7. Assessment of the Arrowtooth flounder stock in the Gulf of Alaska

S. Kalei Shotwell, Ingrid Spies, James N. Ianelli, Kerim Aydin, Dana H. Hanselman, Wayne Palsson, Kevin Siwicke, Jane Sullivan, and Ellen Yasumiishi

Alaska Fisheries Science Center
National Marine Fisheries Service

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Executive Summary

Summary of Changes in Assessment Inputs

The following substantive changes have been made in the Gulf of Alaska (GOA) Arrowtooth flounder assessment relative to last year's GOA SAFE report.

Changes in the input data:

1. Estimates of catch through October 17, 2021.
2. Fishery size compositions for 2019 (updated) and 2020.
3. Biomass point-estimates and standard errors from the 2021 Gulf of Alaska bottom trawl survey.
4. Age data from the 2019 Gulf of Alaska bottom trawl survey.
5. The recommended model includes but does not fit the non-standard Gulf of Alaska bottom trawl survey size compositions from 1985, 1986, and 1989. We also do not fit the most current survey size composition data (2021) as we anticipate ages from this year for the next full assessment.

Changes in the assessment methodology:

There were no changes in the assessment methodology as we continue to use the 2019 assessment model (Model 19.0). Please see Spies et al. (2019) for more details on the 2019 assessment methodology (available online at: https://apps-afsc.fisheries.noaa.gov/refm/docs/2019/GOAatf.pdf).

Summary of Results

The summarized results of the risk table for Arrowtooth flounder are in the table below. All scores of Level 1 suggest no need to set the ABC below the maximum permissible. Further details for each category of this risk table are provided in the *Harvest Recommendations* section.

Assessment-related considerations	*Population dynamics considerations*	*Environmental/ ecosystem considerations*	*Fishery Performance considerations*
Level 1: Normal	**Level 1:** Normal	**Level 1:** Normal	**Level 1:** Normal

Reference values for Arrowtooth flounder are summarized in the following table. The stock is not being subject to overfishing, is not currently overfished, nor is it approaching a condition of being overfished.

Quantity	As estimated or *specified last* year for: 2021	2022	As estimated or *recommended this* year for: 2022	2023
M (natural mortality – Male, Female)	0.35, 0.2	0.35, 0.2	0.35, 0.2	0.35, 0.2
Specified/recommended Tier	3a	3a	3a	3a
Projected total (age 1+) biomass (t)	1,321,700	1,318,860	1,268,140	1,270,850
Female spawning biomass (t)	752,703	724,288	703,853	691,941
Projected				
$B_{100\%}$	1,028,330	1,028,330	1,018,700	1,018,700
$B_{40\%}$	411,331	411,331	407,478	407,478
$B_{35\%}$	359,915	359,915	356,544	356,544
F_{OFL}	0.234	0.234	0.225	0.225
$maxF_{ABC}$ (maximum allowable = $F_{40\%}$)	0.192	0.192	0.185	0.185
Specified/recommended F_{ABC}	0.192	0.192	0.185	0.185
Specified/recommended OFL (t)	151,723	147,515	143,100	141,231
*max*ABC (t)	126,970	123,445	119,779	118,201
Specified/recommended ABC (t)	126,970	123,445	119,779	118,201
Status	As determined *last* year for: 2019	2020	As determined *this* year for: 2020	2021
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 an estimated catch of 10,052 t for 2021, and estimates of 16,991 t and 14,819 t used in place of maximum permissible ABC for 2022 and 2023 in response to a Plan Team request to obtain more accurate two-year projections. Please see section on Specified Catch Estimation subsection in the Harvest Recommendations section for more details regarding these calculations.

The 2021 AFSC GOA bottom trawl survey estimate increased 5% from the 2019 estimate and is now 26% below the long term average. The 2020 AFSC longline survey relative population number (RPN) for Arrowtooth and Kamchatka flounder combined in the GOA increased by 64% since the 2020 survey and is now 71% below the long-term average for the time series. The 2021 International Pacific Halibut Commission (IPHC) RPN estimates for Arrowtooth flounder in the GOA increased by 44% from the 2019 survey and is now 48% below the long-term average for the time series. All three surveys have similar recent trajectories. Catch for Arrowtooth flounder is generally low and has been between 2-19% of the acceptable biological catch (ABC). Current catch as of October 17, 2021 is at 7% of ABC which is lower than the past several years given that approximately 90% of the catch is usually taken by this time. The total allowable catches (TACs) for Arrowtooth flounder are generally set below ABC but have been increasing in recent years. The 2021 ratio of TAC to ABC was 77%.

For the 2022 fishery, we recommend the maximum allowable ABC of 119,779 t using the 2019 accepted model (Model 19.0). This is a 6% decrease from last year's ABC of 126,970 t. The projected female spawning biomass for 2022 is 703,853 t and the projected age 1+ total biomass for 2022 is 1,268,140 t. Female spawning biomass is well above B40%, and projected to decline.

Area Allocation of Harvests

Arrowtooth Flounder is managed as a single stock in the GOA. However, the ABC is apportioned by management area based on the fraction of the survey biomass in each area. The western region (WGOA) is NMFS reporting area 610 (Shumagin), central region (CGOA) is 620 and 630 (Chirikof and Kodiak), and west Yakutat and east Yakutat / southeast Alaska (SE) result from the combined NMFS areas 640 and 650 redistributed such that the west Yakutat area is between 147°W and 140°W and the east Yakutat/SE is the portion east of 140°W. The fraction of the biomass in the four areas was determined by applying a time series of survey biomass estimates (Table 7.1) and their coefficients of variation, CV's, to a random effects model (Table 7.2). The CGOA has shown a decline in biomass since 2003, while the other regions have remained relatively constant, with the exception of 2015 in east Yakutat/SE (Figure 7.1).

The following table shows recommended area apportionments based on the proportion of survey biomass projected for each area using the survey averaging random effects model developed by the survey averaging working group. This year's area apportionment uses the 2021 AFSC GOA bottom trawl survey estimates. We provided the recommended area apportionment for the last full assessment and last year's area apportionment for comparison (Spies et al., 2019).

	Western	Central	West Yakutat	East Yakutat/SE	Total
2019 Area Apportionment	25.5%	54.4%	6.6%	13.5%	100%
2021 ABC (t)	32,377	69,072	8,380	17,141	126,970
2022 ABC (t)	31,479	67,154	8,147	16,665	123,445
2021 Area Apportionment	28.1%	57.1%	5.6%	9.2%	100%
2022 ABC (t)	33,658	68,394	6,707	11,020	119,779
2023 ABC (t)	33,214	67,493	6,619	10,875	118,201

Summaries for Plan Team

Species	Year	Biomass[1]	OFL	ABC	TAC	Catch[2]
Arrowtooth Flounder	2020	1,325,867	153,017	128,060	96,969	21,122
	2021	1,321,700	151,723	126,970	97,372	9,103
	2022	1,268,140	143,100	119,779	n/a	n/a
	2023	1,270,850	141,231	118,201	n/a	n/a

Stock	Area	2021				2022		2023	
		OFL	ABC	TAC	Catch[2]	OFL	ABC	OFL	ABC
Arrowtooth Flounder	W		32,377	14,500	326		33,658		33,214
	C		69,072	69,072	8,709		68,394		67,493
	WY		8,380	6,900	47		6,707		6,619
	EY		17,141	6,900	21		11,020		10,875
	Total	151,723	126,970	97,372	9,103	143,100	119,779	141,231	118,201

[1]Total biomass (ages 1+) from the age-structured model

[2]Current as of October 17, 2021. Source: NMFS Alaska Regional Office Catch Accounting System via the AKFIN database (http://www.akfin.org).

Responses to SSC and Plan Team Comments on Assessments in General

The following group of comments are the 2021 SSC guidance regarding the risk tables:

- *The SSC concluded that the risk table framework is working well. The tables have expanded communication among assessment authors and between assessment authors and ecosystem/process researchers. The framework is intended to provide a clear and transparent basis for communicating assessment-related and stock condition concerns that are not directly captured in model-based uncertainty, the tier system, or harvest control rules.*

- *The SSC recommended no changes to the language in the Risk Table template.*
- *The SSC recognizes that within the context of the risk tables, "risk" is the risk of the ABC exceeding the true (but unknown) OFL. The risk tables are intended to inform the process of adjusting the ABC from the maximum permissible when needed. Recommendations of an ABC reduction from the maximum permissible requires justification. The risk tables provide an avenue for articulating that justification.*
- *The SSC recommends that consideration for reductions from maxABC be based on current year information unless relevant risk factors for a stock continue to be present from previous years.*
- *The SSC recommends that for stocks managed in Tiers 1-3, that risk tables are produced for all full assessments of groundfish (and perhaps crab) stocks and stock complexes in the fishery. Risk tables can be produced in other years at the discretion of the lead author if there have been notable changes to previous conditions.*
- *The SSC recommends that Risk Tables should not be mandatory for other Tiers; however, stock assessments must include compelling rationale for why a Risk Table would not be informative.*
- *For stock complexes, the SSC recommends that the decision concerning which species (or multiple species) to focus on be up to the author.*
- *The SSC recommended maintaining the status quo, where authors are encouraged (but not required) to provide a recommendation on a reduction from maxABC, if warranted, and the Plan Teams and SSC would then evaluate and modify the reductions (if needed) based on the information available for the stock.*
- *Risk scores should be specific to a given stock or stock complex. While comparison across species (e.g., within a tier, with similar life histories) or stocks is useful for consistency, the SSC does not support trying to prescribe a common reduction from the maximum permissible ABC for a given risk score across species or stocks because the processes underlying the score may differ among species and stocks. The SSC recommends that considerations of reductions in ABCs below the maximum permissible continue to be made on a case-by-case basis with justification based on risk scoring. The risk table rankings include qualitative information that requires a certain amount of subjective but well-informed interpretation of the available data by the author(s), the Plan Teams and the SSC, and as such, the SSC feels that blanket comparisons across species or stocks for the purpose of explicitly defining reductions in ABC below the maximum permissible are not prudent.*
- *The SSC encourages the inclusion of LK/TK/S as a source of knowledge about the condition of the stock, a shift in the spatial or temporal distribution of the resource, or changes in the size or condition of species in the fishery.*
- *The SSC recommends that the fishery/community performance column should focus on information that would inform the biological status of the resource (e.g., an unexplained drop in CPUE that could indicate un-modelled stock decline, or a spatial shift indicating changes in species' range), and not the effects of proposed ABCs on the fishery or communities or bycatch-related considerations. The SSC recognizes that the community impact information is critical for Council decision making and supports efforts to effectively communicate where this information can be accessed.*
- *The SSC appreciates the discussion of avoiding double-counting information, in the assessment/Tier system and risk table, or among columns of the risk table. The SSC agrees that authors should avoid inclusion of stock trends/processes that are incorporated in the assessment or reflected in the Tier when scoring the risk tables. For cases where a process external to the assessment is relevant to two or more risk categories, the SSC recommends that the narrative reflect the interconnected relationships that exist between rankings among risk categories.*
- *The SSC suggests a revision to the category levels: from the existing four to three categories (normal, increased, extreme). The SSC recommends postponing this change until 2022 as many authors have already begun working on risk tables for 2021.*

Since this is a full assessment year for GOA Arrowtooth flounder, we provide a risk table as recommended by the Groundfish Plan Teams and the SSC guidance above. Following the completion of this exercise, the highest score for this stock is a Level 1 and the authors do not recommend that the ABC be reduced below maximum permissible ABC. Please see the *Harvest Recommendations* section for further details for each category of this risk table.

Responses to SSC and Plan Team Comments Specific to this Assessment

"There appears to be a shift to lower recruitment in recent years, beginning in 2006 (i.e., the 2005 year class). The Team recommends investigating whether these lower recruitments are related to environmental conditions in the GOA.
"The Team noted that the decrease in biomass began before the recent heatwaves in the north Pacific and is similar to drops observed in other flatfish during this time and may be potentially linked to extended poor recruitment during cold pattern in 2006-2007." (GOA Plan Team, November 2019)

We plan to investigate these lower recruitment trends through the ESP framework in future assessments. The ESP provides a unique opportunity to explore unaccounted-for uncertainty through an ecosystem and socioeconomic approach to fisheries management. The new data in this updated model includes some promising signs for an above-average 2017 year class which is concurrent with a cooler year in the GOA following the 2014-2016 marine heatwaves and suggests improved conditions for Arrowtooth young-of-the-year during 2017.

"The Team also noted the potential of using AFSC longline survey data for Arrowtooth flounder as they are caught in significant numbers on that survey."
"The assessment contains survey length-frequency data from 1985, 1986, and 1989 that were collected opportunistically. Because these data were not part of standard NMFS GOA bottom trawl surveys and the methodology for their collection is unclear, the Team recommends investigating whether they should be removed from the assessment." (GOA Plan Team, November 2019)
"The SSC supports the GPT recommendations to evaluate whether opportunistically collected length frequency data should be removed from the model. The SSC requests the authors investigate including IPHC survey data in this assessment, and whether fishery catch-at-age information is available for inclusion in the model." (SSC, December 2019)

We have grouped the GOA Plan Team and SSC comments regarding alternate surveys, survey length frequency data, and fishery age data together because they pertain to the same recommendation. We plan to investigate the potential for using the AFSC longline survey and survey and the International Pacific Halibut Commission (IPHC) data as auxiliary indices of Arrowtooth flounder in the next full assessment. We provide information regarding the AFSC longline and the IPHC survey as well as current estimates of Arrowtooth flounder in the *Survey* subsection of the *Data* section below as a start at this investigation. Please reference those sections for more detail regarding those surveys and estimates of Arrowtooth flounder. We may also explore the utility of combining these survey estimates with the AFSC bottom trawl survey using model-based methods (e.g., VAST) when possible.

We provide a sensitivity analysis regarding the opportunistically collected length frequency data in the *Survey* subsections of the *Data* section under the AFSC Bottom Trawl Survey Biomass Estimates below and determined that there was very little change in the model output without fitting this information in the model (0.4% for total biomass and 0.2% for female spawning biomass). Given that these are lengths collected from non-standard surveys and the change without this data in the model is minimal, we determined to not fit this information in the model and called this a minor data correction so it did not require a separate model evaluation.

We also explored the availability of fishery ages for Arrowtooth flounder. Since the onset of the Observer Program in 1990, there are very few years with high enough sample sizes in the GOA for inclusion in a catch-at-age stock assessment model (>100, although this is still fairly low as typically 200-300 samples are used as a cutoff) and the sampling has been sporadic (1991, 1995, 2019, 2020). A special ageing request may be initiated through the AFSC Age and Growth program to age these years but this may not be worth the effort given the low samples sizes. Alternatively, more samples could be requested in future years if fishery ages were deemed a priority for this stock. Please see the *Fishery Age and Length Composition* subsection in the *Data* section for more details and a table of the available otoliths by year.

Introduction

Arrowtooth flounder (*Atheresthes stomias*) are relatively large flatfish that range from central California to the eastern Bering Sea (EBS), and as far west as the Kuril Islands (Orlov 2004). Arrowtooth flounder occur in waters from about 20m to 800m, although catch per unit effort (CPUE) from survey data is highest between 100m and 300m. Spawning occurs in deep water (>400 meters) in the GOA and along the shelf break in the eastern Bering Sea (Doyle et al. 2018). Migration patterns are not well known for Arrowtooth flounder; however, there is some indication that Arrowtooth flounder move into deeper water as they grow, similar to other flatfish (Zimmerman and Goddard 1996). Fisheries data off Washington suggest that larger fish may migrate to deeper water in winter and shallower water in summer (Rickey 1995). Arrowtooth flounder spawn in deep waters (>400m) along the continental shelf break in winter (Blood et al. 2007). They are batch spawners, spawning from fall to winter off Washington State at depths greater than 366m (Rickey 1995).

Highly suitable larval habitat was characterized by bottom depth (200-900 m) and low current fluctuations (i.e., variability in surface ocean current direction, Laman et al., 2017). Seasonal progression in distribution of larvae indicates transport onto the shelf from deep water with apparent enhanced shoreward transport in the major canyons intersecting the slope (e.g. Amatuli Trough and Outer Shelikof Strait) where “hot-spots” in larval abundance are observed (Doyle et al., 2018; Goldstein et al., 2020). On-shelf transport of larvae seems critical, and variability in such transport may have a significant influence on larval survival to the early juvenile settlement stage (Goldstein et al., 2020). Early and late juvenile habitat were very similar and indicative of habitat generalists with more restricted depths than the larval stage (30-200 m and 75-235 m, respectively), but including fine and large scale low-lying areas (e.g., flats, embayments, channels, and gullies), low bottom temperature, and low tidal current. Settled early juveniles (age-0) are more ubiquitous across depths in the GOA than previously understood and are encountered throughout coastal and shelf waters, and older juveniles also occur in deep water along the slope (Doyle et al., 2018). Adult habitat included more depth range (100-470 m) than juvenile habitat but still indicative of habitat generalists utilizing benthic habitat extensively throughout the GOA from east to west, with low bottom temperature, low-lying areas, and low tidal current. Differences in distribution of Arrowtooth flounder were compared between warm and cold years, where warm years included 1984, 1987, 1990, 1993, 2001, 2003, 2005, 2015 and cold years included 1996, 1999, 2007, 2009, 2011, and 2013 (Doyle et al. 2018). Results showed some effect of temperature on distribution (Figure 7.2). Fish less than 300mm were found typically <400m in warm years but deeper in cold years. Younger fish <100m were found >200m only in colder years. ATF 300-600mm were found in the deepest stations >800m in warm years. High densities of fish were greater at 200-400m in cold years. Highest densities of larger, older fish >600mm were found over the slope in cold years (Doyle et al. 2018). Recent trends in recruitment and biomass may indicate that Arrowtooth has reached some maximum threshold in terms of habitat utilization in the GOA, and that density-dependent effects at the juvenile stage may dominate population trends going forward (Spies et al., 2019; Doyle et al., 2018).

Historical ichthyoplankton data indicate peak release of Arrowtooth eggs in deep water over the slope in January to early February followed by a more extended peak in recently hatched larvae January to mid-March and continued presence of larvae in the plankton through summer months (Doyle and Mier, 2016). Arrowtooth exhibit an early life strategy termed a “holding pattern” because of slow larval growth in cold, food poor environments during winter to early spring while remaining almost exclusively over deep water (Doyle and Mier, 2016). The extended pelagic larval phase is characterized by very slow growth of larvae through April with an increased growth rate from May-June in association with warming water and spring peak in plankton production. This slow growth during winter is considered advantageous in terms of extending utilization of lipid reserves prior to first-feeding. However, this strategy can cause an extreme mismatch with prey availability for first-feeding Arrowtooth larvae during winter due to both a spatial and temporal separation from spring zooplankton production on shelf. Two hypotheses suggest potential mitigation of this mismatch by 1) “holding pattern” physiology which confers endurance during early ontogeny because of extended lipid reserves at very low physiological rates and 2) spatial/temporal synchrony with winter production of eggs/nauplii of the Necoalanus copepods that may be an important food source for first-feeding larvae (Doyle and Mier, 2016; Doyle et al., 2018; Doyle et al., 2019). These proposed mismatch mitigating factors may provide population resilience under “normal” conditions in the GOA, but Arrowtooth early ontogeny may be particularly vulnerable to anomalous conditions such as significant warming events that could potentially speed up larval growth rates and/or disrupt timing of production of larval zooplankton prey. There was a positive (but weak) correlation between larval length and water temperature across the late spring GOA time series which may be indicative of enhanced growth during “warm” years (Doyle and Mier, 2016).

Trophic studies (Yang 1993, Hollowed, et al. 1995, Hollowed et al. 2000) suggest Arrowtooth flounder are an important component in the dynamics of the GOA benthic ecosystem. They are an apex predator in the GOA and are habitat and prey generalists (Doyle et al. 2018). The majority of the prey by weight of Arrowtooth larger than 40 cm was pollock, the remainder consisting of herring, capelin, euphausids, shrimp and cephalopods (Yang 1993). The percent of pollock in the diet of Arrowtooth flounder increases for sizes greater than 40 cm (Figure 7.3, Doyle et al. 2018). Arrowtooth flounder 15 cm to 30 cm consume mostly shrimp, capelin, euphausiids and herring, with small amounts of pollock and other miscellaneous fish. Groundfish predators include Pacific cod and halibut (see Ecosystem Considerations section).

The age composition of the species shows fewer males relative to females as fish increase in age, which suggests higher natural mortality (M) for males (Wilderbuer and Turnock 2009). To account for this process, natural mortality has typically been fixed at 0.2 for females and 0.35 for males in the model. Different options for natural mortality were considered in the 2017 assessment, which consider natural mortality as a function of the size of the fish (Charnov 1982, Gislason et al. 2010, Lorenzen 1996). The distribution of ages appears to vary by region and sex; male Arrowtooth as old as 36 years have been observed in the Aleutian Islands, but are not commonly observed older than age 10 on the Bering Sea shelf. Males were not observed older than age 20 prior to 2005 in the GOA; however, males age 21 have been observed in every survey since that time. The sex ratio of Arrowtooth flounder also varies by region. In the GOA, the observed ratio from fishery observer length frequency collections is 69% female, 31% male. Survey length compositions from the Bering Sea indicate that the proportion female is 70% on the Bering Sea shelf, 72% on the Bering Sea slope, and 62% in the Aleutian Islands. In British Columbia catches have been over 70% female since 1996 and the stock is assessed solely based on female numbers (DFO 2015).

Information concerning the genetic stock structure of Arrowtooth flounder is not currently available, although efforts are underway to initiate research.

Fishery

Management of the Arrowtooth flounder stock in the GOA has changed over time. Prior to 1990, flatfish catch in the GOA was reported as an aggregate of all flatfish species. The bottom trawl fishery in the GOA primarily targets rock, rex and Dover sole. The North Pacific Fisheries Management Council divided the flatfish assemblage into four categories for management in 1990; “shallow flatfish” and “deep flatfish”, flathead sole, and Arrowtooth flounder. Arrowtooth flounder was separated from the group and managed under a separate ABC because of its present high abundance and low commercial value. In the GOA, Arrowtooth flounder were first managed under a separate assessment in 2001. They are currently managed as a single stock but the ABC is specified separately for the western GOA (NMFS area 610), central GOA (620, 630), west Yakutat, and east Yakutat/southeast Alaska.

The area of highest abundance of Arrowtooth flounder in the GOA is in the central and western gulf (Figure 7.4). The directed fishery takes place throughout the GOA, but is primarily in the central GOA (NMFS area 630). Arrowtooth flounder are typically caught with bottom trawl nets. Outside of the directed fishery, they are primarily caught as bycatch in the Other Flatfish fisheries. Catch of Arrowtooth flounder since 1964 is shown in Table 7.3.

Viable products were developed for Arrowtooth flounder around 2008, which prevented the muscle from degrading rapidly when heated (Greene and Babbitt 1990, Wasson et al. 1992, Porter et al. 1993). Until that time it was not targeted as a commercial fishery. Several methods exist to neutralize the enzymes that cause the flesh to degrade, including chilling to near zero or immediate processing and freezing (Reppond et al. 1993). The Arrowtooth flounder currently caught, processed, and sold each year from the GOA are typically exported to China for reprocessing, with some product going to South Korea and Japan. Reprocessed Arrowtooth from China may also be sold to Japan as fillets and engawa (frills), the US and Europe as fillets, among other countries. They are eaten as less expensive fillets, used raw in sashimi, or used to manufacture surimi.

