	148,894
2009	107,528	107,528
2010	118,624	118,624
2011	151,164	151,164
2012	147,183	147,183
2013	164,944	164,944
2014	156,772	156,772
2015	126,936	126,936
2016	135,345	135,345
2017	132,265	132,265
2018	131,543	131,543
2019	109,620	109,620

Table 4.2: Yellowfin Sole fishery catch-at-age (proportions), 1975-2018 (female), ages 7-17+.

Year	7	8	9	10	11	12	13	14	15	16	17+	Total proportion over age 7
1975	0.1153	0.2888	0.2746	0.1200	0.0537	0.0263	0.0198	0.0230	0.0071	0.0066	0.0040	0.9392
1976	0.0976	0.1615	0.2618	0.2089	0.0916	0.0422	0.0210	0.0159	0.0185	0.0057	0.0053	0.9300
1977	0.1748	0.1957	0.1566	0.1371	0.0742	0.0273	0.0118	0.0058	0.0043	0.0050	0.0016	0.7942
1978	0.0935	0.2048	0.2280	0.1668	0.1341	0.0688	0.0245	0.0104	0.0050	0.0038	0.0044	0.9441
1979	0.0606	0.1427	0.2199	0.1942	0.1284	0.0997	0.0506	0.0180	0.0076	0.0037	0.0028	0.9282
1980	0.0621	0.0693	0.1312	0.1888	0.1705	0.1175	0.0942	0.0487	0.0175	0.0075	0.0036	0.9109
1981	0.0760	0.0983	0.0935	0.1448	0.1738	0.1379	0.0879	0.0675	0.0341	0.0121	0.0051	0.9310
1982	0.0584	0.1349	0.1356	0.0989	0.1262	0.1352	0.1012	0.0627	0.0475	0.0239	0.0085	0.9330
1983	0.0935	0.1008	0.1601	0.1250	0.0805	0.0976	0.1025	0.0761	0.0470	0.0356	0.0179	0.9366
1984	0.0349	0.0949	0.0994	0.1575	0.1235	0.0798	0.0968	0.1017	0.0756	0.0467	0.0354	0.9462
1985	0.0200	0.0565	0.1190	0.1023	0.1469	0.1110	0.0708	0.0856	0.0899	0.0667	0.0412	0.9099
1986	0.0517	0.0525	0.0986	0.1391	0.0949	0.1232	0.0894	0.0563	0.0677	0.0709	0.0526	0.8969
1987	0.0174	0.0480	0.0414	0.0831	0.1304	0.0946	0.1261	0.0925	0.0585	0.0704	0.0738	0.8362
1988	0.0497	0.0438	0.1044	0.0631	0.0910	0.1181	0.0787	0.1015	0.0736	0.0463	0.0556	0.8258
1989	0.0050	0.0784	0.0607	0.1187	0.0623	0.0847	0.1079	0.0716	0.0922	0.0668	0.0420	0.7903
1990	0.0392	0.0229	0.2241	0.0915	0.1107	0.0469	0.0596	0.0744	0.0491	0.0631	0.0457	0.8272
1991	0.0176	0.1024	0.0367	0.2407	0.0809	0.0925	0.0388	0.0492	0.0614	0.0405	0.0521	0.8128
1992	0.0158	0.0397	0.1721	0.0444	0.2317	0.0694	0.0758	0.0312	0.0393	0.0490	0.0323	0.8007
1993	0.0217	0.0249	0.0457	0.1634	0.0397	0.2093	0.0644	0.0719	0.0300	0.0381	0.0477	0.7568
1994	0.0377	0.0549	0.0559	0.0760	0.2002	0.0388	0.1776	0.0506	0.0541	0.0221	0.0278	0.7957
1995	0.0490	0.0894	0.0815	0.0587	0.0685	0.1710	0.0326	0.1485	0.0422	0.0452	0.0185	0.8051
1996	0.0257	0.0774	0.0964	0.0742	0.0516	0.0603	0.1519	0.0291	0.1330	0.0379	0.0405	0.7780
1997	0.0273	0.0372	0.0955	0.1031	0.0722	0.0478	0.0546	0.1361	0.0260	0.1184	0.0337	0.7519
1998	0.0752	0.0523	0.0562	0.1126	0.1016	0.0642	0.0403	0.0450	0.1109	0.0211	0.0958	0.7752
1999	0.0108	0.0441	0.0400	0.0531	0.1183	0.1107	0.0706	0.0444	0.0496	0.1221	0.0232	0.6869
2000	0.0097	0.0277	0.0922	0.0613	0.0604	0.1131	0.0984	0.0612	0.0382	0.0425	0.1046	0.7093
2001	0.0210	0.0421	0.0778	0.1530	0.0665	0.0521	0.0888	0.0748	0.0460	0.0286	0.0318	0.6825
2002	0.0250	0.0253	0.0506	0.0872	0.1583	0.0655	0.0502	0.0848	0.0712	0.0437	0.0272	0.6890
2003	0.0187	0.0928	0.0626	0.0769	0.0911	0.1372	0.0530	0.0396	0.0665	0.0557	0.0342	0.7283
2004	0.0182	0.0440	0.1582	0.0759	0.0743	0.0793	0.1148	0.0437	0.0326	0.0546	0.0457	0.7413
2005	0.0302	0.0401	0.0660	0.1740	0.0703	0.0642	0.0670	0.0966	0.0368	0.0274	0.0459	0.7185
2006	0.1102	0.0909	0.0700	0.0748	0.1505	0.0527	0.0450	0.0456	0.0648	0.0245	0.0182	0.7472
2007	0.0278	0.0742	0.0729	0.0663	0.0774	0.1619	0.0576	0.0495	0.0502	0.0714	0.0270	0.7362
2008	0.0418	0.0557	0.1131	0.0840	0.0638	0.0683	0.1377	0.0483	0.0412	0.0418	0.0594	0.7551
2009	0.0326	0.0762	0.0795	0.1242	0.0797	0.0571	0.0598	0.1198	0.0419	0.0358	0.0362	0.7428
2010	0.0569	0.0665	0.0955	0.0756	0.1085	0.0686	0.0491	0.0516	0.1033	0.0362	0.0309	0.7427
2011	0.0233	0.1013	0.0932	0.1051	0.0716	0.0959	0.0591	0.0419	0.0438	0.0877	0.0307	0.7536
2012	0.0291	0.0463	0.1453	0.1009	0.0972	0.0620	0.0813	0.0497	0.0351	0.0367	0.0734	0.7570
2013	0.0147	0.0338	0.0594	0.1707	0.1053	0.0947	0.0587	0.0759	0.0462	0.0326	0.0341	0.7261
2014	0.0154	0.0449	0.0702	0.0774	0.1677	0.0935	0.0817	0.0503	0.0649	0.0395	0.0279	0.7334
2015	0.0146	0.0283	0.0595	0.0722	0.0723	0.1558	0.0880	0.0776	0.0479	0.0620	0.0378	0.7160
2016	0.0337	0.0485	0.0711	0.1019	0.0855	0.0672	0.1289	0.0695	0.0603	0.0370	0.0478	0.7514
2017	0.0208	0.1146	0.1126	0.1039	0.1030	0.0700	0.0500	0.0923	0.0490	0.0423	0.0259	0.7844
2018	0.0076	0.0292	0.1376	0.1178	0.1007	0.0968	0.0652	0.0464	0.0856	0.0455	0.0392	0.7716

Table 4.3: 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 4.4: Estimates of retained and discarded (t) Yellowfin Sole caught in Bering Sea fisheries through September 25th, 2019, and the proportion discarded.

Year	Retained (mt)	Discarded (mt)	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	4,749	0.03
2012	142,132	5,055	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	4,143	0.03
2017	128,665	3,600	0.03
2018	127,331	4,213	0.03
2019	99,754	2,303	0.02

Table 4.5: Discarded and retained catch of non-CDQ Yellowfin Sole, by fishery, in 2018. 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 (mt). Source: NMFS AKRO BLEND/Catch Accounting System.

	Gear type	Discarded (mt)	Retained (mt)
Greenland Turbot	HAL	0	0
Other Species	HAL	1	0
Pacific Cod	HAL	1,808	154
Alaska Plaice	NPT	0	0
Atka Mackerel	NPT	0	0
Kamchatka Flounder	NPT	21	107
No retained catch	NPT	3	375
Other Species	NPT	224	13,362
Pacific Cod	NPT	1	3
Pollock - bottom	NPT	0	0
Pollock - midwater	NPT	1,606	108,226
Atka Mackerel	POT	333	67
Yellowfin Sole	POT	0	10
Alaska Plaice	PTR	147	253

Table 4.6: Mean weight at age for Yellowfin Sole (unsmoothed), females presented first, followed by males.

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 4.7: Yellowfin Sole biomass estimates (t) from the annual Bering Sea shelf bottom trawl survey, with upper and lower 95% confidence intervals.

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 4.8: Model estimates of Yellowfin Sole age 2+ total biomass (t) from the 2018 and 2019 stock assessments, Model 18.1, Model 18.1a, and 18.2.

	Model 18.2			Model 18.1a			Model 18.1 (for 2018)
	Biomass (t)	LCI	HCI	Biomass (t)	LCI	HCI	Biomass (t)
1954	2,568,990	2,261,130	2,918,770	2,568,990	2,261,130	2,918,770	2,484,660
1955	2,521,590	2,243,160	2,834,590	2,521,590	2,243,160	2,834,590	2,451,520
1956	2,467,720	2,222,200	2,740,360	2,467,720	2,222,200	2,740,360	2,408,730
1957	2,407,370	2,197,530	2,637,240	2,407,370	2,197,530	2,637,240	2,356,260
1958	2,361,270	2,188,490	2,547,690	2,361,270	2,188,490	2,547,690	2,315,130
1959	2,312,040	2,174,940	2,457,780	2,312,040	2,174,940	2,457,780	2,268,770
1960	2,131,950	2,025,970	2,243,480	2,131,950	2,025,970	2,243,480	2,090,420
1961	1,689,120	1,612,230	1,769,680	1,689,120	1,612,230	1,769,680	1,649,020
1962	1,178,470	1,127,240	1,232,040	1,178,470	1,127,240	1,232,040	1,140,340
1963	834,849	801,795	869,266	834,849	801,795	869,266	801,374
1964	875,678	842,106	910,590	875,678	842,106	910,590	843,239
1965	869,728	835,979	904,840	869,728	835,979	904,840	838,326
1966	917,105	881,419	954,236	917,105	881,419	954,236	886,834
1967	905,579	868,346	944,408	905,579	868,346	944,408	875,924
1968	834,485	796,394	874,398	834,485	796,394	874,398	802,782
1969	876,087	833,236	921,142	876,087	833,236	921,142	837,091
1970	860,596	812,394	911,658	860,596	812,394	911,658	809,476
1971	946,723	889,263	1,007,900	946,723	889,263	1,007,900	872,868
1972	1,044,350	975,549	1,118,010	1,044,350	975,549	1,118,010	942,763
1973	1,336,300	1,251,820	1,426,480	1,336,300	1,251,820	1,426,480	1,195,830
1974	1,627,450	1,526,230	1,735,380	1,627,450	1,526,230	1,735,380	1,444,640
1975	2,020,490	1,898,200	2,150,660	2,020,490	1,898,200	2,150,660	1,803,120
1976	2,372,970	2,231,510	2,523,400	2,372,970	2,231,510	2,523,400	2,112,310
1977	2,726,000	2,566,260	2,895,680	2,726,000	2,566,260	2,895,680	2,425,340
1978	3,060,000	2,883,160	3,247,680	3,060,000	2,883,160	3,247,680	2,723,240
1979	3,250,100	3,059,280	3,452,820	3,250,100	3,059,280	3,452,820	2,885,990
1980	3,457,650	3,254,370	3,673,620	3,457,650	3,254,370	3,673,620	3,070,950
1981	3,643,470	3,429,750	3,870,510	3,643,470	3,429,750	3,870,510	3,239,750
1982	3,772,620	3,552,940	4,005,880	3,772,620	3,552,940	4,005,880	3,355,420
1983	3,745,370	3,524,650	3,979,910	3,745,370	3,524,650	3,979,910	3,333,580
1984	4,004,910	3,769,040	4,255,550	4,004,910	3,769,040	4,255,550	3,562,120
1985	4,025,010	3,782,030	4,283,600	4,025,010	3,782,030	4,283,600	3,573,460
1986	3,720,010	3,484,860	3,971,040	3,720,010	3,484,860	3,971,040	3,286,830
1987	3,697,540	3,455,790	3,956,200	3,697,540	3,455,790	3,956,200	3,249,150
1988	3,591,380	3,350,870	3,849,150	3,591,380	3,350,870	3,849,150	3,153,670
1989	3,671,410	3,419,140	3,942,300	3,671,410	3,419,140	3,942,300	3,213,350
1990	3,520,210	3,273,140	3,785,940	3,520,210	3,273,140	3,785,940	3,078,880
1991	3,647,290	3,393,130	3,920,500	3,647,290	3,393,130	3,920,500	3,199,350
1992	3,885,910	3,617,680	4,174,040	3,885,910	3,617,680	4,174,040	3,409,630
1993	3,928,940	3,654,340	4,224,170	3,928,940	3,654,340	4,224,170	3,445,060
1994	3,973,900	3,696,330	4,272,320	3,973,900	3,696,330	4,272,320	3,488,610
1995	3,715,600	3,449,220	4,002,560	3,715,600	3,449,220	4,002,560	3,260,090
1996	3,619,500	3,357,900	3,901,480	3,619,500	3,357,900	3,901,480	3,176,270
1997	3,646,800	3,381,440	3,932,970	3,646,800	3,381,440	3,932,970	3,192,500
1998	3,340,330	3,089,200	3,611,880	3,340,330	3,089,200	3,611,880	2,915,720
1999	3,128,930	2,889,430	3,388,280	3,128,930	2,889,430	3,388,280	2,729,090
2000	3,179,720	2,939,640	3,439,410	3,179,720	2,939,640	3,439,410	2,777,110
2001	3,088,090	2,853,750	3,341,670	3,088,090	2,853,750	3,341,670	2,700,600

2002	3,128,070	2,893,370	3,381,810	3,128,070	2,893,370	3,381,810	2,740,550
2003	3,361,730	3,113,910	3,629,280	3,361,730	3,113,910	3,629,280	2,952,120
2004	3,593,780	3,331,950	3,876,180	3,593,780	3,331,950	3,876,180	3,159,430
2005	3,700,510	3,432,350	3,989,610	3,700,510	3,432,350	3,989,610	3,262,810
2006	3,669,130	3,400,990	3,958,400	3,669,130	3,400,990	3,958,400	3,237,110
2007	3,659,630	3,388,970	3,951,900	3,659,630	3,388,970	3,951,900	3,235,570
2008	3,491,070	3,226,920	3,776,840	3,491,070	3,226,920	3,776,840	3,090,920
2009	3,287,460	3,031,620	3,564,880	3,287,460	3,031,620	3,564,880	2,911,530
2010	3,318,660	3,057,880	3,601,680	3,318,660	3,057,880	3,601,680	2,952,490
2011	3,322,390	3,057,270	3,610,500	3,322,390	3,057,270	3,610,500	2,964,970
2012	3,269,470	3,001,140	3,561,790	3,269,470	3,001,140	3,561,790	2,927,370
2013	3,178,900	2,909,820	3,472,860	3,178,900	2,909,820	3,472,860	2,856,100
2014	2,922,880	2,664,870	3,205,860	2,922,880	2,664,870	3,205,860	2,644,760
2015	2,915,360	2,647,620	3,210,180	2,915,360	2,647,620	3,210,180	2,648,330
2016	3,056,080	2,764,880	3,377,950	3,056,080	2,764,880	3,377,950	2,809,140
2017	2,965,470	2,667,900	3,296,230	2,965,470	2,667,900	3,296,230	2,735,330
2018	3,048,260	2,718,210	3,418,380	3,048,260	2,718,210	3,418,380	2,783,240
2019	3,090,480	2,721,980	3,508,860	3,090,480	2,721,980	3,508,860	-

Table 4.9: 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 4.10: Yellowfin Sole population numbers-at-age (millions) estimated from the annual EBS bottom trawl surveys, 1982-2019. Numbers-at-age from 1982-1986 come from the standard survey area, and years 1987 forward 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+
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	505	228	113	176	183	499	43	313	75
1998	0	9	78	451	399	854	246	193	351	391	350	161	166	251	63	395
1999	0	3	61	188	166	177	699	100	103	236	183	179	69	98	169	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	332	73	171	137	113	169	99
2002	0	15	118	162	241	742	323	271	214	431	208	85	289	109	142	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	415	217	971	223	212	220	221	107	20	168	186
2005	0	52	166	194	584	412	230	471	873	220	136	183	334	163	50	180
2006	8	67	301	375	276	634	470	176	325	737	132	132	70	156	175	1
2007	0	37	514	346	381	274	502	307	123	226	503	119	137	126	104	76
2008	0	23	114	735	620	542	355	359	195	127	253	353	150	78	85	118
2009	5	37	203	203	1,189	596	491	264	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	256	334	106	156	36	150	128	149
2013	0	4	88	268	419	531	256	220	408	405	358	119	134	132	132	94
2014	0	0	36	420	383	248	419	231	228	523	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	260	177	91	263	638	325	230	81	76	41	124	99	103

Year	Age (Males)															
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17+
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	1,144	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	603	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	245	194	213	108	514	78	264	30
1998	0	45	66	332	542	791	150	213	192	256	326	141	148	177	106	248
1999	0	5	95	134	214	232	551	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	313	246	416	182	133	205	149	123	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	998	265	82	196	224	103	47	250	104
2005	0	48	166	178	450	455	238	295	999	122	138	117	130	67	91	125
2006	0	100	172	347	331	504	393	287	298	383	116	154	89	38	11	54
2007	0	57	480	351	405	283	545	209	165	266	334	99	131	69	59	122
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	227	71	234	520	259	187	95	76	72	74	68	29

Table 4.11: 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 each survey.

