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

By
Carey R. McGilliard[1], Wayne Palsson[2], Andrea Havron[3], and Stephani Zador[1]
[1]Resource Ecology and Fisheries Management Division
[2]Resource Assessment and Conservation Engineering Division
[3]Joint Institute for the Study of the Atmosphere and Ocean
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) 2016-2019 catch data were included in the model
(2) 2015 catch was updated to include October-December catch in that year
(3) 2016-2019 fishery length composition data were added to the model and 2015 fishery length composition data were updated to include October-December data in that year
(4) The 2017 and 2019 survey biomass indices were added to the model
(5) The 1984 and 1987 survey biomass indices were excluded from the model
(6) Survey length composition data for 2017 and 2019 were added to the model
(7) 2015 and 2017 survey ages by length bin (conditional age-at-length data) were added to the model
(8) Length composition and conditional age-at length data were iteratively re-weighted using the methods described in Francis (2011)
(9) Input age data for ages 1-3 were disaggregated
(10) The survey timing was specified to occur in June, rather than at the beginning of the year
(11) All historical data were updated to ensure inclusion of the most recent catch estimation methods
(12) Historical fishing mortality was fixed at 0
(13) The first year for recruitment deviation estimation was set to 1978
(14) Natural mortality was estimated with a normal prior (mean = 0.085, standard deviation = 0.03; Natural mortality was equal to 0.085 in the previous assessment).
(15) Separate natural mortality (normal prior mean = 0.085, sd = 0.03) and catchability (normal prior mean = 0.17, sd = 0.145) were estimated for years 2014-2019, thus creating two time-blocks for M and q

Summary of Results

The key results for the assessment of the deepwater flatfish complex are compared to the key results from the accepted 2018 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: 2019	2020	As estimated or *recommended this* year for: 2020*	2021*
Dover sole	*M* (natural mortality rate)	0.085	0.085	0.113(f), 0.119(m)	0.113(f), 0.119(m)
	Tier	3a	3a	3a	3a
	Projected total (3+) biomass (t)	145,926	147,001	86,827	84,771
	Projected Female spawning biomass (t)	49,385	49,418	27,935	27,011
	$B_{100\%}$	57,871	57,871	19,032	19,032
	$B_{40\%}$	23,148	23,148	7,613	7,613
	$B_{35\%}$	20,255	20,255	6,661	6,661
	F_{OFL}	0.12	0.12	0.11	0.11
	$maxF_{ABC}$	0.1	0.1	0.09	0.09
	F_{ABC}	0.1	0.1	0.09	0.09
	OFL (t)	11,190	11,337	6,919	6,796
	maxABC (t)	9,318	9,441	5,847	5,743
	ABC (t)	9,318	9,441	5,847	5,743
Greenland turbot	Tier	6	6	6	6
	OFL (t)	238	238	238	238
	maxABC (t)	179	179	179	179
	ABC (t)	179	179	179	179
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)	11,434	11,581	7,163	7,040
	maxABC (t)	9,501	9,624	6,030	5,926
	ABC (t)	9,501	9,624	6,030	5,926
	Status	As determined *last* year for: 2017	2018	As determined *this* year for: 2018	2019
	Overfishing	no	n/a	no	n/a
	Overfished	n/a	no	n/a	no
	Approaching overfished	n/a	no	n/a	no

*Projections are based on estimated catches of 109 t and 258 t used in place of maximum permissible ABC for 2019 and 2020-2021, respectively. The 2019 projected catch was calculated as the current catch as of October 19, 2019 added to the average October 19 – December 31 catches over the 5 previous years. The 2020-2021 projected catch was calculated as the average catch from 2014-2018.

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 2001-2019 and estimates of 2020 and 2021 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 2020 and 2021 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 2001-2019.

Species	**Year**	**Western**	**Central**	**West Yakutat**	**Southeast**	**Total**
Dover Sole		0.8%	33.3%	36.0%	29.9%	100.0%
	2020	47	1,945	2,104	1,751	5,847
	2021	46	1,911	2,067	1,719	5,743
Greenland Turbot		100.0%	0.0%	0.0%	0.0%	100.0%
	2020	179	0	0	0	179
	2021	179	0	0	0	179
Deepsea Sole		0.7%	72.8%	14.5%	12.0%	100.0%
	2020	0	3	1	0	4
	2021	0	3	1	0	4
Deepwater Flatfish	**2020**	**226**	**1,948**	**2,105**	**1,751**	**6,030**
	2021	**225**	**1,914**	**2,068**	**1,719**	**5,926**

Responses to SSC and Plan Team Comments on Assessments in General

SSC, Oct 2019: The SSC recommends the authors complete the risk table and note important concerns or issues associated with completing the table; SSC, Dec 2018: The SSC requests that all authors fill out the risk table in 2019, and that the PTs provide comment on the author's results in any cases where a reduction to the ABC may be warranted (concern levels 2-4).

A risk table was filled out and included in the 2019 assessment.

SSC, Oct 2019: The SSC also recommends continuing to evaluate using the VAST model to as an apportionment alternative.

The authors fit a VAST model to survey biomass data for Dover sole, but encountered difficulties that were specific to the GOA and this is still in a research phase.

Responses to SSC and Plan Team Comments Specific to this Assessment

PT, Sept, 2019: The Team recommends that, time permitting, the exploratory two-box model be included in the assessment as an appendix.

An exploratory analysis of two-box models for Dover sole including estimation of ontogenetic movement from shallow (<500m) to deep (>500m) areas was done, but is not yet ready for inclusion in the assessment.

PT, Sept, 2019: The author's "clean up" model performed better than the [CIE] reviewer requested runs and it was proposed for moving forward. The Team agreed that the author's preferred model was appropriate to present on in November.

This "cleaned-up" run is presented in the assessment, and a related run with modifications to account for low survey biomass values in 2015-2019 was chosen as the author's preferred model.

SSC, Dec. 2015: The SSC requests the authors to consider whether survey data from 1984 and 1987 are comparable or whether they should be removed from the analysis. If the survey biomass data are deemed incomparable, then further consideration should be given to the utility of size/age composition data from these early years. This question about the utility of the 1984 and 1987 survey data should be addressed by other affected flatfish stock assessments, as well.

The survey years 1984 and 1987 were removed from the assessment in 2019 after investigating the timing of the survey in comparison to that of subsequent years. In addition, the trawl gear used by the Japanese vessels that conducted the 1984 and 1987 surveys differed from the standardized gear used currently.

SSC, Dec. 2015: The SSC also asks the assessment authors to look into the decline in survey biomass in 2015. Given longevity and natural mortality rate of these flatfish species, the SSC questions whether such a decline is biologically reasonable, given relatively low fishery catches in recent years. As part of a broader analysis for all flatfish species, the SSC requests the assessment authors to consider whether a factor, such as temperature, could have negatively affected survey catchability for some flatfishes in 2015.

The low survey index values observed in 2015 were observed again in 2017 and 2019. This year's assessment included model runs exploring plausible reasons for low survey biomass observations, given that Dover sole catches are very low and the population is nearly unfished. Model runs incorporating a time block from 2014-2019 on natural mortality, catchability, or both natural mortality and catchability were conducted. In addition, length-weight residuals calculated using GOA bottom trawl survey data were negative in 2015 and 2019 and were particularly low in 2017.

SSC, Dec. 2015: Finally, the SSC noted some odd selectivity curves for the full coverage survey (Fig. 10, p. 604). The authors are requested to consider the validity of a selectivity curve that appears asymptotic on the left-hand side of the curve, but drops precipitously to zero on the right-hand side of the curve. Is the right-hand side of the relationship informed by convincing data or should a straightforward asymptotic selectivity curve be assumed?

Several updates were made to data inputs that improved estimation of the full coverage survey selectivity curves, which were problematic in the 2015 assessment. The conditional age-at-length data for ages 1-3 were disaggregated. Few age 1 and 2 Dover sole appear in the survey data, providing the model with the necessary information to estimate selectivity values of 0 or close to 0 below age 3. In addition, the timing of the survey was changed within the model to occur in June. Lastly, the selectivity curves were set to be asymptotic because the descending limb of these curves were poorly estimated with very large standard deviations on the estimates. With these updates, the model was able to estimate more realistic survey selectivity curves.

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.

The deepwater complex, the subject of this chapter, is composed of three species: Dover sole (*Microstomus pacificus*), Greenland turbot (*Reinhardtius hippoglossoides*) and deepsea sole (*Embassichthys bathybius*). Kamchatka flounder catches have also been recorded as part of the deepwater flatfish complex since 2011. Kamtchatka flounder is not assigned within the Tier system currently, as little information exists about them, and no information exists prior to 2011. Dover sole dominates the biomass of the deepwater complex in research trawl surveys and fishery catch (on average 77% of the deepwater complex catches over the past five years). Little biological information exists for Greenland turbot or deepsea sole in the GOA. 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

Since passage of the MSFMCA in 1977, the flatfish fishery in the GOA has undergone substantial changes. Until 1981, annual harvests of flatfish were around 15,000 t, taken primarily as bycatch by foreign vessels targeting other species. Foreign fishing ceased in 1986 and joint venture fishing began to account for the majority of the catch. In 1987, the GOA-wide flatfish catch increased nearly four-fold, with joint venture fisheries accounting for all of the increase. Since 1988, only domestic fishing fleets are allowed to harvest flatfish. As foreign fishing ended, catches decreased to a low of 2,441 t in 1986. Catches subsequently increased under the joint venture and then domestic fleets to a high of 43,107 t in 1996. Catches then declined to 23,237 t in 1998 and were 22,700 t in 2004.

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 (~75%, typically; Table 1) and total catch is typically a small percentage of the ABC and TAC (2-3% over the past five years; Table 2). Dover sole have been taken primarily in the Central GOA in recent years.

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 are relatively high, ranging from 27-48% over the past five years.

Historically, catch of Dover sole increased dramatically from a low of 23 t in 1986 to a high of 10,196 t in 1991 (Table 1, Figure 1). Following that maximum, annual catch has declined rather steadily. Catch of Greenland turbot has been sporadic and has been over than 100 t only 5 times since 1978. The highest catch of Greenland turbot (345 t) occurred in 1995. This was followed by a catch of 13 t for Greenland turbot the next year. Annual catch has been less than 25 t since 1996. Deepsea sole is the least caught of the deepwater flatfish species. It has been taken only intermittently, with less than a ton of annual catch in most years.

Annual catches of deepwater flatfish have been well below the TACs in recent years (Table 2). Annual TACs, in turn, have been set equal to their associated ABCs. 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. Closures of the deepwater flatfish fishery in 2015 are shown in Table 3; no closures have occurred since 2016 with the exception of the regular fishery opening date of January 20th each year. 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 and OFL for each year because population biomass estimates based on research trawl surveys for Greenland turbot and deepsea sole are considered unreliable and there is little basic biological information from these two species. As such, ABCs for Greenland turbot and deepsea sole are based on average historic catch levels and do not vary from year to year. Since 2003, the 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-Oct. 19, 2019
Fishery	Catch length composition	1991-Oct. 19, 2019
GOA survey bottom trawl	Survey biomass	Triennial: 1984-1999, Biennial: 2001-2019
GOA survey bottom trawl	Catch length composition	Triennial: 1990-1999, Biennial: 2003-2019 (1984, 1987, and 2001 data are excluded)
GOA survey bottom trawl	Catch age composition, conditioned on length	Triennial: 1990-1999, Biennial: 2003-2019 (1984, 1987, 1990, and 2001 data are excluded)

In addition, Figure 5 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 October 19, 2019 (Table 1, Figure 1). 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. 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). In addition, the 700-1000 m depth range was sampled only in select survey years and areas (Table 4). Maps of survey catch-per-unit-effort (CPUE) for 2009-2019 survey are shown in Figure 2-Figure 3. A random effects model developed for survey averaging (presented at the September 2013 Plan Team Meeting, http://www.afsc.noaa.gov/REFM/stocks/Plan_Team/2013/Sept/SAWG_2013_draft.pdf) was used to estimate survey biomass and variance in missing depth and area strata. The final survey biomass estimates and corresponding standard errors used in the assessment are shown in Table 5. A drop in the survey biomass index of 31,229 t (37%) occurred in 2015 and the survey biomass remained low in 2017 and 2019. 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 (2015-2019).

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 (http://www.afsc.noaa.gov/REFM/Docs/2015/GOA_Dover_Composition_Data_And_SampleSize_2015.xlsx). 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 of 6 year olds appears in the age composition data in 2017. In addition, there was a decline in the number of 30+ year old fish over the most recent three surveys that is consistent with the low survey biomass estimates for the most recent three surveys.

Figure 6-Figure 10 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 (Figure 6-Figure 7). 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 (Figure 8-Figure 10). Finally, a higher proportion of fish that are small for their age appear in the Eastern GOA as compared to the Central GOA (Figure 8-Figure 10).

Analytic Approach

General Model Structure

The assessment was an age- and sex-structured statistical catch-at-age model implemented in Stock Synthesis version 3.30.14.05 (SS) and r4ss (Taylor et al. 2018, R Core Team 2018) using a maximum likelihood approach. SS equations can be found in Methot and Wetzel (2013) and further technical documentation is outlined in Methot (2009). The SS 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 SS 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 (presented at the September 2013 Plan Team Meeting, http://www.afsc.noaa.gov/REFM/stocks/Plan_Team/2013/Sept/SAWG_2013_draft.pdf) was used to estimate survey biomass and variance 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 5).

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 preliminary model runs, 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 1978-2015. Recruitment for 2016-2019 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).

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

Four model runs are shown as a bridging analysis, each including new data through 2019. These models show various steps of model development, but none are proposed for use in 2019.

(1) Model 15.0: the 2015 model structure.

(2) A “cleaned-up” version of the 2015 model. This model disaggregated age data for ages 1-3 because age data for Dover sole under age 3 are sparse to non-existent, and providing these “0” observations to the model helps to inform selectivity at ages 0-2. In addition, the survey biomass estimates for 1984 and 1987 were removed because survey timing and methods differed from those in subsequent years. The selectivity parameters that were being estimated in 2015 were re-evaluated, fixing very poorly informed parameters. In addition, this model run estimates recruitment deviations starting in 1978, rather than 1947 and uses the data weighting method described in Francis (2011). The historical (pre-1978) fishing mortality was set equal to zero, as little fishing for Dover sole was thought to occur and the estimate of historical catches used in 2015 failed to influence model results. Lastly, the timing of the survey was refined to occur in June within the model instead of January.

(3) A model like (2), but with the log of catchability estimated with a normal prior with a mean of 0.17 and a standard deviation of 0.145 developed based on catchability experiments conducted by Somerton et al. (2007). In addition, this model run estimated natural mortality with a normal prior with a mean of 0.085 and a standard deviation of 0.03, which was defined using a weighted estimate of multiple natural mortality estimation methods conducted outside of the assessment model (http://barefootecologist.com.au/shiny_m.html; https://github.com/shcaba/Natural-Mortality-Tool).

(4) A model like (3), but with separate estimates of natural mortality and catchability for the years 2014-2019 to account for a distinct downward shift in survey biomass evident in the 2015, 2017, and 2019 surveys.

2019 Candidate Models

Based on the models conducted as a bridging analysis, the following four models were developed as candidate models for 2019. Each represents a hypothesis about why there was a downward shift in survey biomass for the most recent three surveys over the past five years.

Model 19.0: As for the cleaned-up model, but time-invariant natural mortality (by sex) and Q are estimated. This model explores the hypothesis that the downward shift in survey biomass can be attributed to observation error.

Model 19.1: As for Model 19.0, but natural mortality by sex is estimated separately for 1978-2013 and 2014-2019 (two time blocks). This model explores the hypothesis that the downward shift in survey biomass can be attributed to a change in natural mortality in the population. There is some evidence for this possibility, as length-weight residuals were low in the previous three surveys, especially in 2017 (Figure 17).

Model 19.2: As for Model 19.0, but Q is fixed at the value estimated in Model 19.1 for the years 1978-2013, and estimated for 2014-2019. This model explores the hypothesis that the downward shift in survey biomass can be attributed to a change in survey catchability or availability.

Model 19.3 (Q is fixed at the value estimated in Model 19.1 for the years 1978-2013 and estimated for 2014-2019, and sex-specific natural mortality is estimated separately for 1978-2013 and 2014-2019. This model explores the hypothesis that changes in both catchability/availability and natural mortality led to the downward shift in survey biomass over the most recent three surveys.

The same priors for q and M are used wherever q and M are estimated. The prior for ln(Q) is normal with a mean of 0.17 and a standard deviation of 0.145 and the priors for M are normal with a mean of 0.085 and a standard deviation of 0.03.

Parameters Estimated Outside the Assessment Model

Natural Mortality

Natural mortality was fixed at 0.085 in three of the models used for the bridging analysis, and was estimated in all 2019 candidate models (described below in the section "Parameters Estimated Within the Assessment Model"). The value 0.085 was used in previous accepted Dover sole assessment models (McGilliard et al. 2013) and was estimated using the Hoenig method (Hoenig, 1983).

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.

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

Catchability was equal to 1 in three of the models in the bridging analysis, as for previous Dover sole assessments. Models 19.2 and 19.3 use the value for catchability estimated in Model 19.1 as a fixed value for the years 1978-2013, and estimate catchability from 2014-2019 (see the subsection "2019 Candidate

Models," and the results subsection "Models Estimating Natural Mortality (M) and Catchability (q)" for a full description of the rationale for this method).

Select selectivity parameters

Selectivity parameter definitions and values are shown in (Table 7).

Parameters Estimated Inside the Assessment Model

As for previous assessments, parameters estimated within the assessment model are the log of unfished recruitment (R_0), log-scale recruitment deviations for 1978-2016, 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 7. 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*) is 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, according to the default settings of the following tool developed by Jason Cope: http://barefootecologist.com.au/shiny_m.html (Figure 11). In Models 19.0, 19.1, and 19.3, separate values for male and female natural mortality are estimated for years 2014-2019 using the same prior distribution.

In addition, in models 19.0 and 19.1 a single parameter for the log of catchability is 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). Models 19.2 and 19.3 fix catchability in 1978-2013 to the value estimated in Model 19.1 and estimate catchability in the years 2014-2019. See the results subsection "Models Estimating Natural Mortality (M) and Catchability (q)" for the justification for use of this method.

Results

Model Evaluation

The Bridging Analysis

The Cleaned-Up Model

Figure 12 shows the spawning biomass, recruitment deviations, fishing intensity, and fit to the survey biomass index for all of the models in the bridging analysis, and Figure 13 shows selectivity curves estimated by each model in the bridging analysis. The cleaned-up model resolved several problems with the 2015 model. First, the 2015 model with new data estimated selectivity parameters that were poorly informed. A constraint on the ascending limb of the full-coverage survey selectivity curve was necessary to ensure a realistic survey selectivity curve. Without the constraint, the model estimated a shallow curve that only reached a selectivity of 1 at age 59. Disaggregating the age data for ages 1-3 provided the model with additional information on selectivity at these young ages and led to estimates of the ascending limb parameter of the full-coverage selectivity curve that was much more realistic, reaching 1 at younger ages. In addition, the descending limb of the shallow-coverage survey selectivity curve was unrealistically steep and had a standard deviation of 12.17 ages. Other selectivity parameters were refined in the "cleaned-up" model as well such that the curves increased according to the ascending limb parameter of the double normal and decreased according to the descending limb parameter because the initial and final selectivity parameters were poorly informed in the 2015 model. Figure 14 shows that length-based, sex-specific fishery selectivity estimates were similar among the four models in the bridging analysis. A larger difference in fishery selectivity of males as compared to that of females occurred in the 2015 model than in the other three models in the bridging analysis.

The cleaned-up model removed early recruitment deviations because the first year of age data used in the model is 1993, Dover sole are observed beginning at approximately age 3, we want to observe them a few times before estimating a recruitment deviation for a particular cohort reliably. In addition, we can age a cohort more reliably at younger ages due to ageing imprecision (Table 6). Therefore, there may be little information in the data to inform early recruitment deviations. This may be why we see little variation in early recruitment deviations, with the exception of one year in the 1960s when the model estimates a very large recruitment deviation (Figure 12).

Other changes made in the cleaned-up model improved the accuracy of model assumptions and should be carried forward regardless of model fits. These changes were to remove 1984 and 1987 data, which were collected using different survey methods and timing than for subsequent years, and to adjust the timing of the survey within the model to June instead of the beginning of the year.

Models Estimating Natural Mortality (M) and Catchability (q)

A model estimating M and q was run to better account for uncertainty. In addition, the GOA Dover sole stock is nearly unfished with the exception of a couple of years in the early 1990s (1991-1993 primarily; Figure 1) and old cohorts of Dover sole are observed regularly in the survey, which may provide more information on M than is typically available for assessed stocks. The model estimating M and q (Model 19.0) leads to an estimate of M of 0.069 for females and 0.057 for males, both with a standard deviation about the parameter estimate of 0.003 (Table 9). The model estimating M and q for 1978-2013 and separately for 2014-2019 led to similar estimates of M for the 1978-2013 period of 0.066 for females and 0.053 for males (also with a standard deviation of 0.003) as for the model estimating time-invariant M and q. These estimates were slightly lower than the fixed natural mortality used in the 2015 model and the cleaned-up model (0.085 for both females and males), and indicate that there may be a small difference in natural mortality by sex. Differences in natural mortality by sex have been found in other flatfish species (Beverton 1992).