The catches for Arrowtooth flounder remain below the TAC (Table 7.3); and have ranged from 15,000 – 36,000 t since the year 2000, averaging 24,000 t, and the ratio of catch to TAC averaged 36%. Catches were below 10,000 t, on average, prior to 1990, and increased to an average of approximately 16,000 t in the 1990’s and 24,000 t in the 2000’s. Catch as of October 17, 2021 was 9,103 t. Total allowable catch for 2020 and 2021 was 96,969 t and 97,372 t.

Bycatch

The primary fisheries that catch Arrowtooth flounder as bycatch are the pollock, rockfish, and Pacific cod fisheries (Table 7.4). For the Arrowtooth fishery during 2017-2021 (Table 7.5), the largest bycatch groups are on average Pacific ocean perch (1,423 t/year), Flathead sole (1,277 t/year), Pacific cod (1,037 t/year), pollock (1,019 t/year), Rex sole (746 t/year) and sablefish (713 t/year). Non-FMP species catch in the Arrowtooth fishery is generally dominated on average by giant grenadier, miscellaneous fish, sea stars, and squid (Table 7.6).

Discards

Gulf-wide discard rates (percent of the total catch discarded within management categories) of Arrowtooth flounder were available for the years 1991 to present (Table 7.7). Discards of Arrowtooth flounder have ranged from approximately 5.2% to 98% with an average of 46.6%. Discards have been decreasing steadily since the peak in 1994 to fairly low discard rates in recent years with a small uptick in 2021 (Table 7.7).

Data

New data used in this assessment include estimates of total catch, trawl survey biomass estimates and standard errors from the Alaska Fisheries Science Center (AFSC) GOA bottom trawl survey, sex-specific trawl survey age and fishery length-frequencies from observer sampling. Length composition data are available from each survey; however, length data are only used in the model for each year when age composition data are not available. The model simulates the dynamics of the population and compares the expected values of the population characteristics to data observed from AFSC surveys and fishery sampling programs.

The following data sources (and years of availability) were used in the preferred model. Bolded years indicate new data inputs for this year’s assessment.

Source	Data	Years
AFSC GOA bottom trawl survey	Survey biomass and standard error	1984,1987,1990,1993,1996,1999,2001,2003, 2005,2007,2009,2011,2013,2015,2017,2019,**2021**
	Age Composition	1984,1987,1990,1993,1996,1999,2001,2003, 2005,2007,2009,2011,2013,2015,2017,**2019**
Fishery	Catch Biomass	1977 **- 2020, 2021**
	Length composition	1977 - 1993, 1995-**2020**

Fishery

Catch

The estimate of annual Arrowtooth catch between 1960 and 1993 was extrapolated from total flatfish catch by multiplying the proportion of Arrowtooth in observer sampled flatfish catches (nearly 50%) by the reported flatfish catch (1960-1977 from Murai et al. 1981 and 1978-1993 from Wilderbuer and Brown (1993) (Table 7.3).

Removals from sources other than those that are included in the Alaska Region's official estimate of catch (e.g., removals due to scientific surveys, subsistence fishing, recreational fishing, fisheries managed under other FMPs) are presented in Appendix A.

Fishery Age and Length Compositions

The number of fisheries length observations taken by fisheries observers, and the number of hauls from which those samples were taken, by year, 1975-2021 are presented in Table 7.5. Sample sizes (number of individual fish) for the fishery length data were generally at least 1,000 for the 1970s through 1984 (Table 7.8). Sample sizes were under 800 between 1985-1990, 1992, 1994, 1998, and were not taken in 1989. The data prior to 1989 is referred to as "foreign" data, but the fishing of the latter years was done predominately by joint venture vessels which eventually replaced the foreign fishers (Table 7.3). The number of male and female lengths used in the model as length composition data, by year, are shown in Figure 7.5. Number of fishery lengths from the fishery are presented in Figure 7.6. There are no long-term trends in the length composition data from the fishery (Figure 7.6), but there is variation over time.

Otoliths have been collected sporadically in the fishery since 1982 but sample sizes are generally low following the initiation of the Observer Program in 1990 (see otolith table below). It may be possible to age some of these otoliths during years when the samples were higher (>100) through the AFSC Age and Growth prioritization system; however, the ageing request would need to be evaluated within the scope of the AFSC Age and Growth available staff time and resources (J. Short and B. Matta, pers. commun.). Also, the years when otoliths were higher are fairly sporadic, and aging of these otoliths may not be worth the extra effort given the amount of otoliths aged by the AFSC Age and Growth program each year.

Table of otoliths collected (none aged) in the fishery from 1982 to present:

Year	BSAI Collected	GOA Collected	Total Collected
1982	1926	912	2838
1983	1213	213	1426
1984	1355	456	1811
1985	1784	228	2012
1986	626	6	632
1987	302	80	382
1991	0	100	100
1995	0	160	160
1997	0	50	50
1999	35	2	37
2000	19	9	28
2001	27	2	29
2002	22	29	51
2003	93	0	93
2004	5	1	6
2005	5	0	5
2006	30	0	30
2007	11	4	15
2008	27	15	42
2010	0	4	4
2011	5	8	13
2012	4	0	4
2018	529	79	608
2019	538	110	648
2020	692	110	802
2021	283	33	316

Survey

AFSC Bottom Trawl Survey Biomass Estimates

The survey biomass estimates used in this assessment are from AFSC groundfish bottom trawl surveys (Table 7.9). The triennial AFSC surveys used a nor'easter trawl. The trawl used in the 1984 and 1987 surveys had no bobbin or roller gear, which would cause the gear to be more in contact with the bottom than current trawl gear, and may have restricted the locations of trawl sites to more trawlable areas.

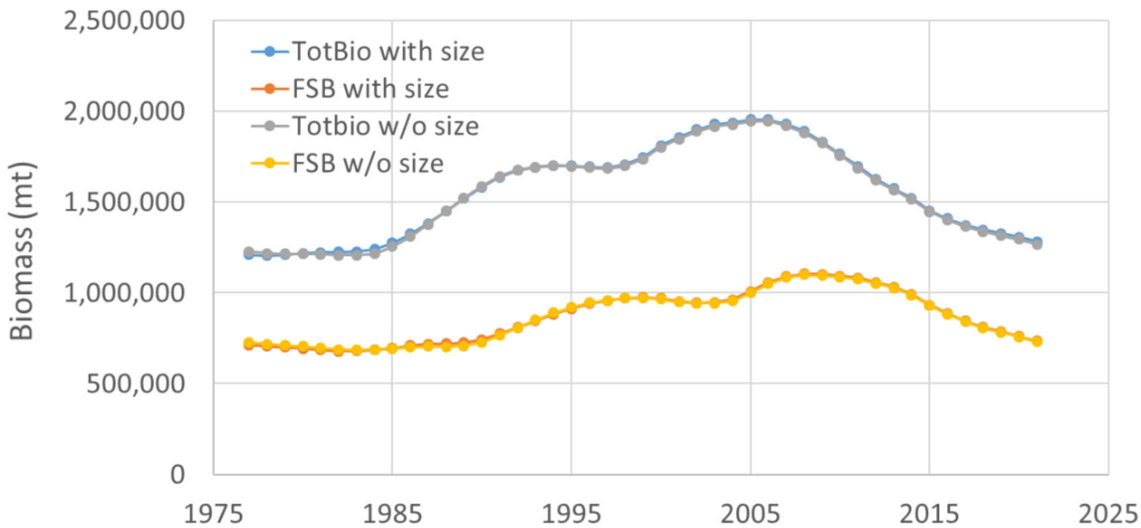
The survey catchability coefficient (q) in the assessment model was assumed to be 1.0. AFSC has conducted studies to estimate the escapement under the survey net and herding of fish into the net. The percent of Arrowtooth flounder caught that were in the path of the net varies by size from about 80% at 27 cm (about age 3) to about 96% at greater than 45cm (equal to or greater than age 7 for females and age 10 for males) (Somerton et al. 2007). Somerton et al. (2007) estimated the effect of herding combined with escapement under the net to be an effective multiplier of about 1.3 on survey catch for Arrowtooth flounder. The combination of escapement under the net and herding into the net indicates that abundance would be about 23% less than the estimated survey abundance. At this time we assume q to be 1.0 but may explore estimating q in the future given this herding experiment.

Total survey biomass estimates increased from approximately 1.3 million metric tons in 1984 and 1987, to 3 million tons in 2003, and have since declined to approximately 1 million metric tons from 2017-2021. Survey biomass has generally been declining since 2003, and the 2017 estimate of 1,053,695 t was the lowest estimate since 1987. The 2019 and 2021 estimates were slightly higher, 1,076,727 t and 1,132,192 t, respectively. The 1984, 1987, 1999, 2005, 2007, 2009, 2011, and 2015 surveys covered depths to 1000m, the 1990, 1993, 1996, and 2001 surveys to 500m and the 2003, 2013, 2017, 2019, and 2021 surveys covered depths to over 700 m (Table 7.9). The 2001 survey excluded the eastern GOA. The average biomass estimated for the 1993 to 1999 surveys was used to estimate the biomass in the eastern GOA for 2001 (Table 7.1). Survey estimates of biomass by area are generally highest in the central GOA, and the eastern and western GOA have similar biomass of Arrowtooth flounder (Table 7.10). The central GOA has experienced the greatest declines in Arrowtooth flounder biomass since 2003. Survey biomass estimates, standard error, number of hauls, and maximum depth are shown in Table 7.9.

Spatial distribution maps of catch per unit effort (CPUE) data since 1984 are available from the AFSC GOA trawl survey (Figure 7.4). CPUE by haul indicates that the highest abundance has generally occurred between about 149 and 156 degrees longitude, in the central GOA, to the southwest and to the northeast of Kodiak Island (Figure 7.4). Results show that CPUE is typically highest in the Chirikof region of the central GOA, NMFS area 620.

AFSC Bottom Trawl Survey Age and Length Compositions

Otoliths from the 1984 to 2017 NMFS trawl surveys have been aged and are used in the model (Table 7.11). Age composition data has been used in the model from all GOA surveys since 1984, except for the most recent survey as ages are not yet available (Table 7.11). Differences in ageing methodology exist but are not expected to bias results (D. Anderl, *pers. commun.*). Length composition data are not used when age data are available or anticipated to be available in the following assessment year. Length frequency data were collected opportunistically for Arrowtooth flounder on three GOA surveys conducted in 1985, 1986, and 1989. These surveys were not part of the standard AFSC GOA bottom surveys but the length frequency data have been included in previous assessments. As these opportunistically collected length compositions are not part of the standard survey protocol, we no longer use this information in the model. Additionally, we conducted a sensitivity model run with and without these length frequencies and compared the total and spawning biomass estimates from Model 19.0 (2021). The average difference in biomass (ADSB) was less than 1% for both spawning and total biomass (see comparison figure below). Based on this result, we determined this change was a minor data correction and did not require a separate model evaluation. Length frequency data from all NMFS surveys indicates no long term trends, and that females are larger than males (Figure 7.7). The number of lengths collected from NMFS surveys are shown in Table 7.11.

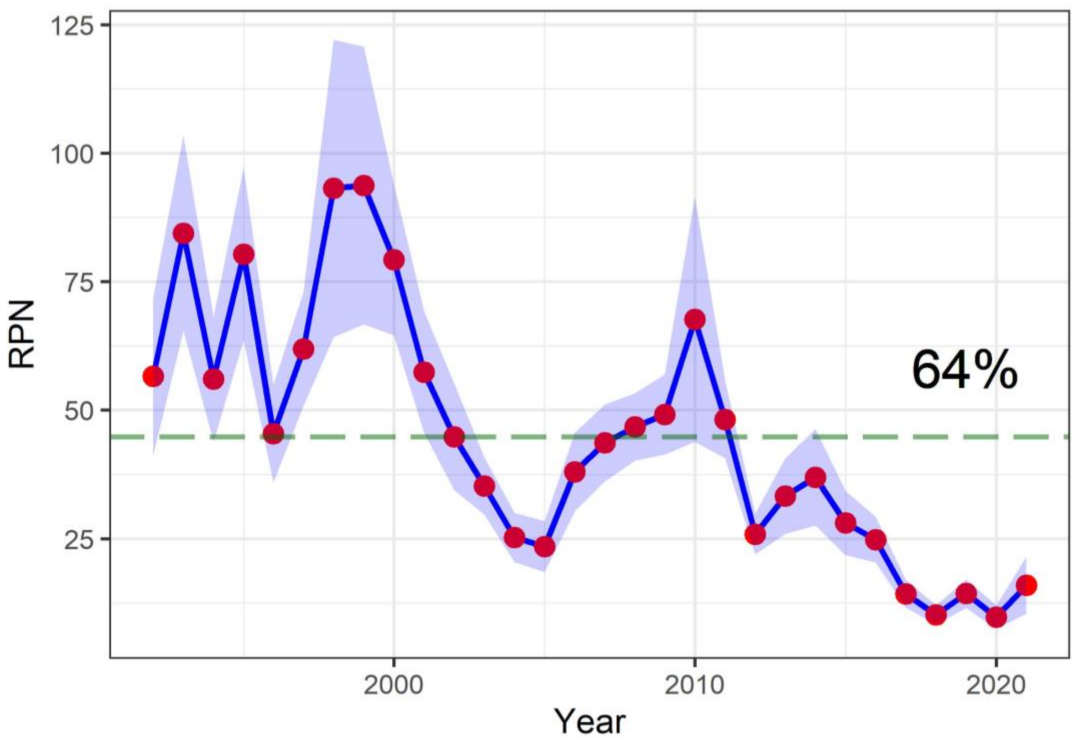


Comparison figure of with and without size compositions: Comparison of total biomass (TotBio) and female spawning biomass (FSB) for model runs using the three AFSC non-standard size compositions (with size), and without using them in the model (w/o size). Average difference in biomass for the whole time series is 0.4% for total biomass and 0.2% for female spawning biomass.

AFSC Longline Survey

The AFSC longline survey has been conducted annually since 1988, and RPNs and RPWs have been computed for each year and are available since 1992 for Arrowtooth and Kamchatka flounder combined (see AFSC RPN time series in the figure below). The AFSC longline survey is conducted annually over the continental slope region of the BSAI and the GOA. The GOA stations are sampled each year while the Bering Sea is sampled on odd years and the Aleutian Islands in even years. This survey provides data on the relative abundance of Arrowtooth flounder in the form of relative population numbers (RPNs) and relative population weights (RPWs) for fish on the continental slope as indices of stock abundance. Relative population abundance indices are computed annually using survey catch per unit of effort (CPUE) rates that are multiplied by the area size of the stratum within each geographic area. These relative population indices are available by numbers (RPN) and weights (RPW) for a given species (Rodgveller et al. 2011). The survey is primarily directed at sablefish, but also catches considerable numbers of Arrowtooth flounder. Also, historically, Arrowtooth flounder and Kamchatka flounder were not separated by species and were just recently separated out in 2019. Therefore, we provide RPNs for Arrowtooth and Kamchatka flounder combined to see changes throughout the entire time series (see RPN figure below). Results for this survey concerning flatfish, should also be viewed with some caution, as the RPNs and RPWs do not take into account possible effects of competition for hooks with other species caught on the longline, especially sablefish.

RPNs in the GOA show a somewhat decadal cyclic pattern since the mid-1990s to about 2010 and then have declined to present low values, with a steep decline at the onset of the 2014 marine heatwave, similar to the bottom trawl survey estimates. Values range from a high in 1999 to a low in 2020. This same pattern is evident in the BSAI time series for Arrowtooth and Kamchatka flounder except the pattern is more variable and the decline is less steep. Some of the fluctuations may be related to changes in the abundance of sablefish regarding competition for hooks among species. The 2021 longline survey RPN value for Arrowtooth and Kamchatka flounder combined is up 64% from 2020 (see AFSC RPN figure below), but is still 71% below the long term mean of the time series.



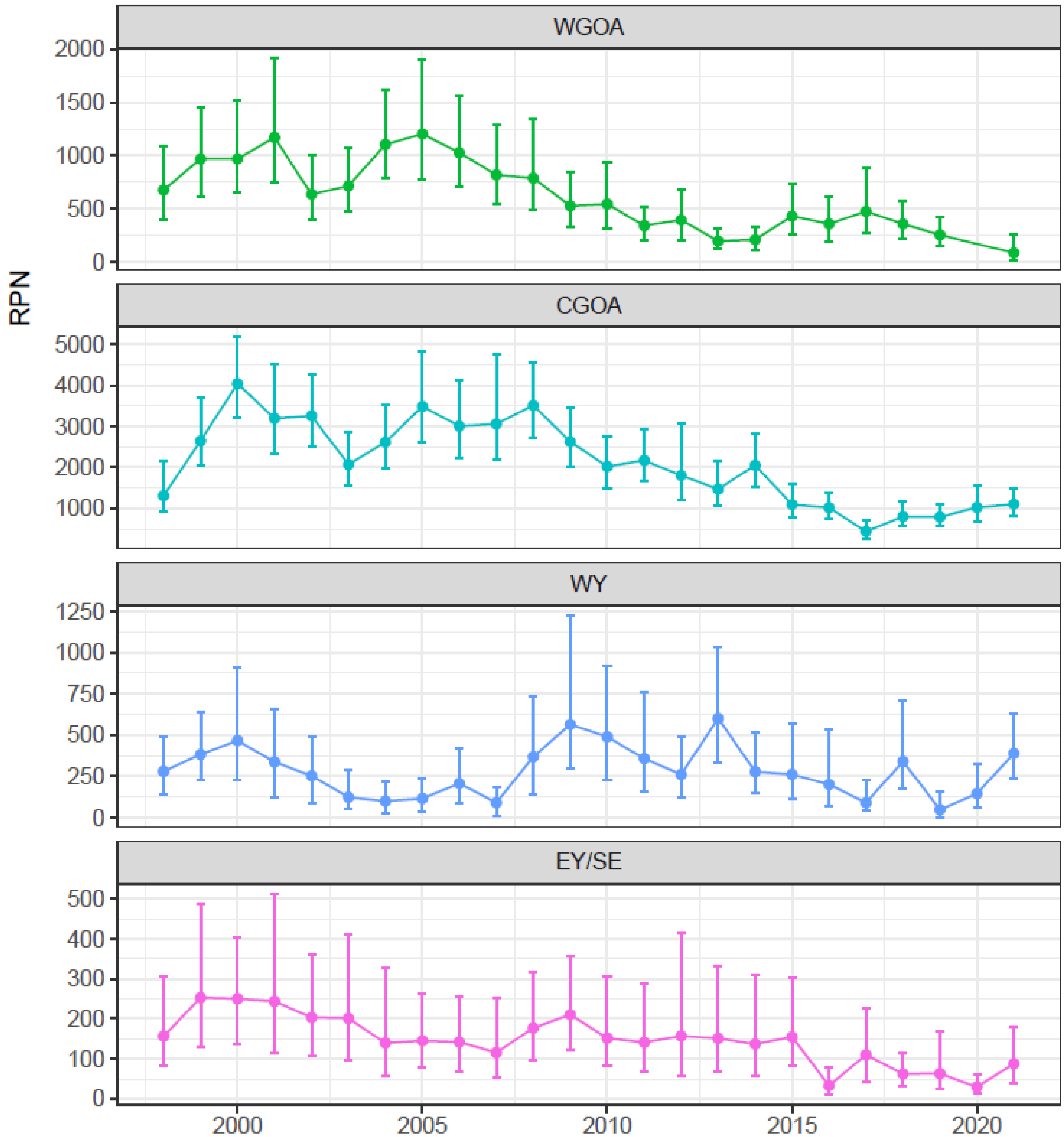
AFSC RPN figure of Arrowtooth and Kamchatka flounder combined from the AFSC longline survey in the Gulf of Alaska

Length data are also collected for Arrowtooth flounder during longline surveys and compositions are available since 1992. A clear shift in size has occurred throughout the time series with increasing abundance of larger fish sampled until the mid-2000s, after which a shift to small fish occurs until about 2017. In recent years there are fewer fish in the survey which may have to do with the declines in the population and less of the stock in the slope environment where the survey primarily samples.

International Pacific Halibut Commission Survey

The International Pacific Halibut Commission (IPHC) conducts a longline survey each year to assess Pacific halibut. This survey differs from the AFSC longline survey in gear configuration and sampling design, but also catches Arrowtooth flounder. More information on this survey can be found in Soderlund et al. (2009). A major difference between the AFSC and the IPHC surveys is that the IPHC survey samples the shelf consistently from 1-500 meters, whereas the AFSC longline survey samples the slope and select gullies from 150 to 1000 meters. Because the majority of effort occurs on the shelf in shallower depths, the IPHC survey samples more suitable Arrowtooth flounder habitat than the AFSC longline survey and is similar to the AFSC bottom trawl survey; however, lengths of Arrowtooth flounder are not taken on the IPHC survey.

RPNs have been computed for each year of the IPHC survey and are available since 1998 to 2021 for Arrowtooth flounder (see IPHC RPN figure below). RPNs in the GOA have ranged from a low RPN in 2017 to a high in 2000 and also generally follow the trajectory of the AFSC bottom trawl survey since 2005 when the population started to decline. RPNs are generally higher in the CGOA as with the AFSC bottom trawl survey. RPNs increased in 2021 in all areas except the WGOA compared to 2020. The 2021 GOA estimate is 44% above the 2019 estimate (2020 was not completely sampled) and is now 48% below the long-term average for the time series. No length data are collected for Arrowtooth flounder on the IPHC survey.



IPHC RPN figure of Arrowtooth flounder from the IPHC longline survey by region in the Gulf of Alaska

Analytic Approach

General Model Structure

We use the base model from the last full assessment (Model 19.0) with updated and new data since the last full assessment. Please see Spies et al. (2019) for more details regarding this reference model. A summary of model results is shown in Table 7.14 comparing Model 19.0 (2021) with Model 19.0 (2019) from the last full assessment. Due to the increase in data in the current model, the likelihoods cannot be directly compared but are there for reference as are spawning and total biomass estimates.

We present model results for the Arrowtooth flounder stock based on an age-structured model using Automatic Differentiation Model Builder (ADMB) software (Fournier et al. 2012). The framework uses automatic differentiation and allows estimation of highly-parameterized and non-linear models. The approach consists of an assessment model, which uses survey and fishery data to generate a historical time series of population estimates, and a projection model which uses results from the assessment model to predict future population estimates and recommended harvest levels. This model does not attempt to fit a stock-recruitment relationship but estimates a mean recruitment, which is adjusted by estimated recruitment deviations for each year.

This age-structured population dynamics model is fit to survey abundance data, survey age data, and fishery length composition data with a harvest control rule to model the status and productivity of these stocks and set quotas. The model is fit to the data by minimizing the objective function, analogous to maximizing the likelihood function. The model implementation language provides the ability to estimate the variance-covariance matrix for all parameters of interest. A "generalized model" has been used in the Gulf of Alaska and the Bering Sea and Aleutian Islands Arrowtooth flounder stock assessments since 2015. The model incorporates ages 1-21+ and estimates age-based selectivity up to age 19, and uses 26 lengths bins (see size range for each bin in *Weight-at-Age* subsection below). A Markov chain Monte Carlo (MCMC) was performed in ADMB to capture variability in recruitment, female spawning biomass, and total (age 1+) biomass. The MCMC was run with 20,000,000 iterations, and thinning every 4000.

No spawner-recruit curve was used in the model. Instead, we calculated average recruitment with an estimated lognormal deviation for each year of the model with the exception of the final year. In the final modeled year, recruitment is set to median recruitment. Recruitment deviations were freely estimated but with a modest penalty on extreme deviations from the mean value (σ_r value). Age at recruitment was set at one in the model. Variation in recruitment is informed by subsequent age and length composition and there is little information to inform recruitment in the final few years because 50% maturity occurs at age 7 and selectivity is low for younger Arrowtooth flounder.