Year	Total hauls	Hauls with length	Number of lengths	Hauls with otoliths	Hauls with ages	Number of otoliths	Number of ages
1982	334	246	37023	35	35	744	744
1983	353	256	33924	37	37	709	709
1984	355	271	33894	56	56	821	796
1985	357	261	33824	44	43	810	802
1986	354	249	30470	34	34	739	739
1987	357	224	31241	16	16	798	798
1988	373	254	27138	14	14	543	543
1989	374	236	29672	24	24	740	740
1990	371	251	30257	28	28	792	792
1991	372	248	27986	26	26	742	742
1992	356	229	23628	16	16	606	606
1993	375	242	26651	20	20	549	549
1994	375	269	24448	14	14	526	522
1995	376	254	22116	20	20	654	647
1996	375	247	27505	16	16	729	721
1997	376	262	26034	11	11	470	466
1998	375	310	34509	15	15	575	570
1999	373	276	28431	31	31	777	770
2000	372	255	24880	20	20	517	511
2001	375	251	26558	25	25	604	593
2002	375	246	26309	32	32	738	723
2003	376	241	27135	37	37	699	695
2004	375	251	26103	26	26	725	712
2005	373	251	24658	34	34	644	635
2006	376	246	28470	39	39	428	426
2007	376	247	24790	66	66	779	772
2008	375	238	25848	65	65	858	830
2009	376	235	22018	70	70	784	752
2010	376	228	20619	77	77	841	827
2011	376	228	21665	65	64	784	753
2012	376	242	23519	72	72	993	973
2013	376	232	23261	70	70	821	803
2014	376	219	20229	52	52	799	790
2015	376	223	20830	73	73	878	875
2016	376	242	26674	69	69	884	876
2017	376	258	25767	78	78	896	886
2018	376	255	1830	68	68	724	720
2019	376	270	25669	67		836	

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	79
2011	77
2012	64
2013	75
2014	81
2015	64
2016	98
2017	98
2018	67
2019	67

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	560.25	560.25
Fishery age	609.64	609.64
Selectivity	62.81	62.81
Survey biomass	95.08	95.08
Recruitment	28.25	28.25
Catchability	0.0069	0.0069
Total	1356.03	1356.03

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	1.3481e-01	1.3279e-03	TotBiom	2020.5	63.091
alpha (q-temp model)	-2.4340e-01	3.9968e-02	TotBiom	2373.0	72.944
beta (q-temp model)	5.8060e-02	1.3047e-02	TotBiom	2726.0	82.323
beta (survey start date)	1.1822e-02	2.9979e-03	TotBiom	3060.0	91.098
beta (start date/temp interaction)	-1.0707e-02	2.8686e-03	TotBiom	3250.1	98.348
mean log recruitment	9.9301e-01	9.3994e-02	TotBiom	3457.6	104.770
log_avg_fmort	-2.4759e+00	7.8643e-02	TotBiom	3643.5	110.150
sel_slope_fsh_f	1.1744e+00	7.8338e-02	TotBiom	3772.6	113.190
sel50_fsh_f	8.6199e+00	2.4541e-01	TotBiom	3745.4	113.770
sel_slope_fsh_m	1.4173e+00	9.8215e-02	TotBiom	4004.9	121.580
sel50_fsh_m	8.2634e+00	2.2890e-01	TotBiom	4025.0	125.340
sel_slope_srv	1.5478e+00	8.3195e-02	TotBiom	3720.0	121.490
sel50_srv	5.0891e+00	6.7953e-02	TotBiom	3697.5	125.040
sel_slope_srv_m	1.8519e-02	7.3259e-02	TotBiom	3591.4	124.510
sel50_srv_m	-2.8682e-03	1.6565e-02	TotBiom	3671.4	130.720
R_logalpha	-4.4071e+00	4.6681e-01	TotBiom	3520.2	128.130
R_logbeta	-6.5778e+00	2.8096e-01	TotBiom	3647.3	131.770
msy	4.4874e+02	1.5897e+02	TotBiom	3885.9	139.010
Fmsy	1.8969e-01	7.7950e-02	TotBiom	3928.9	142.380
logFmsy	-1.6624e+00	4.1094e-01	TotBiom	3973.9	143.920
Fmsyr	1.1321e-01	3.2685e-02	TotBiom	3715.6	138.260
logFmsyr	-2.1785e+00	2.8870e-01	TotBiom	3619.5	135.810
Bmsy	5.4279e+02	8.4647e+01	TotBiom	3646.8	137.800
Bmsyr	3.9637e+03	3.7997e+02	TotBiom	3340.3	130.590
TotBiom	2.5690e+03	1.6413e+02	TotBiom	3128.9	124.630
TotBiom	2.5216e+03	1.4765e+02	TotBiom	3179.7	124.860
TotBiom	2.4677e+03	1.2939e+02	TotBiom	3088.1	121.900
TotBiom	2.4074e+03	1.0983e+02	TotBiom	3128.1	122.030
TotBiom	2.3613e+03	8.9747e+01	TotBiom	3361.7	128.760
TotBiom	2.3120e+03	7.0684e+01	TotBiom	3593.8	135.980
TotBiom	2.1320e+03	5.4364e+01	TotBiom	3700.5	139.230
TotBiom	1.6891e+03	3.9353e+01	TotBiom	3669.1	139.270
TotBiom	1.1785e+03	2.6194e+01	TotBiom	3659.6	140.650
TotBiom	8.3485e+02	1.6865e+01	TotBiom	3491.1	137.390
TotBiom	8.7568e+02	1.7118e+01	TotBiom	3287.5	133.220
TotBiom	8.6973e+02	1.7213e+01	TotBiom	3318.7	135.850
TotBiom	9.1711e+02	1.8201e+01	TotBiom	3322.4	138.210
TotBiom	9.0558e+02	1.9012e+01	TotBiom	3269.5	140.060
TotBiom	8.3449e+02	1.9497e+01	TotBiom	3178.9	140.640
TotBiom	8.7609e+02	2.1971e+01	TotBiom	2922.9	135.130
TotBiom	8.6060e+02	2.4807e+01	TotBiom	2915.4	140.500
TotBiom	9.4672e+02	2.9646e+01	TotBiom	3056.1	153.110
TotBiom	1.0444e+03	3.5597e+01	TotBiom	2965.5	156.900
TotBiom	1.3363e+03	4.3646e+01	TotBiom	3048.3	174.800
TotBiom	1.6274e+03	5.2266e+01	TotBiom	3090.5	196.390

Table 4.15: Comparison of reference points with Model 18.1a and Model 18.2. Values are in metric tons (t)

	Model 18.2		Model 18.1a		Model 18.1	
Quantity	2020	2021	2020	2021	2020	2021
M (natural mortality rate)	0.12, 0.135	0.12, 0.135	0.12	0.12	0.12	0.12
Tier	1a	1a	1a	1a	1a	1a
Projected total (age 6+) biomass (t)	2,726,370	2,733,120	2,629,180	2,762,100	2,462,400	2,411,700
Projected female spawning biomass (t)	1,051,050	1,005,310	893,279	855,661	850,600	821,500
$B_{100\%}$	1,501,510	1,501,510	1,501,510	1,501,510	1,261,080	1,261,080
$B_{MSY\%}$	542,791	542,791	921,529 t	921,529 t	1,245,400 t	1,245,400 t
F_{OFL}	0.118	0.118	0.061	0.061	0.118	0.118
$maxF_{ABC}$	0.109	0.109	0.061	0.061	0.107	0.107
F_{ABC}	0.109	0.109	0.061	0.061	0.107	0.107
OFL	321,794	322,591	154,117	154,720	290,000	284,000
$maxABC$	296,060	296,793	154,117	154,720	263,200	257,800
ABC	296,060	296,793	154,117	154,720	263,200	257,800
Status	2018	2019	2018	2019	2018	2019
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

Projections for Model 18.1a and 18.2 were based on estimated catches of 118,642 t in 2019 and 137,230 used in place of maximum ABC for 2020.

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

	Model 18.2		Model 18.1a	
	Full selection F	Catch/Total Biomass	Full selection F	Catch/Total Biomass
1954	0.006	0.005	0.006	0.005
1955	0.008	0.006	0.008	0.006
1956	0.013	0.010	0.013	0.010
1957	0.013	0.010	0.013	0.010
1958	0.026	0.019	0.026	0.019
1959	0.123	0.080	0.123	0.080
1960	0.411	0.214	0.411	0.214
1961	0.967	0.328	0.967	0.328
1962	4.874	0.357	4.874	0.357
1963	0.319	0.103	0.319	0.103
1964	0.277	0.127	0.277	0.127
1965	0.236	0.062	0.236	0.062
1966	0.436	0.112	0.436	0.112
1967	0.593	0.179	0.593	0.179
1968	0.464	0.101	0.464	0.101
1969	0.654	0.191	0.654	0.191
1970	0.679	0.155	0.679	0.155
1971	0.891	0.169	0.891	0.169
1972	0.287	0.046	0.287	0.046
1973	0.445	0.059	0.445	0.059
1974	0.130	0.026	0.130	0.026
1975	0.118	0.032	0.118	0.032
1976	0.115	0.024	0.115	0.024
1977	0.053	0.021	0.053	0.021
1978	0.103	0.045	0.103	0.045
1979	0.060	0.030	0.060	0.030
1980	0.066	0.025	0.066	0.025
1981	0.052	0.027	0.052	0.027
1982	0.039	0.025	0.039	0.025
1983	0.041	0.029	0.041	0.029
1984	0.063	0.040	0.063	0.040
1985	0.093	0.056	0.093	0.056
1986	0.085	0.056	0.085	0.056
1987	0.084	0.049	0.084	0.049
1988	0.105	0.062	0.105	0.062
1989	0.078	0.042	0.078	0.042
1990	0.034	0.023	0.034	0.023
1991	0.039	0.026	0.039	0.026
1992	0.063	0.041	0.063	0.041
1993	0.047	0.027	0.047	0.027
1994	0.056	0.036	0.056	0.036
1995	0.049	0.034	0.049	0.034
1996	0.053	0.036	0.053	0.036
1997	0.078	0.050	0.078	0.050
1998	0.045	0.030	0.045	0.030
1999	0.034	0.022	0.034	0.022
2000	0.042	0.026	0.042	0.026
2001	0.031	0.021	0.031	0.021

2002	0.035	0.023	0.035	0.023
2003	0.034	0.022	0.034	0.022
2004	0.031	0.019	0.031	0.019
2005	0.042	0.026	0.042	0.026
2006	0.039	0.027	0.039	0.027
2007	0.054	0.033	0.054	0.033
2008	0.061	0.043	0.061	0.043
2009	0.046	0.033	0.046	0.033
2010	0.050	0.036	0.050	0.036
2011	0.064	0.045	0.064	0.045
2012	0.063	0.045	0.063	0.045
2013	0.078	0.052	0.078	0.052
2014	0.077	0.054	0.077	0.054
2015	0.071	0.044	0.071	0.044
2016	0.074	0.044	0.074	0.044
2017	0.068	0.045	0.068	0.045
2018	0.069	0.043	0.069	0.043
2019	0.062	0.038	0.062	0.038

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 2018 and 2019 stock assessments, including Model 18.1a and 18.2.

	Model 18.2			Model 18.1a			Model 18.1 (for 2018)
	FSB (t)	LCI	HCI	FSB (t)	LCI	HCI	Biomass (t)
1954	995,657	769,574	1,288,160	995,657	769,574	1,288,160	965,180
1955	1,005,490	789,513	1,280,540	1,005,490	789,513	1,280,540	974,478
1956	996,743	794,331	1,250,730	996,743	794,331	1,250,730	965,769
1957	972,387	785,412	1,203,870	972,387	785,412	1,203,870	941,937
1958	935,656	764,916	1,144,510	935,656	764,916	1,144,510	906,164
1959	859,116	708,274	1,042,080	859,116	708,274	1,042,080	832,024
1960	672,609	551,965	819,622	672,609	551,965	819,622	652,602
1961	369,438	283,114	482,084	369,438	283,114	482,084	361,684
1962	47,947	19,142	120,097	47,947	19,142	120,097	45,744
1963	12,714	4,771	33,878	12,714	4,771	33,878	11,903
1964	26,218	13,232	51,950	26,218	13,232	51,950	24,680
1965	51,391	32,679	80,816	51,391	32,679	80,816	48,467
1966	91,133	67,413	123,200	91,133	67,413	123,200	86,091
1967	125,614	101,748	155,079	125,614	101,748	155,079	118,615
1968	147,229	123,776	175,127	147,229	123,776	175,127	139,235
1969	152,238	125,818	184,205	152,238	125,818	184,205	144,077
1970	119,798	101,361	141,589	119,798	101,361	141,589	113,084
1971	94,236	79,963	111,058	94,236	79,963	111,058	97,519
1972	65,770	52,544	82,324	65,770	52,544	82,324	79,795
1973	70,963	57,243	87,972	70,963	57,243	87,972	81,181
1974	85,064	70,287	102,948	85,064	70,287	102,948	90,066
1975	137,410	117,002	161,378	137,410	117,002	161,378	142,002
1976	205,495	179,989	234,615	205,495	179,989	234,615	202,257
1977	310,577	277,551	347,533	310,577	277,551	347,533	294,145
1978	446,372	404,443	492,648	446,372	404,443	492,648	409,740
1979	590,091	538,349	646,806	590,091	538,349	646,806	526,788
1980	751,446	689,177	819,341	751,446	689,177	819,341	657,154
1981	903,580	831,201	982,262	903,580	831,201	982,262	777,407
1982	991,653	914,034	1,075,860	991,653	914,034	1,075,860	844,764
1983	1,117,680	1,032,420	1,209,970	1,117,680	1,032,420	1,209,970	946,097
1984	1,219,120	1,127,810	1,317,820	1,219,120	1,127,810	1,317,820	1,025,680
1985	1,284,230	1,186,900	1,389,550	1,284,230	1,186,900	1,389,550	1,072,660
1986	1,278,870	1,178,860	1,387,360	1,278,870	1,178,860	1,387,360	1,059,080
1987	1,280,870	1,177,260	1,393,600	1,280,870	1,177,260	1,393,600	1,052,150
1988	1,219,480	1,117,080	1,331,280	1,219,480	1,117,080	1,331,280	994,324
1989	1,194,240	1,090,210	1,308,200	1,194,240	1,090,210	1,308,200	966,813
1990	1,209,630	1,103,960	1,325,420	1,209,630	1,103,960	1,325,420	977,630
1991	1,306,040	1,194,900	1,427,520	1,306,040	1,194,900	1,427,520	1,058,400
1992	1,405,300	1,288,080	1,533,200	1,405,300	1,288,080	1,533,200	1,140,660
1993	1,450,280	1,328,810	1,582,850	1,450,280	1,328,810	1,582,850	1,175,630
1994	1,455,350	1,333,270	1,588,610	1,455,350	1,333,270	1,588,610	1,178,600
1995	1,456,660	1,333,240	1,591,510	1,456,660	1,333,240	1,591,510	1,177,510
1996	1,378,410	1,259,580	1,508,450	1,378,410	1,259,580	1,508,450	1,111,120
1997	1,336,920	1,219,640	1,465,470	1,336,920	1,219,640	1,465,470	1,074,620
1998	1,261,720	1,148,330	1,386,300	1,261,720	1,148,330	1,386,300	1,010,380
1999	1,251,930	1,139,090	1,375,950	1,251,930	1,139,090	1,375,950	1,002,110
2000	1,235,910	1,124,180	1,358,750	1,235,910	1,124,180	1,358,750	988,818

2001	1,230,060	1,119,290	1,351,790	1,230,060	1,119,290	1,351,790	984,590
2002	1,227,310	1,117,240	1,348,210	1,227,310	1,117,240	1,348,210	982,745
2003	1,236,510	1,126,800	1,356,910	1,236,510	1,126,800	1,356,910	991,529
2004	1,271,980	1,160,670	1,393,960	1,271,980	1,160,670	1,393,960	1,022,050
2005	1,290,030	1,178,040	1,412,670	1,290,030	1,178,040	1,412,670	1,037,800
2006	1,314,510	1,200,540	1,439,300	1,314,510	1,200,540	1,439,300	1,057,890
2007	1,320,870	1,205,670	1,447,070	1,320,870	1,205,670	1,447,070	1,062,520
2008	1,292,010	1,177,360	1,417,830	1,292,010	1,177,360	1,417,830	1,037,420
2009	1,249,410	1,136,430	1,373,620	1,249,410	1,136,430	1,373,620	1,001,290
2010	1,218,970	1,107,310	1,341,890	1,218,970	1,107,310	1,341,890	976,422
2011	1,189,640	1,079,340	1,311,210	1,189,640	1,079,340	1,311,210	953,325
2012	1,166,410	1,056,180	1,288,160	1,166,410	1,056,180	1,288,160	935,446
2013	1,151,250	1,039,910	1,274,520	1,151,250	1,039,910	1,274,520	925,004
2014	1,098,520	987,916	1,221,500	1,098,520	987,916	1,221,500	882,005
2015	1,084,640	971,738	1,210,670	1,084,640	971,738	1,210,670	873,597
2016	1,080,390	964,790	1,209,840	1,080,390	964,790	1,209,840	875,526
2017	1,052,650	936,257	1,183,510	1,052,650	936,257	1,183,510	857,290
2018	1,049,380	929,804	1,184,330	1,049,380	929,804	1,184,330	854,907
2019	1,062,990	938,252	1,204,310	1,062,990	938,252	1,204,310	-

Table 4.18: Model estimates of age 5 recruitment (in billions of fish), 1954-2019, with 95% lower and upper confidence intervals (LCI, HCI).

	Model 18.2			Model 18.1a		
	Recruitment	LCI	HCI	Recruitment	LCI	HCI
1989	0.001	0.000	0.001	0.001	0.000	0.001
1990	0.656	0.082	1.230	0.656	0.082	1.230
1991	1.209	0.202	2.215	1.209	0.202	2.215
1992	1.671	0.351	2.991	1.671	0.351	2.991
1993	2.055	0.520	3.590	2.055	0.520	3.590
1994	2.369	0.700	4.038	2.369	0.700	4.038
1995	2.621	0.885	4.357	2.621	0.885	4.357
1996	2.820	1.070	4.569	2.820	1.070	4.569
1997	2.971	1.251	4.692	2.971	1.251	4.692
1998	3.083	1.425	4.741	3.083	1.425	4.741
1999	3.158	1.588	4.729	3.158	1.588	4.729
2000	3.204	1.738	4.669	3.204	1.738	4.669
2001	3.223	1.875	4.571	3.223	1.875	4.571
2002	3.220	1.994	4.445	3.220	1.994	4.445
2003	3.197	2.097	4.298	3.197	2.097	4.298
2004	3.159	2.179	4.139	3.159	2.179	4.139
2005	3.107	2.241	3.974	3.107	2.241	3.974
2006	3.044	2.279	3.810	3.044	2.279	3.810
2007	2.973	2.291	3.654	2.973	2.291	3.654
2008	2.893	2.273	3.514	2.893	2.273	3.514
2009	2.809	2.225	3.392	2.809	2.225	3.392
2010	2.719	2.147	3.292	2.719	2.147	3.292
2011	2.627	2.043	3.212	2.627	2.043	3.212
2012	2.533	1.920	3.146	2.533	1.920	3.146
2013	2.437	1.785	3.089	2.437	1.785	3.089
2014	2.341	1.645	3.037	2.341	1.645	3.037
2015	2.245	1.503	2.987	2.245	1.503	2.987
2016	2.150	1.363	2.937	2.150	1.363	2.937
2017	2.056	1.227	2.885	2.056	1.227	2.885
2018	1.964	1.096	2.831	1.964	1.096	2.831
2019	1.873	0.971	2.775	1.873	0.971	2.775

Table 4.19: Yellowfin sole TAC, OFL, and ABC levels, 1980-2019. Data is in metric tons.

Year	TAC	OFL	Catch	NA
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	109,620

Table 4.20: Projections of arrowtooth flounder 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).