Model 19.0, estimating time-invariant M and q, led to an estimate of catchability of 0.84, while the model estimating a separate M and q for 2014-2019 estimated catchability to be 1.13 during the period 1978-2013 and 0.85 during the period 2014-2019 (Table 9). Hence, allowing the model to estimate natural mortality and catchability separately for two timeframes leads to similar estimates of natural mortality between the two models for 1978-2013, but a very different estimate of catchability for 1978-2013 between the two models. A retrospective analysis for the model estimating both natural mortality and catchability separately for 1978-2013 and 2014-2019 shows that when the 2015, 2017, and 2019 low survey biomass estimates are removed the estimates of catchability for the 1978-2013 period shift substantially (Figure 15). This may be happening because the model is able to estimate the relative difference in catchability between the two periods (1978-2013 and 2014-2019), but absolute estimates of catchability are less informed by the data. Typically, natural mortality and catchability are confounded and can be identified relative to one another but not in absolute terms, but notably, the estimate of natural mortality remained almost exactly the same for 1978-2013 between the two models, even with a shift in catchability for the same period, and even when estimating natural mortality separately for 2014-2019. In addition, the model that estimated time-invariant M and q led to correlations between ln(q) and M of -

0.36 and -0.35 for female and male M, respectively. The model estimating M and q with a block on both for the 2014-2019 period led to a correlation between ln(q) and M of -0.32 for both female and male M. Natural mortality and catchability are notoriously confounded in most stock assessment models, but may be less confounded for Dover sole because more information is available to estimate natural mortality than is typical for assessed stocks – under-utilization of the stock by the fishery allows fish to grow old, which then provides information on natural mortality. Based on this information, the set of 2019 candidate models was developed to allow for estimation of changes in catchability and natural mortality from 2014 onward without allowing for undue influence of the 2014-2019 estimates (which are informed by few years of data) on the 1978-2013 estimates of catchability (which are informed by many years of data).

The 2019 Candidate Models

Models 19.0-19.3 are a suite of very similar models that each address a hypothesis about why a decline in survey biomass occurred in 2015 and persisted in 2017 and 2019. Model 19.0 represents the hypothesis that the drop is simply observation error and the model does not need to be changed to fit to the 2015-2019 index values. Model 19.1 represents the hypothesis that the change in survey biomass was due to natural mortality, and is supported by evidence of low length-weight residuals corresponding to the years with low survey biomass observations (Figure 17). The length-weight residuals in 2017 were particularly low relative to observations in other survey years. However, length-weight residuals may indicate skinny fish, but could also indicate that there are fewer older fish in the population (for which unstandardized residuals in either direction will be larger). For Dover sole, no analysis has been done to determine what size of length-weight residual would indicate that bioenergetics needs had changed substantially or could lead to higher natural mortality rates. Fish could be skinny without experiencing higher rates of natural mortality and this hypothesis could not be tested within the SS framework at this time. Model 19.2 represents the hypothesis that a change in catchability of Dover sole occurred from 2014-2019. Finally, Model 19.3 models the hypothesis that a change in both natural mortality and catchability affected the survey biomass in 2014-2019. These four models led to nearly identical trajectories of spawning biomass, recruitment, and fishing intensity in 1978-2013, but estimates of spawning biomass for 2014-2019 (corresponding to years where low survey biomass estimates occurred) differed among models (Figure 17). In addition, the four models led to very similar fits to length composition and conditional age-at-length data (Figure 18, Figure 19, and Table 10). Parameter estimates for growth and selectivity were nearly identical among models (Table 10-Table 12). The estimates of natural mortality in the period 1978-2013 were nearly identical among the four models as well (Table 11). As expected, Model 19.1 (which estimates only a separate natural mortality parameter in the 2014-2019 period) led to a natural mortality estimate for 2014-2019 (0.135 for females and 0.14 for males) that was higher than for Model 19.3 (0.11 for females and 0.12 for males), where both separate natural mortality and catchability parameters were estimated for 2014-2019 (Table 11). Model 19.0, which assumed time-invariant population dynamics, led to an estimate of catchability equal to 0.84 and Model 19.1, which assumed a change in natural mortality (only) in 2014-2019 led to an estimate of catchability that was slightly higher (0.87). The low survey biomass in 2015, 2017, and 2019 appears to have affected the catchability estimate in Model 19.0, while model 19.1 is able to better separate the data informing catchability in the years 1978-2013 from dynamics in 2014-2019. Therefore, the estimate of catchability from Model 19.1 was used to fix catchability in Models 19.2 and 19.3 so that catchability could be estimated for 2014-2019 without influencing the catchability estimate in the years 1978-2013. Assuming that a change in catchability (only) led to a change in survey biomass after 2014 (Model 19.2) resulted in an estimate of catchability for 2014-2019 of q=0.64, while assuming that both catchability and natural mortality may have contributed to low survey biomass led to an estimate of catchability that was slightly higher (q = 0.73), and elevated natural mortality as well (0.11 for females and 0.12 for males).

Though these four models are very similar to one another with the exception of how they explain the 2014-2019 period, they have different implications for the value of fishery and biological reference points. Both natural mortality and catchability are plausible explanations for low survey biomass observations in 2015, 2017, and 2019, and both may have occurred. In addition, given that the low survey biomass occurred for three surveys over a five-year period, and that the Model 19.0 fit to these survey biomass data points was outside of the uncertainty interval of the data points (Figure 16, bottom left panel), we select Model 19.3 (estimating a separate natural mortality and catchability in 2014-2019) as the preferred model for 2019.

The 2019 Preferred Model: Model 19.3

Figure 16 shows that a decline in spawning biomass since 2013 for Model 19.3 because the drop in survey biomass estimates that occurred in 2015, 2017, and 2019 is partially attributed to a change in natural mortality. Estimates of recruitment show a large recruitment of 6 year-olds that is consistent with the raw survey age composition data (Figure 4). Fishing intensity is estimated to be very low for the stock in recent years. Fishery selectivity is logistic and fish are fully selected to the fishery at approximately 40 cm (Figure 20). Derived age-based fishery selectivity (the length-based selectivity curves translated through the age-length transition matrix to age-based selectivity) for females is similar to the age-based shallow coverage survey selectivity for females, and occurs at slightly older ages than for the full-coverage survey.

Detailed plots of model fits to length composition and conditional age-at-length data are shown in Figure 19-Figure 24. Fits to length composition data aggregated over years are reasonable for the full-coverage survey (Figure 19). For the shallow-coverage survey there are more males observed around 40cm than predicted by the model and fewer 30cm and 45-50cm males observed than predicted. In addition, there are more 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 (Figure 6-Figure 7). Figure 21-Figure 22 show fits to yearly fishery length composition data. In early years, the model often estimates more long fish than exist in the data (Figure 21) and in later years the model tends to estimate more young fish than exist in the data (Figure 22). 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 (Figure 6-Figure 7). Figure 23 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 24).

Figure 25-Figure 27 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 Figure 6-Figure 10 and 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.

Alternative model configurations considered, but not included

A set of alternative model runs were conducted (not presented) that included two subpopulations of Dover sole, each with their own growth curve (in particular allowing a different L_{inf} between the subpopulations) and estimating a time-varying parameter allocating the proportion of recruits to each subpopulation in each year. This model was able to fit the length composition data corresponding to the shallow-coverage survey (which occurred in 1990-1996 only) much better than Model 19.3. However, the proportion of recruitment between the subpopulation varied from year to year in early model years in an unrealistic fashion.

A set of research models was conducted where the stock was modeled using a two-area model (shallow and deep) with age-specific movement between the two areas, and two subpopulations were modeled allowing growth curves specific to each subpopulation. This set of models is still in development. However, the model runs show (1) there is evidence for two subpopulations with differences in growth curves between subpopulations: the CVs in length-at-age of the growth curves were smaller in these model runs and a ~10cm difference in L_{inf} was estimated and (2) males and females may have different ontogenetic movement patterns, where a higher proportion of older males may inhabit deeper water than older females. Currently, sex-specific movement patterns cannot be estimated using the Stock Synthesis framework. Other challenges exist for this set of models as well because movement parameters can be confounded with selectivity parameters. In addition, one subpopulation was more prevalent in the data in earlier cohorts than the other and while there is sufficient information to estimate L_{inf} for this older subpopulation, less information is available to estimate the other growth parameters for this subpopulation. Lastly, it appears that some Eastern GOA Dover sole are smaller than Western-Central GOA Dover sole, which is a pattern consistent that found for GOA rex sole (Figure 10). This spatial pattern is not taken into account in the two-area framework, where the two areas are shallow and deep areas.

A model was run fixing age-based selectivity to 0 below age 3, as Dover sole are thought to spend an extended time in the plankton before settling around age 3, and the survey selectivity curves in Models 19.0-19.3 suggest that survey selectivity is increasing rapidly by age 3. This model run led to almost identical estimates of key derived quantities, such as spawning biomass and total biomass, and fishing mortality. In addition, the derived age-based fishery selectivity in Models 19.0-19.3 show little to no selectivity before age 3. Therefore, the fishery selectivity curves used in projections presented in this assessment for Model 19.3 appear to be realistic. There are no fishery age data for GOA Dover sole, and there is a time-varying, cohort-specific growth pattern for this stock; as shown in the GOA rex sole assessment (McGilliard 2017), thus ignoring complex population growth patterns in the absence of fishery age data may present issues for estimating fishery selectivity, and therefore GOA Dover sole fishery selectivity estimates are uncertain.

Time Series Results

Time series results are shown in Table 15-Table 16 and Figure 28-Figure 31. A time series of numbers at age is available at (http://www.afsc.noaa.gov/REFM/Docs/2015/GOA_Dover_TimeSeries_of_NumbersAtAge_2015.xlsx). Total biomass for ages 3+, SSB, and standard deviations of SSB estimates for the previous and current assessments are presented in Table 15. Age 3 recruitment, age 0 recruitment, and standard deviations of age 0 recruitment estimates are presented in Table 16 for the previous and current assessments. Figure 28 shows SSB estimates and corresponding asymptotic 95% confidence intervals. Figure 29 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 30-Figure 31 show the spawning stock biomass, recruitment deviations, and fishing mortality for model runs excluding 0 to 10 years of data. Figure 30 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 31 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 for spawning biomass, recruitment, and F are 0.04, -0.05, and -0.05, respectively. Hurtado-Ferro et al. (2014) proposed a rule of thumb for determining whether a problematic retrospective pattern is occurring based on a simulation study. The rule of thumb for long-lived species such as Dover sole is that a Mohn's rho lower than -0.15 or higher than 0.20 may be problematic. The values of Mohn's rho in this assessment are not problematic according to the Hurtado-Ferro rule of thumb.

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.

	Assessment-related considerations	*Population dynamics considerations*	*Environmental/ecosystem considerations*	*Fishery Performance*
Level 1: Normal	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: Substantially increased concerns	Substantially increased assessment uncertainty/ unresolved issues.	Stock trends are unusual; abundance increasing or decreasing faster than has been seen recently, or recruitment pattern is atypical.	Some indicators showing an adverse signals relevant to the stock but the pattern is not consistent across all indicators.	Some indicators showing adverse signals but the pattern is not consistent across all indicators
Level 3: 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 4: 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 three 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, 2017, and 2019 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 of 5-6 year-old Dover sole. We assign a risk level of 1 for this category.

Environmental/Ecosystem considerations

Ranking concerns for ecosystem/environmental impacts on Dover sole is challenged by limited information about ecological interactions of Dover sole and limited survey sampling within their typical depth distribution (100 - 1500 m). There is minimal concern about changes in impacts on habitat disturbance as the estimated area disturbed by fishing gear on the continental shelf has remained steady. This is the area where older females may have seasonal migrations from deep water where spawning occurs to shallower water mid-shelf in summer time to feed.

Dover sole commonly feed on brittle stars, polychaetes and other miscellaneous worms. Trends in brittle stars in the bottom trawl survey have been roughly stable since 2013, but estimated abundance dropped nearly 50% from 2017 to 2019. Polychaetes are poorly sampled and show no trends. Miscellaneous worms have shown a stable or slightly declining trend since 2003. It’s reasonable to assume that energetic demands of Dover sole may have been elevated during the heatwave years of 2015-2016 and 2019 when warm temperatures extended to depth on the shelf. However, their deeper depth distribution may have tempered this effect. Negative anomalies of weight-length distributions in 2017 and 2019 may indicate that Dover sole were not meeting their energetic demands to the same degree as in earlier years. Given that the major source of Dover sole mortality is from the flatfish fishery, there is little concern about increases in predation from other predators. Overall, limited data suggest there are no apparent ecosystem or environmental concerns that warrant a risk level above 1.

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 2%. 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 1978-2019 year classes estimated in this assessment 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 2020 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. For this tier, $FABC$ is constrained to be $\leq F_{40\%}$, and F_{OFL} is defined to be $F_{35\%}$. The values of these quantities are:

SSB 2020	27,935
$B_{40\%}$	7,613
$F_{40\%}$	0.09
maxF_{ABC}	0.09
$B_{35\%}$	6,661
$F_{35\%}$	0.11
F_{OFL}	0.11

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 2019 numbers-at-age estimated in the assessment. This vector is then projected forward to the beginning of 2032 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2019. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 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 2020 and 2021, are as follows ("max F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, *F* is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, *F* is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2020 recommended in the assessment to the *max*F_{ABC} for 2020. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, *F* is set equal to 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 2015-2019 average *F*. (Rationale: For some stocks, TAC can be well below ABC, and recent average *F* may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 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 17-Table 19. 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 1) above its MSY level in the current year, or 2) above ½ of its MSY level in 2019 and expected to be above its MSY level in 2029 under this scenario, then the stock is not overfished.)

Scenario 7: In 2020 and 2021, *F* is set equal to *max*F_{ABC}, and in all subsequent years, *F* is set equal to 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 in 2032 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 2019 of Scenario 6 is 28,923 t, more than $B_{35\%}$ (6,661 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 2032 of Scenario 7 (9,462 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 2001-2019 and estimates of 2020 and 2021 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 2020 and 2021 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 2001-2019.

Species	**Year**	**Western**	**Central**	**West Yakutat**	**Southeast**	**Total**
Dover Sole		0.8%	33.3%	36.0%	29.9%	100.0%
	2020	47	1,945	2,104	1,751	5,847
	2021	46	1,911	2,067	1,719	5,743
Greenland Turbot		100.0%	0.0%	0.0%	0.0%	100.0%
	2020	179	0	0	0	179
	2021	179	0	0	0	179
Deepsea Sole		0.7%	72.8%	14.5%	12.0%	100.0%
	2020	0	3	1	0	4
	2021	0	3	1	0	4
Deepwater Flatfish	**2020**	**226**	**1,948**	**2,105**	**1,751**	**6,030**
	2021	**225**	**1,914**	**2,068**	**1,719**	**5,926**

Ecosystem Considerations

Ecosystem Effects on the Stock

Based on results from an ecosystem model for the GOA (Aydin et al., 2007), Dover sole adults occupy an intermediate trophic level (Figure 32-Figure 34). Dover sole commonly feed on brittle stars, polychaetes and other miscellaneous worms (Figure 33; Buckley et al., 1999). 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 (Figure 34). 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

Table 20 shows the catch of non-target species in the deepwater flatfish fishery in recent years. In recent years and since the last assessment in 2015, the deepwater flatfish fishery has caught 0% of any of the non-target species, which is consistent with the very low catches of deepwater flatfish (Table 1). A table of the proportions of prohibited species catch taken in the deepwater flatfish fishery is not shown because all values are confidential.

Data Gaps and Research Priorities

There is time-varying cohort-specific pattern in the maximum size of Dover sole that is not currently taken into account in the model. This appears as a spatial pattern as well because Dover sole move ontogenetically. Resolving the uncertainty in growth in the assessment could lead to better-fitting models, much lower CVs in length-at-age, and improved selectivity estimates. Appendix B explores several two-area models meant to explicitly take into account the ontogenetic movement patterns and spatial growth patterns, but lead to some confounding among selectivity, growth, and movement parameters. In addition, it appears that males and females may have different movement patterns. Fish in the Eastern GOA appear to not grow as large as fish in the Western-Central GOA, and fewer old fish are found in the Eastern GOA. Genetic stock structure is unknown for Dover sole, so it is not known whether the fish in the Eastern GOA are a separate sub-population, if they don't grow as old, or if older Eastern GOA Dover sole migrate offshore and west to deeper water. Further study of genetic stock structure of Dover sole would be interesting, though it may be difficult to obtain the funding that would be necessary to explore this. However, exploration of how these growth and movement patterns and our uncertainty about growth and movement may influence the performance of stock assessment models would be useful.

For GOA rex sole, resolving the spatial uncertainty in growth dramatically changed the fishery selectivity curve and fishery reference points, and the appropriateness of the new fishery reference points was confirmed by the addition of newly-aged historical fishery ages to the model. GOA Dover sole currently depends only on fishery length composition data, as there are no fishery otoliths or ages available. Changing the observer sampling protocol to obtain even one year of fishery ages could lead to improved estimates of fishery selectivity.

A contributing factor to the uncertainty in the relationship between length and age is the large amount of ageing error for older Dover sole. The stock assessment incorporated ageing error by using an existing ageing error matrix for West Coast Dover sole. A priority for future assessments is to analyze ageing error data for GOA Dover sole using methods described in Punt et al. (2008) and to incorporate a resulting ageing error matrix that is specific to GOA Dover sole into the assessment.

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. 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. .

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 October 19, 2019. 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	9	72	4	86

Table 2. 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	48%	2%
2019*	11,434	9,501	9,501	27%	1%

*As of October 19, 2019

Table 3. 2016 closures of the GOA deepwater flatfish fishery (no closures occurred other than "Bycatch" status January 1-January 19 of each year for 2017-2019).

Status Type	GOA Sub-Area	Program	Status	Reason	Effective Date
Trawl Gear	Central	All	Bycatch	Halibut	30-Apr-16
Trawl Gear	Central	All	Open	Halibut	15-May-16
Trawl Gear	Central	All	Bycatch	Halibut	16-Mar-16
Trawl Gear	Central	All	Open	Regulations	1-Apr-16
Hook and Line Gear	Central	All	Open	Regulations	1-Jan-16
Trawl Gear	Central	All	Bycatch	Regulations	1-Jan-16
Trawl Gear	Central	All	Open	Regulations	20-Jan-16
Jig Gear	Central	All	Open	Regulations	1-Jan-16
Pot Gear	Central	All	Open	Regulations	1-Jan-16
Hook and Line Gear	Central	Catcher Vessel	Bycatch	Halibut	11-Mar-16
Trawl Gear	Western	All	Bycatch	Halibut	16-Mar-16
Trawl Gear	Western	All	Bycatch	Halibut	30-Apr-16
Trawl Gear	Western	All	Open	Halibut	15-May-16
Trawl Gear	Western	All	Open	Regulations	1-Apr-16
Hook and Line Gear	Western	All	Open	Regulations	1-Jan-16
Trawl Gear	Western	All	Bycatch	Regulations	1-Jan-16
Trawl Gear	Western	All	Open	Regulations	20-Jan-16
Jig Gear	Western	All	Open	Regulations	1-Jan-16
Pot Gear	Western	All	Open	Regulations	1-Jan-16
Pot Gear	SE Outside	All	Open	Regulations	1-Jan-16
Hook and Line Gear	SE Outside	All	Open	Regulations	1-Jan-16
Jig Gear	SE Outside	All	Open	Regulations	1-Jan-16
Trawl Gear	West Yakutat	All	Bycatch	Halibut	16-Mar-16
Trawl Gear	West Yakutat	All	Bycatch	Halibut	30-Apr-16
Trawl Gear	West Yakutat	All	Open	Halibut	15-May-16
Pot Gear	West Yakutat	All	Open	Regulations	1-Jan-16
Trawl Gear	West Yakutat	All	Open	Regulations	1-Apr-16
Hook and Line Gear	West Yakutat	All	Open	Regulations	1-Jan-16
Trawl Gear	West Yakutat	All	Bycatch	Regulations	1-Jan-16
Trawl Gear	West Yakutat	All	Open	Regulations	20-Jan-16
Jig Gear	West Yakutat	All	Open	Regulations	1-Jan-16

Table 4. Survey biomass by depth and area

	0 to 500m	500 to 700m	700 to 1000m	Total
Central				
1984	36,013	5,147	11,309	52,469
1987	26,281	6,757	806	33,844
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	61		13,777
Eastern				
1984	9,534	589		10,123
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
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

Table 5. Final survey biomass estimates and standard errors used in the assessment, after an adjustment using the survey-averaging random effects model to estimate biomass in missing year-strata combinations.

Year	Biomass	Standard Error
1990	104,959	0.16
1993	93,920	0.13
1996	87,893	0.11
1999	75,093	0.10
2001	78,890	0.10
2003	101,509	0.11
2005	80,560	0.08
2007	71,469	0.10
2009	76,277	0.08
2011	79,032	0.09
2013	84,298	0.21
2015	53,069	0.09
2017	59,955	0.17
2019	48,452	0.12

Table 6. 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 7. Double-normal selectivity curve specifications within the model for all of the candidate 2019 models (Models 19.0-19.3).

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 8. Negative log likelihood components for models in the bridging analysis. The 2015 model includes survey biomass, conditional age-at-length, and length composition data from 1984 and 1987 and the other models omit data from 1984 and 1987 and the likelihood components cannot be compared directly. The cleaned-up model and the models estimating M and Q parameters have different numbers of parameters, but use the same data.

Likelihood Component	2015 Model + new data	Cleaned-up 2015 Model + new data	Estimate M and Q (Model 19.0)	Estimate M & Q 1978-2014, estimate separate 2014-2019 M & Q
TOTAL	1,645	1,414	1,376	1,361
Survey	-1.22	-13.14	-8.76	-24.49
Length_comp	475	232	213	216
Age_comp	1,146	1,196	1,171	1,168

Table 9. Final parameter estimates for bridging analysis models, including biology, growth, and catchability parameters for females (f) and males (m). "Std. Dev" is the standard deviation of the estimate, time-varying parameters were not included in all models; cells are left blank for parameters not estimated in particular model.

