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

Ingrid Spies, Meaghan Bryan, Lewis Barnett, Emily Markowitz, Zack Oyafuso, Elizabeth Siddon
Alaska Fisheries Science Center, National Marine Fisheries Service
National Oceanic and Atmospheric Administration
7600 Sand Point Way NE., Seattle, WA 98115-6349
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Executive Summary

Summary of Changes in Assessment Inputs

The following substantive changes have been made to the BSAI yellowfin sole assessment relative to the 2022 Bering Sea and Aleutian Islands (BSAI) SAFE report. Several models are presented in this document that incorporate new data since the last full assessment in 2022.

Changes in the data

1. The 2022 fishery age compositions were added.
2. The 2022 VAST survey age compositions were added.
3. The estimate of the total catch made through the end of 2022 was updated as reported by the NMFS Alaska Regional office. The catch through the end of 2023 was estimated based on available data to be 79,688 t. Catch for the 2024 and 2025 projections were assumed to be the mean of the past 5 years, 2019 - 2023, 121,103 t.
4. The 2023 NMFS survey biomass estimate and standard error were included. Model-based (VAST) estimate of the EBS and NBS biomass and standard error were used in all models presented.

Changes in the assessment methods

Two models are presented in this assessment. Model 22.1 was the accepted model in 2022 and is presented with updated data. Model 23.0 is based on Model 22.1, except that a single sex time-varying fishery selectivity was used rather than separate time-varying fishery selectivities for males and females. Further details are described below.

1. Model 22.1 was accepted by the BSAI Plan Team and the SSC in 2022. Survey biomass index data (1982-2023) and age compositions consisted of VAST estimates for the combined eastern Bering Sea and northern Bering Sea.
2. Model 23.0 is the same as Model 22.1 except a single-sex fishery selectivity was used rather than a separate fishery selectivity for males and females. Survey index data (1982-2023) and age compositions were based on VAST model-based indices for the combined eastern Bering Sea and northern Bering Sea. This is the authors' preferred model.

Summary of Results

The models presented in this assessment include interpolated survey bottom temperature within the summer bottom trawl area < 100m as a covariate on survey catchability, as well as National Marine Fisheries Service eastern Bering Sea survey start date and the interaction of start date and temperature (Nichol et al. 2019). These models also specify female natural mortality to be fixed at 0.12 while allowing the model to estimate male natural mortality. Model 23.0 builds upon Model 22.1 by collapsing time-varying fishery selectivity into a single set of parameters for males and females. All models use model-based (VAST) survey indices and age compositions from the combined EBS and NBS survey areas. Model 23.0 is the preferred model.

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2023	2024	2024	2025
M (natural mortality rate)	0.12, 0.125	0.12, 0.125	0.12, 0.137	0.12, 0.137
Tier	1a	1a	1a	1a
Projected total (age 6+) biomass (t)	3,321,640 t	4,062,230 t	2,512,810 t	2,616,800 t
Projected female spawning biomass (t)	885,444 t	897,062 t	881,640 t	857,354 t
B_0	1,407,000 t	1,407,000 t	1,516,980 t	1,516,980 t
B_{MSY}	475,199 t	475,199 t	539,657 t	539,657 t
F_{OFL}	0.122	0.122	0.121	0.121
$maxF_{ABC}$	0.114	0.114	0.106	0.106
F_{ABC}	0.114	0.114	0.106	0.106
OFL (t)	404,882 t	495,155 t	305,298 t	317,932 t
$maxABC$	378,499 t	462,890 t	265,913 t	276,917 t
ABC (t)	378,499 t	462,890 t	265,913 t	276,917 t
Status	2021	2022	2022	2023
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

Note: Projections were based on estimated catches of 79,688 t in 2023 and 121,103 t used in place of maximum ABC for 2024. This estimate was based on the mean catch over the past 5 years, 2019 - 2023, which includes the extrapolated catch of 79,688 t for 2023.

In the eastern Bering Sea (EBS) bottom trawl survey performed in 2023, the EBS yellowfin sole model-based biomass estimate was 32% lower than estimated by the 2022 EBS bottom trawl survey, at 2,007,140 t. Spawning biomass estimated by Model 23.0 was 1.63 * B_{MSY}. Therefore, yellowfin sole continues to qualify for management under Tier 1a. The 1978-2017 age-1 recruitments and the corresponding spawning biomass estimates were used to fit the stock recruitment curve and determine the Tier 1 harvest recommendations. Tier 3 estimates were also calculated, which is typical for this assessment. This assessment updates last year's model with total and spawning biomass estimates for 2023 that are lower than the 2022 estimates for 2023. This year's recommended ABC and OFL are lower than the 2022 assessment, coincident with a decrease in the 2023 survey biomass estimate.

Catch of yellowfin sole as of October 1, 2023 in the Bering Sea and Aleutian Islands was 74,848 t. Over the past 5 years (2018 - 2022), approximately 93.9% of the catch has taken place by this date. Therefore, the full year's estimate of catch in 2023 was extrapolated to be 79,688 t. This is lower than the average catch over the past ten years, 128,825 t. Future catch for the next 10 years, 2024 - 2033, was estimated to be the mean of the catch from the past five years, 2019 - 2022, and the extrapolated full year's catch for 2023, which resulted in an estimate of 121,103 t.

Yellowfin sole female spawning biomass continues to be above B_{MSY} and the annual harvest remains below the ABC level. Management quantities are given in the results summary table for the 2022 accepted model (Model 22.1 - 2022) and the 2023 preferred model (Model 23.0). The projected estimate of total biomass for 2024 was lower by 38% from the 2022 assessment of 4,062,230 t, to 2,512,810 t. The model projection of spawning biomass for 2024, assuming catch for 2023 as described above, was 881,640 t, 2% lower than the projected 2024 spawning biomass from the 2022 assessment of 897,062 t. The 2024 and 2025 ABCs using F_{ABC} from this assessment model were lower than last year's 2024 ABC of 462,890 t; 265,913 t and 276,917 t. The 2024 and 2025 OFLs estimated by Model 23.0 were 305,298 t and 317,932 t.

Two elements of the Risk Table, Population dynamics and Environmental/ecosystem components were rated as level 2, "Major concern". The other Risk Table elements were rated as level 1, "No concern". There were no recommended reductions in ABC.

Responses to SSC and Plan Team comments on Assessments in General

SSC December 2022

The SSC recommends that for future Tier 1-3 assessments some consideration be given as to how best to represent biomass estimates in the Executive Summary table for each stock (currently, model total biomass and spawning stock biomass are provided) so that the relationship of the biomass to the OFL and ABC in the stock status table is clear.

Authors' response

Within the document we include biomass estimates that are based on all age classes. However, the estimates involve an application of expected age-specific selectivity which can be variable. Therefore, ABC and OFL are calculated from age 6+ fish because the fishery does not select for ages 5 and under. This should serve as a reasonable proxy for considering ABC and OFLs in the context of exploitation rates.

SSC December 2022

For all assessments using VAST, the SSC requests a figure comparing the VAST estimate used in the previous assessment to the current assessment (if new data are added), noting that VAST will refit the time series when additional data are added, and the estimated extent and directionality of spatial correlation may change. The SSC anticipates the changes will likely be small; however, given these are new methods for many assessments, this figure would provide information on the stability of estimates.

Authors' response

This figure has been created, see Figure 4.1.

SSC December 2022

The SSC reminds authors and PTs to please bring forward and respond to SSC comments from previous assessments, particularly where updates with minimal change to the assessment have been conducted in the intervening year(s).

Authors' response

Noted.

Responses to SSC and Plan Team comments specific to this assessmemt

SSC November 2020

The SSC recommends further investigation of previously noted issues as time allows, including possible further adjustments to estimating separate natural mortality for males and females, explorations of the sex ratio relative to the timing of annual spawning migrations as an alternative explanation for a high proportion of females, a potential link between wave height and catchability, and a single selectivity curve for both sexes. We note that the latter is supported by survey selectivity estimates that are virtually indistinguishable in Model 18.2 (2020 Assessment, Fig. 4.17) and by time-varying fishery selectivities that are very similar between males and females since the early 1980s, but diverge widely and inconsistently in some earlier years (2020 Assessment, Fig. 4.18).

Author's response:

A single fishery selectivity curve was implemented in Model 23.0 in response to this comment. We plan to explore natural mortality estimates in the 2024 assessment.

Introduction

Yellowfin sole (*Limanda aspera*) are one of the most abundant flatfish species in the eastern Bering Sea (EBS) and currently is the target of the largest flatfish fishery in the world. Yellowfin sole are distributed in North American waters from off British Columbia, Canada, (approx. lat. 49°N) to the Chukchi Sea (approx. lat.

70°N) and south along the Asian coast off the South Korean coast in the Sea of Japan (approximately lat. 35°N). Their abundance in the Aleutian Islands region is considered low to negligible.

Adults exhibit a benthic lifestyle and occupy separate spawning areas in winter and feeding distributions in summer on the eastern Bering Sea shelf, Wakabayashi 1989). Adults begin a migration from over-wintering grounds near the shelf margins (>100 m) onto the inner shelf (15-75 m) in April or early May each year for spawning and feeding. Adults migrate back offshore in fall and winter as a response to ice cover/cold water of the inner and central shelf water in winter (Bakkala 1979). Young yellowfin sole remain in the shallow nearshore nursery areas throughout their first few years of life. They begin to disperse offshore age 3-5, and by 5-8 years they follow adult migratory patterns (Bakkala 1979).

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

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

There appear to be several distinct stocks, although the genetic basis remains to be determined. The stocks are referred to as the Unimak group, the Pribilof-west group, and the Pribilof-east group (Figure 4.2). Yellowfin sole are managed as a single stock in the BSAI management area as there is presently no direct evidence of stock structure.

Fishery

Yellowfin sole has been targeted with bottom trawls on the Bering Sea shelf since the fishery began in 1954. It was overexploited by foreign fisheries in 1959 - 1962 when catches averaged 404,000 t annually (Figure 4.3, top panel). Catch is typically taken throughout the Bering Sea shelf, as far north as 65°N and low to negligible amounts are taken in the Aleutian Islands (Figure 4.4). Catches declined to an annual average of 117,800 t from 1963 - 1971 and further declined to an annual average of 50,700 t from 1972 - 1977. The lower yield in this latter period was partially due to the discontinuation of the Union of Soviet Socialist Republics (U.S.S.R.) fishery. In the early 1980s, after the stock condition had improved, catches again increased reaching a peak of over 227,000 t in 1985.

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

The management of the yellowfin sole fishery changed significantly in 2008 with the implementation of Amendment 80 to the BSAI Fisheries Management Plan. The Amendment directly allocated fishery resources among BSAI trawl harvesters in consideration of their historic harvest patterns and future harvest needs to improve retention and utilization of fishery resources by the non-AFA (American Fisheries Act) trawl catcher/processor fleet. This was accomplished by extending the groundfish retention standards to all H&G (headed and gutted, fish are processed with heads and viscera removed) vessels and also by providing the ability to form cooperatives within the newly formed Amendment 80 sector. In addition, Amendment 80 also mandated additional monitoring requirements which included observer coverage on all hauls, motion-compensating scales for weighing samples, flow scales to obtain accurate catch weight estimates for the entire catch, no mixing of hauls and no on-deck sorting. The partitioning of TAC (total allowable catch) and PSC (prohibited species catch) among cooperatives has significantly changed the way the annual catch has accumulated (Figure 4.3, lower panel) and the rate of target catch per bycatch ton. There is now a more even and slow attainment of the annual catch relative to the pre-Amendment 80 fishing behavior.

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

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

Yellowfin sole are typically headed and gutted, frozen at sea, and then shipped primarily to China and South Korea. Reprocessed yellowfin sole from China may also be sold to Japan, US, and Europe as fillets, among other countries (AFSC 2016). The 1997 catch of 182,814 t (retained and discarded) was the largest since the fishery became completely domestic, but decreased from 1998–2010, averaging 94,004 t (Table 4.1, Table 4.2). From 2011-2014 the catch increased, averaging 155,000 t. The 2013 catch totaled approximately 182,814 t (73% of the ABC), and was the highest annual catch since 1988. Catches have declined since 2013 and the average catch over the past ten years was 128,825 t. The full year's estimate of catch in 2023 was 79,684 t. This estimate was based on catch data downloaded October 20, 2023, and projected forward through the remainder of the year.

As of late October 2023, the fishing season is ongoing. To estimate the total 2023 catch for the stock assessment model, the average proportion of the 2018-2022 cumulative catch attained by the end of October was applied to the 2023 catch amount at the same time period and resulted in a 2023 catch estimate of 79,684 t, 17.21% of the 2022 ABC.

Length distributions of yellowfin sole throughout NMFS areas 509, 513, 514, 516, 521, and 524 ranged from 20-50 cm, and were largest in the northern areas 514, 521, and 524 (Figure 4.5).

Data

The data used in this assessment include estimates of total catch, bottom trawl survey biomass estimates and their 95% confidence intervals, catch-at-age from the fishery, eastern Bering Sea survey bottom temperatures <100 m, and population age composition estimates from the bottom trawl survey. Weight-at-age and proportion mature-at-age from studies conducted during the bottom trawl surveys were also used. Estimates of fishery weight-at-age were based on catch-at-age methodology used in the walleye pollock assessment (Ianelli et al. 2019), following Kimura (1989) and modified by Dorn (1992).

Data source	Year
Fishery catch	1954 - 2023
Fishery age composition	1964 - 2022
Fishery weight-at-age	Catch-at-age methodology
Survey biomass and standard error	1982 - 2023 (not 2020)
Bottom temperature	1982 - 2023
Survey age composition	1979 - 2022 (not 2020)
Annual length-at-age and weight-at-age from surveys	1979 - 2022 (not 2020)
Age at maturity	Combined 1992 and 2012 samples

Fishery

Age Determination

Yellowfin sole ages have been determined at the AFSC by using the break and burn method on otoliths collected in surveys and from fisheries since 1979. In 2016 the age determination methods for yellowfin sole were validated using the bomb-produced uptake measurement of 14C method (Kastelle et al. 2016). There have been an average of 721 fish aged on EBS trawl surveys since 1982 and 735 fish aged from fishery collections during that time period (Table 4.3). The number of hauls which from which otoliths have been taken from the survey has averaged 44 per year (Table 4.3).

Trends for males and female ages from the fishery indicate that the 2010 year class has been the dominant cohort and the 2015 age class may be entering the fishery as a new dominant cohort at age 7 (Figure 4.6). Survey age data shows a different trend, likely due to higher survey selectivity at younger ages. Survey age data indicates an extremely strong 2017 year class that has appeared as 5 year olds in the survey (Figure 4.7).

Catch

This assessment uses fishery catch data from 1954-2023 (Table 4.1), and fishery catch-at-age (proportions) from 1964-2022 (Table 4.4). Removals from sources other than those that are included in the Alaska Region's official estimate of catch including removals due to scientific surveys, subsistence fishing, recreational fishing, fisheries managed under other FMPs are tabulated and presented in Table 4.5. Catch per unit effort calculated from fishery trawl data, based on the catch in kg and duration of the tow, does not indicate a strong upward or downward trend through the time series, 1996 - 2023 for vessels >125 feet (Figure 4.8), although 2022 showed an increase, and 2023 appeared back to a relative mean value. Vessels <125 feet appear to have increased CPUE through time. The CPUE shows a negative correlation with bottom temperature, with increased CPUE in 2022, which was a cooler/average year in the Bering Sea. This relationship does not appear to be strong in all years, including 2023, in which temperature was average but CPUE was down.

Bycatch of yellowfin sole takes place primarily in the directed rock sole fishery, followed by the flathead sole fishery, and smaller amounts in the pollock fisheries (Table 4.6).

Numbers at age

The proportion of length at age from the fishery was applied to the length frequencies from the aged sample from the fishery, providing fishery proportions at age. The fishery age composition has always been primarily composed of fish older than 9 years with a large amount of 20+ fish, although the proportion has declined from 90% over age 7 to 70% over age 7 since the 1970's (Table 4.4). The most recent two years (2021 and 2023) show the lowest proportions over age 7 (68%).

Weight-at-age

The fishery weight-at-age composition was based on the catch-at-age methodology of Kimura (1989) and modified by Dorn (1992), as implemented in the 2019 walleye pollock stock assessment (Ianelli et al. 2019). Length-stratified age data were used to construct age-length keys for each stratum and sex. These keys are then applied to randomly sampled catch length frequency data. The stratum-specific age composition estimates were then weighted by the catch within each stratum to arrive at an overall age composition for each year. The three strata were the EBS trimesters of the year (January-April, May-August, and September-December). This method was used to derive the age compositions from 1991–2022 (the period for which all the necessary information was readily available). The catch-at-age estimation method uses a two-stage bootstrap resampling of the data with 1,000 bootstraps. Observed tows were first selected with replacement, followed by resampling actual lengths and age specimens given that set of tows. This method allows an objective way to specify the effective sample size for fitting fishery age composition data within the assessment model. Estimates of stratum-specific fishery mean weights-at-age are a product of this analysis and these were used as input data to the model (Figure 4.9).

Maturity-at-age

Nichol (1995) estimated the age of 50% maturity at 10.5 years based on the histological examination of 639 ovaries collected from yellowfin sole females during the 1992 and 1993 eastern Bering Sea trawl surveys (Table

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

A new study was published in 2022 which provided a new analysis of the maturity-at-age schedule of 209 yellowfin sole samples taken from the northern Bering Sea (TenBrink 2022). The maturity curve resulting from this study was very similar to that of previous studies ($A_{50\%}$ 95% confidence interval: 9.47–10.76 years). This maturity curve was not incorporated into the 2023 assessment because samples were taken from the northern Bering Sea only, but this information may be incorporated into a future assessment model.

Survey

Eastern Bering Sea bottom temperature

The eastern Bering Sea bottom temperatures <100 m were computed within the R package coldpool (https://github.com/afsc-gap-products/coldpool; Rohan et al., in review). Temperatures in 2023 were lower than in 2022 and close to the mean for the time series (Figure 4.8).

Length and Weight-at-Age

Sex-specific size at age used in the model is based on the average length-at-age and weight-at-length relationships from the time-series of survey observations over all years since 1971. The survey age data from 2021 and 2022 indicate that the dominant age classes in 2021 and 2022 were 5 and 6 year olds spawned in 2017 (Figure 4.7). This appears to be a significant age class that may result in an increase in population biomass as it grows over time.

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

Survey Biomass Estimates and Population Age Composition Estimates

Indices of relative abundance available from AFSC surveys showed high NMFS surveys biomass estimates in the 1980s (Table 4.8. High levels of biomass in the late 1970s have been documented through Japanese commercial pair trawl data and catch-at-age modeling in past assessments (Bakkala and Wilderbuer 1990). Average survey CPUE for yellowfin sole has fluctuated from approximately 30-60 $kg/hectare$ over the eastern Bering Sea time survey from 1982-2023 (Figure 4.10). The CPUE for 2023 was the second lowest in the time series, at 27kg/hectare. The lowest occurred in 1999, 25 kg/hectare, which corresponded to the lowest survey biomass estimate for yellowfin sole in the eastern Bering Sea.

Biomass estimates for yellowfin sole from the annual bottom trawl survey on the eastern Bering Sea shelf showed a doubling of survey biomass between 1975 and 1979 with a further increase to over 3.3 million t in 1981 (Table 4.9 and Figure 4.11). Total survey abundance estimates fluctuated from 1983 to 1990 with biomass ranging from as high as 3.5 million t in 1983 to as low as 1.9 million t in 1986. Biomass estimates since 1990 indicate an even trend at high levels of abundance for yellowfin sole, with the exception of the results from the 1999 and 2000 summer surveys, which were at lower levels. Surveys from 2001-2005 estimated an increase each year but the estimates since 2006 indicate a stable level with some annual variability. However, the 2012 estimate is a 19% decrease from 2011 and the 2013 and 2014 surveys have estimated a 17% increase over 2012. Similarly, there was a 24% decrease from 2014 to 2015 followed by a 48% increase from 2015 to 2016, the highest biomass estimate since 1984. Fluctuations of the magnitude shown between 1980 and 1990, 1998 and 1999, 2008 and 2009, 2011 and 2012, 2014 and 2015, and 2015 and 2016 are unreasonable considering the elements of slow growth and long life span of yellowfin sole combined with low to moderate exploitation rate, characteristics which should produce more gradual changes in abundance (Table 4.8).

The 2023 EBS trawl survey estimate for yellowfin sole biomass was the second lowest from the entire time series, and a declining pattern has been observed since 2016 (Table 4.8, Figure 4.11), in addition to a longer term declining pattern since 2005. Similarly, in the northern Bering Sea, Yellowfin sole biomass estimates were the lowest in the time series in 2023 at 2,023 t (Table 4.10).

The center of gravity for yellowfin sole moved west in the late 2010s before moving eastward during the past few years, while the northward trend in the center of gravity as continued since about 2014 and seems to have plateaued in 2023 (Figure 4.12). The VAST analysis indicates that the total effective area occupied by yellowfin sole has decreased since a peak in 2018. The effective area occupied in the eastern Bering Sea has been declining since 2018 and the area occupied in the northern Bering Sea has been on a slowly increasing trend over most of the time series since 2000 (Figure 4.13).

Variability of yellowfin sole survey biomass estimates (Figure 4.11) is in part due to the availability of yellowfin sole to the survey area (Nichol 1998, Nichol et al. 2019). Yellowfin sole are known to undergo annual migrations from wintering areas off the shelf-slope break to near shore waters where they spawn throughout the spring and summer months (Nichol 1995; Wakabayashi 1989; Wilderbuer et al. 1992). Exploratory survey sampling in coastal waters of the eastern Bering Sea during early summer indicate that yellowfin sole concentrations can be greater in these shallower areas not covered by the standard AFSC survey than in the survey proper. Commercial bottom trawlers have commonly found high concentrations of yellowfin sole in areas such as near Togiak Bay (Low and Narita 1990) and in more recent years from Kuskokwim Bay to just south of Nunivak Island. The coastal areas are sufficiently large enough to offer a substantial refuge for yellowfin sole from the current survey.

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. In a previous assessment, 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 (Wilderbuer and Nichol 2003).

Survey biomass estimates for yellowfin sole have shown a positive correlation with shelf bottom temperatures (Nichol, 2019); 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 4.14), and the 2016 estimate of biomass was the highest in 32 years and 48% higher than the 2015 estimate. In the current year, 2023, survey biomass estimates were down for the NBS and the EBS (Table 4.8, Table 4.10).

We propose several possible reasons why survey biomass estimates are often lower during years when bottom temperatures are low. First, catchability may be lower because yellowfin sole may be less active when cold. Less active fish may be less susceptible to herding and more likely to escape under the foot rope of survey gear. Secondly, bottom temperatures may influence the timing of the inshore spawning migrations of yellowfin sole and therefore affect their availability to the survey area (Nichol et al. 2019). Because yellowfin sole spawning grounds include nearshore areas outside the survey area, availability of fish within the survey area can vary with the timing of this migration and the timing of the survey. In the case of 2016, a very warm year in the Bering Sea, it appears that a higher portion of the adult biomass was distributed on the shelf (outside of the spawning areas) relative to the average of all previous survey years, indicating earlier spawning migration. Third, yellowfin sole growth appears to be correlated with temperature, as can be seen with greater length anomalies of 5 year old males in females in warm years and smaller lengths in cold years

(Figure 4.14). Increased biomass estimates in 2022 could be a result of favorable conditions for yellowfin sole for the past several years, as well as temperatures that were lower than in 2021 but still slightly above the long-term mean.

Yellowfin sole population numbers-at-age are estimated based on otolith collections from annual EBS bottom trawl surveys Table 4.11. The occurrence of yellowfin sole in trawl survey hauls and associated collections of lengths and age structures since 1982 have not changed significantly (Table 4.3). The number of hauls from which age structures have been collected increased in 2021 when otolith collections changed from stratified to randome. The total tonnage caught in the resource assessment surveys since 1982 is listed in Table 4.5.

Northern Bering Sea survey

Trawl survey sampling was extended to the northern Bering Sea in 2010, 2017, 2018, 2019, 2021, 2022, and 2023. The trawl surveys conducted in 2010, 2017, 2019, 2021, 2022, and 2023 occupied the same areas with similar sampling densities. The 2018 survey was a reduced effort and only sampled a subset of the northern Bering Sea. Stations in 2018 were 30 nautical miles apart (instead of 20 nm) and excluded Norton Sound and inshore areas north of Nunivak Island. For comparison among years, 2018 biomass estimates were derived by truncating the areal coverage of the 2010 and 2017 surveys to include only the area covered in 2018 that was common to all three surveys, and this was treated as a single stratum. 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, as described above, but it decreased from 2022 to 2023. Large shifts in the abundance of yellowfin sole into the Bering Sea have not been observed, but the center jdistribution of yellowfin sole appears to be slowly shifting northward. The spatial distribution of the yellowfin sole stock in the eastern and northern Bering Sea appears continuous, and the survey data from the region occupied by the entire population was included in the 2022 accepted model 22.1 and the 2023 models 22.1 and 23.0.

A time series based on an ADF&G survey in Norton Sound confirmed that the biomass of yellowfin sole has generally increased since 1980. The mean CPUE/km^2 of yellowfin sole in Norton Sound increased from a mean CPUE of 201 over the first five survey years (1976, 1979, 1982, 1985, and 1988) to a mean CPUE of 411 over the last five survey years (2017, 2018, 2019, 2020, and 2021) (Figure 4.15). There was no Norton Sound survey in 2022 and the 2023 data is not yet available.

VAST abundance

The software versions of dependent programs used to generate model-based estimates were equivalent or later than these minimum standards: R (4.0.2), MKL libraries via Microsoft R Open (4.0.2), INLA (21.11.22), Matrix (1.4-0), TMB (1.7.22), VAST (3.9.0), cpp VAST_v13_1_0, FishStatsUtils (2.10.0), DHARMa (0.4.5).

For model-based indices in the Bering Sea, we fitted observations of biomass per unit area from all grid cells and corner stations in the 83-112 bottom trawl survey of the EBS, 1982-2023, including exploratory northern extension samples in 2001, 2005, 2006, as well as 83-112 samples available in the NBS in 1982, 1985, 1991, 2010, 2017-2019, and 2021-2023 surveys. Assimilating these data therefore required extrapolating into unsampled areas. This extrapolation was facilitated by including a spatially varying response (Thorson 2019a) to the mean bottom temperature for EBS shelf strata with bottom depth <100 m (excluding northwest strata 82 and 90) from an interpolated temperature product computed using the *coldpool* R package (Rohan et al. 2023). This spatially varying response was estimated for both linear predictors of the delta-model, and detailed comparison of results for EBS pollock has shown that it has a small but notable effect on these indices and resulting stock assessment outputs (O'Leary et al. 2020). All models were fitted in the *VAST* R package (Thorson and Barnett 2017; Thorson 2019b).

We used a Poisson-link delta-model (Thorson 2018) involving two linear predictors, and a gamma distribution to model positive catch rates. We extrapolated population density to the entire EBS and NBS in each year, using AFSC GAP-vetted extrapolation grids within FishStatsUtils. These extrapolation grids are defined using 3705 m (2 nmi) × 3705 m (2 nmi) cells; this results in 36,690 extrapolation-grid cells for the eastern Bering Sea and 15,079 in the northern Bering Sea. We used bilinear interpolation to interpolate densities from 750 "knots" to these extrapolation grid cells; knots were approximately evenly distributed over space, in proportion to the dimensions of the extrapolation grid. We estimated geometric anisotropy (how spatial autocorrelation declines with differing rates over distance in some cardinal directions than others) and included a spatial and spatio-temporal term for both linear predictors. To facilitate interpolation of density between unsampled years, we specified that the spatio-temporal fields were structured over time as initially as an AR(1) process (where the magnitude of autocorrelation was estimated as a fixed effect for each linear predictor). However, during initial model runs, the AR(1) correlation parameter rho was estimated to be close to 1 for the first linear predictor. As a result, the model was collapsed into a simpler structure by specifying rho = 1, i.e., modeling spatiotemporal variation as a random walk, for both linear predictors. We do not include any temporal correlation for intercepts, which we treated as fixed effects for each linear predictor and year. Finally, we used epsilon bias-correction to correct for retransformation bias (Thorson and Kristensen 2016).

We checked model fits for convergence by confirming that (1) the derivative of the marginal likelihood with respect to each fixed effect was sufficiently small (less than ~ 0.001) and (2) that the Hessian matrix was positive definite. We then checked for evidence of model fit by computing Dunn-Smyth randomized quantile residuals (Dunn and Smyth 1996) and visualizing these using a quantile-quantile plot within the *DHARMa* R package. We also evaluated the distribution of these residuals over space in each year, and inspected them for evidence of residual spatio-temporal patterns.

VAST estimates of age compositions

For model-based estimation of age compositions in the Bering Sea, observations of numerical abundance-at-age were fitted at each sampling location. This was made possible by applying a year-specific, region-specific (EBS and NBS) age-length key to records of numerical abundance and length-composition. These estimates were computed in VAST, assuming a Poisson-link delta-model (Thorson 2018) involving two linear predictors, and a gamma distribution to model positive catch rates. Density covariates were not computed in estimation of age composition for consistency with models used in the previous assessment and due to computational limitations. The same extrapolation grid was used as implemented for abundance indices, but here spatial and spatiotemporal fields were modeled with a mesh with coarser spatial resolution than the index model, using 50 knots. This reduction in the spatial resolution of the model, relative to that used abundance indices, was necessary due to the increased computational load of fitting multiple age categories and using epsilon bias-correction. The same diagnostics were implemented to check convergence and model fit as those used for abundance indices.

Data weighting

Model-based and VAST survey age composition data were weighted using the methodology of Francis (2011). Specifically, survey age composition data in Models 22.1 and 23.0 was initially weighted based on the number of hauls from which otoliths were collected. Stage 2 weighting was performed using Equation TA1.8 of Francis (2011) for two iterations. The mean survey age composition weights were used to weight fishery age composition data, as a constant annual value.

Analytic Approach

General Model Structure

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

The model includes ages one through 20+. In the 20+ group, fish older than twenty are allowed to accumulate into an age category that includes fish of age twenty and older (20+). Since the sex-specific weight-at-age for yellowfin sole diverges after age of maturity (about age 10 for 40% of the stock), with females growing larger than males, the current assessment model is coded to accommodate the sex-specific aspects of the population dynamics of yellowfin sole. The model allows for the input of sex-specific estimates of fishery and survey age composition and weight-at-age and provides sex-specific estimates of population numbers, fishing mortality, 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 AD Model Builder software fits the data components using automatic differentiation (Griewank 2000) software developed as a set of libraries (AUTODIFF C++ library). 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.

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

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

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

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

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

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

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

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

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

Recruitment from 1956-1977 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 1978-2023 was determined using the Ricker stock recruitment curve,

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

where S is the spawning stock biomass (Ricker 1958). Parameters α and β were estimated by fitting spawning biomass and recruitment during the period 1978-2017, and are shown from Model 22.1 (Figure 4.16) and Model 23.0 (Figure 4.17).

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

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

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

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

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

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

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

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

Description of Alternative Models

In this assessment we considered Model 22.1 used in the 2022 assessment updated with 2023 data. This model used a fixed value for female natural mortality (M=0.12) and allowed male natural mortality to be estimated within the model. Model 22.1 also used a single value of survey selectivity for males and females. Model 23.0 was similar to Model 22.1 except it used a single annual value of time-varying fishery selectivity for males and females. All models used model-based VAST estimates of biomass from the eastern Bering Sea plus northern Bering Sea survey area, rather than standard design-based estimates of biomass.