Scenarios 1 and 2 Maximum ABC harvest permissible			
Year	FSB	Catch	F
2019	1,038,560	154,200	0.075
2020	1,007,260	154,200	0.081
2021	946,518	199,709	0.112
2022	878,921	196,518	0.112
2023	844,586	201,497	0.112
2024	838,018	203,855	0.112
2025	840,600	199,738	0.112
2026	831,891	194,024	0.112
2027	814,213	190,500	0.112
2028	799,416	188,413	0.111
2029	793,242	186,778	0.110
2030	792,306	185,943	0.109
2031	793,740	185,872	0.108
2032	796,411	186,750	0.108

Scenario 3, Maximum Tier 3 ABC harvest permissible set at F60			
Year	FSB	Catch	F
2019	1,038,560	154,200	0.075
2020	1,007,260	154,200	0.081
2021	965,026	95,593	0.052
2022	947,176	98,770	0.052
2023	956,823	105,412	0.052
2024	991,549	110,543	0.052
2025	1,034,127	112,071	0.052
2026	1,060,874	112,173	0.052
2027	1,071,956	112,829	0.052
2028	1,080,892	114,186	0.052
2029	1,094,815	116,055	0.052
2030	1,109,740	117,613	0.052
2031	1,123,834	118,957	0.052
2032	1,137,140	120,439	0.052

Scenario 4 Harvest at average F over past 5 years			
Year	FSB	Catch	F
2019	1,038,560	154,200	0.075
2020	1,007,260	154,200	0.081
2021	964,193	100,352	0.055
2022	944,022	103,460	0.055
2023	951,501	110,218	0.055
2024	984,096	115,393	0.055
2025	1,024,528	116,803	0.055
2026	1,049,280	116,743	0.055
2027	1,058,649	117,287	0.055
2028	1,066,082	118,587	0.055
2029	1,078,638	120,434	0.055
2030	1,092,375	121,971	0.055
2031	1,105,435	123,297	0.055
2032	1,117,818	124,772	0.055

Scenario 5 No fishing			
Year	FSB	Catch	F
2019	1,038,560	154,200	0.075
2020	1,007,260	154,200	0.081
2021	981,480	0	0.000
2022	1,011,226	0	0.000
2023	1,067,695	0	0.000
2024	1,150,579	0	0.000
2025	1,243,629	0	0.000
2026	1,319,457	0	0.000
2027	1,375,139	0	0.000
2028	1,425,306	0	0.000
2029	1,478,399	0	0.000
2030	1,528,881	0	0.000
2031	1,575,254	0	0.000
2032	1,618,526	0	0.000

Alternative 6, Determination of whether arrowtooth flounder are currently overfished			
Year	FSB	Catch	F
2019	1,038,560	154,200	0.075
2020	990,143	248,239	0.134
2021	894,100	225,914	0.134
2022	816,193	219,842	0.134
2023	775,200	217,576	0.130
2024	765,387	216,637	0.128
2025	765,655	211,713	0.128
2026	755,946	202,528	0.127
2027	739,829	194,639	0.124
2028	728,385	191,259	0.122
2029	725,539	191,958	0.121
2030	727,000	193,510	0.121
2031	729,739	195,090	0.121
2032	732,804	196,990	0.122

Scenario 7, Determination of whether stock is approaching an overfished condition			
Year	FSB	Catch	F
2019	1,038,560	154,200	0.075
2020	997,229	209,658	0.112
2021	919,343	194,426	0.112
2022	849,270	227,501	0.134
2023	802,435	230,281	0.134
2024	785,511	226,722	0.132
2025	779,814	218,472	0.131
2026	765,503	206,859	0.128
2027	746,071	197,351	0.125
2028	732,374	192,935	0.122
2029	728,027	192,961	0.122
2030	728,450	194,060	0.121
2031	730,531	195,365	0.121
2032	733,211	197,113	0.122

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

Year	Arrowtooth.Flounder	Atka.Mackerel	Alaska.Plaice	BSAI.Kamchatka.Flounder	BSAI.Other.Flatfish	Flathead.Sole	Flounder	Greenland.Turbot	SR.RE.Sharpchin.N..RF
1992	366	1	0	0	0	0	16,826	0	0
1993	1,017	0	0	0	0	0	9,620	4	0
1994	1,595	0	0	0	0	0	12,422	4	0
1995	345	0	0	0	0	3,929	0	67	0
1996	819	0	0	0	0	3,165	0	8	0
1997	386	0	0	0	0	3,896	0	4	0
1998	2,382	0	0	0	0	5,323	0	103	1
1999	1,631	32	0	0	0	2,309	0	69	15
2000	1,998	0	0	0	0	2,644	0	23	0
2001	1,845	0	0	0	0	3,231	0	32	0
2002	997	0	10,395	0	0	2,190	0	2	0
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	11,996	0	977	2,690	0	1	0
2011	2,331	0	18,305	91	1,585	3,229	0	5	0
2012	987	0	13,576	122	1,206	2,095	0	5	0
2013	2,042	0	15,978	148	388	4,179	0	35	0
2014	2,214	0	14,363	497	2,886	3,994	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	15,341	218	3,287	3,966	0	26	0
2019	1,634	0	11,438	122	1,459	2,912	0	5	0

Year	Northern.Rockfish	Other.Flatfish	Other.Rockfish	Pacific.Cod	Pacific.Ocean.Perch	Pollock	Rock.Sole	Sablefish	Sharpchin.Northern.RF
1992	0	0	0	8,700	0	13,100	14,646	0	0
1993	0	0	0	8,723	4	15,253	7,300	0	0
1994	0	0	0	16,415	0	33,200	8,096	0	0
1995	0	12,239	3	13,181	0	27,041	7,486	0	0
1996	0	10,962	22	8,684	0	22,254	12,903	0	0
1997	0	17,222	12	12,825	0	24,100	16,693	0	0
1998	0	9,182	1	10,233	1	15,339	9,826	0	0
1999	0	11,449	3	4,383	12	8,701	10,774	4	0
2000	0	10,286	3	5,192	1	13,425	7,345	0	0
2001	0	6,844	0	6,531	0	16,502	5,810	0	1
2002	0	519	0	6,259	1	14,489	10,664	0	0
2003	0	0	0	4,634	10	11,578	8,314	0	0
2004	0	0	2	3,574	0	10,383	9,972	0	0
2005	3	0	0	3,769	15	10,312	10,090	1	0
2006	0	0	0	2,545	0	5,966	7,971	0	0
2007	0	0	0	2,519	0	4,020	8,241	0	0
2008	0	0	0	5,767	0	9,827	10,468	0	0
2009	0	0	0	10,716	0	7,036	8,978	0	0
2010	0	0	0	11,097	0	5,156	9,606	0	0
2011	0	0	0	16,204	0	8,673	9,694	0	0
2012	0	0	0	19,344	0	11,199	9,148	0	0
2013	0	0	0	24,339	16	20,171	7,688	0	0
2014	0	0	0	15,217	0	24,700	7,022	0	0
2015	0	0	0	12,168	0	21,281	9,772	0	0
2016	0	0	0	11,985	2	22,306	7,948	0	0
2017	0	0	0	14,648	0	23,414	12,196	0	0
2018	0	0	0	12,582	0	28,235	9,362	6	0
2019	0	0	0	9,957	0	19,828	8,721	0	0

Table 4.22: Bycatch of Other Species Bycatch 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	0
1994	0	0	0	0	0	0	0	4
1995	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	0	10
1997	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	1
1999	0	0	0	0	26	0	0	0
2000	0	0	0	0	3	0	0	0
2001	0	0	0	0	21	0	0	0
2002	0	0	0	0	1,042	0	0	0
2003	73	0	1	0	0	1,529	0	0
2004	0	0	0	0	0	598	0	0
2005	0	0	0	0	0	944	0	0
2006	0	0	0	0	0	1,133	0	0
2007	0	0	0	0	0	1,410	0	0
2008	0	0	0	0	0	1,303	0	0
2009	0	0	0	0	0	1,785	0	0
2010	0	0	0	0	0	1,905	0	0
2011	0	2,107	0	1	0	0	1	0
2012	0	2,231	0	1	0	0	0	0
2013	0	2,683	0	0	0	0	0	0
2014	0	1,970	0	0	0	0	0	0
2015	0	1,072	0	0	0	0	1	0
2016	0	1,294	0	0	0	0	3	0
2017	0	1,931	0	0	0	0	1	0
2018	0	2,561	0	0	0	0	4	0
2019	0	2,212	0	0	0	0	1	0

Table 4.23: Catch and bycatch (t) of other BSAI target species in the yellowfin sole directed fishery from 1992-2019 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.

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Benthic.urochordata	1,671	1,701	674	520	114	347	204	155	133	140	197	116	260	225	319	214	137
Bivalves	1	1	1	0	0	1	1	1	1	0	1	0	1	0	0	0	1
Brittle.star	34	32	28	19	7	18	5	4	14	13	5	11	11	6	2	2	2
Capelin	0	4	0	0	0	0	0	0	3	2	0	1	1	0	0	0	0
Corals.Bryozoans	0	0	1	9	0	8	0	0	0	0	3	0	0	0	0	1	0
Deep.sea.smelts	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eelpouts	19	12	7	4	2	5	5	5	29	14	51	69	30	56	8	26	8
Eulachon	0	0	0	0	5	0	0	0	0	0	0	0	0	2	0	0	0
Giant.Grenadier	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0
Gunnels	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	16	15	9	6	8	4	2	2	0	2
Invertebrate.unid.	556	625	421	177	40	70	30	25	65	121	25	44	6	7	11	3	2
Large.Sculpins	238	823	1,057	1,058	2,269	0	0	0	0	0	0	0	0	0	0	0	0
Bigmouth.Sculpin	0	0	0	0	0	47	26	0	0	0	0	0	0	0	0	0	0
Great.Sculpin	0	0	0	0	0	1,203	1,346	0	0	0	0	0	0	0	0	0	0
Hemilepidotus.Unid.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Myoxocephalus.Unid.	0	0	0	0	0	129	4	0	0	0	0	0	0	0	0	0	0
Plain.Sculpin	0	0	0	0	0	1,273	914	0	0	0	0	0	0	0	0	0	0
Red.Irish.Lord	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Warty.Sculpin	0	0	0	0	0	68	49	0	0	0	0	0	0	0	0	0	0
Yellow.Irish.Lord	0	0	0	0	0	133	145	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	4
Misc.crustaceans	0	0	0	2	1	0	1	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	21	20
Other.osmerids	4	4	0	0	35	9	0	2	2	4	1	9	4	5	2	0	13
Other.Sculpins	1,157	131	105	68	195	38	74	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
Polychaete.unid.	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2	0
Scypho.jellies	111	298	115	46	42	145	223	152	307	179	463	804	381	67	93	146	227
Sea.anemone	6	6	2	4	8	24	25	20	14	6	23	5	4	1	2	2	3
Sea.star	1,941	1,867	1,611	1,308	1,462	1,828	683	794	1,673	1,732	1,372	2,106	2,247	2,050	1,616	1,490	1,312
Snails	118	191	69	141	95	139	57	57	74	33	46	33	36	24	24	14	14
Sponge.unid.	11	6	12	3	0	6	69	16	15	14	16	1	2	1	2	3	2
urchins.dollars.cucumbers	2	0	2	0	3	4	7	1	0	0	0	0	0	0	2	0	2

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

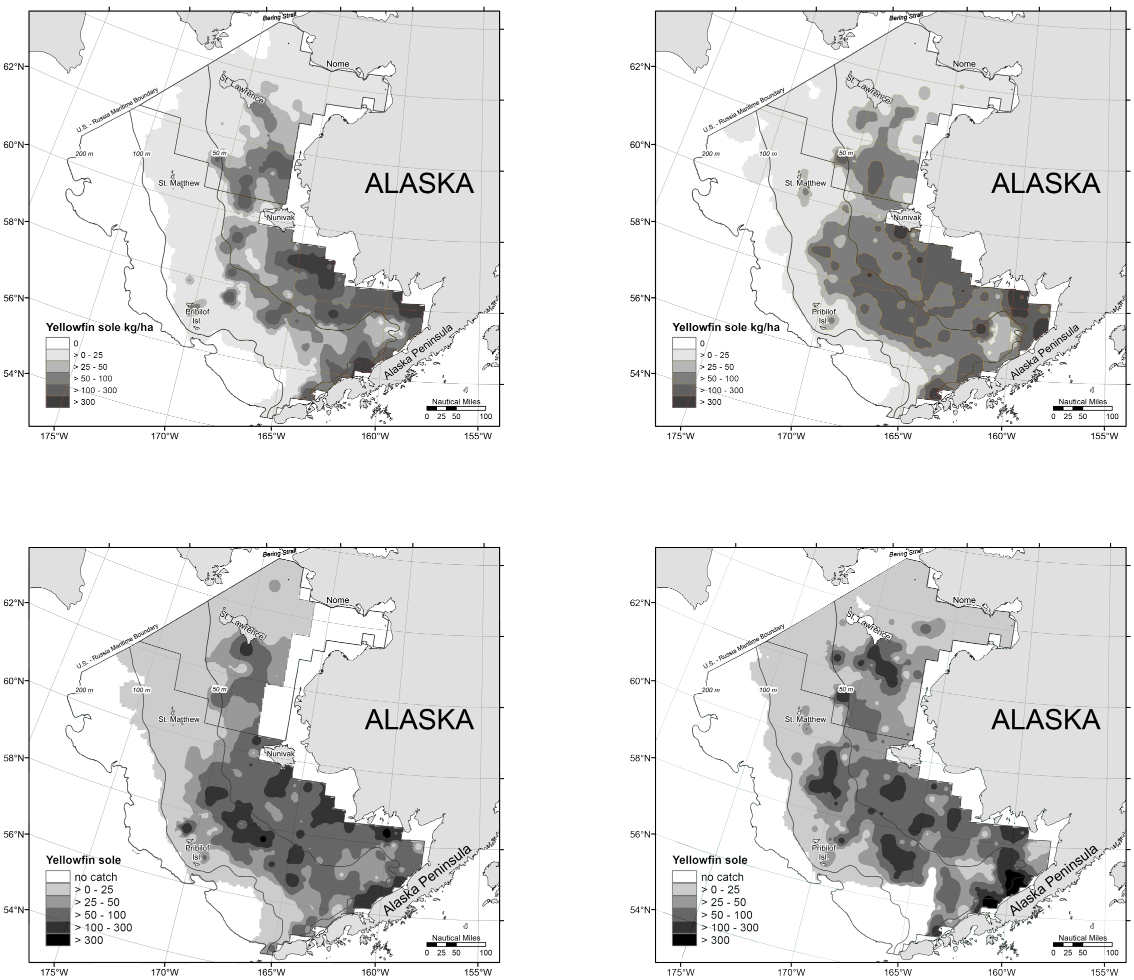


Figure 4.1: Distribution of Yellowfin Sole in the eastern and northern Bering sea based on surveys conducted in 2010 (upper left), 2017 (upper right), 2018 (lower left), and 2019 (lower right).

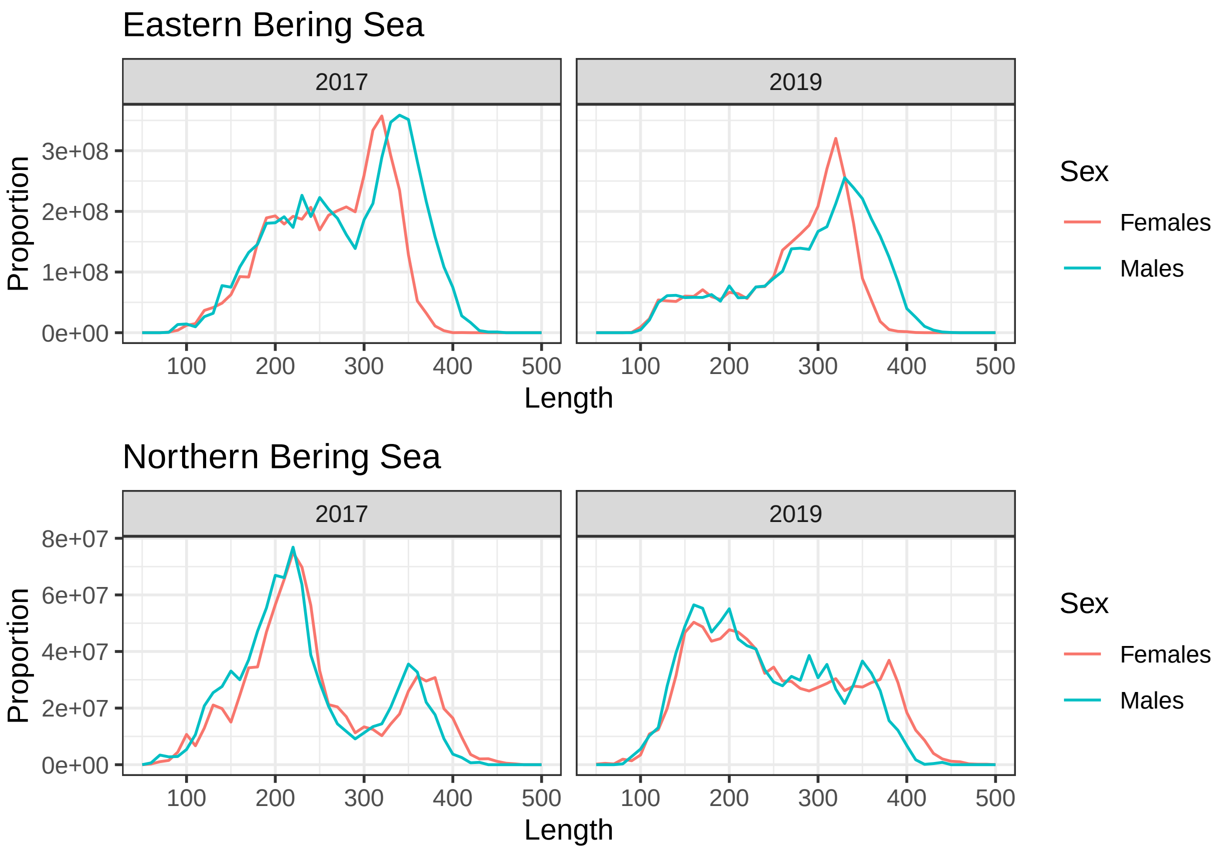


Figure 4.2: Estimated numbers at length (mm) of Yellowfin Sole from the Eastern Bering Sea and the Northern Bering Sea surveys, 2017 and 2019.

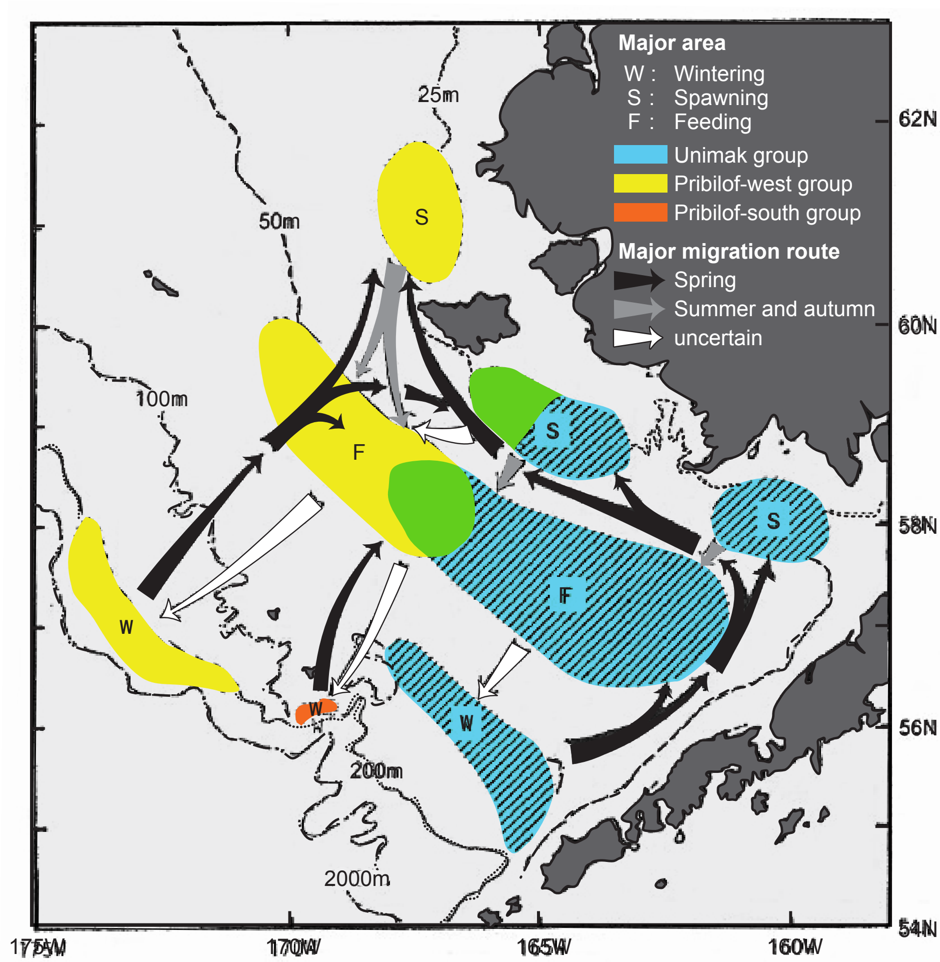


Figure 4.3: Distribution of wintering, spawning, and feeding areas for Yellowfin Sole in the Bering Sea, and observed regional grouping. Migration routes from wintering to feeding take place in spring, and the dates that Yellowfin Sole return to their wintering areas are unknown.