	2015 Model + new data		**Cleaned-up 2015 Model + new data**		**Est time-invariant M and Q (Model 19.0)**		**Est M & Q 1978-2014, est separate 2014-2019 M & Q**	
Parameter	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
Natural mortality (f)	0.085		0.085		0.069	0.003	0.066	0.003
Natural mortality (m)	0.085		0.085		0.057	0.003	0.053	0.003
Natural mortality (f), 2014-2019							0.105	0.02
Natural mortality (m), 2014-2019							0.111	0.02
Length at age 3 (f)	26.30	0.50	24.26	0.75	24.55	0.76	24.47	0.77
Length at age 59 (f)	52.55	0.46	51.24	0.34	50.83	0.31	50.75	0.31
von Bertalanffy k (f)	0.11	0.01	0.15	0.01	0.16	0.01	0.16	0.01
CV in length at age 3 (f)	0.15	0.01	0.16	0.01	0.16	0.01	0.16	0.01
CV in length at age 59 (f)	0.10	0.00	0.10	0.00	0.10	0.00	0.10	0.00
Length at age 3 (m)	23.82	0.84	26.65	0.93	26.53	0.89	26.54	0.91
Length at age 59 (m)	43.50	0.21	43.80	0.30	43.48	0.28	43.44	0.27
von Bertalanffy k (m)	0.24	0.02	0.20	0.02	0.20	0.02	0.20	0.02
CV in length at age 3 (m)	0.17	0.01	0.15	0.01	0.15	0.01	0.15	0.01
CV in length at age 59 (m)	0.09	0.00	0.08	0.00	0.08	0.00	0.08	0.00
$\ln(R_0)$	9.44	0.04	9.65	0.04	9.36	0.14	9.13	0.11
Log catchability (ln(q))	0.00	NA	0.00		-0.17	0.12	0.12	0.10
Log catchability (ln(q)), 2014-2019							-0.16	0.10

Table 10. Negative log likelihood components for Models 19.0-19.3. The models differ in the number of parameters estimated as detailed in the model descriptions. Models 19.0 and 19.2 have the same number of parameters and Models 19.1 and 19.3 have the same number of parameters. The lowest negative log likelihoods among models are highlighted in bold.

	Model 19.0	Model 19.1	Model 19.2	Model 19.3
Likelihood Component	Estimate time-invariant M and Q	Estimate M and Q 1978-2013, estimate separate 2014-2019 M	Estimate M 1978-2013, estimate separate 2014-2019 Q	Estimate M 1978-2014, estimate separate 2014-2019 M and Q
TOTAL	1,376	1,365	1,367	**1,362**
Survey	-8.76	-20.06	-22.97	**-24.18**
Length_comp	**213**	214	215	215
Age_comp	1,171	1,168	1,168	**1,167**
Recruitment	-2.830	-2.799	-2.552	-2.636

Table 11. Final parameter estimates for biology, growth, and catchability parameters for females (f) and males (m). "Std. Dev" is the standard deviation of the estimate, time-varying parameters were not included in all models; cells are left blank for parameters not estimated in particular model.

	Model 19.0		**Model 19.1**		**Model 19.2**		**Model 19.3**	
	Est time-invariant M and Q		**Est M & Q, est separate M 2014-2019**		**Est M, est separate Q 2014-2019**		**Est M, est separate M & Q 2014-2019**	
Parameter	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
Natural mortality (f)	0.069	0.003	0.067	0.003	0.068	0.003	0.068	0.003
Natural mortality (m)	0.057	0.003	0.055	0.003	0.056	0.003	0.055	0.003
Natural mortality (f), 2014-2019			0.135	0.02			0.113	0.02
Natural mortality (m), 2014-2019			0.14	0.02			0.119	0.02
Length at age 3 (f)	24.55	0.76	24.54	0.77	24.51	0.77	24.51	0.77
Length at age 59 (f)	50.83	0.31	50.78	0.31	50.78	0.31	50.77	0.31
von Bertalanffy k (f)	0.16	0.01	0.16	0.01	0.16	0.01	0.16	0.01
CV in length at age 3 (f)	0.16	0.01	0.16	0.01	0.16	0.01	0.16	0.01
CV in length at age 59 (f)	0.10	0.00	0.10	0.00	0.10	0.00	0.10	0.00
Length at age 3 (m)	26.53	0.89	26.58	0.91	26.51	0.91	26.55	0.91
Length at age 59 (m)	43.48	0.28	43.45	0.27	43.45	0.27	43.44	0.27
von Bertalanffy k (m)	0.20	0.02	0.20	0.02	0.20	0.02	0.20	0.02
CV in length at age 3 (m)	0.15	0.01	0.15	0.01	0.15	0.01	0.15	0.01
CV in length at age 59 (m)	0.08	0.00	0.08	0.00	0.08	0.00	0.08	0.00
ln(R_0)	9.36	0.14	9.33	0.14	9.36	0.07	9.36	0.07
Log catchability (ln(q))	-0.17	0.12	-0.12	0.13	-0.12	Fixed	-0.12	Fixed
Log catchability (ln(q)), 2014-2019					-0.44	0.07	-0.32	0.08

Table 12. Fishery, full coverage survey, and shallow coverage selectivity parameters for Model 19.3. “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.

	Fishery (length-based)		**Full Coverage Survey (age-based)**		**Shallow Coverage Survey (age-based)**	
Double-normal selectivity parameters	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
Peak: beginning size for the plateau	44.92	2.83	5.27	0.55	11.59	1.22
Width: width of plateau	0	Fixed	8.00	Fixed	-3.45	2.34
Ascending width (log space)	4.05	0.62	1.14	0.49	3.26	0.31
Descending width (log space)	10.00	Fixed	15.00	Fixed	15.00	Fixed
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	-5.45	3.00	-0.54	0.66	-4.24	1.19
Male ascending width offset (log space)	-0.98	0.79	-0.32	0.68	-1.43	0.47
Male descending width offset (log space)	0.00	Fixed	0.00	Fixed	-9.15	0.38
Male "Final" offset (transformation required)	0.00	Fixed	Follow desc width		Follow desc width	
Male apical selectivity	1.00	Fixed	1.00	Fixed	1.00	Fixed

Table 13. 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	0.769	0.421	2012	0.145	0.374
1979	0.398	0.478	2013	-0.066	0.386
1980	0.291	0.448	2014	0.278	0.455
1981	0.300	0.430	2015	0.930	0.441
1982	0.308	0.415	2016	0.581	0.542
1983	0.212	0.380	2017	0.011	0.485
1984	-0.041	0.363	2018	-0.007	0.485
1985	-0.250	0.346	2019	0.000	0.487
1986	-0.143	0.320			
1987	0.002	0.294			
1988	-0.218	0.300			
1989	-0.503	0.291			
1990	-0.550	0.308			
1991	0.163	0.231			
1992	-0.395	0.306			
1993	-0.102	0.273			
1994	-0.280	0.303			
1995	-0.271	0.310			
1996	-0.278	0.329			
1997	-0.176	0.322			
1998	-0.052	0.322			
1999	0.602	0.229			
2000	0.063	0.303			
2001	-0.355	0.317			
2002	-0.284	0.294			
2003	-0.190	0.307			
2004	0.223	0.258			
2005	-0.262	0.308			
2006	-0.458	0.308			
2007	-0.502	0.307			
2008	-0.402	0.315			
2009	-0.279	0.339			
2010	0.235	0.335			
2011	0.554	0.316			

Table 14. Estimated fishing mortality rates for the current model. "Std. Dev" is the standard deviation of the estimate.

Year	Fishing Mortality	Std. Dev.	Year	Fishing Mortality	Std. Dev.
Initial F	--	--	1998	0.0264	0.0011
1978	0.0073	0.0003	1999	0.0277	0.0011
1979	0.0047	0.0002	2000	0.0120	0.0005
1980	0.0051	0.0002	2001	0.0101	0.0004
1981	0.0041	0.0002	2002	0.0070	0.0003
1982	0.0041	0.0002	2003	0.0114	0.0004
1983	0.0031	0.0001	2004	0.0081	0.0003
1984	0.0012	0.0000	2005	0.0047	0.0002
1985	0.0004	0.0000	2006	0.0040	0.0002
1986	0.0002	0.0000	2007	0.0029	0.0001
1987	0.0005	0.0000	2008	0.0063	0.0002
1988	0.0091	0.0004	2009	0.0052	0.0002
1989	0.0127	0.0005	2010	0.0066	0.0003
1990	0.0198	0.0008	2011	0.0054	0.0002
1991	0.0890	0.0035	2012	0.0031	0.0001
1992	0.0788	0.0032	2013	0.003	0.000
1993	0.0680	0.0028	2014	0.003	0.000
1994	0.0325	0.0014	2015	0.003	0.000
1995	0.0205	0.0008	2016	0.003	0.000
1996	0.0244	0.0010	2017	0.003	0.000
1997	0.0422	0.0017	2018	0.002	0.000
			2019	0.001	0.000

Table 15. Time series of age 3+ total biomass, spawning biomass, and standard deviation of spawning biomass for the previous and current assessment models. "Stdev_SPB" is the standard deviation of the estimate of spawning biomass.

	2015 Assessment			*2019 Assessment*		
Year	**Total Biomass (age 3+)**	**Spawning Biomass**	**Stdev_SPB**	**Total Biomass (age 3+)**	**Spawning Biomass**	**Stdev_SPB**
1978	120,778	51,020	3,107	134,286	48,489	2,083
1979	134,217	51,407	3,045	133,490	48,158	2,076
1980	134,229	51,802	2,971	133,010	47,951	2,072
1981	135,421	52,070	2,886	135,584	47,754	2,063
1982	136,746	52,284	2,794	137,003	47,621	2,055
1983	137,648	52,424	2,696	138,173	47,519	2,043
1984	138,410	52,565	2,595	139,525	47,502	2,029
1985	139,318	52,791	2,495	141,136	47,632	2,013
1986	140,679	53,095	2,392	142,494	47,866	1,996
1987	143,724	53,454	2,292	143,062	48,186	1,979
1988	146,052	53,857	2,195	142,902	48,576	1,966
1989	147,024	53,942	2,096	141,669	48,650	1,952
1990	148,060	53,925	2,002	140,144	48,619	1,948
1991	147,451	53,649	1,909	137,224	48,290	1,949
1992	145,726	50,560	1,787	126,252	44,947	1,898
1993	136,787	48,081	1,684	117,041	42,217	1,864
1994	128,845	47,410	1,612	110,951	40,015	1,836
1995	125,731	46,984	1,550	107,437	39,143	1,827
1996	122,511	46,901	1,500	105,638	38,645	1,816
1997	120,281	46,702	1,461	103,257	37,926	1,793
1998	118,793	45,791	1,430	99,527	36,534	1,750
1999	116,188	45,337	1,412	97,275	35,672	1,713
2000	114,512	44,740	1,401	95,243	34,758	1,673
2001	112,363	44,576	1,395	94,844	34,359	1,641
2002	110,906	44,486	1,393	96,908	34,043	1,610
2003	116,657	44,417	1,391	97,776	33,848	1,581
2004	117,503	44,244	1,391	97,484	33,546	1,550
2005	121,498	44,195	1,393	97,485	33,395	1,523
2006	121,783	44,358	1,400	97,851	33,405	1,500
2007	123,584	44,624	1,413	99,265	33,501	1,481
2008	124,228	45,064	1,433	99,680	33,693	1,466
2009	125,778	45,495	1,463	99,370	33,835	1,454
2010	125,144	46,072	1,503	98,916	34,056	1,449
2011	125,025	46,670	1,552	98,357	34,263	1,449
2012	123,584	47,300	1,608	97,999	34,510	1,456
2013	122,244	47,939	1,666	99,050	34,817	1,469
2014	120,702	48,516	1,726	101,565	35,116	1,487
2015	123,619	48,918	1,782	97,493	33,784	1,518
2016	141,926	49,180	0	93,250	32,493	1,816
2017				90,009	31,216	2,233
2018				89,916	30,023	2,683
2019				88,868	28,923	3,131
2020				86,827	27,935	--
2021				84,771	27,011	--

Table 16. Time series of age 3 and age 0 recruits and standard deviation of age 0 recruits for the previous and current assessment models. “Std. dev” is the standard deviation of the estimate of Age 0 recruits.

	2015 Assessment			*2019 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	16,025	29,490	15,584	9,626	24,745	10,459
1979	18,841	23,807	11,720	9,626	16,966	8,210
1980	23,597	22,749	10,716	9,626	15,128	6,844
1981	22,852	23,592	11,090	20,577	15,160	6,554
1982	18,449	25,838	12,820	14,109	15,182	6,313
1983	17,628	37,721	17,055	12,580	13,699	5,234
1984	18,281	29,205	12,768	12,607	10,566	3,906
1985	20,022	18,855	7,899	12,625	8,510	3,008
1986	29,231	28,628	9,151	11,392	9,408	3,065
1987	22,632	18,791	7,177	8,786	10,796	3,235
1988	14,611	17,966	6,308	7,077	8,650	2,650
1989	22,184	14,524	4,924	7,824	6,505	1,945
1990	14,561	12,981	4,617	8,977	6,204	1,970
1991	13,922	19,497	5,662	7,193	12,661	2,997
1992	11,255	13,788	4,695	5,409	7,243	2,276
1993	10,059	15,540	5,618	5,159	9,714	2,683
1994	15,108	22,192	7,662	10,528	8,128	2,508
1995	10,684	22,122	7,622	6,023	8,199	2,589
1996	12,042	17,638	6,534	8,077	8,146	2,721
1997	17,196	13,993	4,582	6,759	9,019	2,926
1998	17,143	11,008	3,946	6,818	10,206	3,344
1999	13,668	65,463	10,035	6,774	19,636	4,558
2000	10,843	14,696	5,896	7,500	11,450	3,494
2001	8,530	42,611	7,319	8,487	7,541	2,455
2002	50,728	8,036	2,727	16,328	8,099	2,426
2003	11,388	22,223	5,218	9,522	8,895	2,806
2004	33,020	14,484	4,797	6,271	13,437	3,484
2005	6,227	23,644	5,831	6,734	8,279	2,617
2006	17,221	9,683	3,243	7,397	6,802	2,145
2007	11,224	16,798	4,464	11,174	6,510	2,073
2008	18,322	9,103	2,972	6,884	7,196	2,328
2009	7,503	12,625	4,179	5,657	8,133	2,848
2010	13,017	11,648	4,468	5,414	13,624	4,671
2011	7,054	46,614	18,935	5,984	18,966	6,080
2012	9,783	40,703	20,978	6,763	12,744	4,889
2013	9,026	14,435	5,777	11,329	10,449	4,181
2014	36,122	19,452	889	15,772	14,916	6,999
2015	31,541	19,452		10,037	28,991	12,901
2016	17,409	21,884		7,794	20,700	11,567
2017				10,540	11,698	5,729
2018				20,486	11,496	5,633
2019				14,628	11,573	
Average				9,592	11,809	

Table 17. 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
2019	28,923	28,923	28,923	28,923	28,923	28,923	28,923
2020	27,934	27,934	27,934	27,934	27,934	27,934	27,934
2021	27,009	27,009	27,009	27,009	27,009	24,477	24,883
2022	26,218	26,218	26,218	26,218	26,218	21,600	22,309
2023	23,564	23,564	25,602	25,090	25,656	19,216	19,826
2024	21,320	21,320	25,107	24,125	25,212	17,246	17,769
2025	19,410	19,410	24,710	23,295	24,862	15,607	16,055
2026	17,782	17,782	24,390	22,574	24,587	14,243	14,626
2027	16,380	16,380	24,120	21,934	24,361	13,094	13,418
2028	15,150	15,150	23,874	21,344	24,155	12,108	12,381
2029	14,080	14,080	23,617	20,779	23,935	11,269	11,499
2030	13,130	13,130	23,360	20,249	23,712	10,533	10,724
2031	12,288	12,288	23,078	19,717	23,463	9,893	10,051
2032	11,537	11,537	22,762	19,192	23,171	9,332	9,462

Table 18. 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
2019	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00	0.11	0.09
2021	0.00	0.00	0.00	0.00	0.00	0.11	0.09
2022	0.09	0.09	0.00	0.02	0.00	0.11	0.11
2023	0.09	0.09	0.00	0.02	0.00	0.11	0.11
2024	0.09	0.09	0.00	0.02	0.00	0.11	0.11
2025	0.09	0.09	0.00	0.02	0.00	0.11	0.11
2026	0.09	0.09	0.00	0.02	0.00	0.11	0.11
2027	0.09	0.09	0.00	0.02	0.00	0.11	0.11
2028	0.09	0.09	0.00	0.02	0.00	0.11	0.11
2029	0.09	0.09	0.00	0.02	0.00	0.11	0.11
2030	0.09	0.09	0.00	0.02	0.00	0.11	0.11
2031	0.09	0.09	0.00	0.02	0.00	0.11	0.11
2032	0.09	0.09	0.00	0.02	0.00	0.11	0.11

Table 19. 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
2019	109	109	109	109	109	109	109
2020	258	258	258	258	258	6,918	5,846
2021	258	258	258	258	258	6,223	5,336
2022	5,645	5,645	145	1,523	0	5,641	5,802
2023	5,157	5,157	143	1,471	0	5,138	5,273
2024	4,724	4,724	140	1,421	0	4,701	4,815
2025	4,339	4,339	138	1,372	0	4,320	4,415
2026	4,000	4,000	135	1,324	0	3,990	4,068
2027	3,705	3,705	132	1,278	0	3,707	3,771
2028	3,450	3,450	129	1,236	0	3,466	3,518
2029	3,228	3,228	127	1,196	0	3,260	3,303
2030	3,049	3,049	124	1,160	0	3,096	3,130
2031	2,893	2,893	122	1,127	0	2,953	2,981
2032	2,766	2,766	120	1,098	0	2,843	2,865

Table 20. Non-target catch in the directed flathead sole fishery as a proportion of total non-target catch of each species in the BSAI by weight. Conditional highlighting from white (lowest numbers) to green (highest numbers) is applied. “NA” indicates that no catch of the species occurred in that year. No seabird bycatch was recorded.

Bycatch	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Benthic urochordata	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bivalves	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Brittle star unidentified	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Capelin	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Corals Bryozoans - Corals Bryozoans Unidentified	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000
Corals Bryozoans - Red Tree Coral	0.000	0.000	0.000	0.000	0.000	0.000	0.000	NA	0.000	NA
Deep sea smelts (bathylagidae)	0.000	NA	NA	NA	NA	NA	NA	NA	0.000	NA
Eelpouts	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eulachon	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Giant Grenadier	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Greenlings	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Grenadier - Pacific Grenadier	0.000	NA	NA	NA	NA	NA	NA	NA	NA	0.000
Grenadier - Rattail Grenadier Unidentified	0.000	0.001	0.000	0.431	0.000	0.000	0.000	0.000	0.000	0.000
Gunnels	NA	NA	0.000	0.000	NA	0.000	NA	0.000	NA	NA
Hermit crab unidentified	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Invertebrate unidentified	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000
Lanternfishes (myctophidae)	0.000	NA	0.000	0.000	1.000	0.075	0.000	0.000	0.000	0.000
Misc crabs	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Misc crustaceans	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Misc deep fish	NA	NA	NA	0.000	NA	NA	0.000	0.000	NA	0.000
Misc fish	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Misc inverts (worms etc)	0.000	0.000	NA	NA	0.000	0.000	0.000	NA	0.000	NA
Other osmerids	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pacific Hake	NA	NA	NA	NA	NA	0.000	0.000	0.000	0.000	NA
Pacific Sand lance	0.000	0.000	0.000	0.000	0.000	NA	0.000	0.000	0.000	NA
Pacific Sandfish	0.000	NA	0.000	0.000	0.000	0.000	NA	NA	NA	0.000
Pandalid shrimp	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Polychaete unidentified	0.000	0.000	NA	0.000	NA	0.000	0.000	0.000	0.000	0.000
Scypho jellies	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sea anemone unidentified	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sea pens whips	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Sea star	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Snails	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sponge unidentified	0.000	0.000	0.000	0.000	0.003	0.019	0.000	0.000	0.000	0.000
Squid	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.000
State-managed Rockfish	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stichaeidae	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Surf smelt	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
urchins dollars cucumbers	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Figures

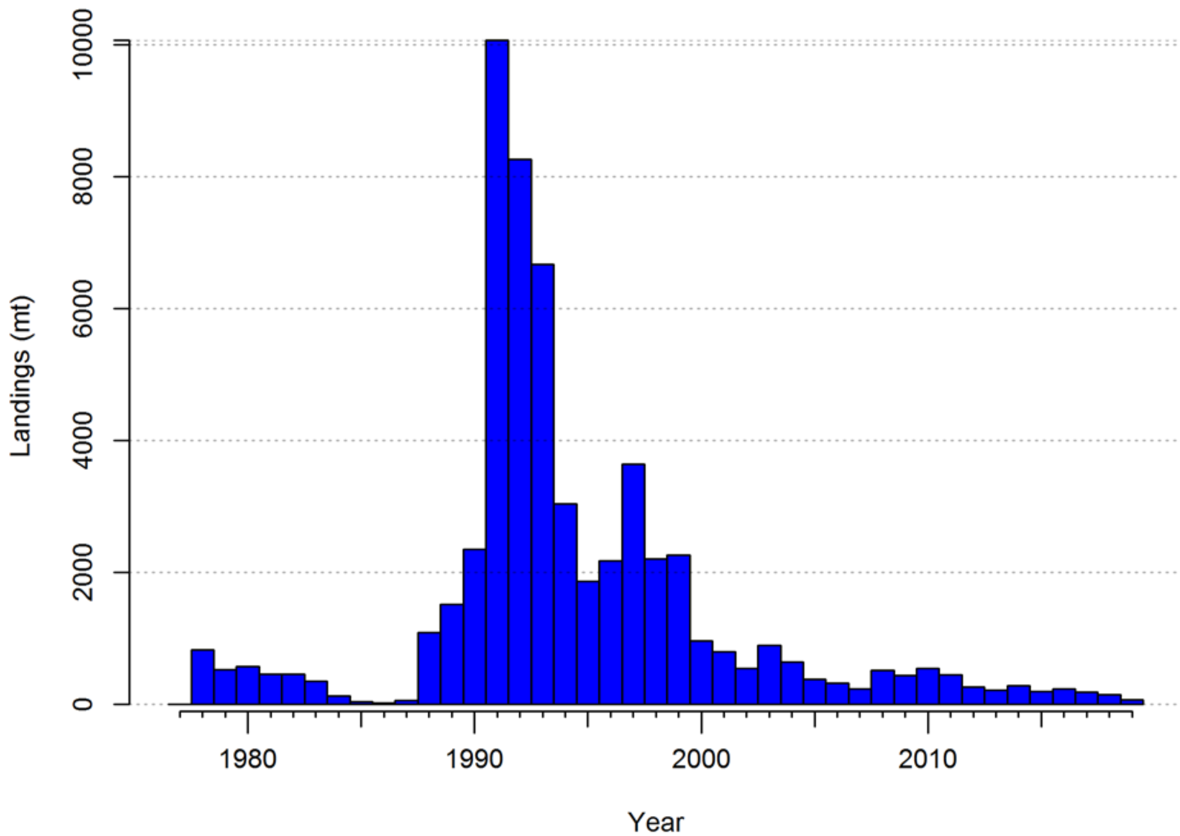

Figure 1. Catch biomass of Dover sole in metric tons 1978-2019 (as of October 19, 2019).

