5. Assessment of the Deepwater Flatfish Stock Complex in the Gulf of Alaska

By
Carey R. McGilliard[1] and Bridget Ferriss[1]
[1]Resource Ecology and Fisheries Management Division
Alaska Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
7600 Sand Point Way NE., Seattle, WA 98115-6349

Executive Summary

Summary of Changes in Assessment Inputs

(1) 2020-2023 catch data were included in the model and 2019 catch was updated to include October-December catch in that year
(2) 2020-2023 fishery length composition data were added to the model and 2019 fishery length composition data were updated to include October-December data in that year
(3) The 2021 and 2023 survey biomass indices were added to the model
(4) Survey length composition data for 2021 and 2023 were added to the model
(5) 2019 and 2021 survey ages by length bin (conditional age-at-length data) were added to the model
(6) The logspace standard error corresponding to survey biomass estimates in years for which there were missing survey strata (1990, 1993, 1996, and 2001) was set equal to the largest value for the logspace standard error from other years with a survey biomass index such that the assessment inputs assume less precision in years with missing survey strata than in fully sampled years.
(7) The relative weighting of length composition and conditional age-at-length data sources used the approach from Francis (2011; as for the previous full assessment), with a modification that set the Francis weights assigned to survey length and conditional age-at-length data from fully-sampled years equal to weights for survey length and conditional age-at-length data from survey years with missing strata (which are modeled with separate selectivity curves in the assessment). Francis weights could not be computed separately for data corresponding to years with missing survey strata.

Summary of Results

The key results for the assessment of the deepwater flatfish complex are compared to the key results from the accepted 2022 partial assessment in the table below. The results for Dover sole are based on the author's base case model and Tier 3a management. A risk matrix approach was used to evaluate whether the ABC should be set at a lower value than the *max*ABC (see "Harvest Recommendations" section). The risk matrix levels are 1 for all categories except for "Assessment-related considerations," where a risk level of 2 was assigned. Based on these risk levels, the ABC was set equal to the *max*ABC.

Species	Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
		2023	2024	2024*	2025
Dover sole	*M* (natural mortality rate)	0.119(f), 0.113(m)	0.119(f), 0.113(m)	0.129(f), 0.128(m)	0.129(f), 0.128(m)
	Tier	3a	3a	3a	3a
	Projected total (3+) biomass (t)	81,328	79,578	86,182	84,080
	Projected Female spawning biomass (t)	25,717	25,215	24,938	24,375
	$B_{100\%}$	19,032	19,032	15,968	15,968
	$B_{40\%}$	7,613	7,613	6,387	6,387
	$B_{35\%}$	6,661	6,661	5,589	5,589
	F_{OFL}	0.11	0.11	0.15	0.15
	$maxF_{ABC}$	0.09	0.09	0.12	0.12
	F_{ABC}	0.09	0.09	0.12	0.12
	OFL (t)	6,605	6,489	8,263	8,133
	maxABC (t)	5,581	5,484	6,969	6,860
	ABC (t)	5,581	5,484	6,969	6,860
Greenland turbot	Tier	6	6	6	6
	OFL (t)	238	238	49*	49*
	maxABC (t)	179	179	37	37
	ABC (t)	179	179	37	37
Kamchatka flounder	Tier	6	6	6	6
	OFL (t)	69	69	69	69
	maxABC (t)	51.75	51.75	52	52
	ABC (t)	51.75	51.75	52	52
Deepsea sole	Tier	6	6	6	6
	OFL (t)	6	6	6	6
	maxABC (t)	4	4	4	4
	ABC (t)	4	4	4	4
Deepwater Flatfish Complex	OFL (t)	6,918	6,802	8,387	8,257
	maxABC (t)	5,816	5,719	7,062	6,953
	ABC (t)	5,816	5,719	7,062	6,953
	Status	As determined *last* year for:		As determined *this* year for:	
		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

*Projections are based on estimated catches for Dover sole of 103 t used in place of maximum permissible ABC for 2023-2026. The 2023-2026 projected catch was calculated as the average catch from 2018-2022. The historical average catch from 1978-1995 that defines the Tier 6 OFL for GOA Greenland turbot was updated to reflect the most recent reliable estimates of historical catch for this species from the Alaska Regional Office's Catch Accounting System. Natural mortality values are sex-specific: female (f) and male (m).

Area apportionment for ABC of deepwater flatfish is currently based on the proportion of survey biomass of Greenland Turbot and deepsea sole found within each management area from 2005-2023 and estimates of 2024 and 2025 survey biomass for Dover sole in each management area based on results from REMA, a survey-averaging random effects model. An ABC exists only at the level of the complex (deepwater flatfish) and not for each species individually. The ABC by area for the deepwater flatfish complex is then the sum of the species-specific portions of the ABC.

The random effects model is used to fill in depth and area gaps in the Dover sole survey biomass by area and to calculate an area- and depth-specific projection of 2024 and 2025 survey biomass. These estimates are summed over depths and the resulting relative biomass in each management area is used as the basis for apportionment of the Dover sole portion of the deepwater complex. This method of conducting area apportionment for deepwater flatfish was recommended by the GOA Plan Team in 2016 (McGilliard 2016). The method was chosen because it accounts for time and area gaps in the survey for Dover sole, which comprises nearly all of the deepwater flatfish catch and Dover sole moves to deeper waters ontogenetically, and explicitly accounts for differences in the spatial distributions of Dover sole and Greenland turbot. Greenland turbot were found exclusively in the Western GOA region by the survey over the period 2005-2023. In addition, Kamchatka flounder has been found exclusively in the Central GOA from 2017-2023; this led to a shift in the long-term average proportion of Kamchatka flounder towards the Central GOA. ABC values are in tons.

Species	Year	Western	Central	West Yakutat	Southeast	Total
Dover Sole		2.6%	37.5%	26.6%	33.2%	100.0%
	2024	183	2,617	1,856	2,313	6,969
	2025	180	2,576	1,827	2,277	6,860
Greenland Turbot		100.0%	0.0%	0.0%	0.0%	100.0%
	2024	37	0	0	0	37
	2025	37	0	0	0	37
Kamchatka Flounder		32.1%	67.9%			100.0%
	2024	17	35	0	0	52
	2025	17	35	0	0	52
Deepsea Sole		0.0%	74.9%	11.2%	13.9%	100.0%
	2024	0	3	0	1	4
	2025	0	3	0	1	4
Deepwater Flatfish	**2024**	**237**	**2,655**	**1,856**	**2,314**	**7,062**
	2025	**234**	**2,614**	**1,827**	**2,278**	**6,953**

Responses to SSC and Plan Team Comments on Assessments in General

SSC, October 2023: When there are time-varying biological and fishery parameters in the model, the SSC requests that a table be included in the SAFE that documents how reference points are calculated.

Catchability and sex-specific natural mortality parameters were estimated separately for a time block of 2014-present for the Dover sole Tier 3 model. The natural mortality values estimated for the more recent time block (2014-present) were used when running the projection model and calculating reference points. A small table was included in the Harvest Recommendations section, as requested, and the natural mortality estimates used are also listed in the Executive Summary table.

SSC, December 2022: The SSC recommends that for future Tier 1-3 assessments some consideration be given as to how best to best 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.

The author will follow any advice from the program or Plan Team on how to implement such a change.

Responses to SSC and Plan Team Comments Specific to this Assessment

SSC, December 2019: The SSC supports the collection and processing of fishery age data to address potential bias and uncertainty in estimates of selectivity. The SSC also supports the development of a GOA-specific ageing error matrix, as the model is currently borrowing an ageing error matrix from the West Coast.

The author spoke with the Observer Program about changing otolith collection rules for Dover sole in fishery catches. However, the catches for Dover sole have been extremely low (103 t is the 5-year average catch) and it seems unlikely that a meaningful fishery age sample could be collected from so few fish in the catch; therefore a change to collection rules for Dover sole was not pursued further at this time. A GOA-specific Dover sole ageing error matrix will be developed and used in the next full assessment.

SSC, December 2019: For the next assessment, the SSC requests that the author include a summary or description of the historical catches that were used in the Tier 6 assessment for Greenland turbot and deepwater sole.

Historically, the catches of GOA Greenland turbot and deepsea sole were calculated based on the proportion of each of these species sampled in the Observer data for each haul, multiplied by the extrapolated weight of the haul, and then summed over hauls. In 2020, conversations with Alaska Regional Office and data from the Alaska Regional Office Catch Accounting System led to updated reliable catch estimates for Greenland turbot and the addition of Kamchatka flounder to the deepwater flatfish complex. The AKRO Catch Accounting System does not track deepsea sole. Therefore, the OFL of deepsea sole is still based on this historical method. The authors thank the SSC for realizing that the OFL and ABC for Greenland turbot should be updated according to the newest reliable catch estimates from the AKRO Catch Accounting System. The average catch of Greenland turbot from 1978-1995 was 49 t. Therefore, the authors present an updated Executive Summary Table with an OFL for Greenland turbot of 49 t and an ABC of 37 t.

PT, November 2019: The Team recommends Kamchatka flounder be included in the 2021 partial assessment as a Tier 6 species using 2011–2019 maximum catch (69 t) as the OFL. The Team suggests maximum catch is more appropriate than average catch based on the high variability and short time series of catch. The Team also recommends the author examine area apportionment relative to Kamchatka flounder and consider whether it's appropriate to apportion across the entire GOA or just the WGOA.

The methodology used for apportionment of the Tier 6 components of the ABC across GOA is to use the average proportion of survey biomass by Regulatory Area from 2005-2023. This led to 67.9% of the Kamchatka flounder ABC assigned to the Central GOA, and the remainder assigned to the Western GOA. The authors found that a shift in survey biomass has occurred in recent years, with a higher proportion of biomass in the Central GOA. The 2020-2022 partial assessments for the deepwater flatfish complex used 69 t for the OFL of Kamchatka flounder, following this Plan Team recommendation.

SSC, December 2019: The SSC recommends including a Tier 6 OFL and ABC for Kamchatka flounder in the combined GOA deepwater flatfish complex OFL and ABC during the next partial assessment year (2020), using the maximum catch from 2011-2019 (69 t) as the OFL. The SSC supports the GPT recommendation that the author examine area apportionment relative to Kamchatka flounder and consider whether it is appropriate to apportion across the entire GOA or just the WGOA.

See the response above to the November 2019 PT recommendation.

Introduction

The "flatfish" species complex previous to 1990 was managed as a unit in the Gulf of Alaska (GOA). It included the major flatfish species inhabiting the region, with the exception of Pacific halibut. The North Pacific Fishery Management Council divided the flatfish assemblage into four categories for management in 1990; "shallow flatfish" and "deep flatfish", flathead sole and arrowtooth flounder. This classification was made because of significant differences in halibut bycatch rates in directed fisheries targeting the shallow-water and deepwater flatfish species. Arrowtooth flounder, because of high abundance and low commercial value, was separated from the group and managed under a separate acceptable biological catch (ABC). Flathead sole were likewise assigned a separate ABC since their distribution over depths overlaps with that of the shallow-water and deepwater groups. In 1993, rex sole was split out of the deepwater management category because of concerns regarding the bycatch of Pacific ocean perch in the rex sole target fishery. In 2019, Kamchatka flounder was assigned to Tier 6 within the deepwater flatfish assessment.

The deepwater complex, the subject of this chapter, is composed of four species: Dover sole (*Microstomus pacificus*), Greenland turbot (*Reinhardtius hippoglossoides*), Kamchatka flounder (*Atheresthes evermanni*) and deepsea sole (*Embassichthys bathybius*). Dover sole dominates the biomass of the deepwater complex in research trawl surveys and fishery catch (on average 79% of the deepwater complex catches over the past five years). Little biological information exists for Greenland turbot or deepsea sole in the GOA. Kamchatka flounder was split out from Arrowtooth flounder as a separate species for the first time in 2011; species-specific data are missing prior to that time. More information exists for Dover sole, which allowed the construction of an age-structured assessment model in 2003 (Turnock et al., 2003).

Greenland turbot have a circumpolar distribution and occur in both the Atlantic and Pacific Oceans. In the eastern Pacific, Greenland turbot are found from the Chukchi Sea through the Eastern Bering Sea and Aleutian Islands, in the GOA and south to northern Baja California. Greenland turbot are typically distributed from 200-1600 m in water temperatures from 1-4 °C, but have been taken at depths up to 2200 m.

Dover sole occur from Northern Baja California to the Bering Sea and the western Aleutian Islands; they exhibit a widespread distribution throughout the GOA (Hart, 1973; Miller & Lea, 1972). Adults are demersal and are mostly found at depths from 300 m to 1500 m.

Dover sole are batch spawners and may exhibit skip spawning (Rideout et al. 2005); spawning in the GOA has been observed from January through August, peaking in May (Hirschberger & Smith, 1983). The average 1 kg female may spawn 83,000 advanced yolked oocytes in about 9 batches (Hunter et al., 1992). Although the duration of the incubation period is unknown, eggs have been collected in plankton nets east of Kodiak Island in the summer (Kendall & Dunn, 1985). Larvae are large and one study showed evidence of an extended pelagic phase that averages about 21 months (Markle et al., 1992), while Abookire and Bailey (2006) found no evidence that Dover sole spent longer than 9 months in a pelagic larval phase. They have been collected in bongo nets only in summer over mid-shelf and slope areas in the GOA. The age or size at metamorphosis is unknown, but pelagic postlarvae as large as 48 mm have been reported and juveniles may still be pelagic at 10 cm (Hart, 1973). Juveniles less than 25 cm are rarely caught with the adult population in bottom trawl surveys (Martin & Clausen, 1995).

Dover sole move to deeper water as they age and older females may have seasonal migrations from deep water on the outer continental shelf and upper slope where spawning occurs to shallower water mid-shelf in summer time to feed (tagging data from California to British Columbia; Demory et al., 1984, Westrheim et al., 1992). Older male Dover sole may also migrate seasonally but to a lesser extent than females. The maximum observed age for Dover sole in the GOA is 59 years.

Fishery

McGilliard et al. (2019) provides a full description of the history of the fishery. The GOA deepwater flatfish complex of species is caught in a directed multi-species bottom trawl fishery primarily. Fewer than 20 shore-based catcher-type vessels participate in this fishery, together with about 6 catcher-processor vessels. The deepwater flatfish complex catch is dominated by Dover sole and has been particularly small in recent years, with a five year average of 131 t and 2023 catches as of September 27 of 98 t (Table 1). Deepwater flatfish are primarily caught at depths of 101-500m, but a substantial proportion of yearly catches have occurred in 0-500m and 700-1000m depths in some years. For instance, 46% of catches in 2016 occurred at 501-700m depths and 43% of catches in 2022 occurred in 0-500m depths (Table 2). Deepwater flatfish are largely caught in the Central GOA, with over 90% of deepwater flatfish caught in the Central GOA over the past 5 years (Table 3). Total catch is typically a small percentage of the ABC and TAC (1.8% on average over the last five years; Table 4). Deepwater flatfish are also caught in pursuit of other bottom-dwelling species as bycatch. They are taken as bycatch in Pacific cod, bottom pollock and other flatfish fisheries. The gross discard rates for deepwater flatfish across all fisheries have been particularly high in recent years, ranging from 8-13% over the past five years; the long-term average discard rate from 1995-2023 is 50% (Table 4).

Annual TACs for deepwater flatfish have typically been set equal to their associated ABCs (Table 4). Low catches relative to the TAC in the deepwater flatfish complex are thought to be driven by targeting decisions. Restrictions on halibut Prohibited Species Catch (PSC) is thought to be one factor influencing targeting decisions. Table 5 lists closures related to halibut and Chinook salmon PSC from 2019-2023.

Currently, ABCs for the entire complex are based on summing ABCs for the individual species. Tier 6 calculations are used to obtain species-specific contributions to the complex-level ABC for each year for Greenland turbot, deepsea sole, and Kamchatka flounder because population biomass estimates based on research trawl surveys for these species are considered unreliable and there is little basic biological information available for them. As such, ABCs for Greenland turbot and deepsea sole are based on average historic catch levels from 1978-1995 and do not vary from year to year. The Greenland turbot component of the ABC was updated this year to reflect the newest and most reliable information on historical catches from the Alaska Regional Office. Kamchatka flounder is a Tier 6 species, but historical catches from 1978-1995 are not available due to a lack of species-level identification, and therefore the OFL component for this species was defined as the maximum catch of Kamchatka flounder between 2011-2022, where 2011 is the first year of catch data specifically for Kamchatka flounder in the GOA. Since 2003, the Tier 3 ABC for Dover sole has been based on an age-structured assessment model (Turnock et al., 2003).

Data

The following table specifies the source, type, and years of all data included in the assessment models.

Source	Type	Years
Fishery	Catch biomass	1978-Sept 27, 2023
Fishery	Catch length composition	1991-Sept 27, 2023
GOA survey bottom trawl	Survey biomass	Triennial: 1984-1999, Biennial: 2001-2023
GOA survey bottom trawl	Catch length composition	Triennial: 1990-1999, Biennial: 2003-2023 (1984, 1987, and 2001 data are excluded)
GOA survey bottom trawl	Catch age composition, conditioned on length	Triennial: 1990-1999, Biennial: 2003-2021 (1984, 1987, 1990, and 2001 data are excluded)

In addition, Figure 1 is a chart indicating yearly relative sample size of each data source used in the assessment model.

Fishery

The assessment included catch data from 1978 to September 27, 2023 (Table 1, Figure 2). Fishery length composition data were included in 2cm bins from 6-70cm. Fishery length composition data were voluminous and can be accessed at the following link.

Survey

Biomass and Numerical Abundance

Survey biomass estimates originate from a cooperative bottom trawl survey between the U.S. and Japan in 1984 and 1987 and a U.S. bottom trawl survey conducted by the Alaska Fisheries Science Center Resource Assessment and Conservation Engineering (RACE) division thereafter. Starting in 2019, the Dover sole model is no longer fit to 1984 and 1987 survey data because of differences in survey design before and after 1990. Calculations for final survey biomass and variance estimates by strata are fully described in Wakabayashi et al. (1985). Survey depth and area coverage was variable over time; the 1990, 1993, and 1996 surveys sampled only 0-500m depths, while the 2001 survey excluded the West Yakutat and Southeast management areas (the eastern GOA), and only sampled 0-500m depths in the Western and Central GOA. In addition, the 700-1000 m depth range was sampled only in select survey years and areas (Table 6). Maps of Dover sole survey catch-per-unit-effort (CPUE) for 2009-2019 survey are shown in McGilliard et al. (2019) and maps of 2019, 2021 and 2023 survey CPUE are shown in Figure 3 for a comparison across years. The maps show a similar distribution of Dover sole across the GOA in each of these survey years, with the highest CPUE of Dover sole typically in the Central GOA.

A random effects model developed for survey averaging (REMA; Sullivan et al. 2022) was used to estimate survey biomass and variance in missing depth and area strata. Design-based estimates were used in all sampled strata to maintain assessment inputs for survey biomass that were as close to the raw data as possible such that non-smoothed fluctuations in survey biomass could be evaluated with consideration of population dynamics. The final survey biomass estimates and corresponding standard errors used in the assessment are shown in Table 7, and are compared to estimates from the 2019 assessment. With the addition of new years of data to the REMA analysis in each assessment cycle, historical survey biomass estimates used in each assessments are expected to change slightly from those used in the previous assessment. The logspace standard errors used as input to the assessment were recalculated this year to account for the fact that there is more uncertainty in years with missing survey strata. Previously, REMA estimates of logspace standard error by strata were converted into variance estimates and used to fill in survey variance values for missing strata; to calculate variance corresponding to the total survey biomass estimates for each year, the variance estimates by strata were summed using design-based variance estimates for sampled strata and REMA estimates for missing strata. This led to some total variance estimates (and thus logspace standard errors) that were smaller in years with missing strata than in some fully sampled years. In the 2023 assessment, variance by strata in years with missing strata was set equal to the maximum variance for that strata across fully sampled years; this still led to some variance estimates that were lower than total variance for some fully sampled years. Therefore, an additional adjustment was made to set the variance in years with missing strata equal to the maximum total variance estimate across years. While this seems more appropriate than the method used previously, the next full stock assessment could provide an exploration of alternative methods for estimating survey biomass variance in years with missing strata, or alternative ways to handle survey biomass in years with missing strata.

A drop in the survey biomass index of 31,227 t (37%) occurred in 2015 and the survey biomass has remained low in all subsequently sampled years (2017-2023). The survey biomass of Dover sole on the EBS slope, EBS shelf, and Aleutian Islands did not show substantial increases in Dover sole over these years (2015-2023; Table 8).