Parameters Estimated Outside the Assessment Model

Weight at age

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

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

A sex-specific length-weight relationship was also calculated from the survey database using the power function, $Weight(g) = a * Length(cm)^b$, where a and b are parameters estimated to provide the best fit to the data.

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

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

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

The mean weight at age from 2022 was used as an estimate for weight at age in 2023, as the 2023 ages have not yet been processed. The most recent data was used for 2023 in consideration of the increase in average size at age (Figure 4.18, Table 4.12,Table 4.13).

Natural mortality

Natural mortality (M) was initially estimated by a least squares analysis where catch at age data were fitted to Japanese pair trawl effort data while varying the catchability coefficient (q) and M simultaneously. The best fit to the data (the point where the residual variance was minimized) occurred at a value of M=0.12 (Bakkala and Wespestad 1984). This was also the value which provided the best fit to the observable population characteristics when M was profiled over a range of values in the stock assessment model using data up to 1992. Since then, natural mortality has been estimated as a free parameter in some of the stock assessment model runs which have been evaluated the past five years. A fixed female natural mortality at M=0.12 and male natural mortality estimated by the model is used in Models 22.1 and 23.0.

Maturity

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

Parameter Estimates

A list of selected parameters estimated inside the model are shown for Model 22.1 in Table 4.14, and for Model 23.0 in Table 4.15.

Parameters Estimated Inside the Assessment Model

There were 524 parameters estimated by Model 22.1, and 382 estimated by Model 23.0. Model 22.1 from 2022 had 518 parameters. The number of key parameters are presented below:

Fishing mortality	Selectivity	Survey catchability	Year-class strength	Spawner-recruit	M	Total
70	330 (182)	4	117	2	1	524 (382)

The increase in the number of parameters estimated in this assessment compared to last year (6) can be accounted for by the input of another year of fishery data and the entry of another year-class into the observed population and four more sex-specific fishery selectivity parameters. Model 23.0 has only 382 estimated parameters, due to the removal of separate male time varying fishery selectivity parameters (2 parameters per year for 70 years). 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

Survey selectivity in all models was combined over males and females. Fishery selectivity was time-varying for all models. However, time-varying fishery selectivity was modeled separately for males and females in Model 22.1 and combined in Model 23.0. The selectivity pattern was asymptotic increasing logistic for the fishery and survey. The oldest year-classes in the surveys and fisheries were truncated at 20 and allowed to accumulate into the 20+ age category. For Models 22.1 and 23.0, a single selectivity curve, for both males and females, was fit for all years of survey data (Figure 4.19). Time-varying fishing selectivity curves were estimated because there have been annual changes in management, vessel participation and possibly gear selectivity (Figure 4.20, Figure 4.21). A logistic equation was used to model fishery selectivity and is a function of time-varying parameters specifying the age and slope at 50% selection, φ_t and η_t, respectively. The fishing selectivity (S^f) for age a and year t is modeled as,

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

where φ_t and η_t are time-varying and partitioned (for estimation) into parameters representing the mean and a vector of deviations (log-scale) conditioned to sum to zero. The deviations are constrained by a lognormal prior with a variance that was iteratively estimated. The process of iterating was to first set the variance to a high value to estimate the deviations. The next step was to compare the variability of model estimates. The variance of the model estimates was then rounded up slightly and fixed for subsequent runs. The 2023 values were fixed as the average of the 3 most recent years.

Fishing Mortality

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

Survey Catchability

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

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

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

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

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

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

Spawner-Recruit Estimation

Annual recruitment estimates from 1978-2017 were constrained to fit a Ricker (1958) form of the stock recruitment relationship as follows:

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

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

Results

Model Evaluation

For this assessment, Model 22.1 and Model 23.0 are presented. Model 22.1 was the accepted model in the 2022 yellowfin sole stock assessment, and Model 23.0 is the preferred model for 2023.

Model 22.1 estimated male natural mortality 0.136254 to be higher than female natural mortality 0.12, which is in common with known life history parameters of other Alaska flatfish. Models 23.0 also estimated higher male than female natural mortality, 0.137. In Arrowtooth Flounder, higher natural mortality is assumed for males and is consistent with their skewed sex ratio (Wilderbuer and Turnock 2009). Higher natural mortality for male flatfish has been assumed for flatfish from other regions as well (Maunder and Wong 2011). Higher natural mortality indicates greater productivity of a stock and therefore higher management quantities.

Overall, Models 22.1 and 23.0 provided very similar results. Models 22.1 and 23.0 used the same input data (EBS and NBS VAST survey estimates of biomass index). The Akaike Information Criterion was calculated from the hessian and objective function value OFV of the ADMB output .par file to compare models 22.1 and 23.0. The hessian $Hess$ was transformed back into the original parameter space and the marginal likelihood $Likelihood_{MAR}$ was estimated as:

$$Likelihood_{MAR} = -0.5 * Hess_T - OFV, \tag{5}$$

The marginal likelihood was then used to calculate AIC, as follows:

$$AIC = 2 * k - 2 * Likelihood_{MAR}, \tag{6}$$

where k is the number of parameters used in the model. The AIC for Model 23.0 was lower (AIC = 2670.419) than for Model 22.1 (AIC = 3345.167), indicating that Model 23.0 is a more parsimonious and better-fit model.

In other respects, Models 23.0 and 22.1 appeared to fit the data almost identically. The survey selectivity was similar (Figure 4.19), survey catchability was similar (Figure 4.22), sex ratio appeared similar (Figure 4.23), predicted survey biomass was similar (Figure 4.24), as were total biomass, numbers at age, and spawning stock biomass (Figure 4.25,Figure 4.26, and Figure 4.27). Therefore, Model 23.0 was considered a better fit to the data, with fewer parameters.

Models 22.1 (2023) and 23.0 (Figure 4.22) indicate a shift towards higher survey catchability, than Model 22.1, corresponding with lower bottom temperatures than in 2022 (Figure 4.14). The proportion female was estimated to be closer to 50% in Model 22.1 (2022) than Model 23.0 and 22.1, which have slightly higher proportion of females (Figure 4.23). In addition, the anomalous spike in the proportion female in the 1960s is reduced for Model 22.1 (2023). Notably, Model 23.0 indicates the most stable sex ratio composition during the 1960 biomass decline.

Models 22.1 and 23.0 similarly provided a good fit the survey age compositions (Figure 4.28, Figure 4.29), as well as the fishery age compositions (Figure 4.30, Figure 4.31). Models 22.1 and 23.0 fit survey biomass similarly (Figure 4.11).

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 1977-2017 spawner-recruit data in the model. The resulting stock recruitment curve shows average recruitment for the years 2016-2021 except 2017 and 2019 which are above average, based on Model 22.1 (Figure 4.16), and Model 23.0 (Figure 4.17).

Model 23.0 is the preferred model for estimating the yellowfin sole stock size and management quantities for the 2024 fishing season because it provides the best fit to the data, lowest AIC, and the most parsimonious set of parameter estimates. Comparison between Models 22.1 and 23.0 show that a single fishery selectivity provides a better model fit. A summary table for Model 22.1 shows that reference points and management quantities are very similar to Model 23.0 (Table 4.16)

Time Series Results

The data was updated in 2023 to include current values of catch, survey biomass estimates, and fishery and survey age compositions from 2022. The latest year of fishery weight-at-age data was included. The eight past years in the Bering Sea have had bottom temperature anomalies above the mean, to varying degree, but 2022 and 2023 have been near-average. The temperature-dependent q adjustment for 2023 was 1.07 for Model 22.1, 1.06 for Model 23.0.

Fishing Mortality and Selectivity

The full-selection fishing mortality, F, has averaged 0.0714 over the 5 years, 2019 -2023 (Table 4.17). Model estimated selectivities, Figure 4.19 and Figure 4.20 indicate that yellowfin sole are 50% selected by the fishery at about age 9 and nearly fully selected by age 13, with annual variability. Based on results from the stock assessment model, annual average exploitation rates of yellowfin sole since 1977 ranged from 3% to 7% of the total biomass, and have averaged approximately 4%.

Abundance Trends

Model 22.1 estimated catchability q at an average value of 1.1 for the period 1982-2023 which resulted in a model estimate of the 2023 age 2+ total biomass at 2.687 million t (Table 4.9). In comparison, catchability was similar and only slightly lower for Model 23.0, which was estimated at 1.11, which resulted in a 2+ total biomass estimate of 2.716 million t. Model results indicate that yellowfin sole total biomass (age 2+) was at low levels during most of the 1960s and early 1970s (700,000-1,000,000 t) after a period of high exploitation (Table 4.9, Figure 4.26). Sustained above average recruitment from 1967-1976 combined with light exploitation resulted in a biomass increase to a peak of approximately 3.6 million t by 1985. The population biomass has since been in a slow decline as the strong 1981 and 1983 year-classes have passed through the population, with only the 1991, 1995 and 2003 year-classes at levels observed during the 1970s. The current model indicates that the population is increasing and predicts that it will continue to increase through 2024. The present biomass is estimated at 76% of the peak 1985 level. The female spawning biomass has also declined since the peak in 1994, with a 2023 estimate of 916,707 t (Table 4.18).

Allowing q to be correlated with annual bottom temperature and survey start date provides a better fit to the bottom trawl survey estimates than using a q fixed at the average value (Fig. 4.18, Wilderbuer et al. 2018). Both the trawl survey and the stock assessment model indicate that the yellowfin sole resource (total biomass) increased during the 1970s and early 1980s to a peak level during the mid-1980s. The yellowfin sole population biomass slowly decreased over the 23 years since the mid-1990s as the majority of year-classes during those years were below average strength. Average to above average recruitment from 2006 to 2009 is expected to maintain the abundance of yellowfin sole at a level above B_{MSY} in the near future. The stock assessment projection model indicates a generally stable trend in female spawning biomass through 2036 if the fishing mortality rate continues at the same level as the average of the past 5 years (Figure 4.32).

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 1967-1976 (Figure 4.33). The 1981 year-class was the strongest observed (and estimated) during the time series, followed by the 1983 year-class. Survey age composition estimates and the assessment model also estimate that the 1987 and 1988 year-classes were average and the 1986 and 1988 year-classes were above average. Recruitment since 1990 has been below the long-term average in most years, and the 2016, 2017, and 2018 year-classes appeared to be one of the lowest on record (Figure 4.33). Recruitment for years subsequent to 2017 may be less reliable given the fit to the stock recruitment curve and lack of survey data to confirm recruitment estimates. Given the large proportion of new recruits from the 2017 year class that are apparent in survey age composition data, it is probable that future assessments will indicate higher recruitment in 2017.

Retrospective Analysis

A within-model retrospective analysis was included for the recommended assessment model (Model 23.0), as well as Model 22.1. In this analysis, retrospective female spawning biomass was calculated by sequentially dropping data one year at a time and then comparing the peeled estimate to the reference stock assessment model used in the assessment (Figure 4.34 and Figure 4.35). Mohn's rho for Model 22.1 was 0.06, and for Model 22.1 it was 0.005. Mohn's rho for Model 22.1 (2022) was 0.007. The directionality of the retrospective peels can provide insight into the retrospective pattern. For Model 22.1 and 23.0 the first four retrospective peels were positively different from the terminal year, but the remaining peels resulted in an upward shift of the entire time series (Figure 4.36 and Figure 4.37), indicating that information in the 3-4 terminal years result in a downward shift of the time series. However, the Mohn's rho values presented here are within the range of acceptable values and do not indicate any significant retrospective issues in either Model 23.0 or Model 22.1. The Mohn's rho does not exceed the rule of thumb guideline for long-lived stocks proposed by Hurtado-Ferro at al. (2015), which includes flatfish, that values of Mohn's rho higher than 0.20 or lower than -0.15 may be an indication of a retrospective pattern.

Risk Table

Assessment related considerations

The BSAI yellowfin sole assessment is based on surveys conducted annually on the EBS shelf from 1982-2023, continually except for 2020 due to the COVID-19 pandemic. Fish ages, derived from otoliths collected during the surveys and the fishery to calculate annual estimates of population and fishery age composition, have been validated. Survey age composition data is used in the assessment from 1982-2022. 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 and Mohn's rho value, 0.06, indicate that there are no significant time varying trends that are not accounted for by the model (Figure 4.34 and Figure 4.35).

We propose a level 1 designation for the assessment category in the risk table.

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 1967-1976 combined with light exploitation resulted in a biomass increase to a peak in 1985. The population biomass has since been in a slow decline over the time series since a peak in the mid-1980s. Only the 1991, 1995 and 2003 year-classes have achieved levels observed during the 1970s. The

2022 EBS survey biomass estimate for yellowfin sole was an increase from the previous year, and the 2023 survey estimate is the second lowest in the time series since 1982. The current model for 2023 estimates B_{MSY} at 539,657 t. Projections indicate that the FSB will remain above the B_{MSY} level through 2037. The large 2017 year class will be age 7 in 2024 and will become selected by the fishery as it grows. This is predicted to result in higher population size estimates for the yellowfin sole stock.

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

Environmental/ecosystem considerations

Environmental processes: Over the last year, broad-scale climate indices, like the North Pacific Index, reflected a transition from La Niña conditions to developing El Niño conditions in the tropic Pacific; the impact of the developing El Niño on the EBS shelf conditions are unknown at this time. The recent warm stanza persisted from approximately 2014 through 2021, since which the Eastern Bering Sea has experienced near average oceanographic conditions. Regional sea surface and bottom temperature trends were largely at or near the long-term average in 2023. Exceptions include (i) slightly warmer than average sea surface temperature (SST) over the outer domain (southern and northern shelf) and over the southern middle domain from approximately December 2022 through April 2023 and (ii) slightly cooler than average bottom temperature over the outer domain of the southern shelf from August 2022 through August 2023. During the standard bottom trawl survey in summer 2023, bottom temperatures were slightly cooler than the time series average with the coldest bottom temperatures in the southern inner domain since 2013. Sea ice metrics, such as early ice extent (Oct. - Dec.), annual ice extent, and sea ice thickness were all near the respective time series averages.

The 2023 cold pool extent was also near its historical average (Hennon et al., 2023). Yellowfin sole (YFS) demonstrate earlier migration to spawning grounds and earlier spawning events under warmer conditions. In addition, somatic growth of YFS increases in warmer temperatures. A proposed thermal window (Yeung et al., 2021) suggests continued warming over the EBS shelf may result in temperatures above the thermal physiological maximum of YFS. Adult yellowfin sole are distributed off-shelf in winter, therefore may have experienced cooler than average bottom temperature conditions this past winter. Yellowfin sole move inshore during summer for spawning and young-of-the-year (YOY) rear in inshore habitats. Therefore, YOY may have experienced cooler hatching and rearing temperatures in 2023.

Prey: The dominant prey of adult YFS are polychaete worms, miscellaneous worms, clams, and benthic amphipods. Direct measurements of infaunal abundance trends are not available, however, abundance trends of motile epifauna that also consume infauna (i.e., indirect measurements) are quantified from the bottom trawl survey. The biomass of motile epifauna from the standard bottom trawl survey grid peaked in 2017 and remains above their long-term mean in 2023, though the guild biomass decreased from 2022 (Siddon, 2023). No direct or indirect measures of prey availability exist for the northern Bering Sea shelf. Early life stages of YFS may consume pelagic zooplankton, such as small copepods. The Rapid Zooplankton Assessment in the southeastern Bering Sea in spring noted a moderate abundance of small copepods, but low abundance and low lipid content of large copepods and euphausiids. In fall, the moderate abundance of small copepods continued, and while the abundance of large copepods and euphausiids remained low, abundances increased from south to north. In the northern Bering Sea in fall, small copepods were ubiquitous and increased in abundance from south to north, while hot spots of large copepods and euphausiids were observed around St. Lawrence Island (Kimmel et al., 2023). In 2023, adult fish condition (as measured by length-weight residuals) was above-average in the standard bottom trawl survey grid, though it decreased from 2022. It is worth noting that the condition of several flatfishes species from the standard bottom trawl survey grid declined from 2022 to 2023, including northern rock sole, arrowtooth flounder, Alaska plaice, and flathead sole. In the northern Bering Sea bottom trawl survey, fish condition was strongly negative, continuing a trend since 2019, though it is based on a shorter time series (Prohaska and Rohan, 2023). Over the southern shelf, trends in motile epifauna, as an indirect measure of prey availability, mirror trends in adult fish condition which was near average, but declined from 2022 to 2023. Over the northern shelf, no indicators of prey availability exist; declining and negative adult fish condition indicate potential concerns in prey availability.

Competitors: Competitors for YFS prey resources include other benthic foragers, like northern rock sole and flathead sole. The trend in biomass of the benthic foragers guild from the standard bottom trawl survey grid decreased from 2022 to 2023 and remained below the time series mean. Trends in benthic forager biomass indirectly indicate availability of infauna (i.e., prey of these species), suggesting competition for prey resources remains low in 2023 (Siddon, 2023).

Predators: Predators of YFS include Pacific cod and Pacific halibut, which are included in the apex predator guild. The biomass of the apex predator guild measured during the standard bottom trawl survey was nearly equal to their long term mean. The trend in the apex predator guild is largely driven by Pacific cod, which had a modest increase from 2022 (Siddon, 2023). While an increase in Pacific cod abundance may represent increased predation pressure for YFS, the spatial distribution of Pacific cod may provide a potential refuge from predation in the inner domain. The Pacific halibut stock decreased from a peak in the early 2000s and remains low in 2023, therefore represents no increase in predation pressure.

Summary for Environmental/Ecosystem considerations:

- Environment: Adult YFS may have experienced cooler than average bottom temperatures in the off-shelf region during winter 2022/2023 (based on ROMS) and YOY may have experienced cooler than average bottom temperatures in inshore spawning and rearing habitats during summer 2023 (based on BTS). Cooler temperatures may result in delayed migration to spawning grounds, delayed spawning, and decreased somatic growth.
- Prey: Sufficient prey may have been available for early life stages of YFS and for adult YFS over the southern shelf based on trends in motile epifauna and fish condition. Declining and negative adult fish condition indicate potential concerns in prey availability over the northern shelf.
- Competition: The trend in biomass of benthic foragers decreased from 2022 to 2023 and remained below the time series mean, suggesting competition for prey resources remains low in 2023.
- Predation: Predation pressure may be mixed; a modest increase in Pacific cod biomass may be countered by potential refuge from predation in the inner domain. Pacific halibut biomass continues to decline in the EBS and represents no increase in predation pressure.

Together, the most recent data available suggest an ecosystem risk Level 2 – “Multiple indicators showing consistent adverse signals a) across the same trophic level as the stock, and/or b) up or down trophic levels (i.e., predators and prey of the stock).” Multiple indicators “across the same trophic level” are present in the consistent declines in fish condition for flatfishes. In addition there are indicators down trophic levels due to prey concerns.

Fishery performance considerations

The 2023 fishery CPUE shows no concerns regarding stock biomass trend, unusual spatial pattern of fishing, changes in the percent of TAC taken, or changes in the duration of fishery openings. Catches were low for YFS in 2023, but it was an issue with the market, not the fishery itself. From January through June, the fishery had average catch rates, fish sizes, and market. However in June, demand decreased. For the fishing that has occurred in the fall of 2023, CPUE is reported to be good and the fish are high quality.

An extension to the tariff exclusion was approved in Dec. 2022 and it was set to expire Sept. 30, 2023. On Sept. 6 the exclusions were extended through the end of 2023. While this is good news, the presence of tariffs and exclusions leads to market uncertainty. It is uncertain whether tariffs will be in place January 1, 2024.

We propose a level 1 designation for the fishery performance category in the risk table.

Assessment consideration	Population dynamics	Environmental ecosystem	Fishery performance
Level 1: No concern	Level 2: Major concern	Level 2: Major concern	Level 1: No concern

We recommend no reduction in ABC based on this risk table assessment.

Harvest Recommendations

Scenario Projections and Two-Year Ahead Overfishing Level

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. The 2023 numbers at age from the stock assessment model are projected to 2024 given the 2023 estimated full year's catch, and then a 2024 catch of 128,825 t was applied to the projected 2024 population biomass to obtain the 2024 OFL.

The SSC determined in December 2006 that yellowfin sole would be managed under the Tier 1 harvest guidelines, and therefore future harvest recommendations would be based on maximum sustainable yield MSY and the associated fishing effort F_{MSY} values calculated from a spawner-recruit relationship. MSY is an equilibrium concept and its value is dependent on both the spawner-recruit estimates which are assumed to represent the equilibrium stock size-recruitment relationship and the model used to fit the estimates. In the yellowfin sole stock assessment model, a Ricker form of the stock-recruit relationship was fit to various combinations of these data and estimates of F_{MSY} and B_{MSY} were calculated, assuming that the fit to the stock-recruitment data represents the long-term productivity of the stock (details provided in Wilderbuer et al. 2018). The 2024 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 2024 biomass estimate.

The geometric mean of the 2024 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 2024 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 2024 harvest (now the 1978-2017 time-series) recommendation (Model 23.0), the $F_{ABC} = F_{Hmean} =$ 0.106. The estimate of age 6+ total biomass for 2024 is 2,512,810 t. The calculations outlined above give a Tier 1 ABC harvest recommendation of 265,913 t and an OFL of 305,298 t for 2024. This results in an 13% (39,385 t) buffer between ABC and OFL.

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

Harvest level	F value	2024 Yield
Tier 1 $F_{OFL} = F_{MSY}$	0.121	305,298 t
Tier 1 $F_{ABC} = F_{harmonicmean}$	0.106	265,913 t

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

Status Determination

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was implemented in 1977.

For each scenario, the projections begin with the vector of 2023 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2024 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2023. 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 support the alternative harvest strategies analyzed in the Alaska Groundfish Harvest Specifications Final Environmental Impact Statement. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2024, are as follows (max F_{ABC} refers to the maximum permissible value of F_{ABC} under Amendment 56):

- Scenario 1: In all future years, F is set equal to max F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)
- Scenario 2: In all future years, F is set equal to a constant fraction of max F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2023 recommended in the assessment to the max F_{ABC} for 2024. (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 2018 - 2022 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)
- Scenario 4: In all future years, F is set equal to $F_{60}\%$. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)
- Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

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

- Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is 1) above its MSY level in 2023 or 2) above 1/2 of its MSY level in 2023 and expected to be above its MSY level in 2033 under this scenario, then the stock is not overfished.)
- Scenario 7: In 2024 , F is set equal to max F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is 1) above its MSY level in 2025 or 2) above 1/2 of its MSY level in 2025 and expected to be above its MSY level in 2035 under this scenario, then the stock is not approaching an overfished condition.)

Simulation results shown in Table 4.20 indicate that yellowfin sole are not currently overfished and are not approaching an overfished condition. If fishing continues at the same fishing mortality as in the past 5 years, the stock is projected to remain well above B_{MSY} (Figure 4.32). A phase plane figure of the estimated time-series of yellowfin sole female spawning biomass (FSB) relative to the harvest control rule indicates that the stock is above B_{MSY}, has been consistently fished below F_{MSY} for decades, and that projections of female spawning biomass are expected to be above B_{MSY} for Model 22.1 (Figure 4.38). A phaseplane plot for Model 23.0 shows similar results (Figure 4.39)

The ABC and OFL based on the recommended model 23.0 for 2024 and 2025 assuming average catch rates are shown in the following table.

Year	Catch	FSB	Geom. mean 6+ biomass	ABC	OFL
2024	121,103	881,640	2,512,810	265,913	305,298
2025	121,103	857,354	2,616,800	276,917	317,932

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Tables

Table 4.1: Foreign and domestic catch (t) of yellowfin sole 1954-2023. Foreign catches are designated as joint venture processing (JVP), and non-foreign catches as domestic annual processing (DAP). Domestic catch since 1991 is subdivided into catch from the Aleutian Islands and the Bering Sea. Catch for 2023 was downloaded October 20, 2023.

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

1998	101,155	4.7	101,150	101,155
1999	69,234	12.8	69,221	69,234
2000	84,071	12.5	84,058	84,071
2001	63,579	14.5	63,564	63,579
2002	74,986	28.5	74,957	74,986
2003	79,806	0.4	79,806	79,806
2004	75,511	8.8	75,502	75,511
2005	94,385	1.8	94,383	94,385
2006	99,160	3.8	99,156	99,160
2007	120,964	2.4	120,962	120,964
2008	148,894	0.5	148,893	148,894
2009	107,513	1.1	107,512	107,513
2010	118,624	0.2	118,624	118,624
2011	151,158	1.1	151,157	151,158
2012	147,187	1.1	147,186	147,187
2013	164,944	0.3	164,944	164,944
2014	156,772	0.3	156,772	156,772
2015	126,937	0	126,937	126,937
2016	135,324	0.2	135,324	135,324
2017	132,220	0.6	132,219	132,220
2018	131,496	4.5	131,491	131,496
2019	128,051	4.6	129,061	128,051
2020	133,799	11.1	133,788	133,799
2021	108,788	53.9	108,734	108,788
2022	154,253	8.7	154,245	154,253
2023	74,848	1.2	74,847	74,848

Table 4.2: Estimates of retained and discarded (t) yellowfin sole caught in Bering Sea fisheries from 1991 through October 30th, 2023, and the proportion discarded.

Year	Retained (t)	Discarded (t)	Proportion discarded
1991	88,967	28,337	0.24
1992	102,542	42,840	0.29
1993	76,798	29,012	0.27
1994	104,918	35,132	0.25
1995	96,767	27,980	0.22
1996	101,324	28,335	0.22
1997	150,745	32,068	0.18
1998	80,263	20,887	0.21
1999	56,604	12,617	0.18
2000	69,971	14,087	0.17
2001	54,918	8,646	0.14
2002	63,625	11,332	0.15
2003	68,832	10,974	0.14
2004	62,746	12,756	0.17
2005	85,311	9,072	0.1
2006	90,592	8,564	0.09
2007	109,004	11,958	0.1
2008	141,235	7,659	0.05
2009	100,642	6,870	0.06
2010	113,244	5,379	0.05
2011	146,418	4,739	0.03
2012	142,132	5,054	0.03
2013	158,781	6,163	0.04
2014	152,167	4,605	0.03
2015	123,065	3,871	0.03
2016	131,202	4,121	0.03
2017	128,665	3,554	0.03
2018	127,331	4,160	0.03
2019	126,111	2,951	0.02
2020	131,774	2,025	0.02
2021	106,785	2,003	0.02
2022	151,493	2,760	0.02
2023	93,801	1,503	0.02

Table 4.3: Occurrence of yellowfin sole in the eastern Bering Sea trawl survey and collections of length and age structures and the number of otoliths aged from the survey. The final column represents the number of otoliths read in each year from the fishery.

Year	Total hauls	Hauls with length	Number of lengths	Hauls with otoliths	Hauls with ages	N. otoliths	N. ages (survey)	N. ages (fishery)
1982	334	246	37,023	35	35	744	744	2432
1983	353	256	33,924	37	37	709	709	1178
1984	355	271	33,894	56	56	821	796	338
1985	356	261	33,824	44	43	810	802	840
1986	354	249	30,470	34	34	739	739	1503
1987	357	224	31,241	16	16	798	798	1071
1988	373	254	27,138	14	14	543	543	1361
1989	374	236	29,672	24	24	740	740	1462
1990	371	251	30,257	28	28	792	792	1220
1991	372	248	27,986	26	26	742	742	935
1992	356	229	23,628	16	16	606	606	1203
1993	375	242	26,651	20	20	549	549	1020
1994	375	269	24,448	14	14	526	522	573
1995	376	254	22,116	20	20	654	647	554
1996	375	247	27,505	16	16	729	721	314
1997	376	262	26,034	11	11	470	466	397
1998	375	310	34,509	15	15	575	570	426
1999	373	276	28,431	31	31	777	770	487
2000	372	255	24,880	20	20	517	511	583
2001	375	251	26,558	25	25	604	593	491
2002	375	246	26,309	32	32	738	723	486
2003	376	241	27,135	37	37	699	695	590
2004	375	251	26,103	26	26	725	712	483
2005	373	251	24,658	35	35	663	653	494
2006	376	246	28,470	39	39	428	426	490
2007	376	247	24,790	66	66	779	772	496
2008	375	238	25,848	65	65	858	830	542
2009	376	235	22,018	70	70	783	751	515
2010	376	228	20,619	77	77	841	827	535
2011	376	228	21,665	65	64	784	753	525
2012	376	242	23,519	72	72	992	973	504
2013	376	232	23,261	70	70	821	803	670
2014	376	219	20,229	52	52	799	790	502
2015	376	223	20,830	73	73	878	875	622
2016	376	242	26,674	69	69	884	876	495
2017	376	258	25,767	78	78	896	886	595
2018	376	262	27,285	68	68	724	720	608
2019	376	270	25,669	67	67	836	832	589
2020								660
2021	376	234	18,757	201	200	1030	983	700
2022	376	238	16,765	195	195	619	581	635
2023	376	233	15,501	172		515		

Table 4.4: Yellowfin sole fishery catch-at-age (proportions), 1975-2022 female first then male, ages 7-17+.