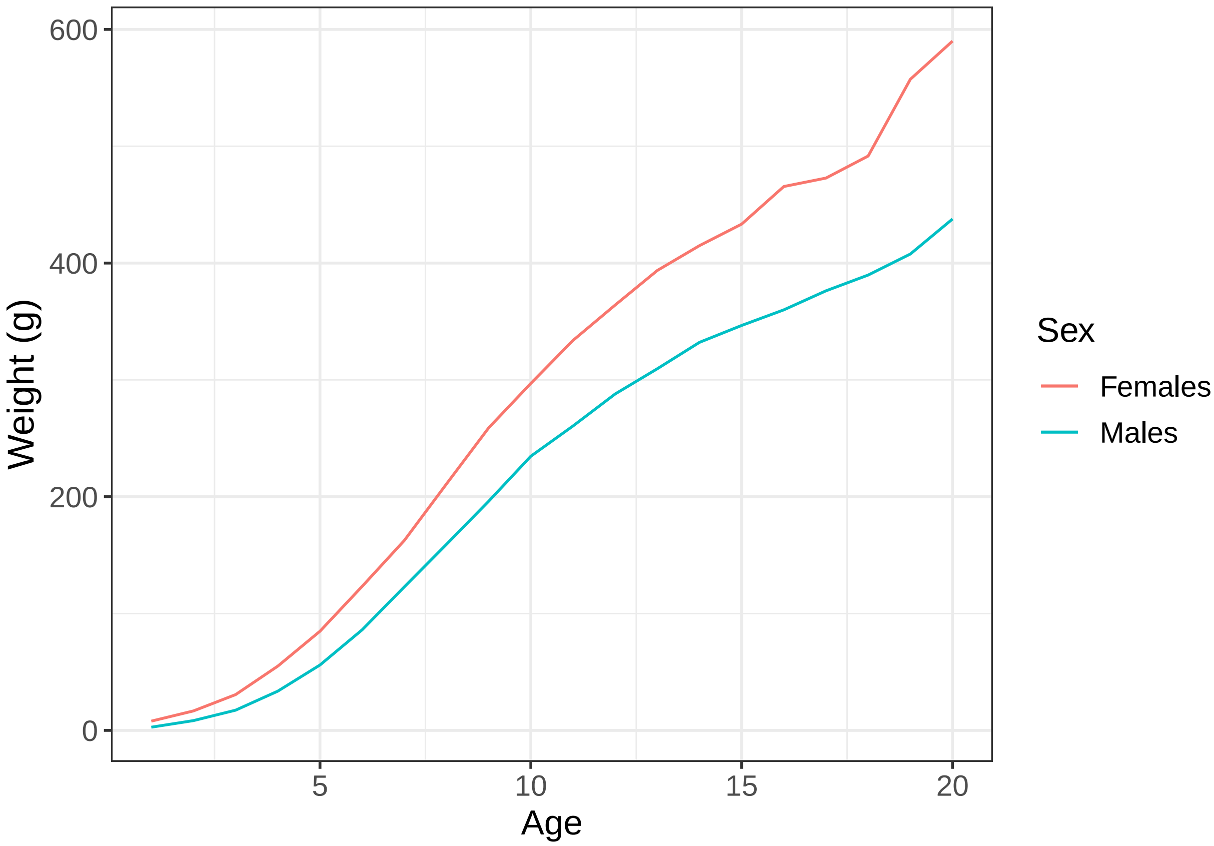


Figure 4.4: Average Yellowfin Sole weight-at-age (g) from trawl survey observations.

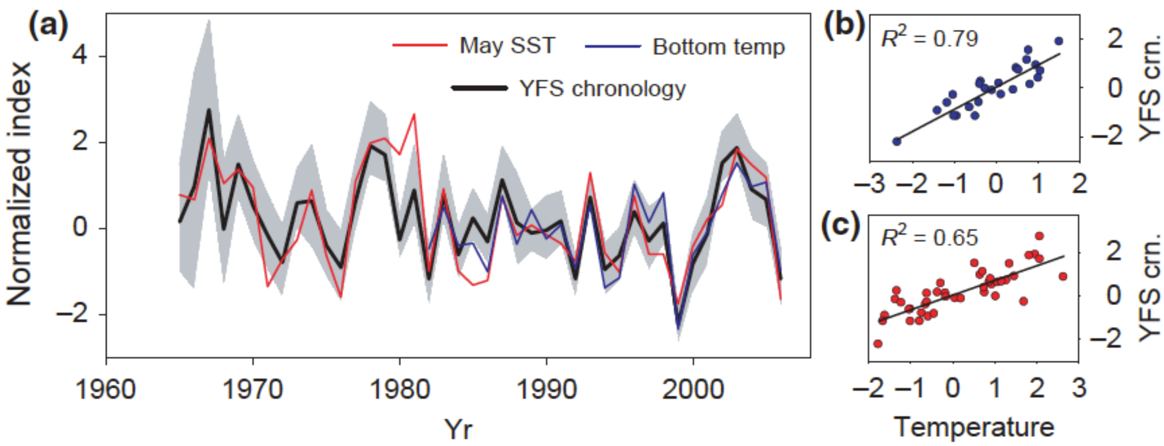


Figure 4.5: Master chronology for Yellowfin Sole and time series of mean summer bottom temperature and May sea surface temperature for the southeastern Bering Sea (Panel A). All data were normalized to a mean of 0 and standard deviation of 1. Correlations of chronologies with bottom temperature and sea surface temperature are shown in panels B and C, respectively (Matta et al. 2010).

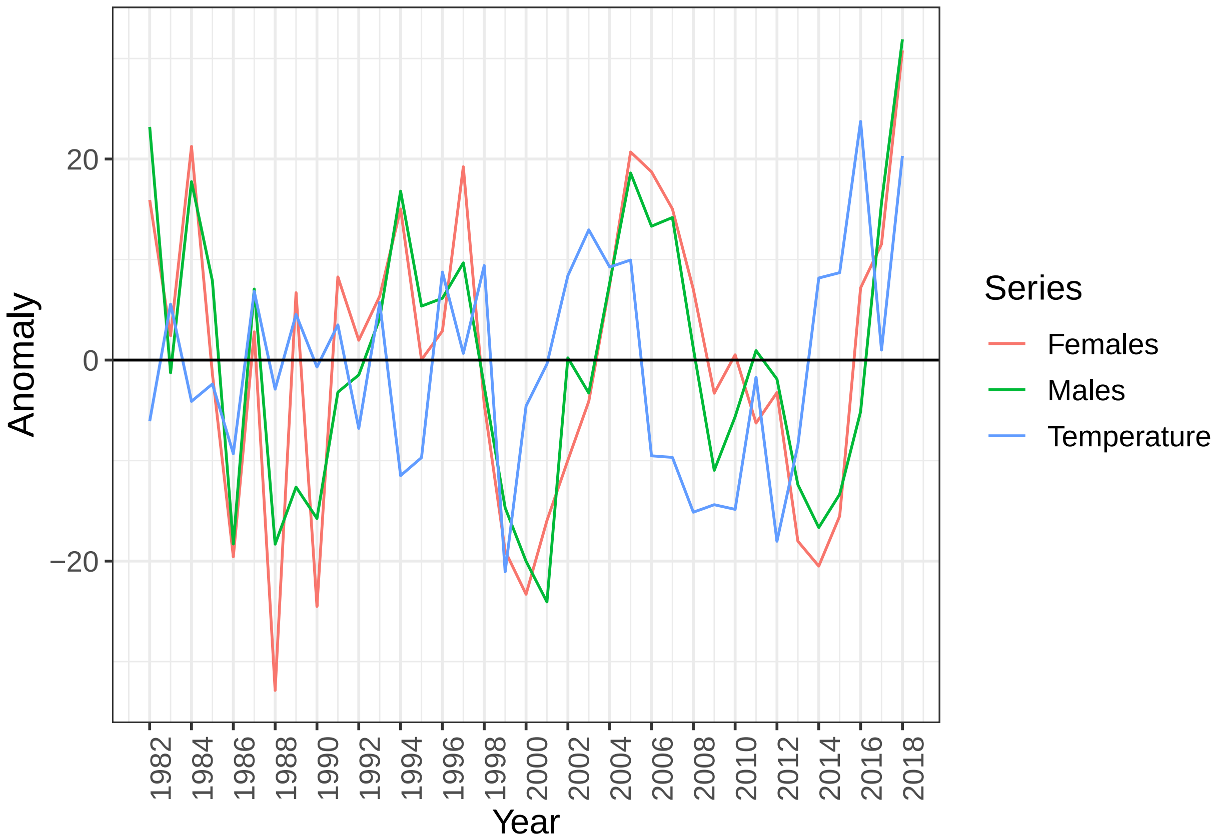


Figure 4.6: Yellowfin sole length-at-age anomalies, for 5-year old males and females, and bottom temperature anomalies. Correspondence in these residuals is apparent with a 2-3 year lag effect from the mid-1990s to 2019. Late 1980s and early 1990s pattern may be a density-dependent response in growth 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.

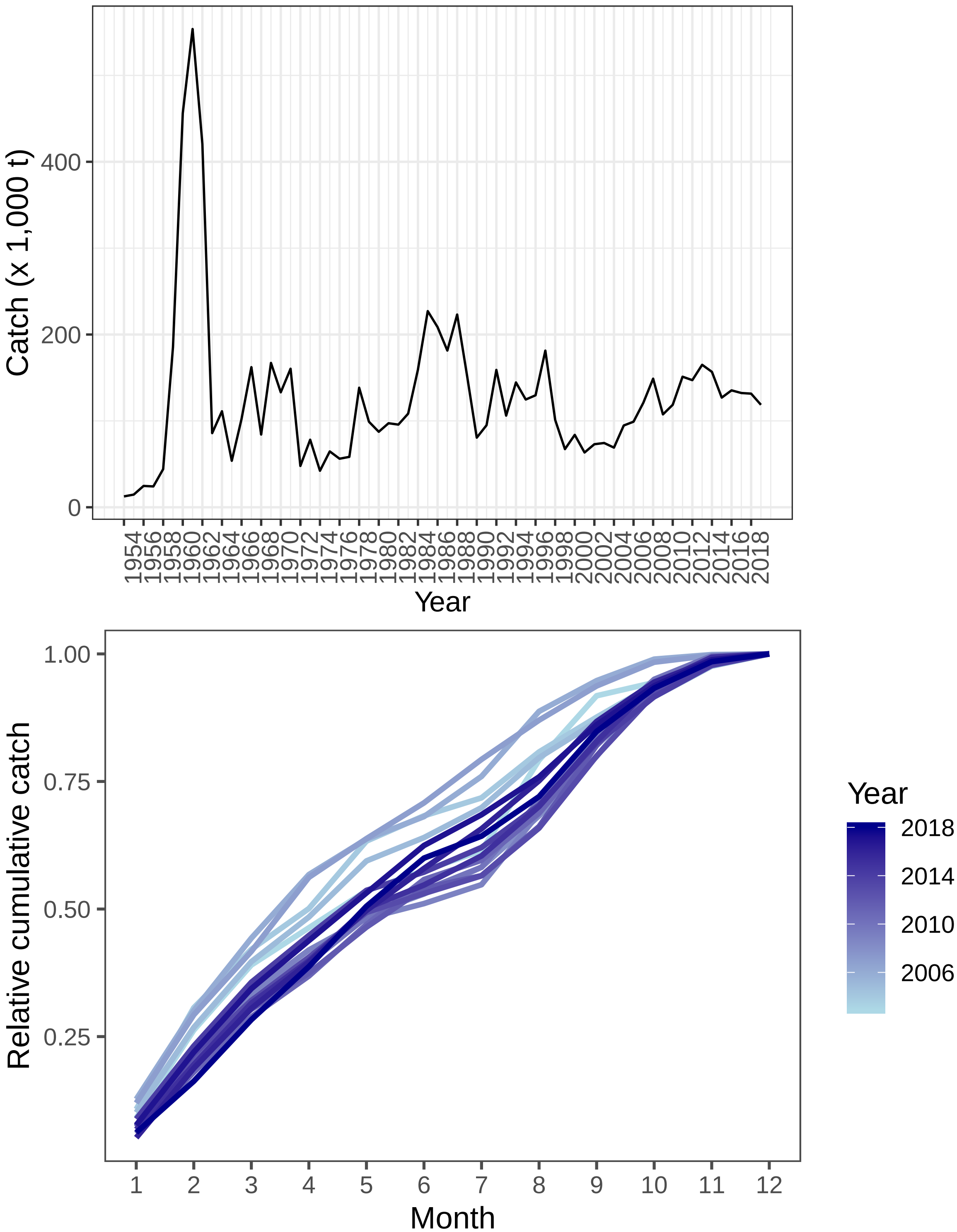


Figure 4.7: Yellowfin Sole annual total catch (1,000s t) in the Eastern Bering Sea from 1954-2019 (upper panel). Yellowfin Sole annual cumulative catch by month and year (non CDQ) 2003-2018 (lower panel).

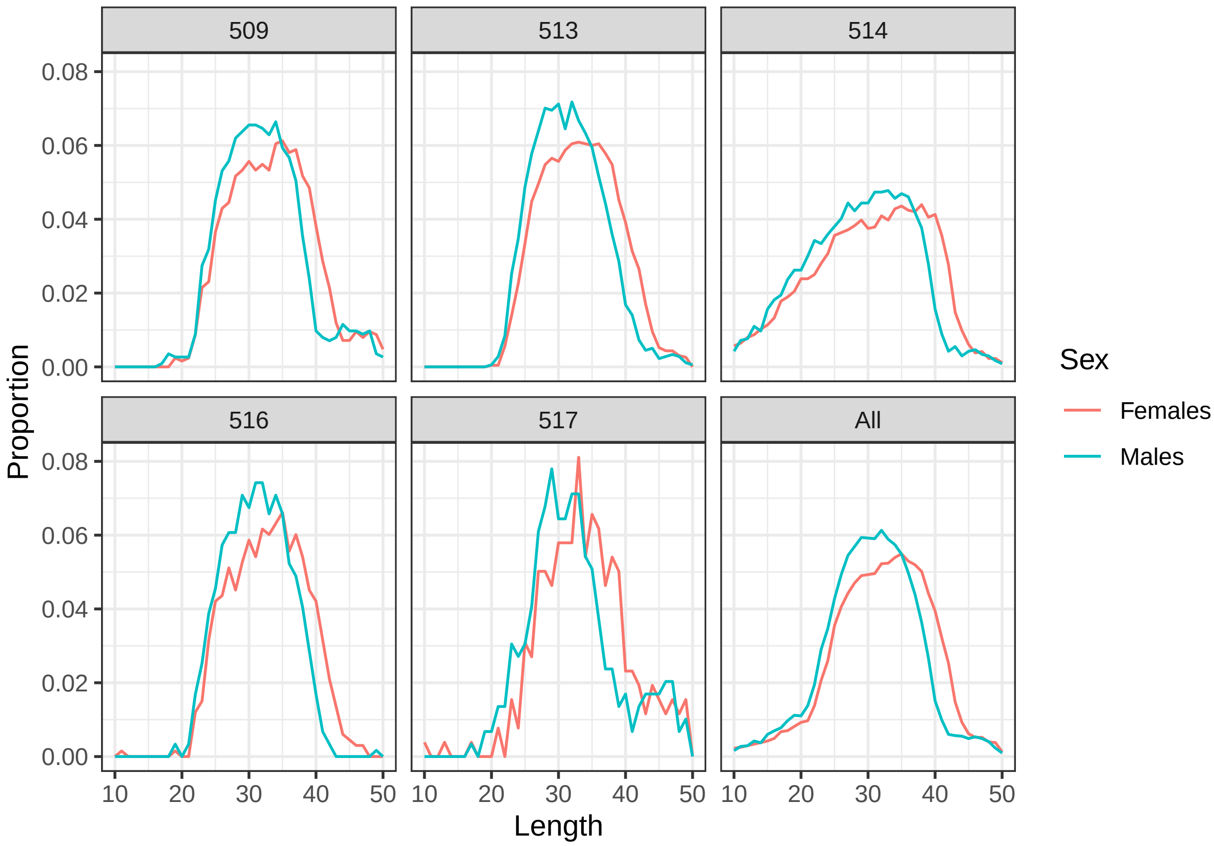


Figure 4.8: Size composition of the yellowfin sole catch in 2019 (through mid-September), by subarea and total.

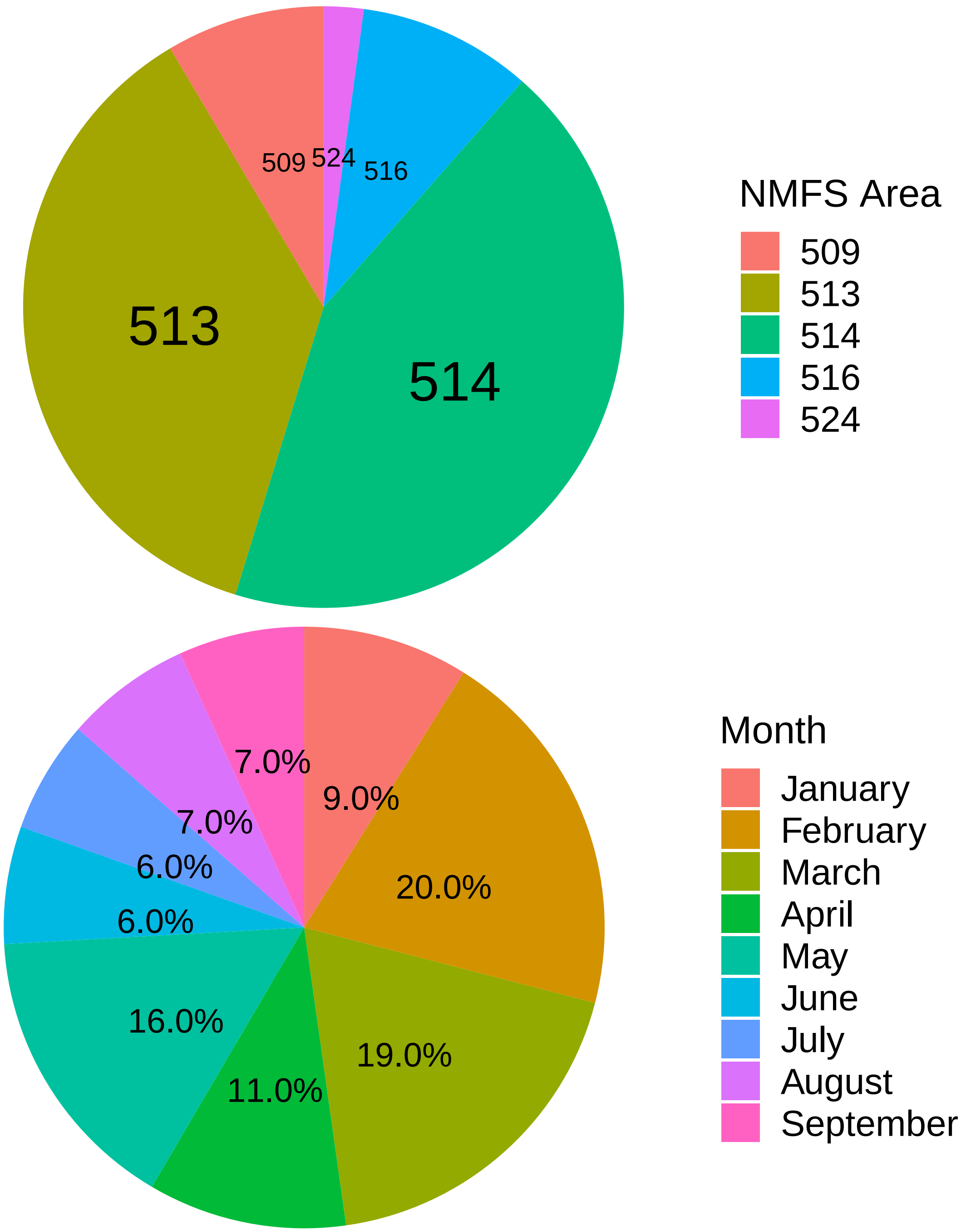


Figure 4.9: Yellowfin Sole catch proportion by area (upper panel) and by month (lower panel) in the Eastern Bering Sea in 2019.