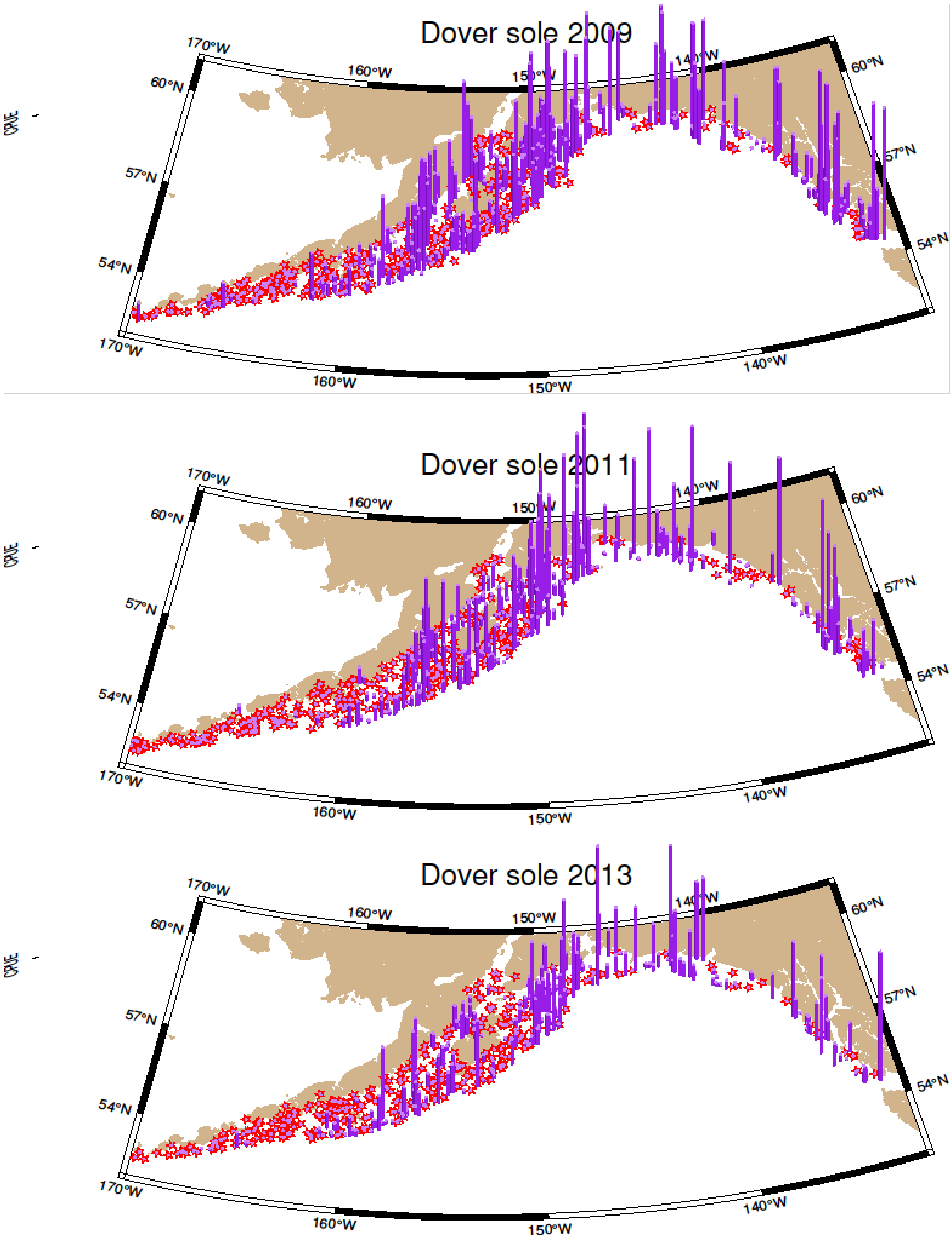

Figure 2. Maps of survey catch-per-unit-effort (CPUE) from the 2011, 2013, and 2015 GOA Groundfish Trawl Survey (1 of 2).

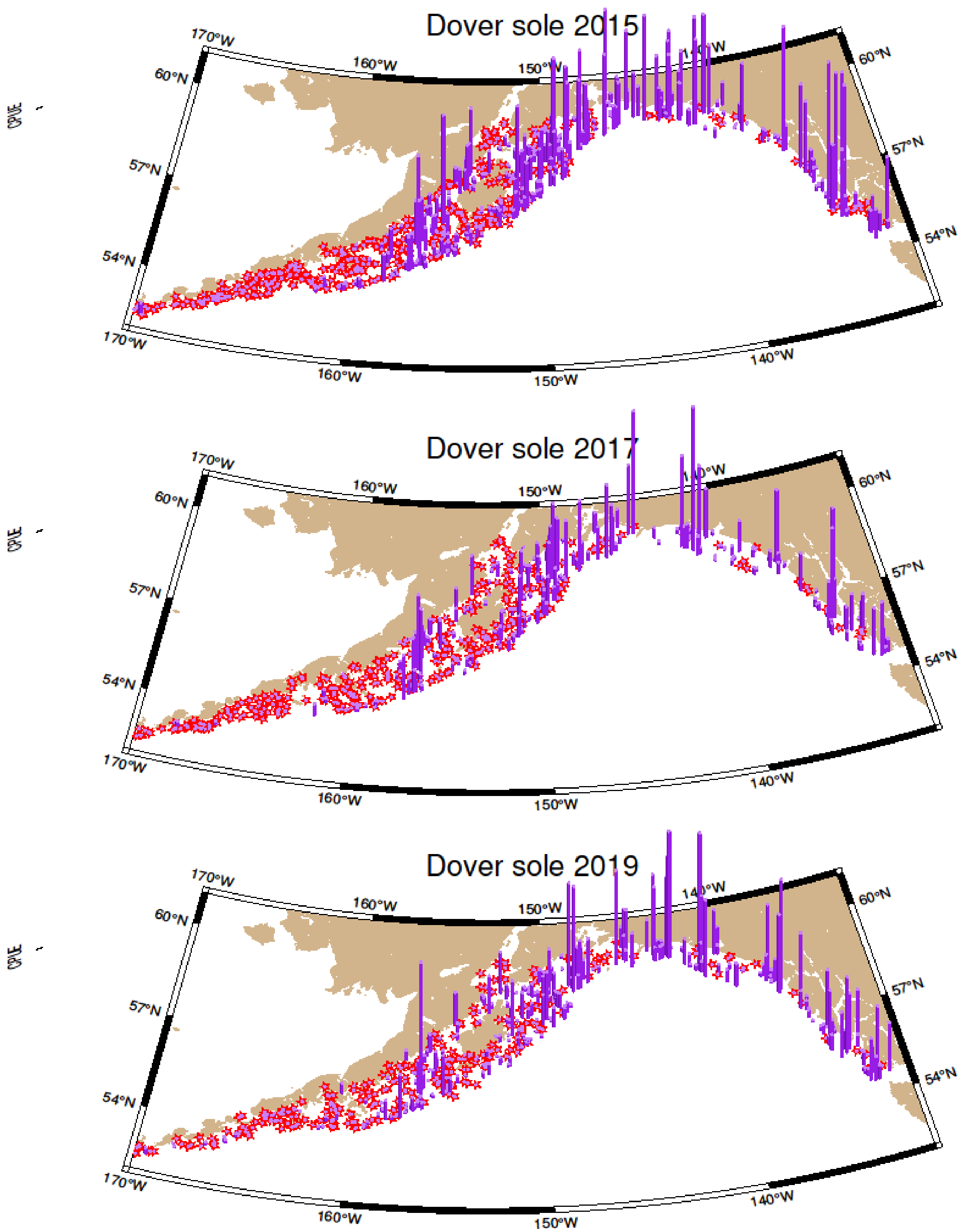

Figure 3. Maps of survey catch-per-unit-effort (CPUE) from the 2011, 2013, and 2015 GOA Groundfish Trawl Survey (2 of 2).

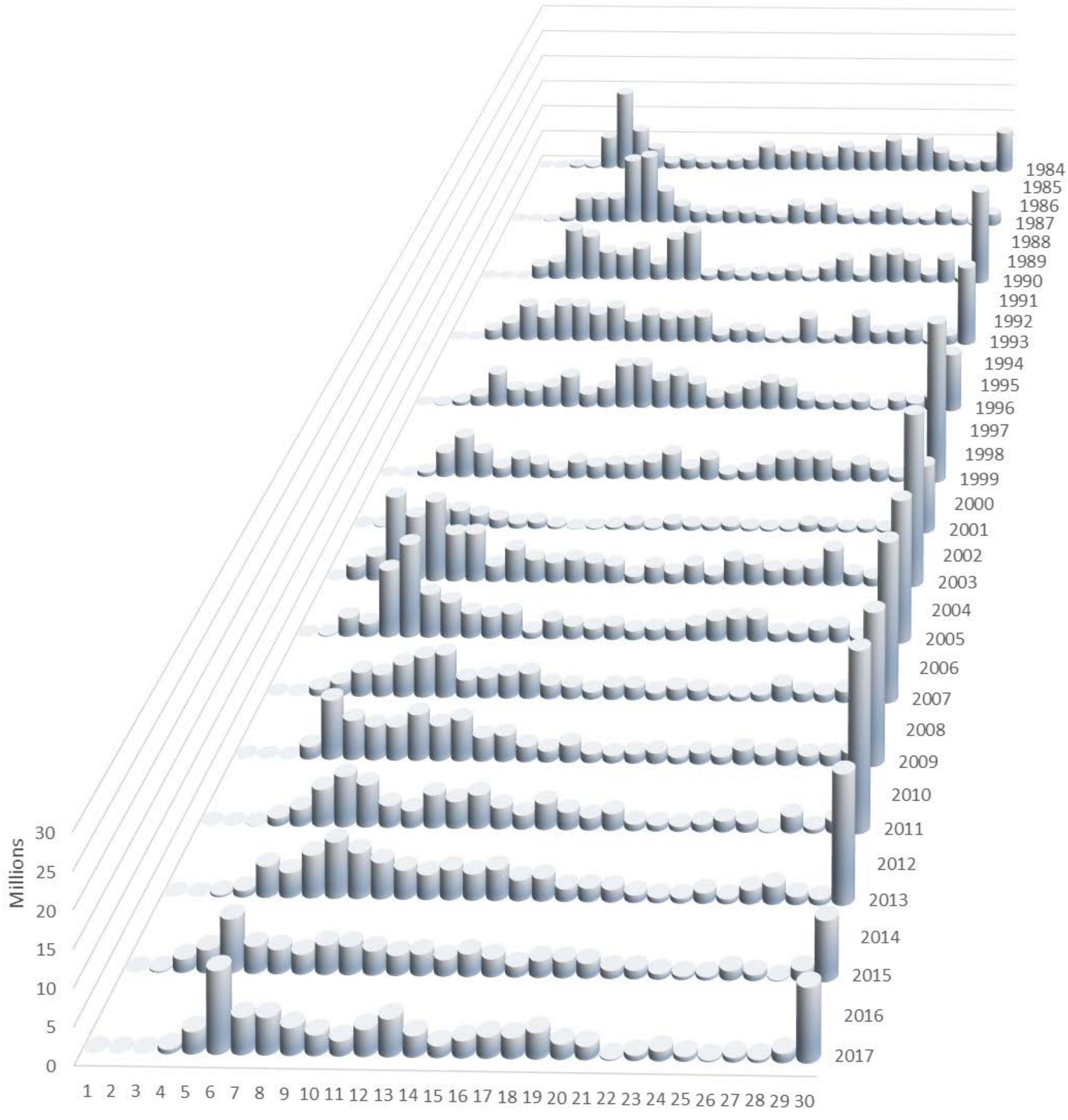

Figure 4. Yearly age composition of GOA Dover sole aggregated over sex in the GOA bottom trawl survey.

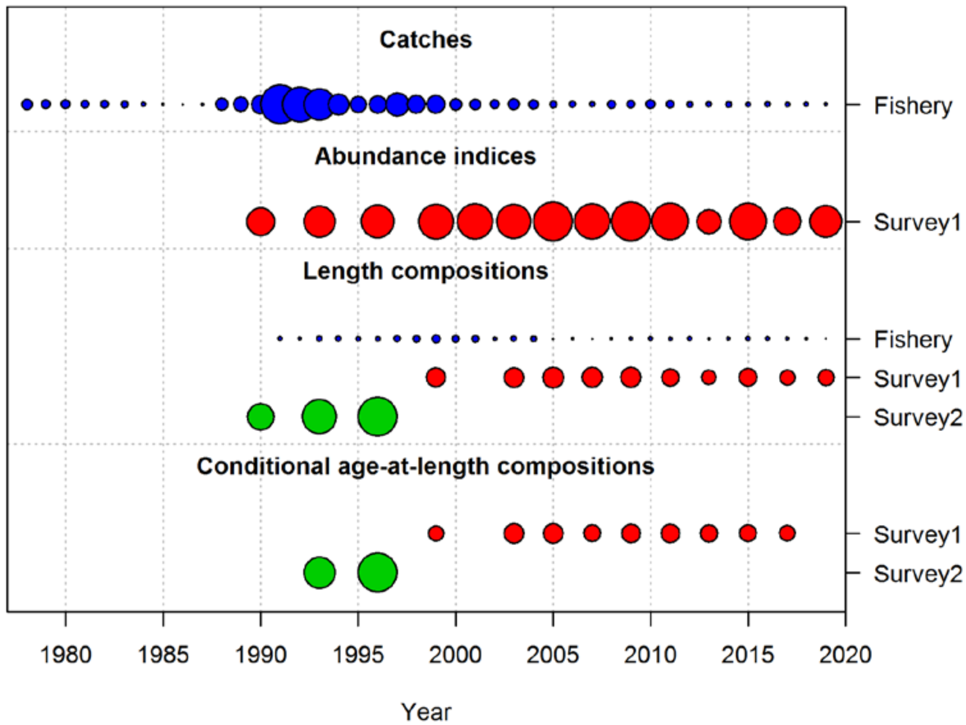

Figure 5. Sources and years of data used in the assessment. "Survey 1" indicates the years in which all depths (0m to >500m) were sampled: the full-coverage survey and "Survey2" indicates the years in which only 0-500m depths were sampled: the shallow-coverage survey. Size of circle for catches indicates 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.

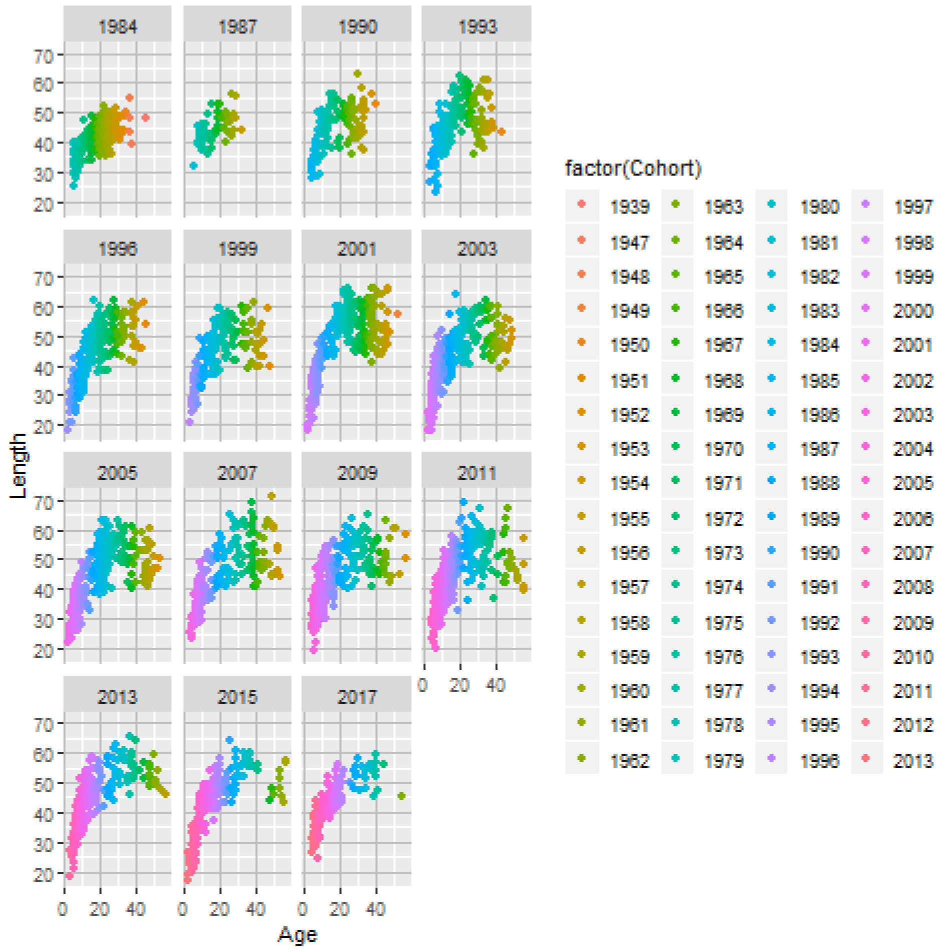

Figure 6. Length-age data for female GOA Dover sole by year and cohort from the GOA bottom trawl survey data.

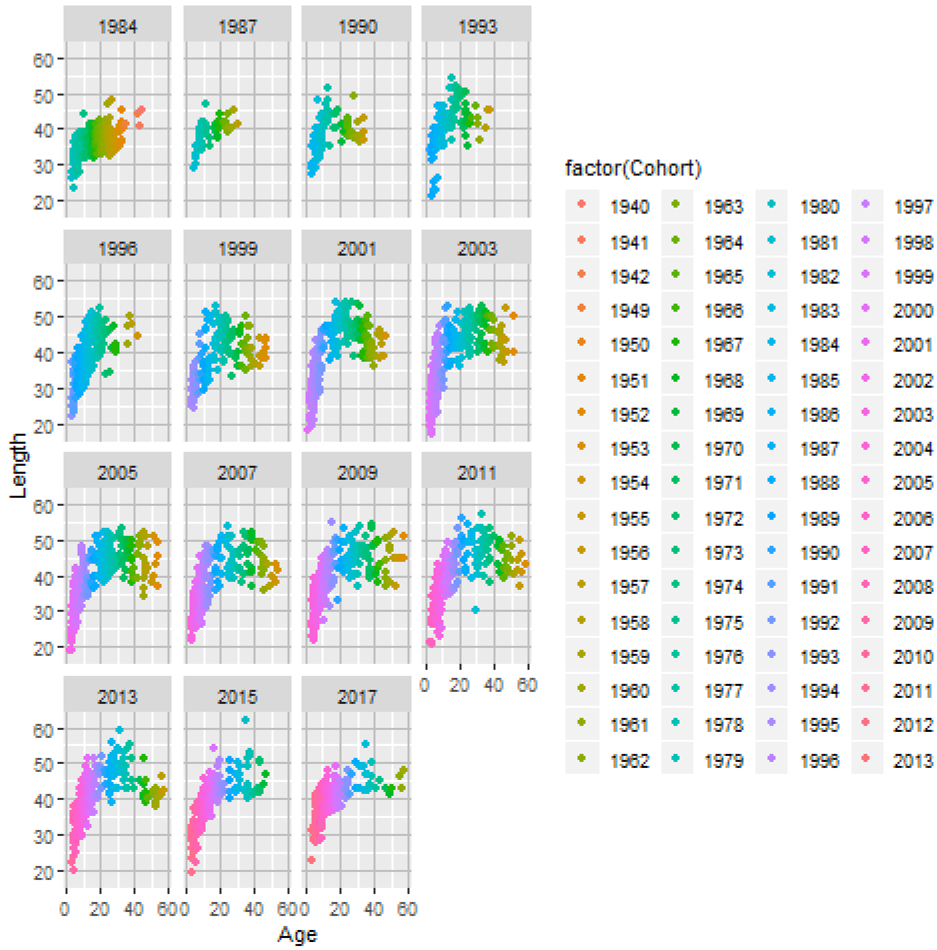

Figure 7. Length-age data for male GOA Dover sole by year and cohort from the GOA bottom trawl survey data.

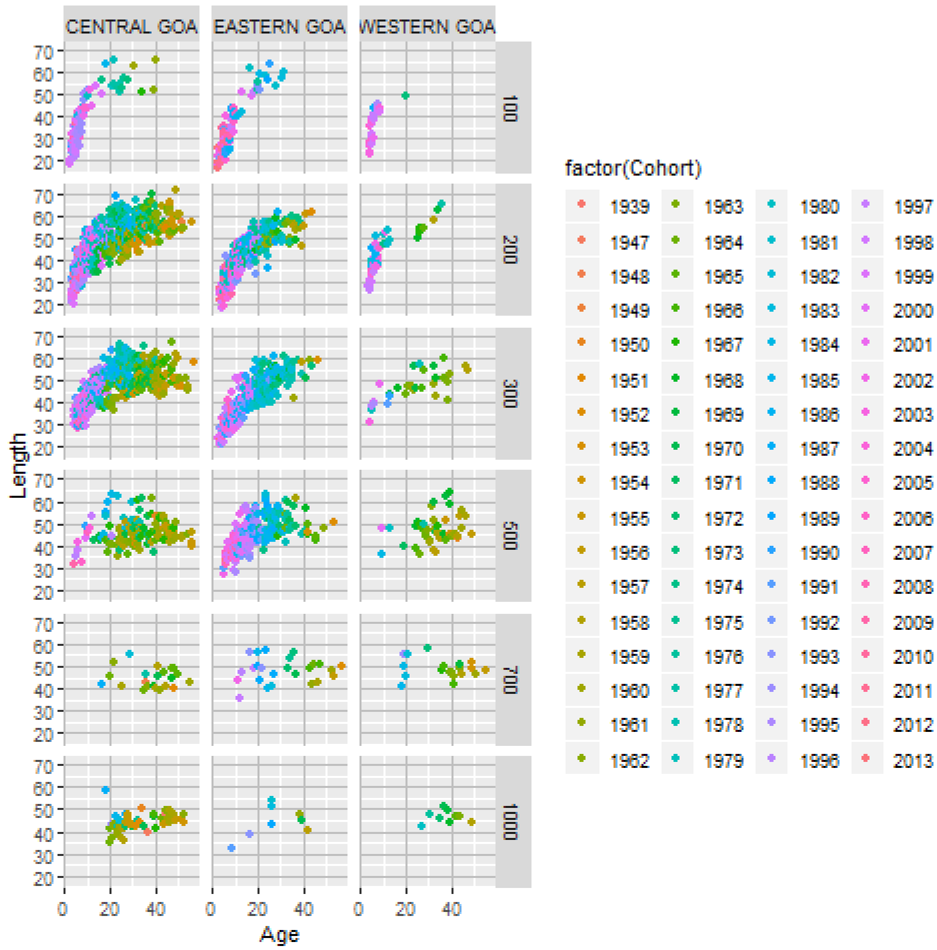

Figure 8. Length-age data for female GOA Dover sole by FMP sub-area, depth and cohort from the GOA bottom trawl survey data.