Year	7	8	9	10	11	12	13	14	15	16	17+	Total female proportion over age 7
1975	0.1401	0.2759	0.2184	0.1019	0.0647	0.0309	0.0216	0.0249	0.0095	0.0081	0.0048	0.9008
1976	0.0998	0.1634	0.2574	0.1874	0.0866	0.0552	0.0265	0.0185	0.0213	0.0081	0.0070	0.9312
1977	0.1574	0.2034	0.1700	0.1620	0.0920	0.0389	0.0241	0.0115	0.0080	0.0092	0.0035	0.8800
1978	0.0876	0.1900	0.2146	0.1585	0.1408	0.0774	0.0323	0.0199	0.0095	0.0066	0.0076	0.9448
1979	0.0583	0.1414	0.2122	0.1864	0.1230	0.1050	0.0570	0.0237	0.0146	0.0069	0.0048	0.9333
1980	0.0665	0.0857	0.1546	0.1932	0.1573	0.1012	0.0858	0.0465	0.0193	0.0119	0.0056	0.9276
1981	0.0814	0.1062	0.1029	0.1488	0.1650	0.1276	0.0805	0.0677	0.0366	0.0152	0.0093	0.9412
1982	0.0591	0.1396	0.1287	0.0973	0.1239	0.1302	0.0987	0.0618	0.0518	0.0280	0.0116	0.9307
1983	0.0726	0.0895	0.1570	0.1210	0.0845	0.1044	0.1086	0.0820	0.0512	0.0430	0.0232	0.9370
1984	0.0341	0.0918	0.0975	0.1555	0.1150	0.0791	0.0972	0.1010	0.0761	0.0476	0.0399	0.9348
1985	0.0237	0.0591	0.1150	0.0988	0.1440	0.1033	0.0703	0.0862	0.0894	0.0674	0.0421	0.8993
1986	0.0390	0.0461	0.0790	0.1191	0.0916	0.1285	0.0910	0.0618	0.0756	0.0784	0.0591	0.8692
1987	0.0220	0.0556	0.0537	0.0803	0.1145	0.0865	0.1208	0.0855	0.0580	0.0709	0.0736	0.8214
1988	0.0549	0.0468	0.0855	0.0600	0.0759	0.1020	0.0757	0.1051	0.0743	0.0503	0.0616	0.7921
1989	0.0086	0.0836	0.0617	0.0936	0.0586	0.0711	0.0943	0.0697	0.0968	0.0683	0.0463	0.7526
1990	0.0414	0.0321	0.1956	0.0821	0.0857	0.0463	0.0536	0.0703	0.0518	0.0718	0.0507	0.7814
1991	0.0369	0.1420	0.0571	0.2053	0.0663	0.0634	0.0334	0.0385	0.0504	0.0372	0.0515	0.7820
1992	0.0224	0.0559	0.1863	0.0620	0.1964	0.0595	0.0554	0.0289	0.0332	0.0434	0.0319	0.7753
1993	0.0240	0.0363	0.0694	0.1906	0.0584	0.1805	0.0544	0.0506	0.0264	0.0304	0.0397	0.7607
1994	0.0243	0.0445	0.0592	0.0887	0.1981	0.0541	0.1593	0.0471	0.0435	0.0226	0.0260	0.7674
1995	0.0430	0.0783	0.0887	0.0735	0.0829	0.1648	0.0433	0.1260	0.0371	0.0343	0.0178	0.7897
1996	0.0228	0.0841	0.1139	0.0970	0.0685	0.0725	0.1409	0.0368	0.1067	0.0314	0.0290	0.8036
1997	0.0261	0.0502	0.1303	0.1261	0.0895	0.0589	0.0609	0.1176	0.0306	0.0888	0.0261	0.8051
1998	0.0346	0.0443	0.0662	0.1381	0.1198	0.0820	0.0534	0.0550	0.1061	0.0276	0.0801	0.8072
1999	0.0118	0.0458	0.0541	0.0725	0.1390	0.1159	0.0782	0.0507	0.0522	0.1007	0.0262	0.7471
2000	0.0149	0.0408	0.1208	0.0904	0.0802	0.1224	0.0932	0.0610	0.0391	0.0401	0.0774	0.7803
2001	0.0194	0.0423	0.0812	0.1577	0.0882	0.0689	0.1009	0.0759	0.0495	0.0317	0.0325	0.7482
2002	0.0243	0.0308	0.0619	0.0988	0.1621	0.0833	0.0630	0.0912	0.0683	0.0445	0.0285	0.7567
2003	0.0248	0.1134	0.0853	0.0922	0.0951	0.1285	0.0618	0.0458	0.0660	0.0494	0.0321	0.7944
2004	0.0195	0.0492	0.1672	0.0937	0.0857	0.0828	0.1095	0.0524	0.0388	0.0558	0.0417	0.7963
2005	0.0326	0.0545	0.0866	0.1931	0.0850	0.0704	0.0658	0.0862	0.0411	0.0304	0.0437	0.7894
2006	0.0549	0.0722	0.0823	0.0941	0.1754	0.0716	0.0577	0.0535	0.0698	0.0332	0.0246	0.7893
2007	0.0331	0.0876	0.0881	0.0830	0.0870	0.1573	0.0636	0.0511	0.0473	0.0617	0.0294	0.7892
2008	0.0514	0.0708	0.1241	0.0908	0.0733	0.0725	0.1284	0.0516	0.0414	0.0383	0.0499	0.7925
2009	0.0384	0.0799	0.0873	0.1266	0.0846	0.0660	0.0645	0.1139	0.0457	0.0367	0.0339	0.7775
2010	0.0695	0.0863	0.1120	0.0872	0.1085	0.0689	0.0529	0.0514	0.0907	0.0364	0.0292	0.7930
2011	0.0323	0.1183	0.1072	0.1111	0.0781	0.0938	0.0589	0.0450	0.0437	0.0771	0.0309	0.7964
2012	0.0369	0.0628	0.1574	0.1084	0.0990	0.0665	0.0787	0.0492	0.0375	0.0365	0.0643	0.7972
2013	0.0309	0.0563	0.0765	0.1615	0.1028	0.0913	0.0608	0.0718	0.0448	0.0342	0.0332	0.7641
2014	0.0246	0.0588	0.0801	0.0835	0.1537	0.0930	0.0814	0.0540	0.0636	0.0396	0.0303	0.7626
2015	0.0211	0.0461	0.0847	0.0890	0.0807	0.1411	0.0841	0.0732	0.0485	0.0571	0.0356	0.7612
2016	0.0413	0.0704	0.0941	0.1057	0.0832	0.0671	0.1130	0.0665	0.0577	0.0382	0.0450	0.7822
2017	0.0260	0.0993	0.1070	0.1001	0.0949	0.0704	0.0557	0.0932	0.0548	0.0475	0.0314	0.7803
2018	0.0160	0.0467	0.1317	0.1125	0.0945	0.0861	0.0631	0.0497	0.0831	0.0488	0.0424	0.7746
2019	0.0257	0.0362	0.0688	0.1427	0.1060	0.0848	0.0762	0.0556	0.0438	0.0731	0.0430	0.7559
2020	0.0306	0.0570	0.0526	0.0741	0.1334	0.0939	0.0738	0.0659	0.0480	0.0377	0.0630	0.7300
2021	0.0576	0.0554	0.0697	0.0511	0.0654	0.1139	0.0794	0.0621	0.0554	0.0403	0.0317	0.6820
2022	0.0673	0.0855	0.0613	0.0652	0.0446	0.0557	0.0962	0.0668	0.0523	0.0466	0.0339	0.6754

Year	7	8	9	10	11	12	13	14	15	16	17+	Total male proportion over age 7
1975	0.1445	0.2799	0.2179	0.1000	0.0625	0.0294	0.0201	0.0229	0.0086	0.0072	0.0042	0.8972
1976	0.1040	0.1675	0.2594	0.1857	0.0844	0.0530	0.0250	0.0171	0.0195	0.0073	0.0061	0.9290
1977	0.1624	0.2063	0.1696	0.1590	0.0888	0.0369	0.0225	0.0105	0.0072	0.0082	0.0031	0.8745
1978	0.0915	0.1950	0.2167	0.1574	0.1375	0.0744	0.0305	0.0185	0.0086	0.0059	0.0067	0.9427
1979	0.0611	0.1459	0.2154	0.1861	0.1208	0.1014	0.0541	0.0221	0.0134	0.0063	0.0043	0.9309
1980	0.0702	0.0890	0.1580	0.1942	0.1555	0.0984	0.0820	0.0437	0.0179	0.0108	0.0050	0.9247
1981	0.0864	0.1109	0.1057	0.1503	0.1640	0.1247	0.0774	0.0640	0.0340	0.0139	0.0084	0.9397
1982	0.0629	0.1461	0.1325	0.0984	0.1233	0.1275	0.0950	0.0585	0.0483	0.0256	0.0104	0.9285
1983	0.0777	0.0941	0.1624	0.1232	0.0846	0.1028	0.1052	0.0781	0.0480	0.0396	0.0210	0.9367
1984	0.0369	0.0977	0.1020	0.1601	0.1165	0.0788	0.0953	0.0973	0.0722	0.0444	0.0366	0.9378
1985	0.0258	0.0633	0.1214	0.1025	0.1470	0.1037	0.0694	0.0837	0.0854	0.0633	0.0389	0.9044
1986	0.0428	0.0497	0.0838	0.1243	0.0940	0.1297	0.0904	0.0603	0.0726	0.0741	0.0549	0.8766
1987	0.0243	0.0607	0.0576	0.0847	0.1187	0.0883	0.1212	0.0844	0.0563	0.0677	0.0691	0.8330
1988	0.0611	0.0512	0.0920	0.0635	0.0790	0.1044	0.0762	0.1041	0.0723	0.0482	0.0580	0.8100
1989	0.0097	0.0922	0.0669	0.0998	0.0615	0.0734	0.0958	0.0696	0.0950	0.0660	0.0440	0.7739
1990	0.0459	0.0350	0.2100	0.0867	0.0890	0.0473	0.0539	0.0695	0.0503	0.0687	0.0477	0.8040
1991	0.0404	0.1531	0.0605	0.2141	0.0680	0.0639	0.0331	0.0376	0.0484	0.0351	0.0478	0.8020
1992	0.0247	0.0606	0.1986	0.0651	0.2026	0.0604	0.0553	0.0284	0.0320	0.0412	0.0298	0.7987
1993	0.0267	0.0397	0.0745	0.2015	0.0607	0.1846	0.0547	0.0501	0.0257	0.0291	0.0373	0.7846
1994	0.0271	0.0488	0.0639	0.0942	0.2069	0.0556	0.1610	0.0468	0.0425	0.0218	0.0246	0.7932
1995	0.0477	0.0854	0.0952	0.0776	0.0860	0.1683	0.0435	0.1244	0.0361	0.0327	0.0168	0.8137
1996	0.0253	0.0919	0.1224	0.1026	0.0712	0.0741	0.1417	0.0364	0.1038	0.0301	0.0273	0.8268
1997	0.0289	0.0548	0.1400	0.1332	0.0931	0.0603	0.0612	0.1163	0.0298	0.0849	0.0246	0.8271
1998	0.0387	0.0487	0.0717	0.1470	0.1254	0.0844	0.0541	0.0548	0.1040	0.0266	0.0759	0.8313
1999	0.0133	0.0510	0.0592	0.0780	0.1472	0.1207	0.0801	0.0511	0.0517	0.0981	0.0251	0.7755
2000	0.0167	0.0451	0.1312	0.0966	0.0842	0.1265	0.0947	0.0609	0.0385	0.0388	0.0736	0.8068
2001	0.0217	0.0466	0.0879	0.1679	0.0924	0.0710	0.1022	0.0756	0.0485	0.0306	0.0308	0.7752
2002	0.0273	0.0342	0.0674	0.1059	0.1710	0.0864	0.0643	0.0915	0.0674	0.0432	0.0272	0.7858
2003	0.0276	0.1240	0.0917	0.0975	0.0989	0.1314	0.0622	0.0454	0.0642	0.0473	0.0302	0.8204
2004	0.0217	0.0538	0.1801	0.0993	0.0892	0.0848	0.1104	0.0519	0.0378	0.0535	0.0393	0.8218
2005	0.0361	0.0594	0.0927	0.2035	0.0880	0.0718	0.0660	0.0850	0.0399	0.0290	0.0410	0.8124
2006	0.0606	0.0784	0.0880	0.0989	0.1813	0.0728	0.0577	0.0526	0.0675	0.0316	0.0230	0.8124
2007	0.0367	0.0956	0.0946	0.0876	0.0904	0.1607	0.0639	0.0505	0.0460	0.0590	0.0276	0.8126
2008	0.0567	0.0770	0.1326	0.0955	0.0758	0.0737	0.1285	0.0508	0.0401	0.0364	0.0468	0.8139
2009	0.0427	0.0872	0.0938	0.1338	0.0880	0.0674	0.0649	0.1127	0.0445	0.0351	0.0319	0.8020
2010	0.0768	0.0938	0.1197	0.0916	0.1122	0.0700	0.0529	0.0506	0.0878	0.0346	0.0273	0.8173
2011	0.0357	0.1287	0.1147	0.1170	0.0809	0.0955	0.0589	0.0443	0.0424	0.0735	0.0290	0.8206
2012	0.0408	0.0683	0.1684	0.1140	0.1025	0.0677	0.0789	0.0484	0.0364	0.0348	0.0603	0.8205
2013	0.0345	0.0617	0.0825	0.1713	0.1072	0.0937	0.0614	0.0712	0.0437	0.0328	0.0314	0.7914
2014	0.0276	0.0648	0.0867	0.0890	0.1611	0.0959	0.0825	0.0538	0.0624	0.0382	0.0287	0.7907
2015	0.0238	0.0511	0.0923	0.0954	0.0850	0.1462	0.0857	0.0734	0.0478	0.0554	0.0340	0.7901
2016	0.0462	0.0774	0.1017	0.1124	0.0871	0.0691	0.1144	0.0662	0.0565	0.0368	0.0426	0.8104
2017	0.0290	0.1089	0.1154	0.1062	0.0990	0.0722	0.0562	0.0925	0.0535	0.0456	0.0297	0.8082
2018	0.0180	0.0514	0.1428	0.1200	0.0991	0.0889	0.0640	0.0496	0.0816	0.0472	0.0402	0.8028
2019	0.0289	0.0400	0.0748	0.1526	0.1115	0.0878	0.0776	0.0556	0.0431	0.0708	0.0409	0.7836
2020	0.0344	0.0630	0.0571	0.0792	0.1402	0.0971	0.0751	0.0659	0.0472	0.0365	0.0600	0.7557
2021	0.0643	0.0609	0.0754	0.0543	0.0684	0.1172	0.0803	0.0618	0.0542	0.0388	0.0300	0.7056
2022	0.0748	0.0935	0.0659	0.0690	0.0464	0.0570	0.0968	0.0662	0.0509	0.0446	0.0319	0.6970

Table 4.5: Total tonnage of yellowfin sole caught in resource assessment surveys in the eastern Bering Sea from 1977-2022.

Year	Research catch (t)
2006	0
2007	0
2010	119
2011	101
2012	83
2013	75
2014	83
2015	65
2016	98
2017	112
2018	73
2019	85
2020	0
2021	72
2022	87

Table 4.6: Discarded and retained catch of non-CDQ yellowfin sole, by fishery, in 2022. Gear types include longline (HAL), bottom trawl (NPT), pot (POT), and pelagic trawl (PTR). Catch was non-zero for all target-gear combinations shown, but may appear as zero as results were rounded to the nearest metric ton (t). Source: NMFS AKRO BLEND/Catch Accounting System.

	Gear type	Discarded (t)	Retained (t)
Other species	HAL	3	0
Pacific cod	HAL	619	0
Arrowtooth flounder	NPT	0	0
Atka mackerel	NPT	1	0
Flathead sole	NPT	60	3,821
Other flatfish	NPT	0	0
Pacific cod	NPT	5	18
Pollock - bottom	NPT	10	451
Rock sole	NPT	49	4,125
Rockfish	NPT	0	0
Sablefish	NPT	0	0
Yellowfin sole	NPT	1,721	142,764
Pacific cod	POT	175	0
Pollock - bottom	PTR	1	104
Pollock - midwater	PTR	114	205

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

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

Table 4.8: Yellowfin sole design-based (DB) biomass estimates (t) from the annual eastern Bering Sea shelf bottom trawl survey, and model-based (MB) biomass estimates for the combined northern and eastern Bering Sea survey areas (EBS+NBS), with upper (UCI) and lower (LCI) 95% confidence intervals. Note that surveys were not conducted in 2020.

Year	EBS Biomass DB (t)	LCI	UCI	EBS+NBS Biomass MB (t)	LCI	UCI
1982	3,509,130	3,508,559	3,509,700	4,027,030	4,026,482	4,027,577
1983	3,672,420	3,672,015	3,672,824	4,568,050	4,567,398	4,568,701
1984	3,341,320	3,340,953	3,341,686	4,185,330	4,184,745	4,185,914
1985	2,398,080	2,397,771	2,398,388	3,024,480	3,024,146	3,024,813
1986	2,031,600	2,031,298	2,031,901	2,336,500	2,336,219	2,336,780
1987	2,530,210	2,529,824	2,530,595	3,022,300	3,021,953	3,022,646
1988	2,195,920	2,195,507	2,196,332	2,635,670	2,635,416	2,635,923
1989	2,329,420	2,329,078	2,329,761	2,775,430	2,775,116	2,775,743
1990	2,192,590	2,192,292	2,192,887	2,622,700	2,622,419	2,622,980
1991	2,406,530	2,406,253	2,406,806	3,153,540	3,153,238	3,153,841
1992	2,215,410	2,215,022	2,215,797	2,884,600	2,884,144	2,885,055
1993	2,484,910	2,484,596	2,485,223	3,137,850	3,137,434	3,138,265
1994	2,615,720	2,615,379	2,616,060	3,556,680	3,556,107	3,557,252
1995	2,026,890	2,026,605	2,027,174	2,529,190	2,528,843	2,529,536
1996	2,230,820	2,230,435	2,231,204	2,723,150	2,722,794	2,723,505
1997	2,176,540	2,176,285	2,176,794	2,871,530	2,871,075	2,871,984
1998	2,222,670	2,222,392	2,222,947	3,551,080	3,550,259	3,551,900
1999	1,266,420	1,266,239	1,266,600	2,020,680	2,020,155	2,021,204
2000	1,600,280	1,600,079	1,600,480	2,125,330	2,124,987	2,125,672
2001	1,690,560	1,690,319	1,690,800	2,338,410	2,338,025	2,338,794
2002	1,923,070	1,922,811	1,923,328	2,603,860	2,603,406	2,604,313
2003	2,171,730	2,171,319	2,172,140	2,915,860	2,915,402	2,916,317
2004	2,557,800	2,557,417	2,558,182	3,494,700	3,494,133	3,495,266
2005	2,840,250	2,839,528	2,840,971	3,568,890	3,568,381	3,569,398
2006	2,146,500	2,146,186	2,146,813	2,898,850	2,898,459	2,899,240
2007	2,168,040	2,167,660	2,168,419	2,825,340	2,824,942	2,825,737
2008	2,112,690	2,112,187	2,113,192	3,012,310	3,011,801	3,012,818
2009	1,752,060	1,751,759	1,752,360	2,407,410	2,407,058	2,407,761
2010	2,388,160	2,387,605	2,388,714	3,118,130	3,117,799	3,118,460
2011	2,422,500	2,422,019	2,422,980	2,876,520	2,876,164	2,876,875
2012	1,965,410	1,965,135	1,965,684	2,875,650	2,875,253	2,876,046
2013	2,295,210	2,294,866	2,295,553	2,817,990	2,817,656	2,818,323
2014	2,531,400	2,530,941	2,531,858	3,047,780	3,047,426	3,048,133
2015	1,946,300	1,946,012	1,946,587	2,396,930	2,396,655	2,397,204
2016	2,876,800	2,876,474	2,877,125	3,796,820	3,796,422	3,797,217
2017	2,805,160	2,804,683	2,805,636	3,711,310	3,710,979	3,711,640
2018	1,903,040	1,902,812	1,903,267	2,961,540	2,961,279	2,961,800
2019	2,017,620	2,017,203	2,018,036	2,875,140	2,874,905	2,875,374
2021	1,633,970	1,633,755	1,634,184	2,476,000	2,475,787	2,476,212
2022	2,039,970	2,039,705	2,040,234	2,936,470	2,936,215	2,936,724
2023	1,393,378	1,136,033	1,650,724	2,007,140	2,006,955	2,007,324

Table 4.9: Model estimates of yellowfin sole age 2+ total biomass (t) from the 2022 and 2023 stock assessments, Model 22.1 (2022), Model 22.1 (2023), and 23.0. All are model-based (VAST) estimates.

Model	22.1 (2022)	22.1 (2023)	23.0		
	Biomass (t)	Biomass (t)	Biomass (t)	LCI	HCI
1954	2,325,940	2,591,780	2,423,160	1,872,860	3,135,140
1955	2,292,910	2,536,300	2,376,930	1,855,420	3,045,040
1956	2,255,750	2,475,950	2,331,800	1,850,140	2,938,850
1957	2,217,200	2,412,740	2,289,230	1,859,080	2,818,920
1958	2,200,690	2,367,830	2,268,840	1,900,940	2,707,930
1959	2,188,520	2,322,920	2,250,120	1,952,030	2,593,720
1960	2,049,610	2,148,840	2,101,830	1,874,950	2,356,160
1961	1,646,620	1,712,240	1,692,110	1,530,900	1,870,290
1962	1,167,170	1,205,890	1,227,300	1,112,890	1,353,470
1963	797,719	858,588	883,637	775,921	1,006,310
1964	841,190	903,237	924,513	810,613	1,054,420
1965	823,902	895,837	919,805	796,948	1,061,600
1966	874,130	956,803	980,248	844,829	1,137,370
1967	865,892	960,543	984,241	834,449	1,160,920
1968	803,119	904,649	929,434	763,653	1,131,200
1969	840,381	962,122	989,666	802,258	1,220,850
1970	831,048	966,000	996,636	785,374	1,264,730
1971	913,093	1,053,920	1,089,240	848,773	1,397,830
1972	1,004,630	1,162,380	1,201,470	928,836	1,554,130
1973	1,282,430	1,446,300	1,489,500	1,178,990	1,881,800
1974	1,557,480	1,721,680	1,768,630	1,421,820	2,200,030
1975	1,931,240	2,104,070	2,159,530	1,765,290	2,641,820
1976	2,266,300	2,434,290	2,489,620	2,061,090	3,007,250
1977	2,602,960	2,755,060	2,810,960	2,353,500	3,357,340
1978	2,920,350	3,050,340	3,106,430	2,625,680	3,675,200
1979	3,097,980	3,201,130	3,255,780	2,759,980	3,840,640
1980	3,294,130	3,359,370	3,411,190	2,904,960	4,005,630
1981	3,472,530	3,483,570	3,532,460	3,021,080	4,130,390
1982	3,596,580	3,514,960	3,559,160	3,059,100	4,140,950
1983	3,570,740	3,451,900	3,493,000	3,001,320	4,065,240
1984	3,822,390	3,593,040	3,632,020	3,131,290	4,212,810
1985	3,842,710	3,538,590	3,575,340	3,074,820	4,157,340
1986	3,544,930	3,223,640	3,257,450	2,781,880	3,814,330
1987	3,526,410	3,115,510	3,148,250	2,678,590	3,700,260
1988	3,429,020	2,971,500	3,001,610	2,548,450	3,535,340
1989	3,497,640	2,997,990	3,027,420	2,567,410	3,569,860
1990	3,357,890	2,839,770	2,868,040	2,426,820	3,389,480
1991	3,479,890	2,937,310	2,965,970	2,520,660	3,489,960
1992	3,693,160	3,126,750	3,156,260	2,695,040	3,696,420
1993	3,760,580	3,213,060	3,242,770	2,771,230	3,794,540
1994	3,810,610	3,287,930	3,318,830	2,840,910	3,877,160
1995	3,562,460	3,063,270	3,092,680	2,635,960	3,628,520
1996	3,470,810	3,009,670	3,039,190	2,587,060	3,570,340
1997	3,502,830	3,078,230	3,109,230	2,646,130	3,653,390
1998	3,201,910	2,810,790	2,840,060	2,399,850	3,361,010
1999	2,990,320	2,613,390	2,641,850	2,222,560	3,140,230
2000	2,823,360	2,492,160	2,519,430	2,122,100	2,991,150
2001	2,815,840	2,477,890	2,505,700	2,105,620	2,981,800

2002	2,868,870	2,579,190	2,608,310	2,203,290	3,087,780
2003	3,167,540	2,903,890	2,936,550	2,491,760	3,460,720
2004	3,292,090	3,080,870	3,115,450	2,652,440	3,659,290
2005	3,352,180	3,188,350	3,223,170	2,751,400	3,775,840
2006	3,376,190	3,225,930	3,260,800	2,785,250	3,817,540
2007	3,294,640	3,179,030	3,211,900	2,747,430	3,754,890
2008	3,152,100	3,049,690	3,081,100	2,635,940	3,601,440
2009	3,167,340	3,077,850	3,110,560	2,652,310	3,647,980
2010	3,308,680	3,215,050	3,248,490	2,770,760	3,808,580
2011	3,259,250	3,174,060	3,205,520	2,744,070	3,744,580
2012	3,089,540	3,017,860	3,049,110	2,604,170	3,570,070
2013	2,971,180	2,898,760	2,928,580	2,499,880	3,430,800
2014	2,947,440	2,857,770	2,887,920	2,461,330	3,388,450
2015	2,936,120	2,836,930	2,866,870	2,434,830	3,375,560
2016	2,983,790	2,851,390	2,881,680	2,451,140	3,387,840
2017	3,018,220	2,841,830	2,873,180	2,430,700	3,396,210
2018	2,809,720	2,586,720	2,615,040	2,214,570	3,087,930
2019	3,010,490	2,644,610	2,673,750	2,258,330	3,165,600
2020	3,065,090	2,546,630	2,574,660	2,168,900	3,056,320
2021	3,443,250	2,596,360	2,623,810	2,214,230	3,109,160
2022	3,782,420	2,690,830	2,719,490	2,284,120	3,237,830
2023		2,687,780	2,716,370	2,264,470	3,258,460

Table 4.10: Yellowfin sole design-based 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	Hauls with length	Otoliths read	Hauls with otoliths
2010	427,374	331,321	523,426	141	121	121	351	46
2017	434,087	336,225	531,949	143	131	130	536	50
2019	520,031	395,637	644,425	144	141	140	0	33
2021	496,045	392,315	599,775	144	138	137	0	122
2022	548,026	365,861	730,191	144	136	135	362	123
2023	393,304	314,123	472,485	116	108	108	0	107

Table 4.11: Yellowfin sole population numbers-at-age (millions) estimated from the annual EBS bottom trawl surveys, 1987-2022 (Current year data is not yet available and there was no survey in 2020). Data in years 1987 or later come from the ‘plusnw’ extended survey area. Females are presented first, followed by males. Continued on next page.

Year	Age (Females)															
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17+
1987	0	0	68	117	786	446	821	252	364	580	344	434	234	261	238	174
1988	0	0	6	344	65	1,363	501	498	164	214	317	187	325	246	198	152
1989	0	0	14	98	720	234	1,341	596	449	74	180	309	235	239	184	82
1990	0	0	70	102	326	1,072	193	1,263	410	484	101	72	107	78	232	127
1991	0	9	127	249	123	407	899	151	1,267	213	527	62	128	87	123	164
1992	0	18	239	464	499	203	274	899	91	794	72	297	124	131	163	104
1993	0	24	100	360	639	437	270	226	1,323	78	872	157	166	69	68	91
1994	0	53	95	223	518	906	556	482	284	1,172	0	516	43	274	142	41
1995	0	19	153	290	182	896	632	276	136	25	638	20	565	104	80	97
1996	0	15	150	793	280	270	421	501	199	141	146	583	112	616	44	29
1997	0	18	326	506	729	257	240	507	229	114	177	184	502	44	315	75
1998	0	9	79	455	401	859	248	194	352	393	351	161	167	252	63	397
1999	0	3	62	189	168	179	704	100	104	238	184	180	70	99	170	102
2000	0	11	54	249	209	307	448	543	191	200	240	221	65	118	146	110
2001	0	1	66	221	478	225	363	371	584	333	74	172	138	114	170	99
2002	0	15	119	163	243	747	325	273	215	433	209	85	290	109	143	137
2003	0	15	114	236	243	278	1,111	218	269	276	242	99	111	163	161	83
2004	10	33	197	442	572	417	218	976	224	213	222	222	107	20	169	187
2005	0	53	168	195	588	414	231	473	877	221	137	184	336	164	50	181
2006	8	67	304	378	277	637	472	177	327	741	133	133	71	157	176	1
2007	0	37	519	349	384	276	505	309	124	228	507	119	138	127	105	77
2008	0	23	115	741	624	545	357	361	196	128	255	355	151	78	85	119
2009	5	37	205	205	1,199	600	495	266	211	219	130	139	197	89	43	1
2010	0	33	330	389	441	902	558	520	331	338	155	167	136	174	99	49
2011	0	14	245	543	712	466	775	413	460	205	227	149	143	145	187	99
2012	10	50	231	397	508	295	244	758	257	336	107	157	37	151	128	150
2013	0	4	89	271	423	535	257	221	411	408	360	120	135	133	133	94
2014	0	0	37	424	386	250	422	232	229	526	343	161	145	230	34	123
2015	0	22	3	168	470	352	309	289	250	150	283	260	135	99	80	68
2016	0	32	71	45	165	748	568	405	365	301	144	246	230	140	163	170
2017	16	79	384	381	122	319	1,007	484	337	379	229	149	203	201	149	118
2018	0	49	182	262	178	91	265	641	326	231	81	76	41	124	99	103
2019	1	124	209	309	156	241	79	211	548	360	130	160	125	123	72	43
2021	0	258	100	1,450	457	317	123	176	94	157	162	108	105	67	54	61
2022	0	97	360	282	1,405	424	404	88	160	80	126	174	86	72	77	66

Year	Age (Males)															
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17+
1987	0	4	39	104	820	456	655	430	316	267	202	142	102	136	177	211
1988	0	1	9	413	45	1,087	507	406	77	171	25	163	308	173	25	106
1989	0	2	23	181	789	177	1,310	515	358	135	50	104	53	205	35	38
1990	0	10	47	121	318	894	196	1,151	319	265	39	65	67	24	54	73
1991	0	0	103	357	140	277	1,051	68	1,143	330	245	74	64	60	53	91
1992	0	0	141	428	542	251	216	778	109	875	186	206	11	12	59	37
1993	0	20	52	235	651	396	280	248	1,105	70	849	53	53	50	0	48
1994	4	21	71	166	427	954	657	308	191	824	25	623	45	132	11	36
1995	0	0	170	120	272	672	570	95	181	75	481	13	608	49	24	77
1996	0	74	92	822	238	220	413	335	321	137	135	388	58	436	122	92
1997	0	9	216	428	803	182	184	449	246	195	215	109	518	79	266	31
1998	0	46	66	335	546	796	151	215	193	258	328	142	149	178	107	250
1999	0	5	96	136	216	234	555	141	91	299	261	72	51	27	115	34
2000	0	0	35	220	261	144	514	589	79	217	134	77	93	78	66	154
2001	0	0	81	130	604	309	341	324	513	190	80	144	59	67	129	55
2002	0	56	70	152	297	726	303	315	247	419	183	134	207	151	124	20
2003	0	23	93	174	251	244	1,046	231	354	51	277	168	9	69	56	104
2004	4	64	116	477	454	201	400	1,005	267	82	198	226	104	48	253	104
2005	0	48	167	179	453	458	239	297	1,007	123	139	118	131	68	91	126
2006	0	101	174	350	333	508	395	289	300	386	117	156	90	39	11	55
2007	0	58	485	355	408	285	549	210	166	268	336	100	132	70	59	123
2008	0	10	100	667	465	486	346	455	226	145	186	331	63	66	34	104
2009	0	65	145	292	960	467	548	249	251	218	78	31	196	30	29	51
2010	0	78	201	421	373	1,040	466	514	173	190	160	53	117	152	79	53
2011	0	6	151	388	486	360	798	401	226	177	78	81	137	103	157	97
2012	0	69	276	355	348	277	241	429	300	181	98	67	91	34	100	59
2013	0	6	92	369	387	485	212	270	448	201	202	33	89	100	118	18
2014	0	0	8	368	399	288	341	312	253	403	207	194	20	193	94	108
2015	0	29	36	132	430	335	303	314	320	48	181	131	81	0	80	111
2016	0	43	85	20	142	709	548	404	369	126	118	228	181	88	35	92
2017	9	121	233	399	107	262	886	501	312	277	196	108	217	156	37	12
2018	0	39	175	188	229	72	236	523	261	189	95	77	73	75	69	29
2019	0	136	252	234	103	272	109	148	491	271	130	155	84	68	57	94
2021	0	52	189	1,079	517	373	87	106	69	84	158	42	62	37	41	55
2022	0	74	120	444	1,040	487	308	79	95	62	106	143	67	25	136	66

Table 4.12: Mean unsmoothed survey weight-at-age (grams) for yellowfin sole, females, 1964-2023.