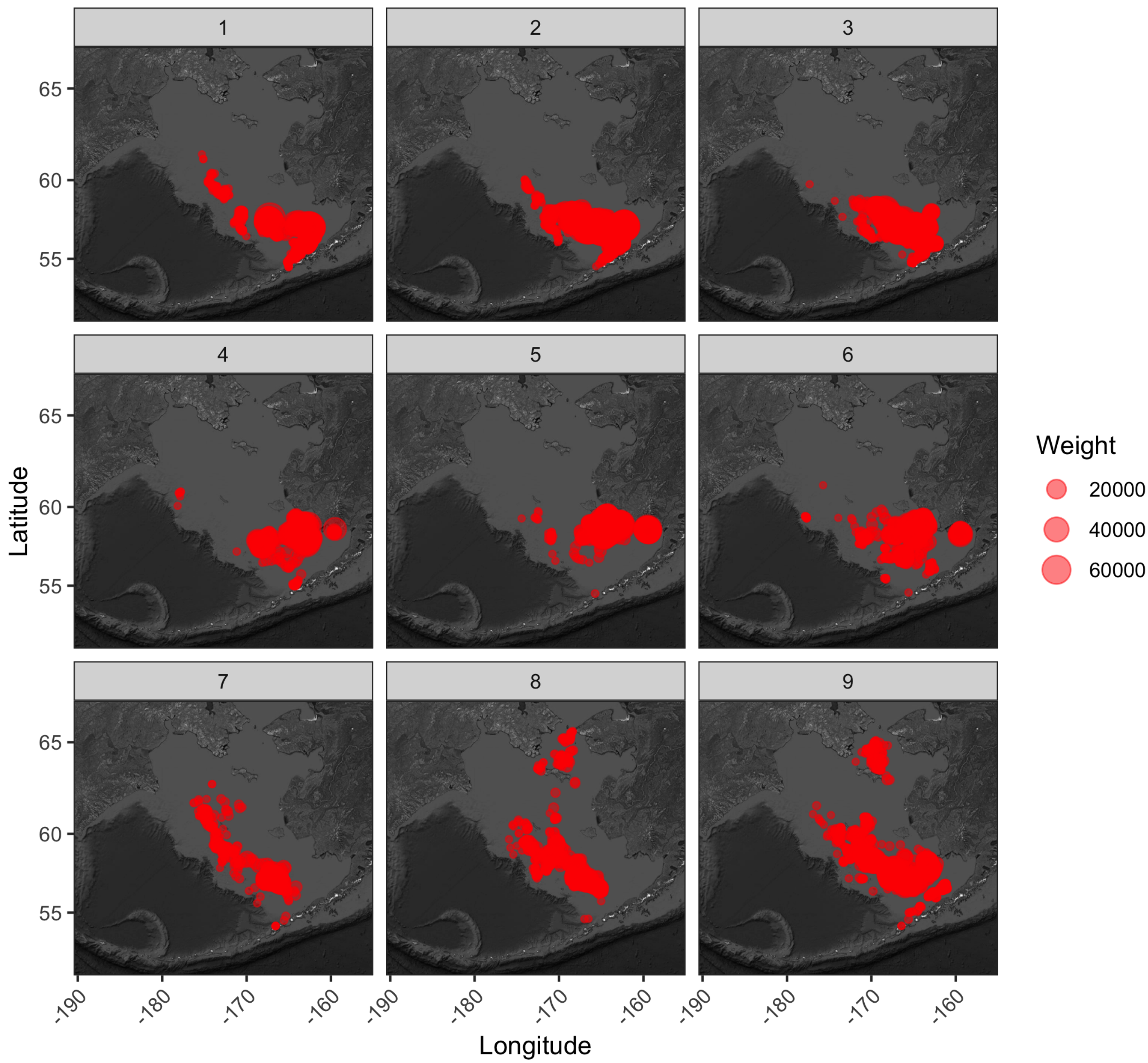


Figure 4.10: Fishery locations by month, 2019.

Figure 4.11: Catch per unit effort on NMFS eastern Bering Sea surveys, 1982-2019. Units are in kg/km2.

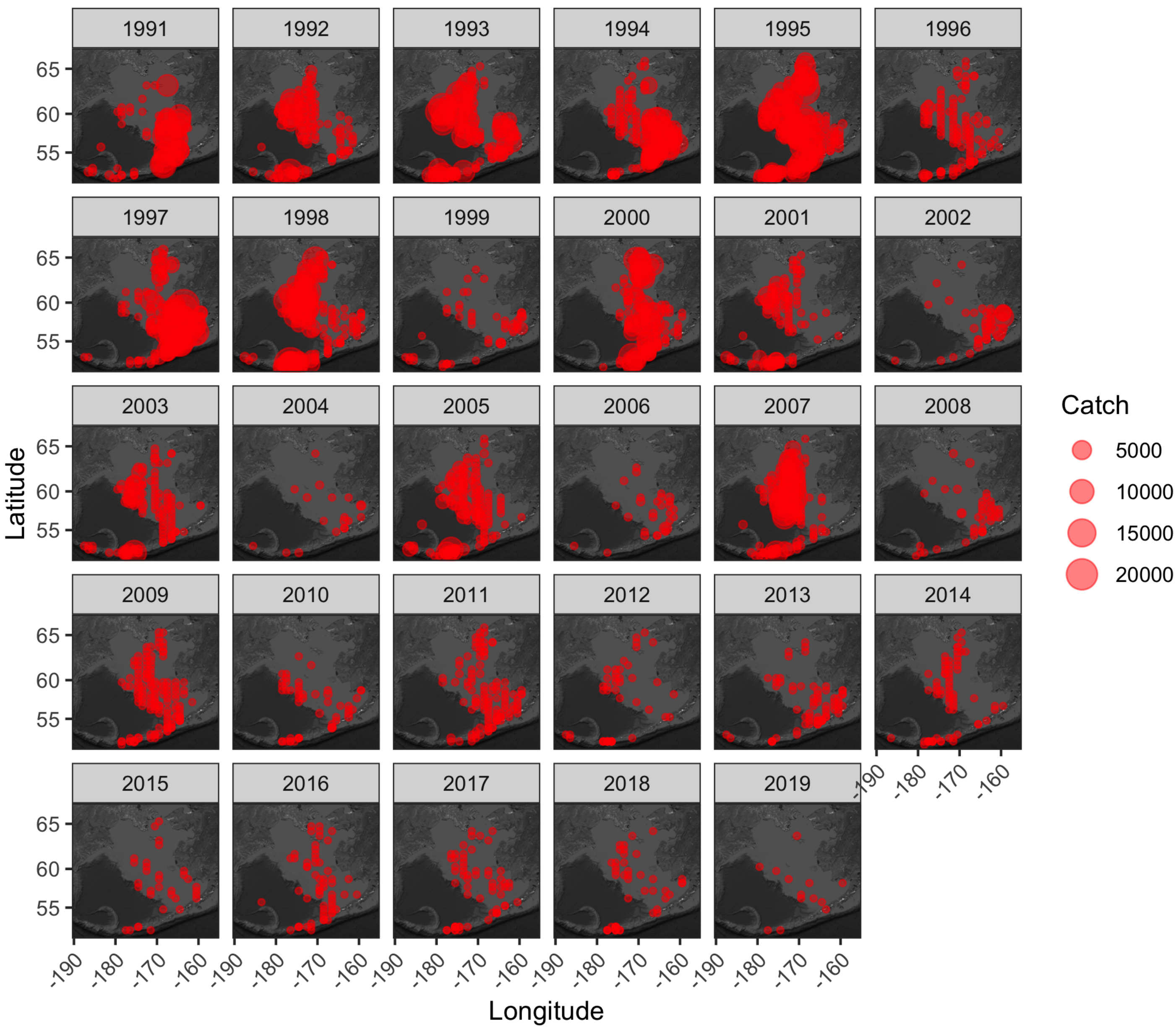


Figure 4.12: Catch of Yellowfin Sole in the BSAI, 1991-2019. Circles represent relative catch in ADFG Statistical Areas.

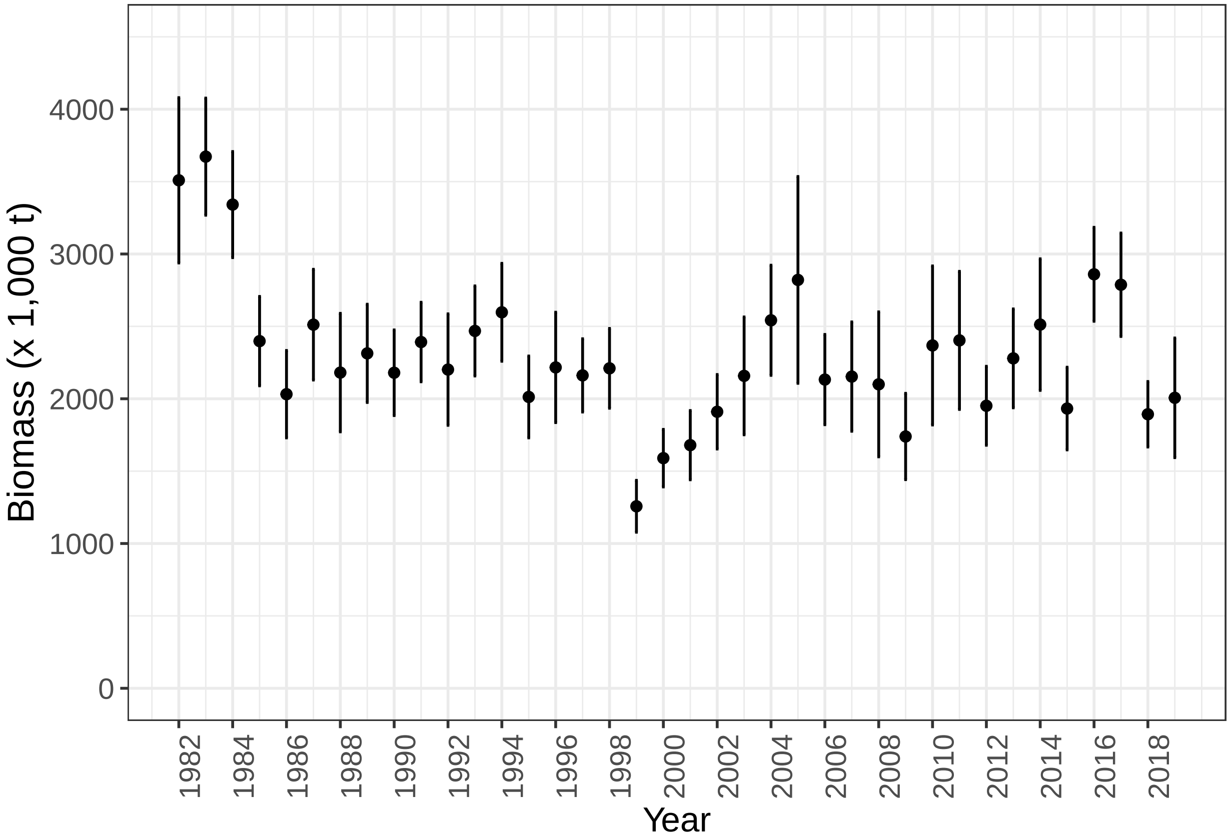


Figure 4.13: Annual eastern Bering Sea bottom trawl survey biomass point estimates and 95% confidence intervals for Yellowfin Sole, 1982-2019.

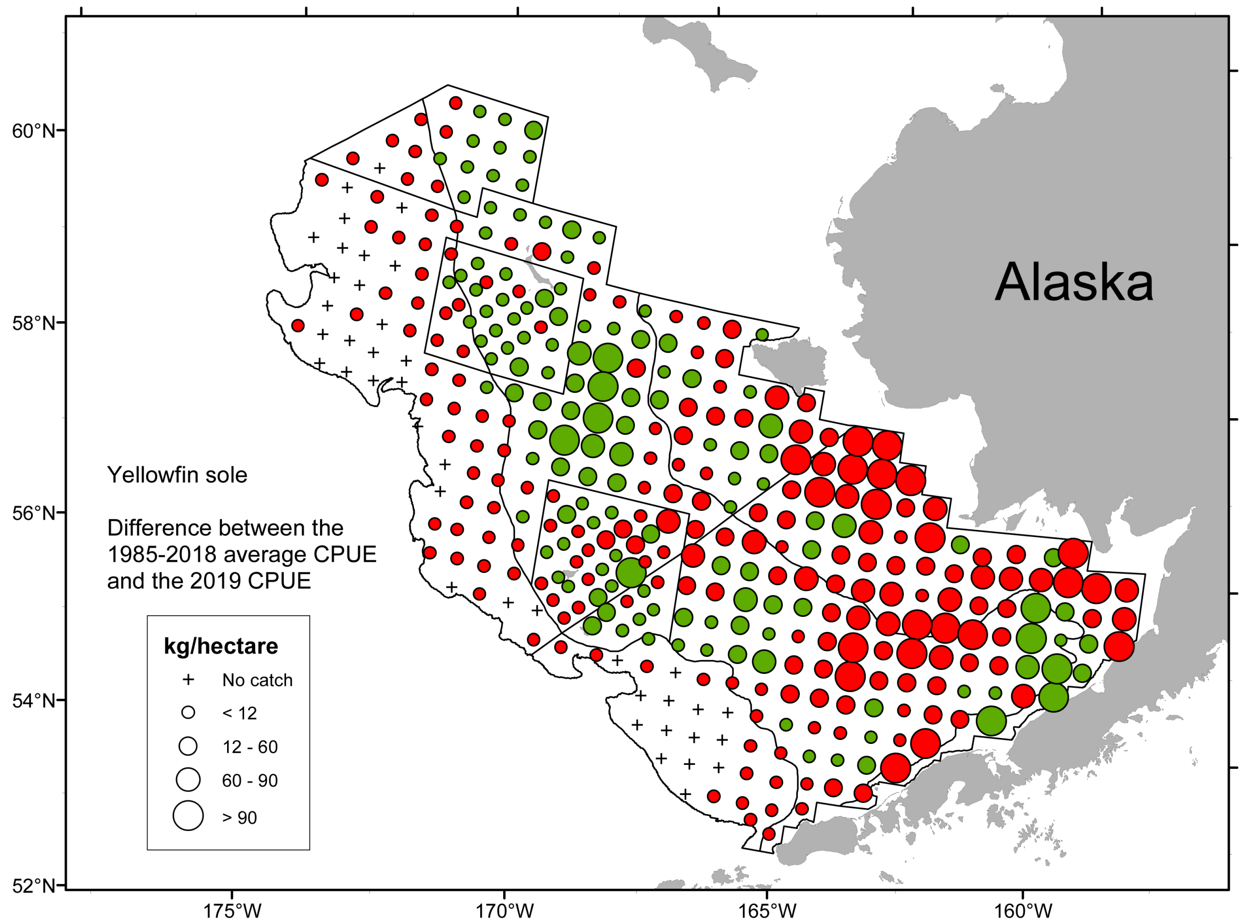


Figure 4.14: Difference between the 1985-2018 average trawl survey CPUE for Yellowfin Sole and the 2019 survey CPUE. Red circles indicate that the magnitude of the catch was greater in 2019 than the long-term average, green circles indicate the catch was lower in the long-term average than in 2019.

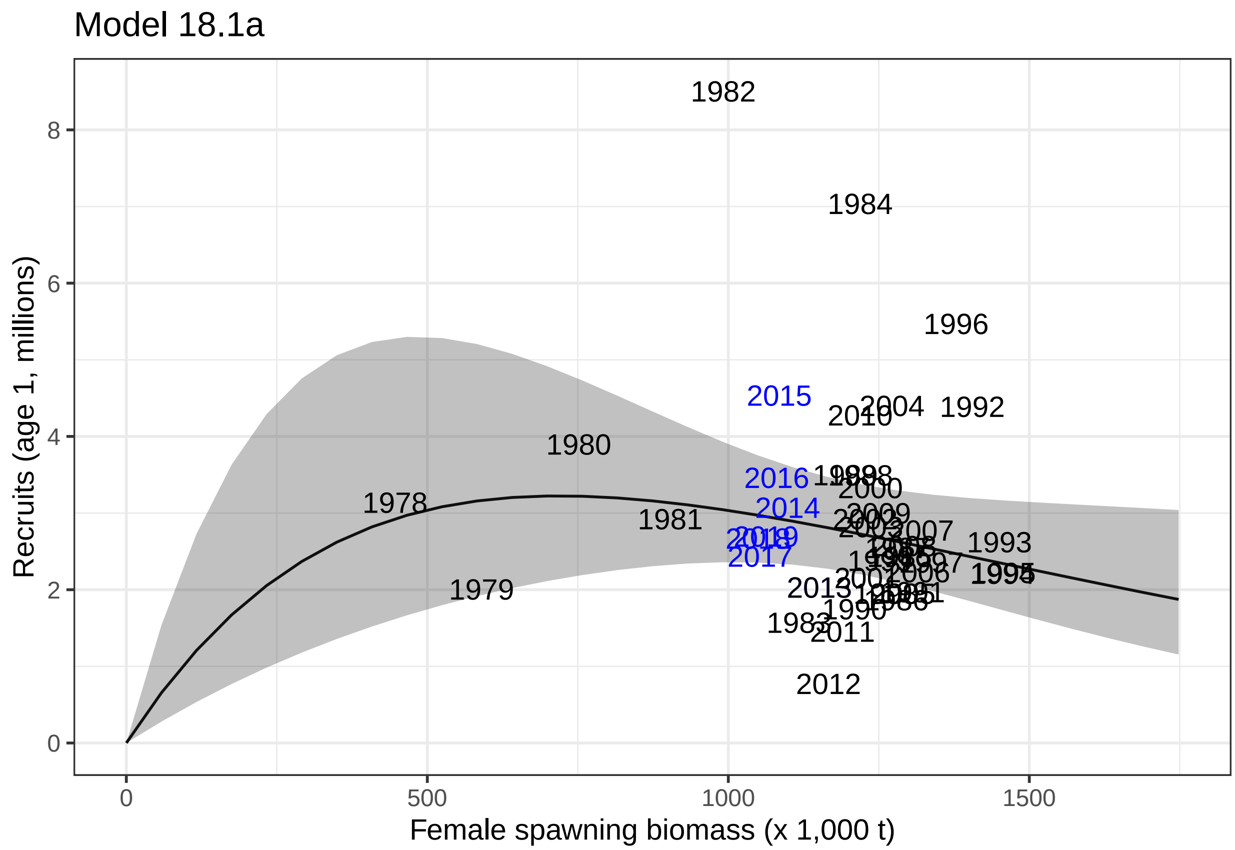


Figure 4.15: Ricker stock recruitment curve for Model 18.1a with 95% confidence intervals (shaded region) fit to female spawning biomass and recruitment data from 1978-2013. Years in black indicate data used to fit the model.