Survey biomass of the Tier 6 species in the deepwater flatfish complex are shown in Table 9.

Survey size and age composition

Sex-specific survey length composition data and age frequencies of fish by length (conditional age-at-length) were used in the assessment and can be found at (linked here). There are several advantages to using conditional age-at-length data. The approach preserves information on the relationship between length and age and provides information on variability in length-at-age such that growth parameters and variability in growth can be estimated within the model. In addition, the approach resolves the issue of double-counting individual fish when using both length- and age-composition data (as length-composition data are used to calculate the marginal age compositions). See Stewart (2005) for an additional example of the use of conditional age-at-length data in fishery stock assessments.

Figure 4 shows the yearly age composition data from the GOA bottom trawl survey. A large year class appears in the age composition data in 2015. In addition, there was a decline in the number of 30+ year old fish incrementally in each survey year since 2015 that is consistent with the low survey biomass estimates for these years.

McGilliard et al. (2019) show temporal and spatial patterns in GOA sole growth. A time-varying, cohort-specific pattern in growth exists, where fish from early cohorts (~pre-1977) appear smaller in the survey data at older ages than younger fish from later cohorts. Dover sole exhibit ontogenetic movement from shallow to deep water and the interaction between movement and cohort-specific growth appears to contribute to a spatial growth pattern where individuals that are small for their age are more likely to appear in deep depth strata. Finally, a higher proportion of fish that are small for their age appear in the Eastern GOA as compared to the Central GOA.

Analytic Approach

General Model Structure

The assessment was an age- and sex-structured statistical catch-at-age model implemented in Stock Synthesis version 3.30.21 (SS3) and r4ss (Taylor et al. 2018, R Core Team 2018) using a maximum likelihood approach. SS3 equations can be found in Methot and Wetzel (2013) and further technical documentation is outlined in Methot (2009). The SS3 framework is coded in AD Model Builder (Fournier et al. 2012). Before 2013 assessments were conducted using an ADMB-based age- and sex-structured population dynamics model (Stockhausen et al., 2011). A detailed description of the transition of the 2011 model to SS3 and potential benefits of transitioning the assessment to SS3 were presented at the 2013 September Plan Team Meeting and the September SAFE chapter is included in the 2013 assessment (McGilliard et al., 2013).

The bottom trawl survey was modeled as two separate surveys for the purpose of fitting to length composition and age data. A "full coverage" survey was modeled and fit to bottom trawl survey length composition and conditional age-at-length data in years where depths from 0 to greater than 500m were sampled. An additional "shallow coverage" survey was modeled and fit to length composition and conditional age-at-length data for years when the bottom trawl survey excluded depths deeper than 500m (1990, 1993, and 1996 for length composition data and 1993 and 1996 for age data). The 1990 age data were excluded from the model because the surface ageing method used in that year is biased, especially for otoliths of older fish.

A random walk, random effects model developed for survey averaging (REMA; https://github.com/afsc-assessments/rema; Sullivan et al. 2022) was used to estimate survey biomass in missing depth and area strata, as described in the "Survey" section of this document. This approach was used to transform these data to reflect a best available estimate of what would have been caught had all strata been sampled in all survey years. The resulting biomass estimates and data from existing strata were aggregated to comprise a single survey biomass index that corresponded to the "full coverage" survey fleet (Table 7). In years where missing strata were estimated the variance for the estimates in missing strata were set equal to the maximum variance over years for that strata. This still led to small estimates of variance in years with missing strata and so the variance for the survey biomass index was further adjusted by setting it equal to the maximum variance over years for the total survey biomass. The observation error estimates from REMA are inappropriate for use in this context because REMA partitions variance between process and observation error, reducing observation error relative to the design-based observation error estimates being used in fully sampled years.

The selectivity curves in the modeling framework account for both selectivity and availability. Therefore, separate selectivity curves were estimated for the "full coverage" and "shallow coverage" surveys. Dover sole exhibit ontogenetic movement from shallow to deep depths and older ages are expected to be sampled be sampled incompletely in "shallow coverage" survey years. In addition, it appears that male movement patterns may differ from female movement patterns between shallow and deep depths, based on a set of research assessment models for

Dover sole that estimate movement between shallow (<500m) and deep (>500m) areas. Selectivity curves for the "shallow" and "full-coverage" categories were modeled with age-based sex-specific double-normal curves. Selectivity for the "full coverage" survey was assumed to be asymptotic, while selectivity for the "shallow coverage" allowed the potential for dome-shaped selectivity. Fishery selectivity was modeled with a double-normal length-based, sex-specific curve. A descending limb parameter for fishery selectivity was modeled in some previous model runs (McGilliard et al. 2019), but a descending curve occurred only for very large lengths for which little data exist, and the standard deviation of the parameter estimate was very large. Therefore, the descending limb of the fishery selectivity curves were fixed to a large value such that the curves are asymptotic.

A conditional age-at-length approach was used: expected age composition within each length bin was fit to age data within each length bin (conditional age-at-length) in the objective function, rather than fitting to marginal age composition data (which are typically calculated as a function of the conditional age-at-length data and the length-composition data outside of the assessment). The conditional age-at-length approach provides the information necessary to estimate growth curves and variability about mean growth (CVs in length-at-age) within the assessment model. In addition, the approach allows for all of the length and age information to be used in the assessment without double-counting each sample.

Age 0 Recruitment deviations were estimated from 1978-2019. Recruitment for 2020-2023 were fixed to mean recruitment because Dover sole are generally not observed until age 3 and little to no data exist to inform recruitment deviations for the most recent years.

To account for process error (e.g. variance in selectivities among years), relative weights for length composition and age data sources were adjusted according to the method described in Francis (2011; data-weighting method number T3.4 was used), with the modification that the weight assigned to the length composition data and conditional age-at-length data from shallow survey years was set equal to those for the full-coverage survey years, respectively.

Ageing Error Matrix

Ageing uncertainty was incorporated into the assessment model. An ageing error matrix estimated from age-read data from the U.S. West Coast Dover sole ageing program (CAP) and used in the 2011 U.S. West Coast Dover sole assessment (Hicks & Wetzel, 2011) was used. Future Dover sole assessments should analyze GOA Dover sole age-read data to develop an ageing error matrix to use in the assessment instead of the west coast matrix. However, the CAP and AFSC ageing programs employ equivalent methods where ages are determined based on break-and-burn methods and each otolith is aged by two readers. Hicks and Wetzel (2011) estimated an ageing error matrix using methods described in Punt et al. (2008) whereby a relationship between true and estimated age is modeled and used to construct a probability that an otolith is observed to be age a' given a true age a. The ageing error matrix estimated in Hicks and Wetzel (2011) and used in this assessment shows that ageing uncertainty increases non-linearly with age and does not include ageing bias (Table 7). Accounting for ageing error is an important addition to the assessment methods because many Dover sole otoliths are particularly difficult to age (Kastelle et al. 2008). Ignoring ageing error in assessments can lead to bias in estimation of management quantities (Reeves, 2003).

Bridging analysis

Three model runs are shown as a bridging analysis, each including new data through 2023.

(1) Model 19.3: the 2019 model structure.

(2) A model like (1), but adjusting the variance corresponding to survey biomass estimates that uses the maximum variance across years for years where missing survey strata were filled in using REMA estimates.

(3) Model 19.3.1: A model like (2), but updating the relative weighting assigned to each length- and conditional age-at-length data source according to methods described in Francis (2011), with the modification that relative weights for length composition and conditional age-at-length data from shallow survey years were set equal to those from full-coverage survey years. Francis (2011) weights could not be computed reliably for the shallow survey years.

Model 19.3.1 is presented as the author's preferred model for 2023. The key elements of the structure of Model 19.3 were maintained with the two adjustments described by the bridging analysis.

Parameters Estimated Outside the Assessment Model

Weight-Length Relationship

The weight-length relationship used in the assessment was estimated for GOA Dover sole by Abookire and Macewicz (2003). The relationship was $w_L = \alpha L^{\beta}$, where $\alpha = 2.9E-06$ and $\beta = 3.3369$, length (*L*) was measured in centimeters and weight (*w*) was measured in kilograms.

Maturity-at-Age

Maturity-at-age (O_a) in the assessment was defined as $O_a = 1/(1+\gamma e^{(a-a_{50})})$, where the slope of the curve was $\gamma = -0.363$ and the age-at-50%-maturity was $a_{50} = 12.47$.

A logistic maturity-at-length relationship estimated in Abookire and Macewicz (2003) was converted into a maturity-at-age relationship using the mean length-at-age relationship estimated within the assessment model. The maturity curve does not influence the estimation of the mean length-at-age relationship because spawning stock biomass (SSB) is the only quantity influenced by maturity in the model and SSB does not influence model fits because no stock-recruitment relationship is used.

A maturity-at-length curve was not used because slow-growing fish in the model never become large enough to mature, regardless of age. This is unrealistic. Abookire and Macewicz (2003) estimated maturity-at-age as well as a maturity-at-length. However, the relatively low sample size of aged fish used in the Abookire and Macewicz (2003) study, combined with the large magnitude of ageing error known to exist for Dover sole suggested that the maturity-at-age relationship estimated in the paper may be unreliable.

Ageing Error

An ageing error matrix was estimated outside of the model based on age data from U.S. West Coast Dover sole (Table 10).

Standard deviation of the Log of Recruitment (σ_R)

Variability of the recruitment deviations that were estimated in previous Dover sole assessments was approximately σ_R =0.49 and this value was used in the current assessment.

Catchability

The model uses the value for catchability estimated in Model 19.1 (McGilliard et al. 2019) as a fixed value for the years 1978-2013, and catchability is estimated from 2014-2023 (see the subsection “2019 Candidate Models,” and the results subsection “Models Estimating Natural Mortality (M) and Catchability (q)” in McGilliard et al. (2019) for a full description of the rationale for this method).

Select selectivity parameters

Selectivity parameter definitions and values are shown in (Table 11).

Parameters Estimated Inside the Assessment Model

Parameters estimated within the assessment model are the log of unfished recruitment (R_0), log-scale recruitment deviations for 1978-2020, yearly fishing mortality, sex-specific parameters of the von-Bertalanffy growth curve, CV of length-at-age for ages 2 and 59, and selectivity parameters for the fishery, the “full coverage” survey, and the “shallow-coverage” survey. The selectivity parameters are described in greater detail in Table 11. The descending limb for the female shallow coverage survey selectivity and the descending limbs of the fishery selectivity are fixed to be asymptotic based on preliminary model runs in 2019 showing very large standard deviations corresponding these parameter estimates and indicating a lack of information to inform the shape of these descending limbs. In all models estimating M and or Q, the male scale parameter for survey 2 was estimated to be 1 (at the upper bound) and was therefore fixed at 1 in final model runs.

In this year’s assessment, male and female natural mortality (*M*) are estimated within the model using a normal prior distribution with a mean of 0.085 and a standard deviation of 0.03. This prior was developed as a weighted average of multiple methods for estimating natural mortality outside of the assessment model (McGilliard et al. 2019). Separate values for natural mortality are estimated for years 2014-2023 using the same prior distribution.

In Model 19.1 described in the 2019 assessment (McGilliard et al. 2019), a single parameter for the log of catchability was estimated within the model using a normal prior distribution with a mean of 0.17 and a standard deviation of 0.145, which was based on results from trawl net efficiency studies for GOA flatfish species conducted by Somerton et al. (2007). Model 19.3.1 and all models presented in 2023 fix catchability in 1978-2013 to the value estimated in 2019’s Model 19.1 and estimate catchability in the years 2014-2023. See the results subsection in McGilliard et al. (2019) “Models Estimating Natural Mortality (M) and Catchability (q)” for the justification for use of this method.

Results

Model Evaluation

The Bridging Analysis

The spawning biomass, recruitment deviations, fishing intensity, and fit to the survey biomass index for all of the models in the bridging analysis show that overall there are no major differences between models (Figure 5). Adding new data since 2019 and updating the relative weighting of data sources using the Francis method (adjusted to set the weights of length and conditional age-at-length data for shallow and full-coverage surveys equal to each other) both led to very small increases in the magnitude of recruitment and spawning biomass throughout the time series. Each model shows very similar trends over time in spawning biomass, recruitment, fishing intensity, and the fit to the survey biomass index. Values of negative log likelihood for each relevant likelihood component are shown in Table 12, but many values cannot be directly compared. Negative log likelihood values for fits to the survey index for models with new data through 2023 are similar, with Model 19.3 with new data as the best negative log likelihood value for the survey index. However, the adjustments made in the bridging analysis are needed because they make logical sense, not because of any improvement in negative log likelihood values. Model 19.3.1 was chosen as the author's preferred model in 2023, as the adjustments to Model 19.3 were logical, minor changes.

The 2023 Preferred Model: Model 19.3.1

Figure 6 shows a decline in spawning biomass since 2013 for Model 19.3.1. Spawning biomass declines because the drop in survey biomass estimates that occurred between 2015 and 2023 is partially attributed to a change in natural mortality within the model. The model estimates natural mortality to be 0.07 yr^{-1} for females and 0.07 yr^{-1} for males prior to 2014; from 2014 onward, the model estimates natural mortality to be 0.13 yr^{-1} for both females and males (Table 13). This change in natural mortality is consistent with steadily declining numbers of age 30+ fish observed in the bottom trawl survey from 2015-2023 (Figure 4). The 2014-2023 estimates of natural mortality are slightly higher than in the 2019 assessment (0.11 yr^{-1} and 0.12 yr^{-1} for females and males, respectively; Table 13). The standard deviations corresponding to natural mortality estimates were particularly small during the historical period (0.003 for females and males) and 0.02 for the 2014-2023 estimates, which is likely due to extremely low fishing intensity that allows fish in this population to grow very old. The estimate of catchability for 2014-2023 was 0.70, which was lower than for the historical period prior to 2014 (the historical estimate used was 0.87) and similar to the 2014-2023 estimate from the 2019 assessment (0.72; Table 13). The covariance between logspace catchability and natural mortality in 2014-2023 was 0.48 for females and 0.42 for males, indicating that catchability and natural mortality in 2014-2023 are not completely confounded, but there is some uncertainty as to how much of the downward shift in survey biomass could be attributed to natural mortality versus catchability.

Estimates of recruitment show a large year class in 2015 that is consistent with the raw survey age composition data in 2019 and 2021 (Figure 4; Figure 5; Table 15). Fishing intensity is estimated to be very low for the stock in recent years (Figure 5, top right panel; Table 16). Fishery selectivity is asymptotic and fish are fully selected to the fishery at approximately 55 cm (Table 14; Figure 7). Derived age-based fishery selectivity (the length-based selectivity curves translated through the age-length transition matrix to age-based selectivity) occurs at older ages than for the surveys (Figure 8, Figure 9). Female derived age-based fishery selectivity reaches an asymptote below 1 that is caused by considerable variability in age-at-length. McGilliard et al. 2019 show that there is a cohort-specific time-varying pattern in growth that shows up as a spatial pattern in growth due to the ontogenetic movement pattern displayed by Dover sole, and an additional spatial pattern in growth between the Western-Central and Eastern GOA. The standard deviations corresponding to the parameters defining the offset of the male fishery selectivity curve relative to the female fishery selectivity curve are relatively large. Factors contributing to uncertainty in the fishery selectivity curves are that the fishery has caught very few fish historically, especially since the year 2000 and no otoliths have been collected from catches, so estimates rely on information from fishery length data only, with lengths translated into ages within the model in the context of a substantial amount of variability in age-at-length (Table 13).

Detailed plots of model fits to length composition and conditional age-at-length data are shown in Figure 10-Figure 14. Fits to length composition data aggregated over years are reasonable for the full-coverage survey (Figure 10). For the shallow-coverage survey there are more males observed around 40cm than predicted by the model. In addition, there are more 20-45cm females observed than predicted by the model. The mismatches in fits to the shallow-coverage length composition data may be related to modeling a constant growth curve while, in reality, a time-varying, cohort-specific pattern exists (McGilliard et al. 2019). Figure 11-Figure 12 show fits to yearly fishery length composition data. In early years, the model often estimates more long fish than exist in the data (Figure 11) and in later years the model tends to estimate more young fish than exist in the data (Figure 12). These patterns are consistent with yearly patterns showing a cohort-specific time-varying pattern in growth where the oldest cohorts are smaller than some newer, younger cohorts (McGilliard et al. 2019). Figure 13 shows the yearly fits to length composition data for the full-coverage survey, which are generally reasonable, with a larger mismatch between the model and data in 2013 and some smaller mismatches in other years, but there is no persistent pattern in differences between model predictions and the data. Notably, the full-coverage survey length composition data include only the years 1999-present, excluding the years when the most fish from very old cohorts would be expected to appear. Fits to yearly length composition data for the shallow-coverage survey are consistent among years and match the pattern that appears in the aggregated plot described above (Figure 14).

Figure 15-Figure 18 show yearly model fits to mean age observations by length bin. The variation in ages within length bins is fairly high as compared to other GOA stocks, such as GOA flathead sole (Turnock et al. 2017). In 1993-1996 (shallow coverage years), the uncertainty in ages within length bins is substantially lower. Based on our knowledge of ontogenetic movement of Dover sole this may occur because a lower proportion of the oldest (and therefore smallest) Dover sole may occur in the sample. In many years, the estimated mean age-at-length is lower than observed for a subset of lengths. This occurs in some years for intermediate lengths and in other years for the oldest lengths, and is also consistent with cohort-specific time-varying growth dynamics.

Time Series Results

Time series results are shown in Table 17-Table 18 and Figure 6-Figure 21. A time series of numbers at age is available at (link here). Total biomass for ages 3+, SSB, and standard deviations of SSB estimates for the previous and current assessments are presented in Table 17. Age 3 recruitment, age 0 recruitment, and standard deviations of age 0 recruitment estimates are presented in Table 18 for the previous and current assessments. Figure 6 shows SSB estimates and corresponding asymptotic 95% confidence intervals. Figure 19 is a plot of biomass relative to $B_{35\%}$ and F relative to $F_{35\%}$ for each year in the time series, along with the OFL and ABC control rules.

Retrospective analysis

Figure 20-Figure 21 show the spawning stock biomass, recruitment deviations, and fishing mortality for model runs excluding 0 to 10 years of data. Figure 20 shows little retrospective pattern in spawning biomass, except in the most recent 3-5 years, which correspond to the three years of low survey biomass estimates. Here, the model has progressively more evidence that a shift has occurred, leading to progressively lower estimates of spawning biomass as additional years of data are added. Figure 21 shows stable estimates of recruitment deviations over historical years that are informed with data and stable estimates of F over retrospective runs. Mohn's rho values (as defined in Hurtado-Ferro 2015) for spawning biomass, recruitment, and F are 0.05, -0.122, and -0.08, respectively.

Harvest Recommendations

Should the ABC be reduced below the maximum permissible ABC?

The SSC in its December 2018 minutes recommended that all assessment authors use the risk table when determining whether to recommend an ABC lower than the maximum permissible. The SSC also requested the addition of a fourth column on fishery performance, which has been included in the table below.

Risk Table Levels of Concern				
	Assessment-related considerations	*Population dynamics considerations*	*Environmental/ecosystem considerations*	*Fishery Performance*
Level 1: No Concern	Typical to moderately increased uncertainty/minor unresolved issues in assessment.	Stock trends are typical for the stock; recent recruitment is within normal range.	No apparent environmental/ecosystem concerns	No apparent fishery/resource-use performance and/or behavior concerns
Level 2: Major Concern	Major problems with the stock assessment; very poor fits to data; high level of uncertainty; strong retrospective bias.	Stock trends are highly unusual; very rapid changes in stock abundance, or highly atypical recruitment patterns.	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 showing consistent adverse signals a) across different sectors, and/or b) different gear types
Level 3: Extreme Concern	Severe problems with the stock assessment; severe retrospective bias. Assessment considered unreliable.	Stock trends are unprecedented; More rapid changes in stock abundance than have ever been seen previously, or a very long stretch of poor recruitment compared to previous patterns.	Extreme anomalies in multiple ecosystem indicators that are highly likely to impact the stock; Potential for cascading effects on other ecosystem components	Extreme anomalies in multiple performance indicators that are highly likely to impact the stock

The table is applied by evaluating the severity of four types of considerations that could be used to support a scientific recommendation to reduce the ABC from the maximum permissible. These considerations are stock assessment considerations, population dynamics considerations, environmental/ecosystem considerations, and fishery performance. Examples of the types of concerns that might be relevant include the following:

1. Assessment considerations—data-inputs: biased ages, skipped surveys, lack of fishery-independent trend data; model fits: poor fits to fits to fishery or survey data, inability to simultaneously fit multiple data inputs; model performance: poor model convergence, multiple minima in the likelihood surface, parameters hitting bounds; estimation uncertainty: poorly-estimated but influential year classes; retrospective bias in biomass estimates.