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	6	8	14	33	36	92	142	192	211	231	294	336	378	361	393	458	491	522	505	609
2001	6	4	8	31	39	62	99	148	195	242	284	383	392	436	424	442	474	528	530	663
2002	6	8	19	27	45	66	105	156	229	246	276	343	328	394	451	480	504	552	560	631
2003	6	8	14	29	56	87	127	171	224	299	328	357	413	454	417	505	374	600	575	652
2004	6	8	14	38	64	101	163	162	231	300	328	359	440	524	551	476	485	500	500	654
2005	6	4	21	40	72	114	156	217	236	284	349	356	377	464	509	505	612	472	620	693
2006	6	6	16	36	76	114	149	206	236	303	308	360	368	592	493	495	532	568	618	740
2007	6	8	16	38	70	113	170	196	239	330	304	351	361	406	456	466	558	568	683	740
2008	6	8	24	31	57	106	140	203	239	281	309	345	395	432	422	501	567	555	594	660
2009	6	6	10	22	51	92	142	182	248	321	334	377	434	429	433	575	874	556	565	697
2010	6	2	16	25	57	84	136	186	218	343	337	403	446	460	517	557	594	620	744	795
2011	6	8	12	30	49	92	145	210	264	318	329	405	419	441	448	621	534	516	623	696
2012	6	6	11	27	53	91	146	167	258	317	367	321	452	529	502	514	562	654	598	730
2013	6	8	12	21	40	102	131	195	275	318	366	399	415	474	473	518	550	555	606	702
2014	6	8	19	16	37	85	145	201	252	306	368	360	428	421	495	592	536	577	570	715
2015	6	8	15	12	40	62	130	215	262	355	418	437	411	484	474	596	647	593	531	731
2016	6	12	25	37	69	86	130	211	329	378	417	415	517	465	509	522	581	580	618	723
2017	6	9	19	51	69	118	143	187	273	366	382	436	536	503	553	647	601	701	585	824
2018	6	8	22	39	88	111	163	236	248	346	421	447	504	478	542	606	586	571	717	677
2019	6	6	21	47	92	160	180	254	277	346	404	583	503	505	570	680	701	673	698	720
2021	6	6	21	47	92	160	180	254	277	346	404	583	503	505	570	680	701	673	698	720
2022	6	6	21	43	103	188	248	321	365	453	438	478	540	564	592	637	602	635	650	667
2023	6	6	17	49	85	151	244	338	391	437	524	516	518	626	635	646	644	739	784	734

Table 4.13: Mean unsmoothed survey weight-at-age (grams) for yellowfin sole, males, 1964-2023.

Year	Age (Females)																			
	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	8	33	30	34	71	105	157	162	244	218	245	266	272	288	335	304	342	364	428
2001	4	8	20	22	32	49	95	151	170	196	244	259	296	299	313	307	362	436	447	410
2002	4	8	17	22	53	58	91	146	204	213	232	257	274	309	345	362	334	383	440	423
2003	4	8	27	39	53	83	112	170	189	250	265	308	267	443	407	370	360	367	381	469
2004	4	8	14	36	59	95	150	158	207	260	321	311	311	368	469	384	414	392	465	464
2005	4	4	19	40	72	115	134	162	206	265	291	334	395	312	310	364	391	374	418	446
2006	4	8	18	32	67	118	144	183	207	237	233	318	350	417	452	438	352	343	380	449
2007	4	8	17	33	67	105	139	177	208	244	287	282	302	351	408	369	339	381	400	449
2008	4	8	8	27	50	95	121	181	192	244	270	298	312	346	384	405	373	399	436	481
2009	4	8	10	20	42	85	128	155	200	287	276	316	399	338	430	308	439	384	369	481
2010	4	8	13	24	48	80	141	167	183	302	315	322	356	414	402	401	417	512	461	501
2011	4	4	11	31	59	88	133	188	227	262	341	302	398	338	381	445	409	416	440	523
2012	4	8	12	27	53	88	126	183	216	256	283	320	292	422	420	387	431	393	355	475
2013	4	8	12	20	41	77	131	189	228	267	269	346	275	371	383	420	456	407	395	487
2014	4	8	20	30	59	86	154	188	243	292	313	311	321	332	424	466	429	527	492	495
2015	4	6	19	25	38	64	135	202	230	321	361	386	368	367	400	432	445	537	563	494
2016	4	8	33	46	50	83	127	190	260	332	327	340	406	394	416	409	443	474	375	505
2017	4	8	21	46	76	102	110	170	247	311	347	367	404	380	466	483	614	577	496	573
2018	4	8	23	45	89	95	161	178	221	276	316	403	384	435	421	386	424	431	548	484
2019	4	8	20	48	97	126	195	206	237	280	324	384	377	384	431	464	434	454	464	507
2021	4	8	20	48	97	126	195	206	237	280	324	384	377	384	431	464	434	454	464	507
2022	4	8	24	59	110	180	232	250	267	332	331	374	420	428	435	455	462	449	431	448
2023	4	4	21	42	82	162	228	266	325	362	383	414	412	435	447	472	499	547	524	570

Table 4.14: Parameter values and their 95% confidence intervals, Model 22.1 (2023). Total biomass is presented from 1954 - 2023.

Name	Value	Standard Deviation	Name	Value	Standard Deviation
male natural mortality	1.3625e-01	4.9606e-03	TotBiom	3483.6	269.30
alpha (q-temp model)	1.1427e-01	8.3100e-02	TotBiom	3515.0	262.95
beta (q-temp model)	6.8791e-02	1.0886e-02	TotBiom	3451.9	258.87
beta (survey start date)	5.8464e-03	3.0061e-03	TotBiom	3593.0	263.42
beta (start date/temp interaction)	-2.6584e-03	3.1902e-03	TotBiom	3538.6	263.82
mean log recruitment	9.1957e-01	1.0577e-01	TotBiom	3223.6	251.63
log_avg_fmort	-2.4794e+00	1.1543e-01	TotBiom	3115.5	249.03
sel_slope_fsh_f	1.1875e+00	1.9746e-01	TotBiom	2971.5	240.58
sel50_fsh_f	8.1269e+00	3.8217e-01	TotBiom	2998.0	244.45
sel_slope_fsh_m	1.1843e+00	2.1741e-01	TotBiom	2839.8	234.76
sel50_fsh_m	8.4860e+00	4.4429e-01	TotBiom	2937.3	236.53
sel_slope_srv	1.5791e+00	2.3838e-01	TotBiom	3126.8	244.43
sel50_srv	4.3215e+00	2.0127e-01	TotBiom	3213.1	249.85
R_logalpha	-4.5148e+00	6.1058e-01	TotBiom	3287.9	253.00
R_logbeta	-6.5082e+00	4.0221e-01	TotBiom	3063.3	242.38
q_srv	1.0714e+00	9.0915e-02	TotBiom	3009.7	240.02
ABC_biom	4.7154e+03	8.5763e+02	TotBiom	3078.2	245.79
Bmsy	5.2119e+02	1.3332e+02	TotBiom	2810.8	234.37
Bmsyr	4.2618e+03	4.6482e+02	TotBiom	2613.4	223.70
TotBiom	2.5918e+03	2.6009e+02	TotBiom	2492.2	211.78
TotBiom	2.5363e+03	2.4206e+02	TotBiom	2477.9	213.48
TotBiom	2.4759e+03	2.1884e+02	TotBiom	2579.2	215.46
TotBiom	2.4127e+03	1.9078e+02	TotBiom	2903.9	236.02
TotBiom	2.3678e+03	1.5899e+02	TotBiom	3080.9	245.26
TotBiom	2.3229e+03	1.2613e+02	TotBiom	3188.3	249.60
TotBiom	2.1488e+03	9.6193e+01	TotBiom	3225.9	251.52
TotBiom	1.7122e+03	7.2604e+01	TotBiom	3179.0	245.59
TotBiom	1.2059e+03	5.9199e+01	TotBiom	3049.7	235.37
TotBiom	8.5859e+02	5.5850e+01	TotBiom	3077.9	242.71
TotBiom	9.0324e+02	5.7271e+01	TotBiom	3215.1	252.97
TotBiom	8.9584e+02	6.1041e+01	TotBiom	3174.1	243.98
TotBiom	9.5680e+02	6.6496e+01	TotBiom	3017.9	235.50
TotBiom	9.6054e+02	7.3498e+01	TotBiom	2898.8	226.98
TotBiom	9.0465e+02	8.2407e+01	TotBiom	2857.8	226.01
TotBiom	9.6212e+02	9.4125e+01	TotBiom	2836.9	229.30
TotBiom	9.6600e+02	1.0844e+02	TotBiom	2851.4	228.27
TotBiom	1.0539e+03	1.2558e+02	TotBiom	2841.8	235.24
TotBiom	1.1624e+03	1.4421e+02	TotBiom	2586.7	212.83
TotBiom	1.4463e+03	1.6393e+02	TotBiom	2644.6	221.08
TotBiom	1.7217e+03	1.8324e+02	TotBiom	2546.6	216.26
TotBiom	2.1041e+03	2.0742e+02	TotBiom	2596.4	218.20
TotBiom	2.4343e+03	2.2545e+02	TotBiom	2690.8	232.58
TotBiom	2.7551e+03	2.4056e+02	TotBiom	2687.8	242.52
TotBiom	3.0503e+03	2.5268e+02			
TotBiom	3.2011e+03	2.6107e+02			
TotBiom	3.3594e+03	2.6658e+02			

Table 4.15: Parameter values and their 95% confidence intervals, Model 23.0. Total biomass is presented from 1954 - 2023.

Name	Value	Standard Deviation	Name	Value	Standard Deviation
male natural mortality	1.3657e-01	4.9348e-03	future_TotBiom	4023.8	738.37
alpha (q-temp model)	1.0349e-01	8.4087e-02	future_TotBiom	4361.2	843.12
beta (q-temp model)	6.8618e-02	1.0890e-02	future_TotBiom	4658.3	953.49
beta (survey start date)	5.8988e-03	3.0066e-03	future_TotBiom	2829.5	269.70
beta (start date/temp interaction)	-2.6649e-03	3.1919e-03	future_TotBiom	2780.8	294.62
mean log recruitment	9.3771e-01	1.0623e-01	future_TotBiom	2790.9	353.96
log_avg_fmort	-2.5071e+00	1.1524e-01	future_TotBiom	2863.6	428.92
sel_slope_fsh_f	1.2022e+00	1.4434e-01	future_TotBiom	2976.4	504.00
sel50_fsh_f	8.1960e+00	3.0661e-01	future_TotBiom	3180.9	580.67
sel_slope_srv	1.5805e+00	2.3845e-01	future_TotBiom	3469.8	664.75
rechat	2.6195e+00	4.2843e-01	future_TotBiom	3781.8	764.94
pred_rec	1.3772e+00	3.0951e-01	future_TotBiom	4099.1	889.75
pred_rec	9.2597e-01	2.3658e-01	future_TotBiom	4371.1	1026.70
pred_rec	1.1640e+00	2.6551e-01	future_TotBiom	2829.5	269.70
pred_rec	9.9559e-01	2.3888e-01	future_TotBiom	2926.4	308.06
future_SSB	7.0445e+02	7.5885e+01	future_TotBiom	3056.2	365.34
future_SSB	1.0102e+03	1.6821e+02	future_TotBiom	3229.0	433.27
future_SSB	1.0731e+03	1.9172e+02	future_TotBiom	3422.6	501.83
future_SSB	1.1648e+03	2.1762e+02	future_TotBiom	3694.5	573.75
future_SSB	9.0054e+02	1.0533e+02	future_TotBiom	4044.5	650.00
future_SSB	9.3035e+02	1.0298e+02	future_TotBiom	4402.9	728.41
future_SSB	9.8513e+02	1.0302e+02	future_TotBiom	4769.8	808.88
future_SSB	1.0638e+03	1.0664e+02	future_TotBiom	5098.2	885.59
future_SSB	1.1383e+03	1.1336e+02	future_TotBiom	2829.5	269.70
future_SSB	1.2225e+03	1.2772e+02	future_TotBiom	3043.1	308.11
future_SSB	1.3306e+03	1.5259e+02	future_TotBiom	3283.5	364.27
future_SSB	1.4245e+03	1.8150e+02	future_TotBiom	3562.1	431.18
future_SSB	1.5424e+03	2.1179e+02	future_TotBiom	3852.5	499.83
future_SSB	1.6913e+03	2.4414e+02	future_TotBiom	4213.6	572.81
future_SSB	8.8164e+02	1.0501e+02	future_TotBiom	4648.8	648.45
future_SSB	8.5735e+02	1.0174e+02	future_TotBiom	5074.0	720.10
future_SSB	8.5982e+02	1.0108e+02	future_TotBiom	5501.6	783.77
future_SSB	8.8628e+02	1.0483e+02	future_TotBiom	5886.0	837.21
future_SSB	9.1256e+02	1.1287e+02	future_TotBiom	2829.5	269.70
future_SSB	9.5148e+02	1.2967e+02	future_TotBiom	2930.7	308.63
future_SSB	1.0126e+03	1.5684e+02	future_TotBiom	3067.1	366.36
future_SSB	1.0694e+03	1.8649e+02	future_TotBiom	3249.8	435.60
future_SSB	1.1535e+03	2.1673e+02	future_TotBiom	3457.5	507.08
future_SSB	1.2731e+03	2.4903e+02	future_TotBiom	3746.9	583.83
future_TotBiom	2.8295e+03	2.6970e+02	future_TotBiom	4118.6	666.06
future_TotBiom	2.8430e+03	2.9643e+02	future_TotBiom	4504.0	749.40
future_TotBiom	2.9018e+03	3.5206e+02	future_TotBiom	4907.8	832.57
future_TotBiom	3.0132e+03	4.2239e+02	future_TotBiom	5286.5	910.63
future_TotBiom	3.1558e+03	4.9389e+02			
future_TotBiom	3.3843e+03	5.6809e+02			
future_TotBiom	3.6949e+03	6.4830e+02			

Table 4.16: Summary table for Model 22.1.

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2023	2024	2024	2025
M (natural mortality rate)	0.12, 0.125	0.12, 0.125	0.12, 0.136	0.12, 0.136
Tier	1a	1a	1a	1a
Projected total (age 6+) biomass (t)	3,321,640 t	4,062,230 t	2,488,060 t	2,589,290 t
Projected female spawning biomass (t)	885,444 t	897,062 t	862,542 t	857,354 t
B_0	1,407,000 t	1,407,000 t	1,483,320 t	1,483,320 t
B_{MSY}	475,199 t	475,199 t	539,657 t	539,657 t
F_{OFL}	0.122	0.122	0.122	0.122
$maxF_{ABC}$	0.114	0.114	0.108	0.108
F_{ABC}	0.114	0.114	0.106	0.106
OFL (t)	404,882 t	495,155 t	303,291 t	315,630 t
$maxABC$	378,499 t	462,890 t	267,486 t	278,368 t
ABC (t)	378,499 t	462,890 t	267,486 t	278,368 t
Status	2021	2022	2022	2023
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

Note: Projections were based on estimated catches of 79,688 t in 2023 and 121,103 t used in place of maximum ABC for 2024. This estimate was based on the mean catch over the past 5 years, 2019 - 2023, which includes the extrapolated catch of 79,688 t for 2023.

Table 4.17: Model estimates of yellowfin sole full selection fishing mortality (Full sel. F) and exploitation rate (Catch/Total Biomass) for Models 22.1 (2022), 22.1 (2023), and 23.0.

Year	Model 22.1 (2022)		Model 22.1 (2023)		Model 23.0	
	Full sel. F	Catch/Tot. Biom.	Full sel. F	Catch/Tot. Biom.	Full sel. F	Catch/Tot. Biom.
1954	0.007	0.005	0.006	0.005	0.007	0.005
1955	0.008	0.006	0.007	0.006	0.008	0.006
1956	0.014	0.011	0.013	0.010	0.014	0.011
1957	0.015	0.011	0.013	0.010	0.014	0.011
1958	0.028	0.020	0.026	0.019	0.028	0.019
1959	0.134	0.085	0.122	0.080	0.132	0.082
1960	0.453	0.223	0.401	0.212	0.456	0.217
1961	1.139	0.336	0.892	0.323	1.417	0.327
1962	4.766	0.360	2.179	0.349	1.062	0.343
1963	0.341	0.108	0.355	0.100	0.326	0.097
1964	0.285	0.133	0.374	0.124	0.277	0.121
1965	0.254	0.065	0.223	0.060	0.212	0.059
1966	0.447	0.117	0.358	0.107	0.361	0.104
1967	0.526	0.187	0.470	0.169	0.464	0.165
1968	0.422	0.105	0.265	0.093	0.265	0.091
1969	0.678	0.199	0.603	0.174	0.597	0.169
1970	0.722	0.160	0.449	0.138	0.407	0.134
1971	0.619	0.176	0.558	0.152	0.491	0.147
1972	0.323	0.048	0.202	0.041	0.177	0.040
1973	0.435	0.061	0.276	0.054	0.242	0.053
1974	0.138	0.027	0.086	0.025	0.074	0.024
1975	0.120	0.033	0.104	0.031	0.091	0.030
1976	0.118	0.025	0.078	0.023	0.074	0.023
1977	0.052	0.022	0.048	0.021	0.044	0.021
1978	0.106	0.047	0.098	0.045	0.092	0.045
1979	0.061	0.032	0.059	0.031	0.056	0.030
1980	0.068	0.027	0.047	0.026	0.045	0.026
1981	0.054	0.028	0.047	0.028	0.045	0.028
1982	0.041	0.027	0.041	0.027	0.039	0.027
1983	0.042	0.030	0.044	0.031	0.042	0.031
1984	0.065	0.042	0.066	0.044	0.064	0.044
1985	0.095	0.059	0.098	0.064	0.095	0.064
1986	0.089	0.059	0.094	0.065	0.092	0.064
1987	0.086	0.051	0.090	0.058	0.088	0.058
1988	0.109	0.065	0.118	0.075	0.117	0.074
1989	0.081	0.044	0.089	0.051	0.089	0.051
1990	0.039	0.025	0.046	0.030	0.046	0.029
1991	0.046	0.034	0.054	0.040	0.052	0.040
1992	0.054	0.039	0.069	0.046	0.068	0.046
1993	0.049	0.028	0.055	0.033	0.055	0.033
1994	0.064	0.037	0.078	0.043	0.077	0.042
1995	0.055	0.035	0.071	0.041	0.070	0.040
1996	0.052	0.037	0.067	0.043	0.066	0.043
1997	0.084	0.052	0.107	0.059	0.105	0.059
1998	0.058	0.032	0.069	0.036	0.069	0.036
1999	0.041	0.023	0.047	0.026	0.048	0.026
2000	0.047	0.030	0.055	0.034	0.055	0.033
2001	0.035	0.023	0.040	0.026	0.040	0.025

2002	0.040	0.026	0.047	0.029	0.047	0.029
2003	0.035	0.025	0.041	0.027	0.040	0.027
2004	0.032	0.023	0.036	0.025	0.036	0.024
2005	0.038	0.028	0.043	0.030	0.042	0.029
2006	0.040	0.029	0.045	0.031	0.044	0.030
2007	0.052	0.037	0.057	0.038	0.055	0.038
2008	0.066	0.047	0.073	0.049	0.071	0.048
2009	0.046	0.034	0.048	0.035	0.047	0.035
2010	0.050	0.036	0.054	0.037	0.053	0.037
2011	0.065	0.046	0.069	0.048	0.068	0.047
2012	0.064	0.048	0.068	0.049	0.066	0.048
2013	0.075	0.056	0.079	0.057	0.077	0.056
2014	0.077	0.053	0.079	0.055	0.078	0.054
2015	0.066	0.043	0.065	0.045	0.065	0.044
2016	0.072	0.045	0.071	0.047	0.070	0.047
2017	0.068	0.044	0.069	0.047	0.068	0.046
2018	0.068	0.047	0.071	0.051	0.070	0.050
2019	0.070	0.043	0.075	0.048	0.074	0.048
2020	0.072	0.044	0.080	0.053	0.078	0.052
2021	0.058	0.032	0.066	0.042	0.064	0.041
2022	0.076	0.034	0.089	0.057	0.085	0.057
2023	0.007	0.005	0.048	0.028	0.047	0.028

Table 4.18: Model estimates of yellowfin sole female spawning biomass (FSB) in the eastern Bering Sea in metric tons (t) and upper (HCI) and lower (LCI) 95% confidence intervals from the 2022 and 2023 stock assessments, including Model 22.1 (2022), 22.1 (2023), and 23.0.

Model	22.1 (2022)	22.1 (2023)			23.0		
Year	FSB (t)	FSB (t)	LCI	HCI	FSB (t)	LCI	HCI
1954	902,163	1,009,550	747,089	1,364,210	942,185	669,184	1326560
1955	910,428	1,019,200	764,201	1,359,290	950,817	682,656	1324320
1956	901,639	1,009,930	766,235	1,331,130	941,647	682,378	1299420
1957	878,436	984,705	754,577	1,285,020	917,440	669,672	1256880
1958	843,822	946,727	731,335	1,225,560	881,269	646,586	1201130
1959	770,719	868,309	671,186	1,123,320	805,469	587,675	1103980
1960	590,420	680,368	510,780	906,261	618,848	426,433	898084
1961	297,337	382,539	250,173	584,939	298,863	134,248	665332
1962	33,713	110,451	37,041	329,348	116,917	43,620	313377
1963	5,894	34,633	6,852	175,048	75,738	37,009	154997
1964	12,024	40,164	11,390	141,626	84,800	50,807	141537
1965	21,594	51,912	19,576	137,657	100,964	67,548	150909
1966	36,321	74,103	35,011	156,842	123,067	87,301	173485
1967	51,718	89,542	47,306	169,487	131,833	94,348	184210
1968	68,311	97,591	53,704	177,342	132,825	93,216	189263
1969	69,140	102,234	57,749	180,987	131,256	88,926	193735
1970	69,115	91,616	49,422	169,833	113,644	70,969	181980
1971	74,327	82,268	39,215	172,586	102,921	58,707	180434
1972	67,047	76,709	33,772	174,232	96,388	49,935	186056
1973	74,523	88,683	39,470	199,253	109,262	55,857	213726
1974	87,493	108,469	51,276	229,454	130,058	68,558	246725
1975	137,928	172,936	91,772	325,880	200,295	115,430	347554
1976	200,473	246,678	147,134	413,569	275,727	172,869	439786
1977	296,953	355,359	232,776	542,497	386,760	260,797	573561
1978	421,756	488,649	342,439	697,288	523,068	373,051	733411
1979	552,840	625,546	457,205	855,870	662,815	490,181	896249
1980	699,582	780,161	589,623	1,032,270	820,285	625,415	1075870
1981	835,554	927,097	717,879	1,197,290	969,633	756,487	1242830
1982	912,222	1,005,260	790,314	1,278,660	1,047,420	828,856	1323610
1983	1,024,230	1,117,590	891,019	1,401,770	1,160,050	930,045	1446930
1984	1,112,620	1,197,990	966,406	1,485,070	1,238,910	1,003,890	1528960
1985	1,166,280	1,238,160	1,001,480	1,530,770	1,276,440	1,036,010	1572670
1986	1,155,190	1,203,420	969,720	1,493,430	1,237,270	999,653	1531370
1987	1,153,440	1,172,470	939,380	1,463,390	1,202,480	965,322	1497910
1988	1,096,160	1,081,000	858,934	1,360,470	1,105,970	879,813	1390260
1989	1,074,330	1,018,440	802,292	1,292,810	1,039,080	818,816	1318580
1990	1,091,800	993,169	782,716	1,260,210	1,010,820	796,426	1282940
1991	1,181,860	1,033,990	822,410	1,299,990	1,050,570	835,173	1321530
1992	1,277,710	1,084,160	870,850	1,349,720	1,100,260	883,004	1370970
1993	1,323,910	1,107,650	893,553	1,373,050	1,122,900	904,920	1393400
1994	1,318,420	1,104,910	893,803	1,365,870	1,119,520	904,879	1385090
1995	1,306,810	1,095,890	885,700	1,355,960	1,110,750	897,410	1374810
1996	1,229,900	1,036,740	835,344	1,286,680	1,051,540	847,189	1305170
1997	1,192,110	1,010,000	811,964	1,256,330	1,025,010	824,082	1274930
1998	1,120,550	953,793	762,121	1,193,670	967,906	773,338	1211430
1999	1,108,230	952,462	760,774	1,192,450	966,259	771,889	1209570
2000	1,041,530	901,738	718,467	1,131,760	914,905	729,169	1147950

2001	1,106,600	963,023	767,526	1,208,320	977,689	779,568	1226160
2002	1,074,700	950,004	760,348	1,186,970	965,461	773,138	1205630
2003	1,134,740	1,018,300	818,397	1,267,030	1,036,050	833,149	1288350
2004	1,177,520	1,078,760	870,780	1,336,410	1,098,610	887,288	1360270
2005	1,210,830	1,127,750	913,074	1,392,900	1,148,700	930,420	1418180
2006	1,253,620	1,183,450	959,126	1,460,250	1,206,230	977,920	1487840
2007	1,201,800	1,154,590	936,159	1,423,980	1,176,780	954,450	1450900
2008	1,129,350	1,105,760	896,836	1,363,350	1,127,590	914,724	1389980
2009	1,178,930	1,170,720	947,817	1,446,040	1,194,250	967,065	1474810
2010	1,236,230	1,240,280	1,003,310	1,533,210	1,264,790	1,023,370	1563180
2011	1,144,810	1,163,980	943,644	1,435,770	1,186,290	961,872	1463060
2012	1,143,040	1,168,490	945,688	1,443,790	1,190,830	963,920	1471150
2013	1,094,710	1,123,650	909,788	1,387,780	1,144,280	926,529	1413210
2014	1,064,040	1,093,170	882,054	1,354,820	1,112,410	897,460	1378840
2015	1,096,900	1,131,030	911,606	1,403,270	1,149,250	925,999	1426320
2016	1,080,390	1,116,720	900,977	1,384,110	1,133,570	914,256	1405500
2017	1,114,700	1,153,160	926,382	1,435,460	1,171,400	940,773	1458550
2018	1,018,300	1,045,950	843,034	1,297,700	1,062,240	856,132	1317970
2019	1,081,010	1,095,600	881,193	1,362,180	1,113,460	895,683	1384190
2020	1,045,950	1,043,360	835,355	1,303,150	1,061,580	850,278	1325400
2021	967,874	953,089	760,503	1,194,440	971,291	775,613	1216340
2022	923,828	959,936	760,333	1,211,940	980,120	777,156	1236090
2023	NA	896,720	706,333	1,138,430	916,707	722,973	1162360

Table 4.19: Yellowfin sole total allowable catch (TAC), overfishing limit (OFL), and acceptable biological catch (ABC) levels, 1980-2021. Catch for the Bering Sea and Aleutian Islands was recorded through October 20, 2023. Data is in metric tons. Estimates for 2023 were calculated using Model 23.0, and the 2023 TAC has not yet been set.

Year	TAC	ABC	OFL	Catch
1980	117,000	169,000	n/a	87,391
1981	117,000	214,500	n/a	97,301
1982	117,000	214,500	n/a	95,712
1983	117,000	214,500	n/a	108,385
1984	230,000	310,000	n/a	159,526
1985	229,900	310,000	n/a	227,107
1986	209,500	230,000	n/a	208,597
1987	187,000	187,000	n/a	181,428
1988	254,000	254,000	n/a	223,156
1989	182,675	241,000	n/a	153,165
1990	207,650	278,900	n/a	83,970
1991	135,000	250,600	n/a	117,303
1992	235,000	372,000	452,000	145,386
1993	220,000	238,000	275,000	105,810
1994	150,325	230,000	269,000	140,050
1995	190,000	277,000	319,000	124,752
1996	200,000	278,000	342,000	129,659
1997	230,000	233,000	339,000	182,814
1998	220,000	220,000	314,000	101,155
1999	207,980	212,000	308,000	69,234
2000	123,262	191,000	226,000	84,071
2001	113,000	176,000	209,000	63,579
2002	86,000	115,000	136,000	74,986
2003	83,750	114,000	136,000	79,806
2004	86,075	114,000	135,000	75,511
2005	90,686	124,000	148,000	94,385
2006	95,701	121,000	144,000	99,160
2007	136,000	225,000	240,000	120,964
2008	225,000	248,000	265,000	148,894
2009	210,000	210,000	224,000	107,513
2010	219,000	219,000	234,000	118,624
2011	196,000	239,000	262,000	151,158
2012	202,000	203,000	222,000	147,187
2013	198,000	206,000	220,000	164,944
2014	184,000	239,800	259,700	156,772
2015	149,000	248,800	266,400	126,937
2016	144,000	211,700	228,100	135,324
2017	154,000	260,800	287,000	132,220
2018	154,000	277,500	306,700	131,496
2019	154,000	263,200	290,000	128,051
2020	150,700	260,918	287,307	133,800
2021	200,000	313,477	341,571	108,788
2022	250,000	354,014	377,014	106,096
2023		265,913	305,298	74,848

Table 4.20: Projections of yellowfin sole female spawning biomass (FSB), future catch, and full selection fishing mortality rates (F) for seven future harvest scenarios. Estimates of FSB and catch are in metric tons (t). All estimates are based on Model 23.0.