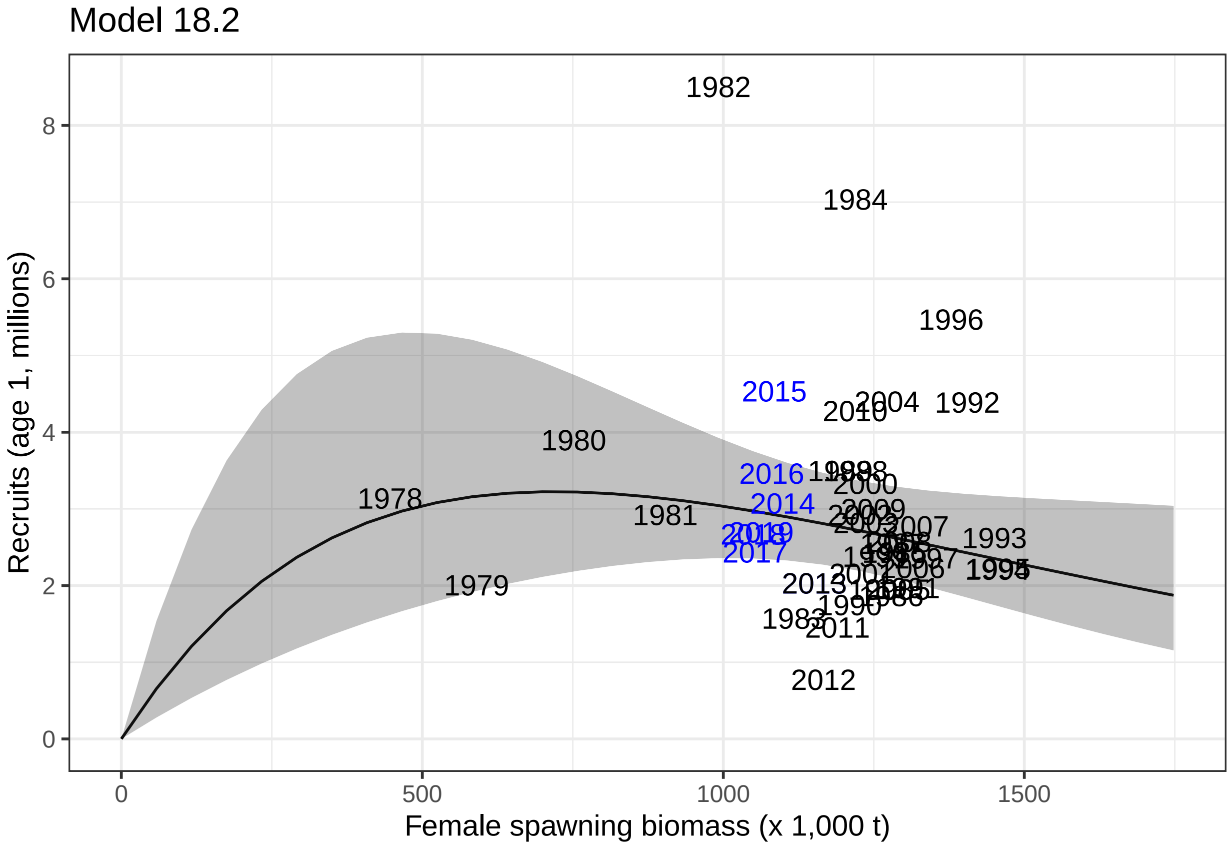


Figure 4.16: Ricker stock recruitment curve for Model 18.2 with 95% confidence intervals (shaded region) fit to female spawning biomass and recruitment data from 1978-2013. Years in black indicate data used to fit the model.

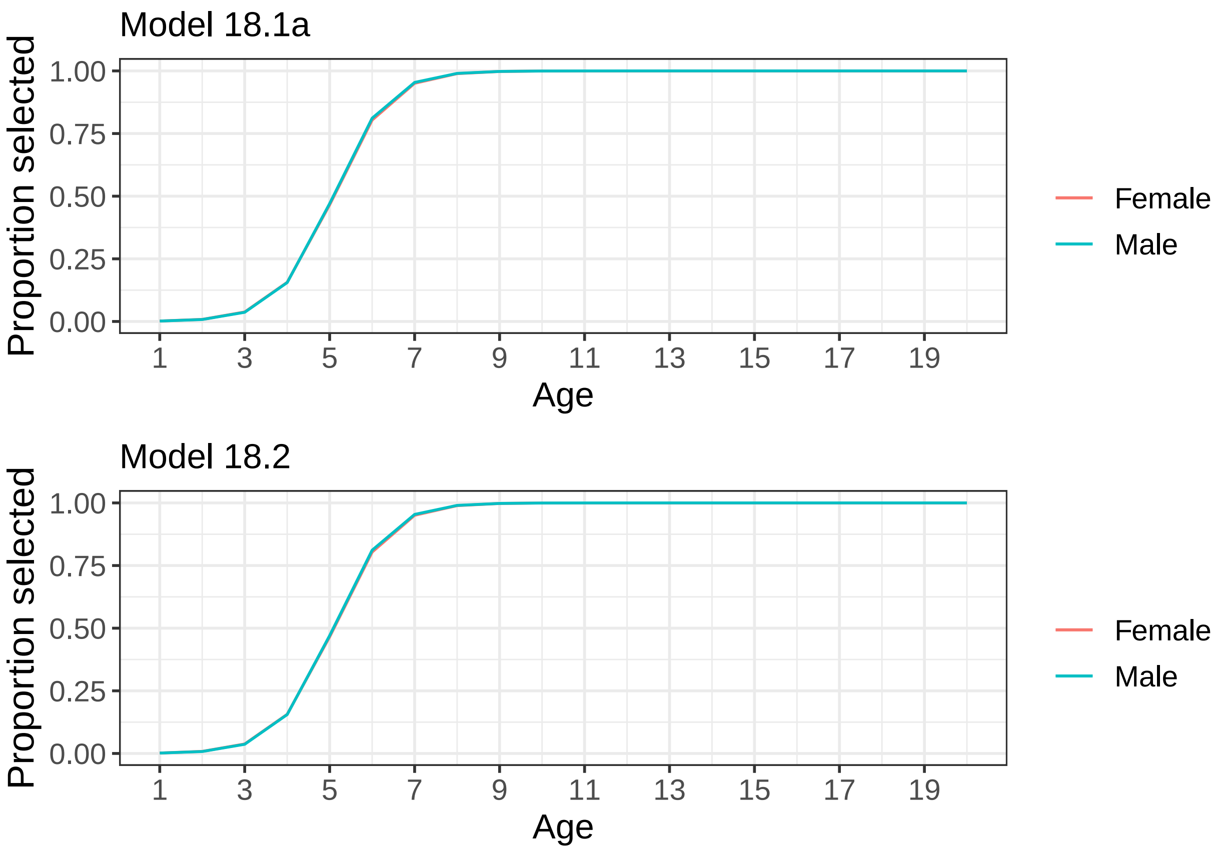


Figure 4.17: Estimate of survey selectivity for males and females, Model 18.1a upper panel, Model 18.2 lower panel.

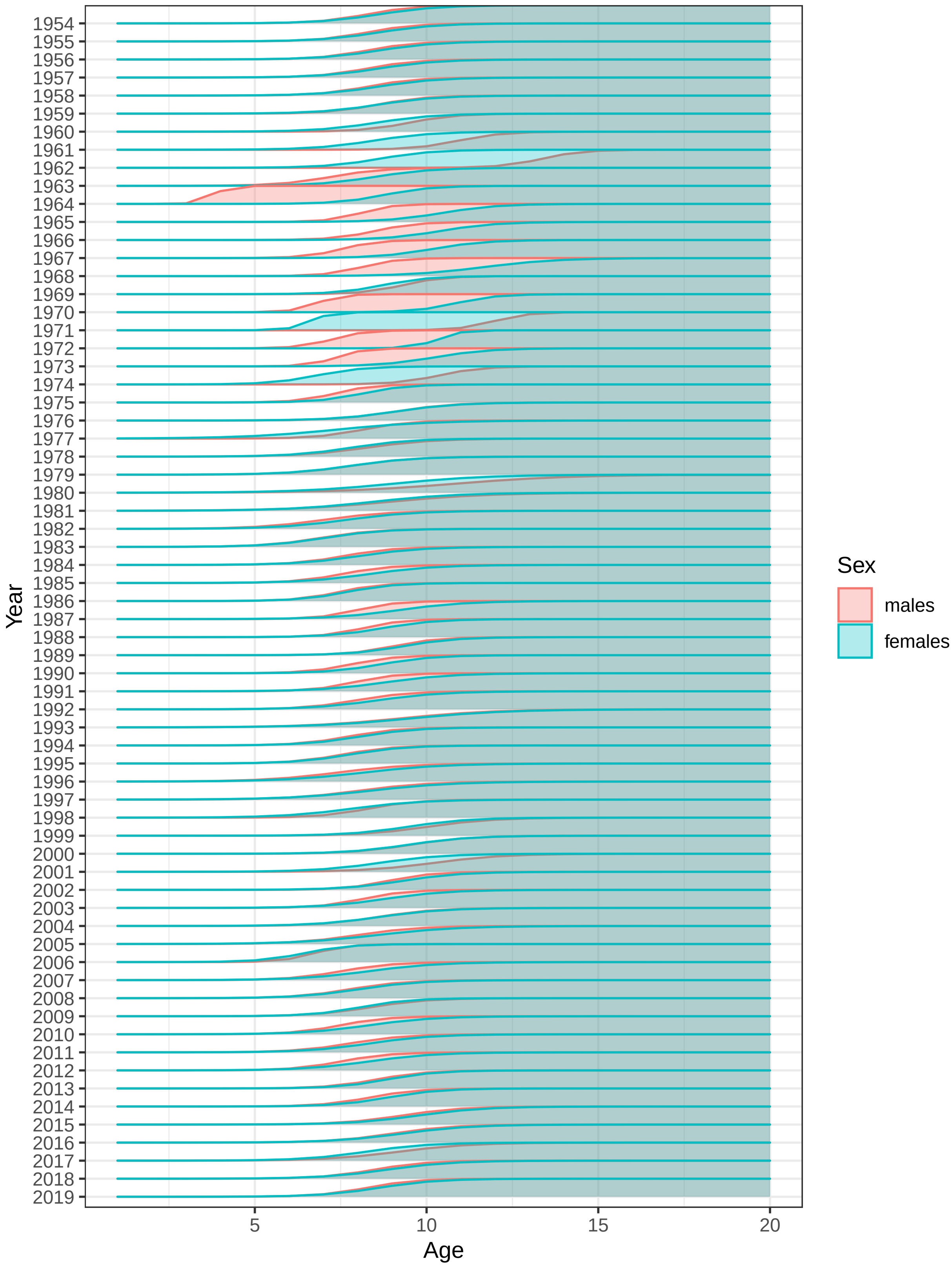


Figure 4.18: Estimate of fishery selectivity for males and females, 1954-2019.

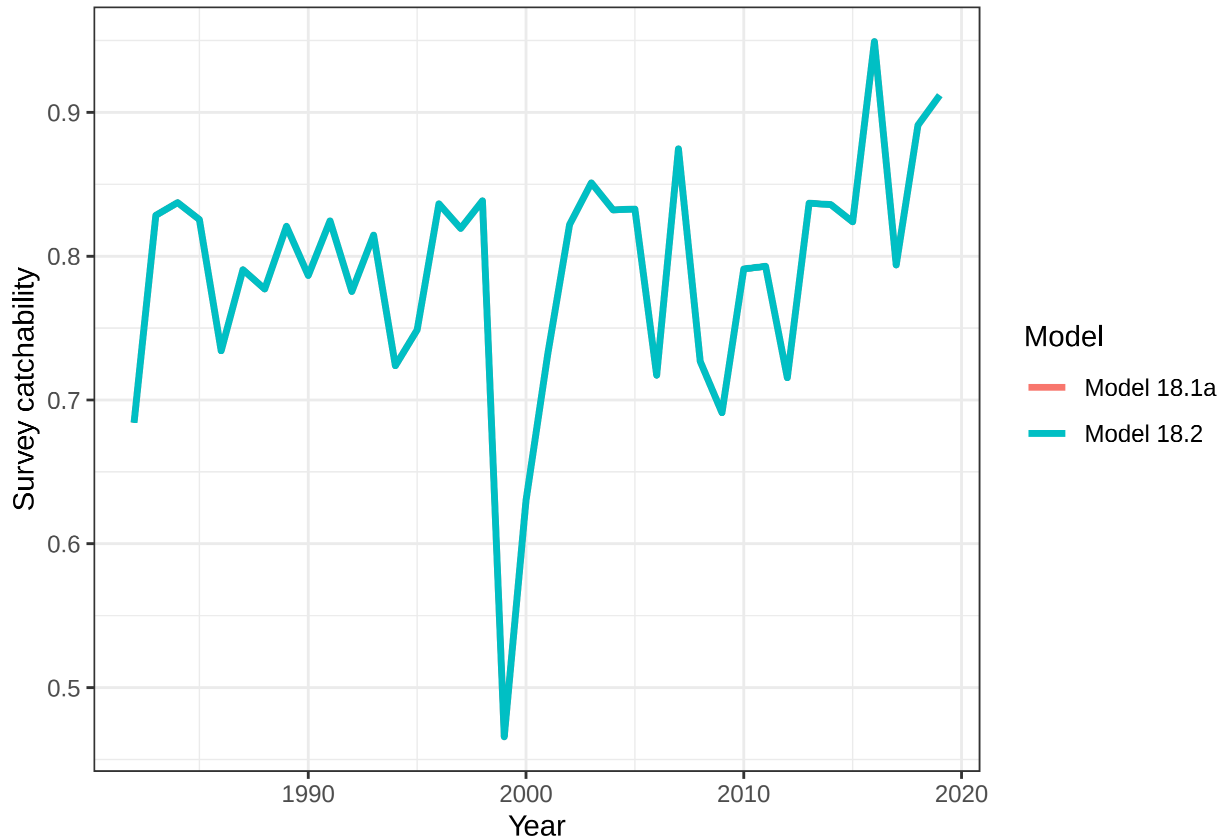


Figure 4.19: Survey catchability for Model 18.1a and 18.2, 1982-2019.

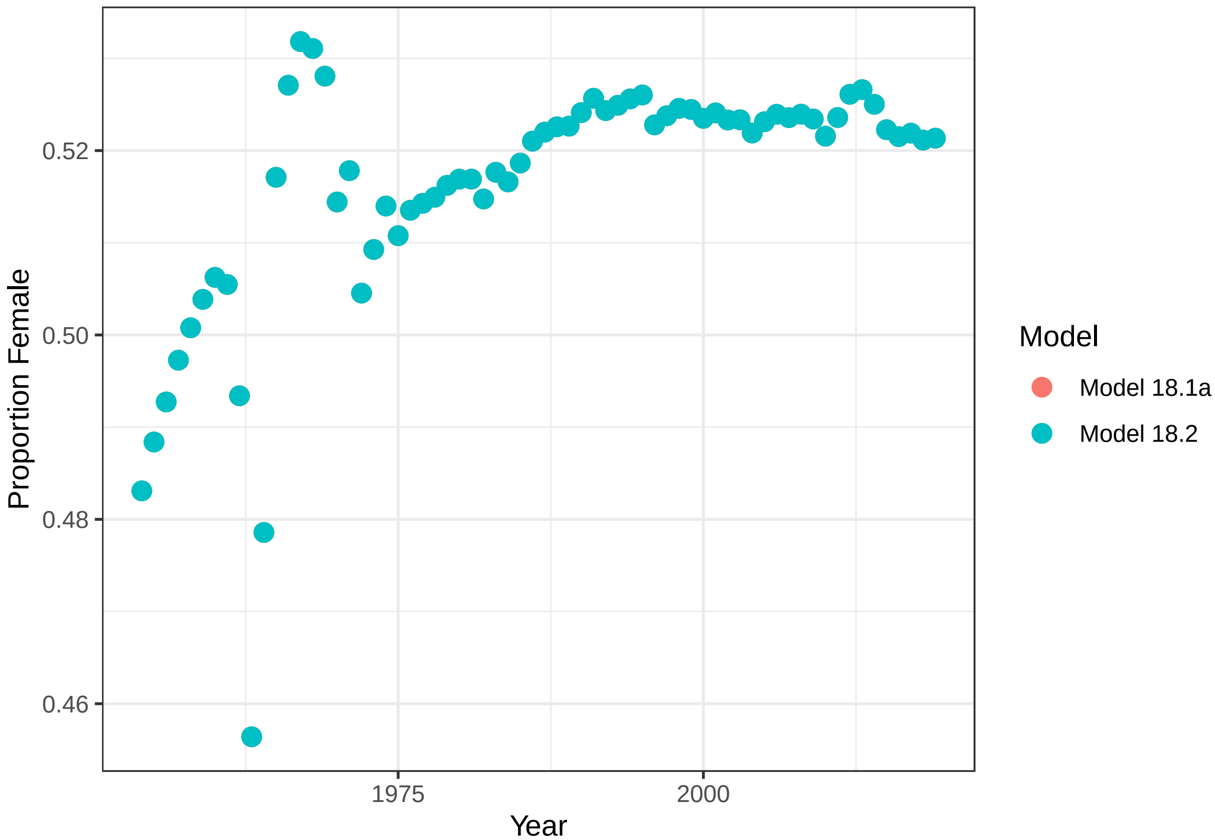


Figure 4.20: Model estimates of the proportion of female Yellowfin Sole in the population, 1982-2019.

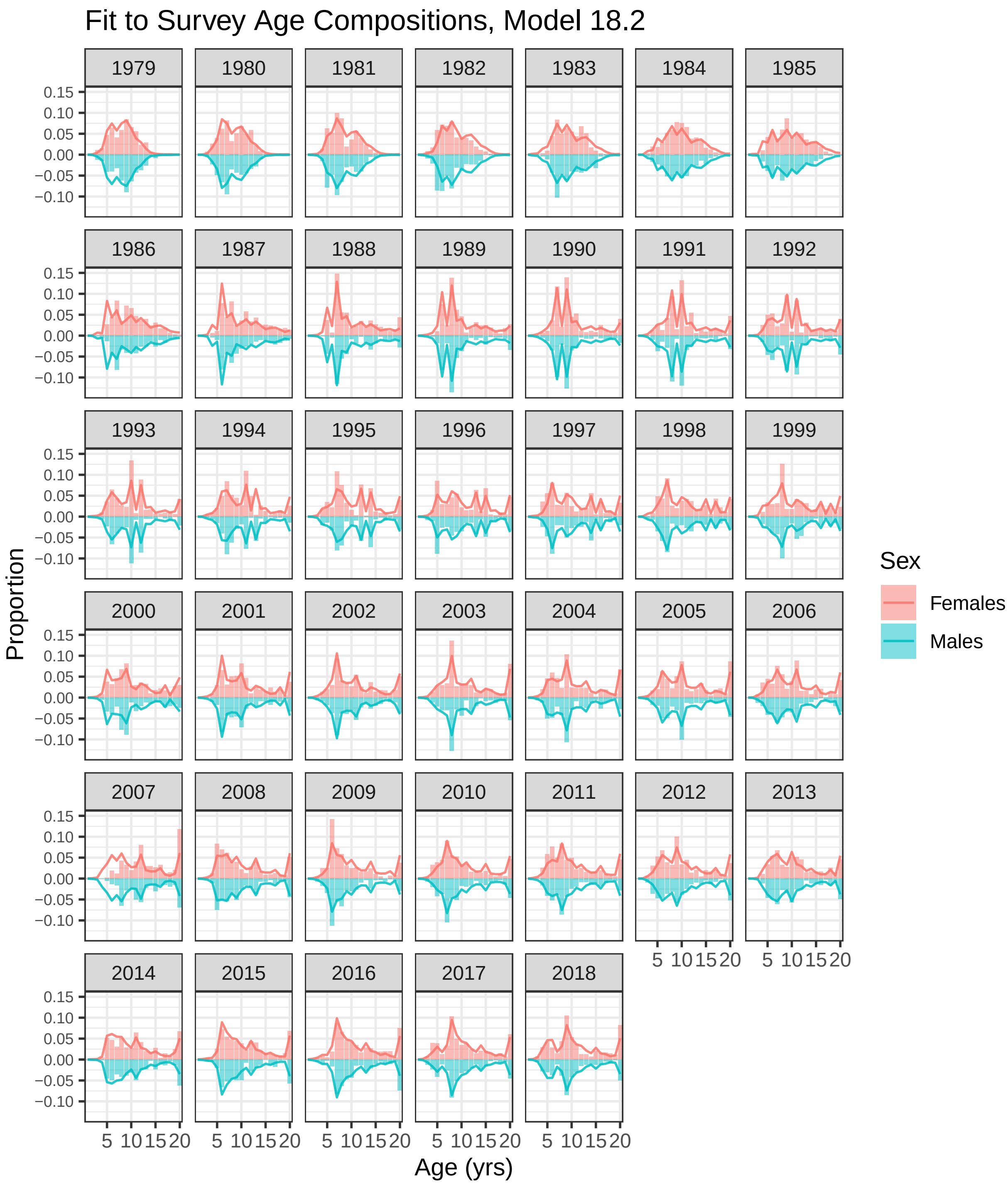


Figure 4.29: Model 18.1a fit to the time-series of survey age composition, by sex, 1979-2018.