2. Population dynamics considerations—decreasing biomass trend, poor recent recruitment, inability of the stock to rebuild, abrupt increase or decrease in stock abundance.

3. Environmental/ecosystem considerations—adverse trends in environmental/ecosystem indicators, ecosystem model results, decreases in ecosystem productivity, decreases in prey abundance or availability, increases or increases in predator abundance or productivity.

4. Fishery performance—fishery CPUE is showing a contrasting pattern from the stock biomass trend, unusual spatial pattern of fishing, changes in the percent of TAC taken, changes in the duration of fishery openings.

Assessment considerations

The GOA Dover sole assessment shows little retrospective bias and no parameters hitting bounds. The assessment model takes into account two explanations of why survey biomass has been low over the past five surveys. However, there is a cohort-specific time-varying growth pattern occurring in the data that is not taken into account within the model, as well as differences in growth between the Eastern GOA and the Central GOA. Dover sole move ontogenetically to deeper water, but this movement may be sex-specific and it may be that some Dover sole move to deep water as they grow old, while others remain in ~500m depths. Ontogenetic movement is taken into account only through separate selectivity curves for years where the survey only sampled to 500m. In addition, fishery age data do not exist for Dover sole. The 2017 GOA rex sole assessment showed that a major bias in fishery reference points was possible in situations where spatial patterns in growth were not taken into account (McGilliard et al. 2017) because the data showed a lot of variability in growth, which led to uncertainty and bias in the fishery selectivity curve. It is possible that a similar problem could be occurring in the GOA Dover sole assessment. It is unlikely that there is as much bias caused by estimating a single growth curve as there was for GOA rex sole because the GOA Dover sole fishery selectivity curve is estimated to occur at younger ages than maturity, while the single-area model for GOA rex sole estimated a fishery selectivity curve with selectivity occurring after maturity (which then led to extremely high F reference points). Therefore, we assign a risk level of 2 for the GOA Dover sole assessment in this category.

Population dynamics considerations

The GOA Dover sole population is nearly unfished. In 2015-2023 the survey biomass estimates were low, which corresponded to fewer old individuals in the age composition data. However, the age composition data and recruitment trend in the assessment show a strong year-class in 2015. We assign a risk level of 1 for this category.

Environmental/Ecosystem considerations

This summary of environmental considerations for the deepwater flatfish complex is based on representatives of the dominant species retained in the catch by biomass, Dover sole (Microstomus pacificus), and minor species, Kamchatka flounder, Greenland turbot (Reinhardtius hippoglossoides) and deepsea sole (Embassichthys bathybius).

Environment: While optimal temperatures for deepwater flatfish life stages are not known, it is reasonable to expect that the 2023 average ocean temperatures at depth on the shelf edge and shelf were adequate to meet metabolic demands (AFSC longline survey: Siwicke, 2023, AFSC bottom trawl survey, O'Leary, 2023a). Deepwater flatfish are found at depths of 200 m / 300 m - 1500 m/ 1600 m (Dover sole/ Greenland turbot), moving between spawning locations on the outer continental shelf (spawning Jan-Aug) and feeding habitat on the upper slope/shelf. Greenland turbot are found in 1-4 °C waters, but the ocean temperatures at those depths are not well monitored. Winds and surface currents can increase transport of eggs and larvae from offshore to nearshore nursery areas, and eddy activity can retain larvae nearshore (Bailey et al. 2008). The winter of 2022/2023 had variable eddy kinetic energy across the GOA, with above average eddy kinetic energy in the Haida and Seward locations and below average in the Sitka and Kodiak eddy locations, producing approximately average potential transport of larvae onto the shelf habitat (Cheng, 2023). Dover sole has had low observed survey biomass (NOAA bottom trawl) since 2015, coinciding with the beginning of multiple warm years at the surface and at depth on the GOA shelf (including the marine heatwaves of 2014-2016 and 2019). The depth distribution of Dover sole caught in the NOAA bottom trawl survey was minimally affected during the 2014-2016 heatwave (Li et al., 2019), potentially due to the relatively stable temperatures in deeper habitat along the slope. The pelagic larval stage of Dover sole may be more vulnerable to warm temperatures. Dover sole begin to be observed by the survey at age 3 and they mature around age 10. Therefore, we would expect to see effects of temperature on recruitment with at least a three year lag and any signal of temperature impact on the recruitment classes from that period would only become apparent in the spawning stock biomass in the next few years. In addition, there is a strong recruitment class in 2015.

Prey: The status of deepwater flatfish prey is largely unknown, with signs of decrease. Dover sole commonly feed on brittle stars, polychaetes and other miscellaneous worms. Greenland turbot are epibenthic feeders, preying on crustaceans and fishes. There were signs of decreased abundance in invertebrate prey in 2023 (shrimp, brittle stars, and motile epifauna; ADF&G trawl survey:Worton, 2023, AFSC bottom trawl survey: Whitehouse, 2023). Polychaetes and infauna are not well monitored. Dover sole have had below average condition (length-at-weight residuals) since 2015, potentially indicating reduced prey quality or quantity, although 2023 increased to approximately average (O'Leary, 2023b).

Predators & Competitors: Predation and competitive pressure on the deepwater flatfish complex are expected to be moderate. Primary predators of Dover sole include Pacific cod, P. halibut, sablefish, and seabirds (larval predators). P. cod and P. halibut populations remain at relatively low abundance (Hulson, 2023). The sablefish population has had strong year classes since 2016 and continues to increase (Goethel, 2023). The status of seabird populations is not well known but there have been no major changes (e.g., die offs) in the past few years (Jones, 2023).

The most recent data available suggest an ecosystem risk level of 1, given moderate environmental conditions, limited and mixed information on the abundance of prey, predators, and competitors, and a lack of a mechanistic understanding for the direct and indirect effects of environmental change on the survival and productivity of deepwater flatfish.

Fishery performance

There are no concerns about fishery performance for GOA Dover sole. Dover sole are an underutilized flatfish species and catches have been very low over time with the exception of 1991-1993. The five year average percentage of the TAC that is caught by the fishery is 1.8%. The risk level for fishery performance is 1.

Tier 3 Approach for Dover Sole

The reference fishing mortality rate for Dover sole is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the GOA). Estimates of $F_{40\%}$, $F_{35\%}$, and $SPR_{40\%}$ were obtained from a spawner-per-recruit analysis. Assuming that the average age-3 recruitment from the 1978-2023 year classes estimated in this assessment (noting that the most recent four year classes are set equal to mean recruitment due to lack of observations) represents a reliable estimate of equilibrium recruitment, then an estimate of $B_{40\%}$ can be calculated as the product of $SPR_{40\%}$ times the equilibrium number of recruits. Since reliable estimates of the 2023 spawning biomass (B), $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist and $B > B_{40\%}$, the Dover sole reference fishing mortality is defined in Tier 3a. Natural mortality for males and females is used in the calculation of reference points and is time-varying within the assessment, with separate estimates estimated for 2 time blocks: a historical time block covering 1978-2013 and a recent time block covering 2014-2023. The natural mortality values from the recent time block (2014-2023) were used in the calculation of reference points, as follows:

Parameter	**Value Used in Projection Model and for Calculation of Reference Points**
Female natural mortality	0.129
Male natural mortality	0.128

For this tier, $FABC$ is constrained to be ≤ $F_{40\%}$, and F_{OFL} is defined to be $F_{35\%}$. The values of these quantities are:

SSB 2024	24,938
B_{40}	6,387
F_{40}	0.12
$maxF_{ABC}$	0.12
B_{35}	5,589
F_{35}	0.15
F_{OFL}	0.15

Because the Dover sole stock has not been overfished in recent years and the stock biomass is relatively high, we do not recommended adjusting F_{ABC} downward from its upper bound of the maximum permissible F_{ABC} (maxF_{ABC}).

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 MSFCMA. 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 2036 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 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2024 and 2025, 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 2024 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 50% of max F_{ABC}. (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 4: In all future years, *F* is set equal to the 2019-2023 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 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.)

The 12-year projections of the mean SSB, fishing mortality, and catches for the five scenarios are shown in Table 19-Table 21. The recommended F_{ABC} and the maximum F_{ABC} are equivalent in this assessment, so scenarios 1 and 2 yield identical results.

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

Scenario 6: In all future years, *F* is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above its MSY-proxy level of $B_{35\%}$ in the current year then it is not overfished. If the stock is expected to be below ½ of $B_{35\%}$ in 2023, then it is overfished. If the stock is above ½ of $B_{35\%}$ in 2023, but below $B_{35\%}$, then the stock is determined to be overfished if is below $B_{35\%}$ in 2033.

Scenario 7: In 2024 and 2025, *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 expected to be above its MSY level ($B_{35\%}$) in 2036 under this scenario, then the stock is not approaching an overfished condition.)

The results of these two scenarios indicate that the stock is not overfished and is not approaching an overfished condition. With regard to assessing the current stock level, the expected stock size in the year 2023 of Scenario 6 is 25,642 t, more than $B_{35\%}$ (5,589 t). Thus the stock is not currently overfished. With regard to whether the stock is approaching an overfished condition, the expected spawning stock size in the year 2036 of Scenario 7 (11,674 t) is greater than $B_{35\%}$; thus, the stock is not approaching an overfished condition.

Area Allocation for Harvests

ABCs and TACs for deepwater flatfish in the GOA are divided among four smaller management areas (Eastern, Central, West Yakutat and Southeast Outside). Area apportionment for ABC of deepwater flatfish is currently based on the proportion of survey biomass of Greenland Turbot and deepsea sole found within each management area from 2005-2023 and estimates of 2024 and 2025 survey biomass for Dover sole in each management area based on results from the random effects model. An ABC exists only at the level of the complex (deepwater flatfish) and not for each species individually. The ABC by area for the deepwater flatfish complex is then the sum of the species-specific portions of the ABC.

The random effects model is used to fill in depth and area gaps in the Dover sole survey biomass by area and to calculate an area- and depth-specific projection of 2024 and 2025 survey biomass. These estimates are summed over depths and the resulting relative biomass in each management area is used as the basis for apportionment of the Dover sole portion of the deepwater complex. This method of conducting area apportionment for deepwater flatfish was recommended by the GOA Plan Team in 2016 (McGilliard 2016). The method was chosen because it accounts for time and area gaps in the survey for Dover sole, which comprises nearly all of the deepwater flatfish catch and moves to deeper waters ontogenetically, and explicitly accounts for differences in the spatial distributions of Dover sole and Greenland turbot. Greenland turbot were found exclusively in the Western region by the survey over the period 2005-2023.

Species	Year	Western	Central	West Yakutat	Southeast	Total
		2.6%	37.5%	26.6%	33.2%	100.0%
Dover Sole	2024	183	2,617	1,856	2,313	6,969
	2025	180	2,576	1,827	2,277	6,860
		100.0%	0.0%	0.0%	0.0%	100.0%
Greenland Turbot	2024	37	0	0	0	37
	2025	37	0	0	0	37
		32.1%	67.9%			100.0%
Kamchatka Flounder	2024	17	35	0	0	52
	2025	17	35	0	0	52
		0.0%	74.9%	11.2%	13.9%	100.0%
Deepsea Sole	2024	0	3	0	1	4
	2025	0	3	0	1	4
Deepwater Flatfish	**2024**	**237**	**2,655**	**1,856**	**2,314**	**7,062**
	2025	**234**	**2,614**	**1,827**	**2,278**	**6,953**

F corresponding to a catch equal to last year's 2023 OFL

The *F* (based on the 2023 model 19.3.1) that would have produced a catch for last year equal to last year's OFL is equal to 0.12.

Ecosystem Considerations

Ecosystem Effects on the Stock

Refer to the 2019 full assessment for a full description of Ecosystem Considerations (McGilliard et al. 2019). Based on results from an ecosystem model for the GOA (Aydin et al., 2007), Dover sole adults occupy an intermediate trophic level. Dover sole commonly feed on brittle stars, polychaetes and other miscellaneous worms. Trends in prey abundance for Dover sole are unknown.

Important predators identified in the GOA ecosystem model include walleye pollock and Pacific halibut; however, the major source of Dover sole mortality is from the flatfish fishery. The ecosystem model was developed using food habits data from the early 1990s when GOA pollock biomass was much larger than it is currently and fishing mortality on Dover sole was much higher than it is now.

Little is known regarding the roles of Greenland turbot, Kamchatka flounder or deepsea sole in the GOA ecosystem. Within the 200-mile limits of the Exclusive Economic Zone of the United States, Greenland turbot are mainly found in the Bering Sea and the Aleutian Islands (Ianelli et al., 2006). Greenland turbot are epibenthic feeders and prey on crustaceans and fishes. Walleye pollock are important predators on turbot in the Bering Sea, but it is unknown whether this holds true in the GOA as well.

Fishery Effects on the Ecosystem

In recent years and since 2015, the targeted deepwater flatfish fishery has caught no FMP, ecosystem, bycatch species, or Prohibited Species Catch (PSC), which is consistent with the very low catches of deepwater flatfish, and the fact that most catch of deepwater flatfish in recent years has been discarded in other target fisheries (Table 1; Table 4).

Data Gaps and Research Priorities

Please see the most recent full assessment (McGilliard et al. 2019) for the deepwater flatfish complex for a complete discussion of data gaps and research priorities.

Literature Cited

Abookire, A.A., & Bailey, K. (2007). The distribution of life cycle stages of two deep-water pleuronectids, Dover sole (*Microstomus pacificus*) and rex sole (*Glyptocephalus zachirus*), at the northern extent of their range in the Gulf of Alaska. 57: 198–208.

Abookire, A. A., & Macewicz, B. J. (2003). Latitudinal variation in reproductive biology and growth of female Dover sole (*Microstomus pacificus*) in the North Pacific, with emphasis on the Gulf of Alaska stock. *Journal of Sea Research, 50*, 187-197.

Beverton, R. J. H. (1992). Patterns of reproductive strategy parameters in some marine teleost fishes. J. Fish Biol. 41(Suppl. B):137-160.

Demory, R. L., Golden, J. T., & Pikitch, E. (1984). Status of Dover sole (Microstomus pacificus) in INPFC Columbia and Vancouver areas in 1984. Status f Pacific Coast Groundfish Fishery and Recommendations for Management in 1985. Pacific Fishery Management Council. Portland, Oregon 97201.

Fournier, D.A., Skaug, H.J., Ancheta, J., Ianelli, J., Magnusson, A., Maunder, M.N., Nielsen, A., and Sibert, J. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim. Methods Softw. 27:233-249.

Francis, R. I. C. C. (2011). Data weighting in statistical fisheries stock assessment models. *Canadian Journal of Fisheries and Aquatic Sciences, 68*, 1124-1138.

Hart, J. L. (1973). Pacific fishes of Canada. Fish Res. Board Canada, Bull. No. 180. 740 p.

Hicks, A., & Wetzel, C. R. (2011). The Status of Dover Sole (*Microstomus pacificus*) along the U.S. West Coast in 2011. Pacific Fishery Management Council. Portland, Oregon. www.pcouncil.org.

Hirschberger, W. A., & Smith, G. B. (1983). Spawning of twelve groundfish species in the Alaska and Pacific coast regions. 50 p. NOAA Tech. Mem. NMFS F/NWC-44. U.S> Dep. Commer., NOAA, Natl. Mar. Fish. Serv.

Hoenig, J. (1983). Empirical use of longevity data to estimate mortality rates. *Fish Bulletin, 82*, 898-903.

Horn, & Francis, R. I. C. C. (2010). Stock assessment of hake (Merluccius australis) on the Chatham Rise for the 2009–10 fishing year. New Zealand Fisheries Assessment Report 2010/14, Ministry of Fisheries, Wellington, New Zealand.

Hunter, J. R., Macewicz, B. J., Lo, N. C. H., & Kimbrell, C. A. (1992). Fecundity, spawning, and maturity of female Dover sole, Microstomus pacificus, with an evaluation of assumptions and precision. . *Fish. Bull., 90*, 101-128.

Hurtado-Ferro, F., Szuwalski, C.S., Valero, J.L., Anderson, S.C., Cunningham, C., Johnson, K.F., Licandeo, R., McGilliard, C.R., Monnahan, C.C., Muradian, M.L., Ono, K., Vert-Pre, K.A., Whitten, A.R., and Punt, A.E. Looking in the rearview mirror: bias and retrospective patterns in integrated, age-structured stock assessment models. ICES J. Mar.Sci. 72(1): 99-110.

Kastelle, C. R., Anderl, D. M., Kimura, D. K., & Johnston, C. G. (2008). Age validation of Dover sole (Microstomus pacificus) by means of bomb radiocarbon. *Fishery Bulletin, 106(4)*, 375-385.

Kendall, A. W. J., & Dunn, J. R. (1985). Ichthyoplankton of the continental shelf near Kodiak Island, Alaska. NOAA Tech. Rep. NMFS 20, U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv.

Markle, D. F., Harris, P. M., & Toole, C. L. (1992). Metamorphosis and an overview of early life-history stages in Dover sole *Microstomus pacificus*. *Fish Bulletin, 90*, 285-301.

Martin, M. H., & Clausen, D. M. (1995). Data report: 1993 Gulf of Alaska Bottom Trawl Survey. U.S. Dept. Commer., NOAA, Natl. Mar. Fish. Serv., NOAA Tech. Mem. NMFS-AFSC-59, 217p.

McAllister, M.K. and Ianelli, J.N. 1997. Bayesian stock assessment using catch-age data and the sampling –importance resampling algorithm. Can. J. Fish. Aquat. Sci. 54: 284-300.

McGilliard, C.R., Palsson, W., Havron, A., and Zador, S. 2019. 5. Assessment of the Deepwater Flatfish Stock in the Gulf of Alaska. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Gulf of Alaska as Projected for 2019.

McGilliard, C.R. and Palsson, W. 2015. 5. Assessment of the Deepwater Flatfish Stock in the Gulf of Alaska. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Gulf of Alaska as Projected for 2015.

McGilliard, C.R., Palsson, W., Stockhausen, W., and Ianelli, J. 2013. 5. Assessment of the Deepwater Flatfish Stock in the Gulf of Alaska. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Gulf of Alaska as Projected for 2013. pp. 403-536.

Methot, R. D. (2009). User manual for stock synthesis, model version 3.04b. NOAA Fisheries, Seattle, WA.

Methot, R. D., & Wetzel, C. R. (2013). Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. *Fisheries Research, 142*, 86-99.

Miller, D. J., & Lea, R. N. (1972). Guide to the coastal marine fishes of California. Calif. Dept. Fish Game, Fish. Bull. 157, 235p., *157*.

Pennington, M., & Volstad, J. H. (1994). Assessing the effect of intra-haul correlation and variable density on estimates of population characteristics from marine surveys. *Biometrics, 50*, 725-732.

Punt, A. E., Smith, D. C., KrusicGolub, K., & Robertson, S. (2008). Quantifying age-reading error for use in fisheries stock assessments, with application to species in Australia's southern and eastern scalefish and shark fishery. *Canadian Journal of Fisheries and Aquatic Sciences, 65*(9), 1991-2005. doi: 10.1139/f08-111

R Core Team (2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Reeves, S. A. (2003). A simulation study of the implications of age-reading errors for stock assessment and management advice. *Ices Journal of Marine Science*, *60*, 314-328.

Rideout, R.M., Rose, G.A., Burton, M.P.M. (2005). Skipped spawning in female iteroparous fishes. Fish and Fisheries. 6:50-72.

Somerton, D.A., Munro, P.T., and Weinberg, K.L. 2007. Whole-gear efficiency of a benthic survey trawl for flatfish. Fish. Bull. 105:278-291.

Stewart, I. J. (2005). Status of the U.S. English sole resource in 2005. Pacific Fishery Management Council. Portland, Oregon. www.pcouncil.org. 221 p. .

Sullivan, J., C. Monnahan, P. Hulson, J. Ianelli, J. Thorson, and A. Havron. 2022. REMA: a consensus version of the random effects model for ABC apportionment and Tier 4/5 assessments. Plan Team Report, Joint Groundfish Plan Teams, North Pacific Fishery Management Council. 605 W 4th Ave, Suite 306 Anchorage, AK 99501. Available through the Oct 2022 Joint GPT e-Agenda.

Stockhausen, W. T., Wilkins, M. E., & Martin, M. H. (2011). 5. Assessment of the Deepwater Flatfish Stock in the Gulf of Alaska. In Stock Assessment and Fishery Evaluation Document for Groudfish Resources in the Gulf of Alaska as Projected for 2012. pp. 547-628. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.