Scenarios 1 and 2 Maximum ABC harvest permissible			
Year	FSB	Catch	F
2023	751,980	121,103	0.068
2024	703,832	190,122	0.110
2025	655,756	176,358	0.104
2026	635,994	170,204	0.101
2027	628,709	168,501	0.100
2028	632,470	173,211	0.101
2029	641,483	177,834	0.102
2030	654,103	183,311	0.104
2031	665,351	187,538	0.106
2032	671,331	188,526	0.107
2033	679,924	189,517	0.107
2034	685,601	188,648	0.106
2035	690,501	188,530	0.105
2036	694,295	188,388	0.105

Scenario 3 Harvest at average F over past 5 years			
Year	FSB	Catch	F
2023	751,980	121,103	0.068
2024	712,890	123,222	0.070
2025	687,857	123,548	0.070
2026	685,977	125,890	0.070
2027	693,457	128,163	0.070
2028	710,345	132,533	0.070
2029	731,734	135,592	0.070
2030	757,013	138,496	0.070
2031	781,297	140,797	0.070
2032	799,298	142,211	0.070
2033	820,082	144,199	0.070
2034	836,230	145,287	0.070
2035	850,140	146,729	0.070
2036	861,188	147,862	0.070

Scenario 4, Maximum Tier 3 ABC harvest permissible set at F60			
Year	FSB	Catch	F
2023	751,980	121,103	0.068
2024	716,550	95,785	0.054
2025	701,622	97,277	0.054
2026	709,241	100,234	0.054
2027	725,790	102,991	0.054
2028	751,341	107,320	0.054
2029	780,880	110,531	0.054
2030	814,014	113,569	0.054
2031	845,749	116,063	0.054
2032	870,216	117,747	0.054
2033	897,519	119,879	0.054
2034	919,371	121,172	0.054
2035	938,463	122,737	0.054
2036	953,939	124,027	0.054

Scenario 5 No fishing			
Year	FSB	Catch	F
2023	751,980	121,103	0.068
2024	729,084	0	0.000
2025	750,385	0	0.000
2026	794,380	0	0.000
2027	847,877	0	0.000
2028	910,762	0	0.000
2029	977,286	0	0.000
2030	1,047,577	0	0.000
2031	1,116,075	0	0.000
2032	1,174,192	0	0.000
2033	1,236,336	0	0.000
2034	1,290,279	0	0.000
2035	1,339,791	0	0.000
2036	1,382,560	0	0.000

Alternative 6, Determination of whether yellowfin sole are currently overfished			
Year	FSB	Catch	F
2023	751,980	121,103	0.068
2024	699,032	224,987	0.131
2025	639,525	200,187	0.122
2026	612,051	188,556	0.116
2027	599,078	183,520	0.113
2028	598,509	186,520	0.113
2029	604,198	190,005	0.114
2030	614,053	194,747	0.116
2031	622,991	198,441	0.118
2032	627,281	199,708	0.119
2033	633,773	202,073	0.120
2034	637,220	201,820	0.120
2035	639,770	201,950	0.120
2036	641,385	201,725	0.119

Scenario 7, Determination of whether stock is approaching an overfished condition			
Year	FSB	Catch	F
2023	751,980	121,103	0.068
2024	703,832	190,122	0.110
2025	655,756	176,358	0.104
2026	632,192	200,377	0.120
2027	614,804	192,316	0.117
2028	610,442	193,024	0.116
2029	612,862	194,613	0.116
2030	620,047	197,877	0.118
2031	626,945	200,472	0.119
2032	629,750	200,941	0.120
2033	635,266	202,761	0.120
2034	638,097	202,188	0.120
2035	640,264	202,138	0.120
2036	641,632	201,811	0.119

Figures

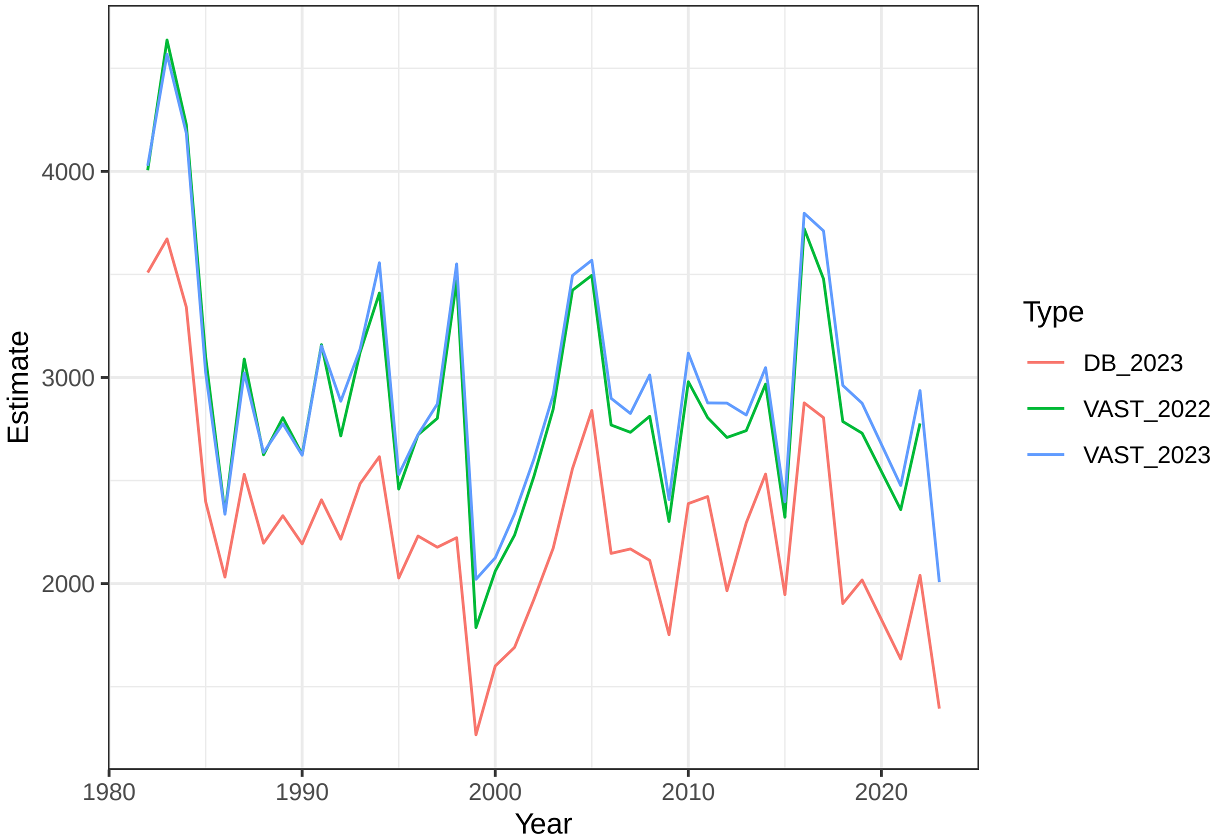

Figure 4.1: VAST biomass estimates for the EBS+NBS, generated in 2023 (VAST_2023) and 2022 (VAST_2022), and the design-based estimate for the eastern Bering Sea only (DB_2023).

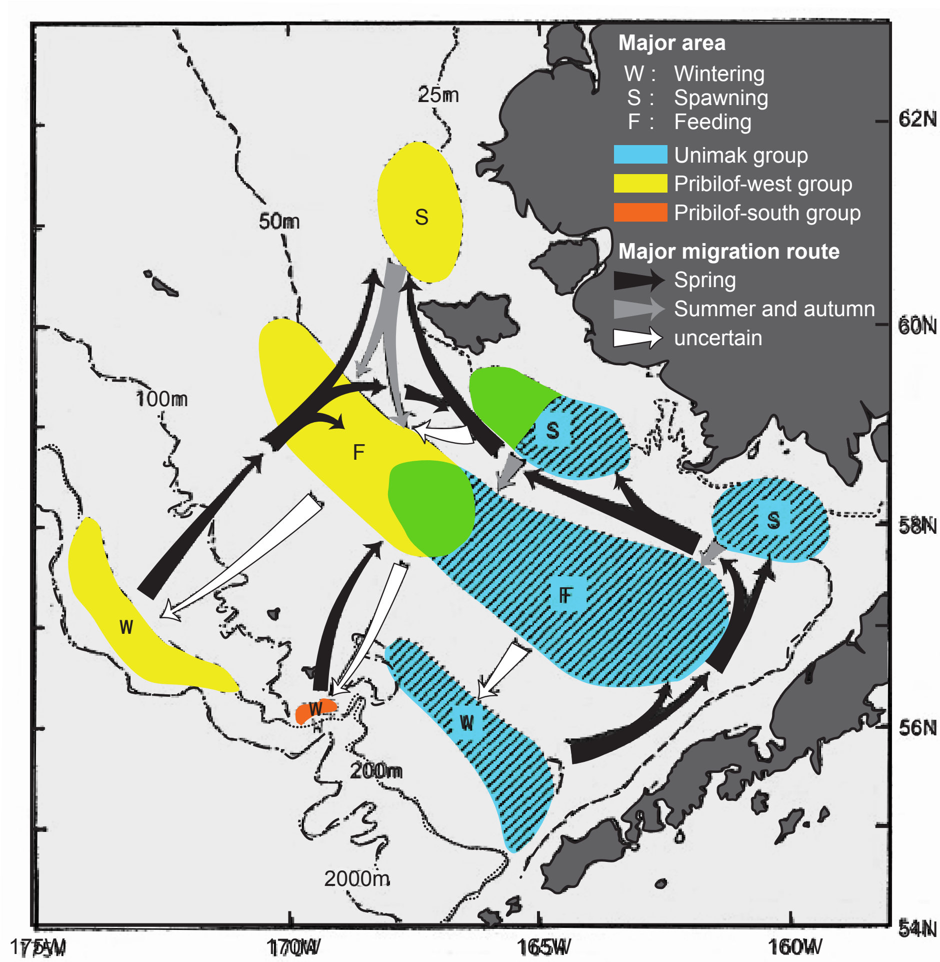

Figure 4.2: Distribution of wintering, spawning, and feeding areas for yellowfin sole in the Bering Sea, and observed regional grouping. Migration routes from wintering to feeding take place in spring, and the dates that yellowfin sole return to their wintering areas are unknown, adapted from Wakabayashi (1989).

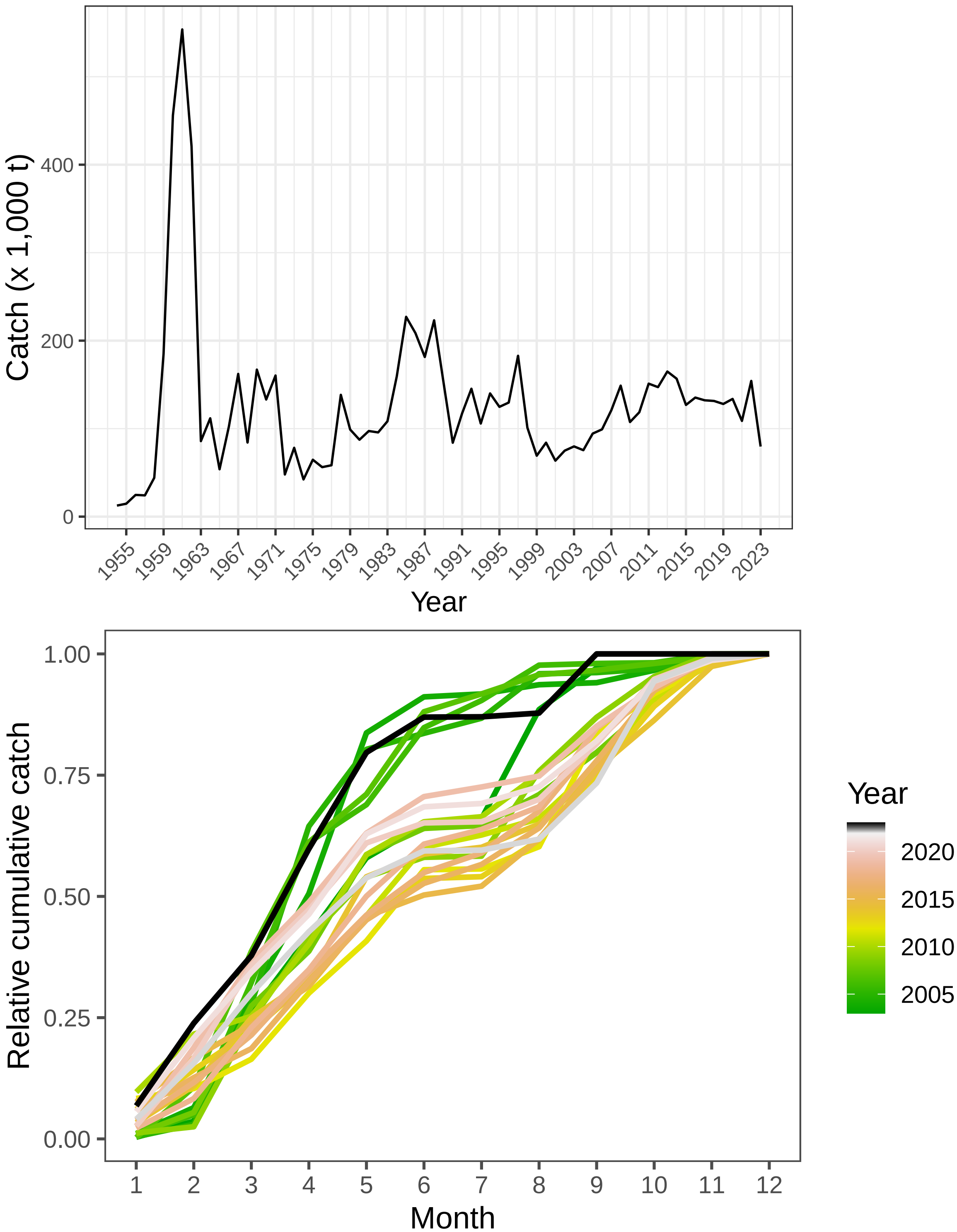

Figure 4.3: Yellowfin sole annual total catch (1,000s t) in the eastern Bering Sea from 2003-2023 (upper panel). Yellowfin sole annual cumulative catch by month and year (non CDQ) 2003-October 20, 2023 (lower panel).

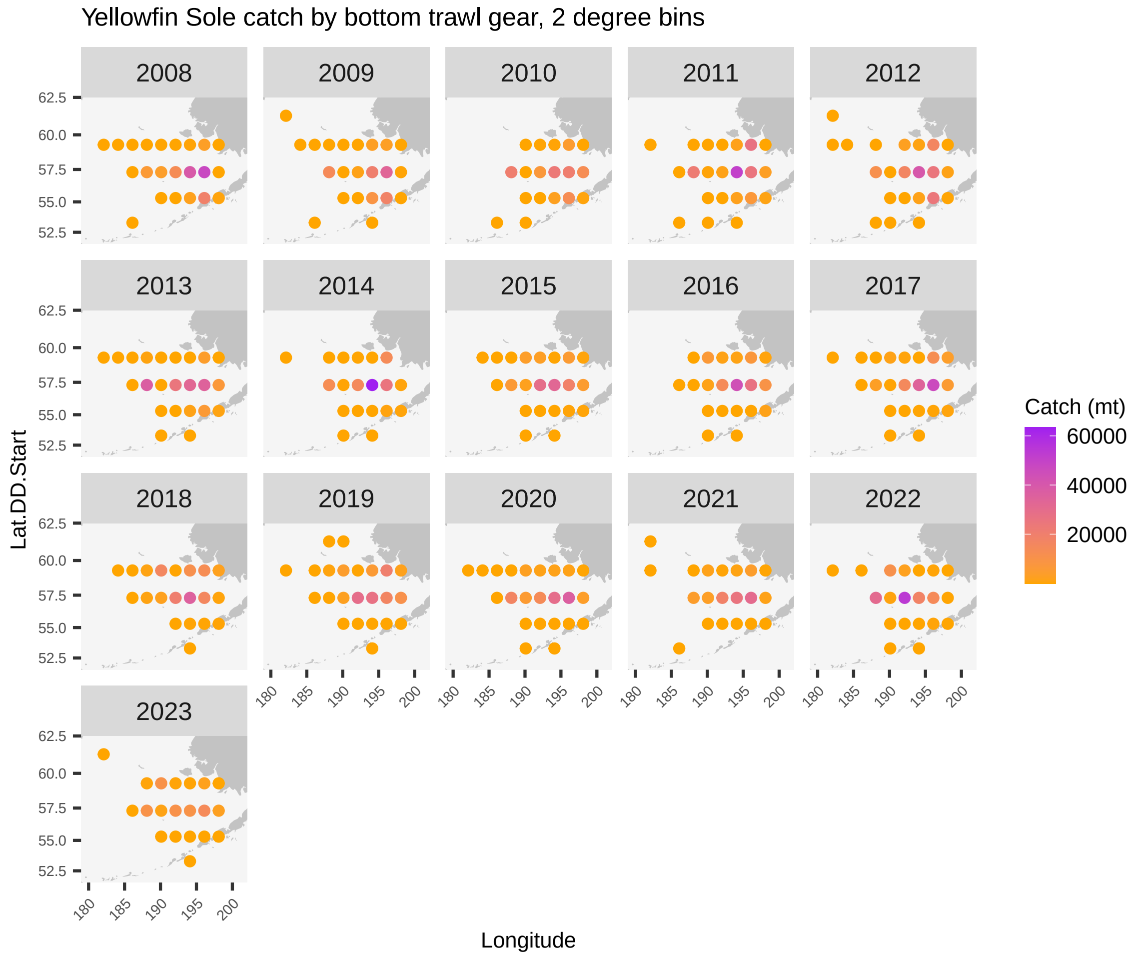

Figure 4.4: Catch of yellowfin sole by non-pelagic trawl gear in the eastern Bering Sea, 2008-2023, by year, reported by observers. Colored circles represent catch of yellowfin sole, with darker shades representing higher catch.

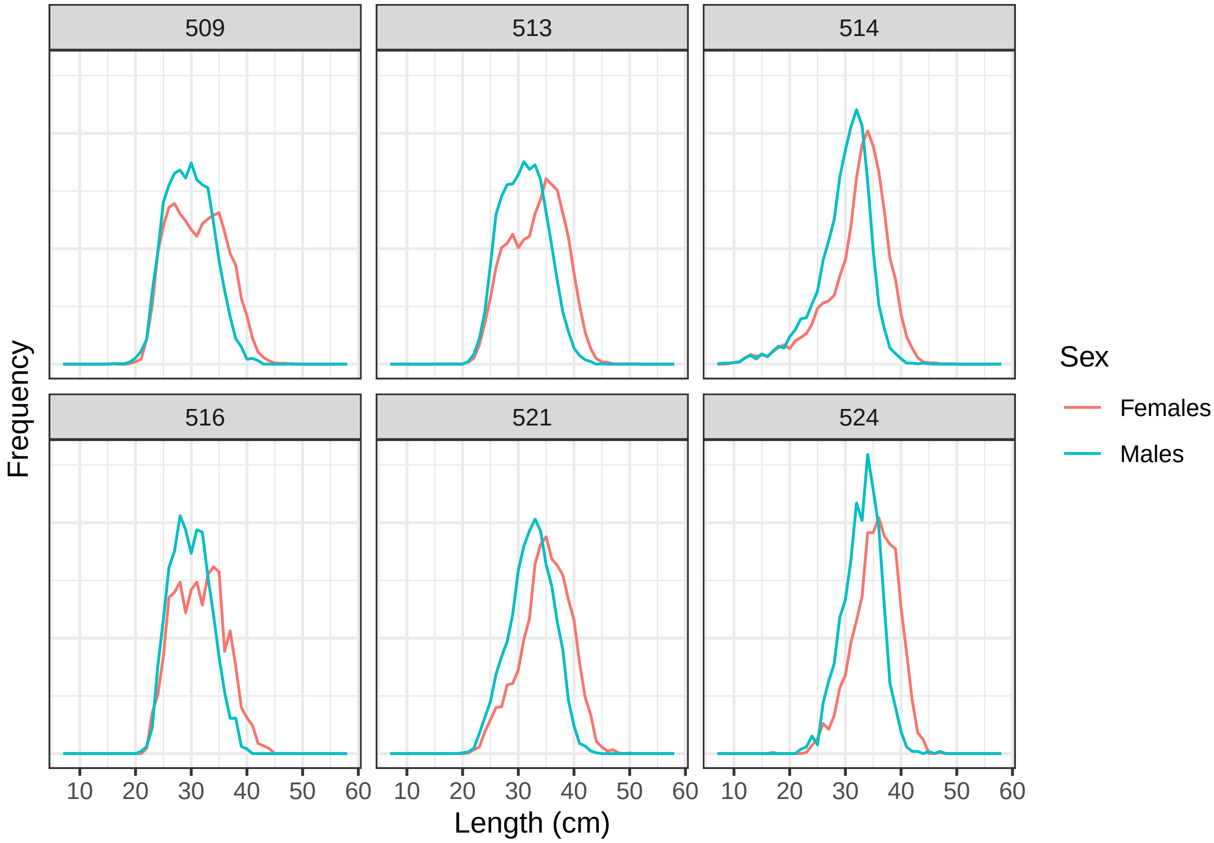

Figure 4.5: Size composition of the yellowfin sole catch in 2023 (through October 28) caught by trawl gear, by subarea, for the primary areas where yellowfin sole are caught, 509, 513, 514, 516, 521, and 524.

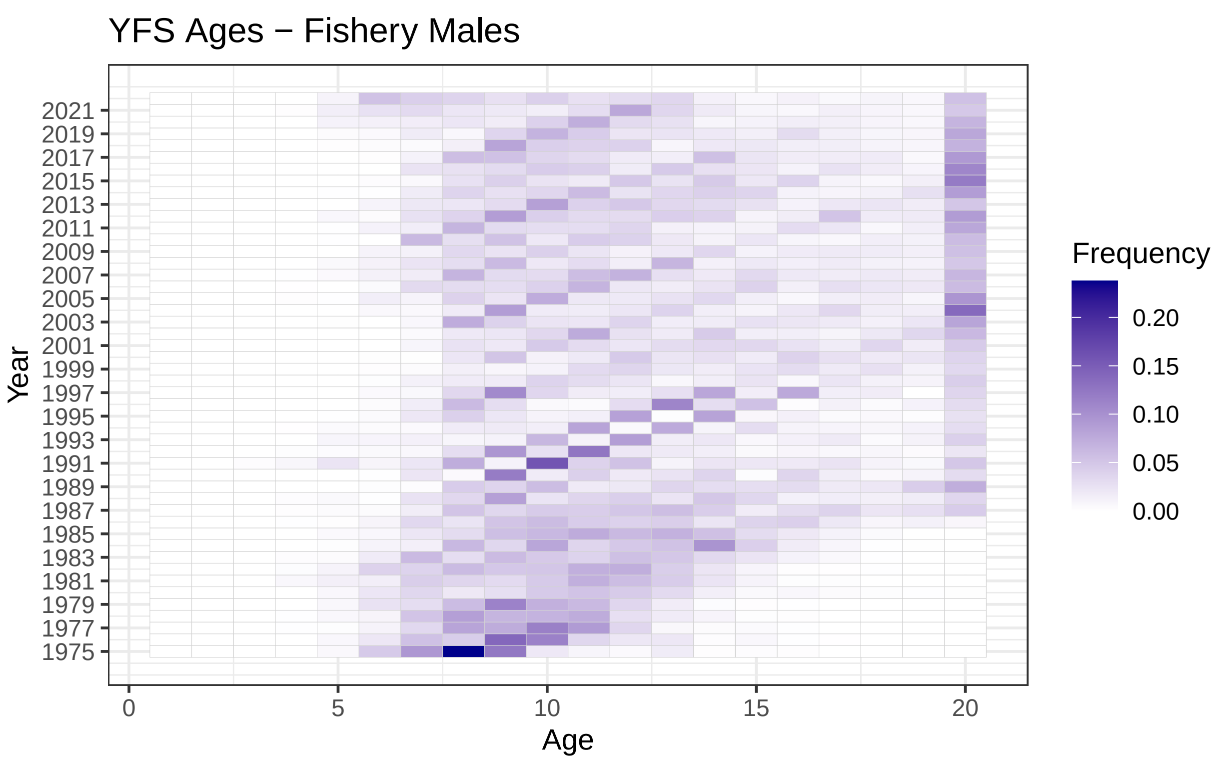

Figure 4.6: Age frequency of females and males from the yellowfin sole fishery, 1975 - 2022.

Figure 4.7: Age frequency of yellowfin sole females and males from the AFSC/NMFS research surveys, 1977-2022.

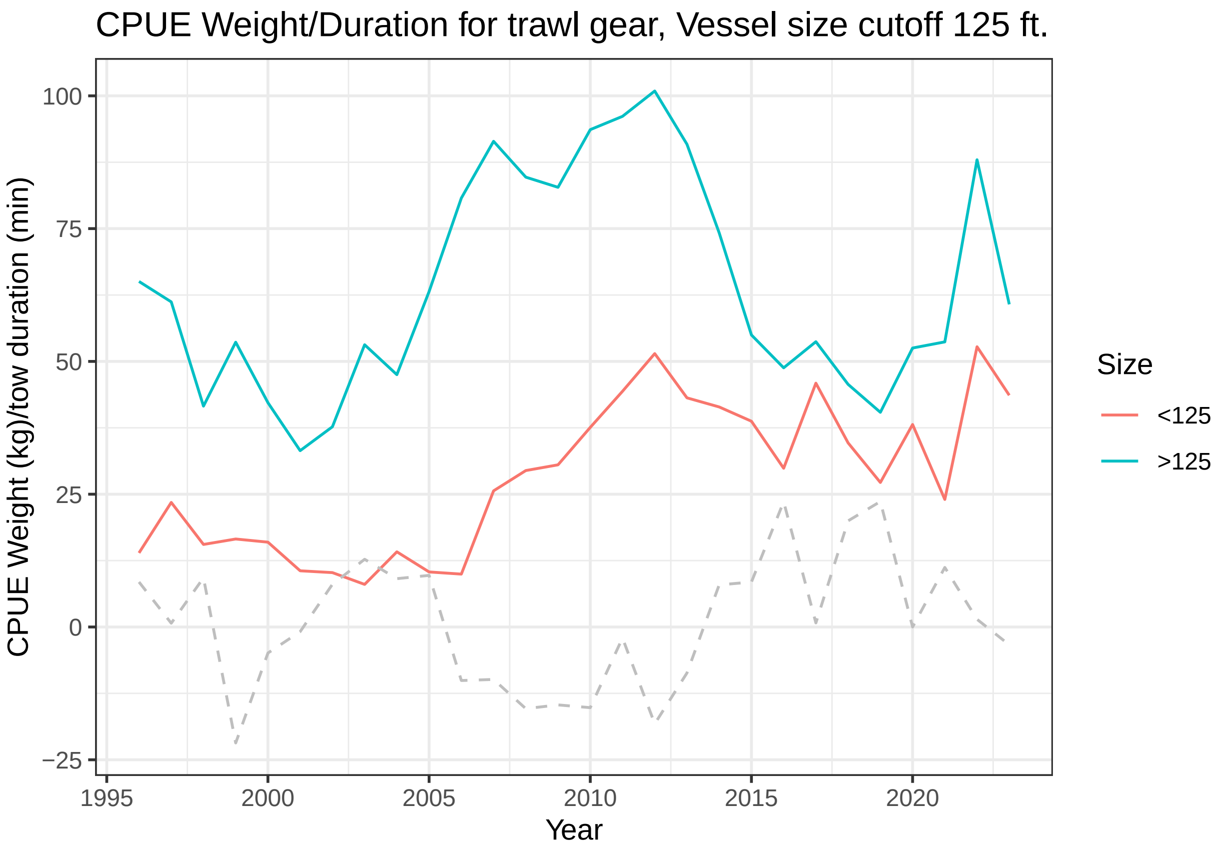

Figure 4.8: Catch per unit effort based on yellowfin sole fishery data, 1996-2023. CPUE weight (kg)/trawl duration (min) is shown for vessels greater and less than 125 ft, and only including self-made tows. Estimates of relative CPUE are complete through October 26, 2023. Results are limited to Catcher/Processor and Catcher vessels and tow duration >0 and <the 90% percentile of all the data (974 minutes). Source: NMFS/AKRO Catch Accounting System. The EBS bottom temperature anomalies from 1996-2023 (x10 for visualization) are shown as a dotted line.

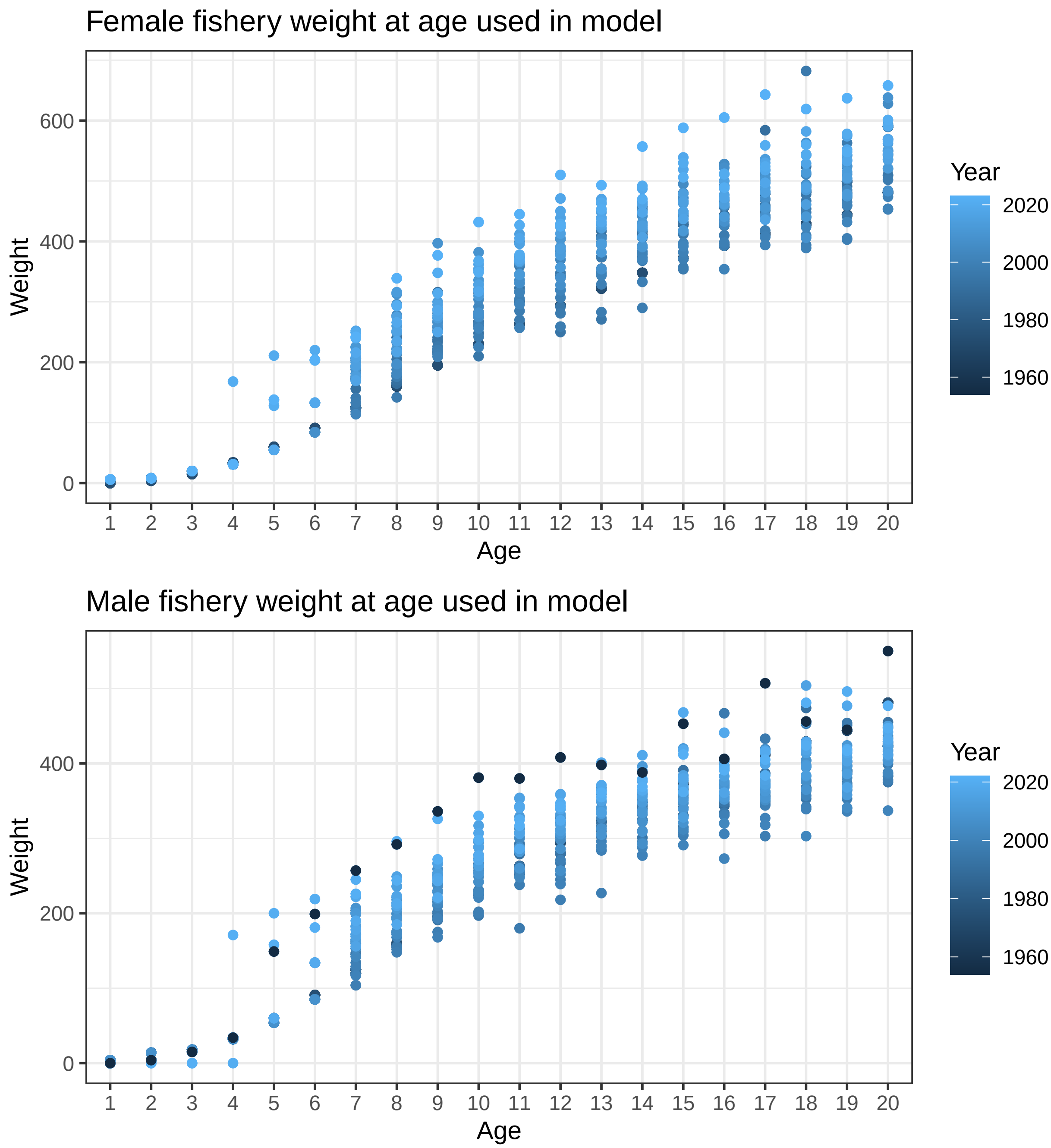

Figure 4.9: Estimates of weight (g) at age for yellowfin sole females and males, based on fishery data 1954-2022, and used in this year's models.

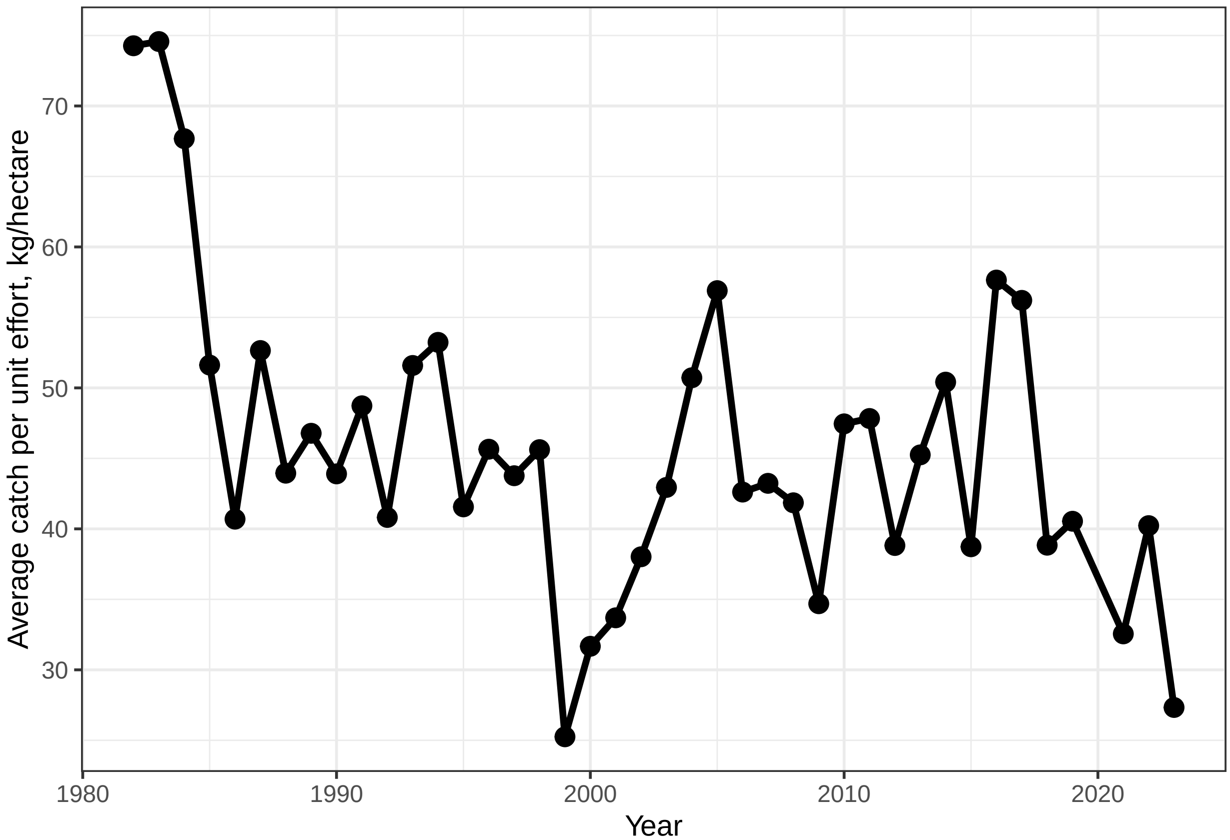

Figure 4.10: Average catch per unit effort on NMFS eastern Bering Sea surveys, 1987-2023, in kg/hectare.