Equilibrium age structure in the unfished population is based on mean recruitment. Ages 2-21 are subject to a sex- specific vector of instantaneous rates of natural mortality, M_{sex}. Natural mortality is subscripted for sex, as males appear to have higher natural mortality than females in this species (Wilderbuer and Turnock 2009).

$$\tilde{N}_{sex,a} = \begin{cases} e^{\overline{log(R)}} & \text{if a=0,} \\ \tilde{N}_{sex,a-1} e^{-M_{sex}} & \text{if } 1 \leq \text{a} \leq \text{x-1,} \\ \tilde{N}_{sex,x} e^{-M_{sex}} \big/ (1 - e^{-M_{sex}}) & \text{if a=x.} \end{cases}$$

where a represents age, $\tilde{N}$ is equilibrium numbers of fish by sex and age, and M represents sex-specific natural mortality.

The numbers-at-age for all years in the model are computed allowing for fishery selectivity, and fishing and natural mortality.

$$\tilde{N}_{sex,y+1,a} = \begin{cases} e^{\overline{log(R)}+recdev_y} & \text{if a=0,} \\ N_{sex,y,a-1}e^{-(S_{sex,a-1}F_{sex,y}+M_{sex})} & \text{if } 1\leq a\leq x\text{-1,} \\ N_{sex,y,x-1}e^{-(S_{sex,x-1}F_{sex,y}+M_{sex})} + N_{sex,y,x}e^{-(S_{sex,x}F_{sex,y}+M_{sex})} & \text{if a=x.} \end{cases}$$

where $N_{sex,y+1,a}$ is the number of fish of each sex at age *a* at the start of year *y+1*, $S_{sex,a}$ is the sex-specific selectivity-at-age for the fishery, F_y is the instantaneous fully-selected fishing mortality rate during year *y* and is calculated from the log of the mean fishing mortality and a vector of fishing mortality deviations (fmort_devs) for each year of the model, $F_y = e^{\overline{\log F}+fmort\_dev_y}$

There were 157 parameters estimated by the model examined in the current assessment (Table 7.13). Parameters were estimating by minimizing the objective function. Several likelihood equations contributed to the final likelihood: recruitment, fishery catches, fishery length compositions, age composition from the trawl survey, and biomass. Observation errors for age and length compositions were assumed to be multinomial distributed, while recruitment deviations, and catch and biomass observation errors were assumed to be lognormally distributed. Log-likelihood components for each data type are as follows:

$$recruitmentL = 0.5\sum_{y=Styr}^{Endyr}\left(\frac{rec\_dev_y}{\sqrt{0.5}}\right)^2$$

$$biomassL = 0.5\sum_{y=Styr}^{Endyr}\left(\frac{\log(Biomass_{obs,y}) - \log(Biomass_{pred,y})}{BiomassSD_{obs,y} / Biomass_{obs,y}}\right)^2,$$

where the observed annual coefficient of variation (CV, Table 7.1) is used as an estimate of standard deviation.

$$catchL = 0.5\sum_{y=Styr}^{Endyr}\left(\frac{\log(Catch_{obs,y}+d) - \log(Catch_{pred,y}+d)}{\sqrt{0.5}}\right)^2,$$

where d is a small value needed in the case of zero catches.

(6)

$$LengthL = \sum_y\sum_{sex}\sum_{length}\phi_{y,sex,length}Nhauls_{sex,y}\left(obs\_prop_{sex,length,age}+\delta\right)\times log\left(pred\_prop_{sex,length,age}+\delta\right)$$

Where ϕ is a logical value indicating whether there are applicable observed data in year *y*

Length composition likelihood for the fishery and the survey are calculated as in Equation 6. We do not fit length composition data when there are ages available or anticipated to be available, therefore, no survey lengths are included in the model when we have age data. Three non-standard survey years have been included in the model in previous years. In the author recommended model, we set the sample sizes to zero to effectively not fit the non-standard survey lengths. In this way, we do not change the model, but allowed for the data correction. Delta (d) is a small number less than 1 added to account for the possibility of zero observations in a length (or age category). The weights ("Nhauls") applied to the fishery length composition data are shown in Table 7.8. Lower weights are applied to length compositions in the years prior to 1989 because the number of hauls are not known. Length compositions reflect the number of hauls from 1990-1998 and are generally 200 from 1998 through 2020.

The proportion of males and females sum to 1 in each year of the model. This also allows for the model to fit the observed skewed sex ratio, approximately 69% females and 31% males, based on the fishery length composition data. Length composition data was only used in the model in years in which there is no age data or when there were sufficient samples. There are no fishery ages available, so we fit all available fishery lengths, with the exception of 1994 when there were too few samples (121 lengths).

The likelihood for survey ages assumes that observation error is distributed multinomially. The negative log-likelihood is similar to equation (6):

$$AgeL = \sum_{y}\sum_{sex}\sum_{age}\phi_{y,sex,age}Nhauls_{sex,y}\left(obs\_prop_{y,sex,age}+\delta\right)\times log\left(pred\_prop_{y,sex,age}+\delta\right)$$

Age data exists for all standard GOA surveys, and have been read for all but the most recent survey (2021). For the survey age composition data, the number of hauls was assumed to be 200 for each year of data. The number of fish aged in each year ranged from 325-1,534 (Table 7.11). Survey age composition data for the years 1984-2019 were fit to in the model. Detailed cruise information for each survey from which age data were taken is shown in Table 7.9.

For the multinomial likelihood (used for composition data), an offset was calculated which decreases as the number of samples increases, and when observations are less frequent than 0.5.

Catch, in units of fish, is estimated in the model using the standard equation (below) and then multiplied by weight-at-age:

$$Catch_{year,age} = \frac{F_{year,age}}{Z_{year,age}}(1 - e^{-Z_{year,age}})N_{year,age},$$

where Z represents total mortality and is the sum of fishery and sex-specific natural mortality.

Female spawning biomass is calculated as the product of the weight of mature females in each year.

$$FSB_{year} = \sum_{age} wt_{age}\phi_{age}N_{age,year},$$

where ϕ_{age} is the proportion of mature females at each age from Stark (2011), $N_{age,year}$ is the number of females in the population, and wt_{age} is the weight at age for females. Weight-at-age is defined by first converting predicted ages to lengths using a sex-specific static conversion matrix, and then using a sex-invariant length-weight relationship; both steps are described in the following section.

Parameters Estimated Outside the Assessment Model

The instantaneous natural mortality rate *M*, catchability for the survey *q* and the Von Bertalanffy growth parameters, and weight at length by sex were all fixed in the model. Parameters estimated outside the model are summarized in Table 7.12.

Natural mortality

Natural mortality (*M*) rates for Gulf of Alaska Arrowtooth flounder were estimated using the methods of Wilderbuer and Turnock (2009). A higher natural mortality for males than females was used to fit the age and size composition data, which are about 70% females. A value of *M*=0.35 for males was chosen so that the survey selectivities for males and females both reached a maximum close to 1.0. A likelihood profile on male natural mortality resulted in a mean and mode of 0.354 with 95% confidence intervals of 0.32 to 0.38 (Turnock et al. 2002, Figure 10.14). Model runs examining the effect of different natural mortality values for male Arrowtooth flounder can be found in the Appendix of the 2000 SAFE (https://www.afsc.noaa.gov/REFM/stocks/Historic_Assess.htm). Differential natural mortality by sex can be a factor that needs consideration in management of targeted fish stocks, however, since GOA Arrowtooth flounder is currently exploited at low levels, this effect is not a concern for this stock (Wilderbuer and Turnock 2009).

Data used to calculate length at age and weight at length

Data used to estimate parameters of the von Bertalanffy length-at-age function and the weight-at-length relationship, which were both fixed in the assessment model, consisted of age data from 1984-2013 GOA RACE groundfish surveys. There were 9,686 such data points, each associated with age, length, and weight for each fish and 12,308 that had age and length (Table 7.11). Ageing methods have changed throughout the time series but this is not expected to cause bias over time or errors in the earlier datasets (D. Anderl, AFSC Age and Growth, pers. comm.).

Weight at Length

The weight-length relationship for Arrowtooth flounder was evaluated to be: $\textit{Weight} = 0.004312\ \textit{Length}^{3.186}$, for both sexes combined, where weight is in grams and length in centimeters. Analysis was performed using nonlinear least squares fit to all weight and length data from the AFSC bottom trawl surveys in the GOA from 1984 to 2013. The nonlinear least squares (nls) method was implemented from the R package stats (Bates and Chambers 1992). The length-weight relationship was the same among male and females.

Growth

Growth was estimated from length and age data from RACE Gulf of Alaska surveys from 1984 to 2013 and incorporated in the assessment using a length-age conversion matrix. Length (adjusted for survey length frequencies) was converted to weight with the weight-at-length relationship described above. Age frequencies from length-stratified sampling for age data was corrected using length frequencies from surveys for which there is more data, averaging 12,000 female and 6,500 male lengths per survey (Table 7.11). Differences in growth show up around the age at maturity of age 6 (Figure 7.9).

Length at Age

There are two length-age conversion matrices (one for females and one for males) that are generated from all years of data predict lengths from ages to compare with observed lengths.

The length-age conversion matrix was generated by simulating 107 data points for each length observed from survey lengths of Arrowtooth Flounder, from 90 to 880mm (see midpoints table below). The simulations were generated from a normal distribution, with the mean length at age determined by the male and female von Bertalanffy fit to the length-age data and the CV for each length determined by the parameters of the linear models described below. These data were binned into 26 length categories from sizes less than 10 cm to greater than 75 cm. These length categories were used for all length composition data in the model.

	1	2	3	4	5	6	7	8	9	10	11	12	13
Range (mm)	<100	100-160	160-180	180-200	200-220	220-240	240-260	260-280	280-300	300-320	320-340	340-360	360-380
Midpoints	90	130	170	190	210	230	250	270	290	310	330	350	370

	14	15	16	17	18	19	20	21	22	23	24	25	26
Range (mm)	380-400	400-430	430-460	460-490	490-520	520-550	550-580	580-610	610-640	640-670	670-700	700-750	>750
Midpoints	390	415	445	475	505	535	565	595	625	655	685	725	850

A von Bertalanffy individual growth model,

$$Length = L\infty(1 - e-(K*age-t0)),$$

was applied to the corrected length at age data, separately for males and females, using the R package fishmethods, resulting in the following parameter estimates. The plus group contains all ages 21 and above, and was calculated as a weighted average of the von Bertalanffy mean length and the proportion estimated to be in each of those upper age categories based on M=0.2 for females and M=0.35 for males.

Sex	L_{inf}	K	t_0
Females	837.6	0.07587	-2.57872
Males	524.1	0.1672	-1.4684

The coefficient of variation (CV) typically decreases with age. This was not the case with the GOA Arrowtooth flounder data, although Bering Sea data for females did fit this pattern. Therefore, female CV of length at age was fitted as a straight line and adjusted slightly so that a normal distribution around the von Bertalanffy estimate of length at age did not exceed the range of lengths observed, $CV = -0.003 * age + 0.14$. Male variance was also fitted to a linear model, but not adjusted, $CV = -0.0008637 * age + 0.1184688$. Growth values were last revisited in the 2017 assessment (Spies et al., 2017).

Weight at age

Weight at age used in the model is based on length at age corrected by survey length frequencies, as shown in Figure 7.8 Weight at age of females determined by this method is slightly lower than weight at age determined by a weight-at-age von Bertalanffy relationship determined from the stratified age collection. Differences in male weight at age between methods were not as significant as differences in female weight at age (Figure 7.8).

Maturity

Maturity at age was based on a maturity-at-length study by Zimmerman (1997) through 2013. Length at 50% maturity was estimated at 47 cm with a logistic slope of -0.3429 from Arrowtooth flounder sampled in hauls from in the September 1993 bottom trawl survey (Zimmerman 1997). Elsewhere in their range, length at 50% maturity was 36.8 cm for females and 28.0 cm for males from survey data in 1992 off Washington, with logistic slopes of -0.54 and -0.893 respectively (Rickey 1995). Arrowtooth flounder had length at 50% maturity of 44 cm for females and 29 cm for males of the coast of Oregon (Rickey 1995). Spawning fish were found in depths from 108m to 360m in March to August in the Gulf of Alaska (Hirshberger and Smith 1983) from analysis of trawl surveys from 1975 to 1981. Most observations of spawning fish have been in the northeastern Gulf, off Prince William Sound, off Cape St. Elias, and Icy Bay.

A study was conducted in 2008 that examined maturity-at-age that estimates age at maturity rather than length at maturity (Stark 2008). In this study, a sample of 301 fish was taken in February 2002 and a separate collection (226 fish) was taken in July 2003, both from the central GOA. Parameter estimates based on the February sample were used in the current study because Arrowtooth flounder spawn during winter months. The estimate of logistic 50% maturity was 7 years, the logistic slope (B) was 1.3817 and the intercept (A) was -9.6183. Fish matured at a slightly younger age in the 2008 study compared to the 1997 study. This maturity ogive (Stark 2008) has been used in the model since 2015. Age at 50% maturity is age 7 in females, and is 20% in age 6 fish.

$$Maturity_{age} = \frac{1}{1 + e^{-A+B*ages}}.$$

Likelihood weights were adjusted using the methodology of Francis (2011) and are described in more detail in the Model Evaluation section from the 2013 assessment (Spies and Turnock, 2013). The parameter s1,

$$s1 = [\chi^2_{0.95,m-1}/(m-1)]^{0.5},$$

was used to evaluate model weighting, where $\chi^2_{0.95,m-1}$ is the 95th percentile of a chi-sqared distribution with *m-1* degrees of freedom and m is the number of observations (Francis 2011). Weights were left at the values in the 2019 assessment (Spies et al., 2019).

Ageing error matrix

Ageing error in Arrowtooth Flounder is relatively high compared to walleye pollock and Pacific cod. Therefore, we implemented an ageing error transition matrix to convert population numbers at age to expected survey numbers at age. The matrix was computed using the estimated percent agreement among two age readers. We used the percent agreement for ages from 1987-2015. The model incorporates a linear increase in the standard deviation of ageing error and assumes that ageing error is normally distributed (Dorn et al. 2003, Methot 2000). Percent agreement is predicted by the sum probability that both readers are correct, that both readers are off by one year in the same direction, and the probability that both age readers are off by two years in the same direction (Methot 2000). Ageing agreement is 88% at age 1 and declines to 50% at age 5 and 12% at age 15. There is higher variation in the percent agreement at older ages, which could be due to a sampling effect; there are fewer older fish and therefore lower probability of selecting an older fish for double-reading.

Parameters Estimated Inside the Assessment Model

Parameters estimated inside the model are described in Table 7.13.

Year class strengths

The population simulation specifies the numbers-at-age in the beginning year of the simulation, the number of recruits in subsequent years, and the survival rate for each cohort as it moves through the population calculated from the population dynamics equations.

Fishing Mortality

The fishing mortality rates (F) for each age and year are calculated to approximate the catch in weight by solving for F while allowing for observation error in catch measurement.

Selectivity

Fishery selectivity was estimated as a smooth, age- and sex-specific non-parametric function through age 19 (Figure 7.10). Survey selectivity was modeled using a two parameter ascending logistic function for males and females (four parameters total). The differential natural mortality and selectivities by sex resulted in a predicted fraction female of about 0.70, which is close to the fraction female in the fishery and survey length and age data.

Results

Model Evaluation

Model 19.0 was selected in the last full assessment (2019) as the authors' preferred model because it provided the best fit to the data and incorporated necessary changes to the model configuration. There were no changes in the assessment methodology as we continue to use the 2019 assessment model (Model 19.0). Please see Spies et al. (2019) for more details on the 2019 assessment methodology (available online at: https://apps-afsc.fisheries.noaa.gov/refm/docs/2019/GOAatf.pdf).

Time Series Results

Estimates of fishing mortality have increased over the model time series, consistent with the recent trend of decreasing biomass (Figure 7.14). The estimates of fishing mortality were similar for Model 19.0 (2019) and Model 19.0 (2021), with the exception of the early 1990s. The fit to survey biomass estimates is shown in Figure 7.15, and shows an increasing trend in estimated total biomass through 2006 and estimated spawning biomass through 2008, with a decrease in both quantities since then. Model 19.0 (2021) estimates nearly identical levels of total and female spawning biomass for the historical time series as Model 19.0 (2019) and estimates a continued drop, due to the addition of new data in the model (Figure 7.15). Model 19.0 (2021) indicated that female spawning biomass in 2021 was 92% of the estimate in 2019 (Table 7.15). Current levels of female spawning biomass are similar to values estimated in the present model for the early 1990s (Figure 7.16). The 2019 model estimated total age 1+ biomass of 1,333,540 t in 2019, and the 2021 model estimated a 5% decline to 1,267,240 t in 2021. Model estimates of total and female spawning biomass with 95% credible intervals based on MCMC posterior distributions are presented in Table 7.16.

Age 1 recruitment has been below average since 2007 (Figure 7.17 and Table 7.17). Recruitment peaked in 2000 and has declined since that time. Recent estimates of recruitment are likely not reliable, as the presence of older fish in the time series is needed to lend certainty to recruitment estimates. However, the size of the 2017 year class appears to be supported by the most recent age composition data with an increase in age 2 compositions from the 2019 survey age composition data and the recruitment estimate for the 2017 year class appears to be above the longer term mean.

Reference fishing mortality rates and yields

Reliable estimates of biomass, $B_{40\%}$, $F_{35\%}$, and $F_{40\%}$ are available for Arrowtooth flounder. The current projection model (Model 19.0) estimate of female spawning biomass in 2022 is 703,853, which is 1.73 times the estimate of $B_{40\%}$, 407,478 t. Therefore, the Arrowtooth flounder stock in the GOA is in Tier 3a of the ABC and overfishing definitions. Under this definition, $F_{OFL} = F_{35\%}$, and F_{ABC} is less than or equal to $F_{40\%}$.

The acceptable biological catch (ABC) for 2022 using $F_{40\%} = 0.185$ (2019 assessment $F_{40\%} = 0.196$) was estimated at 119,779 t. The OFL for 2022 at $F_{35\%} = 0.225$ was estimated at 143,100 t. The ABC for 2023 is 118,201 t, and the OFL for 2023 is 141,231 t. Model estimates of fishing mortality have been below $F_{40\%}$ for the entire time series (Figure 7.18). The highest fishing mortality was estimated to be 0.04 in 2014 (Table 7.18), which corresponds with the highest catch on record of 36,300 t (Table 7.3).

Maximum sustainable yield

Since there is no estimate of the spawner-recruit relationship for Arrowtooth flounder, no attempt has been made to estimate MSY. However, using the projection model described in the next section, spawning biomass with no fishing was estimated at 1,018,700 t in 2021. The equilibrium spawning biomass with fishing at $F_{35\%}$, $B_{35\%}$, was estimated at 356,544 t and $B_{40\%}$ was 407,478 t.

Retrospective analysis

Retrospective analysis is the examination of the consistency among successive estimates of the same parameters obtained as new data are added to a model. Retrospective analysis has been applied most commonly to age-structured assessments and can arise for many reasons, ranging from bias in the data (e.g., catch misreporting, non-random sampling) to different types of model misspecification (e.g., incorrect values of natural mortality, temporal trends in values set to be invariant). For this assessment, a within-model retrospective analysis of the preferred model was conducted for the last 10 years of the time-series by dropping all data one year at a time from the current preferred model.

A retrospective analysis was performed, in which data were sequentially removed from the preferred model for ten years, and spawning biomass was estimated for the duration of the truncated time series (Figure 7.19). One common measure of the retrospective bias is Mohn's revised ρ ("rho") which indicates the size and direction of the bias (Hanselman et al. 2013). The revised Mohn's ρ statistic is small at 0.018 (compared to most AFSC assessments, Hanselman et al. 2013), indicating that the model estimates of spawning biomass increase relative to the terminal year estimates as data are removed from the assessment. In most retrospective years, the estimate for respective terminal-year spawning biomass was slightly higher than the current model's spawning biomass estimate in 2021. The difference between the current model and retrospective spawning biomass was highest for the 2016 retrospective year, indicating a small potential retrospective bias (Figure 7.20).

Although there are no guidelines regarding how large ρ (absolute value) should be before an assessment is declared to exhibit an important retrospective bias, 0.018 is very small compared with many other Alaska groundfish species. Examining retrospective trends can show potential biases in the model, but may not identify their source. Other times a retrospective trend is merely a matter of the model having too much inertia in the age-structure and other historic data to respond to the most recent data. This retrospective pattern considered mild, though the cause may be the "one-way" nature of the survey biomass trend during the 10-year retrospective window. It is difficult to isolate the cause of this pattern but several possibilities exist. For example, hypotheses could include environmental changes in catchability, time-varying natural mortality, or changes in selectivity of the fishery or survey.

Harvest Recommendations

Amendment 56 Reference Points

In the author recommended model, the estimate of projected 2022 total biomass from the stock assessment projection model is 1,268,140 t and the female spawning biomass is estimated at 703,853 t.

The reference fishing mortality rate for Arrowtooth flounder is determined by the amount of reliable population information available. Equilibrium female spawning biomass is calculated by applying the female spawning biomass per recruit resulting from a constant $F_{40\%}$ harvest to an estimate of average equilibrium recruitment. Year classes spawned in 1977-2020 are used to calculate the average equilibrium recruitment. This results in an estimate of $B_{40\%}$ = 407,478 t for 2022. Projected 2022 female spawning biomass is compared to $B_{40\%}$ to determine the Tier level. The stock assessment model estimates the 2022 level of female spawning biomass at 703,853 t. Since reliable estimates of B, $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist and $B>B_{40\%}$, Arrowtooth flounder reference fishing mortality is defined in Tier 3a. For 2022 the recommended $F_{ABC} = F_{40\%} = 0.185$ and $F_{OFL} = F_{35\%} = 0.225$ (fully-selected F values).

Specification of OFL and Maximum Permissible ABC

Acceptable biological catch is estimated for 2022 by applying the $F_{40\%}$ fishing mortality rate and age-specific fishery selectivities to the projected 2022 estimate of age-specific total biomass. This results in a 2022 ABC of 119,779 t. There were no retrospective patterns or risk table concerns to suggest that altering the ABC from this value is warranted. The overfishing level is estimated for 2022 by applying the

$F_{35\%}$ fishing mortality rate and age-specific fishery selectivities to the projected 2022 estimate of age-specific total biomass. This results in a 2022 OFL of 143,100 t.

Standard Harvest Scenarios, Projection Methodology, and Projection Results

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 Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of current year (2021) numbers at age estimated in the assessment. This vector is then projected forward to the beginning of the following year (current year +1) using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for the current year. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1,000 times for each scenario 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 next year (2022), 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 next year's (current year +1) recommended in the assessment to the *max* F_{ABC} for next year. 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 most recent 5-year (current year -6 – current year -1) 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.

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

Scenario 6: In all future years, F is set equal to F_{OFL}. Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above ½ of its MSY level in the current year and above its MSY level in 10 (current year +10) years under this scenario, then the stock is not overfished.

Scenario 7: In the next year and the following year (current year +1, current year +2), 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 13 years (current year +13) under this scenario, then the stock is not approaching an overfished condition.

Simulation results for the seven projection scenarios indicate that Arrowtooth flounder are not currently overfished and the stock is not considered to be approaching an overfished condition (Table 7.19). The stock projection at the average exploitation rate for the past 5 years (Figure 7.21) indicates that the stock will remain above $B_{40\%}$ if fished at this rate for the next 12 years. A phase-plane diagram showing the time-series of female spawning biomass estimates relative to the harvest control rule (Figure 7.18) shows that the female spawning biomass is above $B_{40\%}$ and that the stock is lightly exploited relative to reference points, and that this trend is expected to continue through at least 2023. The ABC and TAC values that have been used to manage the combined stock since 1990 are presented in Table 7.3.