Taylor, I.G., Ian J. Stewart, Allan C. Hicks, Tommy M. Garrison, Andre E. Punt, John R. Wallace, Chantel R. Wetzel, James T. Thorson,Yukio Takeuchi, Kotaro Ono, Cole C. Monnahan, Christine C. Stawitz, Z. Teresa A'mar, Athol R. Whitten, Kelli F. Johnson, Robbie L. Emmet, Sean C. Anderson, Gwladys I. Lambert, Megan M. Stachura, Andrew B. Cooper, Andi Stephens, Neil L. Klaer and Carey R. McGilliard (2018). r4ss: R Code for Stock Synthesis. R package version 1.32.1. https://github.com/r4ss

Turnock, B., McGilliard, C.R. and Palsson, W. 2017. 5. Assessment of the Flathead Sole Stock in the Gulf of Alaska. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Gulf of Alaska as Projected for 2017.

Turnock, B. J., Wilderbuer, T. K., & Brown, E. S. (2003). Gulf of Alaska Dover sole. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Gulf of Alaska as Projected for 2004. pp. 341-368. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage AK 99510.

Wakabayashi, K., Bakkala, R.G. , and Alton, M.S. (1985). Methods of the U.S.-Japan demersal trawl surveys. In Richard G. Bakkala and Kiyoshi Wakabayashi (editors), Results of cooperative U.S.-Japan groundfish investigations in the Bering Sea during May-August 1979, p. 7-29. . *Int. North Pac. Fish. Comm. Bull., 44*.

Westrheim, S. J., Barss, W. H., Pikitch, E. K., & Quirollo, L. F. (1992). Stock Delineation of Dover Sole in the California-British Columbia Region, Based on Tagging Studies Conducted during 1948-1979. North American Journal of Fisheries Management 12:172-181.

Tables

Table 1. Total annual catch of GOA deepwater flatfish by species through September 27, 2023. Deepsea sole is included in the deepwater flatfish complex, but is not formally tracked and catches are estimated to be 0-4t based on observer data. Kamchatka flounder was added to the deepwater flatfish complex in 2011 when it was separated from Arrowtooth flounder based on improvements in identifying the two species. Kamchatka flounder has not been assigned to an FMP Tier and the OFL and ABC are undefined. Catches include areas NMFS Reporting Areas 649 and 659. Unidentified flatfish were included in the assessment model as Dover sole.

Year	Greenland turbot	Dover sole	Unidentified	Total
1978	51	827		878
1979	24	530		554
1980	57	570		627
1981	8	457		465
1982	23	457		480
1983	145	354		499
1984	18	132		150
1985	0	43		43
1986	0	23		23
1987	44	56		100
1988	256	1,087		1,343
1989	56	1,521		1,577
1990	0	2,348		2,348
1991			10,196	10,196
1992			8,497	8,497
1993	19	1,869	1,935	6,706
1994	3	2,538	537	3,078
1995	78	1,416	721	2,215
1996	6	1,485	704	2,195
1997	3	2,676	996	3,674
1998	10	2,111	168	2,289
1999	6	1,833	447	2,285
2000	5	813	167	985
2001	4	654	146	804
2002	4	411	146	560
2003	3	899	51	902
2004	1	646	41	647
2005	1	378	41	379
2006	10	327	74	337
2007	1	235	47	236
2008	4	517	53	521
2009	0	435	42	435
2010	0	546		546

Year	Greenland turbot	Dover sole	Kamchatka Flounder	Total
2011	3	453	12	467
2012	0	260	4	265
2013	15	216	15	245
2014	3	284	69	356
2015	26	198	35	259
2016	4	231	5	240
2017	8	188	67	263
2018	3	144	40	186
2019	7	92	14	113
2020		97	15	112
2021	9	67	20	96
2022	18	116	13	147
2023	22	56	20	98

Table 2. Proportion of deepwater flatfish fishery catches by depth (in meters) from 1990-2023. Conditional highlighting is darker green for higher proportions and lighter green for lower proportions.

Year	0 to 100m	101 to 500m	501 to 700m	>701m
1990	0.02	0.87	0.11	0.00
1991	0.01	0.91	0.08	0.00
1992	0.00	0.55	0.44	0.00
1993	0.00	0.76	0.22	0.01
1994	0.01	0.71	0.27	0.00
1995	0.02	0.82	0.15	0.00
1996	0.02	0.79	0.19	0.00
1997	0.00	0.94	0.05	0.00
1998	0.01	0.72	0.26	0.00
1999	0.00	0.81	0.19	0.00
2000	0.01	0.86	0.13	0.00
2001	0.01	0.76	0.23	0.00
2002	0.03	0.90	0.07	0.00
2003	0.01	0.96	0.03	0.00
2004	0.01	0.75	0.24	0.00
2005	0.01	0.97	0.02	0.00
2006	0.11	0.88	0.01	0.00
2007	0.10	0.86	0.04	0.00
2008	0.03	0.89	0.08	0.00
2009	0.05	0.86	0.09	0.00
2010	0.01	0.60	0.39	0.00
2011	0.00	0.76	0.24	0.00
2012	0.01	0.79	0.19	0.01
2013	0.03	0.75	0.20	0.02
2014	0.02	0.71	0.26	0.00
2015	0.01	0.74	0.25	0.01
2016	0.02	0.50	0.46	0.03
2017	0.13	0.72	0.15	0.00
2018	0.08	0.80	0.09	0.02
2019	0.02	0.65	0.29	0.04
2020	0.08	0.81	0.10	0.01
2021	0.37	0.52	0.11	0.00
2022	0.43	0.46	0.10	0.00
2023	0.35	0.58	0.06	0.01

Table 3. Proportion of deepwater flatfish fishery catches by fishery management area from 1990-2023. Conditional highlighting is darker green for higher proportions and lighter green for lower proportions.

Year	Western	Central	Southeast	West Yakutat
1990	0.06	0.71	0.04	0.19
1991	0.02	0.92	0.02	0.04
1992	0.00	0.95	0.01	0.03
1993	0.02	0.95	0.01	0.02
1994	0.01	0.87	0.07	0.04
1995	0.03	0.81	0.00	0.16
1996	0.01	0.83	0.05	0.11
1997	0.01	0.53	0.44	0.03
1998	0.00	0.93	0.00	0.06
1999	0.01	0.89	0.00	0.10
2000	0.02	0.91	0.01	0.06
2001	0.04	0.78	0.00	0.18
2002	0.06	0.93	0.01	0.00
2003	0.05	0.94	0.00	0.00
2004	0.07	0.92	0.01	0.00
2005	0.02	0.94	0.01	0.04
2006	0.05	0.89	0.01	0.05
2007	0.08	0.86	0.01	0.05
2008	0.08	0.91	0.01	0.00
2009	0.05	0.93	0.00	0.02
2010	0.01	0.97	0.00	0.02
2011	0.10	0.87	0.00	0.03
2012	0.01	0.98	0.00	0.01
2013	0.03	0.95	0.01	0.01
2014	0.29	0.70	0.00	0.00
2015	0.15	0.84	0.00	0.00
2016	0.02	0.96	0.00	0.02
2017	0.02	0.95	0.00	0.03
2018	0.18	0.80	0.00	0.02
2019	0.01	0.92	0.01	0.07
2020	0.01	0.95	0.00	0.03
2021	0.00	0.94	0.01	0.04
2022	0.02	0.97	0.01	0.01
2023	0.03	0.94	0.00	0.02

Table 4. Historical OFLs, ABCs, TACs for the deepwater flatfish complex, the percent of catch retained each year, and the percent of TAC caught in each year (including retained and discarded catches).

Year	OFL	ABC	TAC	Percent of Catch Retained	Percent of TAC Caught (Retained + Discarded)
1995	17,040	14,590	11,080	79%	20%
1996	17,040	14,590	11,080	72%	20%
1997	9,440	7,170	7,170	82%	51%
1998	9,440	7,170	7,170	90%	32%
1999	8,070	6,050	6,050	80%	38%
2000	6,980	5,300	5,300	71%	19%
2001	6,980	5,300	5,300	75%	15%
2002	6,430	4,880	4,880	64%	11%
2003	6,430	4,880	4,880	50%	18%
2004	8,010	6,070	6,070	80%	11%
2005	8,490	6,820	6,820	41%	6%
2006	11,008	8,665	8,665	39%	4%
2007	10,431	8,707	8,707	40%	3%
2008	11,343	8,903	8,903	37%	6%
2009	11,578	9,168	9,168	22%	5%
2010	7,680	6,190	6,190	62%	9%
2011	7,823	6,305	6,305	50%	7%
2012	6,834	5,126	5,126	28%	5%
2013	6,834	5,126	5,126	58%	5%
2014	16,159	13,472	13,472	67%	3%
2015	15,993	13,334	13,334	42%	2%
2016	11,102	9,226	9,226	39%	3%
2017	11,182	9,292	9,292	27%	3%
2018	11,294	9,384	9,384	36%	2%
2019	11,434	9,501	9,501	26%	1%
2020	7,163	6,030	6,030	52%	2%
2021	7,040	5,926	5,926	9%	2%
2022	7,026	5,908	5,908	13%	2%
2023	6,918	5,816	5,816	8%	2%

*As of September 27, 2023

Table 5. Non-regulation bycatch status and prohibited species catch status for the GOA deepwater flatfish fishery from 2019-2023. This information can be found on the Alaska Regional Office Website: https://alaskafisheries.noaa.gov/status-of-fisheries/.

Effective Date	Gear	Sub Area	Program	Status	Reason	IB
3/26/2019	Trawl Gear		All	Bycatch	Specifications	34
3/7/2020	Trawl Gear	Central	All	Bycatch	Halibut	
3/7/2020	Trawl Gear	Western	All	Bycatch	Halibut	
3/7/2020	Trawl Gear	Eastern	All	Bycatch	Halibut	
3/26/2021	Trawl Gear	Central	Catcher Vessel	Bycatch	Chinook	17
3/26/2021	Trawl Gear	Western	Catcher Vessel	Bycatch	Chinook	17

Table 6. Dover sole survey biomass by depth and area

	0-500m	501-700m	700-1000m	Total
Central				
1984	36,013	5,147	11,309	52,469
1987	26,281	6,757	1,539	34,577
1990	71,109			71,109
1993	43,515			43,515
1996	37,144			37,144
1999	30,550	2,889	716	34,155
2001	31,529			31,529
2003	40,545	8,738		49,283
2005	35,492	1,617	1,772	38,881
2007	38,145	3,604	1,655	43,404
2009	33,816	1,769	236	35,820
2011	34,047	1,501		35,548
2013	20,907	2,273		23,180
2015	16,944	1,222	1,901	20,067
2017	19,730	765		20,495
2019	13,717	1,240		14,956
2021	15,908	1,414		17,322
2023	16,751	1,680		18,431
Eastern				
1984	9,534	1,728	330	11,592
1987	23,677	2,518		26,194
1990	23,839			23,839
1993	39,664			39,664
1996	40,928			40,928
1999	35,566	2,476	606	38,648
2003	44,399	2,466		46,865
2005	37,572	1,206	69	38,847
2007	24,164	1,298	278	25,740
2009	30,835	4,144	411	35,389
2011	40,249	902		41,150
2013	57,456	1,125		58,580
2015	30,368	2,256	42	32,667
2017	37,134	419		37,552
2019	30,251	2,337		32,588
2021	27,412	965		28,377
2023	29,112	1,222		30,334
Western				
1984	2,251	1,290	919	4,460
1987	1,248	1,267	108	2,623
1990	1,649			1,649
1993	2,379			2,379
1996	1,458			1,458
1999	757	685	-	1,442
2001	895			895
2003	1,816	1,333		3,149
2005	1,673	312	848	2,832
2007	1,061	208	1,056	2,325
2009	1,355	3,712	-	5,067
2011	523	311		833
2013	837	142		979
2015	276	60	-	336

2017	260	-	260
2019	400	39	439
2021	252	128	380
2023	169	-	169

Table 7. Final Dover sole survey biomass estimates and logspace standard errors used in the assessment model in 2019 and 2023, after an adjustment using the survey-averaging random effects model (REMA) to estimate biomass in missing year-strata combinations; this random effects model is run each assessment cycle and leads to historical biomass estimates that can differ from assessment to assessment. The 2023 assessment used the maximum Log SE estimate for all years with missing strata. The 2019 assessment summed variances estimated within the survey-averaging random effects model for missing strata with designed-based variances and converted these values to logspace standard errors, however this leads to underestimation of the standard errors.

Year	2019 Biomass	2019 Log SE	2023 Biomass	2023 Log SE
1990	104,959	0.16	104,915	0.24
1993	93,920	0.13	93,875	0.24
1996	87,893	0.11	87,849	0.24
1999	75,093	0.1	75,292	0.24
2001	78,890	0.1	77,653	0.24
2003	101,509	0.11	101,708	0.10
2005	80,560	0.08	80,560	0.08
2007	71,469	0.1	71,469	0.10
2009	76,277	0.08	77,324	0.08
2011	79,032	0.09	80,078	0.09
2013	84,298	0.21	85,344	0.21
2015	53,069	0.09	54,116	0.09
2017	59,955	0.17	61,077	0.17
2019	48,452	0.12	50,677	0.12
2021			48,773	0.11
2023			51,720	0.13

Table 8. Dover sole survey biomass from the Eastern Bering Sea (EBS) shelf bottom trawl survey, the Aleutian Islands bottom trawl survey, and the EBS slope bottom trawl survey. No Dover sole have been found in the Northern Bering Sea bottom trawl survey.

Year	EBS Shelf	Aleutian Islands	EBS Slope
1987	76		
1988	39		
1989	-		
1990	47		
1991	54	224	
1992	135		
1993	35		
1994	73	438	
1995	-		
1996	-		
1997	-	374	
1998	41		
1999	15		
2000	10	630	
2001	16		
2002	7	576	97
2003	146		
2004	31	868	141
2005	158		
2006	89	2,157	
2007	73		
2008	358		330
2009	460		
2010	199	2,874	463
2011	400		
2012	67	1,214	702
2013	27		
2014	608	1,025	
2015	5		
2016	12	1,459	594
2017	-		
2018	16	975	
2019	141		
2021	469		
2022	867	361	
2023	333		

Table 9. Survey biomass estimates over time for the Tier 6 species in the deepwater flatfish complex (t): Greenland turbot, Kamchatka flounder, and deepsea sole.

Year	deepsea sole	Greenland turbot	Kamchatka flounder
1984	218	292	-
1987	160	143	-
1990	-	-	-
1993	-	-	-
1996	-	-	197
1999	97	-	90
2001	52	-	33
2003	180	109	125
2005	262	-	10
2007	270	122	-
2009	249	-	4
2011	41	-	10
2013	74	-	-
2015	453	-	117
2017	31	-	11
2019	122	-	8
2021	173	-	6
2023	187	-	15

Table 10. Ageing error uncertainty assumed in the assessment model.

True Age	Standard Deviation	True Age	Standard Deviation
0	0.210	30	4.224
1	0.210	31	4.464
2	0.284	32	4.715
3	0.361	33	4.975
4	0.441	34	5.247
5	0.525	35	5.530
6	0.612	36	5.824
7	0.703	37	6.131
8	0.797	38	6.450
9	0.896	39	6.783
10	0.998	40	7.129
11	1.105	41	7.490
12	1.216	42	7.866
13	1.332	43	8.257
14	1.452	44	8.664
15	1.578	45	9.089
16	1.709	46	9.531
17	1.845	47	9.991
18	1.987	48	10.470
19	2.134	49	10.969
20	2.288	50	11.489
21	2.448	51	12.031
22	2.615	52	12.594
23	2.789	53	13.182
24	2.970	54	13.793
25	3.158	55	14.430
26	3.354	56	15.093
27	3.559	57	15.784
28	3.771	58	16.503
29	3.993	59	17.252

Table 11. Double-normal selectivity curve specifications within the model for Model 19.3.1 and all models in the bridging analysis.

Double-normal selectivity parameters	**Fishery**	**"Full-coverage" Survey**	**"Shallow-coverage" Survey**
Peak: beginning size for the plateau (in cm)	Estimated	Estimated	Estimated
Width: width of plateau	0	8	Estimated
Ascending width (log space)	Estimated	Estimated	Estimated
Descending width (log space)	10	15	15
Initial: selectivity at smallest length or age bin	Follow asc width	Follow asc width	Follow asc width
Final: selectivity at largest length or age bin	Follow desc width	Follow desc width	Follow desc width
Male Peak Offset	Estimated	Estimated	Estimated
Male ascending width offset (log space)	Estimated	Estimated	Estimated
Male descending width offset (log space)	0	0	Estimated
Male "Final" offset (transformation required)	0	Follow desc width	Follow desc width
Male apical selectivity	1	1	1

Table 12. Negative log likelihood components for the 2019 assessment (Model 19.3), models in the bridging analysis, and for the 2023 preferred model (Model 19.3.1). Line-by-line, values for negative log likelihood that can be compared to one another are highlighted in the same color. Model 19.3 has less data and cannot be compared directly to values for the other models. Model 19.3.1 re-weights the length composition data and the age data and therefore only the value for the survey likelihood component can be compared to other 2023 models.

Likelihood Component	Model 19.3	Model 19.3 + new data	Model 19.3 + new data + max survey index variance	Model 19.3.1: new data + max survey index variance + adj. Francis data weighting
TOTAL	1362.28	1543.65	1546.97	2697.83
Survey	-24.178	-28.6767	-25.4796	-24.4798
Length Composition	214.809	301.149	300.892	111.121
Age Composition	1166.8	1261.69	1261.76	2598.2

Table 13. Final parameter estimates for biology, growth, and catchability parameters. “SD” is the standard deviation of the estimate.

	2019 Model 19.3		**2023 Model 19.3**		**2023 19.3+Max Variance**		**19.3.1: 2023 19.3 + Max Variance + Francis Re-weighting**		**Parameter Type**
Parameter	Est	SD	Est	SD	Est	SD	Est	SD	
Female Natural Mortality 1978-2013	0.07	0.00	0.07	0.00	0.07	0.00	0.07	0.00	Nat. Mort.
Female length-at-age-3	24.51	0.77	24.65	0.69	24.65	0.69	25.10	0.64	Growth
Female length-at-age-59	50.77	0.31	50.99	0.32	50.99	0.32	51.20	0.45	Growth
Female von-Bertalanffy k	0.16	0.01	0.16	0.01	0.16	0.01	0.14	0.01	Growth
Female CV of length-at-age-3	0.16	0.01	0.15	0.01	0.15	0.01	0.14	0.01	Growth
Female CV of length-at-age-59	0.10	0.00	0.10	0.00	0.10	0.00	0.10	0.00	Growth
Male Natural Mortality 1978-2013	0.06	0.00	0.06	0.00	0.06	0.00	0.06	0.00	Nat. Mort.
Male length-at-age-3	26.55	0.91	26.20	0.80	26.21	0.80	25.53	0.73	Growth
Male length-at-age-59	43.44	0.27	43.49	0.27	43.50	0.27	44.15	0.27	Growth
Male von-Bertalanffy k	0.20	0.02	0.19	0.02	0.19	0.02	0.18	0.01	Growth
Male CV of length-at-age-3	0.15	0.01	0.14	0.01	0.14	0.01	0.15	0.01	Growth
Male CV of length-at-age-59	0.08	0.00	0.08	0.00	0.08	0.00	0.08	0.00	Growth
Female Natural Mortality 2014-2023	0.11	0.02	0.13	0.01	0.13	0.01	0.13	0.02	Nat. Mort.
Male Natural Mortality 2014-2023	0.12	0.02	0.13	0.01	0.13	0.01	0.13	0.02	Nat. Mort.
Logspace mean recruitment	9.36	0.07	9.45	0.06	9.47	0.07	9.50	0.07	Recruitment
Logspace survey catchability 1978-2013 (fixed)	-0.12	--	-0.12	--	-0.12	--	-0.12	--	Catchability
Logspace survey catchability 2014-2023	-0.32	0.08	-0.29	0.08	-0.30	0.08	-0.35	0.08	Catchability

Table 14. Fishery, full coverage survey, and shallow coverage selectivity parameters for Model 19.3.1. “Est” refers to the estimated value and “Std. Dev” is the standard deviation of the estimate. “Follow asc width” indicates that the selectivity curve is parameterized such that the ascending width parameter determines the initial selectivity at the smallest size or age bin. “Follow desc width” indicates that the selectivity curve is parameterized such that the descending width parameter determines the final selectivity at the largest size or age bin. Fishery selectivity was length-based and survey selectivity was age-based. The descending limb for the female shallow coverage survey selectivity and for male and female fishery selectivity were fixed to be asymptotic based on previous runs showing very large standard deviations corresponding these parameter estimates.