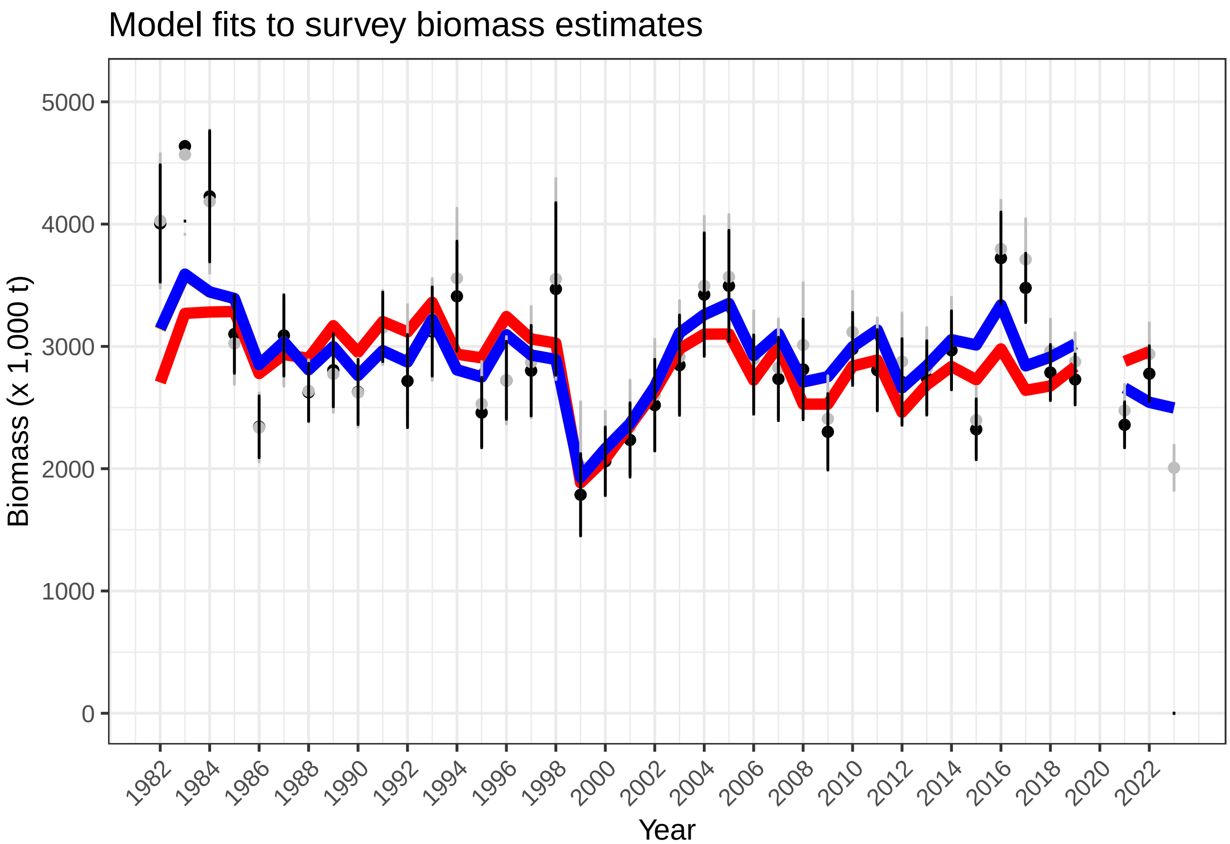

Figure 4.11: Annual eastern Bering Sea bottom trawl survey biomass point estimates and 95% confidence intervals for yellowfin sole, 1982-2023, with 2022 Model 22.1 (red line), Model 22.1 (orange line), and Model 23.0 (blue line). Model 22.1 and Model 23.0 biomass estimates were identical, and the blue line covers the orange line. VAST survey estimates with 95% confidence intervals are in grey (2023 estimate) and black (2022 estimate).

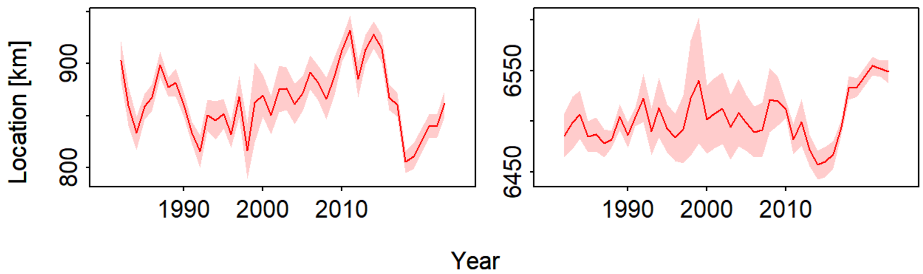

Figure 4.12: Center of gravity plot with eastings (Longitude) in the left panel and northings (Latitude) in the right panel. The units are in kilometers.

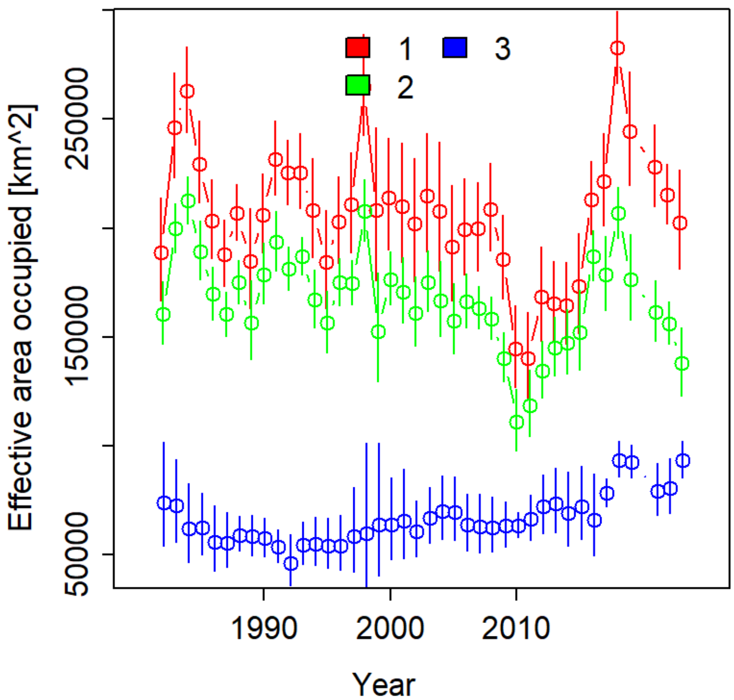

Figure 4.13: The effective area occupied by yellowfin sole, estimated in the VAST analysis, in the eastern Bering Sea (green), northern Bering Sea (blue) and the combined region (red).

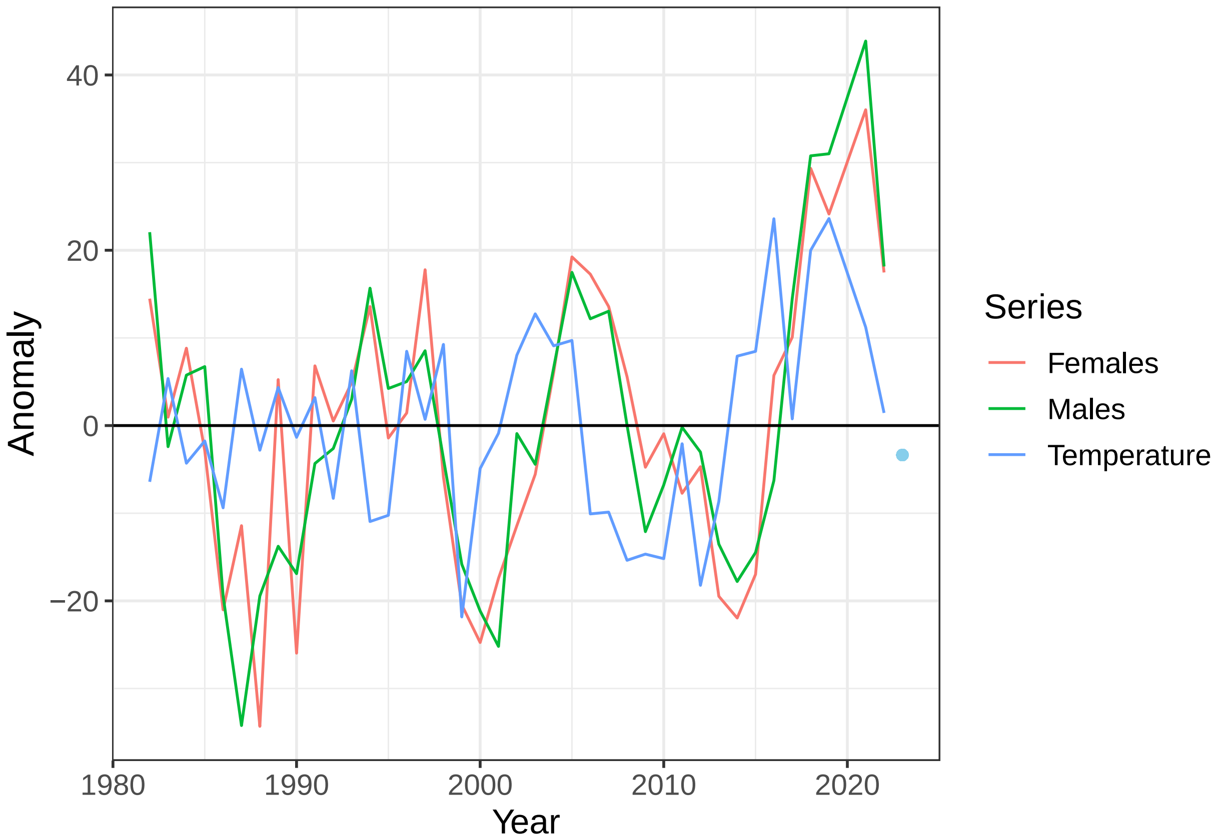

Figure 4.14: Yellowfin sole length-at-age anomalies, for 5-year old males and females, and bottom temperature anomalies from the eastern Bering Sea survey area <100 m. Correspondence in these residuals is apparent with a 2-3 year lag effect from the mid-1990s to 2022 (excluding 2020). Late 1980s and 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. Age data is not yet available for 2023, but the 2023 temperature anomaly is represented by a blue point.

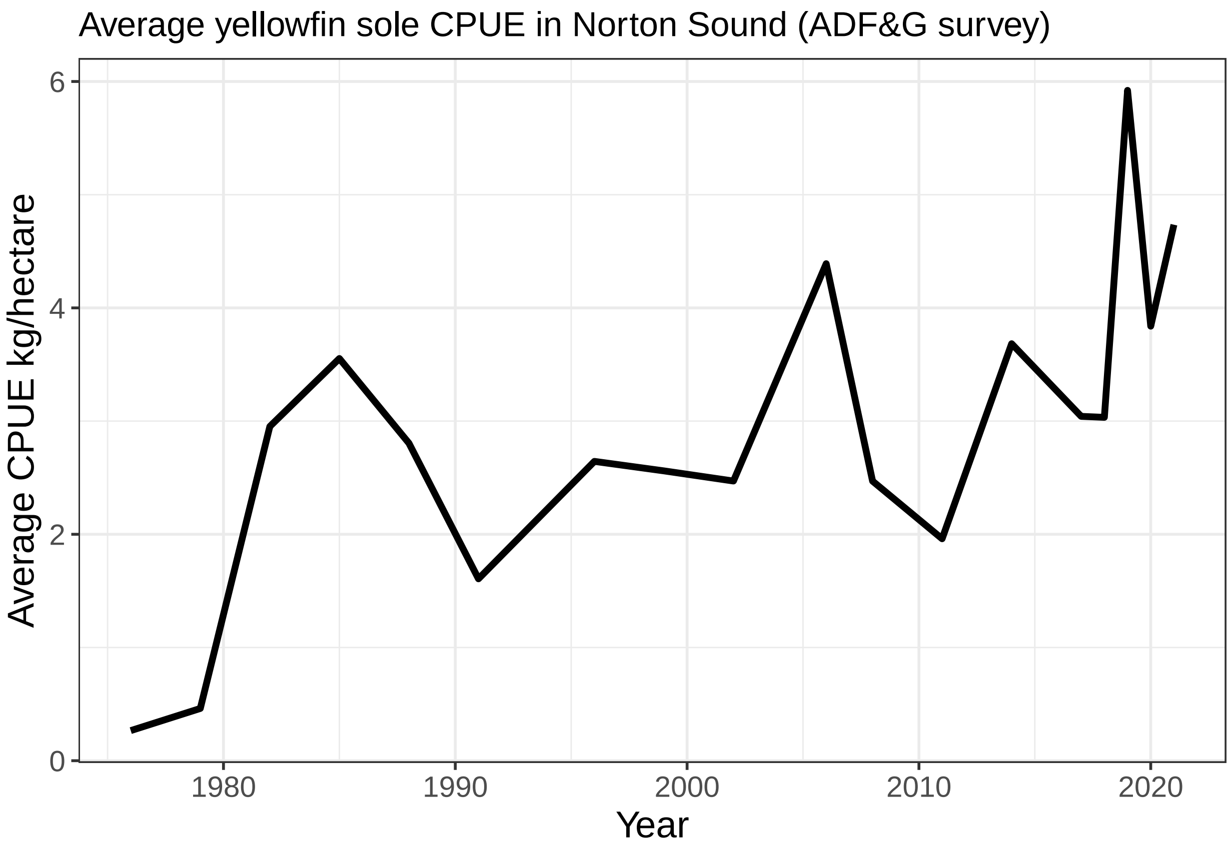

Figure 4.15: Average catch per unit effort (CPUE) of yellowfin sole in Norton Sound, based on ADF&G survey time series, 1976 - 2021. There was no survey in 2022 and the 2023 data is not yet available.

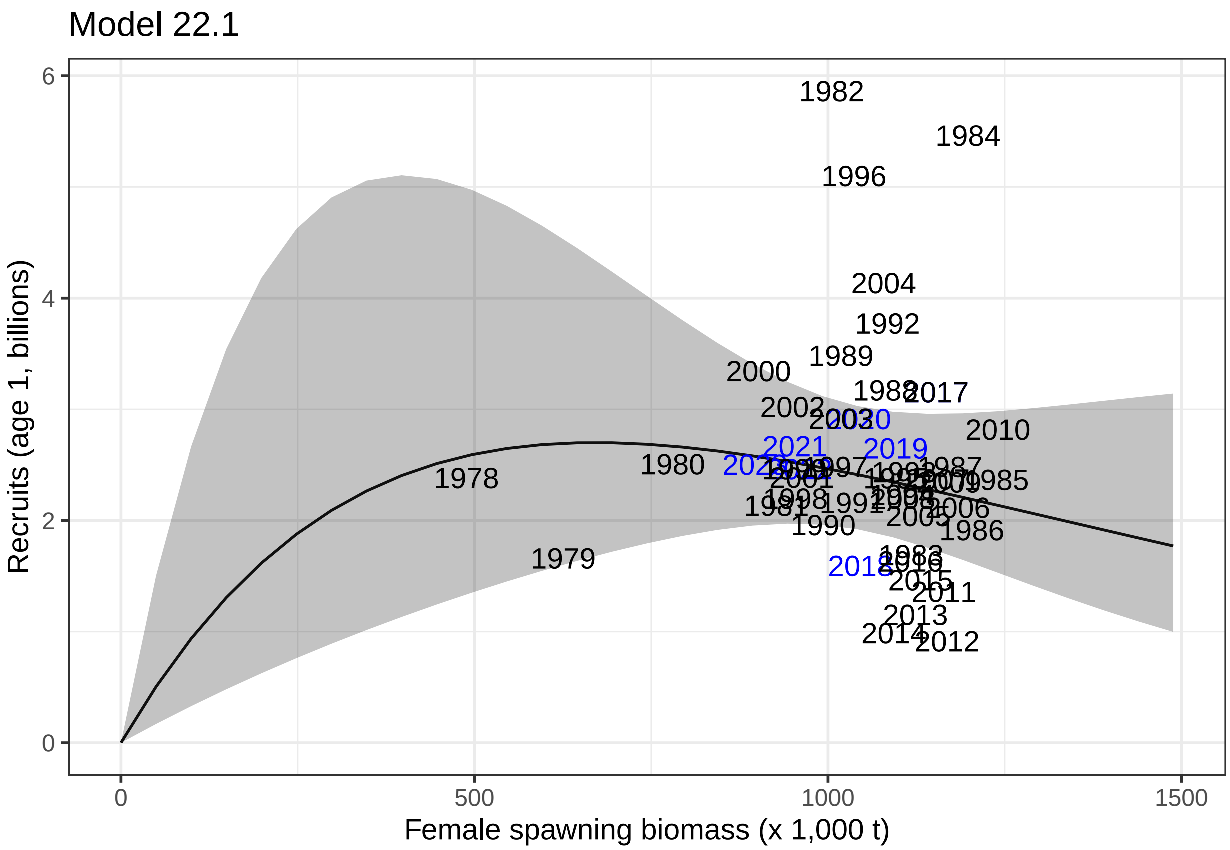

Figure 4.16: Ricker stock recruitment curve for yellowfin sole Model 22.1 with 95% confidence intervals (shaded region) fit to female spawning biomass and recruitment data from 1978-2017. Years in black indicate data used to fit the model, years in blue were not used to fit the model.

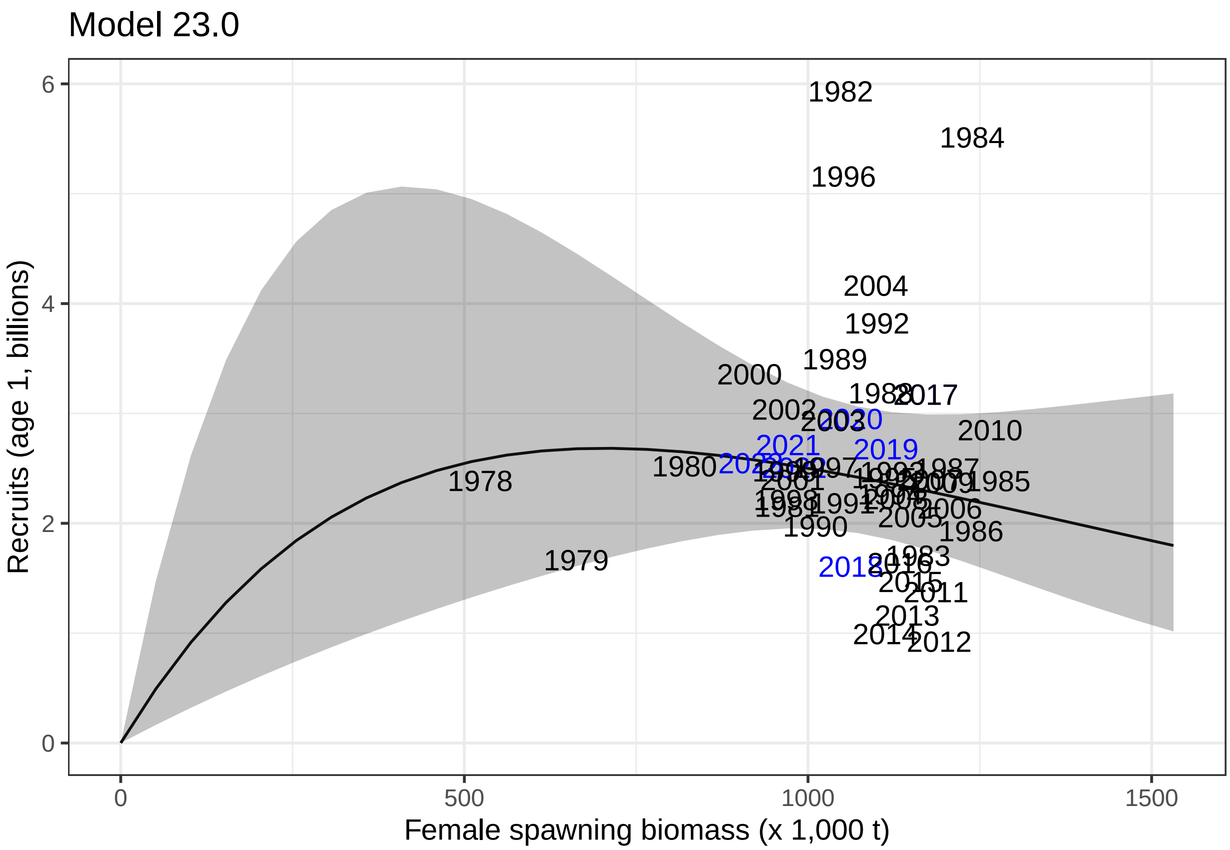

Figure 4.17: Ricker stock recruitment curve for yellowfin sole Model 23.0 with 95% confidence intervals (shaded region) fit to female spawning biomass and recruitment data from 1978-2017. Years in black indicate data used to fit the model, years in blue were not used to fit the model.

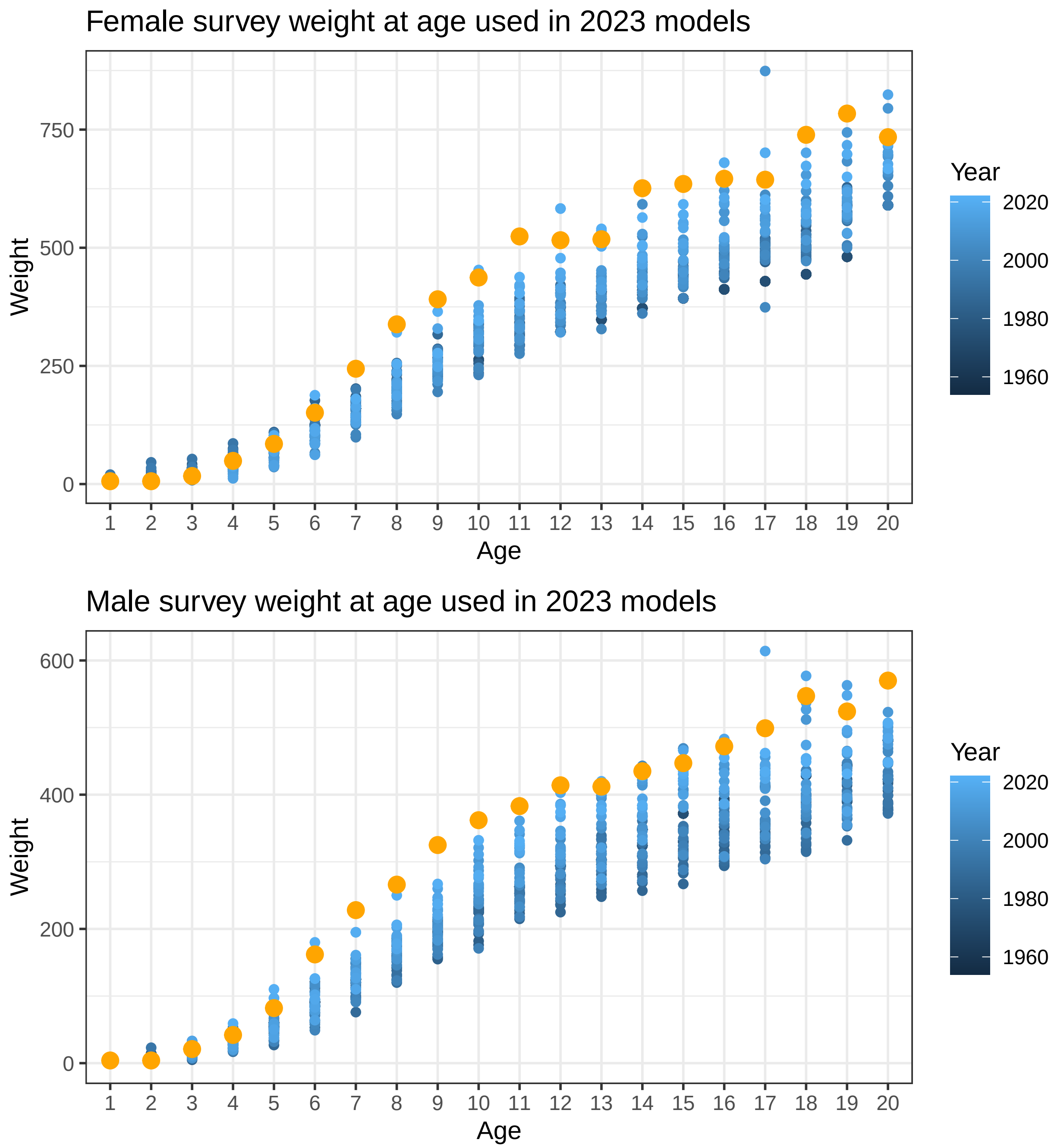

Figure 4.18: Mean weight at age (g) for yellowfin sole females and males from the eastern Bering Sea survey, 1954-2023 used in Model 22.1 and 23.0. Estimates for 2023 are highlighted in yellow.

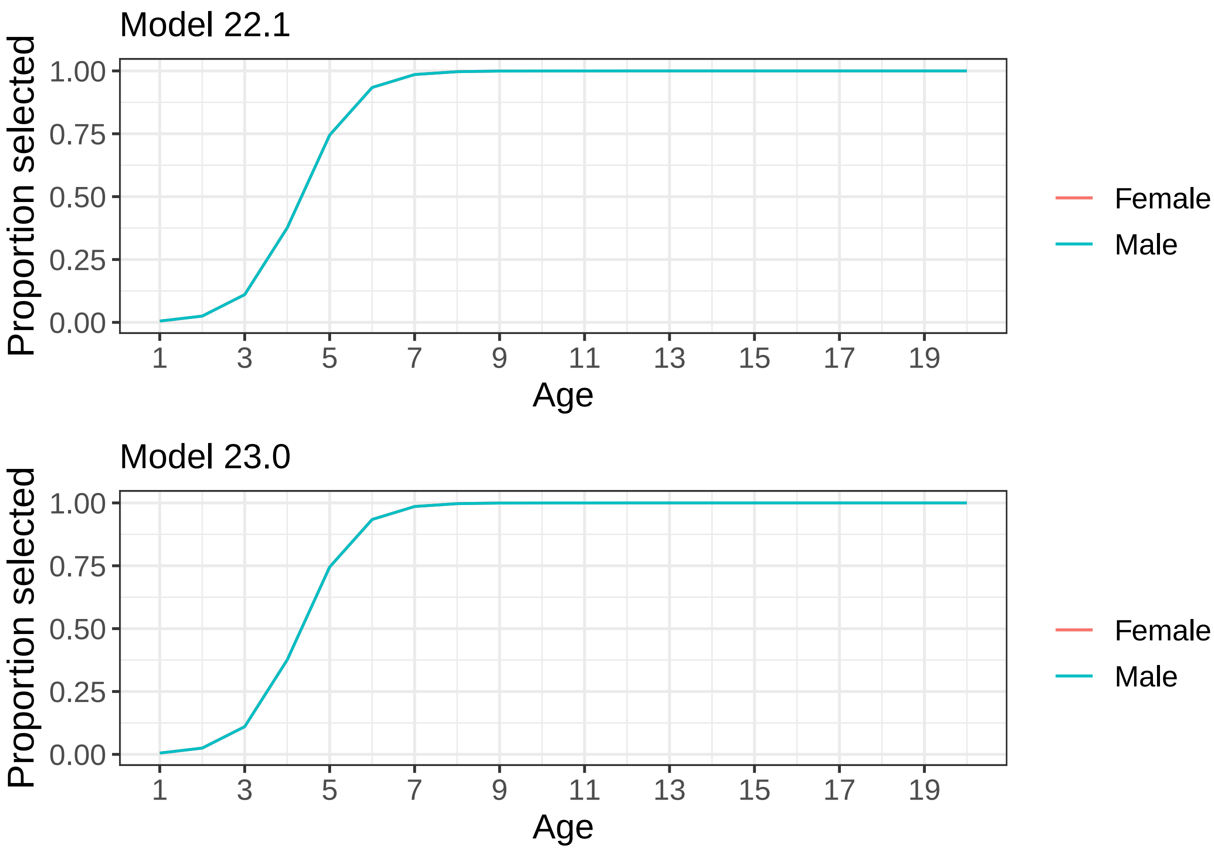

Figure 4.19: Estimate of yellowfin sole survey selectivity for males and females, Model 22.1 upper panel, and Model 23.0 lower panel.

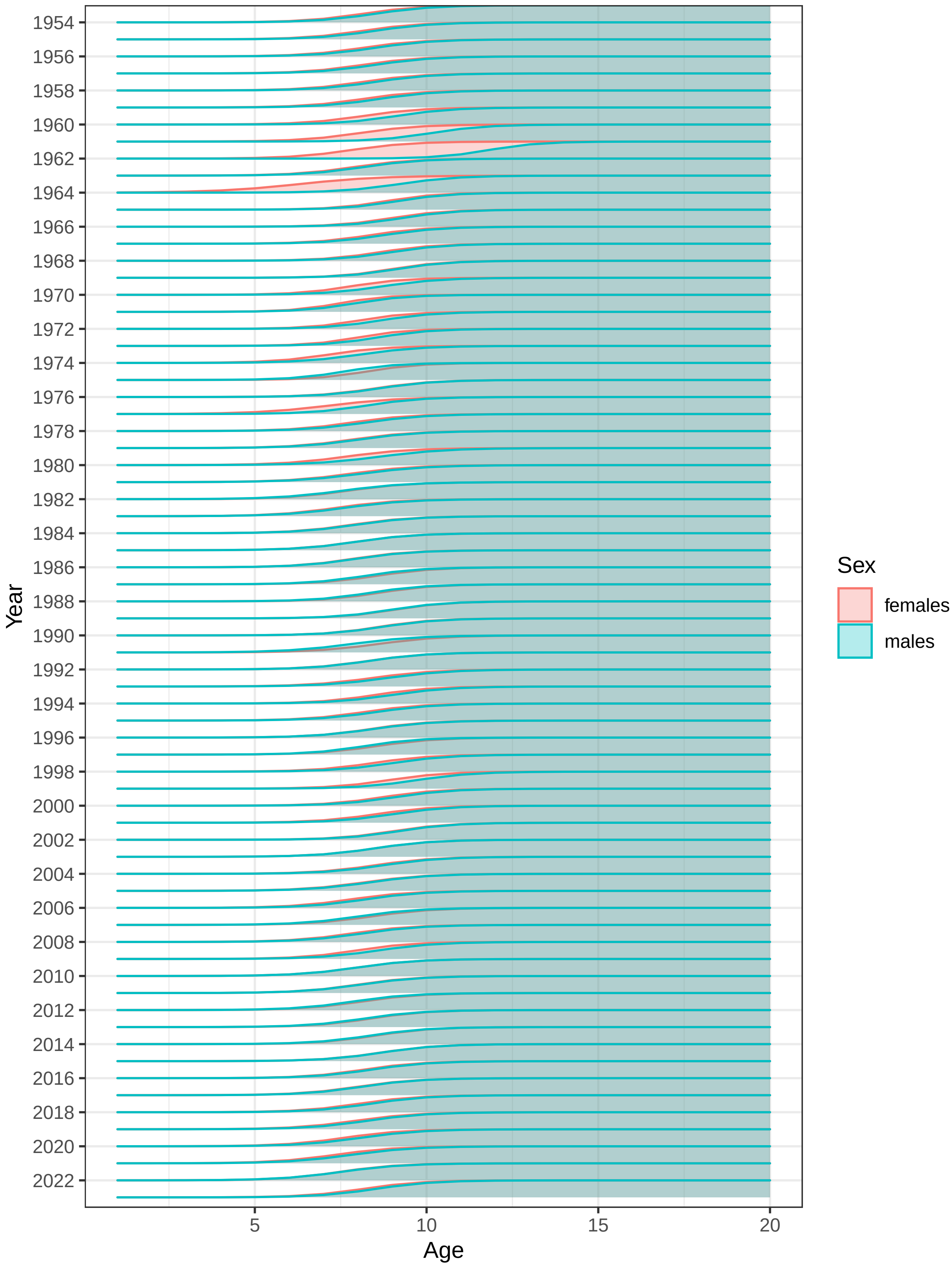

Figure 4.20: Estimate of yellowfin sole fishery selectivity for males and females, 1954-2023, Model 22.1.