Risk Table

The following table is used to complete the risk table as directed by SSC guidance.

	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 Arrowtooth flounder assessment is based on a time series of all standard NMFS groundfish surveys dating back to 1984. Ages from NMFS surveys are available (or will be) for all of those years. The model exhibits good fits to abundance and composition data. The retrospective pattern from the current assessment is good, and Mohn's rho was calculated to be 0.018 for Model 19.0 (2021), indicating that there is little effect due to retrospective bias.

Population dynamics considerations

Stock assessment model results show that Arrowtooth flounder biomass (age 1+) was at low levels during the 1960s and 1970s, although surveys used during that time period used unconventional methods. The population increased throughout the 1980's and reached a peak in the 2000's at which time biomass was estimated at approximately 2 million tons. The biomass has recently declined over roughly the past 10 years, and is now in the vicinity of 1 million metric tons, but still well above reference points. Population dynamics are not a concern for this assessment.

Environmental/Ecosystem considerations

We scored this category as level 1 (normal concern) given moderate environmental conditions, limited and mixed information on the abundance of prey, predators, and competitors, and a lack of a mechanistic understanding for the direct and indirect effects of environmental change on the survival and productivity of Arrowtooth flounder.

GOA Arrowtooth flounder adults are demersal ranging from shallow shelf to deep slope habitats. Spawning occurs during winter months of January and February in the GOA. Eggs, larva, and juveniles are passively transported by tidal current from benthic to pelagic and slope to shallow shelf habitats from February through April. Impacts of sea temperatures are relatively unknown. Sea temperatures were cooler during 2021 than during the recent warm stanza. Heat wave conditions were not present in the GOA during the spring and summer of 2021 (Watson and Callahan 2021). No significant relationships were found between February-April sea temperatures and an analysis of drift patterns using the OSCURS model in the GOA (near Amatuli), although the unusually high recruitment in 1999, a La Niña year, corresponded with unusual drift directed south into the GOA.

Physical and biological mechanisms regulating the feeding, growth, and survival of Arrowtooth flounder are poorly understood. Arrowtooth flounder are generalist predators, and their diets often reflect the relative abundance of prey in their environment and diet changes substantially with body size. Smaller Arrowtooth flounder (15-30 cm) typically consume shrimp, krill, large copepods, and cephalopods, while larger Arrowtooth flounder consume small fishes such as capelin, sand lance, and herring. During 2021, krill densities were above average in Icy Strait the eastern GOA and of lower densities around Kodiak in May (Kimmel 2021, Fergusson 2021). CPUE of shrimp from bottom trawl surveys were moderate around the Kodiak, Southeast Alaska, Kodiak, and Shumigan, and high around Chirikof (Palsson 2021). During the EcoFOCI spring larval survey in the western GOA, larval fish abundances were above average for Arrowtooth flounder and below average for all other fish species (Deary et al. 2021). Adult Arrowtooth flounder catch was below average offshore and above average in inshore areas near Kodiak from the ADF&G trawl survey (Worton et al. 2021). Body condition was slightly below average for Arrowtooth flounder and lower for other adult groundfish species captured near the seafloor in the AFSC bottom trawl surveys (O'Leary et al. 2021). Forage fish had mixed to positive trends, including a continued increase in herring spawning stock biomass (SEAK and potentially other regions in GOA; Hebert 2021), sand lance are present in moderate amounts in piscivorous seabird diets (Middleton Island), and capelin still remains reduced since the 2014-2016 marine heatwave (AFSC summer Acoustic Trawl Survey & AFSC Bottom Trawl Survey: McGowan 2021, Middleton Island seabird diets: Hatch 2021), In general, piscivorous seabirds had average to positive reproductive success, suggesting foraging success (Drummond 2021). Overall, environmental and prey conditions for Arrowtooth flounder were mixed during 2021.

Primary predators of Arrowtooth flounder include pinnipeds, Pacific cod, halibut, sharks, skates, and other Arrowtooth flounder (Spies et al. 2017). Population trends for halibut and Pacific cod in the GOA have declined >50% since the 1990s (Barbeaux et al. 2018, Stewart et al. 2020). Steller sea lion trends have stabilized (eastern GOA) or remain greatly reduced (western GOA) in the GOA. Little is known about the impacts of these predators on Arrowtooth flounder population levels, but these predator population levels remain relatively low. Bycatch of sablefish, a potential competitor of Arrowtooth flounder, was lower in 2021 indicating reduced overlap in their distribution and likely less competition between adult Arrowtooth flounder and sablefish, generalist predators.

Fishery performance

There is no concern regarding the ability of the fishery to catch Arrowtooth flounder. At the current time, fishery CPUE is not showing a contrasting pattern from the stock biomass trend, unusual spatial pattern of fishing, changes in the percent of TAC taken, or changes in the duration of fishery openings.

Assessment-related considerations	*Population dynamics considerations*	*Environmental/ ecosystem considerations*	*Fishery Performance considerations*
Level 1: Normal	**Level 1:** Normal	**Level 1:** Normal	**Level 1:** Normal

All scores for the risk table are Level 1, suggesting no need to set the ABC below the maximum permissible.

Area Allocation of Harvests

Arrowtooth Flounder is managed as a single stock in the GOA. However, the ABC is apportioned by management area based on the fraction of the survey biomass in each area. The western region (WGOA) is NMFS reporting area 610 (Shumagin), central region (CGOA) is 620 and 630 (Chirikof and Kodiak), and west Yakutat and east Yakutat / southeast Alaska (SE) result from the combined NMFS areas 640 and 650 redistributed such that the west Yakutat area is between 147°W and 140°W and the east Yakutat/SE is the portion east of 140°W. The fraction of the biomass in the four areas was determined by applying a time series of survey biomass estimates (Table 7.1) and their coefficients of variation, CV's, to a random effects model (Table 7.2). The CGOA has shown a decline in biomass since 2003, while the other regions have remained relatively constant, with the exception of 2015 in east Yakutat/SE (Figure 7.1).

The following table shows recommended area apportionments based on the proportion of survey biomass projected for each area using the survey averaging random effects model developed by the survey averaging working group. This year's area apportionment uses the 2021 AFSC GOA bottom trawl survey estimates. We provided the recommended area apportionment for the last full assessment and last year's area apportionment for comparison (Spies et al., 2019).

	Western	Central	West Yakutat	East Yakutat/SE	Total
2019 Area Apportionment	25.5%	54.4%	6.6%	13.5%	100%
2021 ABC (t)	32,377	69,072	8,380	17,141	126,970
2022 ABC (t)	31,479	67,154	8,147	16,665	123,445
2021 Area Apportionment	28.1%	57.1%	5.6%	9.2%	100%
2022 ABC (t)	33,658	68,394	6,707	11,020	119,779
2023 ABC (t)	33,214	67,493	6,619	10,875	118,201

Status Determination

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2022, it does not provide the best estimate of OFL for 2023, because the mean 2022 catch under Scenario 6 is predicated on the 2022 catch being equal to the 2022 OFL, whereas the actual 2022 catch will likely be less than the 2022 OFL. The executive summary contains the appropriate one- and two-year ahead projections for both ABC and OFL.

Under the MSFCMA, the Secretary of Commerce is required to report on the status of each U.S. fishery with respect to overfishing. This report involves the answers to three questions: 1) Is the stock being subjected to overfishing? 2) Is the stock currently overfished? 3) Is the stock approaching an overfished condition?

Is the stock being subjected to overfishing? The official catch estimate for the most recent complete year (2020) is 21,122 t. This is less than the 2020 OFL of 153,017 t. Therefore, the stock is not being subjected to overfishing.

Harvest Scenarios #6 and #7 are intended to permit determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock that is below its MSST is defined to be overfished. Any stock that is expected to fall below its MSST in the next two years is defined to be approaching an overfished condition. Harvest Scenarios #6 and #7 are used in these determinations as follows:

Is the stock currently overfished? This depends on the stock's estimated spawning biomass in 2020:

a) If spawning biomass for 2021 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b) If spawning biomass for 2021 is estimated to be above $B_{35\%}$ the stock is above its MSST.
c) If spawning biomass for 2021 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest Scenario #6 (Table 7.19). If the mean spawning biomass for 2031 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest Scenario #7:

a) If the mean spawning biomass for 2023 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.
b) If the mean spawning biomass for 2023 is above $B_{35\%}$, the stock is not approaching an overfished condition.
c) If the mean spawning biomass for 2023 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2034. If the mean spawning biomass for 2034 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

Based on the above criteria and Table 7.19, the stock is not currently overfished, and is not approaching an overfished condition. The tests for evaluating these two statements on status determination require examining the current model projections of spawning biomass relative to $B_{35\%}$ for 2021 and 2023. The estimates of spawning biomass for 2021 and 2023 from the current year (2021) projection model are 717,925 t and 691,941 t, respectively. Both estimates are well above the estimate of 2022 $B_{35\%}$ at 356,544 t and, therefore, the stock is not currently overfished nor approaching an overfished condition. The *F* from the author's recommended model that would have produced a catch for last year equal to last year's *OFL* was F=0.238.

Specified Catch Estimation

In response to Plan Team recommendations, we have established a consistent methodology for estimating current-year and future year catches in order to provide more accurate two-year projections of ABC and OFL to management. In the past, two standard approaches in flatfish models have been employed; assume the full TAC will be taken, or use a certain date prior to publication of assessments as a final estimate of catch for that year. Both methods have disadvantages. If the author assumes the full TAC is taken every year, but it rarely is, the ABC will consistently be underestimated. Conversely, if the author assumes that the catch taken by around October is the final catch, and substantial catch is taken thereafter, ABC will consistently be overestimated.

The Arrowtooth flounder assessment extrapolates current year catch in October using the 5-year average of catch taken between October 17 and December 31 in the last five complete catch years (e.g. 2016-2020). The 2021 catch through October 17, 2021 was 9,103 t. The total catch in 2021 was estimated to be 10,052 t based on the proportion caught through this date for the past 5 years (91%).

Overfishing Definition

Based on the definitions for overfishing in Amendment 44 in Tier 3a (i.e., $F_{OFL} = F_{35\%}$ =0.225), the overfishing limit is set equal to 143,100 t in 2022 and 141,231 t in 2023 for GOA Arrowtooth flounder.

Data Gaps and Research Priorities

We recommend studies on genetic population structure of Arrowtooth flounder, as stock structure has not been examined in this species. Analysis of the herding and escapement studies for Arrowtooth flounder would result in improved estimates of selectivities and catchability. Otoliths have been aged through the 2019 survey, but continued aging will allow monitoring of growth trends. Some fishery ages are available, although sporadic, and it may be useful to include those in the model in the future or to request more samples be collected in future years. A correlation between bottom temperatures and catchability has been observed in Arrowtooth flounder and other flatfish; whether a similar relationship exists for GOA Arrowtooth flounder would provide helpful information for the estimation of catchability. In addition, an examination of catchability may benefit the model. In the future, we may plan to explore the utility of model-based survey time series (e.g., VAST model) as a way to integrate the additional surveys that may be useful to include for the GOA Arrowtooth flounder model (e.g., AFSC longline survey or IPHC longline survey). Growth and age-length conversion matrices have not been updated for several years and should be revisited in future assessments. Additionally, we plan to investigate the lack of fit in female survey age and fishery length compositions, potentially examining the interaction between female natural mortality and selectivity. The GOA CEATTLE model is now more developed and has potential to provide a gap-free index of predation mortality for GOA Arrowtooth flounder (Adams et al., 2021). We will consider exploring incorporating estimates of predation mortality from the most recent GOA CEATTLE model and will include efforts to streamline data pulls and processing between the single and multi-species models. Investigation into the proper weighting for sample sizes is ongoing and we plan to use "best practices" guidance on this topic when it becomes available. We may also explore using the dirichlet-multinomial in the future to better estimate effective sample size for the composition data.

Ecosystem Considerations

Please see Appendix B for more details on ecosystem considerations for Arrowtooth flounder in the GOA. Also please see Appendix C for more details on the economic performance of flatfish fisheries in the GOA. In the future, we plan to investigate ecosystem and socioeconomic considerations through the Ecosystem and Socioeconomic Profile or ESP framework. The ESP provides a unique opportunity to explore unaccounted-for uncertainty through an ecosystem and socioeconomic approach to fisheries management. The new data in this updated model includes some promising signs for an above-average 2017 year class which is concurrent with a cooler year in the GOA following the 2014-2016 marine heatwaves and suggests improved conditions for Arrowtooth young-of-the-year during 2017. Recruitment trends could be explored within the ESP.

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Tables

Table 7.1: Survey estimates of biomass in the four Gulf of Alaska regulatory areas, Western GOA (NMFSarea 610), Central GOA (620 and 630), West Yakutat, and East Yakutat/SE Alaska.

Year	Western		Central		West Yakutat		East Yakutat/SE	
	Biomass	CV	Biomass	CV	Biomass	CV	Biomass	CV
2003	341,620	0.13	2,195,096	0.17	94,184	0.27	188,195	0.19
2005	215,278	0.14	1,440,854	0.08	122,390	0.30	121,064	0.30
2007	263,856	0.13	1,434,851	0.09	104,952	0.38	132,361	0.34
2009	285,427	0.19	1,201,756	0.12	114,665	0.30	170,181	0.25
2011	225,683	0.15	1,175,072	0.14	91,580	0.42	255,004	0.25
2013	205,752	0.24	763,845	0.14	196,318	0.22	124,812	0.28
2015	237,919	0.14	912,713	0.12	129,075	0.29	381,574	0.17
2017	311,318	0.12	519,312	0.09	76,627	0.36	146,437	0.26
2019	275,024	0.12	585,238	0.08	70,680	0.29	145,785	0.20
2021	362,567	0.17	620,495	0.08	53,915	0.21	95,215	0.16

Table 7.2. Random effects model applied to survey biomass estimates in the four Gulf of Alaska regulatory areas, Western GOA (NMFS area 610), Central GOA (620 and 630), West Yakutat, and East Yakutat/SE Alaska.

Year	Western		Central		West Yakutat		East Yakutat/SE	
	Biomass	CV	Biomass	CV	Biomass	CV	Biomass	CV
2003	287,222	0.13	1,915,530	0.15	102,457.0	0.22	178,904.0	0.18
2004	274,953	0.09	1,681,560	0.14	106,860.0	0.22	157,627.0	0.27
2005	263,207	0.09	1,476,160	0.07	111,452.0	0.20	138,880.0	0.23
2006	262,428	0.09	1,443,210	0.13	111,763.0	0.22	141,510.0	0.29
2007	261,652	0.08	1,410,990	0.08	112,075.0	0.21	144,190.0	0.24
2008	260,382	0.09	1,310,600	0.13	114,374.0	0.22	157,963.0	0.28
2009	259,119	0.09	1,217,350	0.10	116,721.0	0.20	173,052.0	0.20
2010	255,146	0.10	1,159,600	0.14	120,000.0	0.22	194,574.0	0.27
2011	251,233	0.12	1,104,590	0.11	123,372.0	0.21	218,773.0	0.21
2012	252,021	0.13	963,445	0.14	135,546.0	0.21	195,376.0	0.27
2013	252,812	0.13	840,336	0.11	148,922.0	0.20	174,481.0	0.24
2014	257,271	0.11	834,002	0.14	133,199.0	0.21	234,729.0	0.26
2015	261,808	0.10	827,716	0.10	119,136.0	0.19	315,782.0	0.18
2016	271,964	0.08	678,667	0.13	102,902.0	0.21	232,000.0	0.25
2017	282,513	0.08	556,458	0.09	88,880.0	0.20	170,447.0	0.21
2018	285,733	0.09	570,699	0.13	80,216.7	0.21	154,946.0	0.26
2019	288,990	0.09	585,303	0.07	72,397.9	0.19	140,854.0	0.17
2020	296,057	0.11	600,576	0.13	66,028.5	0.21	118,529.0	0.25
2021	303,298	0.14	616,248	0.08	60,219.5	0.19	99,742.3	0.15

Table 7.3. Catch, OFL, ABC, and TAC for Arrowtooth Flounder in the Gulf of Alaska from 1964 to October 17, 2021. Values are in metric tons. Arrowtooth Flounder ABC was separated from the Flatfish ABC after 1990. Source: AKFIN database (https://akfinbi.psmfc.org/analytics/). Catch value for 2021 is accurate as of October 17, 2021.

Year	Catch	OFL	ABC	TAC	Year	Catch	OFL	ABC	TAC
1964	514				2001	19,964	173,546	148,151	38,000
1965	514				2002	21,231	171,057	146,264	38,000
1966	2,469				2003	29,994	181,394	155,139	38,000
1967	2,276				2004	15,304	228,134	194,900	38,000
1968	1,697				2005	19,770	228,134	194,900	38,000
1969	1,315				2006	27,653	207,700	177,800	38,000
1970	1,886				2007	25,494	214,828	184,008	43,000
1971	1,185				2008	29,293	266,914	226,470	43,000
1972	4,477				2009	24,937	261,022	221,512	43,000
1973	10,007				2010	24,268	254,271	215,882	43,000
1974	4,883				2011	30,903	251,068	213,150	43,000
1975	2,776				2012	20,565	250,100	212,882	103,300
1976	3,045				2013	21,612	247,196	210,451	103,300
1977	9,449				2014	36,300	229,248	195,358	103,300
1978	8,409				2015	19,056	226,390	192,921	103,300
1979	7,579				2016	19,835	219,430	186,188	103,300
1980	7,848				2017	26,866	219,327	186,083	103,300
1981	7,433				2018	18,873	180,697	150,945	76,300
1982	4,639				2019	20,061	174,598	145,841	99,295
1983	6,331				2020	21,122	153,017	128,060	96,969
1984	3,457				2021	9,103	151,723	126,970	97,372
1985	1,539								
1986	1,221								
1987	4,963								
1988	5,138								
1989									
1990	7,706		343,300						
1991	10,034		340,100	20,000					
1992									
1993	15,970	427,220	303,889	25,000					
1994	15,559	451,690	321,287	30,000					
1995	23,560	275,930	236,240	30,000					
1996	22,583	231,420	198,130	35,000					
1997	16,319	280,800	197,840	35,000					
1998	12,975	295,970	208,337	35,000					
1999	16,207	308,875	217,106	35,000					
2000	24,252	173,915	145,361	35,000					

Table 7.4. Catch (t) of Arrowtooth flounder as bycatch in other fisheries from 1991 - present. Other fisheries and Atka Mackerel category not included due to confidentiality (# vessels or # processors is fewer than or equal to 2). Source: NMFS AKRO Blend/Catch Accounting System via AKFIN 10/30/2021.

Year	Flatfish	Halibut	Pacific Cod	Pollock	Rockfish	Sablefish
1991	3,202		283	1,375	2,941	197
1992	11,295		3,005	1,314	3,657	1,235
1993	12,919		1,970	862	1,044	1,702
1994	16,656		3,191	Conf.	898	979
1995	12,344		2,795	380	1,671	1,076
1996	17,842		1,341	Conf.	2,062	612
1997	10,976		3,034	Conf.	1,233	506
1998	8,267		2,113	Conf.	1,709	561
1999	7,849		4,000	Conf.	2,378	699
2000	17,856		2,165	Conf.	2,417	840
2001	10,641		4,777	Conf.	1,532	494
2002	18,076		590	Conf.	1,422	464
2003	25,616	50	1,214	659	1,350	254
2004	10,475	47	1,715	1,162	2,020	242
2005	15,597	61	765	2,312	961	274
2006	22,491	36	1,029	2,747	1,085	351
2007	21,201	80	1,433	1,631	688	474
2008	23,647	29	3,007	1,569	517	500
2009	22,658	59	757	759	497	179
2010	20,729	36	373	2,495	707	156
2011	27,843	7	564	2,019	341	181
2012	17,521	5	791	1,341	763	194
2013	17,161	81	1,398	1,784	766	337
2014	30,750	36	1,310	2,598	1,426	190
2015	14,626	28	1,092	1,758	1,397	181
2016	15,828	17	1,354	1,290	1,197	134
2017	23,516	41	489	1,335	1,416	99
2018	14,922	42	95	2,668	761	335
2019	21,428	39	238	2,019	733	125
2020	17,426	28	51	2,417	890	311
2021	5,862	27	42	645	2,452	75
Average	16,685	39	1,515	1,446	1,385	450

Table 7.5. Incidental catch of FMP groundfish species caught in Arrowtooth flounder target fishery in the Gulf of Alaska from 2017 - 2021. Conf. = Confidential data since # vessels or # processors is fewer than or equal to 2. Source: NMFS AKRO Blend/Catch Accounting System via AKFIN 10/30/2021.

Group Name	2017	2018	2019	2020	2021	Average
Arrowtooth Flounder	22,879	14,317	20,500	16,615	5,416	15,945
Pacific Ocean Perch	3,260	531	1,694	956	672	1,423
Flathead Sole	1,451	1,545	1,856	1,318	214	1,277
Pacific Cod	1,256	880	1,439	1,237	373	1,037
Pollock	1,093	1,807	1,501	579	115	1,019
GOA Rex Sole	1,049	925	932	710	112	746
Sablefish	647	1,196	955	494	273	713
GOA Shallow Water Flatfish	385	534	726	679	35	472
GOA Skate, Big	319	464	579	498	24	377
GOA Dusky Rockfish	304	132	291	105	208	208
Shark	300	251	320	53	37	192
GOA Skate, Longnose	191	270	285	176	21	189
Northern Rockfish	154	130	420	66	70	168
Atka Mackerel	61	130	266	Conf.	Conf.	143
GOA Skate, Other	187	136	138	45	20	105
GOA Rougheye Rockfish	79	131	106	87	22	85
GOA Deep Water Flatfish	148	62	30	53	29	64
Sculpin	104	34	136	14		72
GOA Thornyhead Rockfish	15	18	77	37	24	34
Other Rockfish	61	8	41	14	17	28
Octopus	2	9	32	32	Conf.	15
GOA Shortraker Rockfish	19	13	21	13	Conf.	15
Squid	1	2				2

Table 7.6. Non-FMP species bycatch estimates in tons for Gulf of Alaska Arrowtooth flounder fishery 2017 - 2021. Conf. = Confidential data since # vessels or # processors is fewer than or equal to 2. Source: NMFS AKRO Blend/Catch Accounting System via AKFIN 10/30/2021.