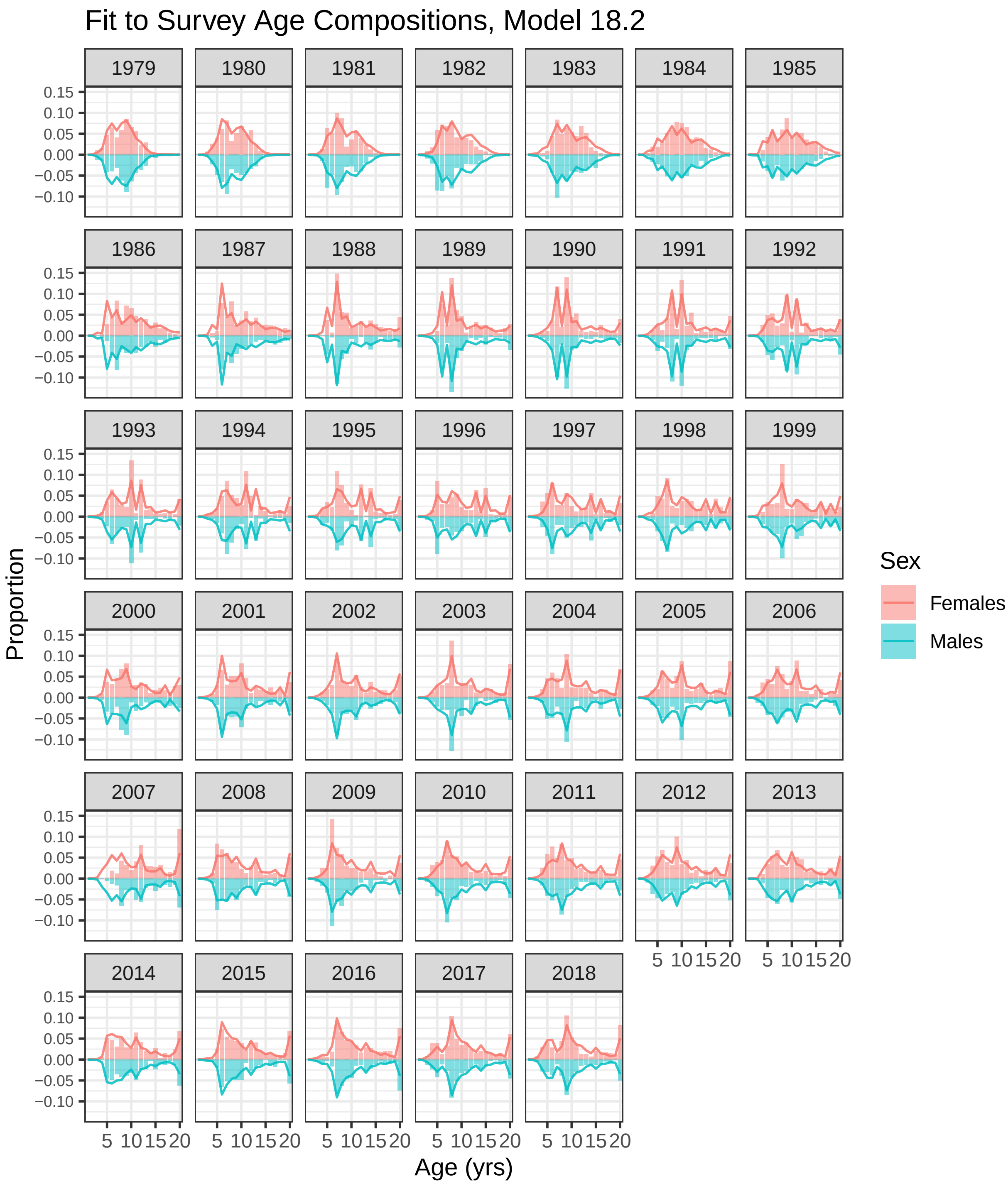


Figure 4.30: Model 18.2 fit to the time-series of survey age composition, by sex, 1979-2018.

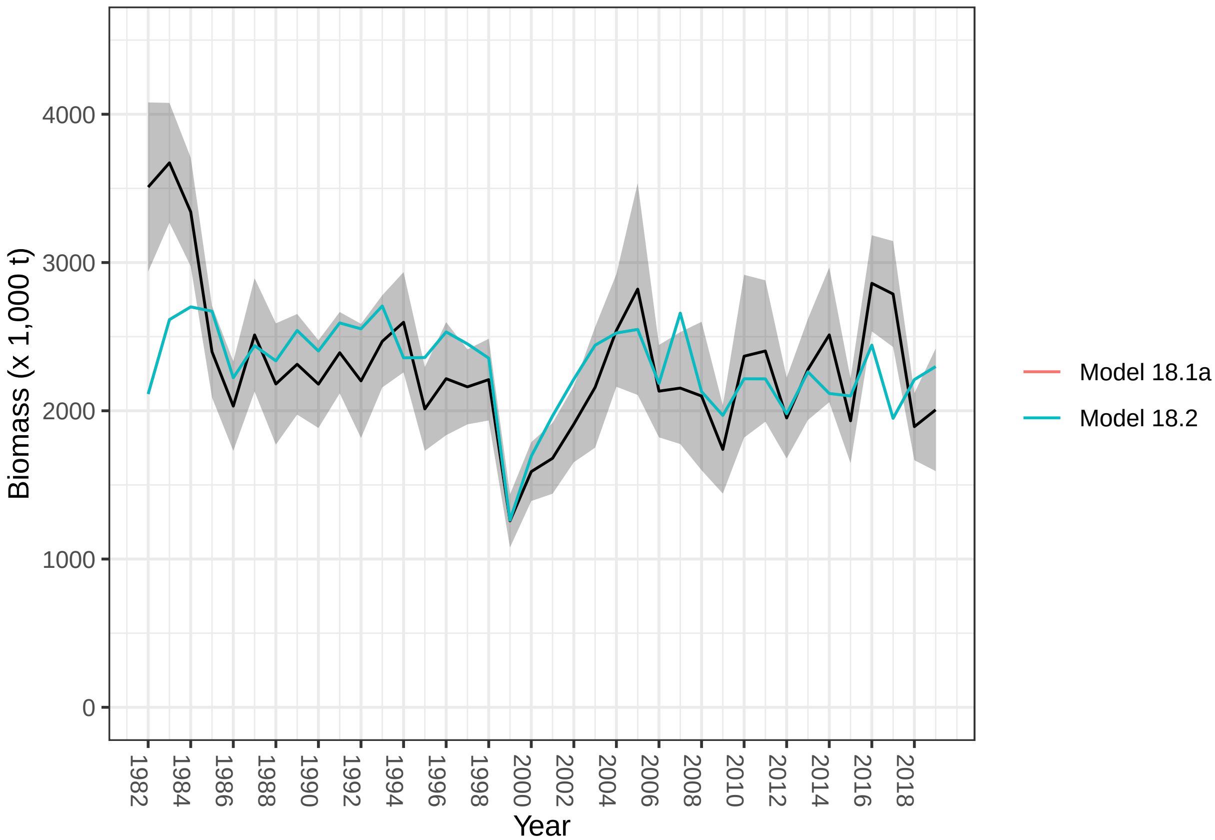
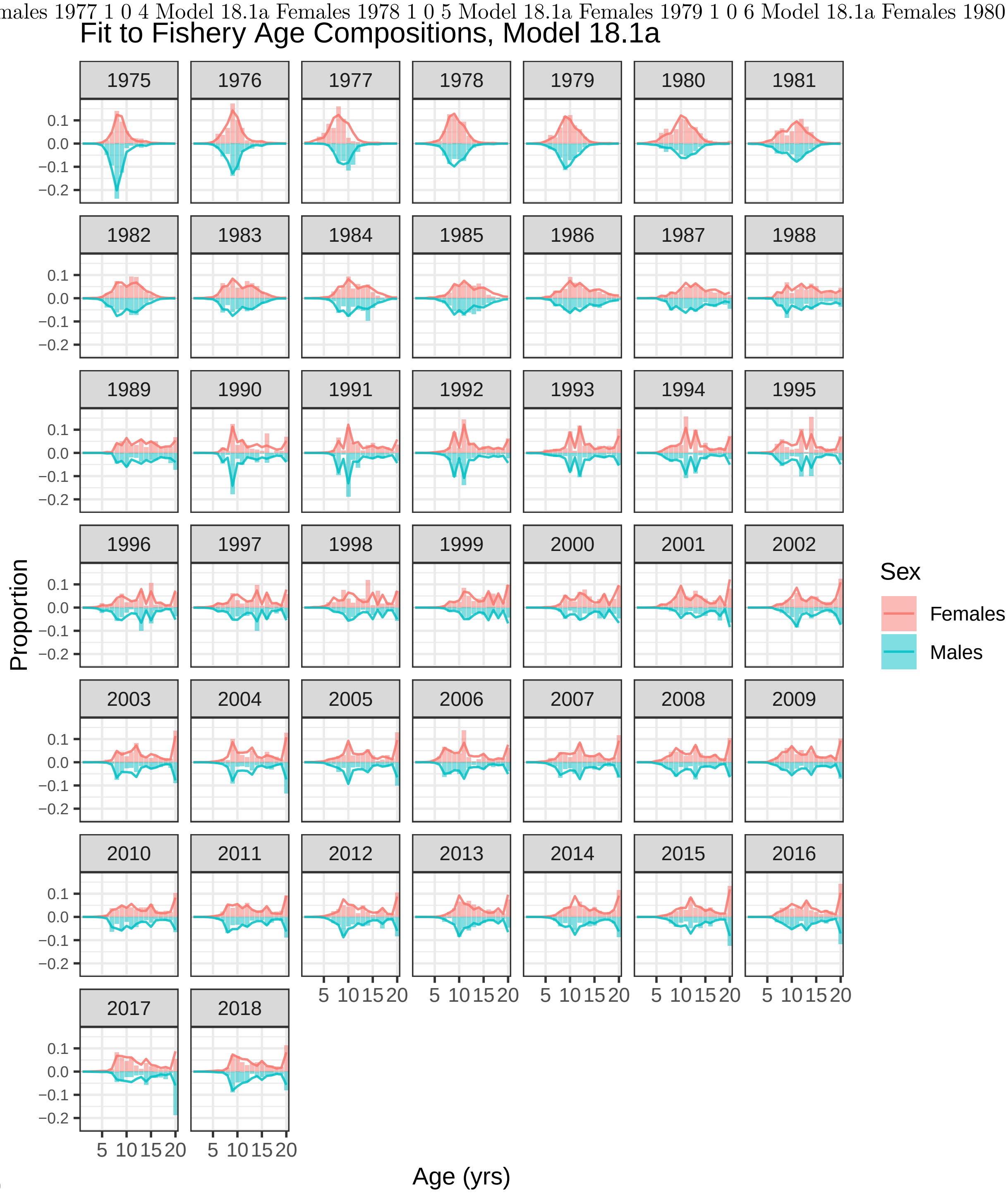


Figure 4.21: NMFS eastern Bering Sea survey biomass estimates, with 95% confidence intervals and Model 18.1a and Model 18.2 fit to survey biomass estimates, from 1982-2019.

Model Sex Year variable value 1 Model 18.1a Females 1975 1 0 2 Model 18.1a Females 1976 1 0 3 Model 18.1a Females 1977 1 0 4 Model 18.1a Females 1978 1 0 5 Model 18.1a Females 1979 1 0 6 Model 18.1a Females 1980



1 0

Figure 4.31: Model 18.2 fit to the time-series of fishery age composition, by sex, 1975-2018.

```
  Model     Sex Year variable value
```

1 Model 18.2 Females 1975 1 0 2 Model 18.2 Females 1976 1 0 3 Model 18.2 Females 1977 1 0 4 Model 18.2 Females 1978 1 0 5 Model 18.2 Females 1979 1 0 6 Model 18.2 Females 1980 1 0

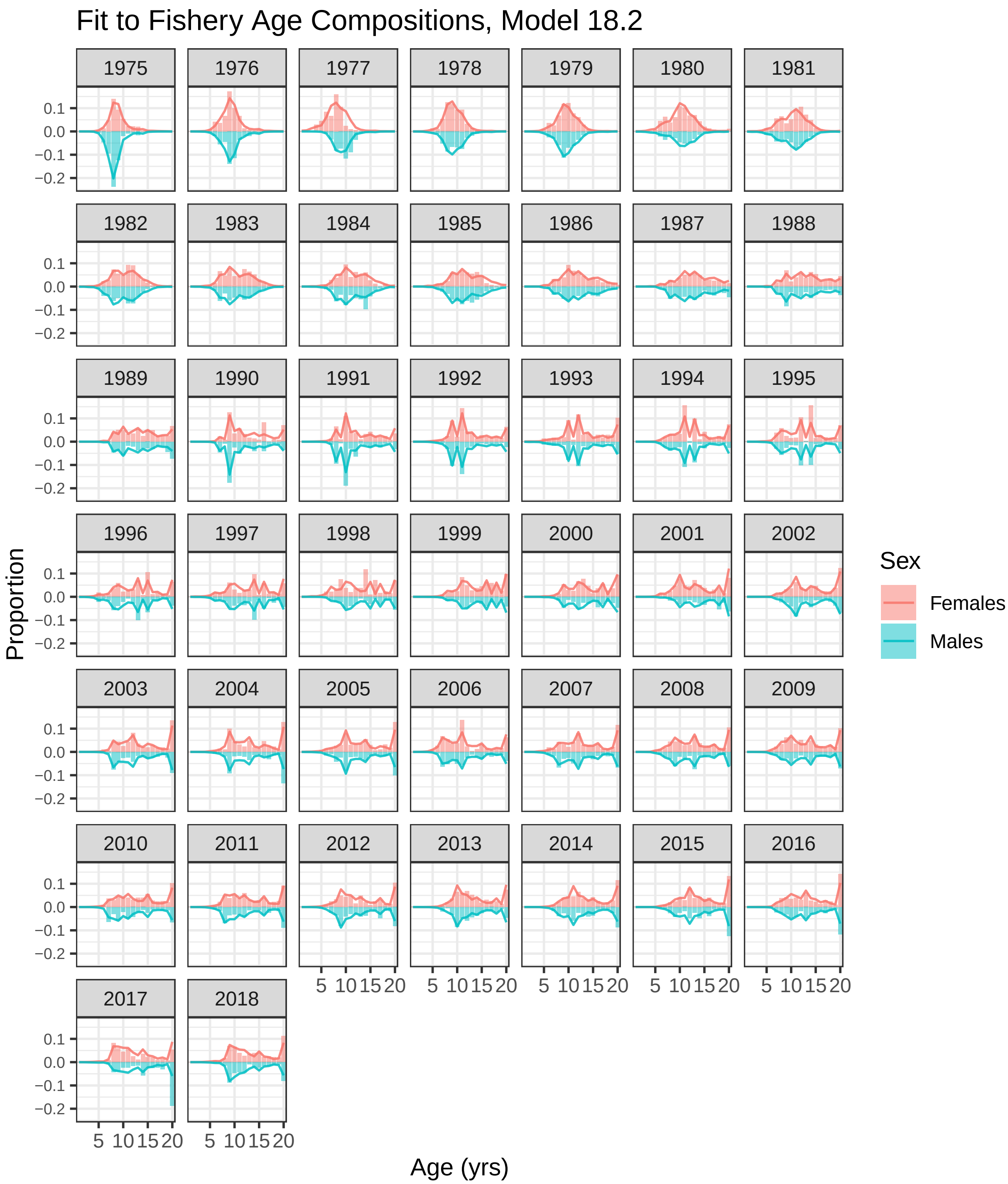


Figure 4.32: Model 18.2 fit to the time-series of fishery age composition, by sex, 1975-2018.

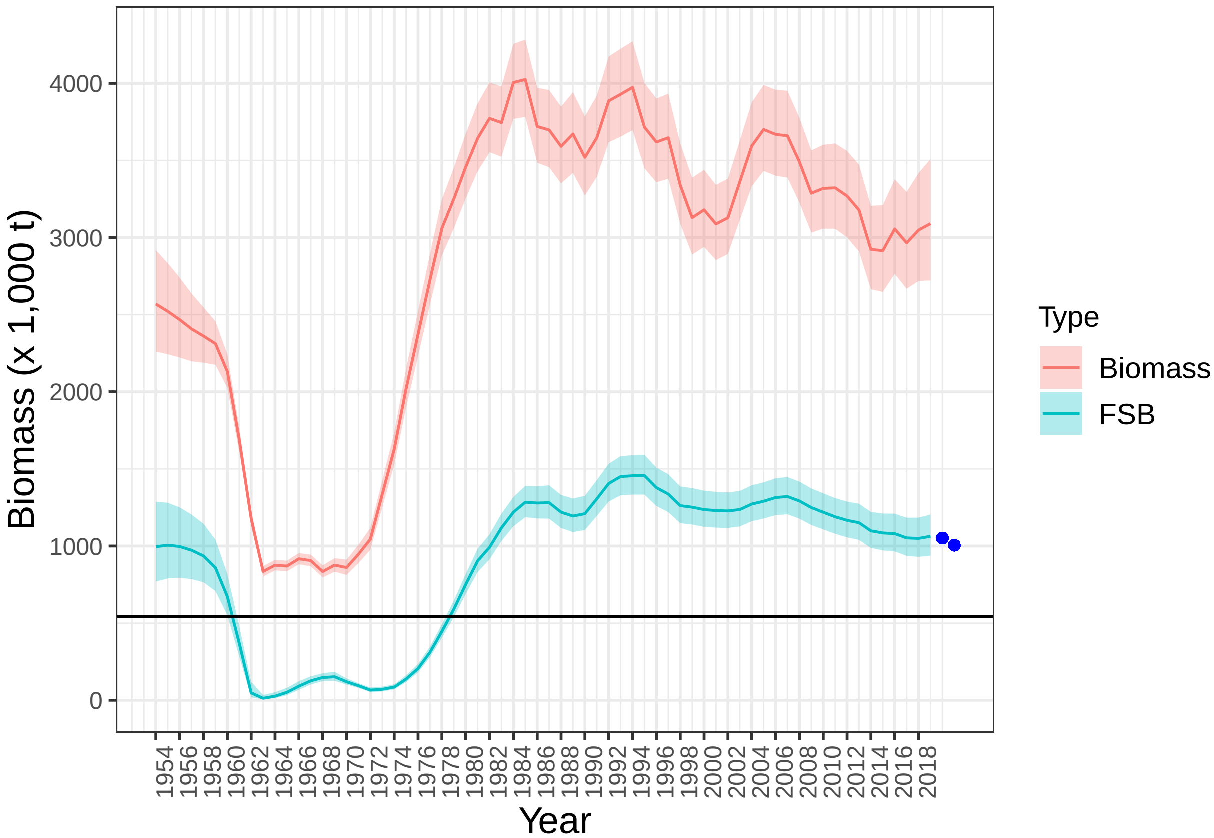


Figure 4.33: Model estimates of total (age 2+) and female spawning biomass with 95% confidence intervals, 1954-2019.