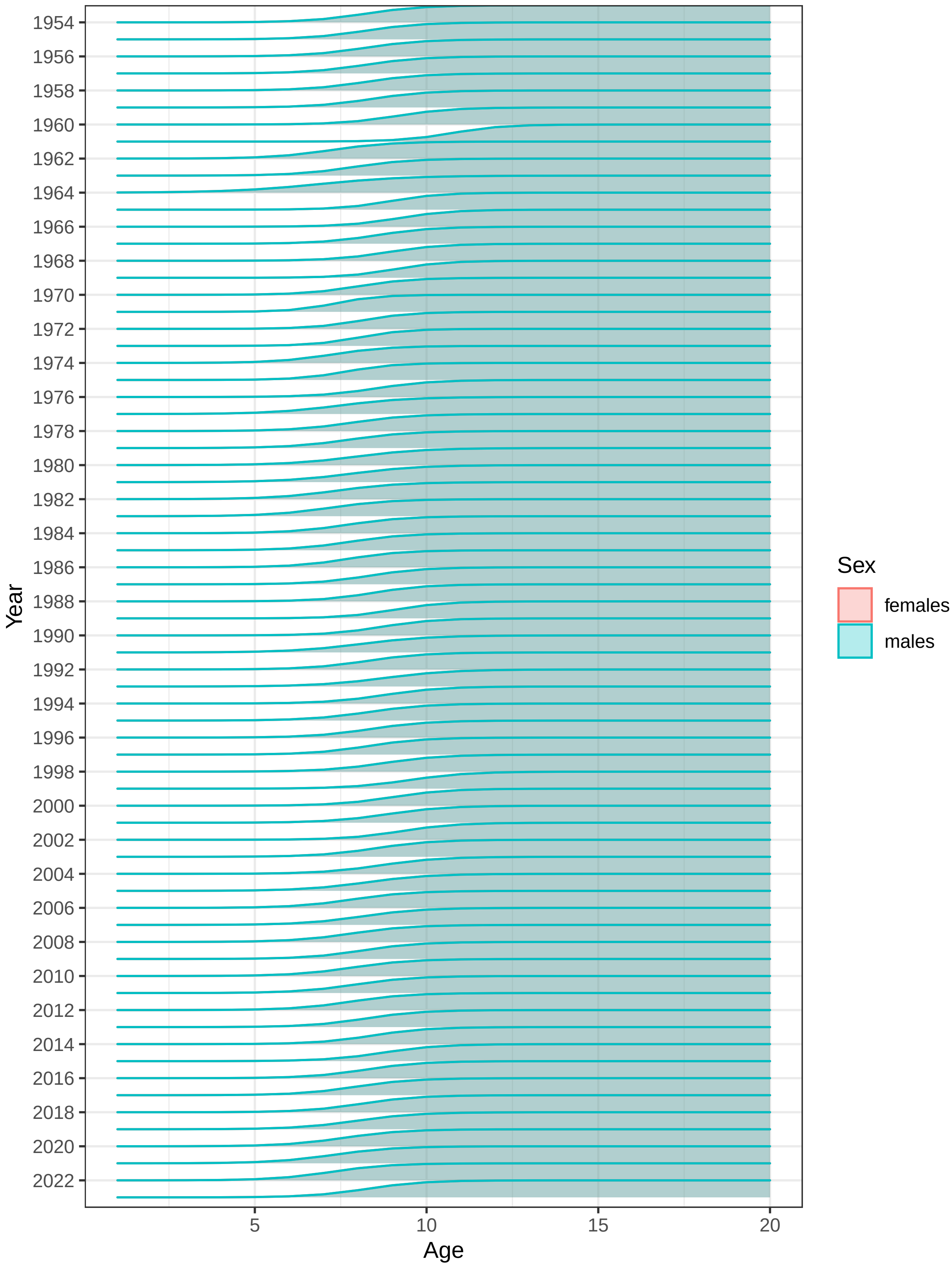

Figure 4.21: Estimate of yellowfin sole fishery selectivity for males and females, 1954-2023, Model 22.1.

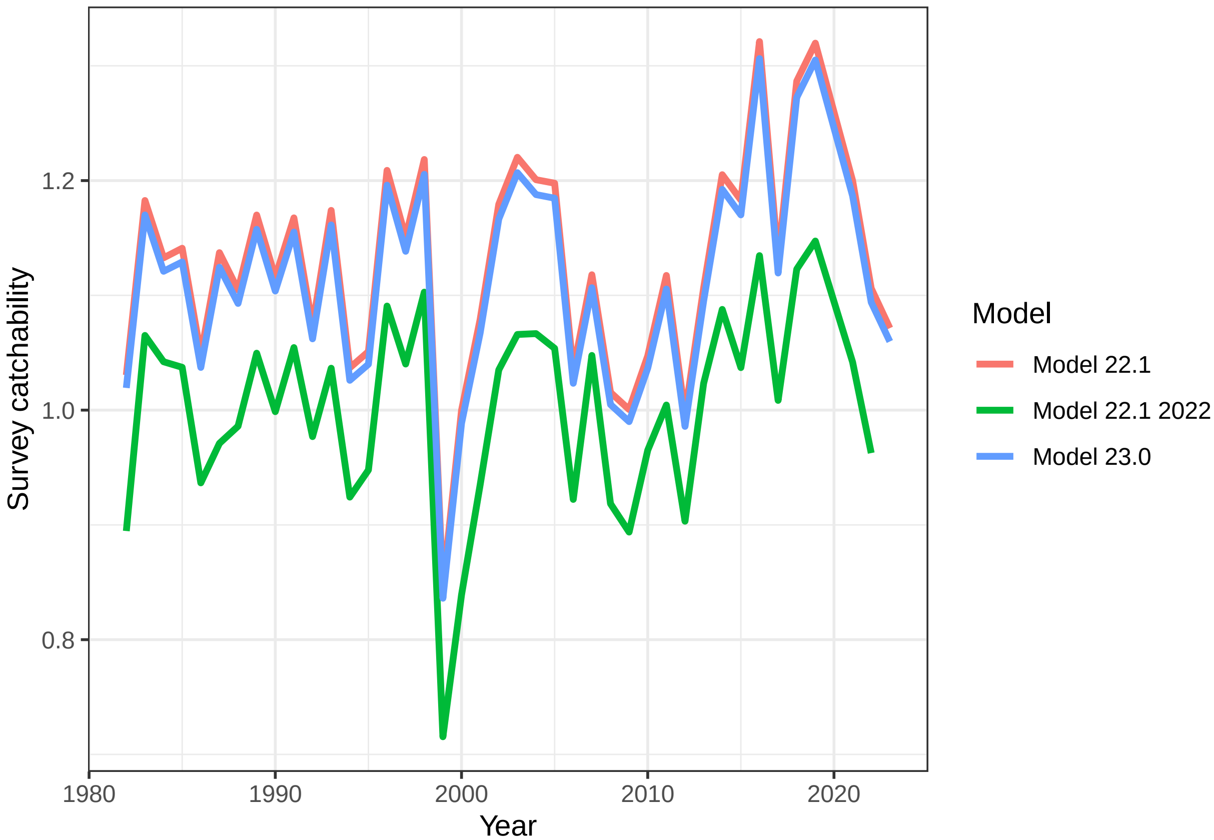

Figure 4.22: Survey catchability for yellowfin sole Model 22.1 (2022 and 2023 versions) and 23.0, 1982-2023.

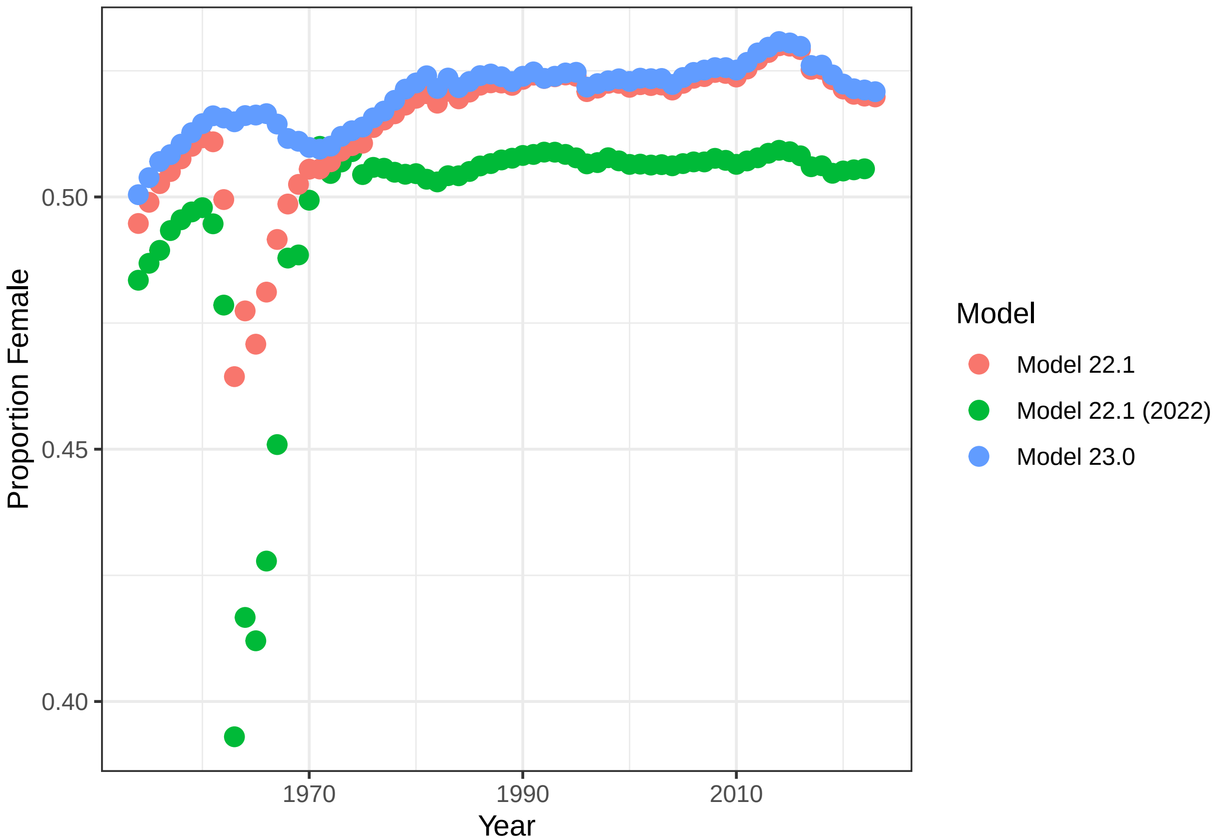

Figure 4.23: Model estimates of the proportion of female yellowfin sole in the population, 1982-2023 for Models 22.1 (from 2022 and 2023), and Model 23.0.

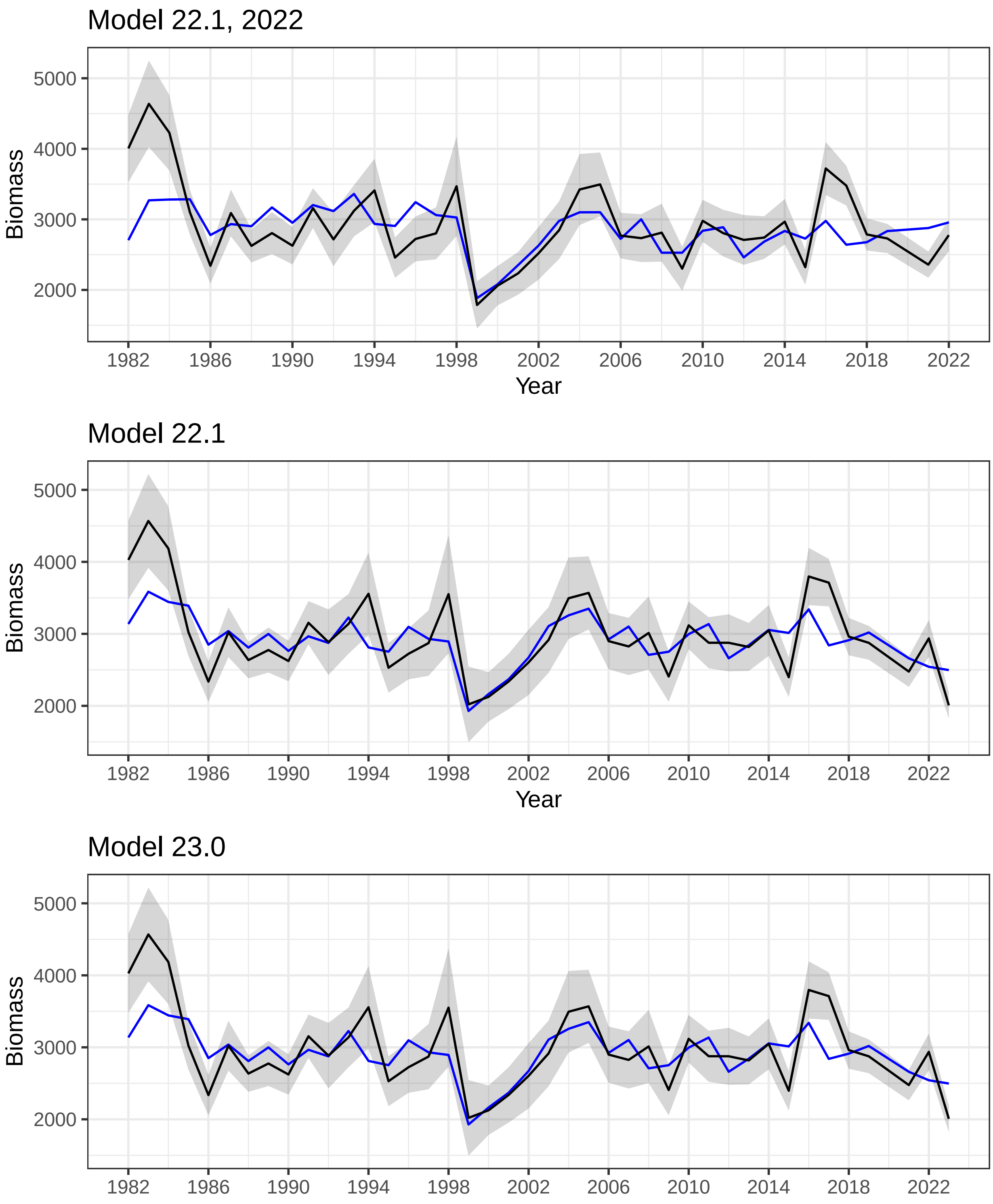

Figure 4.24: Model 22.1 from 2022 (upper panel), Model 22.1 from 2023 (middle panel), and Model 23.0 (lower panel) fit to NMFS NBS+EBS model-based (VAST) estimates for yellowfin sole, from 1982-2023. The 2022 VAST index differs from the 2023 index due to the addition of an additional year (which affects the entire time series). Blue lines are model estimates, grey represent survey estimates.

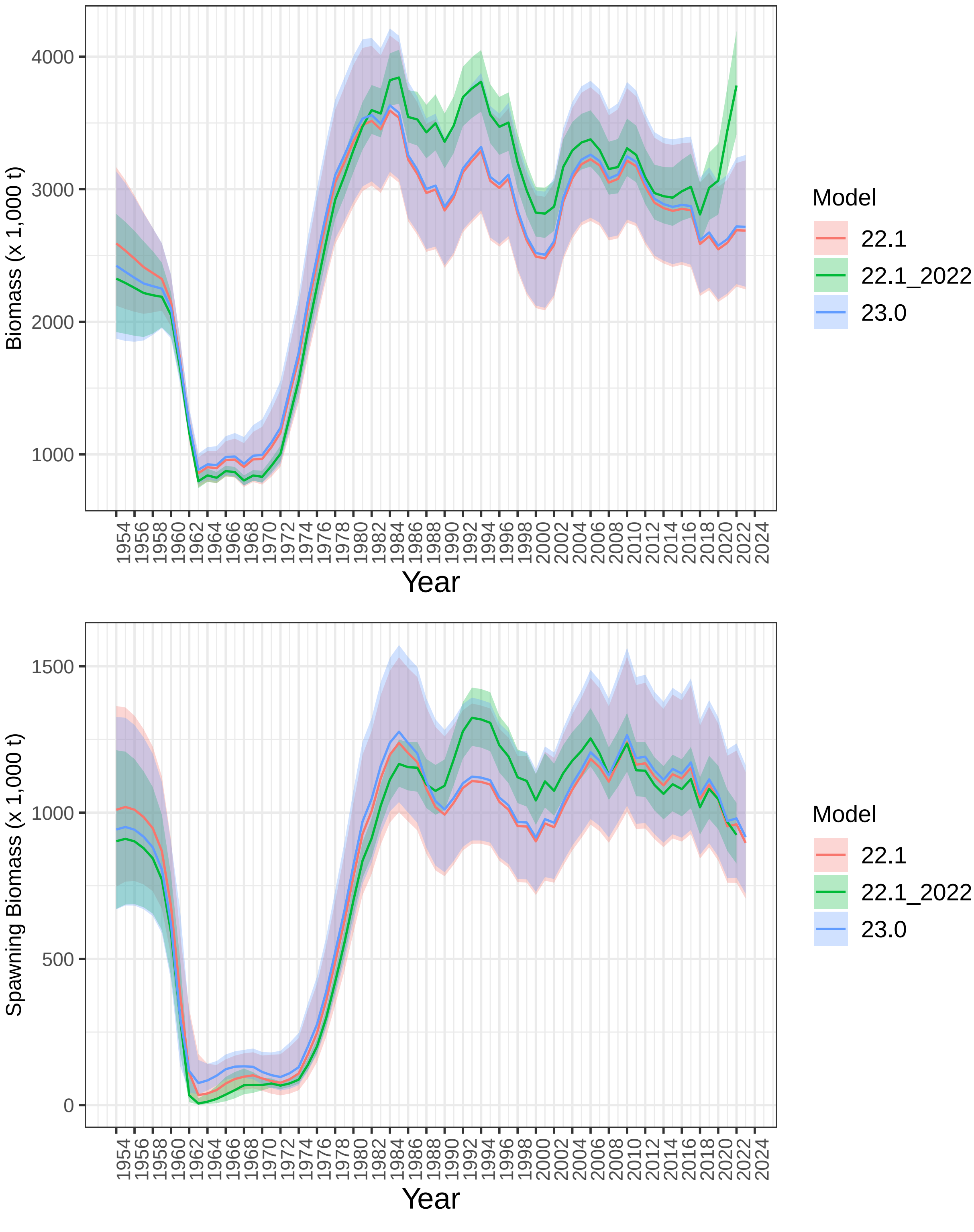

Figure 4.25: Total (age 2+) and spawning stock biomass for yellowfin sole, and total numbers, based on Models 22.1 (2022), 22.1 (2023), and 23.0, 1954-2023.

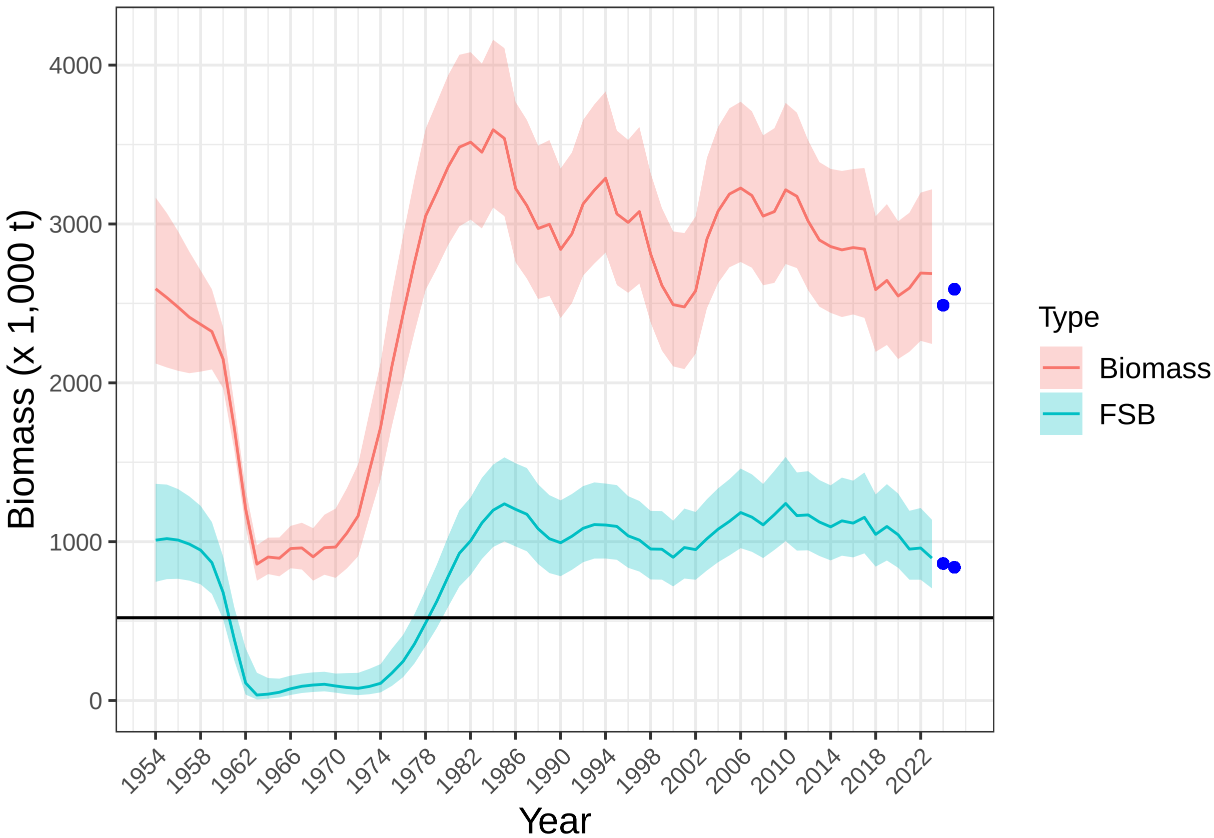

Figure 4.26: Model estimates of yellowfin sole total (age 2+) and female spawning biomass with 95% confidence intervals, 1954-2023, Model 22.1. Dots indicate projections for 2024 and 2025.

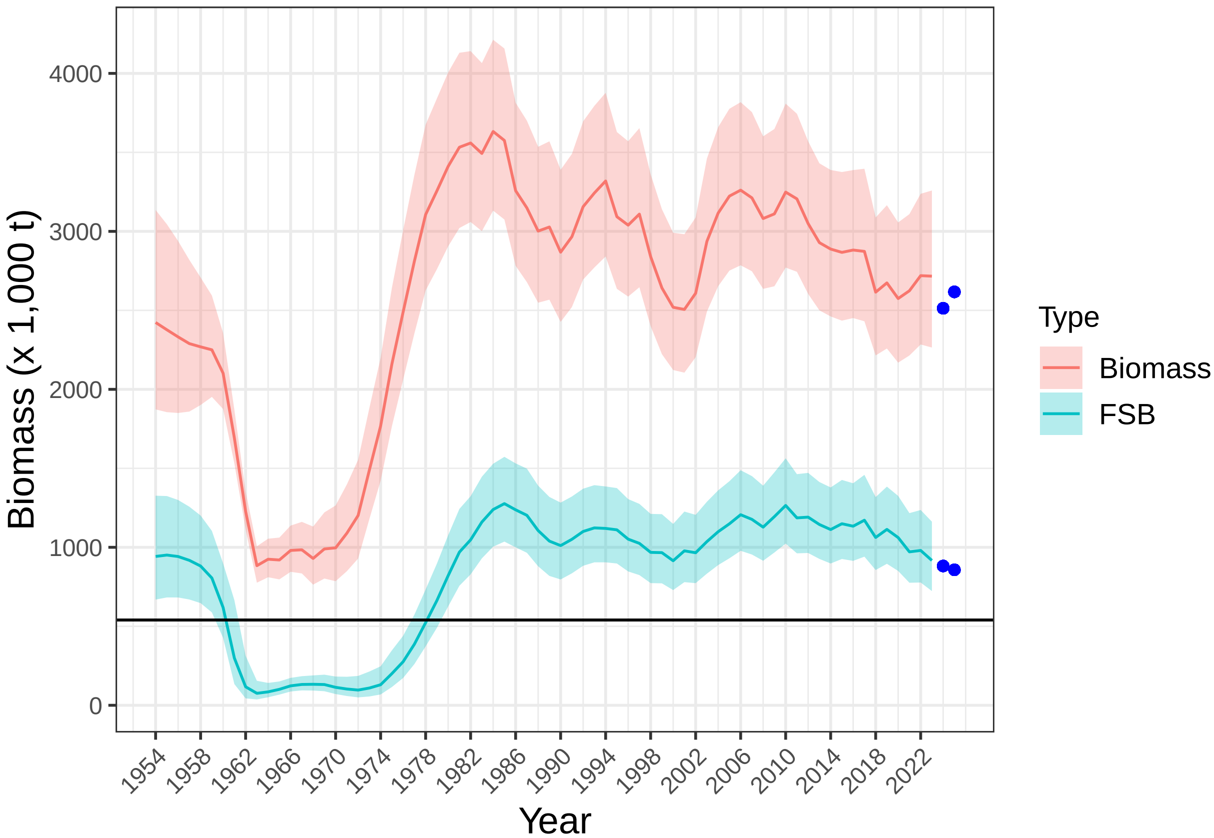

Figure 4.27: Model estimates of yellowfin sole total (age 2+) and female spawning biomass with 95% confidence intervals, 1954-2023, Model 23.0. Dots indicate projections for 2024 and 2025.

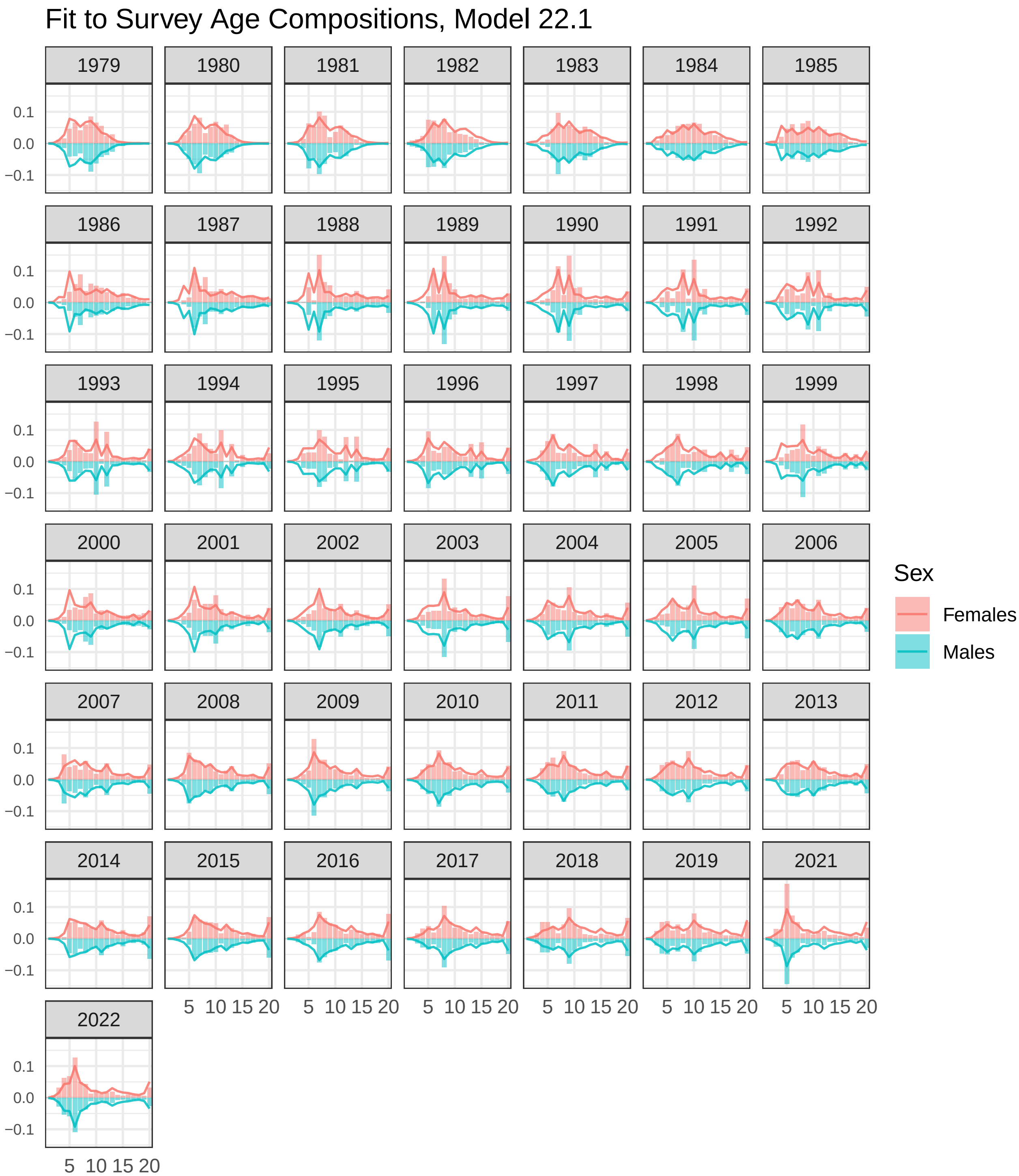

Figure 4.28: Model 22.1 fit to the time-series of yellowfin sole survey age composition, by sex, 1979-2022. The x-axis represents age.