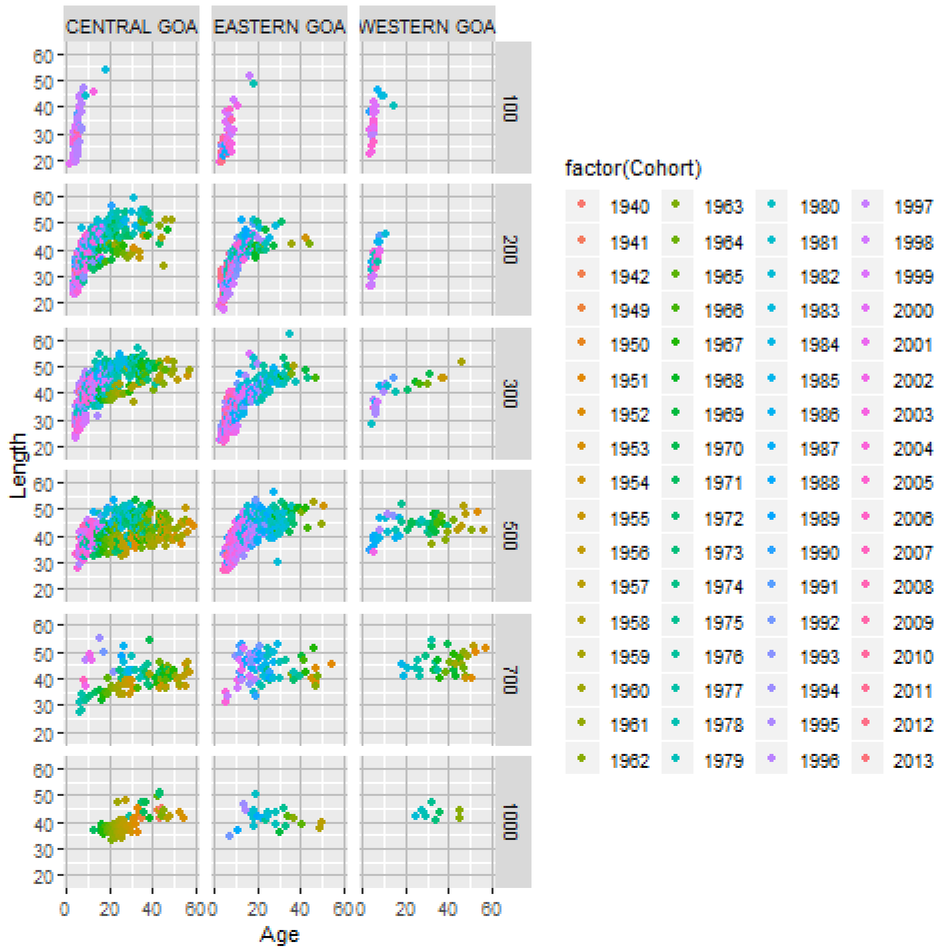

Figure 9. Length-age data for male GOA Dover sole by FMP sub-area, depth and cohort from the GOA bottom trawl survey data.

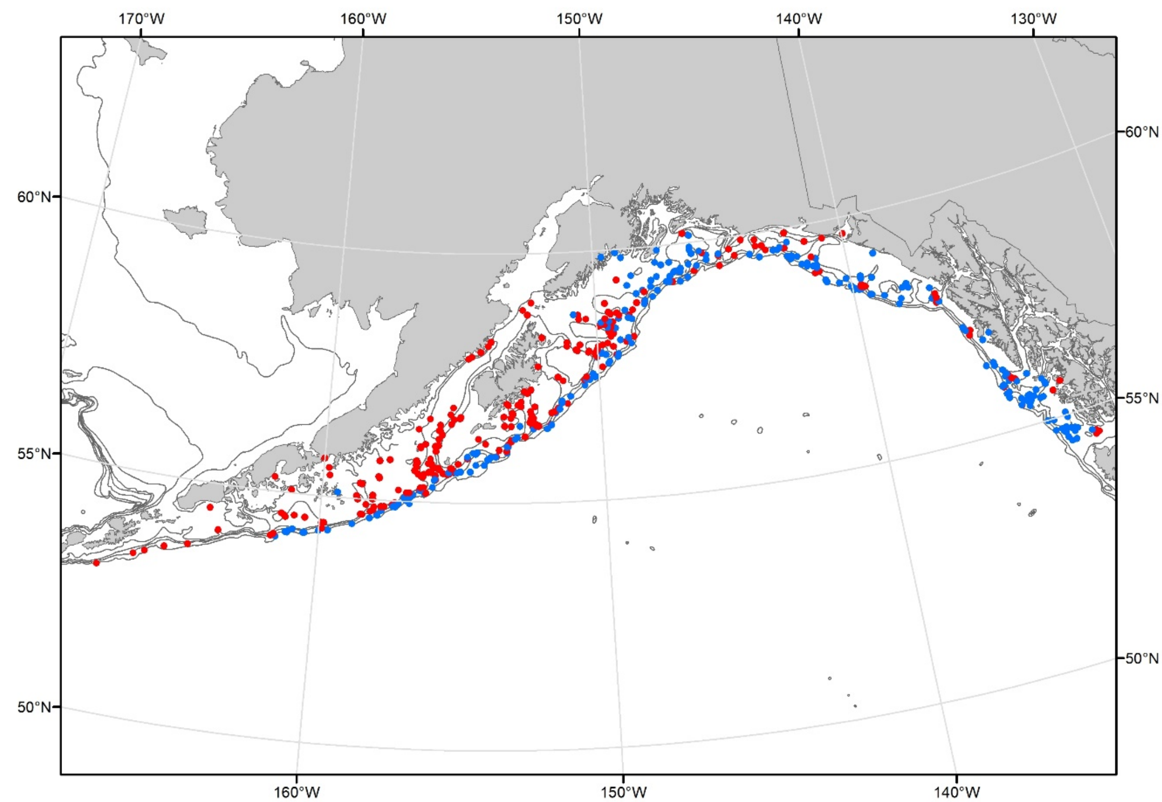

Figure 10. GOA Dover sole standardized residuals from sex-specific von-Bertalanffy growth curves fit outside the assessment model for data from 2001-2015. Residuals in red are more than one residual standard error above the mean curve and residuals in blue are more than one standard error below the mean curve (provided by Beth Matta).

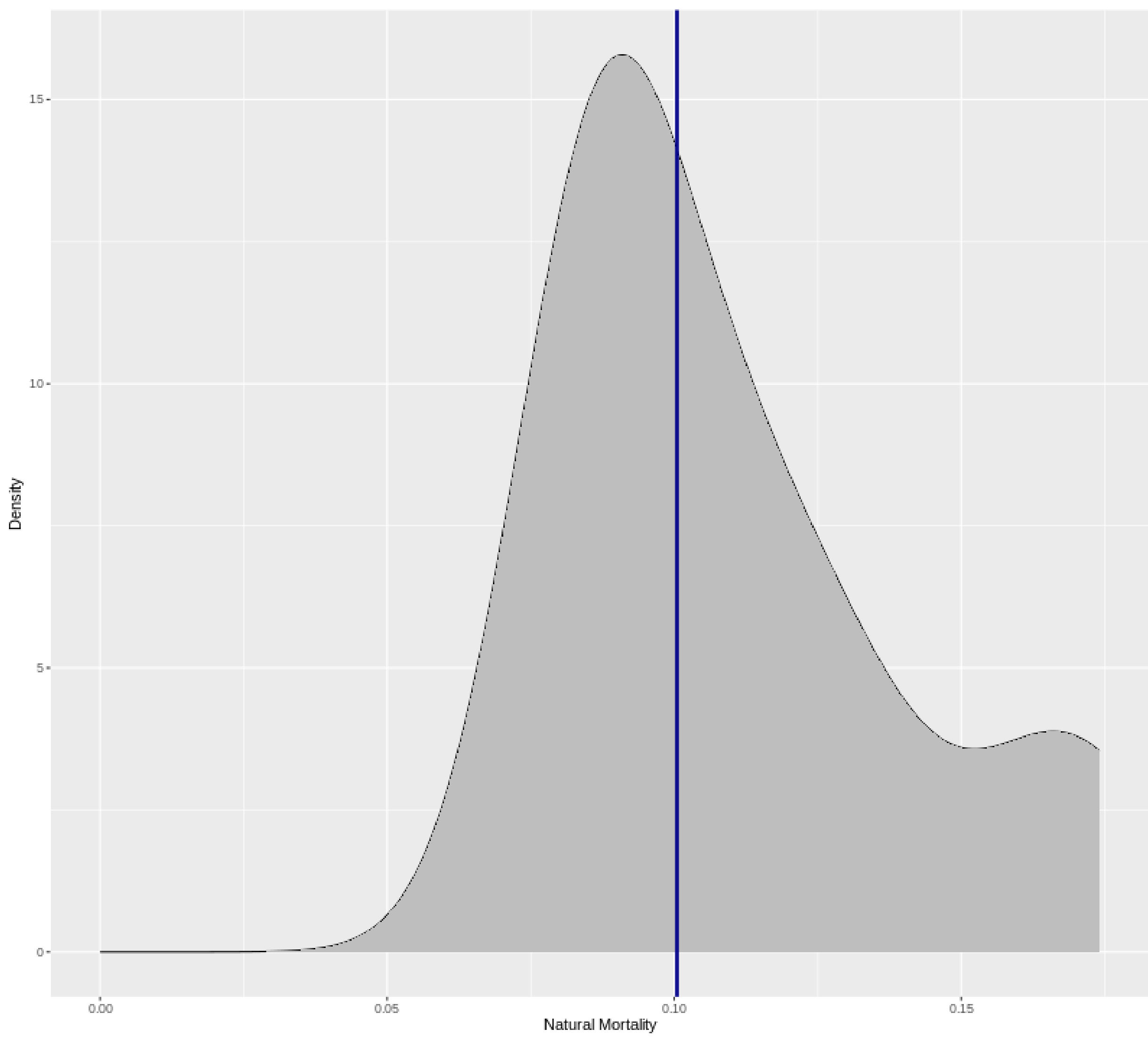

Figure 11. A composite density plot of estimates of natural mortality for Dover sole based on a weighted average of 9 empirical methods using the following tool http://barefootecologist.com.au/shiny_m.html (provided by Jason Cope). The vertical blue line is the average of the 9 methods. The value for natural mortality used in previous assessments was 0.085.

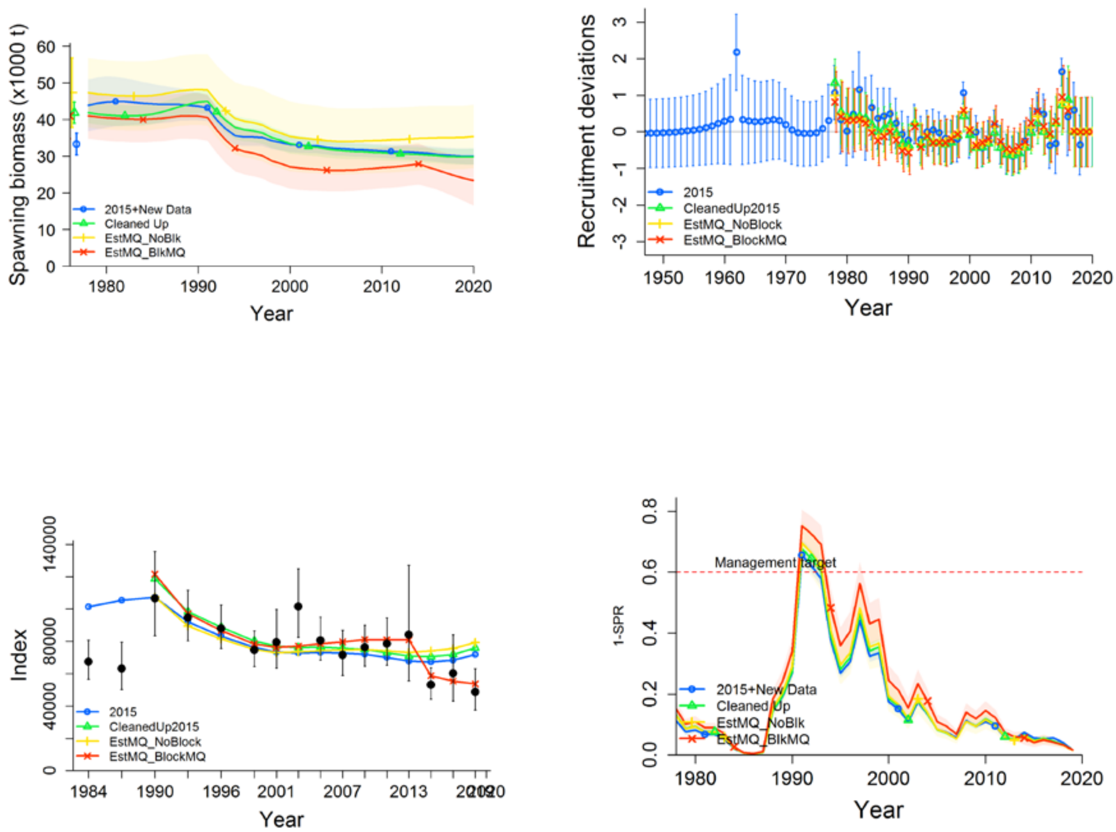

Figure 12. Spawning biomass with 95% asymptotic confidence intervals (top left panel), recruitment deviations and 95% asymptotic confidence intervals (top right panel), survey biomass index (black dots), asymptotic 95% confidence intervals (vertical black lines) and estimated survey biomass (solid lines; 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.

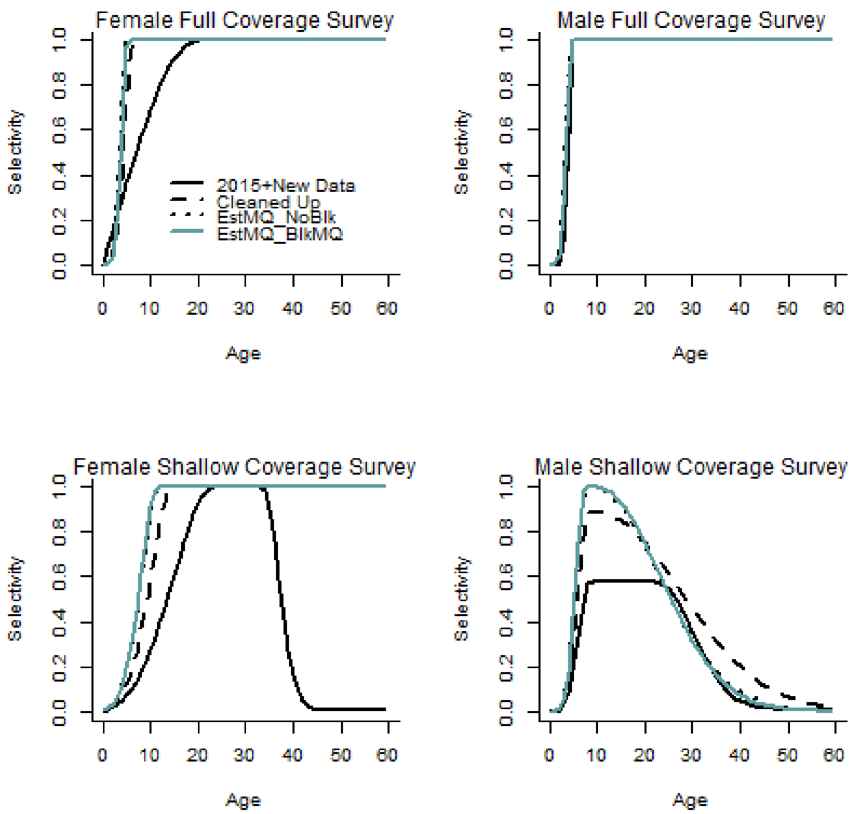

Figure 13. Selectivity-at-age for the full coverage (top panel) and shallow coverage (bottom panel) surveys and for females (left panel) and males (right panel) for the models included in the bridging analysis.

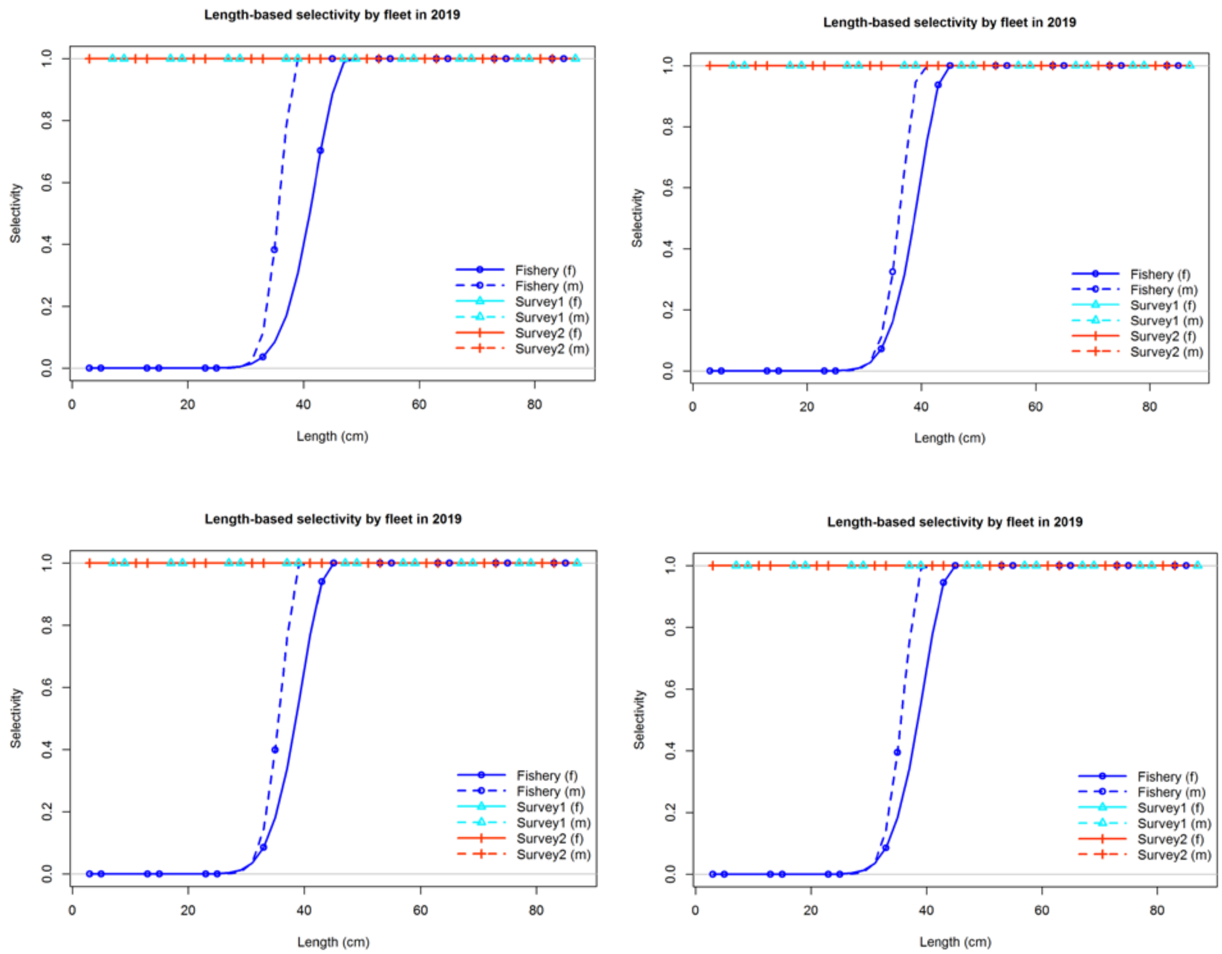

Figure 14. Length-based, sex-specific fishery selectivity for the four models in the bridging analysis: the 2015 model (top left), the “cleaned-up” model (top right), the model estimating time-invariant M and q (bottom left), and the model estimating M and q for two time blocks (bottom right).

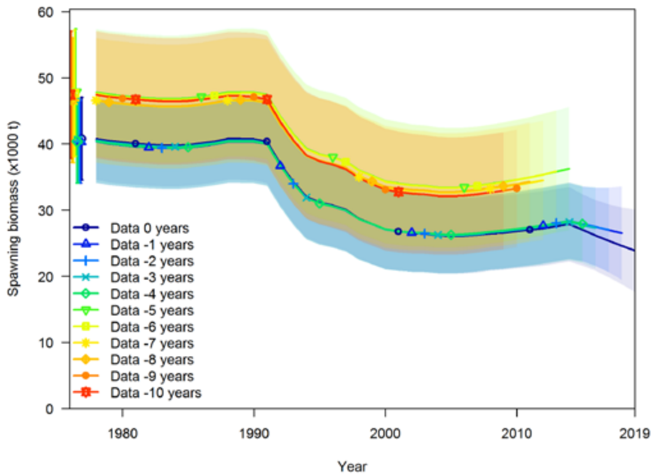

Figure 15. Spawning biomass resulting from retrospective model runs for a bridging analysis model with natural mortality and catchability both estimated separately for two periods (1978-2013 and 2014-2019). The plot shows that the model estimates that the scale of the population shifts with the addition of 2014-2019 data when there was downward shift in the survey biomass.