	Fishery		**Full Coverage Survey**		**Shallow Coverage Survey**	
Double-normal selectivity parameters	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
Peak: beginning size for the plateau	52.34	5.04	6.23	0.46	5.60	1.16
Width: width of plateau	0	Fixed	8.00	Fixed	-2.15	1.77
Ascending width (log space)	5.32	0.60	1.63	0.32	1.42	0.89
Descending width (log space)	10.00	Fixed	15.00	Fixed	15.00	Fixed
Initial: selectivity at smallest length or age bin	-10	Fixed	Follow asc width	Fixed	Follow asc width	Fixed
Final: selectivity at largest length or age bin	Follow desc width	Fixed	Follow desc width	Fixed	Follow desc width	Fixed
Male Peak Offset	-12.44	5.09	-0.44	0.59	-1.84	4.30
Male ascending width offset (log space)	-1.95	0.84	-0.36	0.45	-2.60	10.92
Male descending width offset (log space)	0.00	Fixed	0.00	Fixed	-9.03	0.71
Male "Final" offset (transformation required)	0.00	Fixed	Follow desc width	Fixed	Follow desc width	Fixed
Male apical selectivity	1.00	Fixed	1.00	Fixed	1.00	Fixed

Table 15. Estimated recruitment deviations and associated standard deviations for the current model. "Std. Dev" is the standard deviation of the estimate.

Year	Recruitment Deviations	Std. Dev.	Year	Recruitment Deviations	Std. Dev.
1978	0.672	0.394	2012	0.031	0.286
1979	0.294	0.436	2013	-0.215	0.315
1980	0.171	0.415	2014	0.383	0.294
1981	0.179	0.404	2015	1.288	0.215
1982	0.246	0.401	2016	0.509	0.325
1983	0.271	0.378	2017	0.788	0.339
1984	0.043	0.362	2018	0.644	0.407
1985	-0.248	0.342	2019	0.246	0.458
1986	-0.285	0.321	2020	0.284	0.469
1987	-0.227	0.292	2021	-0.001	0.485
1988	-0.495	0.292	2022	-0.002	0.487
1989	-0.706	0.276	2023	0.000	0.487
1990	-0.776	0.288			
1991	-0.442	0.233			
1992	-0.938	0.278			
1993	-0.512	0.259			
1994	-0.285	0.254			
1995	-0.230	0.260			
1996	-0.332	0.286			
1997	-0.202	0.257			
1998	-0.106	0.252			
1999	0.668	0.152			
2000	-0.246	0.250			
2001	-0.459	0.261			
2002	-0.109	0.227			
2003	-0.029	0.252			
2004	0.556	0.185			
2005	-0.144	0.270			
2006	-0.333	0.269			
2007	-0.256	0.258			
2008	-0.272	0.270			
2009	-0.162	0.288			
2010	0.262	0.255			
2011	0.475	0.238			

Table 16. Estimated fishing mortality rates for the current model. "Std. Dev" is the standard deviation of the estimate.

Year	Fishing Mortality	Std. Dev.
Initial F	--	--
1978	0.0071	0.0005
1979	0.0046	0.0003
1980	0.0049	0.0003
1981	0.0040	0.0003
1982	0.0040	0.0003
1983	0.0031	0.0002
1984	0.0011	0.0001
1985	0.0004	0.0000
1986	0.0002	0.0000
1987	0.0005	0.0000
1988	0.0091	0.0006
1989	0.0127	0.0009
1990	0.0198	0.0014
1991	0.0887	0.0063
1992	0.0782	0.0056
1993	0.0674	0.0049
1994	0.0322	0.0023
1995	0.0203	0.0015
1996	0.0244	0.0017
1997	0.0425	0.0030

Year	Fishing Mortality	Std. Dev.
1998	0.0268	0.0019
1999	0.0284	0.0020
2000	0.0124	0.0009
2001	0.0105	0.0007
2002	0.0073	0.0005
2003	0.0119	0.0008
2004	0.0086	0.0006
2005	0.0050	0.0003
2006	0.0043	0.0003
2007	0.0030	0.0002
2008	0.0066	0.0005
2009	0.0055	0.0004
2010	0.0069	0.0005
2011	0.0056	0.0004
2012	0.0032	0.0002
2013	0.003	0.000
2014	0.003	0.000
2015	0.003	0.000
2016	0.003	0.000
2017	0.003	0.000
2018	0.002	0.000
2019	0.001	0.000
2020	0.002	0.000
2021	0.001	0.000
2022	0.002	0.000
2023	0.001	0.000

Table 17. Time series of age 3+ total biomass, spawning biomass, and standard deviation of spawning biomass ("Stdev_SPB") for the previous and current assessment models.

	2019 Assessment			*2023 Assessment*		
Year	**Total Biomass (age 3+)**	**Spawning Biomass**	**Stdev_SPB**	**Total Biomass (age 3+)**	**Spawning Biomass**	**Stdev_SPB**
1978	134,286	48,489	2,083	145,351	54,355	3,042
1979	133,490	48,158	2,076	144,563	54,031	3,028
1980	133,010	47,951	2,072	144,089	53,829	3,019
1981	135,584	47,754	2,063	146,302	53,639	3,006
1982	137,003	47,621	2,055	147,340	53,507	2,995
1983	138,173	47,519	2,043	148,032	53,399	2,983
1984	139,525	47,502	2,029	148,840	53,367	2,970
1985	141,136	47,632	2,013	150,064	53,468	2,959
1986	142,494	47,866	1,996	151,454	53,660	2,948
1987	143,062	48,186	1,979	152,114	53,922	2,937
1988	142,902	48,576	1,966	151,867	54,235	2,928
1989	141,669	48,650	1,952	150,281	54,218	2,905
1990	140,144	48,619	1,948	148,169	54,085	2,883
1991	137,224	48,290	1,949	144,612	53,654	2,854
1992	126,252	44,947	1,898	133,216	50,245	2,715
1993	117,041	42,217	1,864	123,534	47,466	2,620
1994	110,951	40,015	1,836	115,924	45,213	2,555
1995	107,437	39,143	1,827	111,255	44,280	2,531
1996	105,638	38,645	1,816	108,195	43,694	2,516
1997	103,257	37,926	1,793	105,279	42,848	2,490
1998	99,527	36,534	1,750	101,225	41,264	2,443
1999	97,275	35,672	1,713	98,558	40,166	2,405
2000	95,243	34,758	1,673	96,249	38,957	2,360
2001	94,844	34,359	1,641	95,590	38,240	2,324
2002	96,908	34,043	1,610	98,066	37,583	2,284
2003	97,776	33,848	1,581	98,307	37,028	2,244
2004	97,484	33,546	1,550	97,820	36,369	2,199
2005	97,485	33,395	1,523	98,216	35,897	2,157
2006	97,851	33,405	1,500	99,115	35,636	2,120
2007	99,265	33,501	1,481	102,181	35,532	2,088
2008	99,680	33,693	1,466	103,388	35,586	2,061
2009	99,370	33,835	1,454	103,846	35,662	2,038
2010	98,916	34,056	1,449	104,384	35,890	2,024
2011	98,357	34,263	1,449	104,657	36,172	2,017
2012	97,999	34,510	1,456	105,141	36,564	2,018
2013	99,050	34,817	1,469	106,936	37,080	2,029
2014	101,565	35,116	1,487	109,773	37,646	2,047
2015	97,493	33,784	1,518	104,304	35,929	1,946
2016	93,250	32,493	1,816	98,597	34,301	2,027
2017	90,009	31,216	2,233	94,533	32,722	2,225
2018	89,916	30,023	2,683	95,889	31,257	2,483
2019	88,868	28,923	3,131	93,785	29,873	2,762
2020	86,827	27,935	--	93,235	28,620	3,041
2021	84,771	27,011	--	92,369	27,488	3,313
2022				90,299	26,499	3,576
2023				88,329	25,642	3,832
2024				89,339	24,966	--
2025				90,434	24,453	--

Table 18. Time series of age 3 and age 0 recruits and standard deviation of age 0 recruits ("Std. dev") for the previous and current assessment models.

	2019 Assessment			*2023 Assessment*		
Year	**Recruits (Age 3)**	**Recruits (Age 0)**	**Std. dev of Age 0 Recruits**	**Recruits (Age 3)**	**Recruits (Age 0)**	**Std. dev of Age 0 Recruits**
1978	9,626	24,745	10,459	11,022	25,901	10,215
1979	9,626	16,966	8,210	11,022	17,627	7,787
1980	9,626	15,128	6,844	11,022	15,474	6,507
1981	20,577	15,160	6,554	21,387	15,490	6,335
1982	14,109	15,182	6,313	14,556	16,448	6,637
1983	12,580	13,699	5,234	12,777	16,754	6,353
1984	12,607	10,566	3,906	12,791	13,243	4,838
1985	12,625	8,510	3,008	13,582	9,834	3,420
1986	11,392	9,408	3,065	13,834	9,407	3,063
1987	8,786	10,796	3,235	10,935	9,903	2,930
1988	7,077	8,650	2,650	8,120	7,559	2,250
1989	7,824	6,505	1,945	7,767	6,122	1,728
1990	8,977	6,204	1,970	8,177	5,708	1,681
1991	7,193	12,661	2,997	6,241	7,972	1,889
1992	5,409	7,243	2,276	5,052	4,855	1,387
1993	5,159	9,714	2,683	4,711	7,430	1,964
1994	10,528	8,128	2,508	6,580	9,327	2,408
1995	6,023	8,199	2,589	4,008	9,850	2,598
1996	8,077	8,146	2,721	6,135	8,897	2,578
1997	6,759	9,019	2,926	7,701	10,129	2,632
1998	6,818	10,206	3,344	8,131	11,155	2,891
1999	6,774	19,636	4,558	7,345	24,179	3,749
2000	7,500	11,450	3,494	8,363	9,692	2,492
2001	8,487	7,541	2,455	9,210	7,834	2,104
2002	16,328	8,099	2,426	19,964	11,121	2,590
2003	9,522	8,895	2,806	8,003	12,043	3,136
2004	6,271	13,437	3,484	6,468	21,618	4,106
2005	6,734	8,279	2,617	9,183	10,733	2,998
2006	7,397	6,802	2,145	9,944	8,888	2,476
2007	11,174	6,510	2,073	17,851	9,598	2,568
2008	6,884	7,196	2,328	8,863	9,442	2,644
2009	5,657	8,133	2,848	7,339	10,543	3,147
2010	5,414	13,624	4,671	7,925	16,123	4,274
2011	5,984	18,966	6,080	7,797	20,106	5,007
2012	6,763	12,744	4,889	8,706	12,993	3,877
2013	11,329	10,449	4,181	13,313	10,229	3,353
2014	15,772	14,916	6,999	16,603	18,748	5,764
2015	10,037	28,991	12,901	10,056	46,645	10,696
2016	7,794	20,700	11,567	7,421	21,578	7,324
2017	10,539.89	11,698.00	5,729.00	12,750	28,731	10,137
2018	20,486.10	11,496.00	5,633.00	31,722	25,037	10,565
2019	14,627.58	11,573.00		14,675	16,945	8,034
2020				19,539	17,740	8,635
2021				17,027	13,330	6,534
2022				11,524	13,319	6,547
2023				12,065	13,345	
Average	9,592.14	11,808.81		11,070	14,123	

Table 19. Projected spawning biomass for the seven harvest scenarios listed in the "Harvest Recommendations" section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2023	25,642	25,642	25,642	25,642	25,642	25,642	25,642
2024	24,966	24,966	24,966	24,966	24,966	24,966	24,966
2025	24,453	24,453	24,453	24,453	24,453	21,782	22,204
2026	24,096	24,096	24,096	24,096	24,096	19,237	19,966
2027	23,878	23,878	23,878	23,878	23,878	17,207	17,824
2028	21,640	21,640	23,791	22,722	23,816	15,597	16,118
2029	19,791	19,791	23,802	21,760	23,852	14,325	14,764
2030	18,273	18,273	23,901	20,970	23,974	13,337	13,705
2031	17,035	17,035	24,076	20,330	24,172	12,597	12,896
2032	16,044	16,044	24,325	19,830	24,443	12,101	12,332
2033	15,267	15,267	24,648	19,460	24,786	11,804	11,979
2034	14,670	14,670	25,034	19,203	25,193	11,651	11,781
2035	14,229	14,229	25,470	19,039	25,649	11,597	11,692
2036	13,914	13,914	25,940	18,947	26,137	11,606	11,674

Table 20. Projected fishing mortality rates for the seven harvest scenarios listed in the "Harvest Recommendations" section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2023	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2024	0.00	0.00	0.00	0.00	0.00	0.15	0.12
2025	0.00	0.00	0.00	0.00	0.00	0.15	0.12
2026	0.00	0.00	0.00	0.00	0.00	0.15	0.15
2027	0.12	0.12	0.00	0.06	0.00	0.15	0.15
2028	0.12	0.12	0.00	0.06	0.00	0.15	0.15
2029	0.12	0.12	0.00	0.06	0.00	0.15	0.15
2030	0.12	0.12	0.00	0.06	0.00	0.15	0.15
2031	0.12	0.12	0.00	0.06	0.00	0.14	0.14
2032	0.12	0.12	0.00	0.06	0.00	0.14	0.14
2033	0.12	0.12	0.00	0.06	0.00	0.13	0.13
2034	0.12	0.12	0.00	0.06	0.00	0.13	0.13
2035	0.12	0.12	0.00	0.06	0.00	0.13	0.13
2036	0.12	0.12	0.00	0.06	0.00	0.13	0.13

Table 21. Projected catches for the seven harvest scenarios listed in the "Harvest Recommendations" section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2023	103	103	103	103	103	103	103
2024	103	103	103	103	103	8,290	6,992
2025	103	103	103	103	103	7,388	6,343
2026	103	103	103	103	103	6,684	6,914
2027	6,952	6,952	81	3,488	0	6,156	6,346
2028	6,430	6,430	82	3,374	0	5,778	5,934
2029	6,024	6,024	83	3,289	0	5,515	5,642
2030	5,711	5,711	85	3,229	0	5,300	5,431
2031	5,470	5,470	86	3,186	0	5,026	5,165
2032	5,282	5,282	88	3,155	0	4,817	4,930
2033	5,129	5,129	89	3,133	0	4,692	4,775
2034	4,978	4,978	91	3,117	0	4,631	4,689
2035	4,835	4,835	92	3,105	0	4,611	4,650
2036	4,719	4,719	93	3,097	0	4,616	4,641

Figures

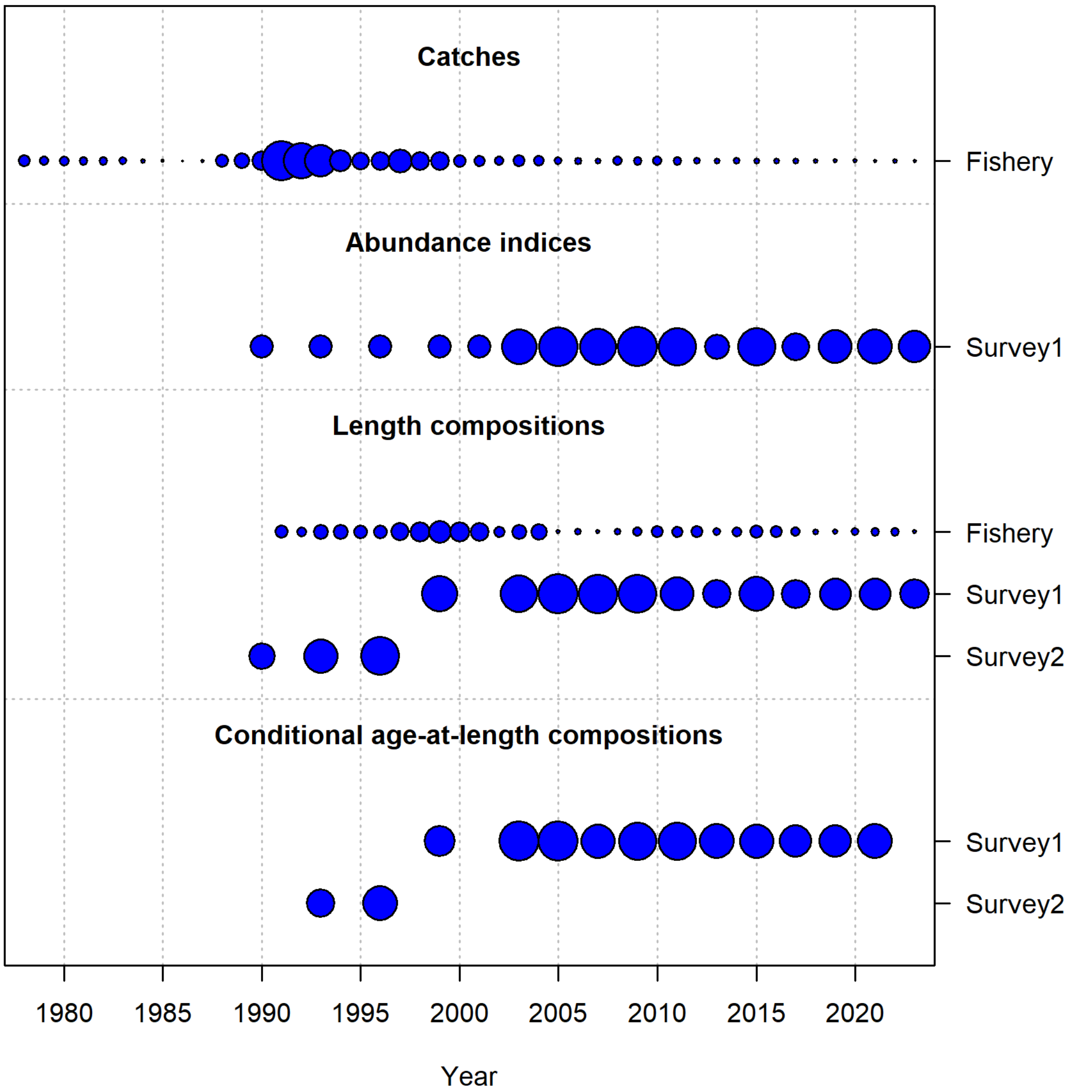

Figure 1. Sources and years of data used in the assessment. “Survey 1” indicates the years in which all depths (0m to >500m) were sampled: the full-coverage survey and “Survey2” indicates the years in which only 0-500m depths were sampled: the shallow-coverage survey. Size of circle for catches indicates the relative magnitude of catches. The size of circles for length-composition data and conditional age-at-length data indicate the relative input sample size by year.

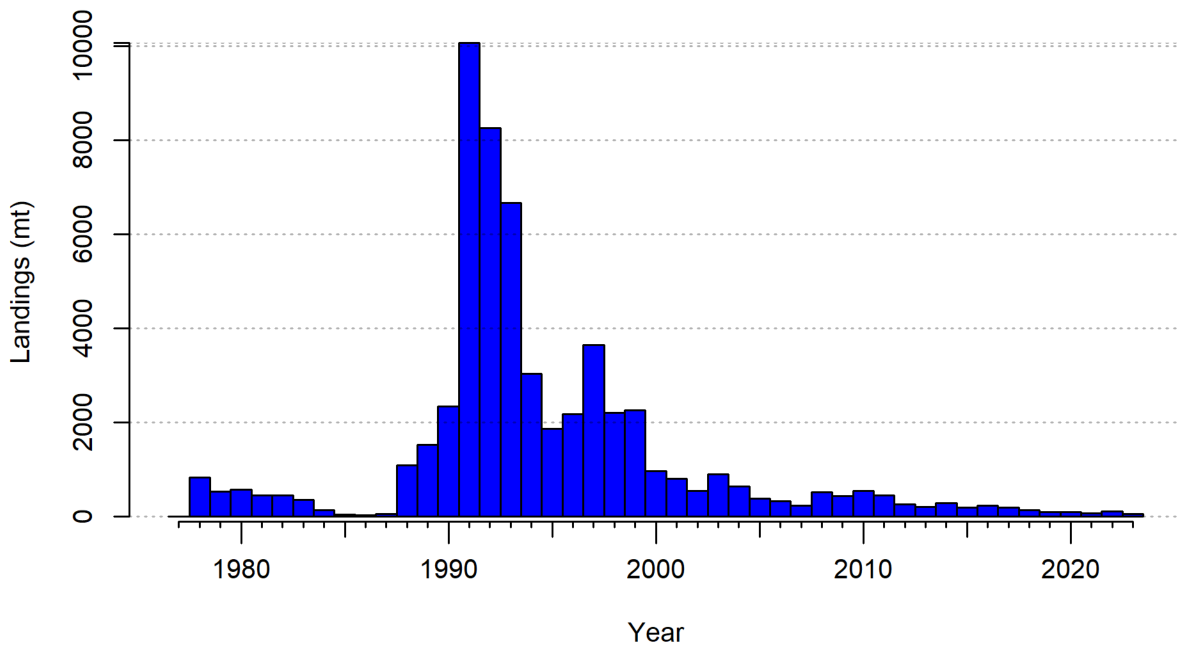

Figure 2. Catch biomass of Dover sole in metric tons 1978-2023 (as of September 26, 2023).