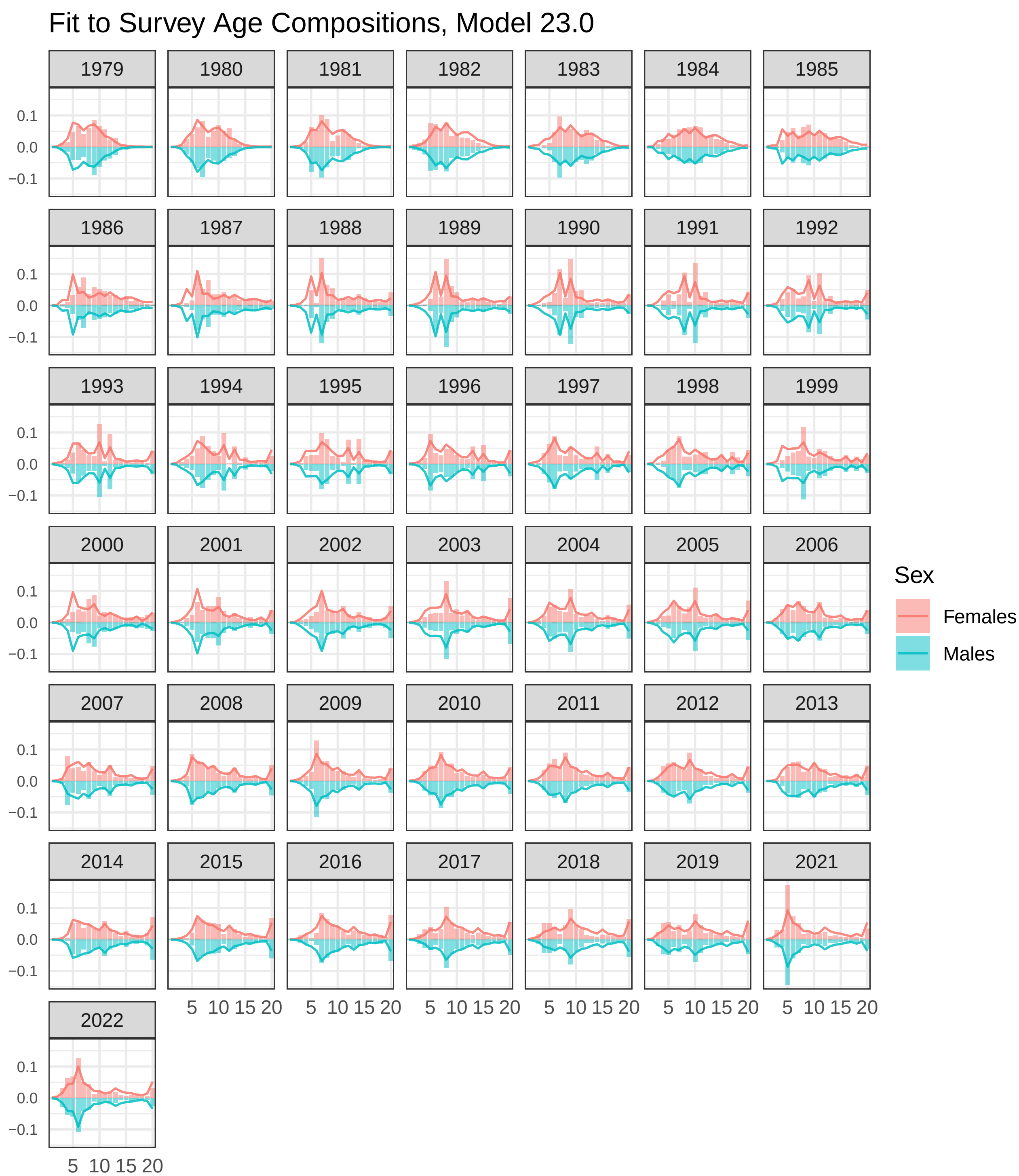

Figure 4.29: Model 23.0 fit to the time-series of yellowfin sole survey age composition, by sex, 1979-2022. The x-axis represents age.

Figure 4.30: Model 22.1 fit to the time-series of yellowfin sole fishery age composition, by sex, 1975-2022. The x-axis represents age.

Figure 4.31: Model 23.0 fit to the time-series of yellowfin sole fishery age composition, by sex, 1975-2022. The x-axis represents age.

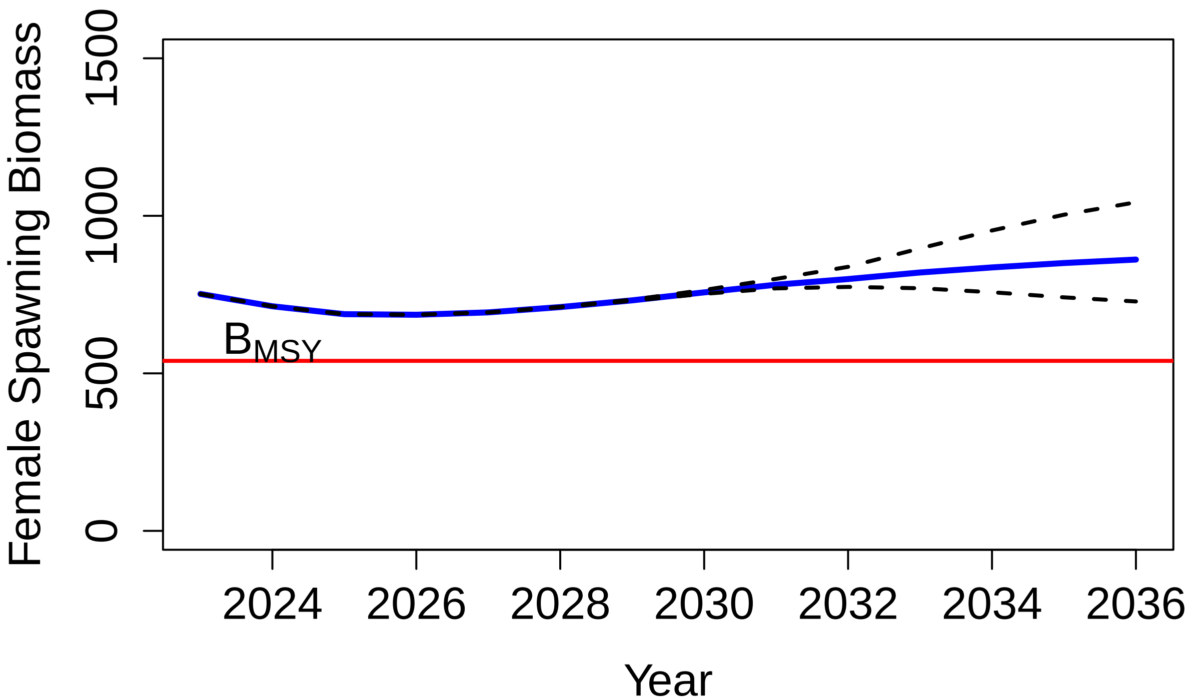

Figure 4.32: Projected yellowfin sole female spawning biomass for 2023 to 2036 (blue line), with 5% and 95% confidence intervals, and fishing at the 5-year (2018-2022) average fishing mortality rate, F= 0.0741 , Model 23.0.

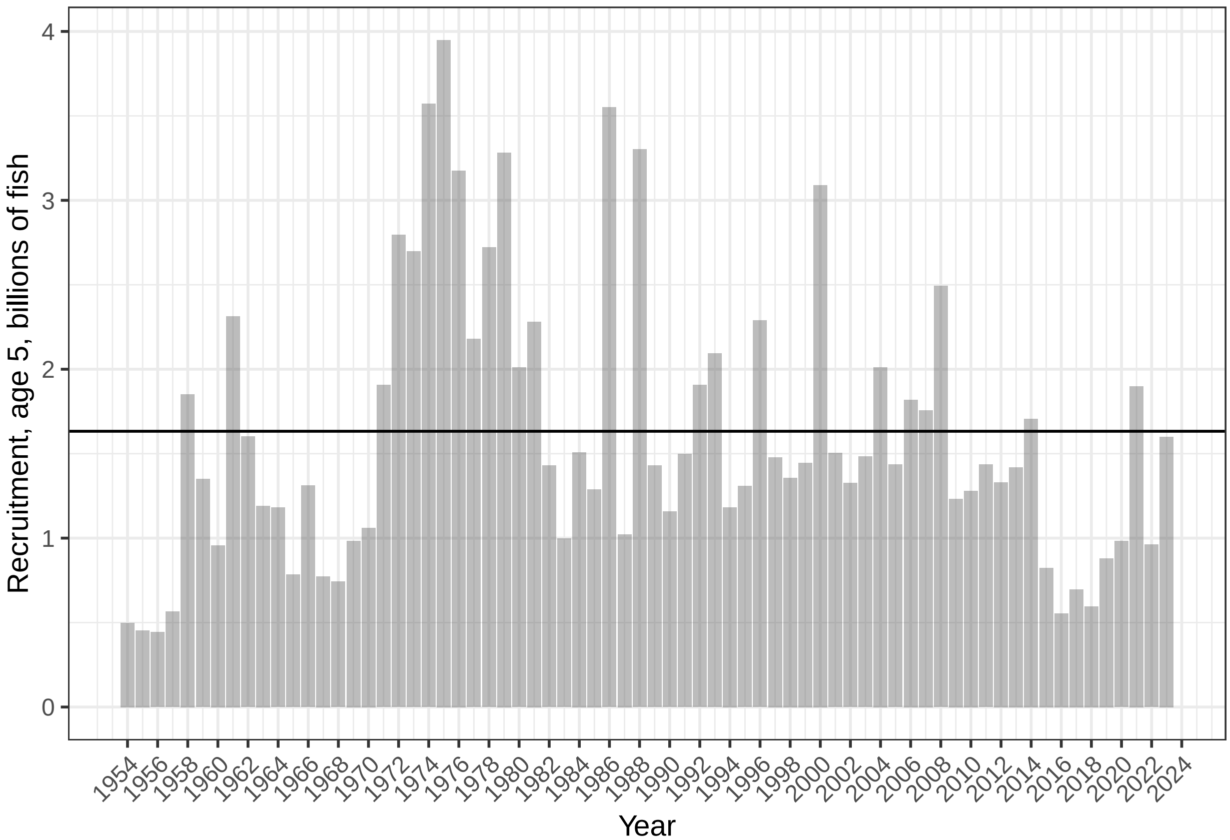

Figure 4.33: Year-class strength of age 5 yellowfin sole estimated by the stock assessment model. The horizontal line represents the average of the estimates from recruitment, 1954-2019, 1.6 billion, Model 23.0.

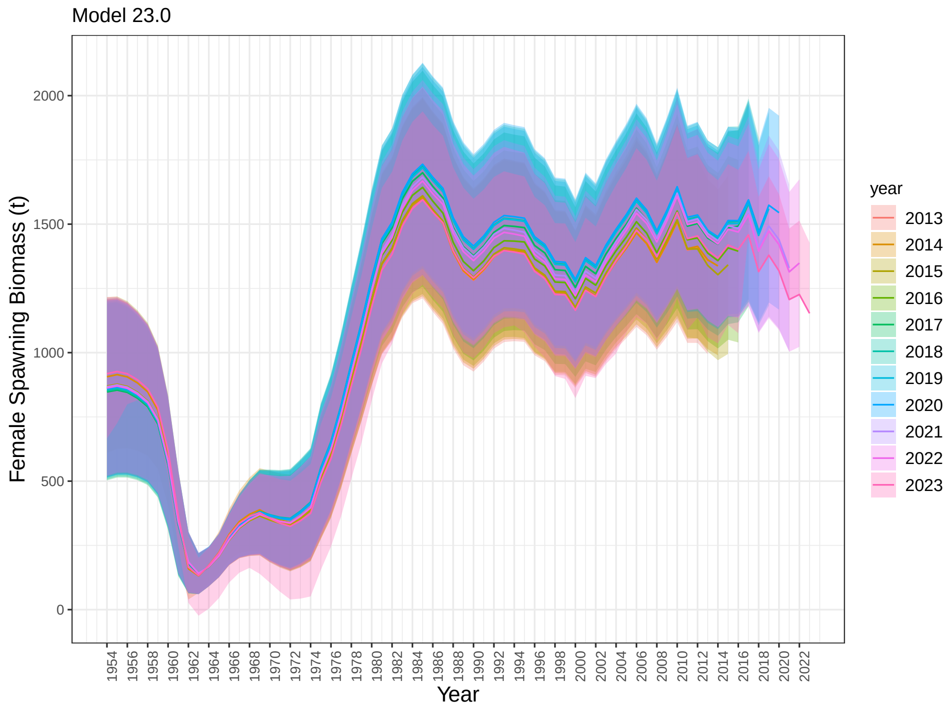

Figure 4.34: Retrospective plot of female spawning biomass for yellowfin sole Model 23.0. Mohn's Rho for this model was 0.06.

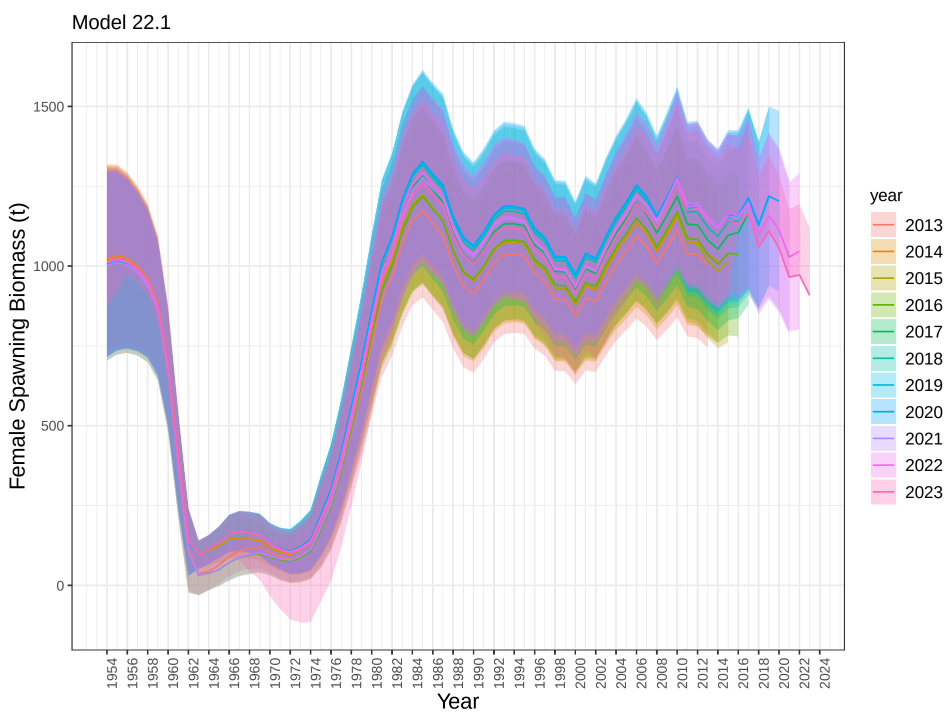

Figure 4.35: Retrospective plot of female spawning biomass for yellowfin sole Model 22.1. Mohn's Rho for this model was 0.005.

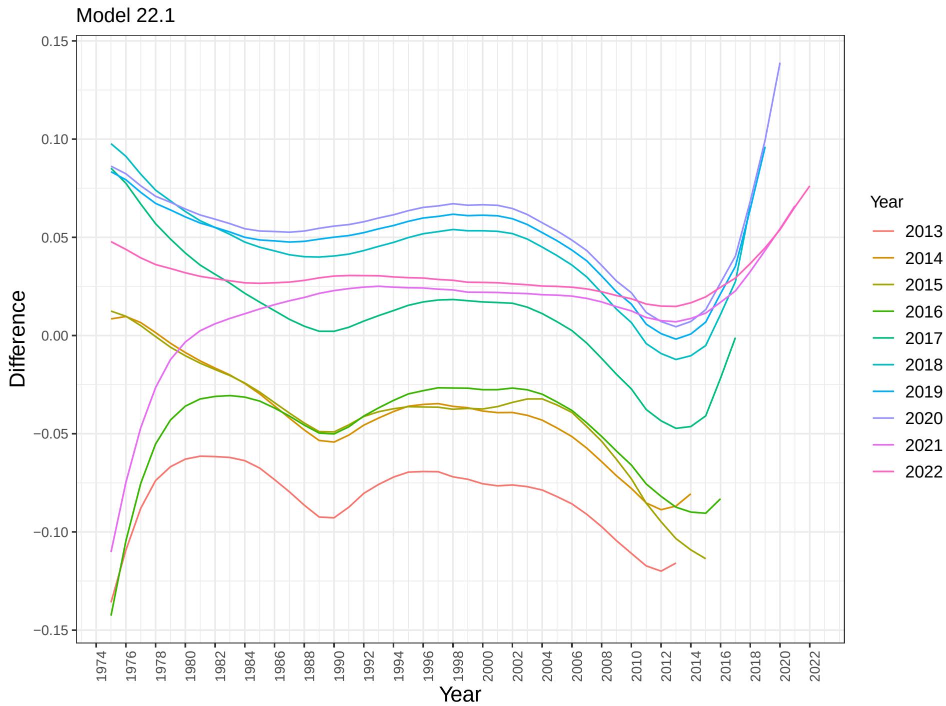

Figure 4.36: Retrospective differences in female spawning biomass between sequential years for yellowfin sole Model 22.1.

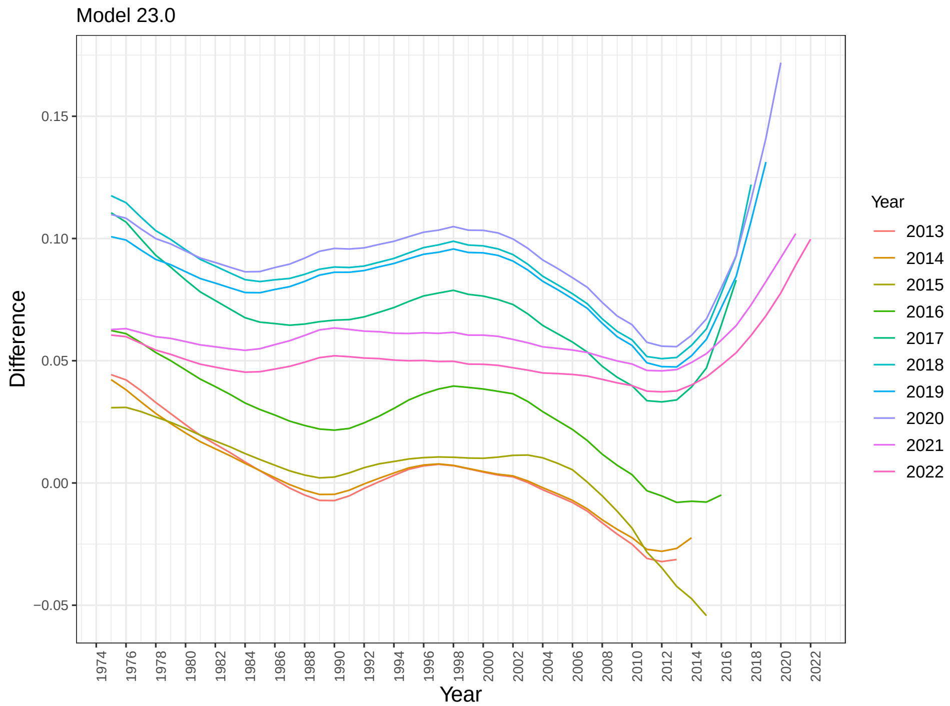

Figure 4.37: Retrospective differences in female spawning biomass between sequential years for yellowfin sole Model 23.0.

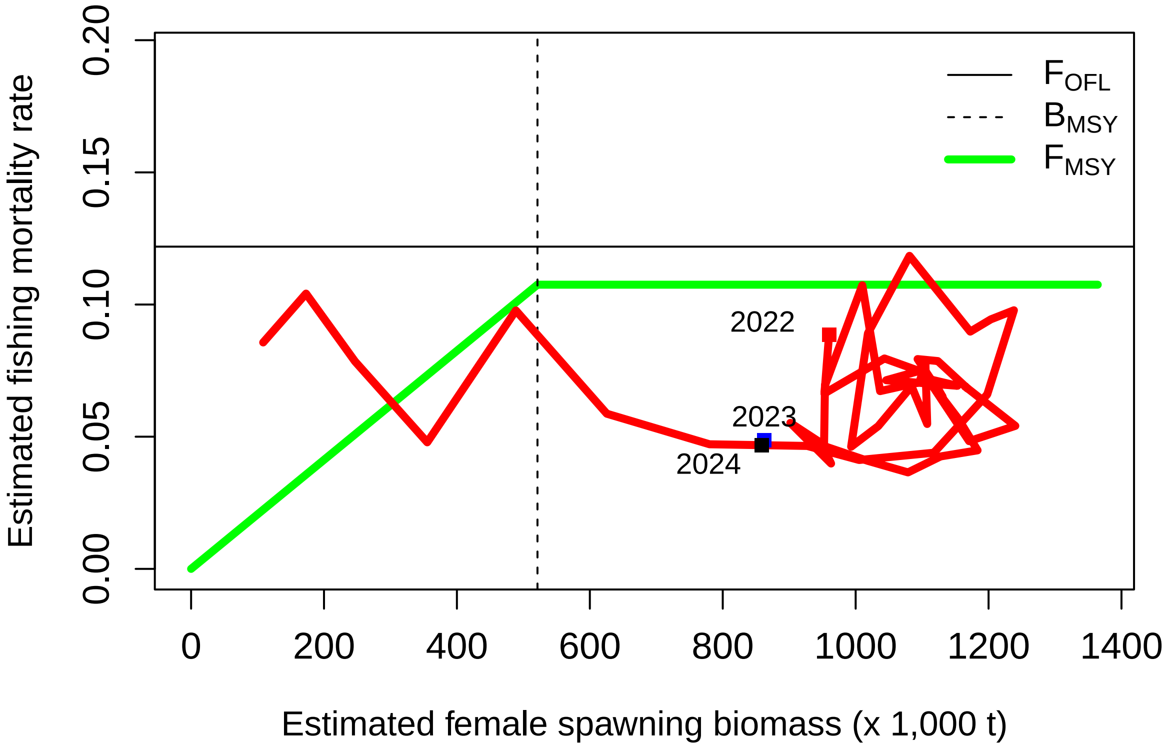

Figure 4.38: Yellowfin sole fishing mortality rate and female spawning biomass from 1975 to 2023 compared to the F35% and F40% control rules, based on Model 22.1. Vertical line is B35%. Squares indicate estimates for 2023, 2024, and 2025.

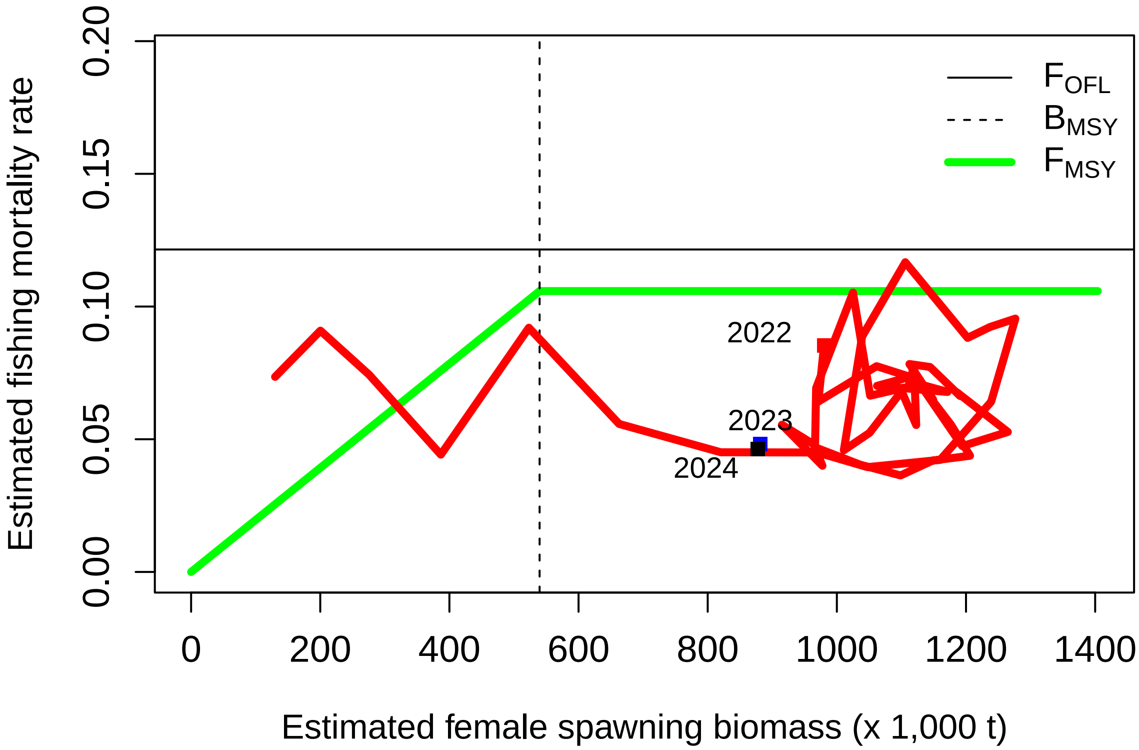

Figure 4.39: Yellowfin sole fishing mortality rate and female spawning biomass from 1975 to 2023 compared to the F35% and F40% control rules, based on Model 23.0. Vertical line is B35%. Squares indicate estimates for 2023, 2024, and 2025.

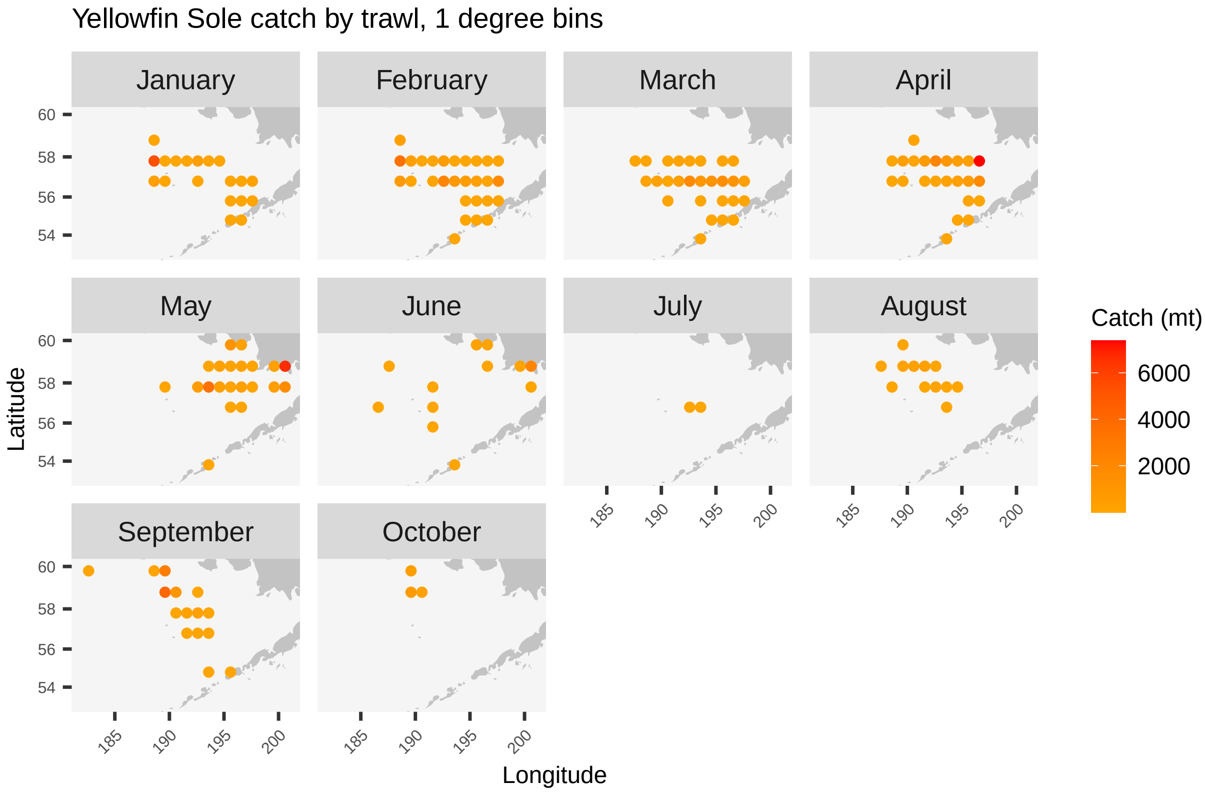

Figure 4.40: Catch of yellowfin sole in the BSAI in 2023 by month (through October 29), reported by observers. Circles represent presence of yellowfin sole catch by the following gear types: non-pelagic trawl, pair trawl, or pelagic trawl.

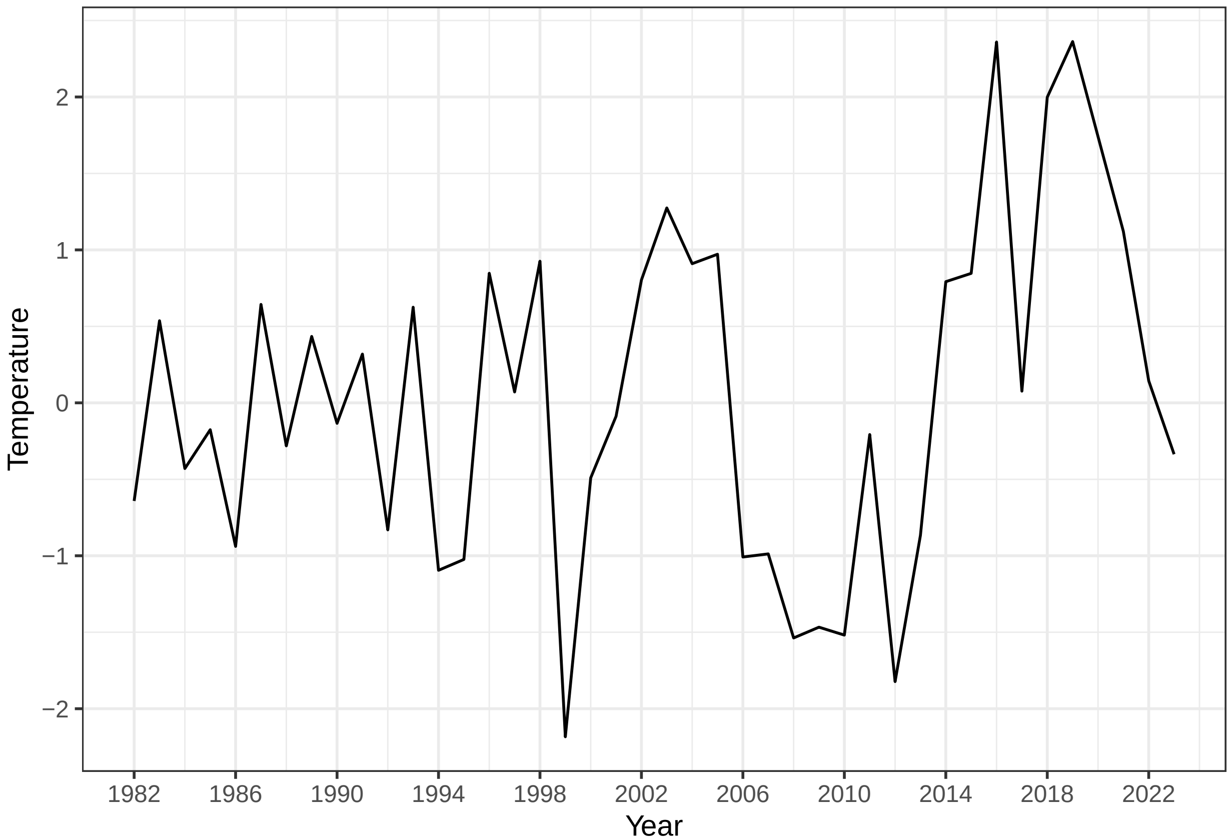

Figure 4.41: Bottom temperature anomalies from the NMFS survey <100 m, 1982-2023.