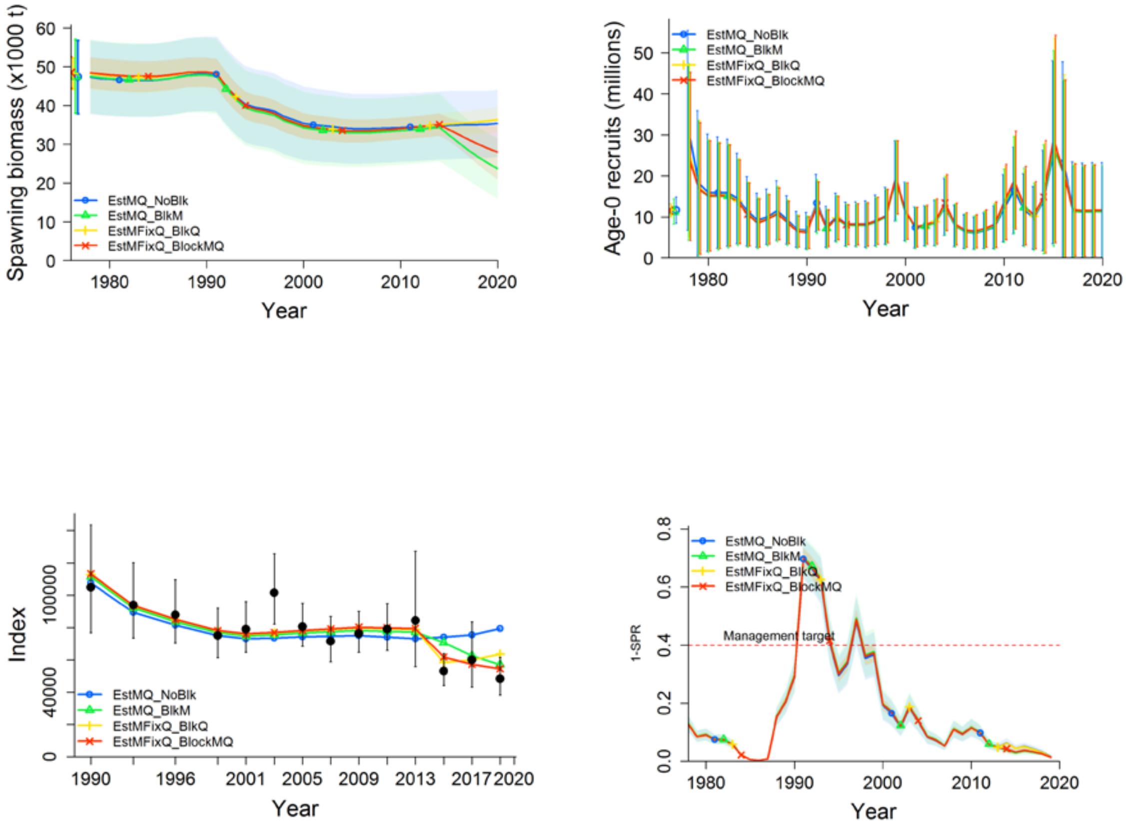

Figure 16. Spawning biomass with 95% asymptotic confidence intervals (top left panel), recruitment deviations and 95% asymptotic confidence intervals (top right panel), survey biomass index (black dots), asymptotic 95% confidence intervals (vertical black lines) and estimated survey biomass (solid lines; bottom left panel), and 1-spawning potential ratio (1-SPR; a measure of fishing intensity; bottom right panel) for the 2019 candidate models. The label “EstMQ_NoBlk” is Model 19.0, “EstMQ_BlkM” is Model 19.1, “EstMFixQ_BlkQ” is Model 19.2, and “EstMFixQ_BlockMQ” is Model 19.3.

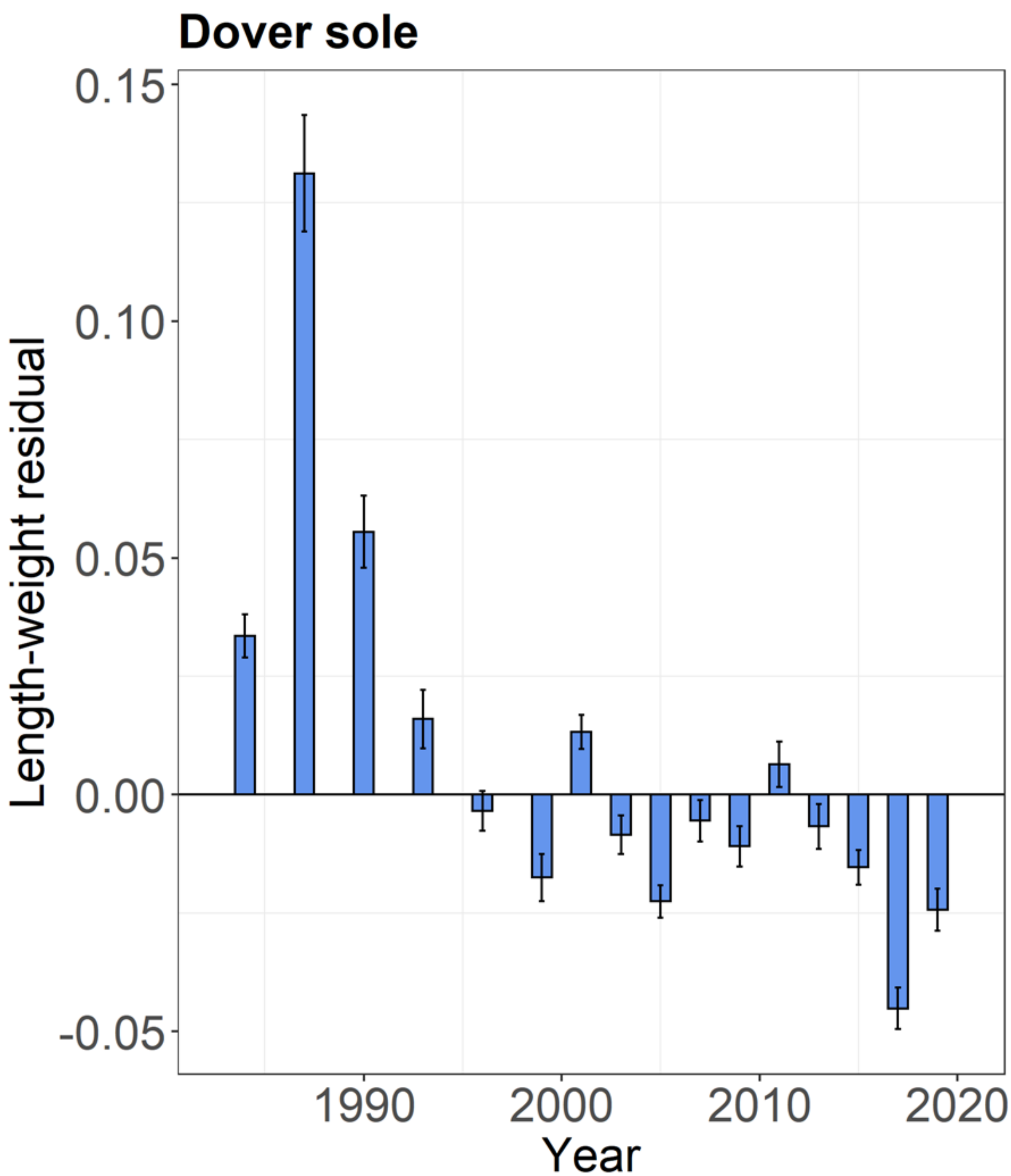

Figure 17. Yearly average length-weight residuals from a length-weight relationship fit outside of the assessment model for GOA Dover sole. Positive residuals indicate fish that are heavier per unit length and negative residuals indicate fish that are lighter than average per unit length.

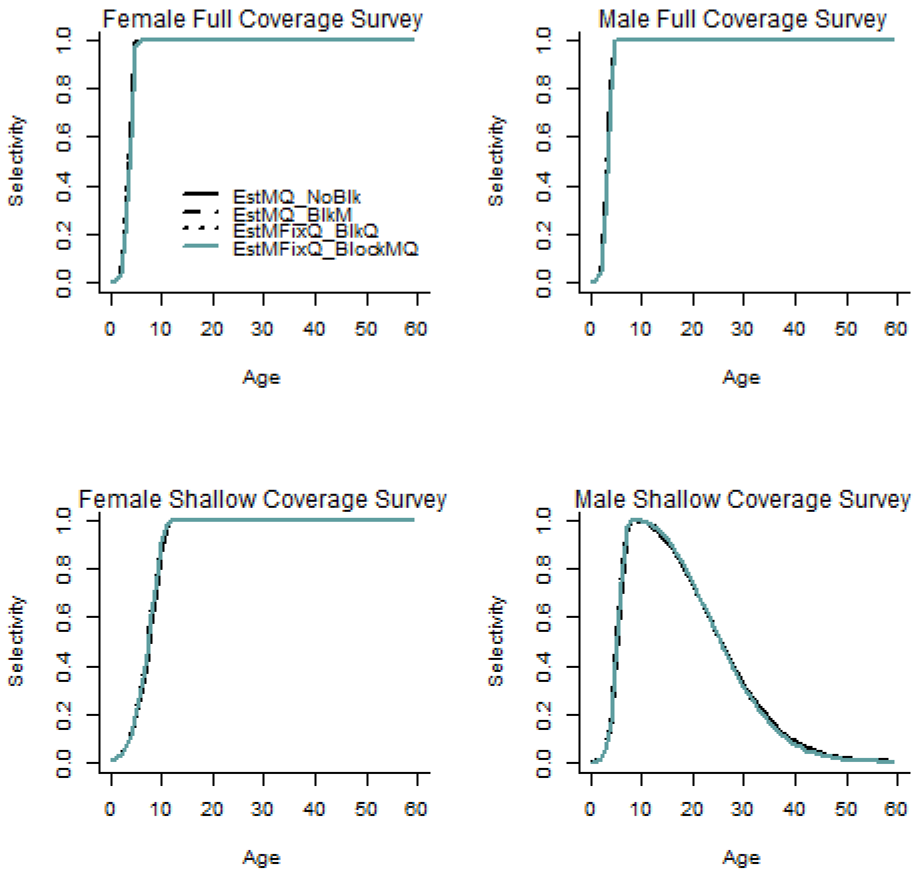

Figure 18. Selectivity-at-age for the full coverage (top panel) and shallow coverage (bottom panel) surveys and for females (left panel) and males (right panel). "EstMQ_NoBlk" is Model 19.0, "EstMQ_BlkM" is Model 19.1, "EstMFixQ_BlkQ" is Model 19.2, and "EstMFixQ_BlockMQ" is Model 19.3.

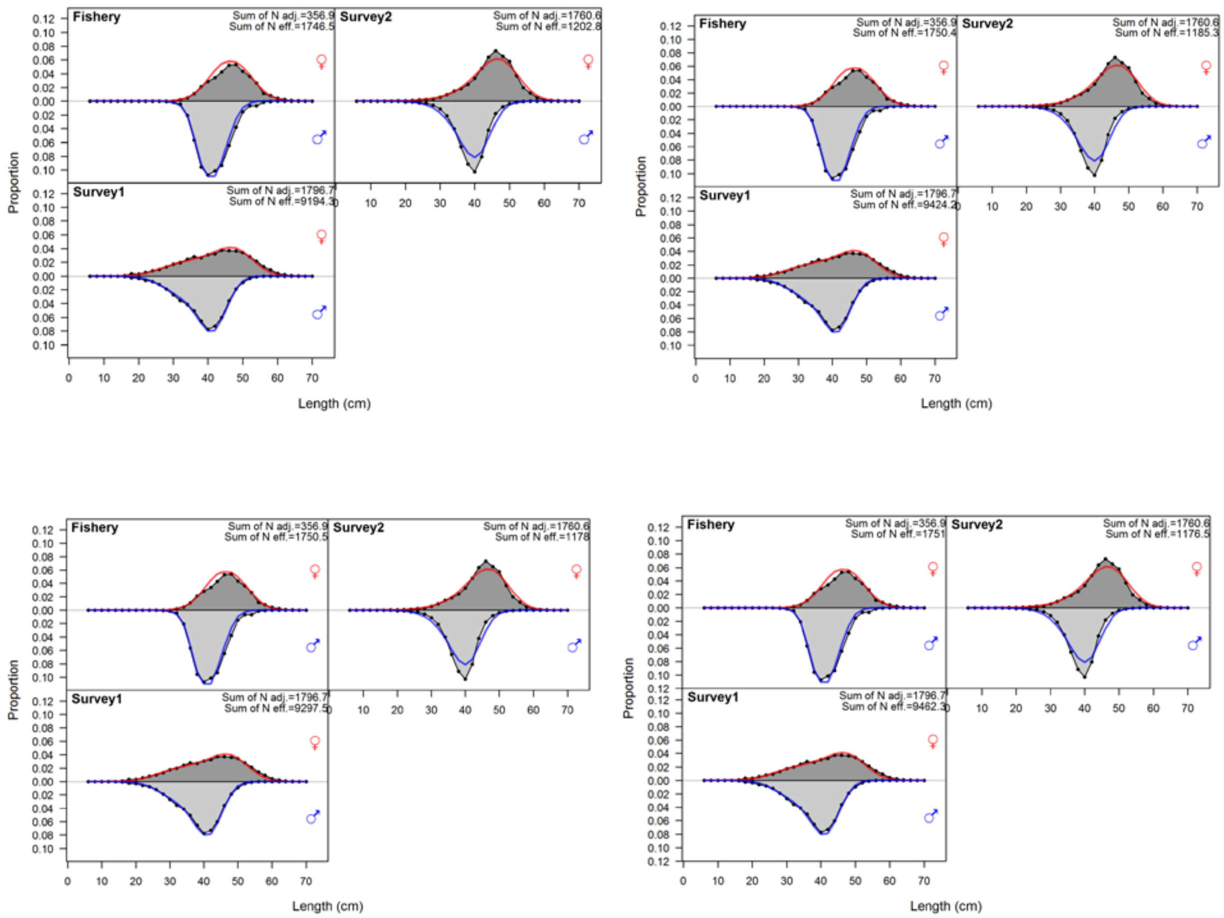

Figure 19. Observed (black lines, dots, and shaded areas) and expected (red lines) proportions-at-length, aggregated over years for the fishery, the full coverage survey, and the shallow coverage survey for Model 19.0 (top left), Model 19.1 (top right), Model 19.2 (bottom left), and Model 19.3 (bottom right).

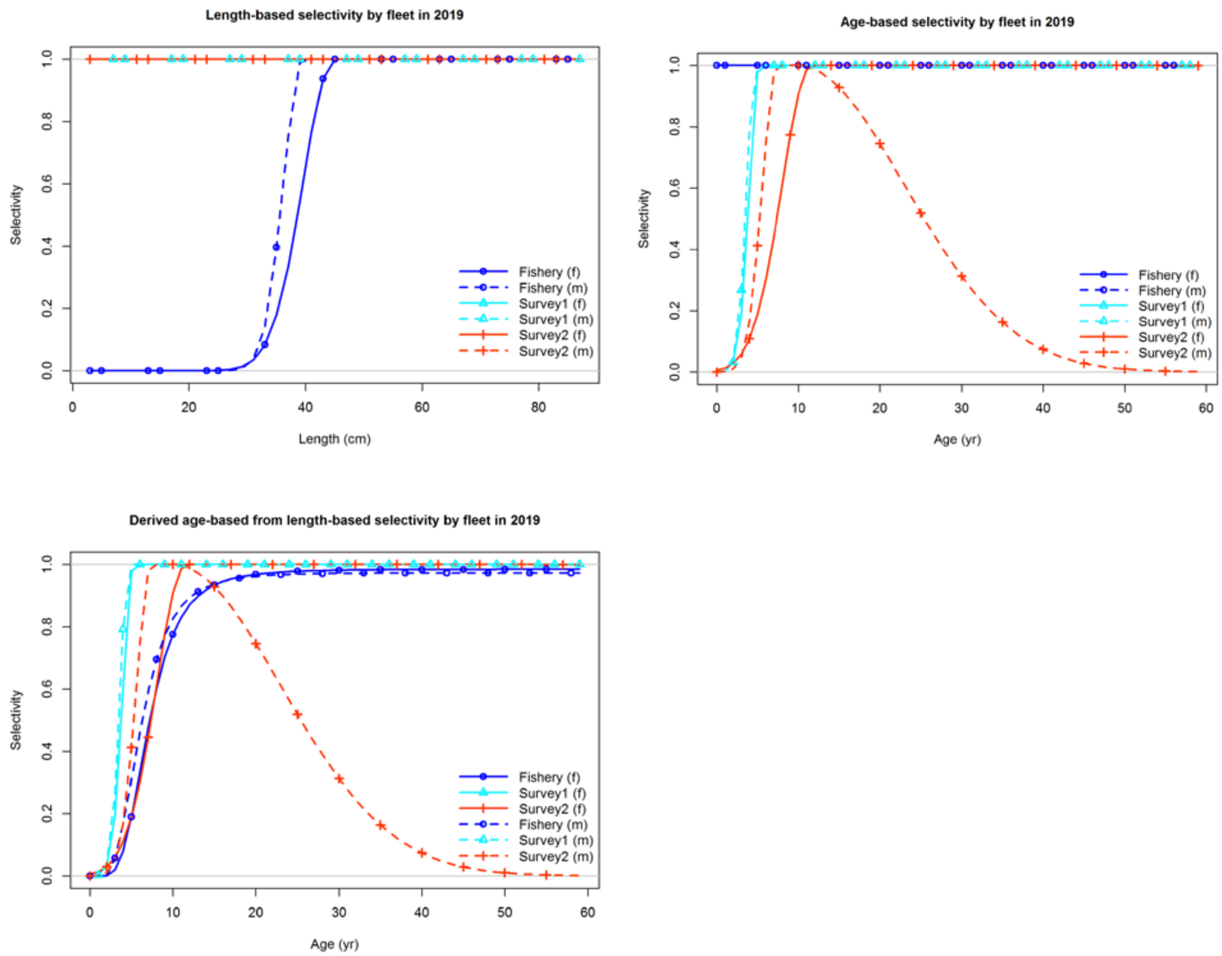

Figure 20. Length-based fishery selectivity (top left panel), age-based survey selectivity for the full-coverage (Survey1) and shallow-coverage (Survey2) surveys (top right panel), and derived age-based selectivity for the fishery and both surveys (bottom right) for Model 19.3 (the author's preferred model). The letter "f" refers to female selectivity and "m" refers to male selectivity.

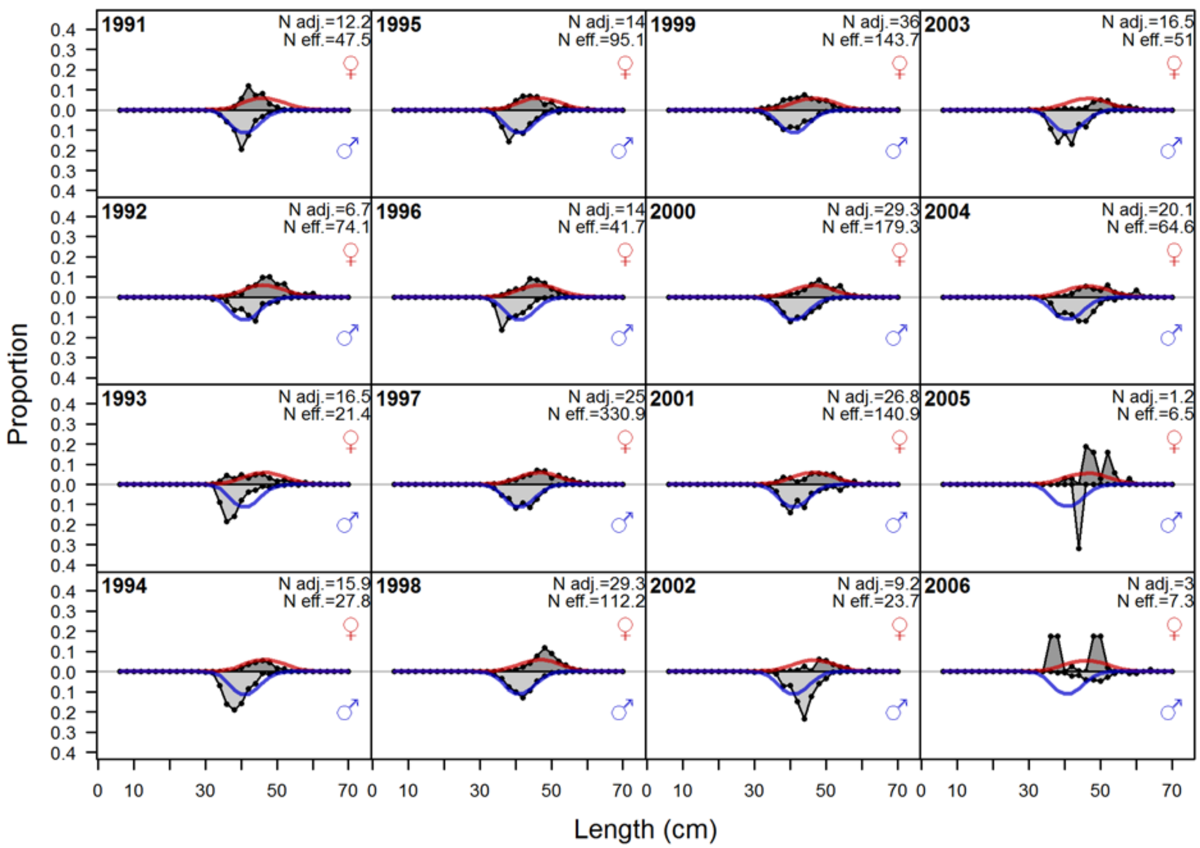

Figure 21. Observed (black lines, dots, and shaded areas) and expected (red and blue lines) yearly fishery proportions-at-length for the current base case model for years 1991-2006 for Model 19.3 (the author's preferred model). Females are plotted above the x-axis; males are plotted below the x-axis.