Group Name	2017	2018	2019	2020	2021
Benthic urochordata	1.57	Conf.	-	0.02	Conf.
Birds - Northern Fulmar	-	-	-	-	-
Bivalves	0.03	0.20	0.25	Conf.	Conf.
Brittle star unidentified	0.06	0.06	0.07	0.00	Conf.
Capelin	0.14	3.89	0.47	Conf.	
Corals Bryozoans – Corals Bryozoans Unidentified	0.13	Conf.	0.19	0.19	0.37
Eelpouts	2.29	0.55	0.72	2.56	0.26
Eulachon	4.07	7.84	8.27	2.45	0.46
Giant Grenadier	86.37	Conf.	Conf.	80.07	1.34
Greenlings	0.57	0.59	0.87	0.74	0.39
Grenadier - Rattail Grenadier Unidentified	10.22	Conf.	Conf.		0.24
Gunnels	0.00				
Hermit crab unidentified	0.11	0.16	0.02	Conf.	0.08
Invertebrate unidentified	0.09	0.33	Conf.		0.02
Misc crabs	0.04	0.03	0.03	0.04	Conf.
Misc crustaceans	0.49	Conf.	2.21	0.08	0.00
Misc deep fish			Conf.		
Misc fish	75.30	116.24	137.32	109.21	18.27
Misc inverts (worms etc)				0.02	
Other osmerids	1.76	0.23		0.22	
Pacific Hake	0.49		Conf.	0.04	
Pacific Sand lance		Conf.	0.13	Conf.	0.01
Pacific Sandfish			Conf.		
Pandalid shrimp	2.22	4.68	14.35	12.31	0.07
Polychaete unidentified	0.02		Conf.		
Saffron Cod			Conf.		
Sculpin					18.88
Scypho jellies	0.97	0.61	13.44	3.12	1.80
Sea anemone unidentified	0.70	1.02	1.00	0.33	Conf.
Sea pens whips	0.03	Conf.	Conf.		
Sea star	32.21	41.77	19.25	5.90	11.25
Snails	0.95	0.45	1.73	0.11	Conf.
Sponge unidentified	0.23	Conf.	Conf.	0.23	0.13
Squid			4.64	44.09	4.96
State-managed Rockfish	0.17	1.75	Conf.	0.15	0.36
Stichaeidae	0.59	0.14	0.76	0.45	0.03
urchins dollars cucumbers	2.24	1.07	0.87	0.81	0.76

Table 7.7: Percent of the Arrowtooth Flounder in the GOA discarded and retained by commercial fishing operations 1991-2021. Source: AKFIN database (https://akfinbi.psmfc.org/analytics/). Data downloaded October 30, 2021.

Year	Percent discarded	Percent retained
1991	87.5	12.5
1992	97.7	2.3
1993	91.9	8.1
1994	98.0	2.0
1995	87.6	12.4
1996	75.8	24.2
1997	81.8	18.2
1998	84.1	15.9
1999	73.6	26.4
2000	57.4	42.6
2001	66.8	33.2
2002	50.3	49.7
2003	56.8	43.2
2004	57.7	42.3
2005	39.9	60.1
2006	42.2	57.8
2007	40.8	59.2
2008	29.9	70.1
2009	48.5	51.5
2010	40.8	59.2
2011	21.4	78.6
2012	23.0	77.0
2013	24.7	75.3
2014	9.4	90.6
2015	10.4	89.6
2016	8.5	91.5
2017	7.1	92.9
2018	8.1	91.9
2019	5.2	94.8
2020	6.0	94.0
2021	12.9	87.1

Table 7.8: The number of fisheries length observations taken by fisheries observers, and the number of hauls from which those samples were taken, by year, 1975-2021 (Source: AKFIN database 10/17/2021).

			Weights applied to fishery length comps	
Year	Number of Observations	Number of Hauls	Females	Males
1977	868		20	20
1978	5,491		20	20
1979	9,499		20	20
1980	4,500		20	20
1981	2,062		20	20
1982	19,139		20	20
1983	14,963		20	20
1984	7,149		20	20
1985	671		20	20
1986	194		20	20
1987	763		20	20
1988	211		20	20
1990	217	48	7	7
1991	5,892	151	95	89
1992	198	5	2	2
1993	1,223	26	12	12
1995	2,628	2	10	10
1996	889	19	15	15
1997	2,999	20	14	14
1998	472	38	6	4
1999	2,642	83	129	122
2000	6,351	193	200	200
2001	6,269	479	200	200
2002	8,275	527	200	200
2003	15,054	658	200	200
2004	4,961	1075	200	200
2005	7,073	517	200	200
2006	8,413	496	200	200
2007	10,004	511	200	200
2008	9,271	501	200	200
2009	8,406	544	200	200
2010	7,600	378	200	200
2011	11,282	396	200	200
2012	9,583	640	200	200
2013	8,182	573	200	200
2014	16,346	621	200	200
2015	11,848	928	200	200
2016	10,979	617	200	200
2017	15,502	582	200	200
2018	7,009	818	200	200
2019	9,223	1981	200	200
2020	7172	2474	200	200
2021	1763	2138	200	200

Table 7.9: Biomass estimates, standard errors, coefficient of variation (CV), number of hauls, and maximum depth (m) from bottom trawl surveys, 1961-2021. *The 2001 survey biomass for the eastern GOA was estimated by using the average of the 1993 to 1999 biomass estimates in eastern GOA.

Survey	Biomass (t)	Standard error	CV	Number of hauls	Maximum depth (m)
NMFS triennial 1984	1,112,215	72,576	0.07	929	1,000
NMFS triennial 1987	931,598	73,963	0.08	783	1,000
NMFS triennial 1990	1,907,177	244,308	0.13	708	500
NMFS triennial 1993	1,553,616	100,227	0.06	775	500
NMFS triennial 1996	1,639,632	114,633	0.07	807	500
NMFS triennial 1999	1,262,151	99,311	0.08	764	1,000
NMFS 2001	1,621,892*	178,408	0.11	489	500
NMFS 2003	2,819,095	370,652	0.13	809	700
NMFS 2005	1,899,587	125,802	0.07	835	1,000
NMFS 2007	1,936,020	150,086	0.08	820	1,000
NMFS 2009	1,772,029	159,402	0.09	823	1,000
NMFS 2011	1,747,339	179,800	0.10	670	700
NMFS 2013	1,290,727	130,349	0.10	548	700
NMFS 2015	1,661,281	134,018	0.08	772	1,000
NMFS 2017	1,053,695	76,190	0.07	536	700
NMFS 2019	1,076,727	67,327	0.06	541	700
NMFS 2021	1,132,192	83,427	0.07	529	700

Table 7.10: Survey biomass estimates (t) for 1984 to 2021 by area; Western (NMFS area 610), Central (areas 620 and 630), and Eastern (areas 640, 650, 649, 659). The 2001 survey biomass for the eastern GOA was estimated by using the average of the 1993 to 1999 biomass estimates in the eastern GOA.

Year	Western GOA	Central GOA	Eastern GOA	Total
1984	72,863	823,216	216,136	1,112,215
1987	118,584	647,596	165,418	931,598
1990	221,858	1,504,638	180,681	1,907,177
1993	214,240	1,117,361	222,015	1,553,616
1996	202,594	1,176,714	260,324	1,639,632
1999	143,374	845,176	273,601	1,262,151
2001	185,432	1,175,305	251,980	1,360,738
2003	341,620	2,195,096	282,379	2,819,095
2005	215,278	1,440,854	243,454	1,899,587
2007	263,856	1,434,851	237,313	1,936,020
2009	285,427	1,201,756	284,846	1,772,029
2011	225,683	1,175,072	346,584	1,747,339
2013	205,752	763,845	321,130	1,290,727
2015	237,919	912,713	510,649	1,661,281
2017	311,318	519,312	223,065	1,053,695
2019	275,024	585,238	216,465	1,076,727
2021	362,567	620,495	149,130	1,132,192

Table 7.11: The number of aged fish for collection years from 1987-2019. The methods of otolith reading are as follows: B = break-and-burn, M = burn and toast, S = otolith surface reading, U = unburned cross section, and V = break-and-toast. Note: fish collected from the 2017 GOA survey have not been aged yet. The ageing collection includes 13,420 total fish, but only 12,308 fish had both age and length data and could therefore be used to construct the length age conversion matrix.

Ageing Method							
Year	B	M	S	U	V	Unknown	Total
1984						1,293	1,293
1987	600	1	378	133	422		1,534
1990	232		93				325
1993	679		363				1,042
1996	239		452			11	702
1999	153		322		456		931
2001	62		684		638		1,384
2003	236		380	1	417		1,034
2005	1	29	230	20	449		729
2007	3		38	21	724		786
2009	590		212	20			822
2011	52	2	77	29	739		899
2013	1		254	16	551		822
2015			177	15	425		617
2017	4		163	9	721		897
2019	3		226	17	650		896
Total	2,855	32	4,049	281	6,192		13,420

Table 7.10: Length data (cm) from NMFS GOA surveys in 1984 through 2021. The numbers are percentages, where the numbers add to 100 within a year for each sex. Please note this data is not fit in the author recommended model.

	Females																								
Year	10	16	18	20	22	24	26	28	30	32	34	36	38	40	43	46	49	52	55	58	61	64	67	70	75	75+
1984	0.00	0.07	0.08	0.14	0.67	1.23	2.08	2.21	2.01	2.99	3.51	4.00	4.19	7.50	16.17	15.42	9.93	7.10	5.29	3.79	3.23	2.96	2.81	1.72	0.76	0.13
1987	0.00	0.05	0.17	0.50	1.59	2.09	2.05	2.59	4.82	5.17	4.75	4.50	5.21	4.64	6.25	7.38	9.55	12.10	9.67	5.04	2.55	2.01	1.96	2.33	2.48	0.54
1990	0.00	0.10	0.17	0.54	1.20	1.59	2.17	2.58	3.70	4.44	3.99	4.17	4.83	4.94	10.19	10.45	9.84	8.31	7.68	5.86	4.15	2.90	1.37	1.17	2.11	1.51
1993	0.00	0.10	0.19	1.07	2.38	2.73	2.42	2.51	2.92	3.18	3.49	3.78	3.91	4.51	7.67	8.86	9.47	11.26	11.94	8.19	4.12	2.01	1.19	0.87	0.78	0.43
1996	0.01	0.11	0.26	1.31	2.30	3.17	2.63	2.16	2.69	3.04	3.49	3.47	4.51	5.06	7.87	7.60	8.23	10.81	12.78	8.56	3.98	2.10	1.33	0.89	1.17	0.48
1999	0.01	0.15	0.43	2.00	3.34	2.59	2.42	3.93	4.55	4.32	4.57	5.01	4.84	4.41	5.84	5.40	6.54	8.05	10.13	9.85	5.57	2.50	1.44	0.94	0.72	0.45
2001	0.01	0.07	0.31	2.06	4.58	5.32	3.25	2.61	3.46	4.21	3.75	3.95	4.48	4.27	6.54	7.16	7.73	7.95	7.27	7.45	5.39	2.98	1.78	1.29	1.66	0.46
2003	0.00	0.37	0.39	1.59	3.27	3.10	2.79	3.11	3.86	4.96	5.44	5.10	5.34	4.88	6.06	5.71	5.90	7.45	10.13	9.69	5.78	2.45	1.15	0.52	0.63	0.33
2005	0.01	0.30	0.42	1.22	1.59	1.63	2.70	3.50	3.79	4.26	4.97	5.75	6.62	7.38	11.07	9.52	8.57	6.70	6.37	5.81	3.65	1.88	0.95	0.58	0.50	0.27
2007	0.03	0.07	0.44	1.59	2.69	2.28	2.62	3.69	4.41	4.27	3.32	3.28	3.31	3.98	6.62	7.81	10.77	13.13	10.36	6.71	4.15	2.07	0.96	0.59	0.45	0.41
2009	0.00	0.13	0.53	2.41	3.29	2.54	2.32	3.50	4.62	5.24	5.16	5.30	5.00	5.15	6.51	5.52	6.48	9.59	12.17	7.51	3.62	1.64	0.82	0.41	0.35	0.19
2011	0.03	0.13	0.10	0.37	1.30	2.00	1.97	2.06	2.90	3.50	3.27	4.10	4.73	4.71	7.92	8.55	9.85	10.67	12.58	9.23	5.40	2.25	1.01	0.58	0.51	0.28
2013	0.02	0.63	0.31	0.55	1.97	4.03	4.33	3.82	3.75	4.00	3.53	2.88	2.87	4.23	7.00	8.53	11.43	12.81	10.29	7.43	3.33	1.19	0.44	0.20	0.28	0.16
2015	0.02	0.15	0.25	0.60	1.25	2.86	4.15	5.81	7.22	8.38	6.84	4.37	3.76	3.38	5.30	5.30	7.80	10.24	10.29	6.74	3.34	1.13	0.42	0.20	0.13	0.06
2017	0.01	0.20	0.35	1.47	2.34	3.33	3.67	3.33	4.34	4.71	5.47	6.32	7.20	7.99	9.77	7.91	6.94	7.09	6.29	4.56	3.09	2.02	0.89	0.40	0.22	0.09
2019	0.00	0.33	0.41	1.70	4.61	5.69	5.71	5.39	5.70	6.43	5.55	5.08	4.89	4.83	7.30	8.13	9.18	7.39	4.34	2.40	1.69	1.36	1.02	0.59	0.20	0.05
2021	0.00	0.22	0.18	0.88	2.50	3.24	3.30	3.86	5.77	6.27	6.23	6.75	7.05	6.77	9.20	7.99	8.12	9.00	6.48	2.82	1.33	0.77	0.57	0.39	0.27	0.06

	Males																								
Year	10	16	18	20	22	24	26	28	30	32	34	36	38	40	43	46	49	52	55	58	61	64	67	70	75	75+
1984	0.00	0.27	0.18	0.45	1.17	2.47	3.88	4.99	5.29	6.03	7.26	8.81	12.46	16.74	17.46	8.45	2.56	0.68	0.26	0.19	0.10	0.07	0.13	0.05	0.02	0.02
1987	0.00	0.42	0.37	1.06	2.08	3.39	3.20	4.70	8.28	9.50	8.91	10.17	9.02	8.68	14.13	10.22	3.65	1.16	0.49	0.34	0.08	0.09	0.03	0.02	0.01	0.00
1990	0.00	0.16	0.21	0.77	1.63	2.20	2.83	3.79	5.57	6.07	7.08	7.48	8.46	10.62	18.01	16.17	7.04	1.34	0.38	0.10	0.02	0.03	0.01	0.02	0.00	0.00
1993	0.00	0.16	0.54	2.06	3.68	3.47	3.15	3.76	4.05	4.19	4.28	4.84	6.10	8.14	16.83	18.34	12.43	3.03	0.49	0.17	0.18	0.04	0.05	0.02	0.00	0.00
1996	0.01	0.28	0.54	1.87	4.05	4.19	3.24	2.77	3.46	4.09	4.88	5.74	6.33	7.32	12.32	17.42	14.95	5.29	0.90	0.14	0.10	0.06	0.01	0.03	0.01	0.00
1999	0.05	0.36	0.76	3.51	5.32	3.73	3.50	5.58	6.03	5.92	5.84	6.11	5.93	6.21	10.08	13.25	11.46	5.35	0.74	0.16	0.08	0.01	0.01	0.01	0.00	0.00
2001	0.02	0.21	0.79	4.76	8.87	7.47	4.13	4.66	6.07	5.70	5.54	5.66	5.65	5.55	10.01	9.92	9.16	4.95	0.87	0.02	0.01	0.00	0.00	0.00	0.00	0.00
2003	0.00	1.20	0.73	4.26	6.42	5.25	4.46	4.22	5.59	7.51	7.56	7.57	8.24	6.07	9.18	9.25	6.67	4.40	1.07	0.30	0.02	0.00	0.02	0.00	0.01	0.00
2005	0.01	0.75	1.05	2.09	3.24	3.08	4.43	4.91	5.47	5.75	6.43	7.22	10.03	10.26	15.60	9.79	6.01	2.88	0.82	0.11	0.04	0.02	0.00	0.01	0.01	0.00
2007	0.01	0.13	0.78	2.45	3.60	2.97	3.74	5.53	6.52	5.81	4.77	4.40	5.09	7.51	19.07	16.54	7.37	2.71	0.85	0.11	0.01	0.01	0.01	0.00	0.00	0.00
2009	0.02	0.34	1.26	4.15	4.87	4.12	3.45	5.29	6.28	7.95	7.30	6.65	6.72	6.74	11.23	12.63	7.25	2.73	0.79	0.19	0.01	0.01	0.01	0.00	0.01	0.00
2011	0.00	0.20	0.36	0.65	2.48	3.62	2.95	3.71	5.34	5.37	5.46	6.06	7.51	8.31	16.77	16.14	10.82	3.50	0.63	0.05	0.04	0.01	0.00	0.00	0.01	0.00
2013	0.01	0.33	0.30	0.80	3.42	4.32	4.56	5.14	4.86	5.04	4.17	4.58	5.88	7.48	15.91	17.14	10.75	4.57	0.55	0.18	0.01	0.01	0.00	0.00	0.00	0.00
2015	0.00	0.19	0.28	0.63	2.20	3.39	5.07	6.82	9.03	9.15	6.03	4.65	5.22	5.41	11.71	14.20	10.54	4.45	0.85	0.14	0.02	0.01	0.00	0.01	0.00	0.00
2017	0.02	0.27	0.56	2.00	3.38	4.68	5.46	6.51	6.17	7.03	7.72	9.54	9.80	9.14	10.61	9.31	5.95	1.62	0.13	0.05	0.02	0.00	0.01	0.00	0.00	0.00
2019	0.00	0.44	0.57	2.07	5.03	6.42	6.43	6.19	7.15	7.56	6.75	6.32	7.27	8.49	14.81	8.98	4.10	1.12	0.18	0.05	0.02	0.03	0.00	0.00	0.00	0.00
2021	0.00	0.31	0.30	1.12	3.56	4.77	3.97	5.20	7.68	7.09	6.18	8.07	8.83	10.29	14.76	10.80	5.43	1.35	0.25	0.02	0.01	0.00	0.00	0.00	0.00	0.00

Table 7.11: The number of male and female Arrowtooth flounder lengths recorded on NMFS GOA surveys, 1984-2021. Please note this data is not fit in the author recommended model.

Year	Females	Males
1984	10,254	5,682
1987	12,741	6,359
1990	12,215	5,921
1993	14,543	6,855
1996	15,448	7,936
1999	15,350	8,076
2001	9,434	4,624
2003	16,879	9,052
2005	17,147	8,680
2007	15,058	7,883
2009	15,468	8,287
2011	12,019	6,518
2013	8,169	4,531
2015	13,178	7,834
2017	9,136	5,393
2019	9,749	6,084
2021	9,376	5,611

Table 7.12: Parameters estimated outside the model, natural mortality, survey catchability, and weight at age.

Parameter name	Description
M = 0.2 females, M = 0.35 males	Natural mortality
Q = 1.0	Survey catchability
Weight at age for males and females	Length at age derived from the length-age conversion matrix was converted to weight based on a von Bertalanffy relationship from 1977-2013 survey data.

Table 7.13: Estimated parameters for the model. There were 157 total parameters estimated in the model.

Parameter name	Number	Description
meanlogrec	1	Log of the geometric mean value of age 1 recruitment
recdevt	44	Recruitment deviation in year t (not estimated in final year)
recdevt_init	21	Recruitment deviation for initial age composition
logavgfmort	1	Log of geometric mean value of fishing mortality
fmortdevt	45	Deviations in fishing mortality rate in year t
Survey selectivity	4	Slope and age at 50% selectivity for male and female logistic survey selectivity curve
Nonparametric estimates of fishery selectivity	38	19 male and 19 female fishery selectivity parameters, one for each age and constrained to smooth function; total of 38
$F_{40\%}$, $F_{35\%}$, $F_{30\%}$	3	

Table 7.14. Negative log likelihoods for the last full assessment model and the current author preferred model for GOA Arrowtooth flounder. Note that the amounts of data differ between the 2019 and 2021 model update so likelihood component values are not comparable between models.

	Model 19.0 (2019)	*Model 19.0 (2021)*
Total -log(Likelihood)		
Catch	0.00000004	0.00000004
Recruitment	4.9668	5.03702
GOA survey biomass	28.4486	27.8613
GOA survey age comp	250.048	276.906
Survey length comp	92.2046	0
Fishery length comp	796.457	816.166
Priors/Penalties	20.1857	21.1585
Fishery selectivity	1.46121	1.70207
Survey selectivity	5.59412	5.59649
Number of parameters	161	165
Total Likelihood	183.487	177.674

Table 7.15: Estimated total (age 1+) biomass (t) and female spawning biomass (FSB) (t), does not include projected estimates.

	Model 19.0 (2019)	Model 19.0 (2021)	Model 19.0 (2019)	Model 19.0 (2021)
Year	Biomass	Biomass	FSB	FSB
1977	1,216,610	1,226,840	718,407	724,860
1978	1,211,520	1,217,860	711,689	718,291
1979	1,215,610	1,215,790	704,950	711,867
1980	1,223,200	1,216,170	697,756	704,909
1981	1,227,650	1,213,430	689,831	696,755
1982	1,229,490	1,208,420	683,641	689,392
1983	1,234,170	1,207,420	683,842	686,996
1984	1,245,340	1,215,980	688,408	687,252
1985	1,280,690	1,254,240	700,123	693,367
1986	1,329,640	1,310,620	713,236	700,724
1987	1,388,170	1,377,880	721,912	704,607
1988	1,452,610	1,449,450	723,910	703,325
1989	1,519,020	1,521,260	728,942	707,227
1990	1,580,890	1,586,480	747,723	728,190
1991	1,634,520	1,640,990	778,416	765,076
1992	1,678,640	1,677,300	818,508	807,847
1993	1,700,620	1,692,930	857,027	849,487
1994	1,711,580	1,699,800	895,568	890,076
1995	1,706,970	1,695,590	923,509	920,516
1996	1,701,290	1,689,520	948,093	945,287
1997	1,696,340	1,683,200	962,028	958,265
1998	1,714,770	1,700,040	974,345	969,222
1999	1,753,150	1,736,690	979,604	973,447
2000	1,818,330	1,800,450	973,346	966,484
2001	1,865,510	1,846,490	957,801	950,339
2002	1,908,910	1,889,030	950,070	941,897
2003	1,937,550	1,916,920	952,762	943,549
2004	1,947,320	1,926,290	966,679	956,312
2005	1,964,790	1,943,540	1,011,570	1,000,360
2006	1,966,630	1,945,340	1,062,000	1,050,130
2007	1,940,850	1,919,540	1,096,690	1,084,240
2008	1,903,920	1,882,570	1,112,470	1,099,520
2009	1,844,400	1,823,200	1,108,960	1,095,640
2010	1,776,750	1,755,930	1,101,150	1,087,590
2011	1,708,910	1,687,840	1,090,360	1,076,310
2012	1,639,270	1,618,680	1,066,940	1,052,990
2013	1,586,650	1,566,580	1,040,800	1,027,160
2014	1,533,040	1,513,960	1,002,030	988,811
2015	1,463,320	1,446,290	942,076	929,268
2016	1,418,830	1,402,090	895,422	883,013
2017	1,378,080	1,363,850	854,232	842,156
2018	1,358,200	1,336,650	817,371	805,638
2019	1,333,540	1,314,860	794,350	783,231
2020	-	1,294,430	-	757,054
2021	-	1,267,240	-	730,753

Table 7.16: Estimated total (age 1+) total biomass (t), and female spawning biomass (FSB) (t), based on MCMC runs for Model 19.0 (2021). Lower 95% and upper 95% credible intervals (CIs) are provided.