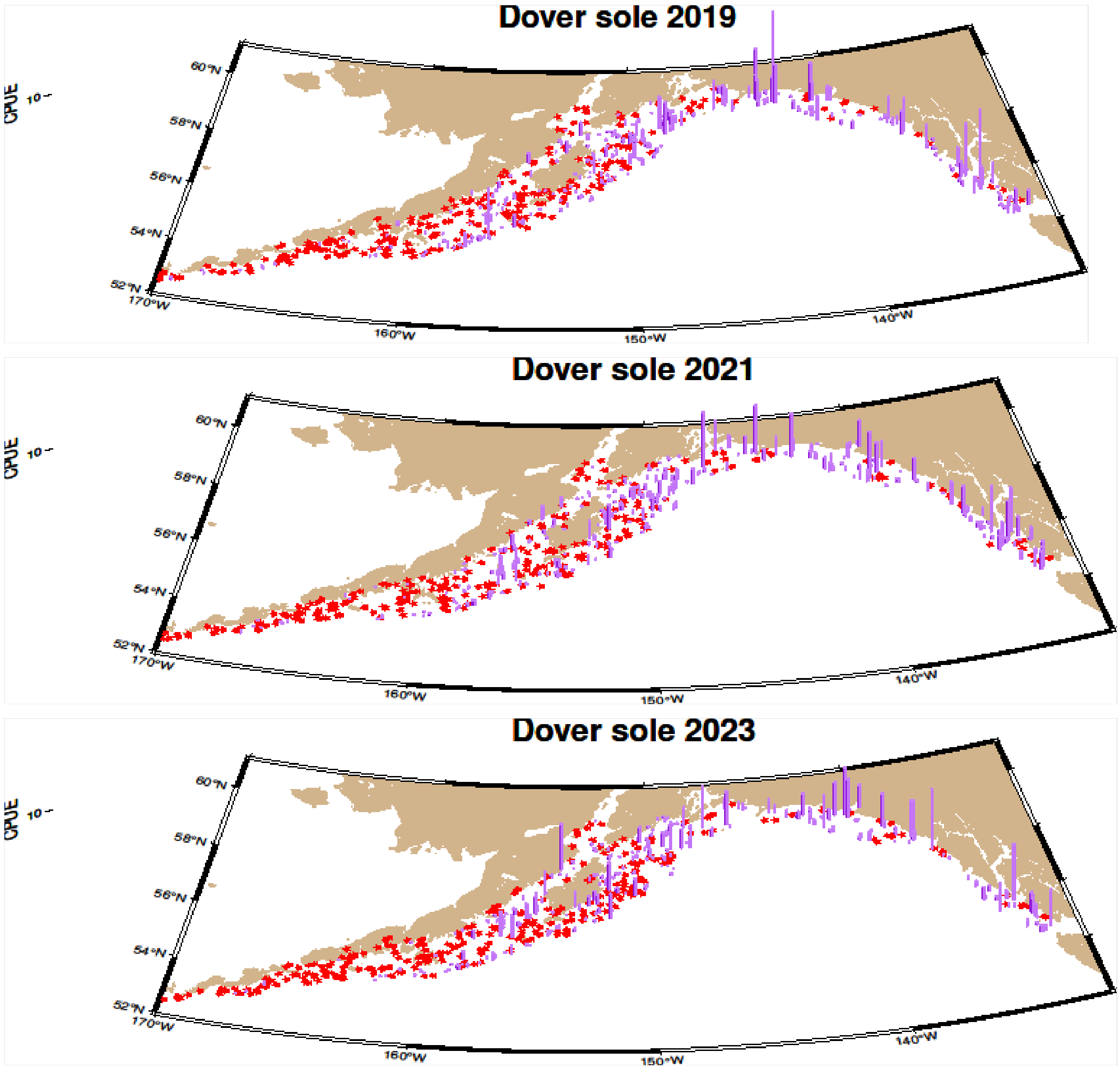

Figure 3. Maps of survey catch-per-unit-effort (CPUE) from the 2019, 2021, and 2023 GOA Groundfish Trawl Survey.

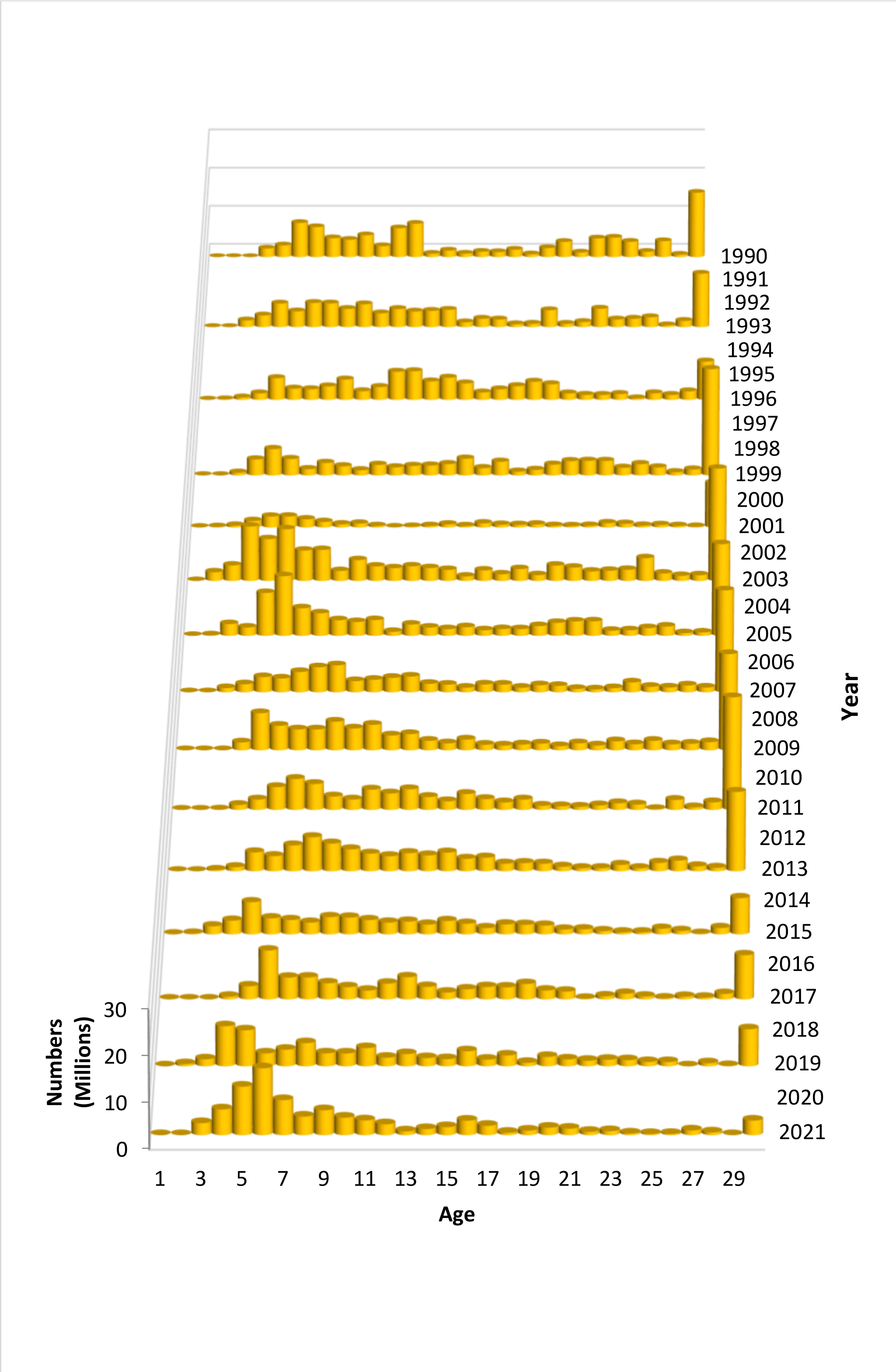

Figure 4. Yearly age composition of GOA Dover sole aggregated over sex in the GOA bottom trawl survey.

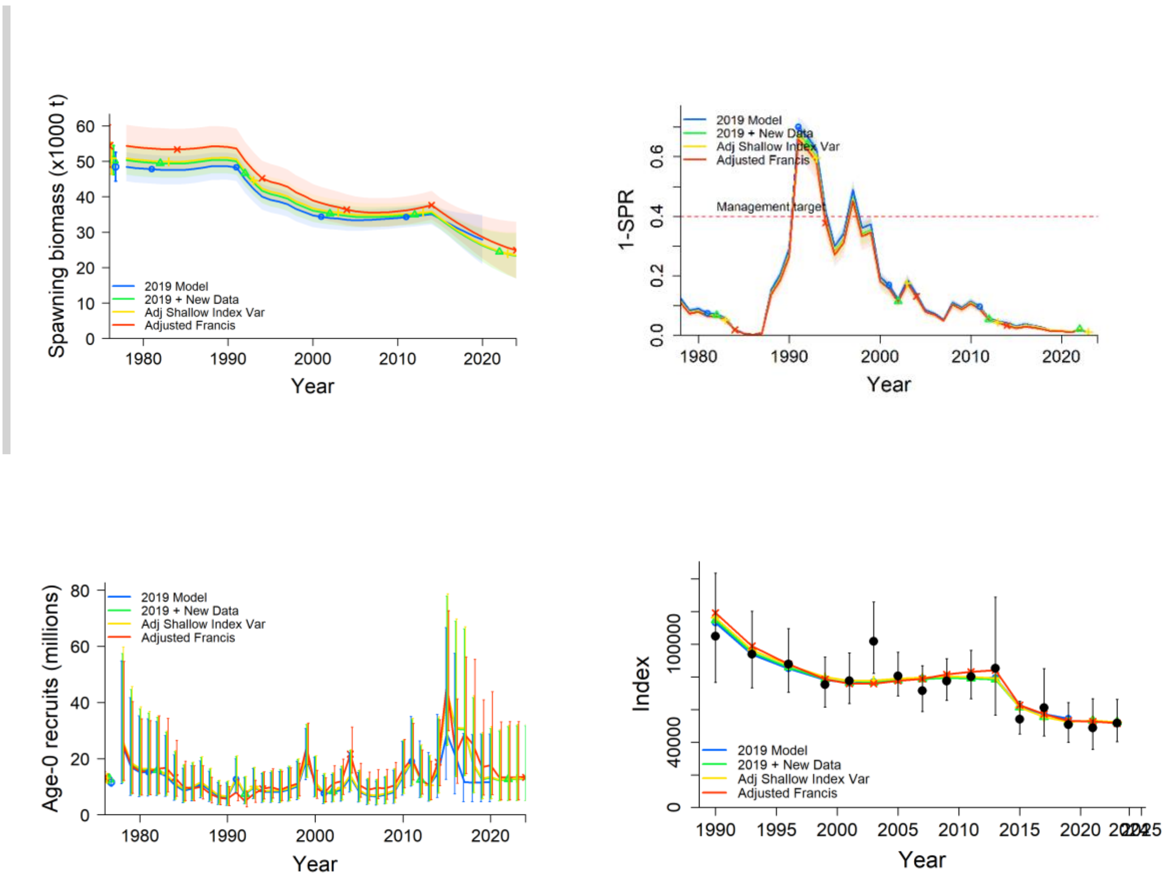

Figure 5. Spawning biomass with 95% asymptotic confidence intervals (top left panel), recruitment deviations and 95% asymptotic confidence intervals (top right panel), survey biomass index (black dots), asymptotic 95% confidence intervals (vertical black lines) and estimated survey biomass (solid lines; bottom left panel), and 1-spawning potential ratio (1-SPR; a measure of fishing intensity; bottom right panel) for the models included in the bridging analysis.

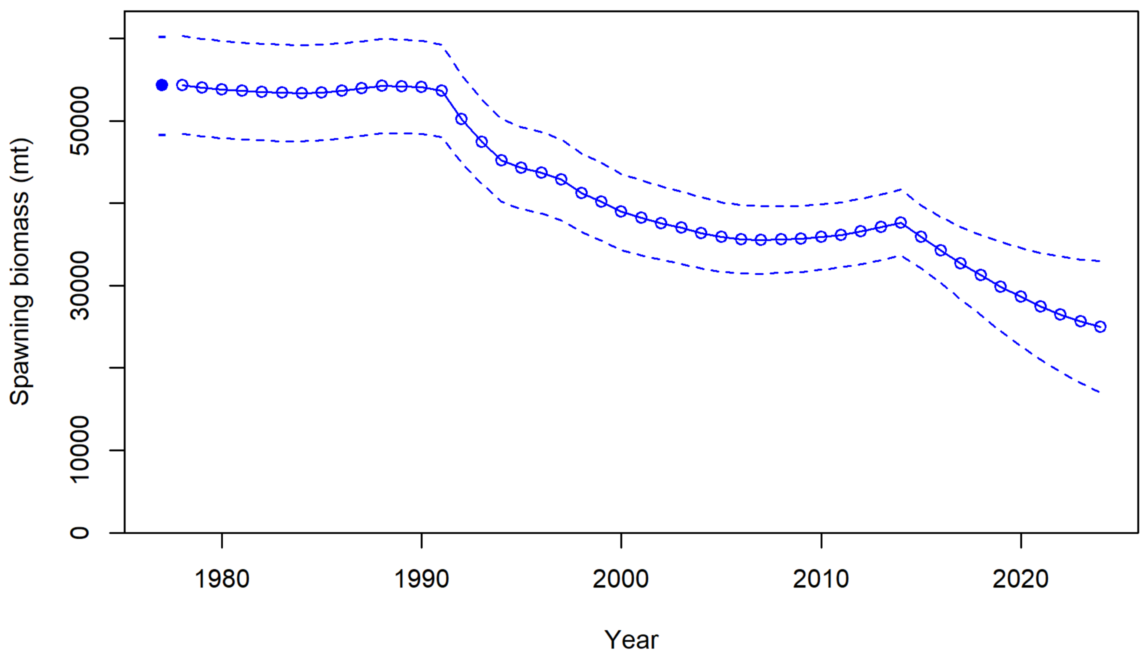

Figure 6. Time series of estimated spawning stock biomass (mt) over time (solid blue line and circles) and asymptotic 95% confidence intervals (blue dashed lines) for Model 19.3.1.

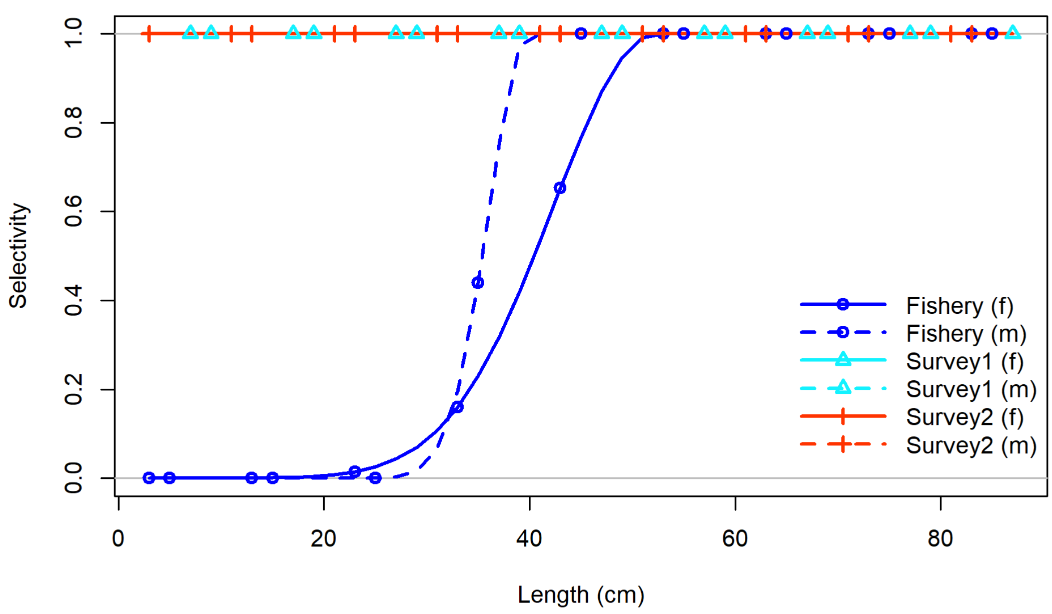

Figure 7. Length-based, sex-specific fishery selectivity for the 2023 model (Model 19.3.1). Survey selectivity is defined to be age-based (and therefore length-based survey selectivity is set to 1 for all lengths).

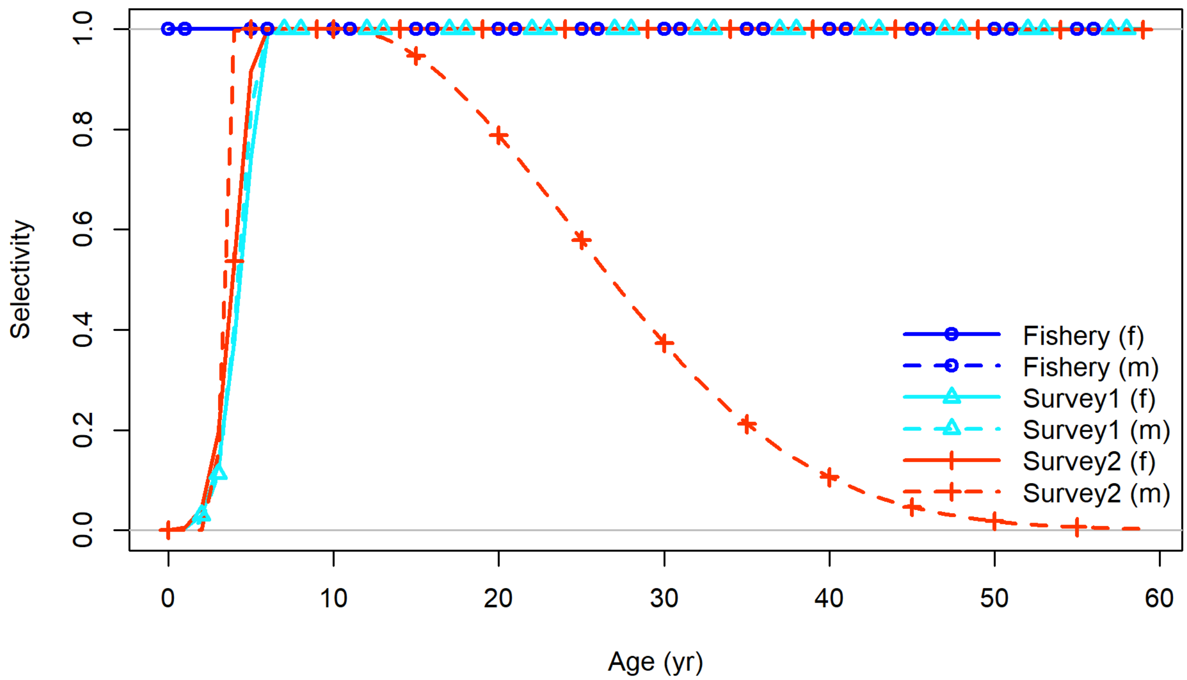

Figure 8. Survey selectivity-at-age for the full coverage (turquoise, "Survey1") and shallow coverage (red, "Survey2") surveys and for females (solid lines) and males (dashed lines) for the 2023 model (Model 19.3.1). The descending limb for the female shallow coverage survey selectivity is fixed to be asymptotic based on previous runs showing very large standard deviations corresponding this parameter estimate. Fishery selectivity is defined to be length-based (and therefore age-based selectivity is set to 1 for all ages).