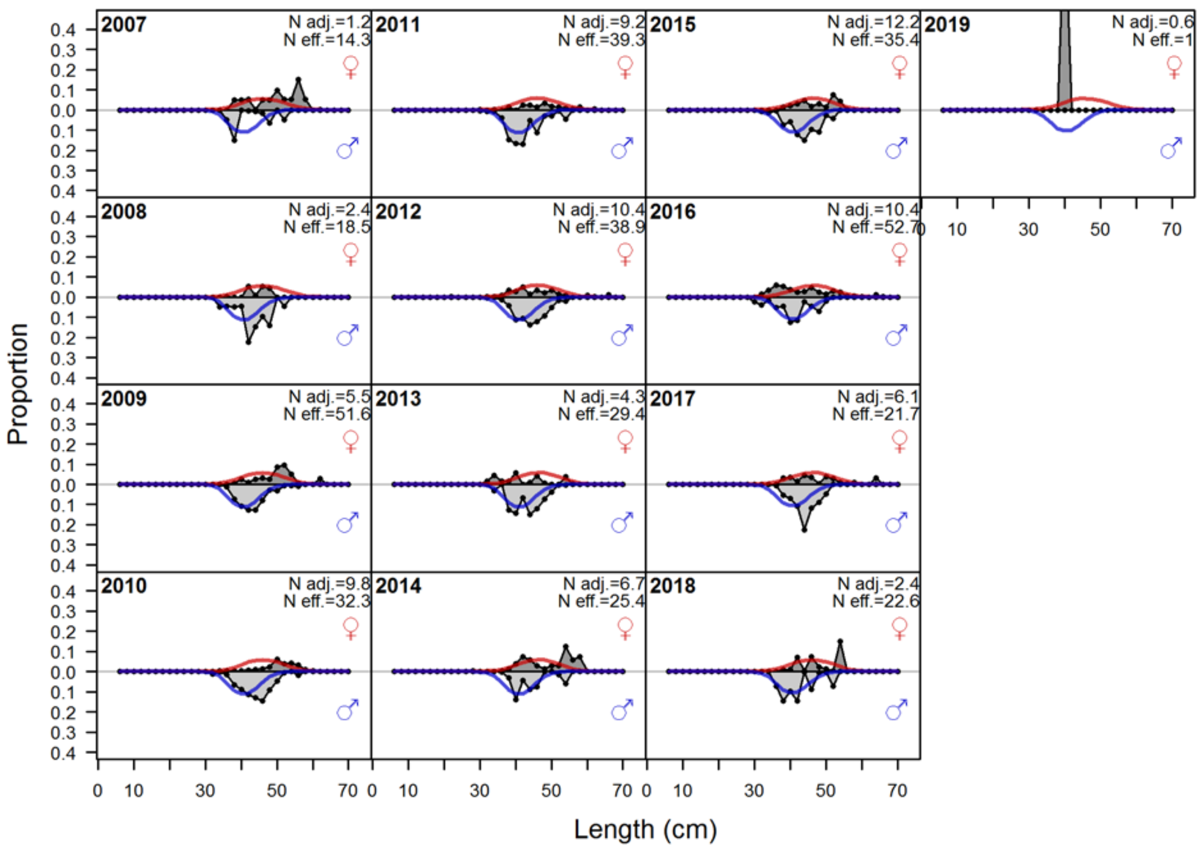

Figure 22. Observed (black lines, dots, and shaded areas) and expected (red and blue lines) yearly fishery proportions-at-length for Model 19.3 (the author's preferred model) for years 2007-2019. Females are plotted above the x-axis; males are plotted below the x-axis.

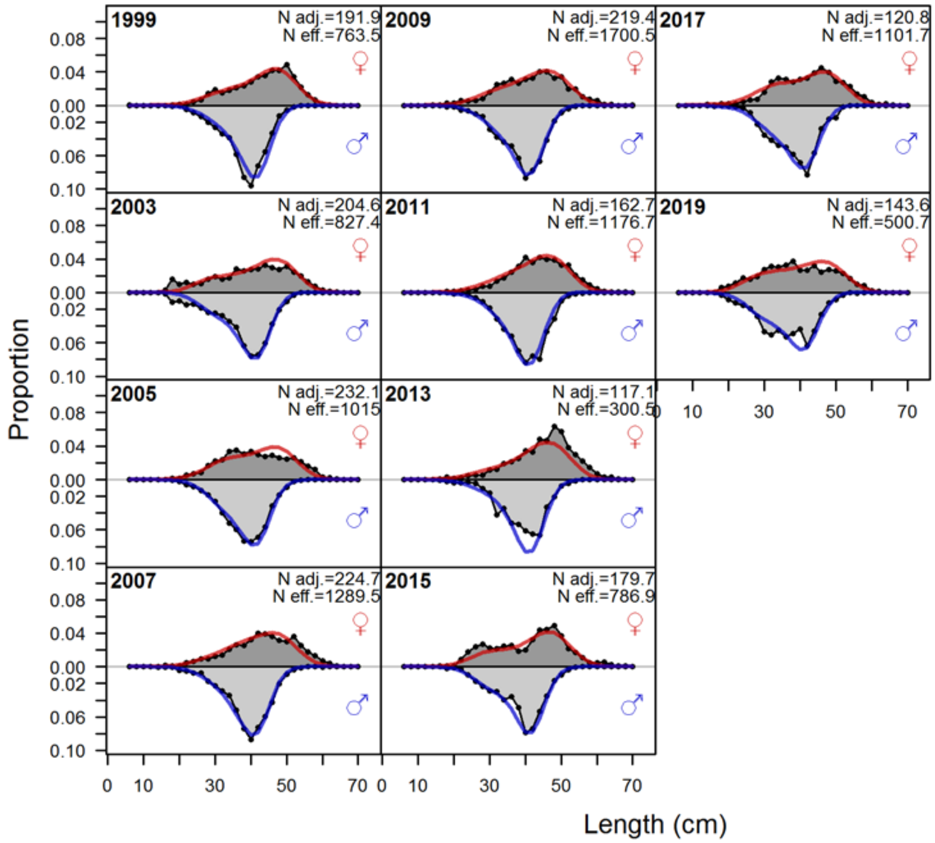

Figure 23. Observed (black lines, dots, and shaded areas) and expected (red and blue lines) yearly full-coverage survey proportions-at-length for Model 19.3 (the author's preferred model) for years 1999-2019. Females are plotted above the x-axis; males are plotted below the x-axis.

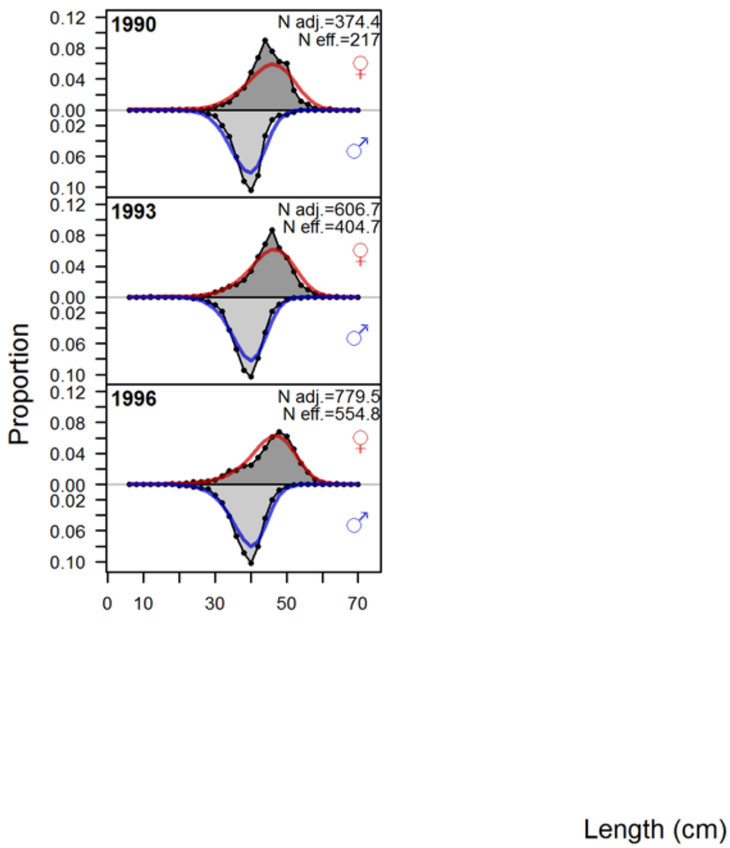

Figure 24. Observed (black lines, dots, and shaded areas) and expected (red and blue lines) yearly shallow-coverage survey proportions-at-length for Model 19.3 (the author's preferred model) for years 1990-1996. Females are plotted above the x-axis; males are plotted below the x-axis.

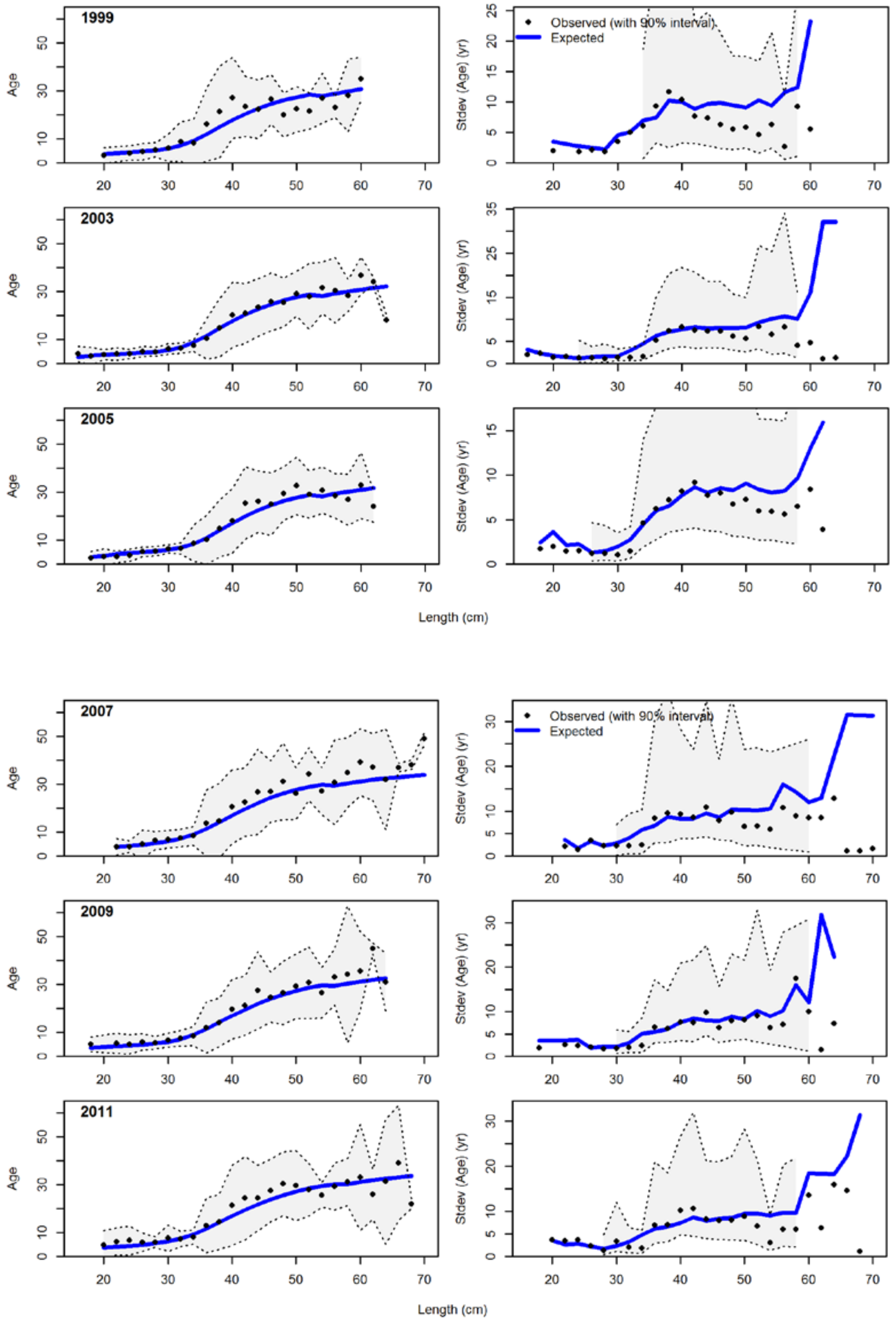

Figure 25. Observed and expected mean age-at-length for males and females combined with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the full coverage survey for Model 19.3 (the author's preferred model; 1 of 2).

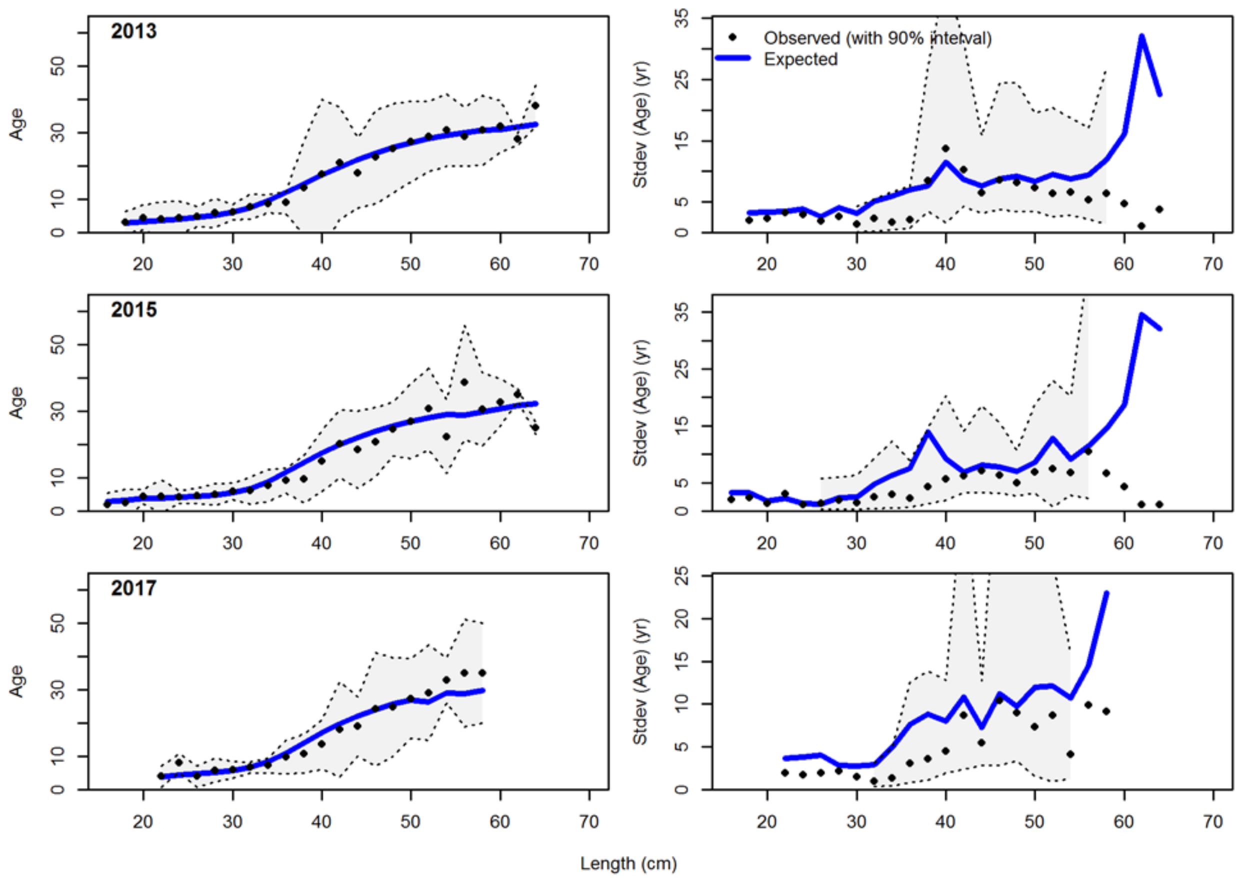

Figure 26. Observed and expected mean age-at-length for males and females combined with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the full coverage survey for Model 19.3 (the author's preferred model; 2 of 2).

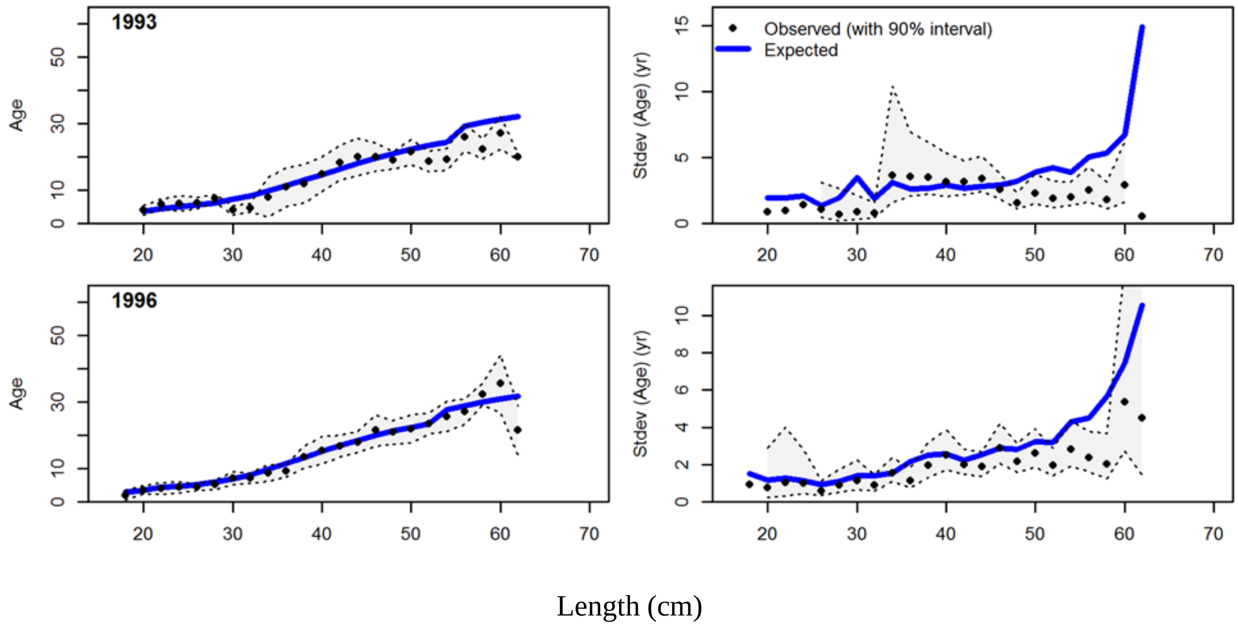

Figure 27. Observed and expected mean age-at-length for males and females combined with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the shallow coverage survey for Model 19.3 (the author's preferred model; 1 of 1).

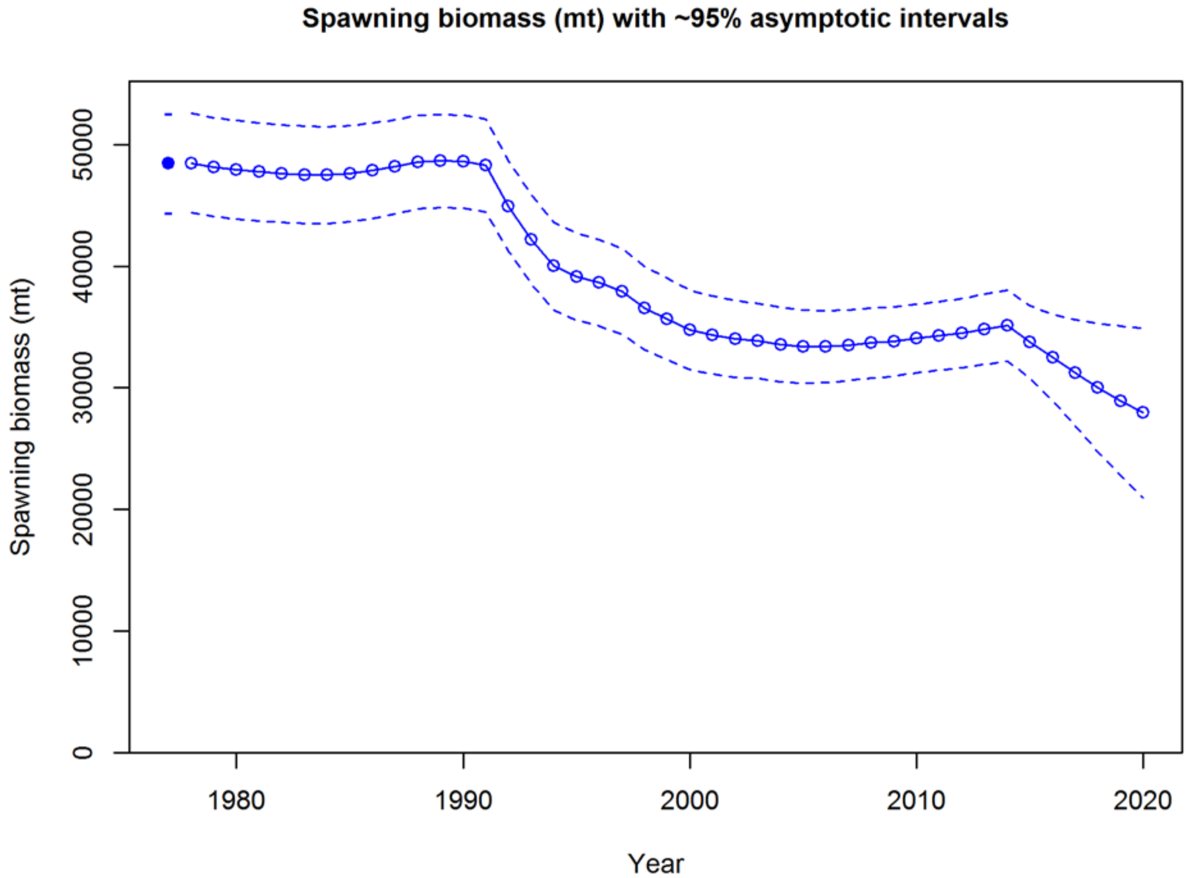

Figure 28. Time series of estimated spawning stock biomass (mt) over time (solid blue line and circles) and asymptotic 95% confidence intervals (blue dashed lines) for Model 19.3.