Year	Biomass	Lower CI	Upper CI	FSB	Lower CI	Upper CI
1977	1,240,840	994,535	1,504,796	742,761	539,622	982,265
1978	1,232,735	1,013,738	1,474,406	733,642	542,275	950,340
1979	1,233,251	1,039,921	1,444,329	724,165	547,738	922,561
1980	1,237,742	1,067,127	1,424,001	714,289	551,648	894,152
1981	1,238,555	1,089,594	1,399,633	703,848	556,680	869,121
1982	1,236,645	1,105,659	1,381,444	695,398	560,326	840,697
1983	1,237,119	1,116,347	1,370,552	693,468	572,530	820,054
1984	1,244,012	1,128,809	1,370,491	696,074	588,774	809,073
1985	1,273,372	1,157,740	1,398,053	705,916	610,601	804,808
1986	1,318,691	1,196,926	1,445,201	717,090	634,844	804,982
1987	1,375,212	1,242,930	1,509,784	723,622	650,445	803,509
1988	1,438,441	1,298,650	1,579,176	723,034	654,990	799,379
1989	1,504,913	1,361,816	1,650,717	725,245	657,339	801,925
1990	1,567,424	1,423,573	1,709,776	740,912	669,654	818,443
1991	1,621,289	1,477,134	1,762,440	768,605	690,474	851,695
1992	1,658,859	1,516,419	1,797,452	800,987	712,472	893,841
1993	1,676,301	1,537,699	1,812,236	835,243	740,018	935,150
1994	1,684,742	1,550,725	1,821,941	872,747	772,236	974,112
1995	1,682,256	1,551,501	1,820,540	903,533	803,047	1,004,431
1996	1,677,537	1,546,880	1,817,261	930,485	834,666	1,026,572
1997	1,672,433	1,541,028	1,815,551	946,290	853,825	1,040,163
1998	1,690,446	1,559,560	1,829,247	960,092	870,414	1,050,990
1999	1,727,265	1,595,592	1,867,501	966,529	879,085	1,056,374
2000	1,791,953	1,660,752	1,929,016	960,849	876,746	1,051,120
2001	1,838,452	1,708,468	1,974,263	945,300	862,830	1,037,157
2002	1,882,026	1,751,802	2,017,050	937,241	854,652	1,029,119
2003	1,911,068	1,779,840	2,049,046	939,098	855,864	1,029,780
2004	1,921,668	1,791,637	2,059,495	951,859	865,655	1,041,971
2005	1,938,875	1,809,916	2,071,791	995,665	909,436	1,084,585
2006	1,941,540	1,812,600	2,074,093	1,045,705	958,389	1,135,455
2007	1,917,033	1,791,287	2,047,875	1,080,609	991,774	1,170,595
2008	1,881,843	1,758,722	2,010,311	1,097,009	1,010,096	1,188,232
2009	1,824,421	1,705,510	1,949,489	1,094,324	1,009,137	1,185,100
2010	1,758,977	1,643,436	1,877,921	1,087,149	1,004,460	1,174,254
2011	1,692,310	1,581,533	1,807,131	1,076,223	995,257	1,162,045
2012	1,624,264	1,517,329	1,732,280	1,053,307	974,038	1,137,183
2013	1,573,538	1,473,790	1,678,812	1,028,362	951,707	1,108,146
2014	1,521,886	1,426,049	1,624,293	991,204	917,101	1,068,562
2015	1,454,678	1,361,588	1,554,554	932,861	861,625	1,007,146
2016	1,410,435	1,319,086	1,508,615	887,589	819,363	958,087
2017	1,371,865	1,277,838	1,471,895	847,341	782,991	914,667
2018	1,344,142	1,243,405	1,450,441	811,201	750,971	875,858
2019	1,323,439	1,215,224	1,440,062	789,217	731,089	853,488
2020	1,308,171	1,179,884	1,451,953	763,363	705,381	826,021
2021	1,284,197	1,137,049	1,462,321	736,937	678,721	798,997

Table 7.17: Estimated age 1 recruitment (x 1,000), from Model 19.0 (2021). Lower 95% and upper 95% credible intervals (CIs) based on MCMC runs. Note 2021 credible intervals not presented, as they are not estimable.

Year	Recruitment	Lower CI	Upper CI
1977	582,420	238,885	1,155,833
1978	641,294	297,996	1,247,098
1979	691,228	339,626	1,268,929
1980	636,376	304,099	1,174,334
1981	546,060	254,080	981,984
1982	527,674	252,337	949,675
1983	596,934	290,467	1,016,042
1984	813,742	392,075	1,302,977
1985	1,187,424	556,453	1,695,094
1986	1,152,620	531,607	1,756,093
1987	1,104,252	523,374	1,771,168
1988	1,124,740	568,846	1,911,814
1989	1,055,272	548,370	1,749,446
1990	905,194	423,943	1,589,155
1991	964,108	487,891	1,629,515
1992	930,370	472,159	1,579,551
1993	743,926	375,956	1,273,742
1994	734,374	351,563	1,223,049
1995	787,372	405,422	1,306,576
1996	765,886	381,841	1,283,473
1997	930,622	497,825	1,492,151
1998	1,203,596	704,875	1,836,199
1999	1,303,134	757,881	1,957,394
2000	1,656,304	1,090,246	2,327,572
2001	1,081,602	623,096	1,641,350
2002	972,888	556,351	1,483,700
2003	888,224	515,967	1,364,766
2004	929,770	541,775	1,435,530
2005	943,978	527,622	1,400,102
2006	883,212	513,810	1,357,960
2007	646,418	361,319	1,048,970
2008	618,376	348,814	1,008,802
2009	462,040	231,273	805,270
2010	451,672	226,626	779,867
2011	578,286	306,905	934,168
2012	689,424	362,128	1,076,017
2013	698,450	410,027	1,090,311
2014	571,098	303,803	937,087
2015	507,486	243,889	845,085
2016	583,086	268,158	1,037,645
2017	637,938	249,714	1,210,711
2018	869,842	312,443	1,713,104
2019	563,286	136,152	1,525,701
2020	670,468	145,443	2,262,823
2021	436,000	-	-

Table 7.18: Estimated age 1 recruitment (1,000's) and fishing mortality (F), from Model 19.0 (2019) and Model 19.0 (2021).

Year	Recruitment (2019)	Recruitment (2021)	F (2019)	F (2021)
1977	605,128	582,420	0.01	0.01
1978	686,990	641,294	0.01	0.01
1979	753,254	691,228	0.01	0.01
1980	687,738	636,376	0.01	0.01
1981	582,398	546,060	0.01	0.01
1982	560,350	527,674	0.01	0.01
1983	617,130	596,934	0.01	0.01
1984	794,548	813,742	0.01	0.01
1985	1,104,574	1,187,424	0	0.00
1986	1,058,484	1,152,620	0	0.00
1987	1,052,612	1,104,252	0.01	0.01
1988	1,126,032	1,124,740	0.01	0.01
1989	1,064,806	1,055,272	0	0.00
1990	920,064	905,194	0.01	0.01
1991	991,674	964,108	0.01	0.02
1992	944,714	930,370	0.02	0.03
1993	751,434	743,926	0.02	0.02
1994	747,804	734,374	0.03	0.03
1995	793,886	787,372	0.02	0.02
1996	774,846	765,886	0.02	0.02
1997	955,058	930,622	0.02	0.02
1998	1,218,528	1,203,596	0.01	0.01
1999	1,320,202	1,303,134	0.02	0.02
2000	1,668,762	1,656,304	0.03	0.03
2001	1,091,764	1,081,602	0.02	0.02
2002	981,680	972,888	0.02	0.02
2003	900,330	888,224	0.03	0.03
2004	939,116	929,770	0.02	0.02
2005	955,116	943,978	0.02	0.02
2006	891,066	883,212	0.03	0.03
2007	652,944	646,418	0.02	0.02
2008	625,840	618,376	0.03	0.03
2009	468,592	462,040	0.02	0.02
2010	456,748	451,672	0.02	0.02
2011	589,224	578,286	0.03	0.03
2012	695,282	689,424	0.02	0.02
2013	705,048	698,450	0.02	0.02
2014	569,194	571,098	0.04	0.04
2015	489,678	507,486	0.02	0.02
2016	612,488	583,086	0.02	0.02
2017	606,838	637,938	0.03	0.03
2018	1,047,082	869,842	0.03	0.03
2019	436,000	563,286	0.03	0.03
2020	-	670,468	-	0.03
2021	-	436,000	-	0.01

Table 7.19 Projected spawning biomass, fishing mortality, and yield for Arrowtooth flounder under seven harvest scenarios (columns) designed to satisfy the requirements of Amendment 56, NEPA, and MSFCMA. Spawning biomass and yield are in t. $B_{40\%}$ = 407,478 t, $B_{35\%}$ = 356,544 t, $F_{40\%}$ = 0.185 and $F_{35\%}$ = 0.225 in 2022. Values are mean/median estimates of 1000 MCMC iterations.

Year	Maximum permissible F	Author's F*	Half maximum F	5-year average F	No fishing	Overfished	Approaching overfished
							Spawning Biomass (t)
2021	717,925	717,925	717,925	717,925	717,925	717,925	717,925
2022	695,708	703,853	700,394	703,688	705,112	693,719	695,708
2023	600,108	691,941	651,274	689,809	707,157	579,617	600,108
2024	531,917	682,043	616,611	684,707	716,567	499,821	530,439
2025	479,360	597,582	588,111	681,098	726,204	440,212	463,630
2026	435,137	526,553	560,489	674,183	731,211	392,340	409,672
2027	400,228	469,632	535,794	666,446	733,944	358,519	368,975
2028	381,960	432,837	521,632	666,707	743,358	345,389	351,501
2029	381,005	415,430	521,270	677,936	762,706	348,167	351,595
2030	386,944	409,226	528,759	694,771	787,056	356,302	358,083
2031	393,727	407,909	538,091	713,116	812,609	363,913	364,743
2032	399,479	408,379	547,338	731,080	837,544	369,486	369,808
2033	403,900	409,385	555,517	747,622	860,692	373,165	373,239
2034	407,424	410,715	562,492	762,596	881,762	375,778	375,744
							Fishing Mortality
2021	0.014	0.014	0.014	0.014	0.014	0.014	0.014
2022	0.185	0.025	0.093	0.028	-	0.225	0.225
2023	0.185	0.022	0.093	0.028	-	0.225	0.225
2024	0.185	0.185	0.093	0.028	-	0.225	0.225
2025	0.185	0.185	0.093	0.028	-	0.225	0.225
2026	0.185	0.185	0.093	0.028	-	0.216	0.216
2027	0.182	0.185	0.093	0.028	-	0.197	0.197
2028	0.173	0.185	0.093	0.028	-	0.189	0.189
2029	0.172	0.183	0.093	0.028	-	0.191	0.191
2030	0.174	0.180	0.093	0.028	-	0.195	0.195
2031	0.176	0.180	0.093	0.028	-	0.199	0.199
2032	0.177	0.179	0.093	0.028	-	0.202	0.202
2033	0.179	0.180	0.093	0.028	-	0.204	0.204
2034	0.179	0.180	0.093	0.028	-	0.205	0.205
							Yield (t)
2021	10,052	10,052	10,052	10,052	10,052	10,052	10,052
2022	119,779	16,991	62,120	19,196	-	143,100	119,779
2023	104,466	14,819	58,140	18,887	-	121,148	104,466
2024	93,270	117,801	55,174	18,736	-	105,483	111,485
2025	85,058	104,146	52,956	18,692	-	94,273	98,812
2026	78,908	93,483	51,195	18,680	-	83,034	89,493
2027	73,176	85,459	49,837	18,679	-	71,554	75,392
2028	67,918	80,279	49,161	18,793	-	67,760	69,888
2029	67,816	76,833	49,325	19,102	-	69,251	70,400
2030	69,968	75,468	50,174	19,600	-	72,804	73,369
2031	72,316	75,551	51,281	20,180	-	76,172	76,401
2032	74,101	75,983	52,275	20,716	-	78,530	78,590
2033	75,464	76,526	53,119	21,189	-	80,047	80,033
2034	76,387	76,977	53,805	21,593	-	80,995	80,956

*Projections are based on estimated catches of 16,991 t and 14,819 t used in place of maximum permissible ABC for 2022 and 2023 in response to a Plan Team request to obtain more accurate two-year projections.

Figures

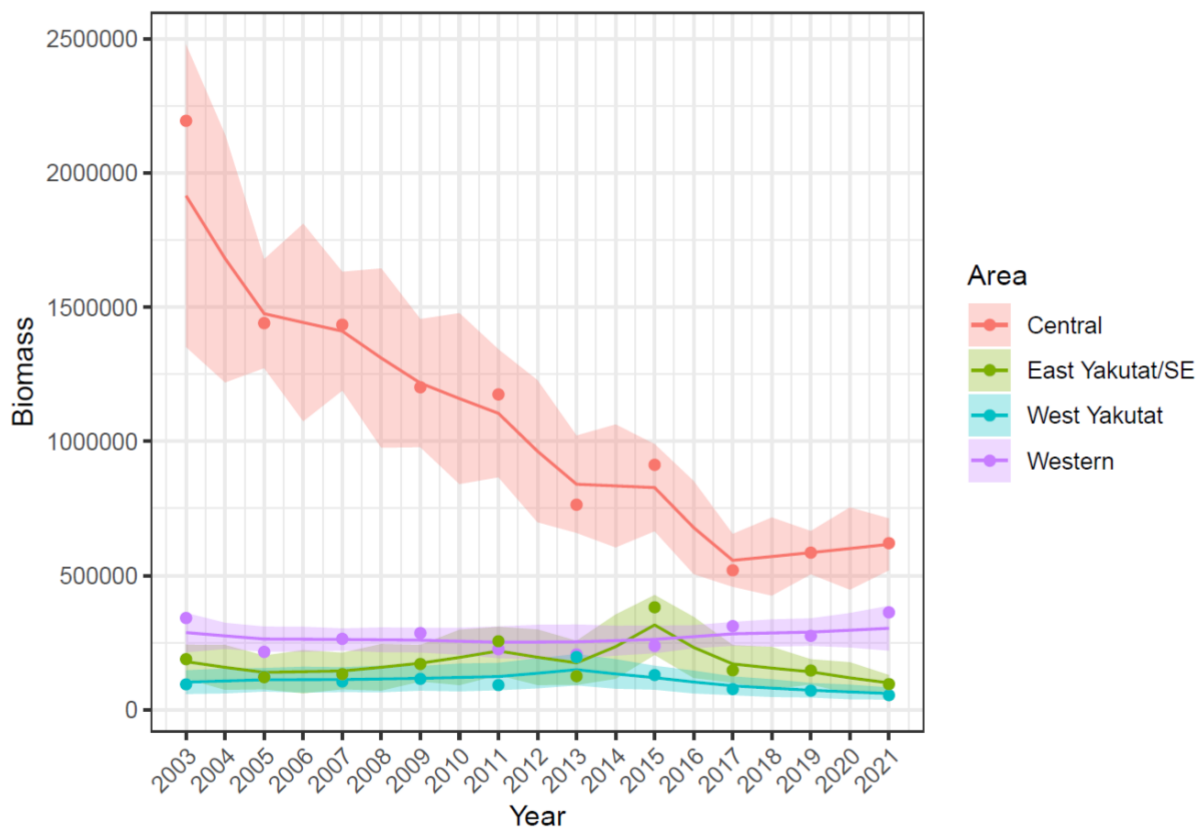

Figure 7.1: Random effects estimates of biomass (solid lines) and AFSC bottom trawl survey estimates (dots) for the four GOA areas among which the catches of Arrowtooth flounder are apportioned, 2003-2021.

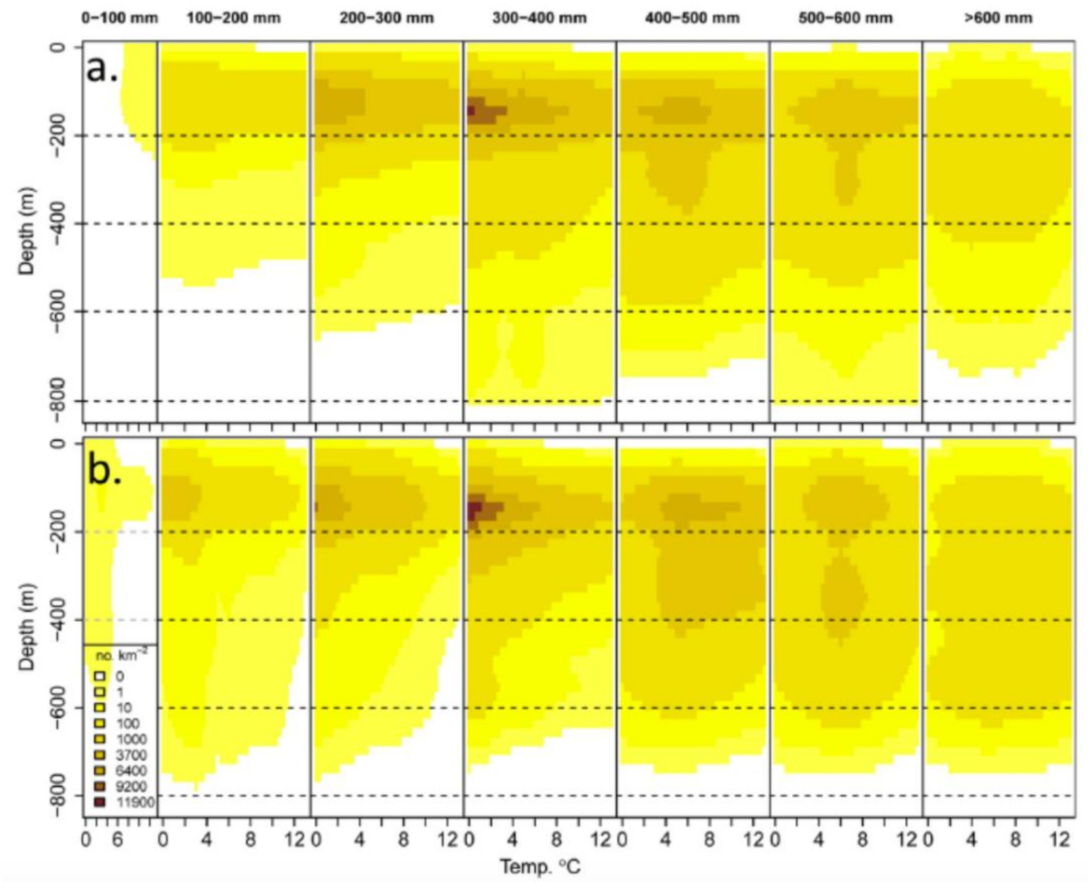

Figure 7.2: Arrowtooth Flounder predicted density, N/kmˆ2 at 56N latitude and 155W longitude from the delta-log gamma model for GOA bottom trawl survey data. Panel a. shows 2001 density using warm years (1984, 1987, 1990, 1993, 2001, 2003, 2005, and 2015) and Panel b. shows density for 2009 using cold years (1996, 1999, 2007, 2009, 2011, and 2013) for seven length bins by bottom depth (m) and bottom temperature (C). Figure from Doyle et al. 2018.

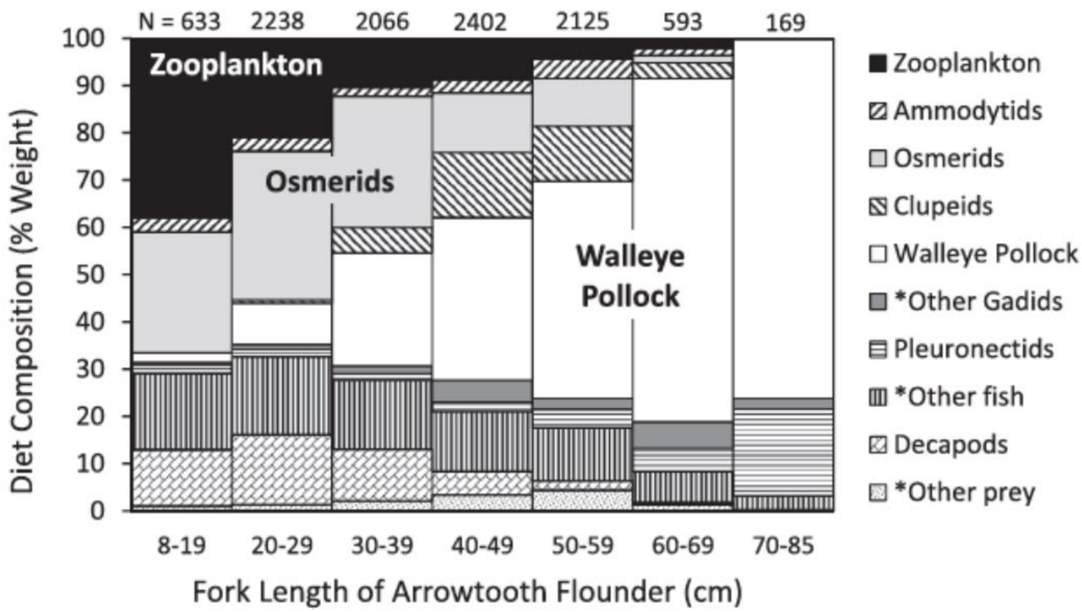

Figure 7.3: Composition of Arrowtooth Flounder diet weight for different size categories of fish, based on stomach content analysis of specimens from groundfish surveys in the Gulf of Alaska.