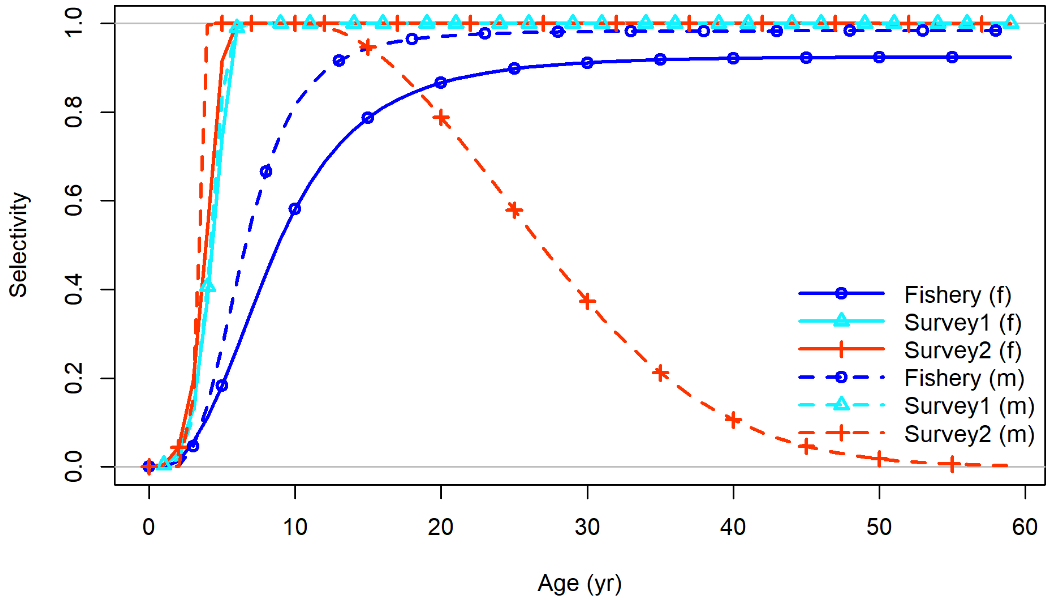

Figure 9. Derived age-based selectivity for the fishery for the 2023 model (Model 19.3.1), overlaid on age-based selectivity estimates for the full-coverage and shallow-coverage surveys. Fishery selectivity is defined in the model as length-based, while survey selectivity is defined to be age-based.

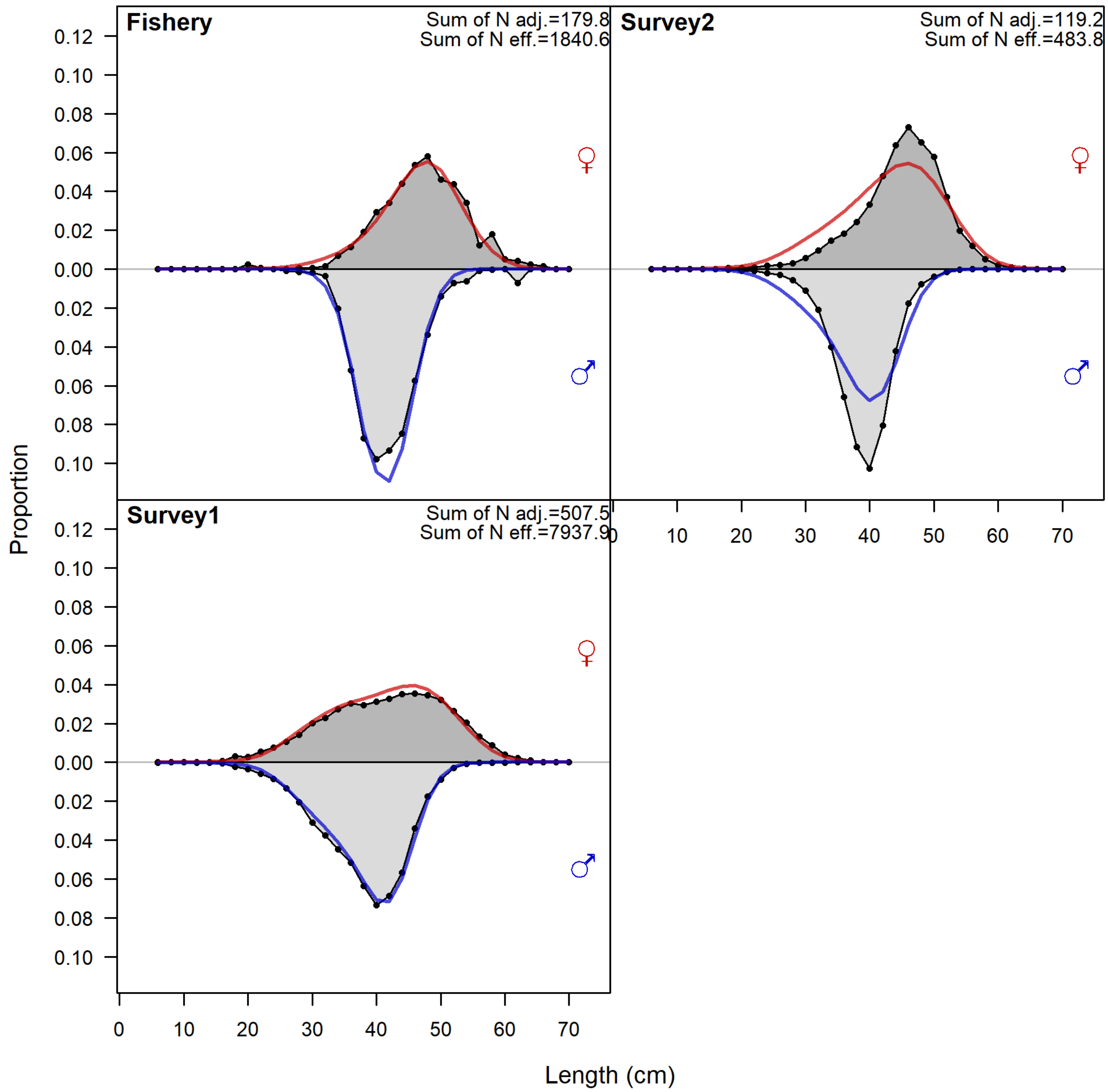

Figure 10. Observed (black lines, dots, and shaded areas) and expected (red lines) proportions-at-length, aggregated over years for the fishery, the full coverage survey (Survey 1), and the shallow coverage survey (Survey 2) for the 2023 model (Model 19.3.1).

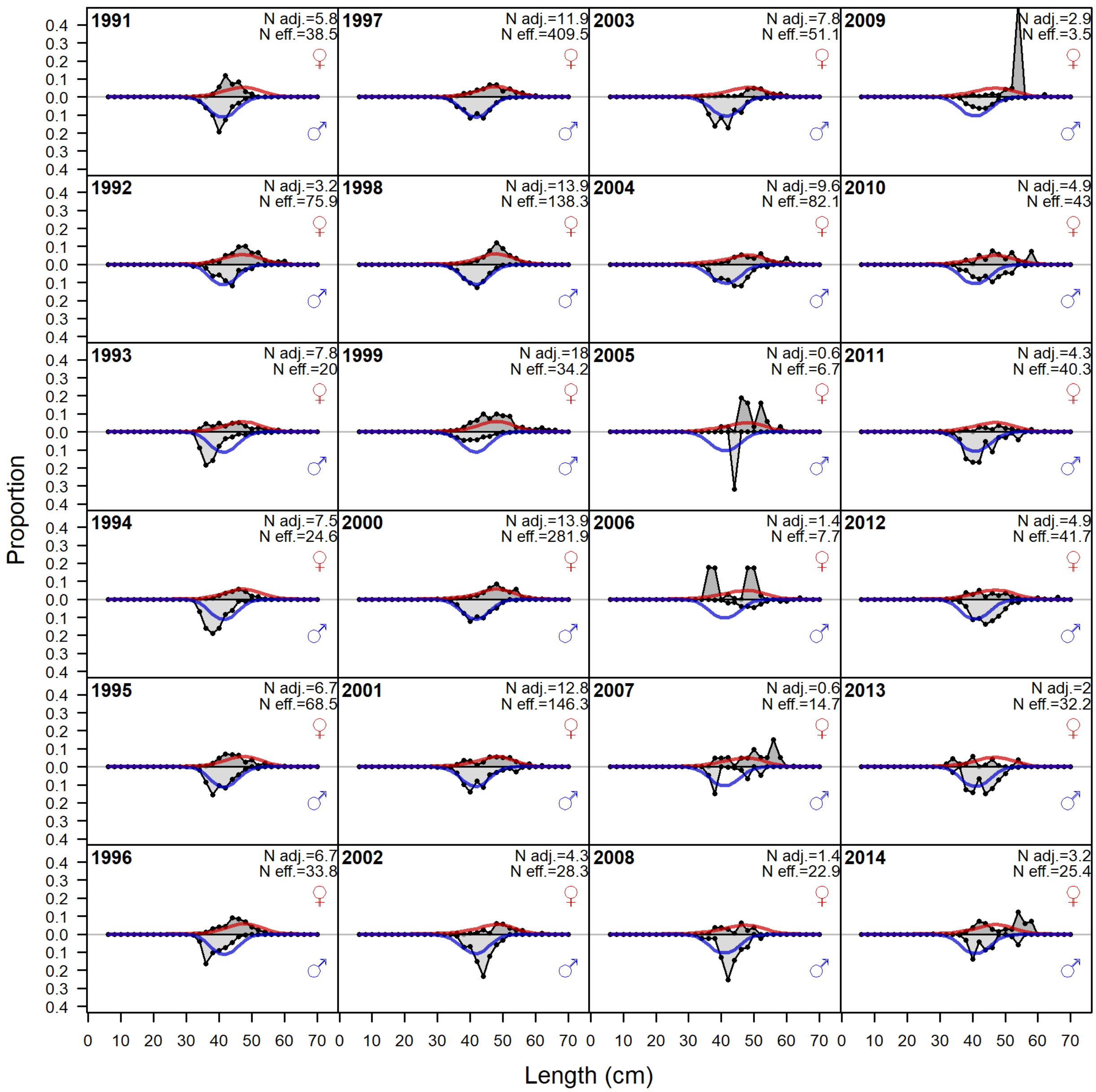

Figure 11. Observed (black lines, dots, and shaded areas) and expected (red and blue lines) yearly fishery proportions-at-length for the current base case model for years 1991-2014 for the

2023 model (Model 19.3.1). Females are plotted above the x-axis; males are plotted below the x-axis.

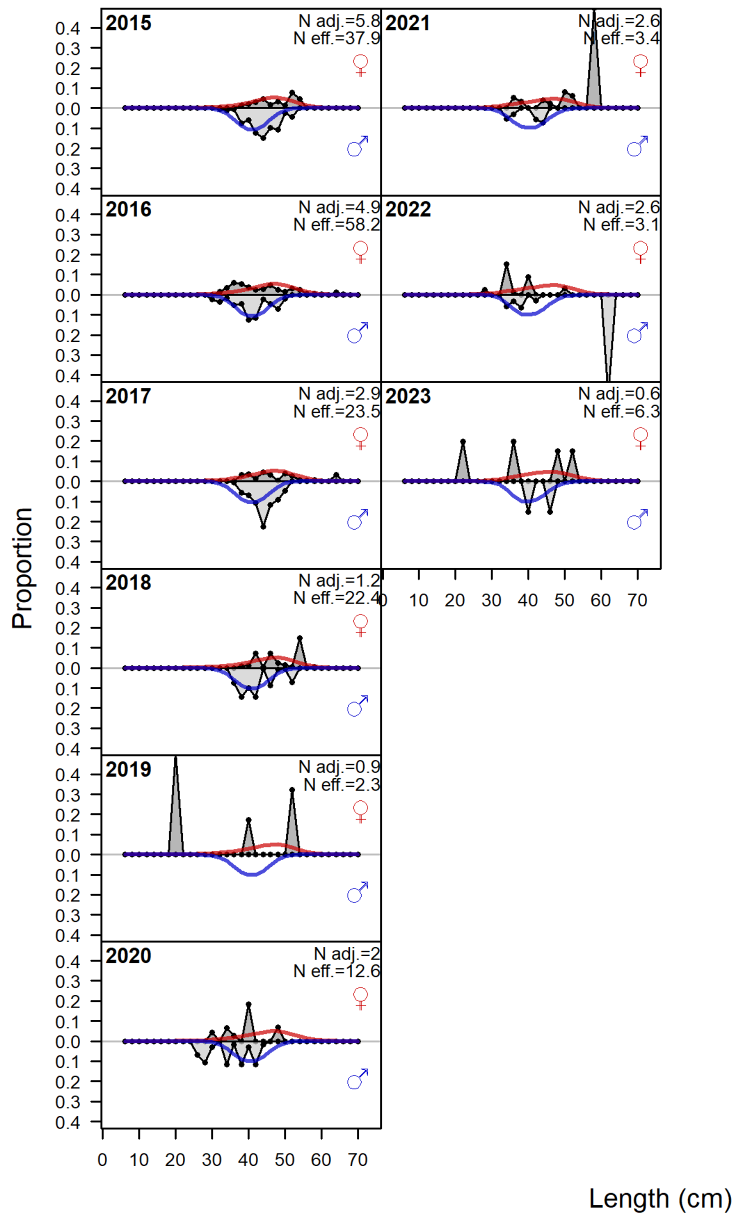

Figure 12. Observed (black lines, dots, and shaded areas) and expected (red and blue lines) yearly fishery proportions-at-length for the 2023 model (Model 19.3.1) for years 2015-2023. Females are plotted above the x-axis; males are plotted below the x-axis.

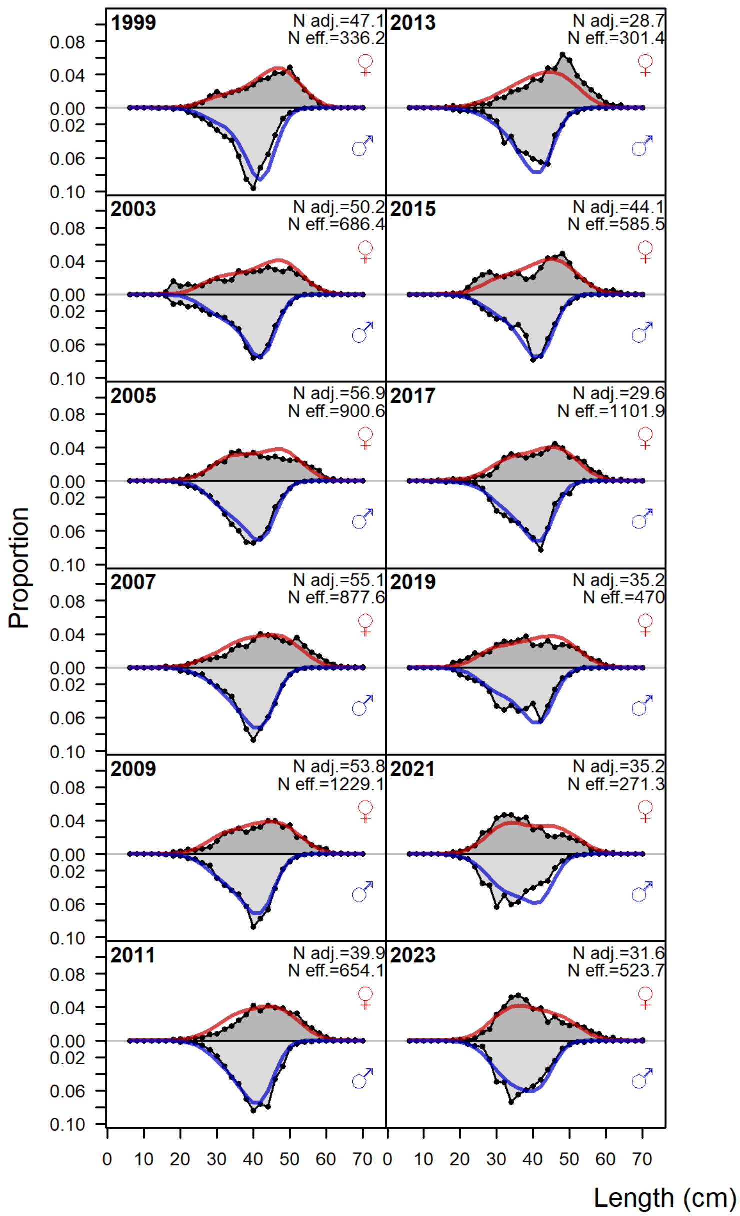

Figure 13. Observed (black lines, dots, and shaded areas) and expected (red and blue lines) yearly full-coverage survey proportions-at-length for the 2023 model (Model 19.3.1) for years 1999-2023. Females are plotted above the x-axis; males are plotted below the x-axis.

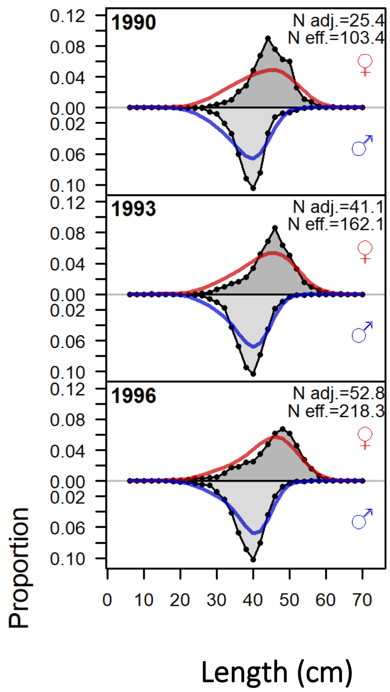

Figure 14. Observed (black lines, dots, and shaded areas) and expected (red and blue lines) yearly shallow-coverage survey proportions-at-length for the 2023 model (Model 19.3.1) for years 1990-1996. Females are plotted above the x-axis; males are plotted below the x-axis.

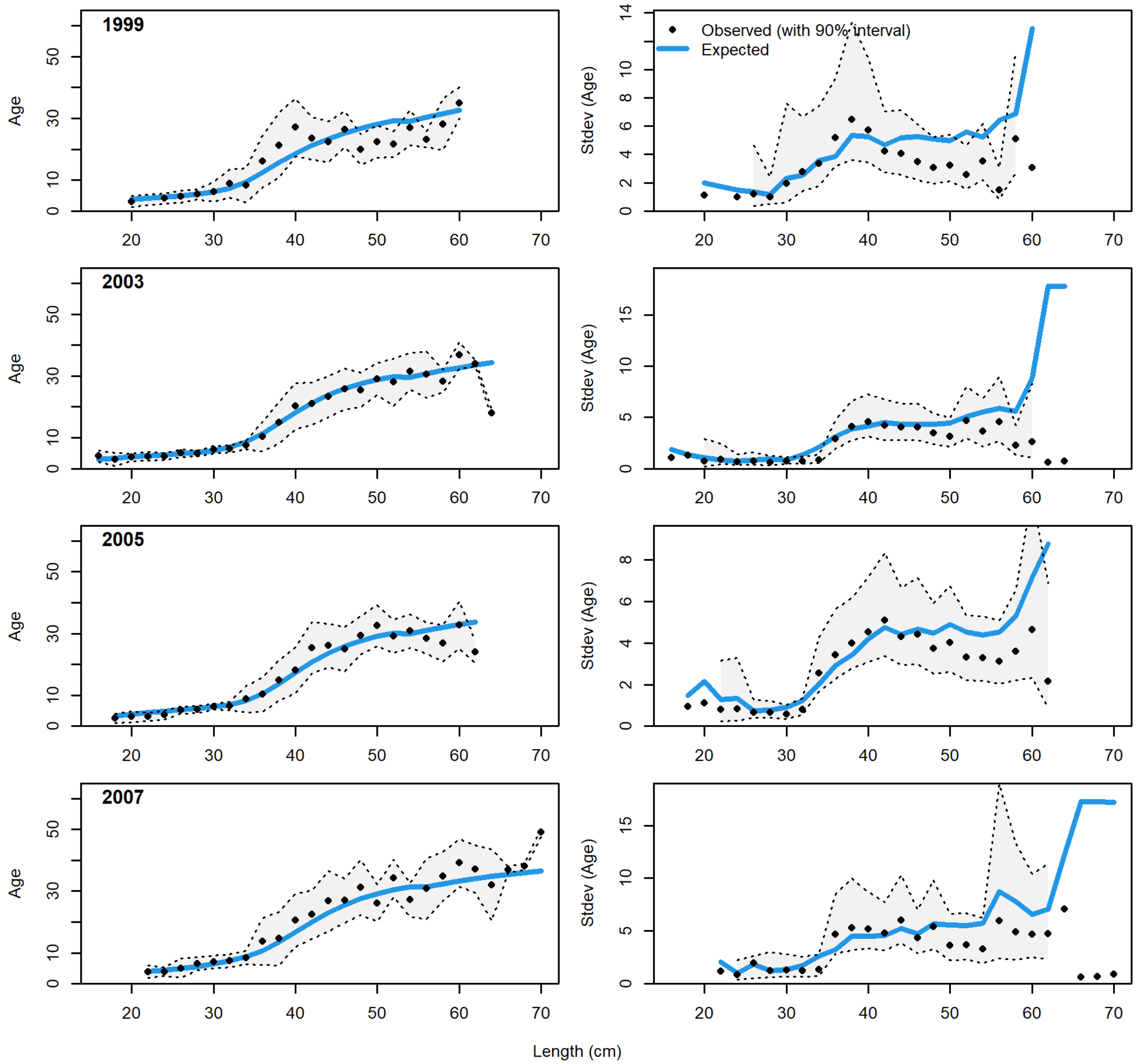

Figure 15. Observed and expected mean age-at-length for males and females combined with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the full coverage survey for the 2023 model (Model 19.3.1; 1 of 3).