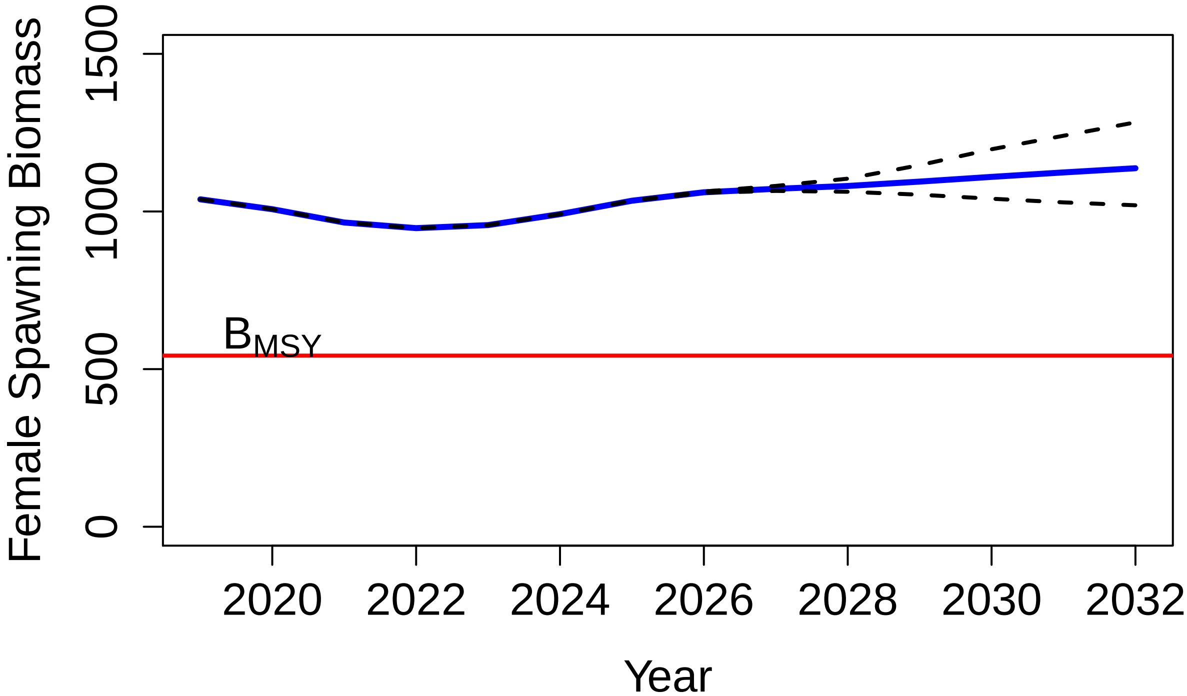


Figure 4.24: Projected female spawning biomass for 2019 to 2032 to 2032 (blue line), with 5% and 95% confidence intervals, and fishing at the 5-year (2014-2018) average fishing mortality rate, F= 0.0717 .

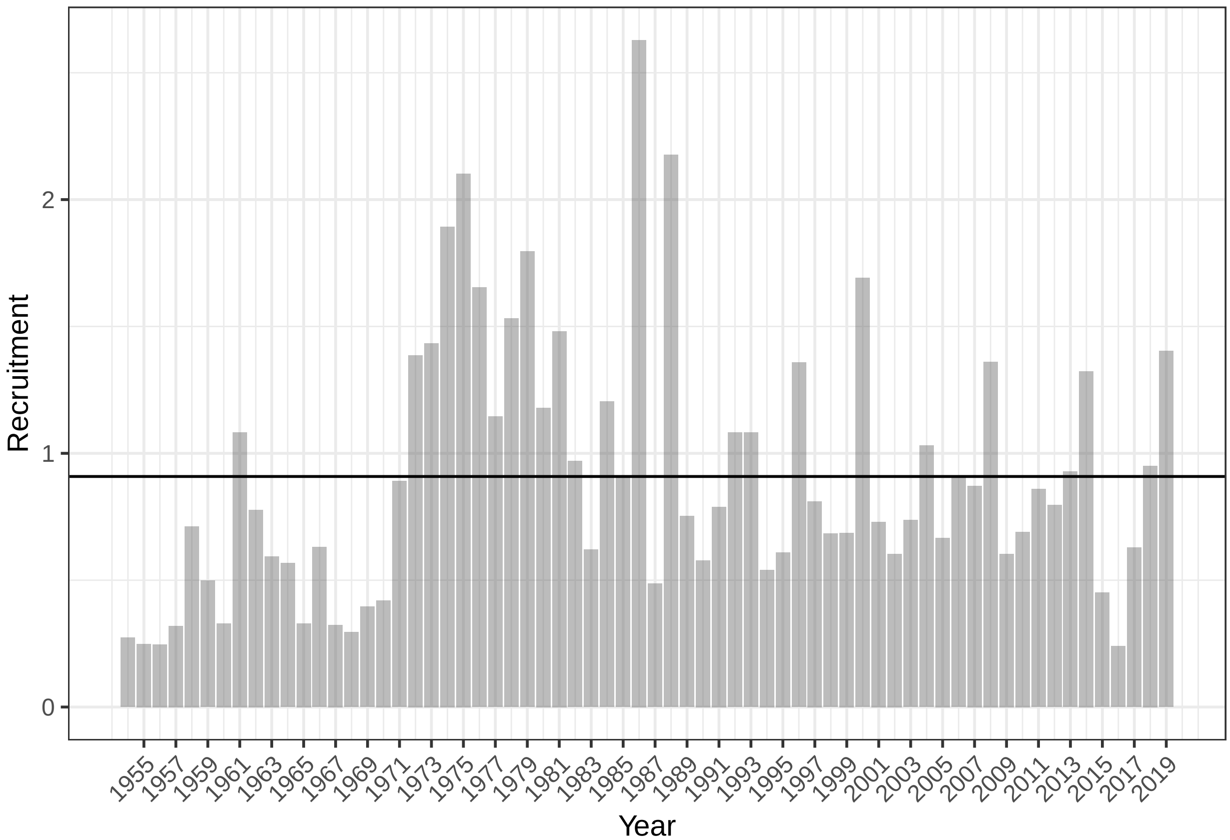


Figure 4.25: Year class strength of age 5 yellowfin sole estimated by the stock assessment model. The dotted line is the average of the estimates from 63 years of recruitment.

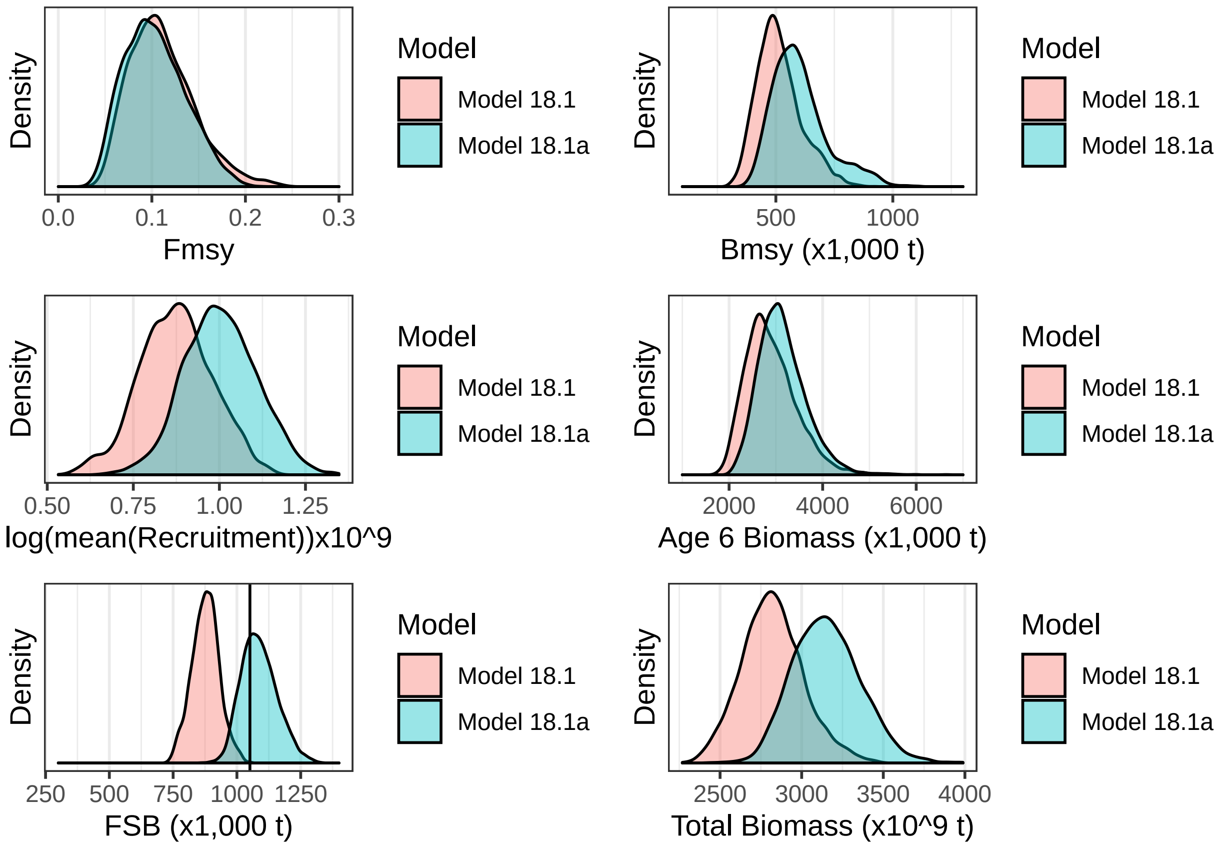


Figure 4.22: MCMC posterior distributions for Fmsy, Bmsy, log(mean(Recruitment)), Age 6 biomass, female spawning biomass (FSB) for 2019, and total biomass for 2019.

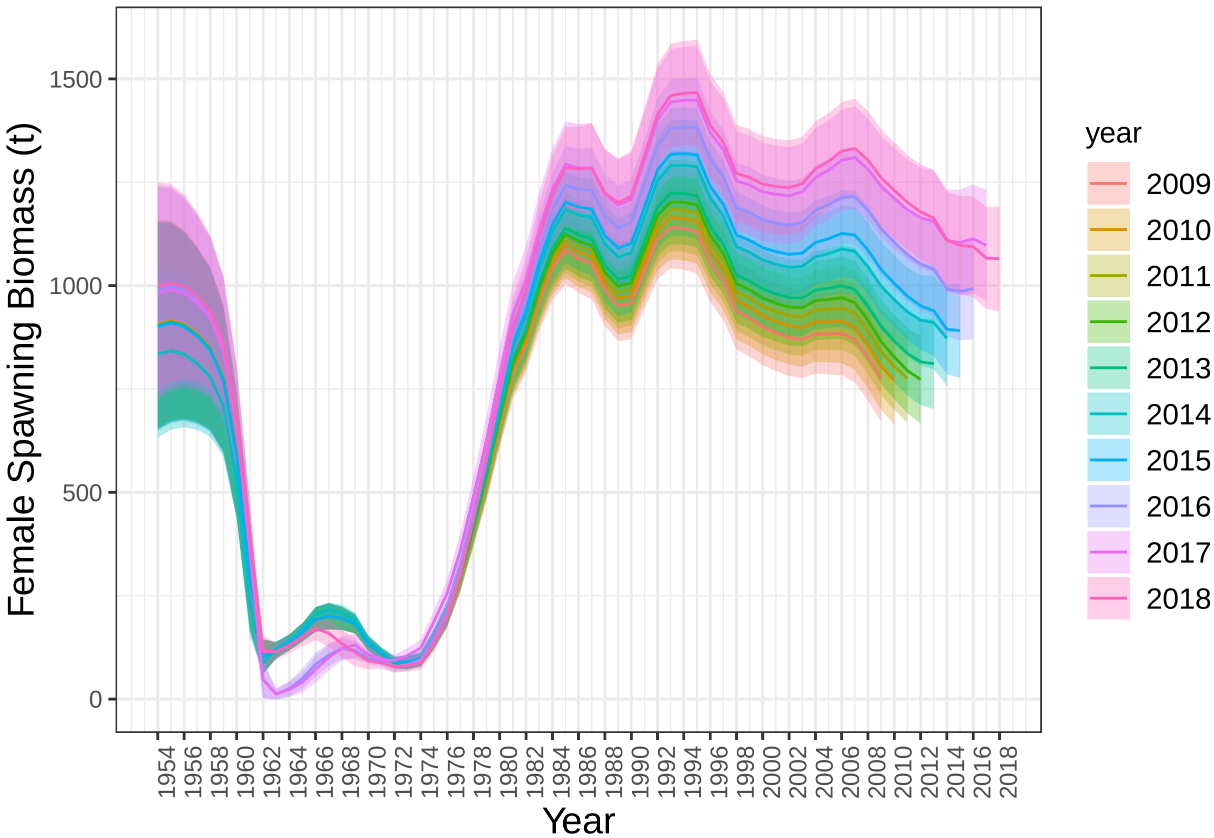


Figure 4.26: Retrospective plot of female spawning biomass. The preferred model with data through 2019 is shown, and data was sequentially removed through 2009.

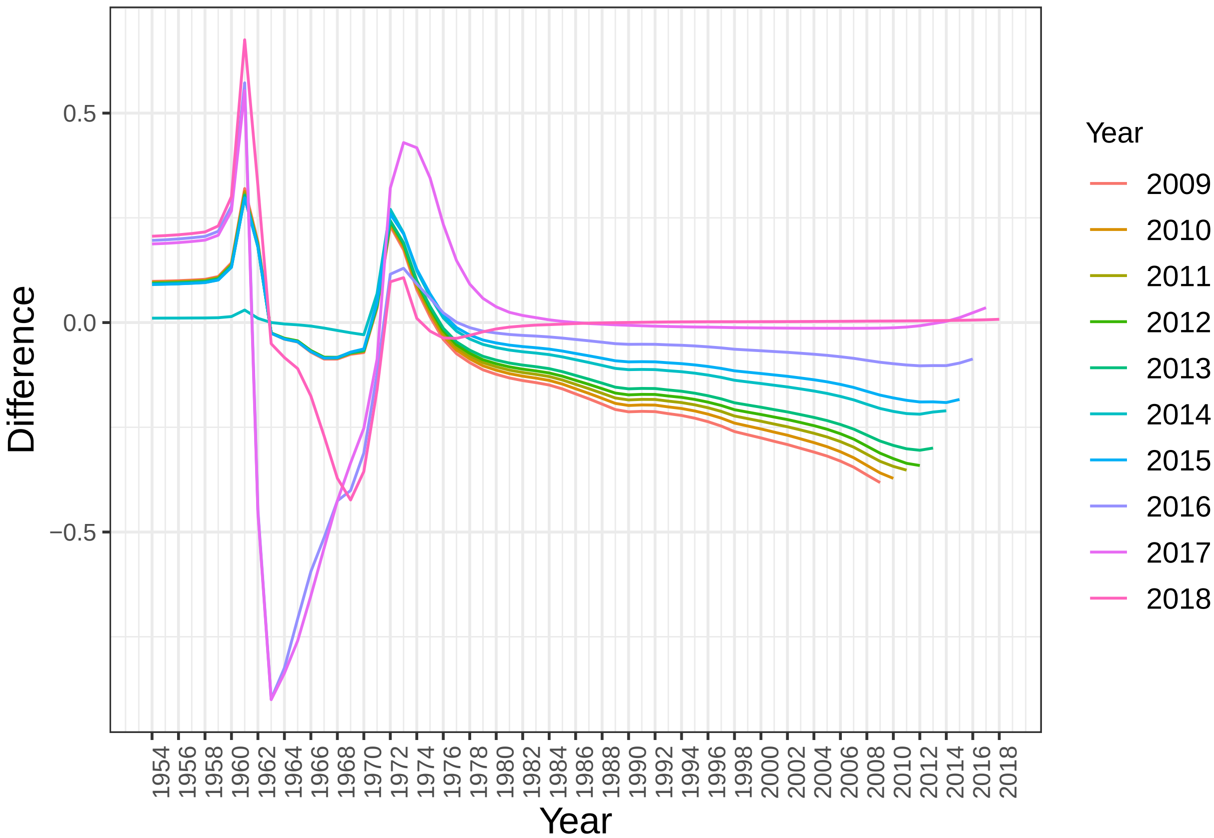


Figure 4.27: Relative differences in estimates of spawning biomass between the 2019 model and the retrospective model run for years 2018 through 2009.

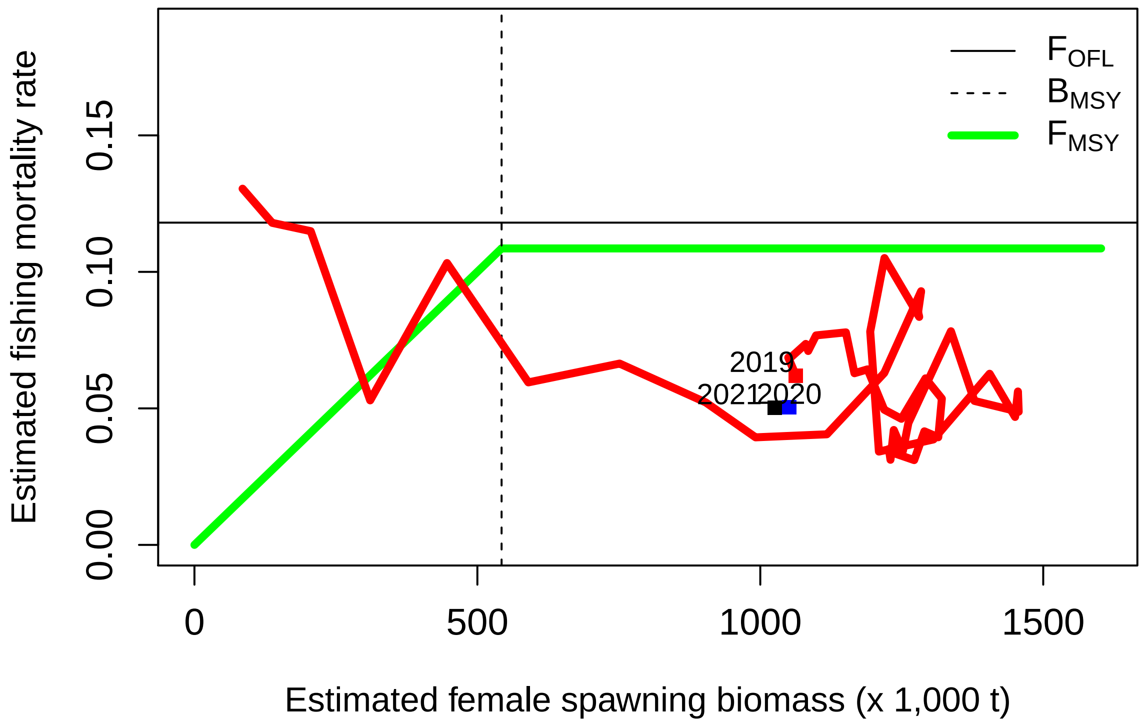


Figure 4.28: Fishing mortality rate and female spawning biomass from 1975 to 2019 compared to the F35% and F40% control rules. Vertical lines are B35% and B40%.

Appendix

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, 1990-2019. Source NMFS Alaska Region: Sourced by the AKR.V_NONCOMMERCIAL_FISHERY_CATCH table, October 31, 2019. 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	64,905
2016	61	15	97,795
2017	38	1	112,121
2018	55	1	72,451