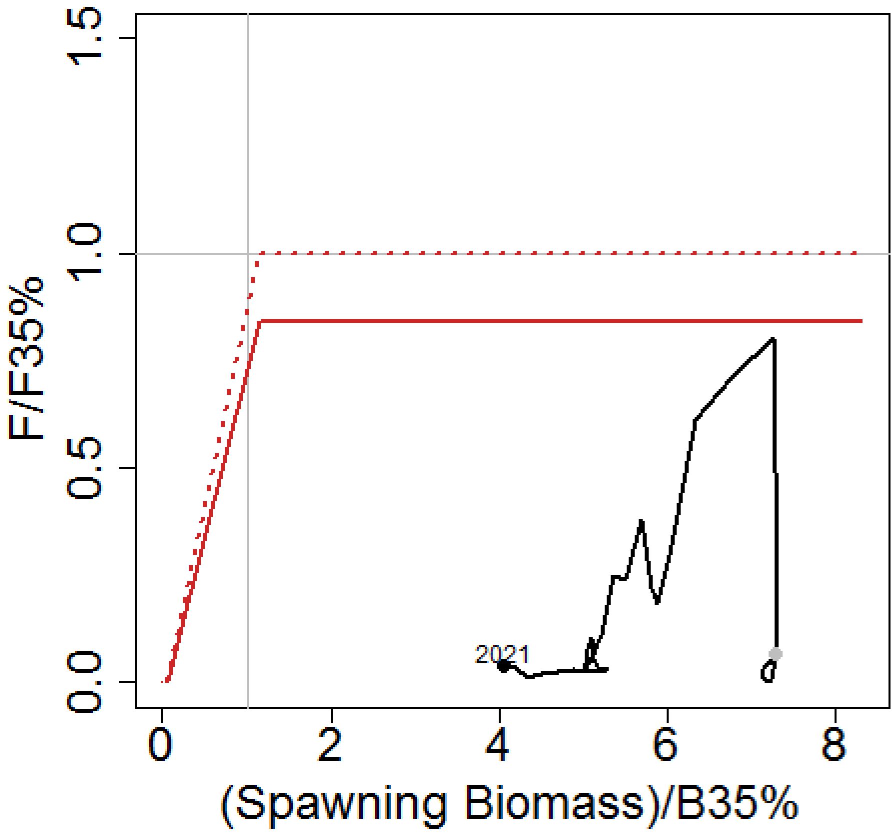

Figure 29. Spawning stock biomass relative to $B_{35\%}$ and fishing mortality (F) relative to $F_{35\%}$ from 1978-2021 (solid black line), the OFL control rule (dotted red line), the maxABC control rule (solid red line), $B_{35\%}$ (vertical grey line), and $F_{35\%}$ (horizontal grey line). Projected biomass for 2020 and 2021 are included. $B_{35\%}$ and $F_{35\%}$ are calculated using population dynamics corresponding to the most recent period (2014-2019) in Model 19.3 (the author's preferred model).

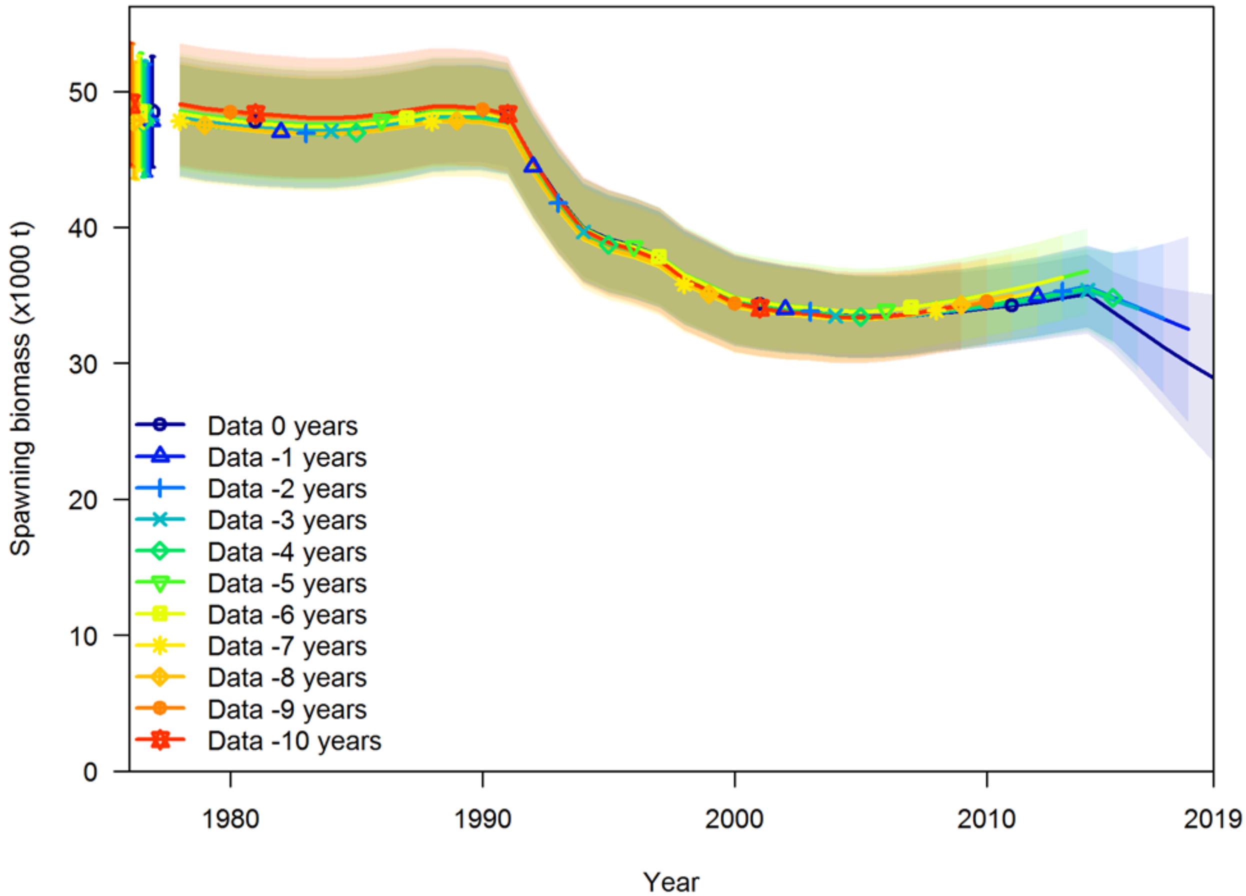

Figure 30. Spawning stock biomass and corresponding 95% asymptotic confidence intervals for base case model runs excluding 0 to 10 years of the most recent data for Model 19.3 (the author's preferred model). Each model assumes that recruitment deviations are 0 for years where data are excluded.

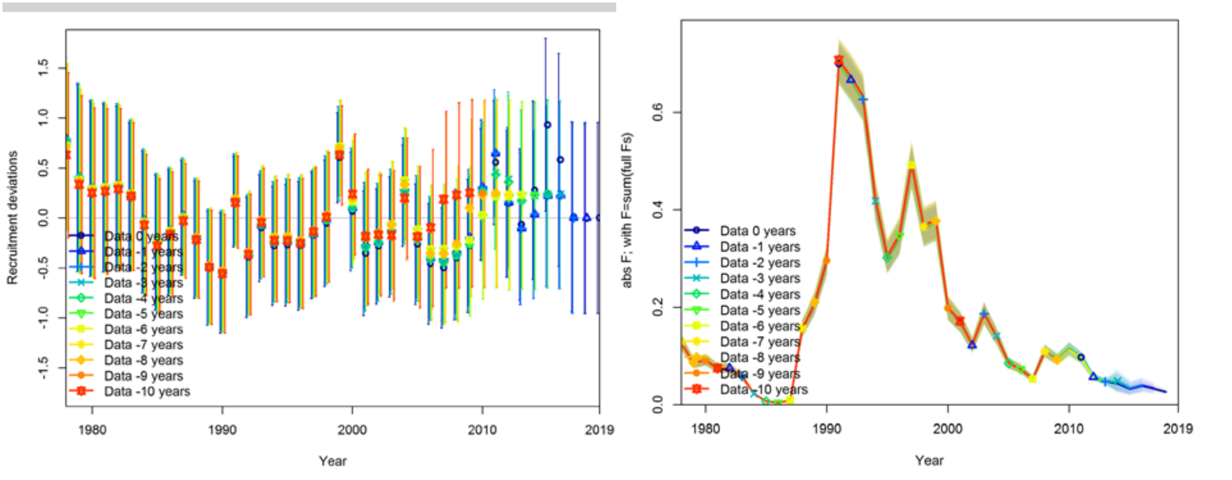

Figure 31. Recruitment deviations with corresponding 95% asymptotic confidence intervals (left panel) and fishing intensity (1-spawning potential ratio; right panel) for Model 19.3 retrospective model runs excluding 0 to 10 years of data.

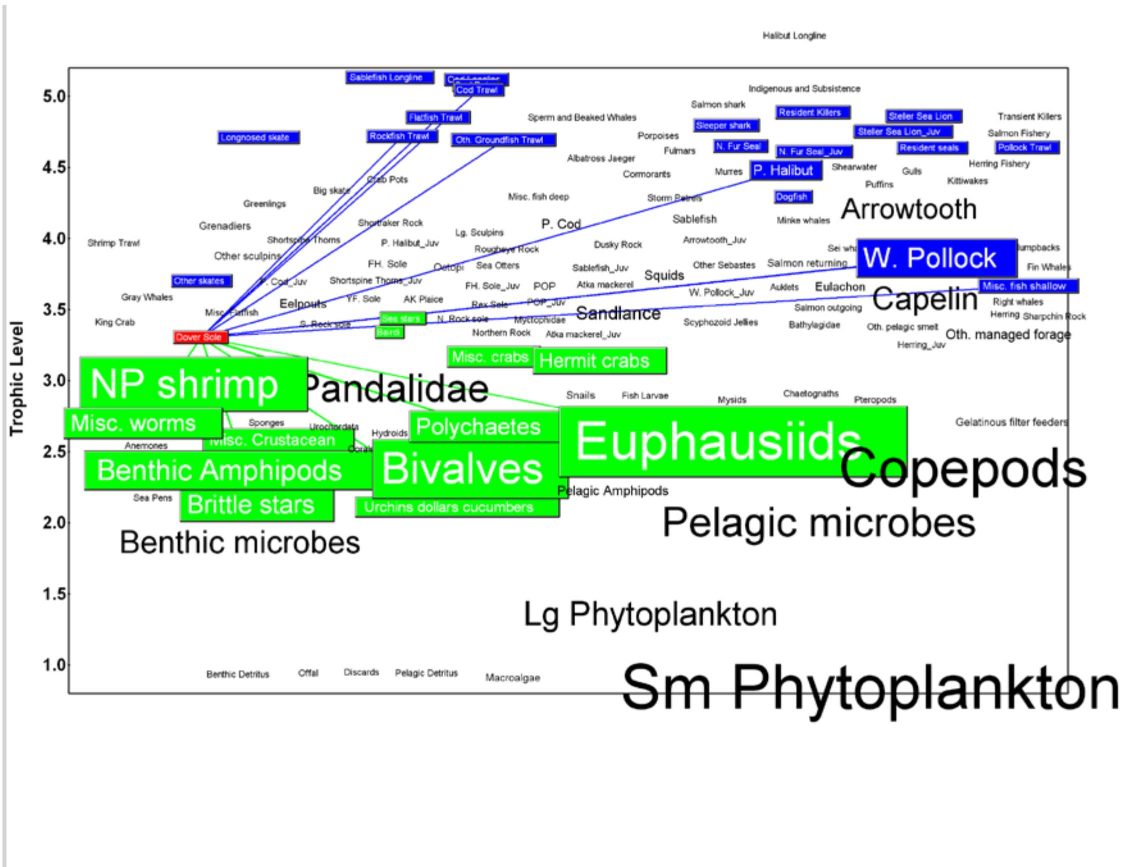

Figure 32. The food web from the GOA ecosystem model (Aydin et al., 2007) highlighting Dover sole links to predators (blue boxes and lines) and prey (green boxes and lines). Box size reflects relative standing stock biomass.

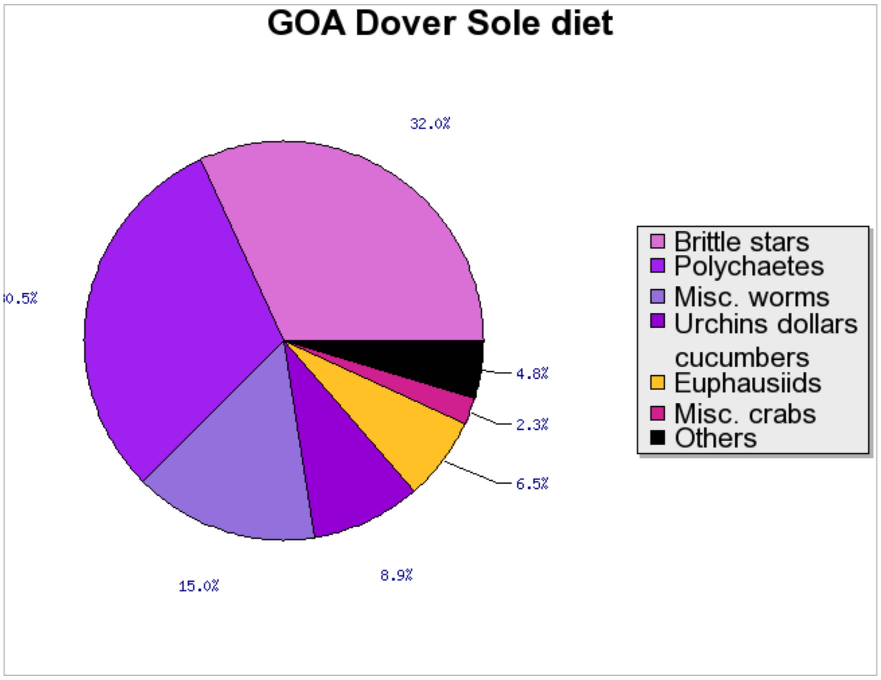

Figure 33. Diet composition for Dover sole from the GOA ecosystem model (Aydin et al., 2007).

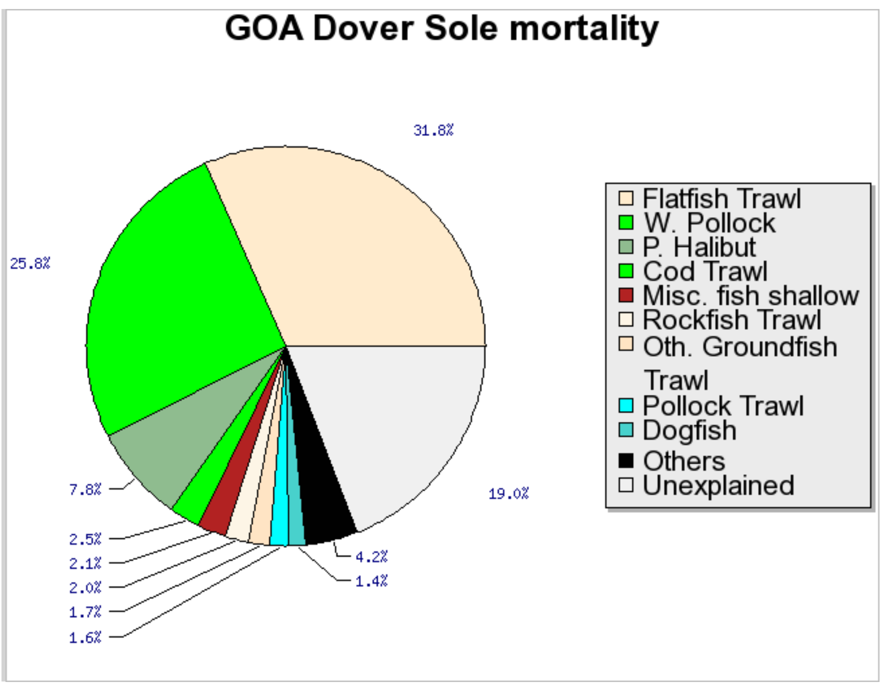

Figure 34. Decomposition of natural mortality for Dover sole from the GOA ecosystem model (Aydin et al., 2007).

Appendix A: Alternative Executive Summary Tables

The following table lists harvest specifications using population dynamics from the 2015 assessment with updated data; projected catches were the same as for the main Executive Summary table:

Species	Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
		2019	2020	2020*	2021*
Dover sole	*M* (natural mortality rate)	0.085	0.085	0.085	0.085
	Tier	3a	3a	3a	3a
	Projected total (3+) biomass (t)	145,926	147,001	99,530	101,696
	Projected Female spawning biomass (t)	49,385	49,418	29,908	29,972
	$B_{100\%}$	57,871	57,871	42,132	42,132
	$B_{40\%}$	23,148	23,148	16,853	16,853
	$B_{35\%}$	20,255	20,255	14,746	14,746
	F_{OFL}	0.12	0.12	0.11	0.11
	$maxF_{ABC}$	0.1	0.1	0.09	0.09
	F_{ABC}	0.1	0.1	0.09	0.09
	OFL (t)	11,190	11,337	6,718	7,021
	maxABC (t)	9,318	9,441	5,615	5,868
	ABC (t)	9,318	9,441	5,615	5,868
Greenland turbot	Tier	6	6	6	6
	OFL (t)	238	238	238	238
	maxABC (t)	179	179	179	179
	ABC (t)	179	179	179	179
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)	11,434	11,581	6,962	7,265
	maxABC (t)	9,501	9,624	5,798	6,051
	ABC (t)	9,501	9,624	5,798	6,051
	Status	As determined *last* year for:		As determined *this* year for:	
		2017	2018	2018	2019
	Overfishing	no	n/a	no	n/a
	Overfished	n/a	no	n/a	no
	Approaching overfished	n/a	no	n/a	no

The following table lists harvest specifications using population dynamics from Model 19.0; projected catches were the same as for the main Executive Summary table:

Species	Quantity	As estimated or *specified last* year for: 2019	2020	As estimated or *recommended this* year for: 2020*	2021*
Dover sole	*M* (natural mortality rate)	0.085	0.085	0.069(f), 0.057(m)	0.069(f), 0.057(m)
	Tier	3a	3a	3a	3a
	Projected total (3+) biomass (t)	145,926	147,001	111,338	113,380
	Projected Female spawning biomass (t)	49,385	49,418	35,371	35,600
	$B_{100\%}$	57,871	57,871	49,199	49,199
	$B_{40\%}$	23,148	23,148	19,680	19,680
	$B_{35\%}$	20,255	20,255	17,220	17,220
	F_{OFL}	0.12	0.12	0.07	0.07
	$maxF_{ABC}$	0.1	0.1	0.06	0.06
	F_{ABC}	0.1	0.1	0.06	0.06
	OFL (t)	11,190	11,337	6,294	6,480
	maxABC (t)	9,318	9,441	5,306	5,463
	ABC (t)	9,318	9,441	5,306	5,463
Greenland turbot	Tier	6	6	6	6
	OFL (t)	238	238	238	238
	maxABC (t)	179	179	179	179
	ABC (t)	179	179	179	179
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)	11,434	11,581	6,538	6,724
	maxABC (t)	9,501	9,624	5,489	5,646
	ABC (t)	9,501	9,624	5,489	5,646
	Status	As determined *last* year for: 2017	2018	As determined *this* year for: 2018	2019
	Overfishing	no	n/a	no	n/a
	Overfished	n/a	no	n/a	no
	Approaching overfished	n/a	no	n/a	no

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

	Alaska Department of Fish and Game Data Sources									
Year	ADF&G Sablefish Longline Survey	Golden King Crab Pot Survey	Kachemak Bay Large Mesh Trawl Survey	Kodiak Scallop Dredge	Large-Mesh Trawl Survey	Prince William Sound Large Mesh Trawl Survey	Prince William Sound Sablefish Tagging	Scallop Dredge Survey	Small-Mesh Trawl Survey	Yakutat Scallop Dredge
1998	2				386			0		
1999	5				1,279					
2000	4				301				12	
2001	5				578					
2002	11				340			2		
2003	21				2,093			0	84	
2004	13	4			960			0	226	
2005		13			1,305			3	512	
2006	4	2			251			72	170	
2007					870			4	29	
2008					176			7		
2009					1,018			4		
2010					2,463			36	138	
2011					2,666			6	49	
2012					1,991			6	29	
2013					1,750		37	10	23	
2014					940				55	
2015					924		1		20	
2016					551			3	24	
2017			189	91	616	468			7	9
2018					1,448				5	

	NMFS Data Sources				
Year	AFSC Annual Longline Survey	GOA Shelf and Slope Walleye Pollock Acoustic-Trawl Survey	Gulf of Alaska Bottom Trawl Survey	Shumigans Acoustic Survey	Structure of Gulf of Alaska Forage Fish Communities
1990	306				
1991	320				
1992	601				
1993	602				
1994	624				
1995	905				
1996	699				
1997	619				
1998	576				
1999	755				
2000	525				
2001	977				
2002	900				
2003	471				
2004	558				
2005	912				
2006	751				
2007	653				
2008	947				
2009	895				
2010	840			2	4
2011	480		4,552		
2012	896				
2013	921		3,259		
2014	631				
2015	479		3,431		
2016	460				
2017	882	1	2,519		
2018	769				

Year	IPHC Annual Longline Survey
2011	12
2012	1
2013	40
2014	75
2015	34
2016	14
2017	31
2018	19