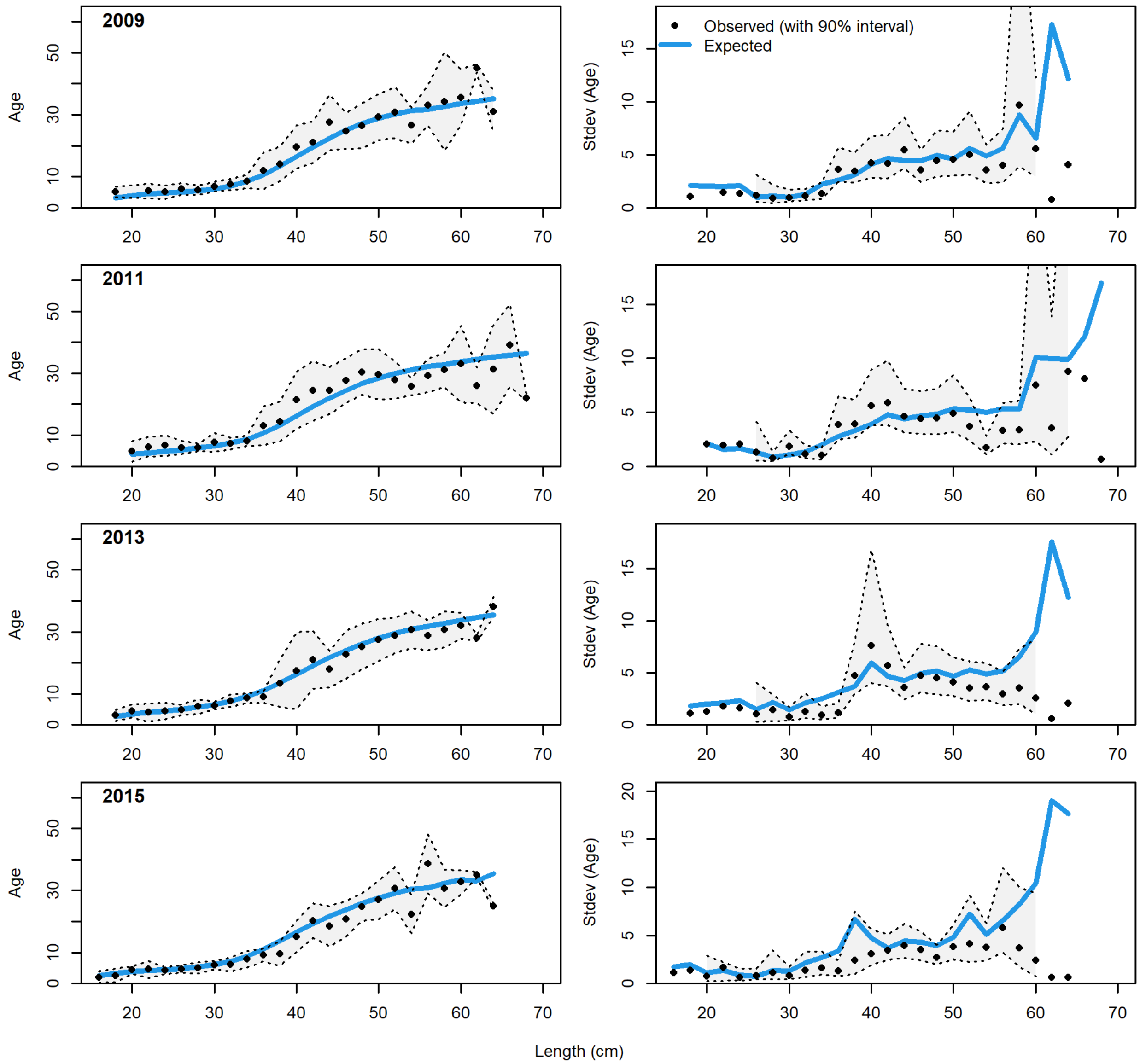

Figure 16. Observed and expected mean age-at-length for males and females combined with 90% intervals about observed age-at-length (left panels) and observed and expected standard

deviation in age-at-length (right panels) for the full coverage survey for the 2023 model (Model 19.3.1; 2 of 3).

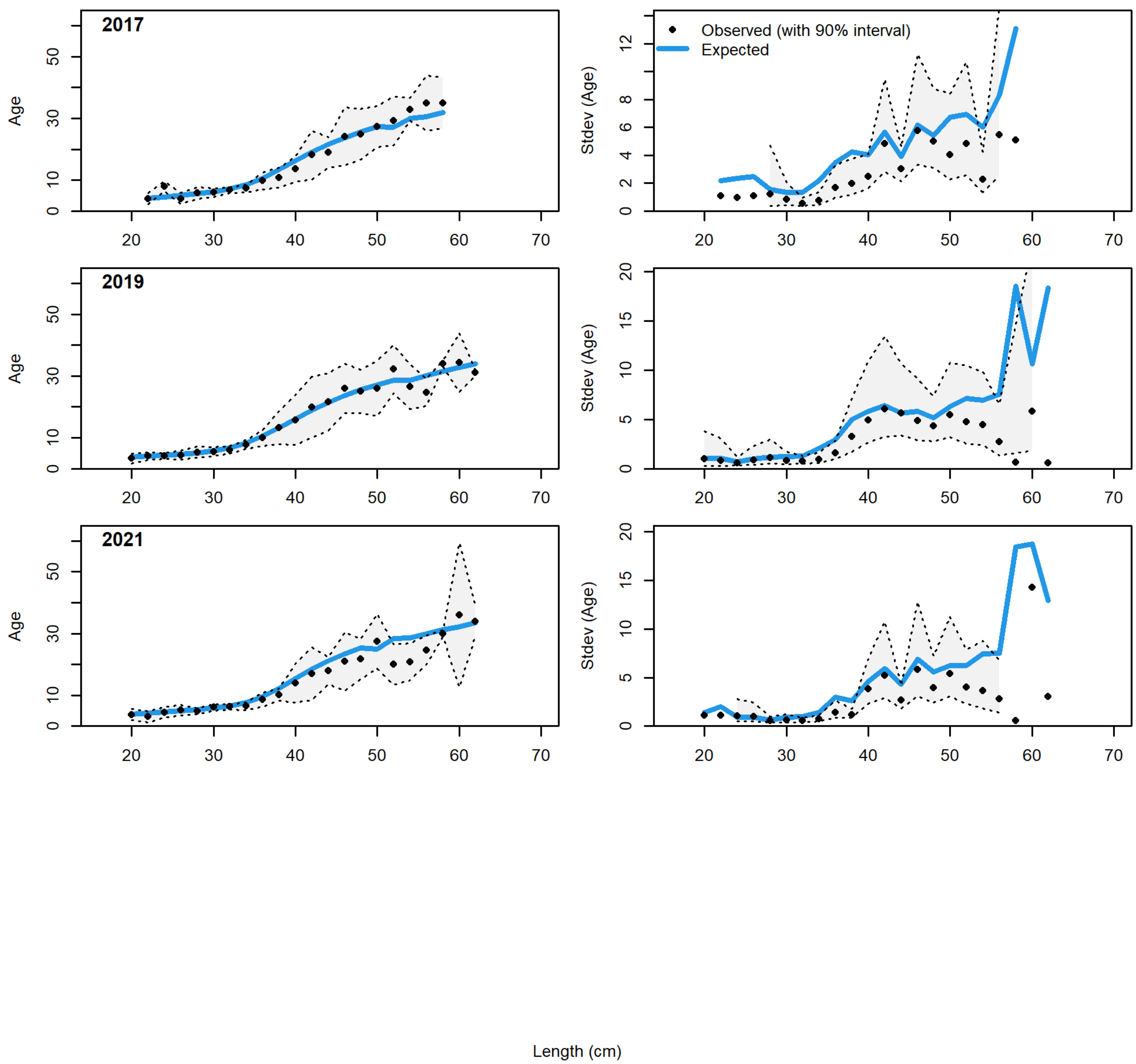

Figure 17. Observed and expected mean age-at-length for males and females combined with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the full coverage survey for the 2023 model (Model 19.3.1; 3 of 3).

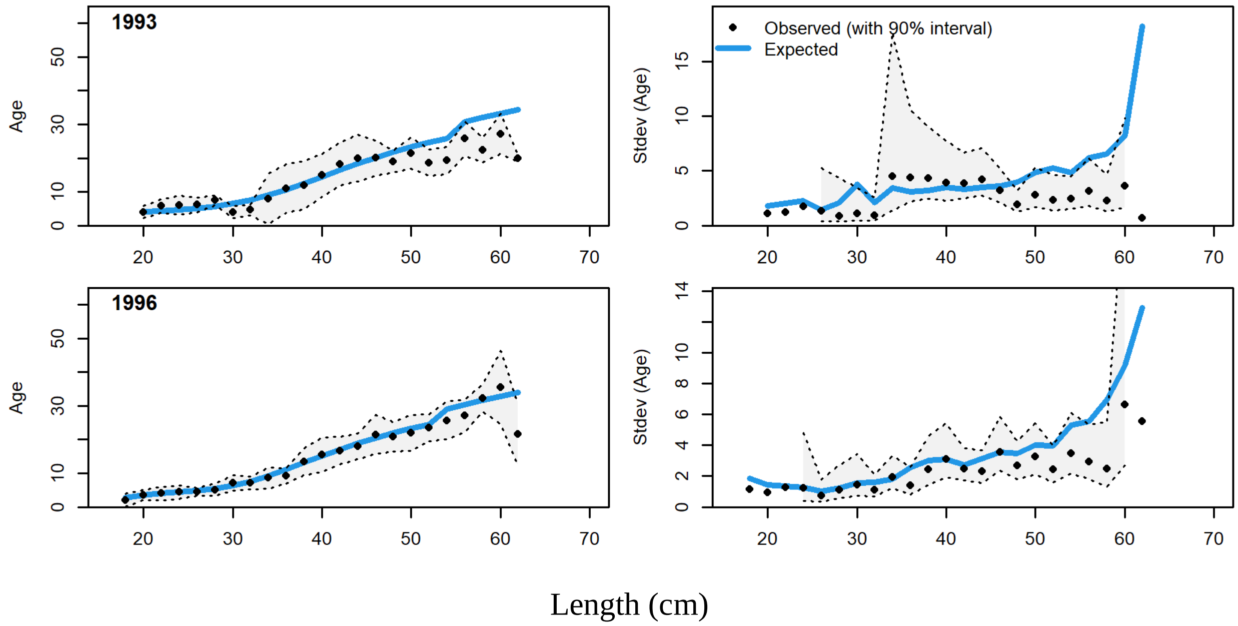

Figure 18. Observed and expected mean age-at-length for males and females combined with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the shallow coverage survey for the 2023 model (Model 19.3.1; 1 of 1).

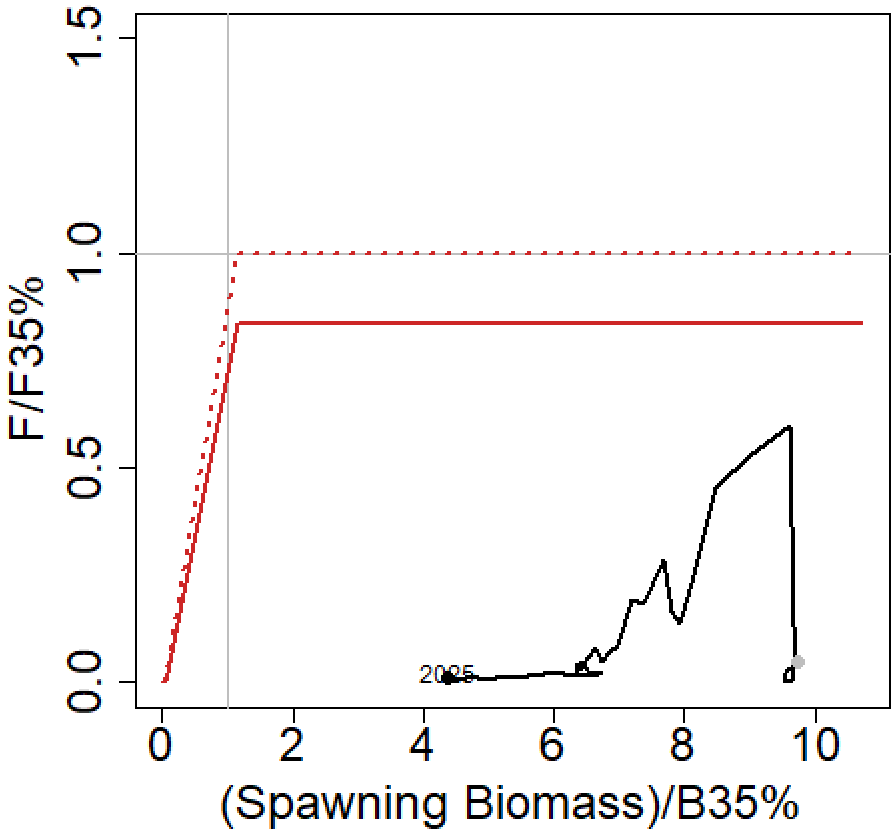

Figure 19. Spawning stock biomass relative to $B_{35\%}$ and fishing mortality (F) relative to $F_{35\%}$ from 1978-2025 (solid black line), the OFL control rule (dotted red line), the maxABC control rule (solid red line), $B_{35\%}$ (vertical grey line), and $F_{35\%}$ (horizontal grey line). Projected biomass for 2024 and 2025 are included. $B_{35\%}$ and $F_{35\%}$ are calculated using population dynamics corresponding to the most recent period (2014-2023) in the 2023 model (Model 19.3.1).

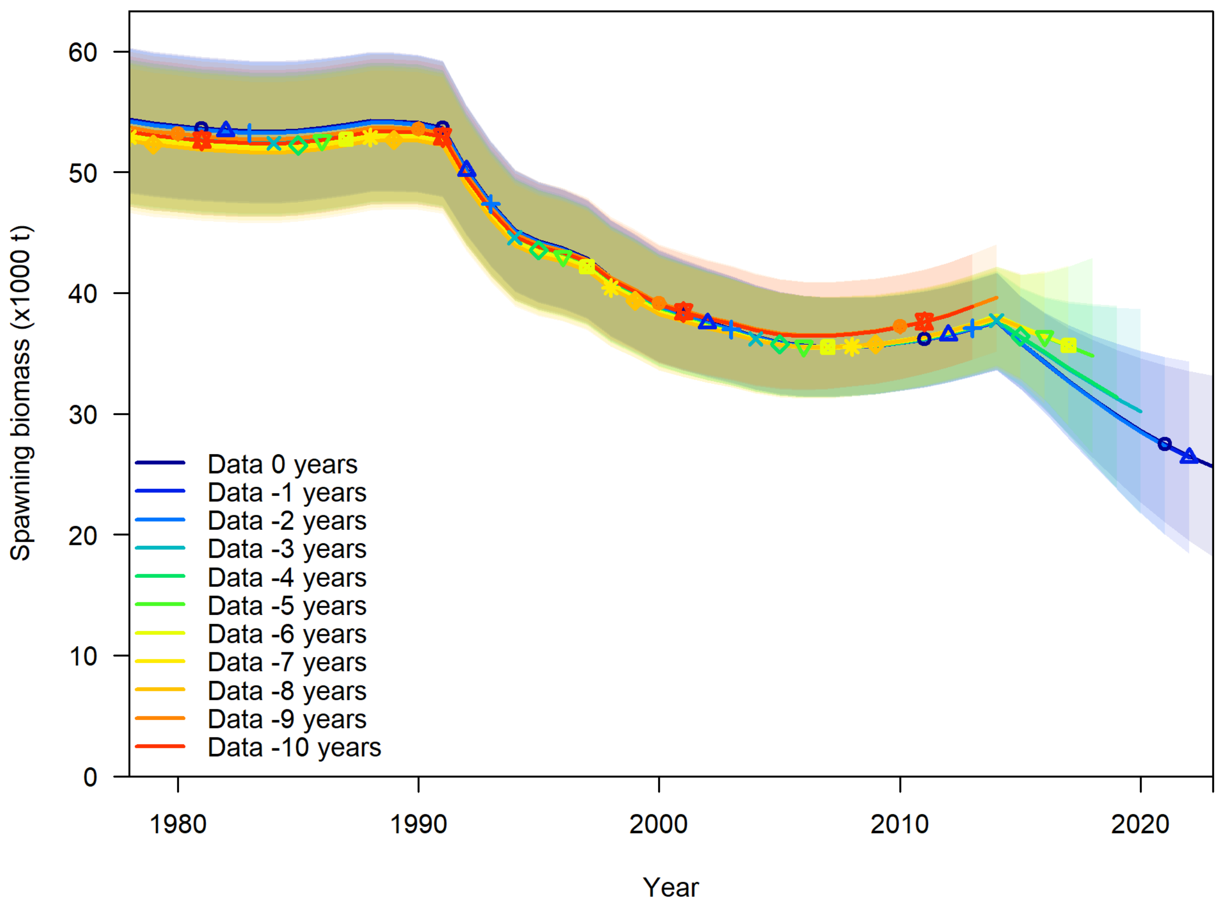

Figure 20. Spawning stock biomass and corresponding 95% asymptotic confidence intervals for base case model runs excluding 0 to 10 years of the most recent data for the 2023 model (Model 19.3.1). Each model assumes that recruitment deviations are 0 for years where data are excluded.

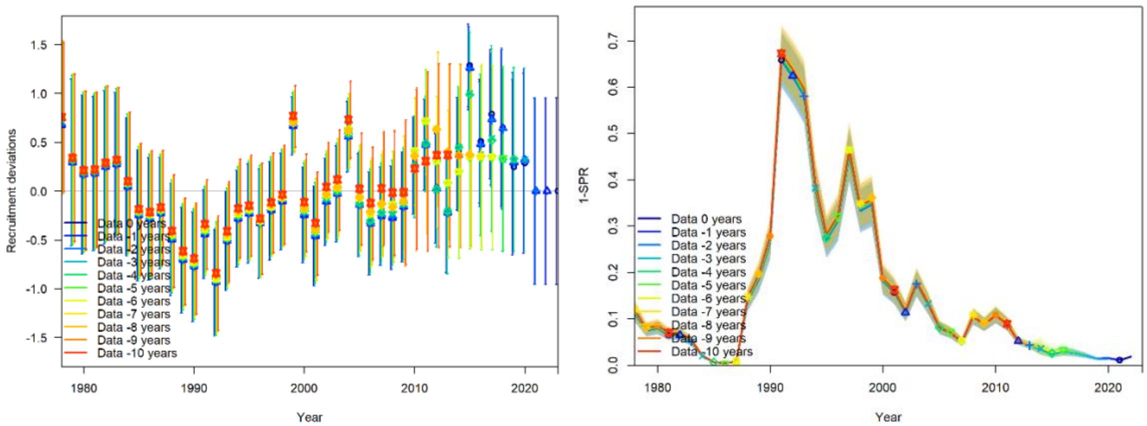

Figure 21. Recruitment deviations with corresponding 95% asymptotic confidence intervals (left panel) and fishing intensity (1-spawning potential ratio; right panel) for the 2023 model (Model 19.3.1) retrospective model runs excluding 0 to 10 years of data.

Appendix A. Non-Commercial Catches of GOA Deepwater Flatfish (t)

Year	AFSC Annual Longline Survey	GOA Shelf and Slope Walleye Pollock Acoustic-Trawl Survey	IPHC Annual Longline Survey	Large-Mesh Trawl Survey	Scallop Dredge Survey	Small-Mesh Trawl Survey
2019	489		14	1,722	4	
2020	442			2,192	25	68
2021	225	3	7	3,473		
2022	237		12	4,458		6