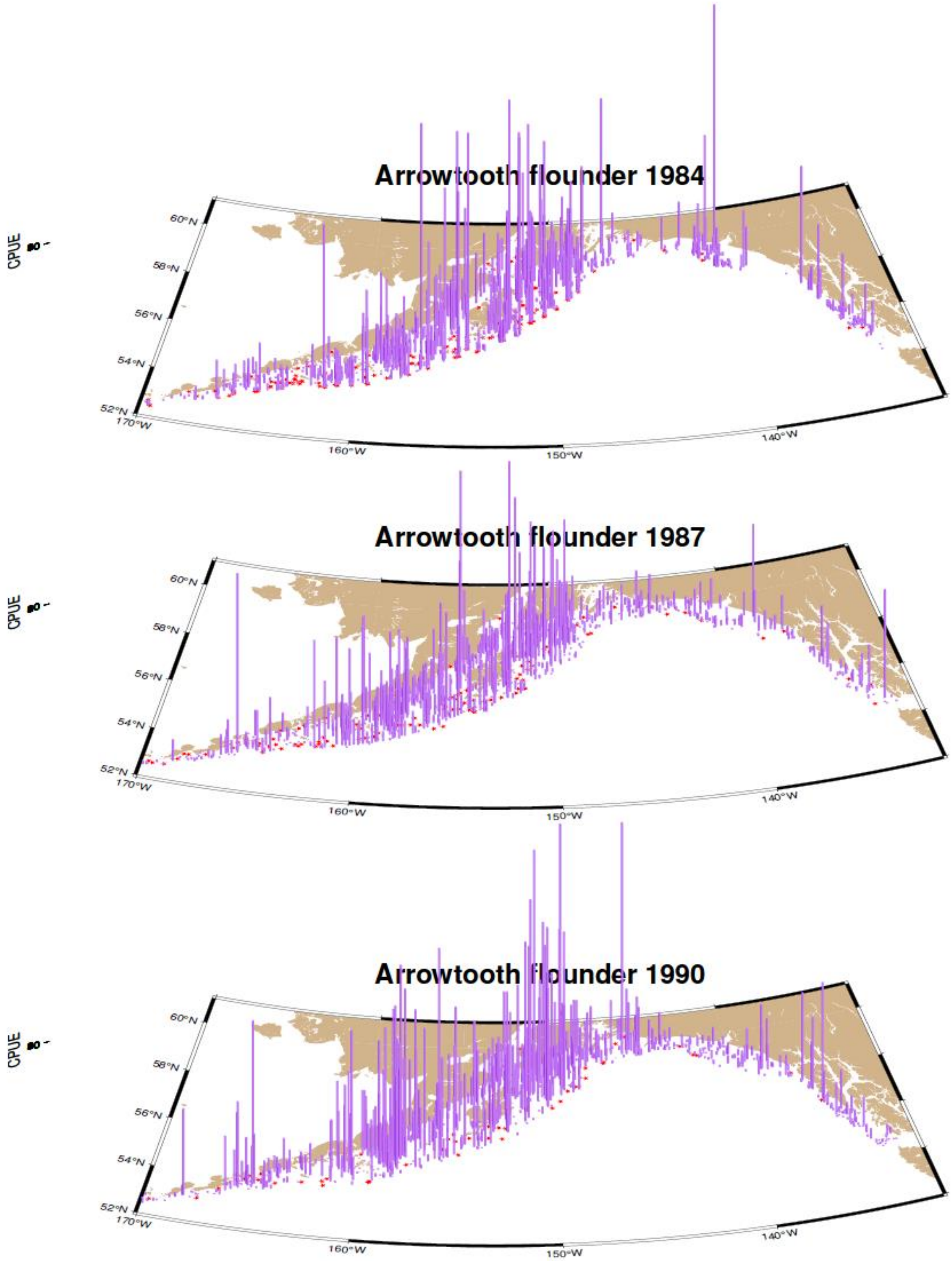

Figure 7.4: Arrowtooth Flounder survey cpue by tow from 1984 to present

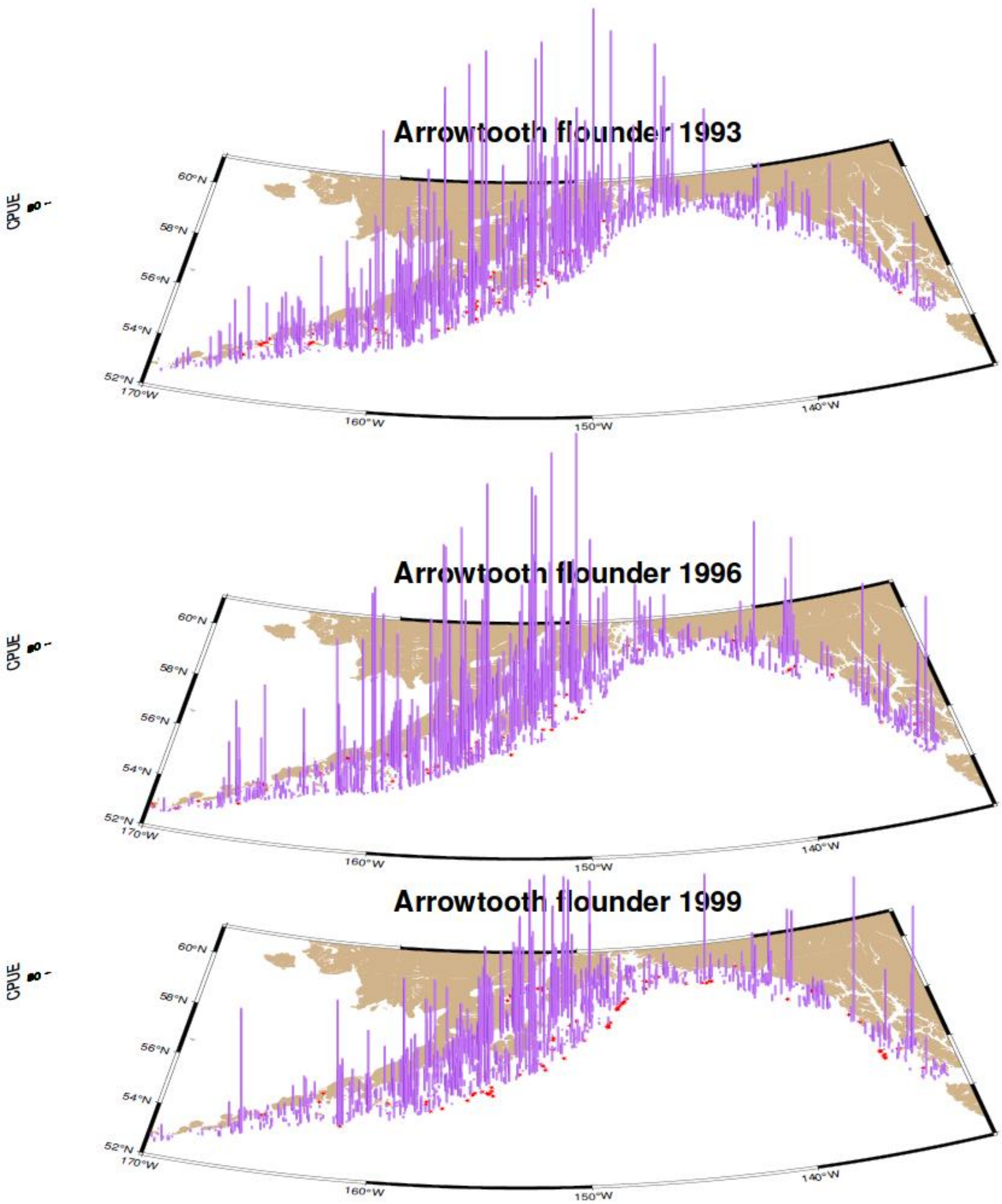

Figure 7.4 (cont.): Arrowtooth Flounder survey cpue by tow from 1984 to present

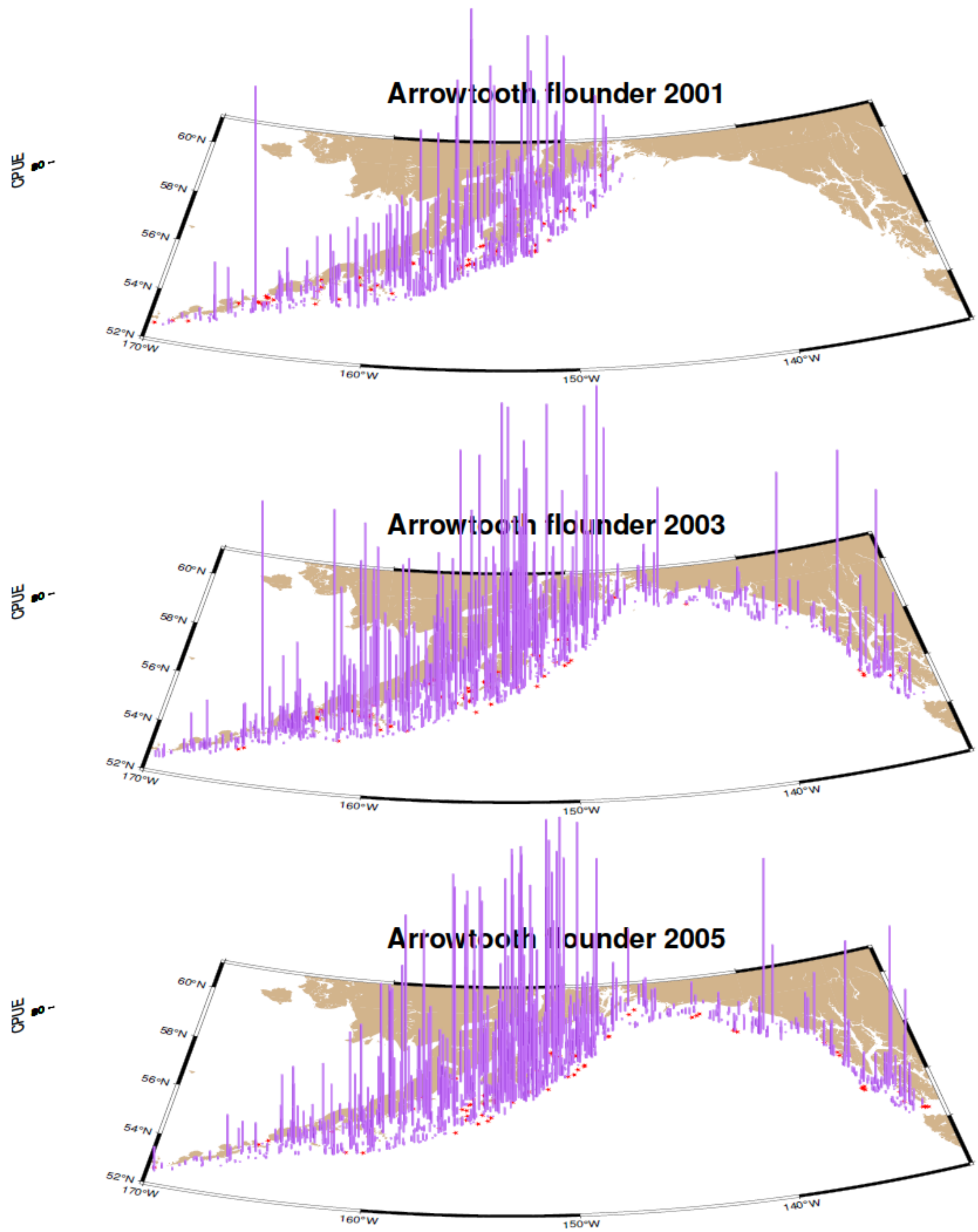

Figure 7.4 (cont.): Arrowtooth Flounder survey cpue by tow from 1984 to present

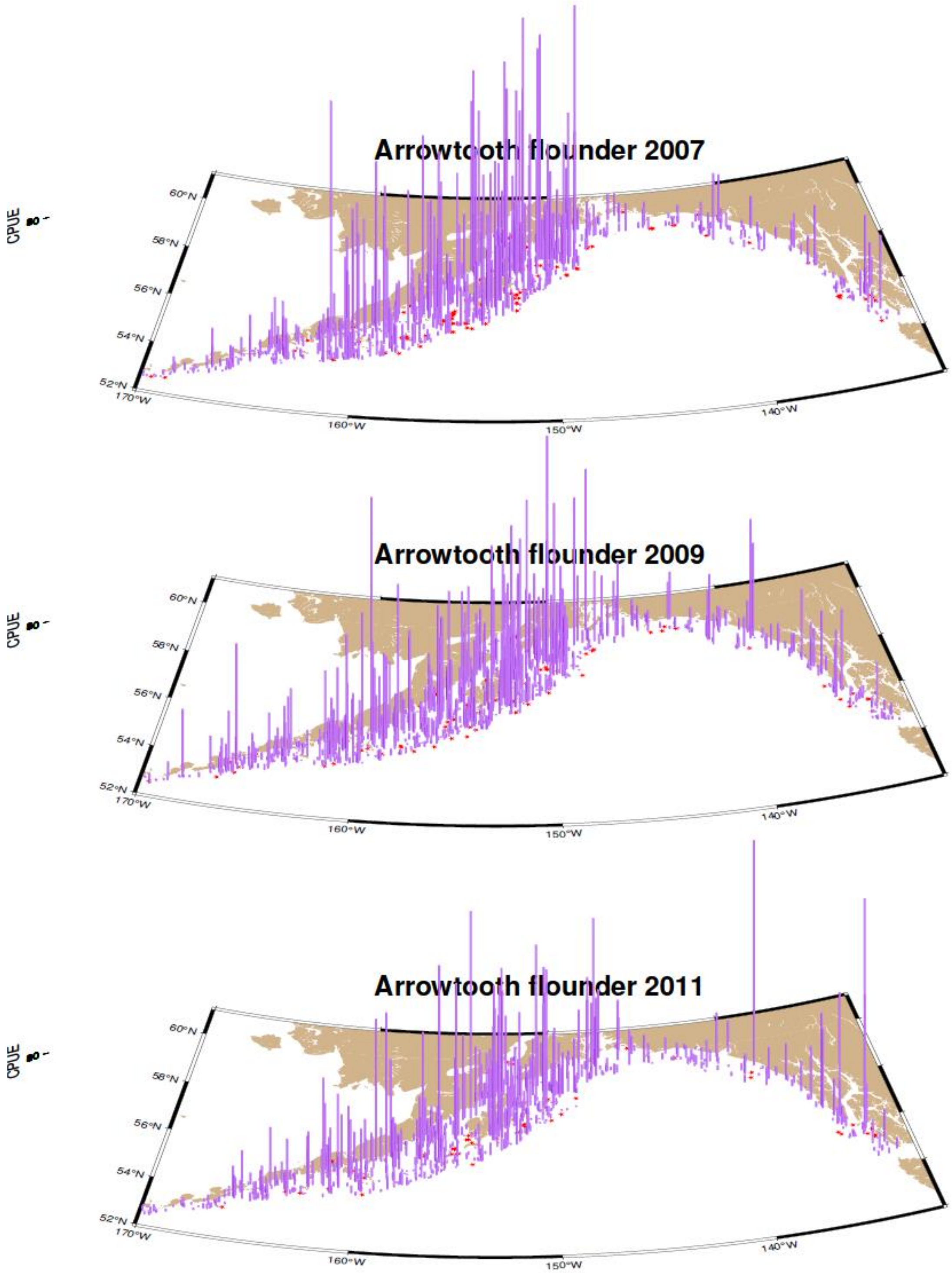

Figure 7.4 (cont.): Arrowtooth Flounder survey cpue by tow from 1984 to present

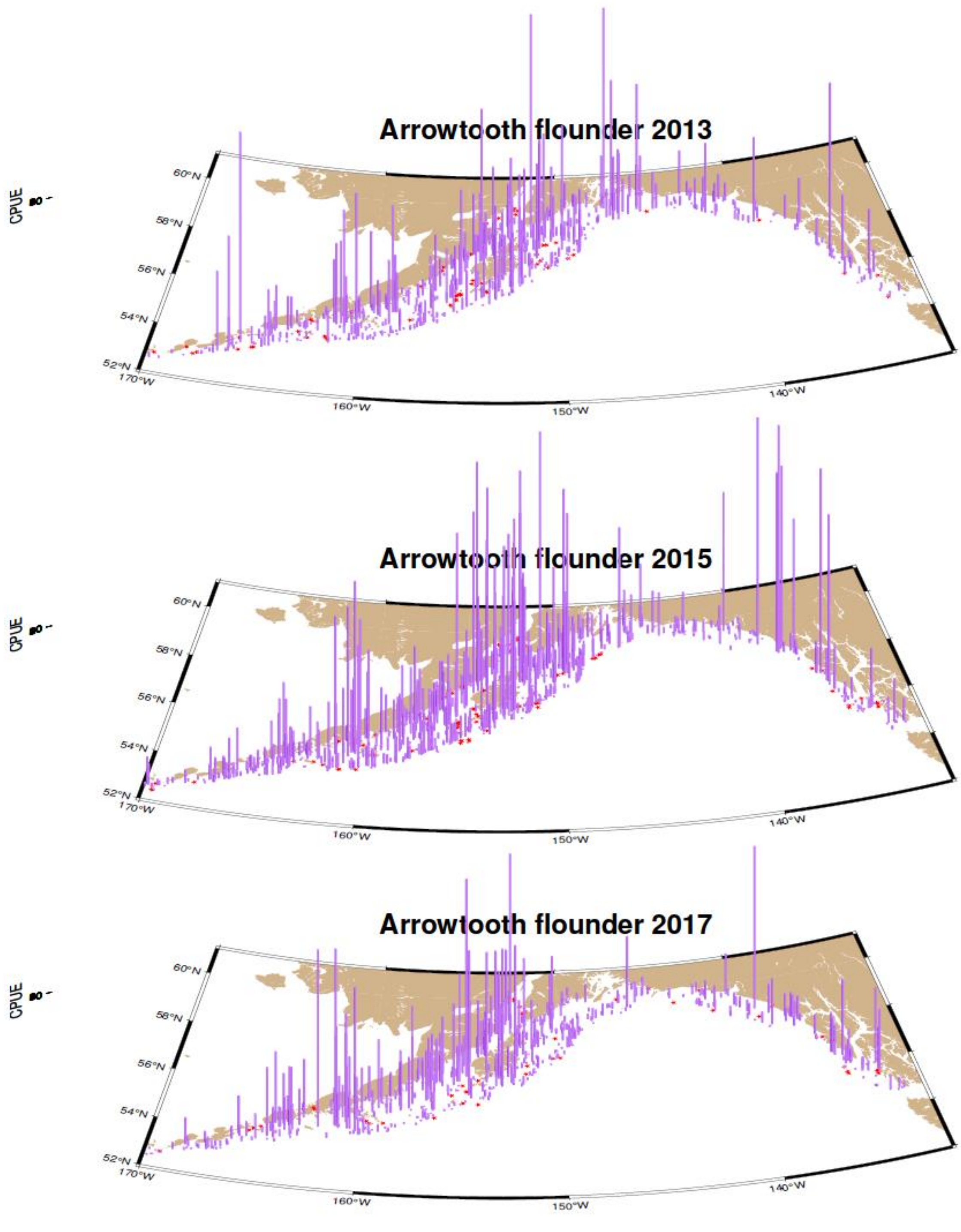

Figure 7.4 (cont.): Arrowtooth Flounder survey cpue by tow from 1984 to present

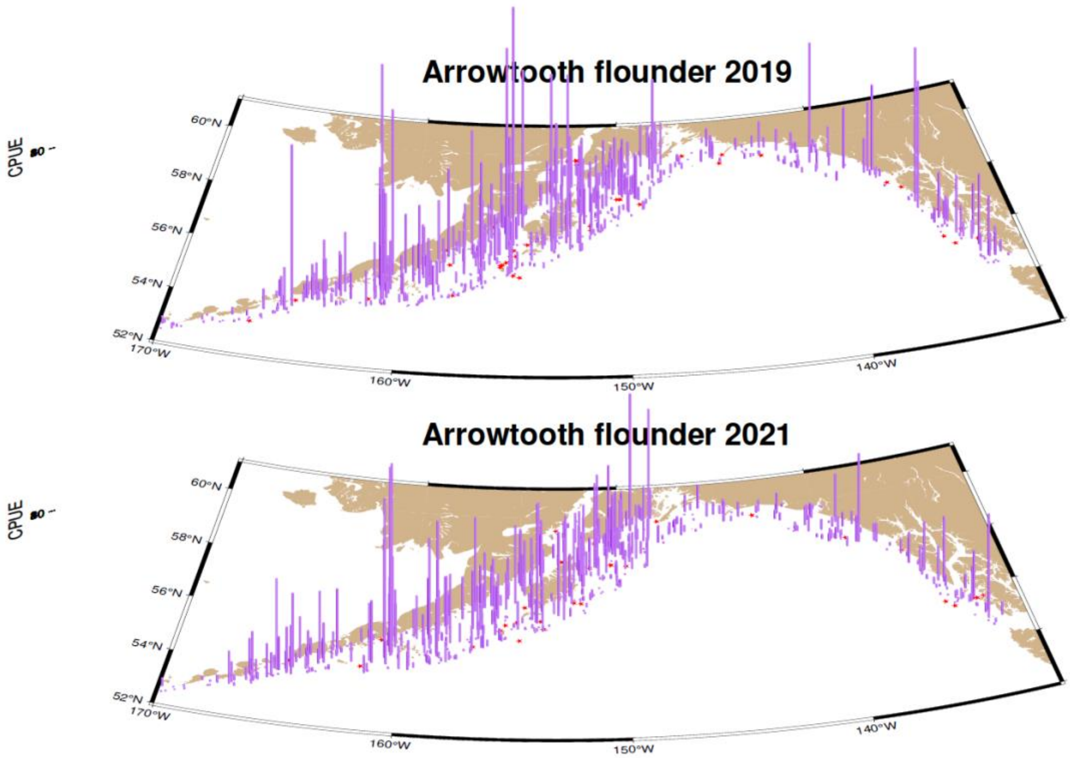

Figure 7.4 (cont.): Arrowtooth flounder survey cpue by tow from 1984 to present

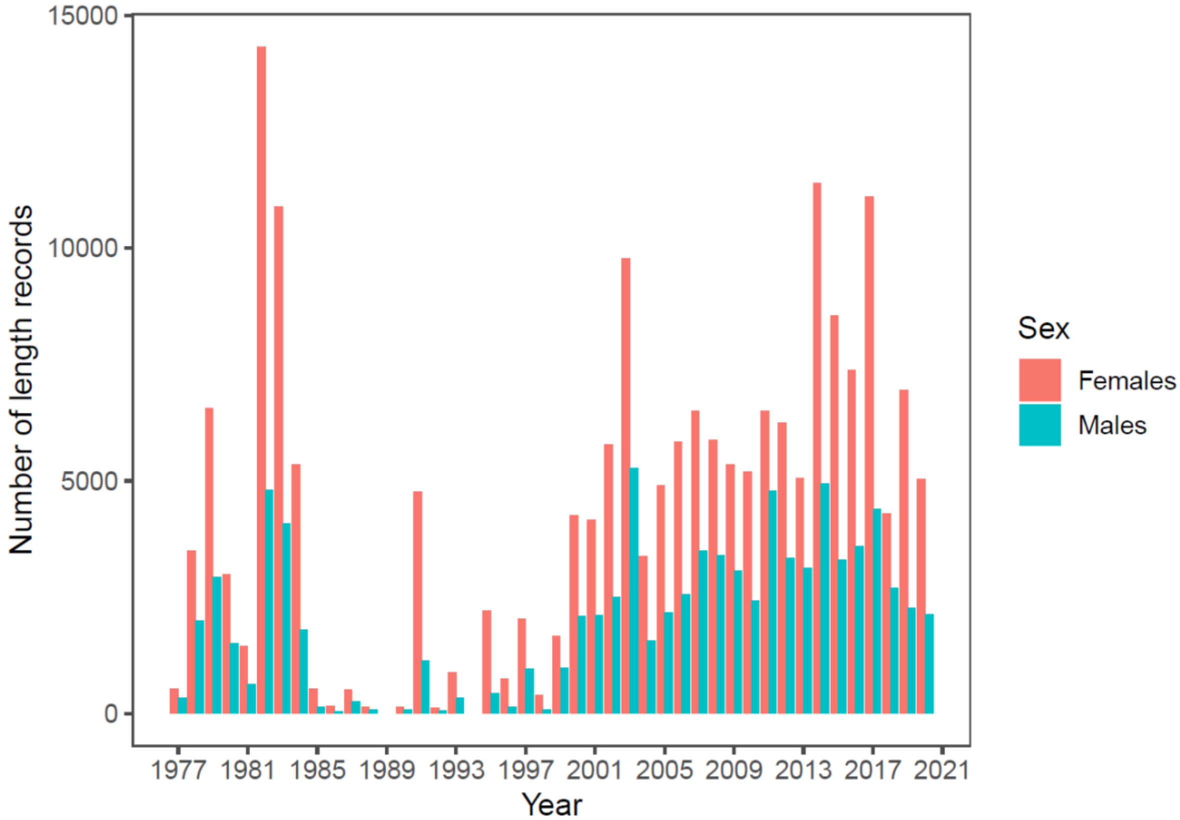

Figure 7.5: Fishery length records (numbers of individual fish by sex) used in this assessment.

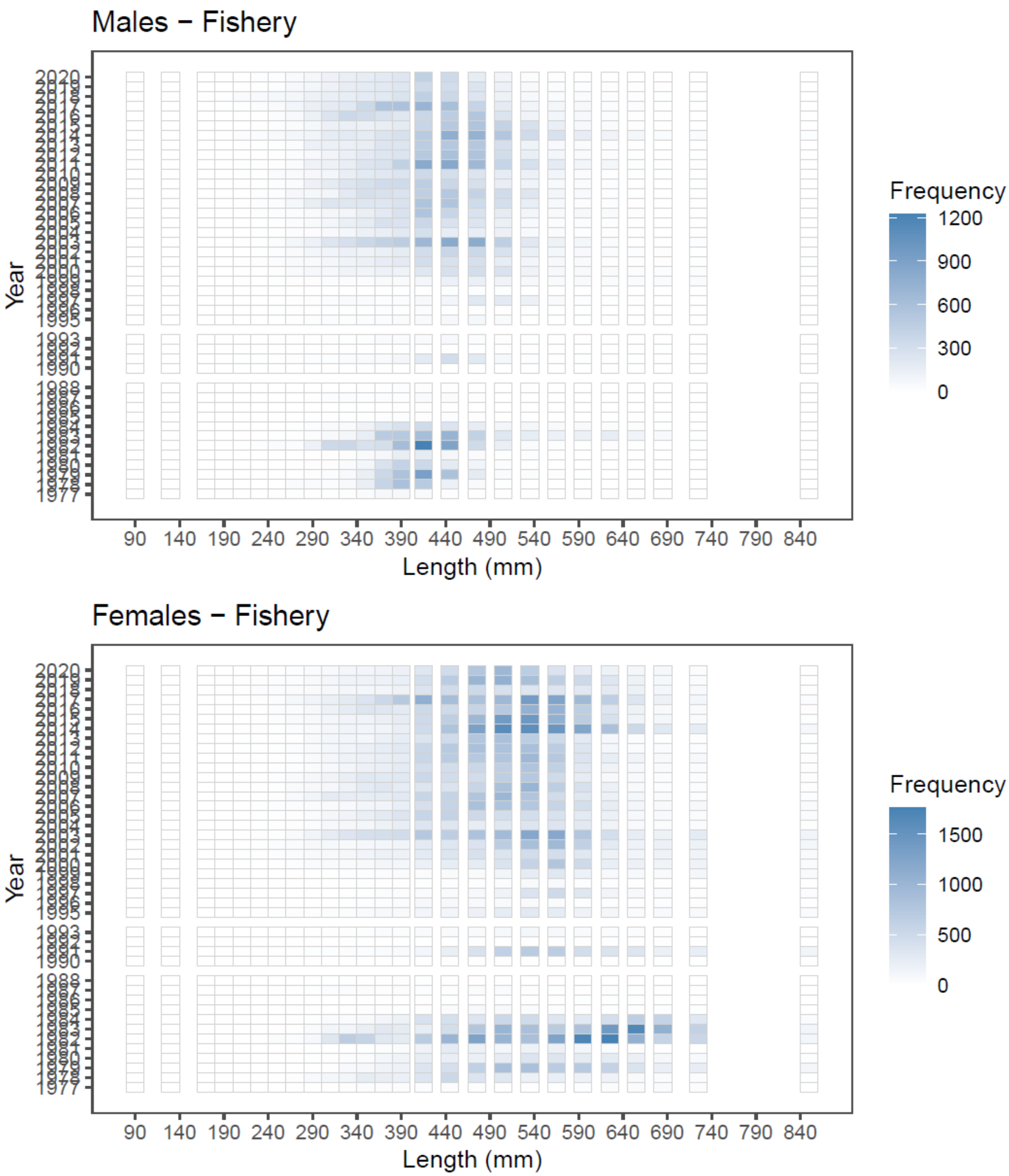

Figure 7.6: Number of fishery lengths by year, males above, females below

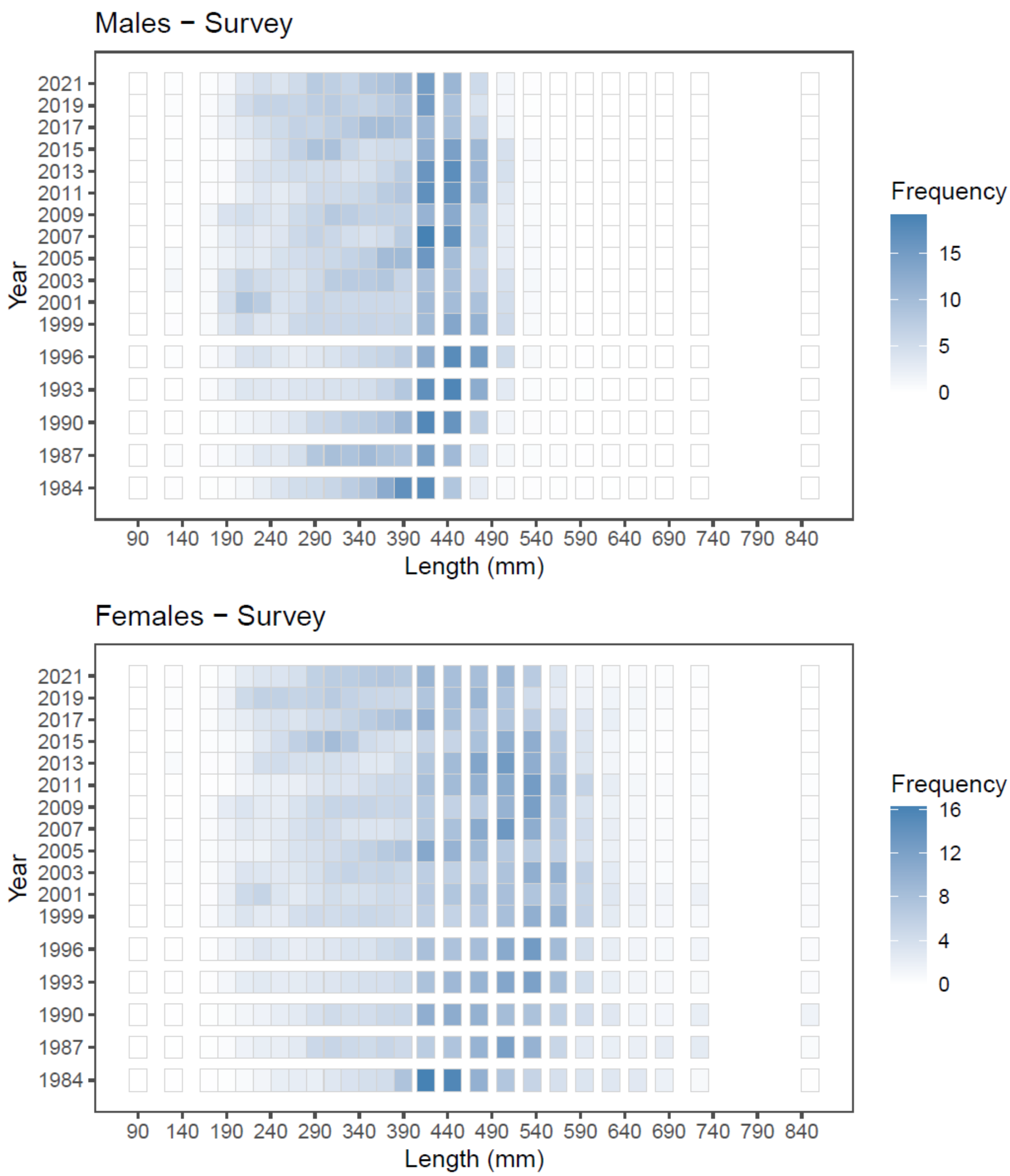

Figure 7.7: Length frequency composition for survey data, males above, females below. Numbers in legend represent percentages in each length bin by year. Please note this data is not fit in the author recommended model.

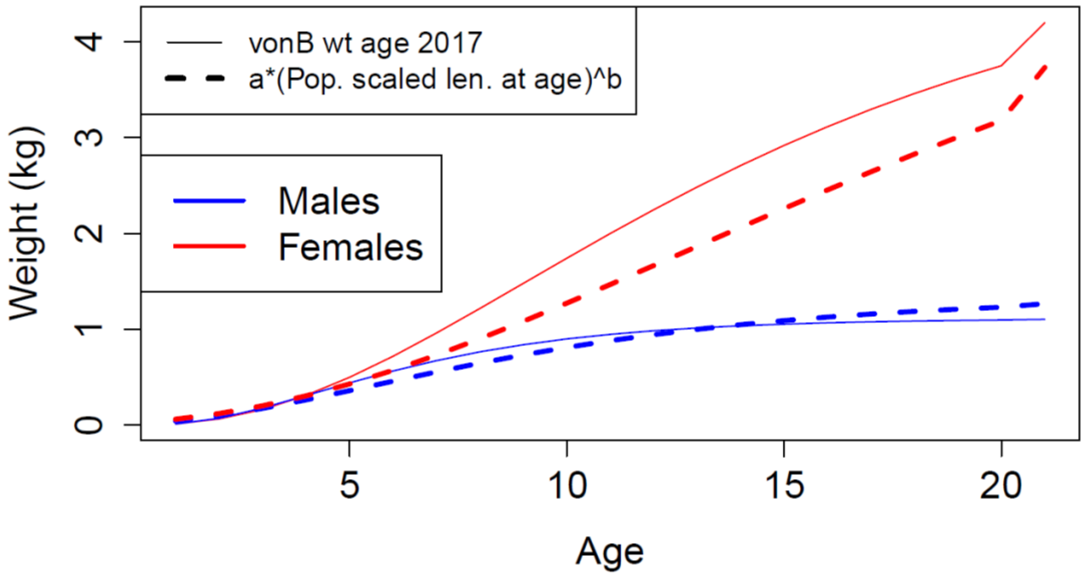

Figure 7.8: Weight at age used in the model is based on length at age corrected by survey length frequencies. Weight at age of females determined by this method is slightly lower than weight at age determined by a weight-at-age von Bertalanffy relationship determined from the stratified age collection. Differences in male weight at age at higher ages were not as dramatic as differences in female weight at age.

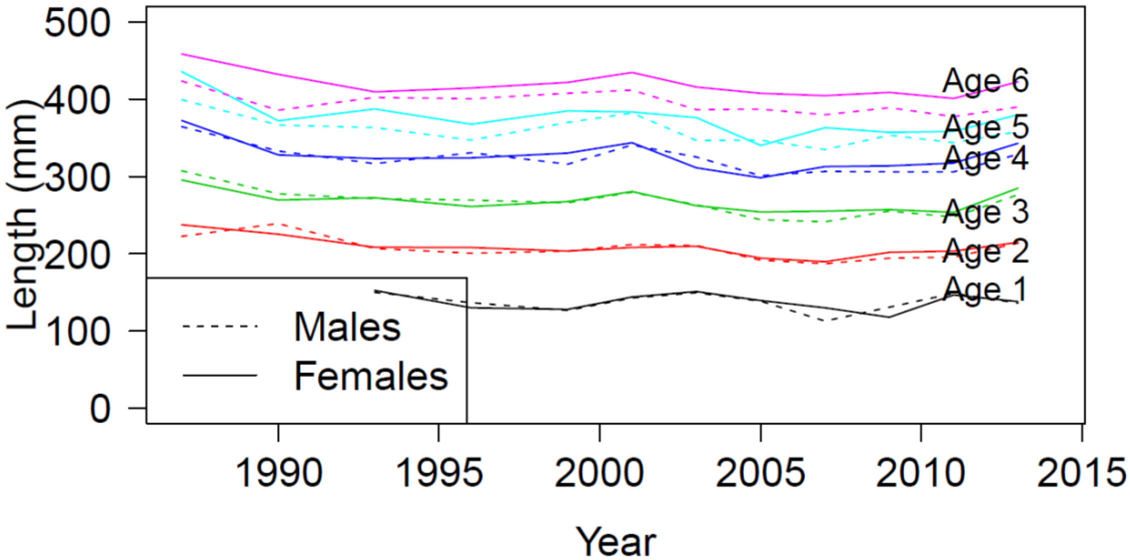

Figure 7.9: Growth differences among males and females start to appear around age 6. Age at 50% maturity is age 7 in females, and is 20% in age 6 female fish.

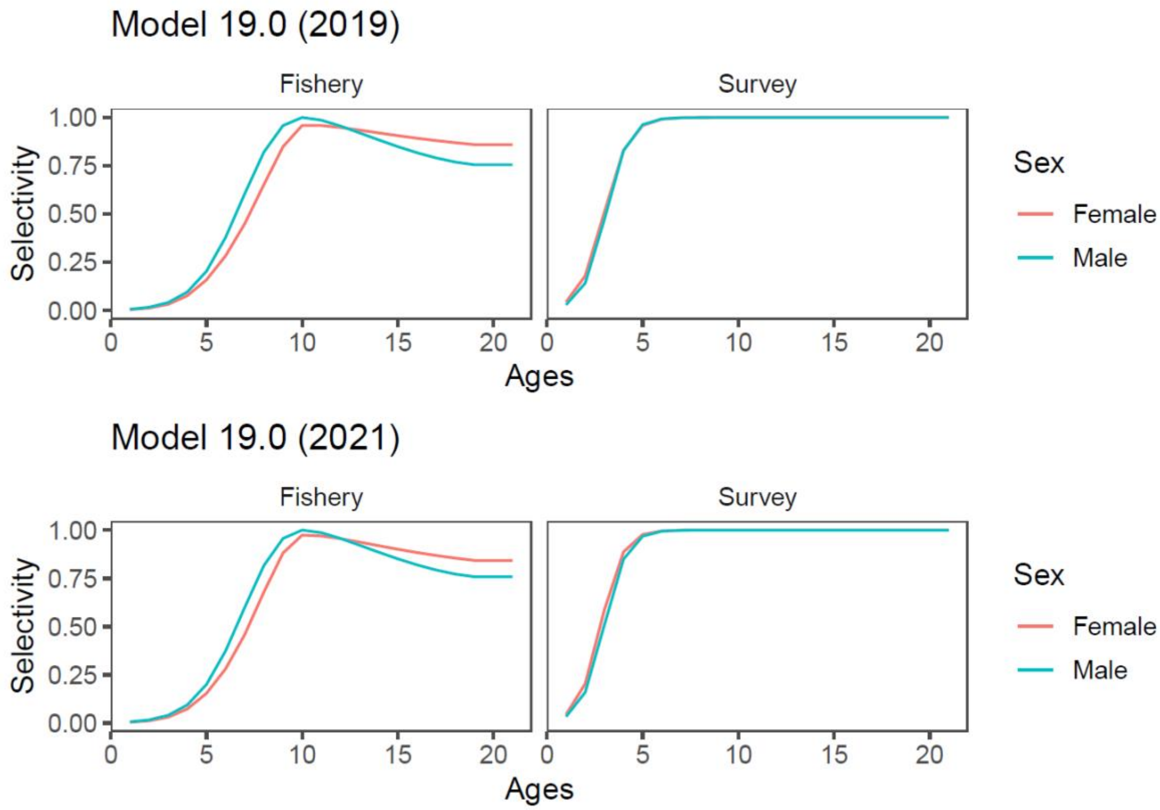

Figure 7.10: Selectivities for fishery and survey estimated by Model 19.0 (2019) and Model 19.0 (2021).

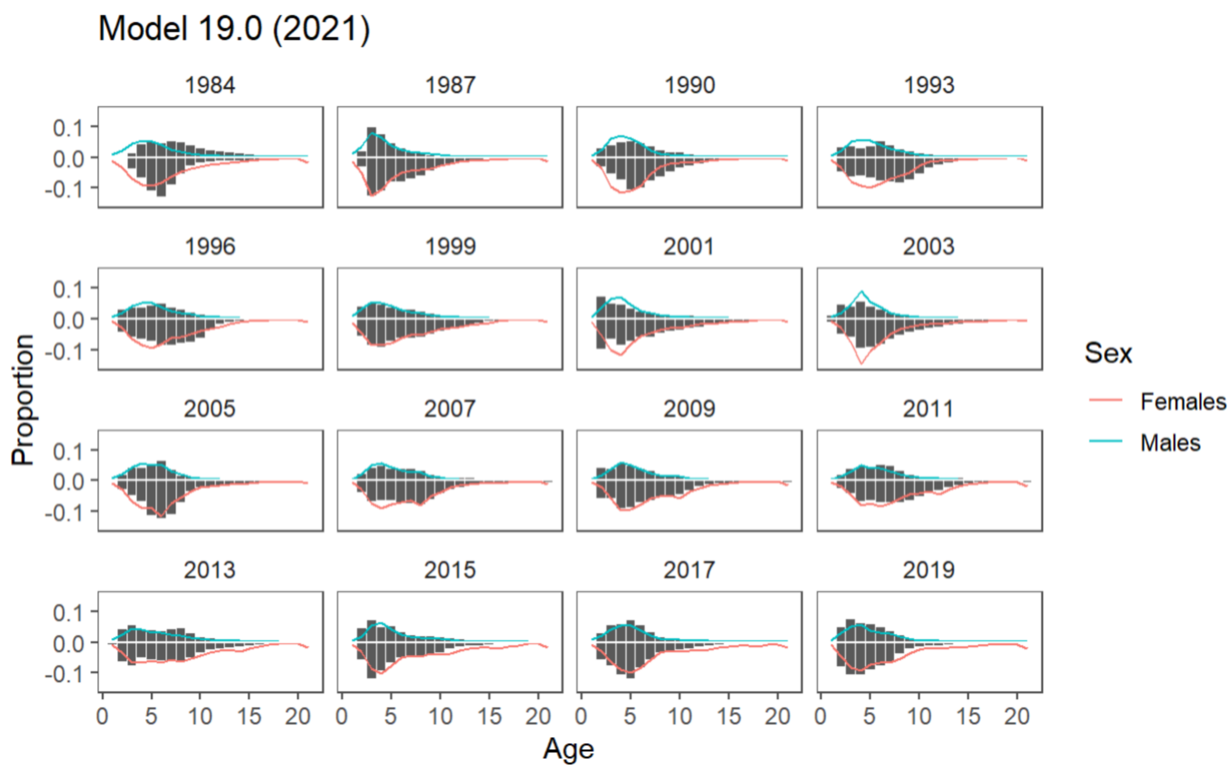

Figure 7.11: Model fits to survey age frequency data by sex. Solid line is predicted frequency, for author recommended model.

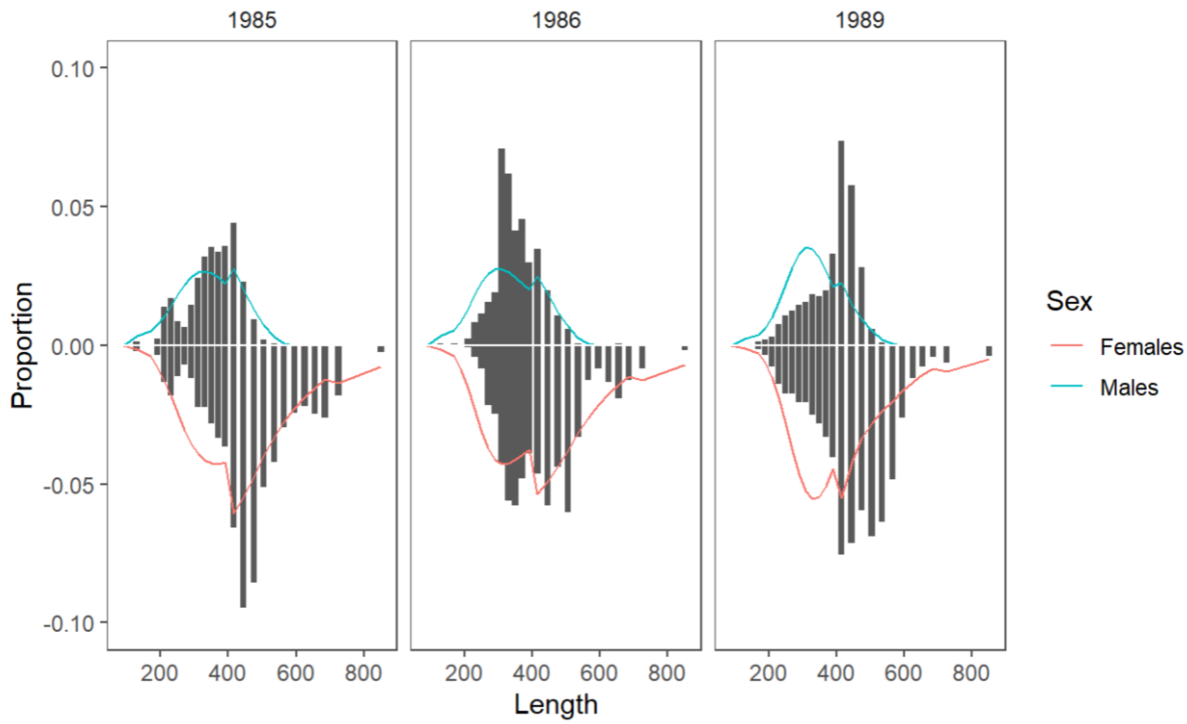

Figure 7.12: Survey length frequency for non-standard surveys, 1985, 1986, and 1989. These data are not fit in the model, but are provided here for reference, males above, females below, solid line is predicted.

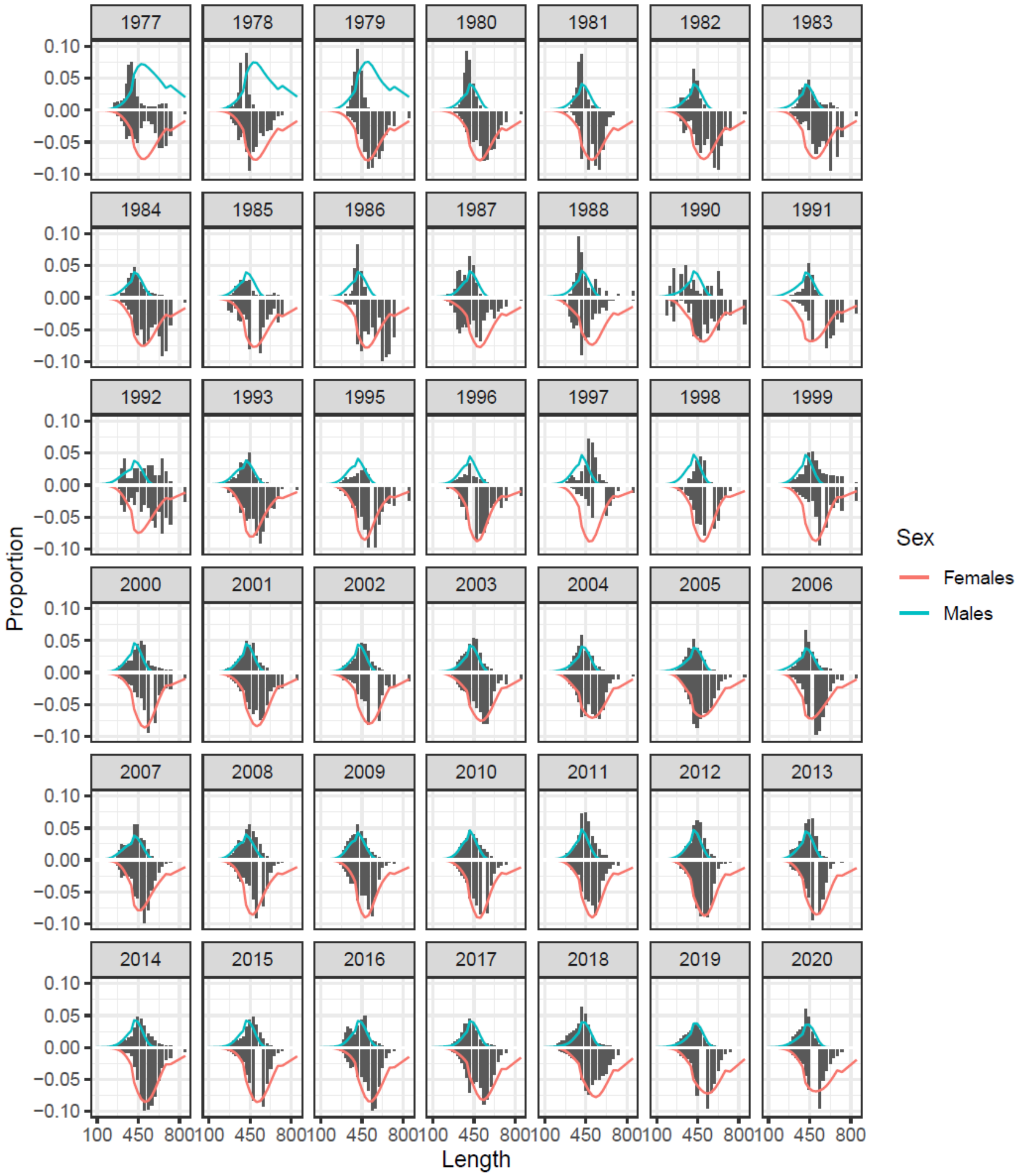

Figure 7.13: Fit to the male and female fishery length composition data for Model 19.0 (2021), solid line is predicted, for author recommended model.

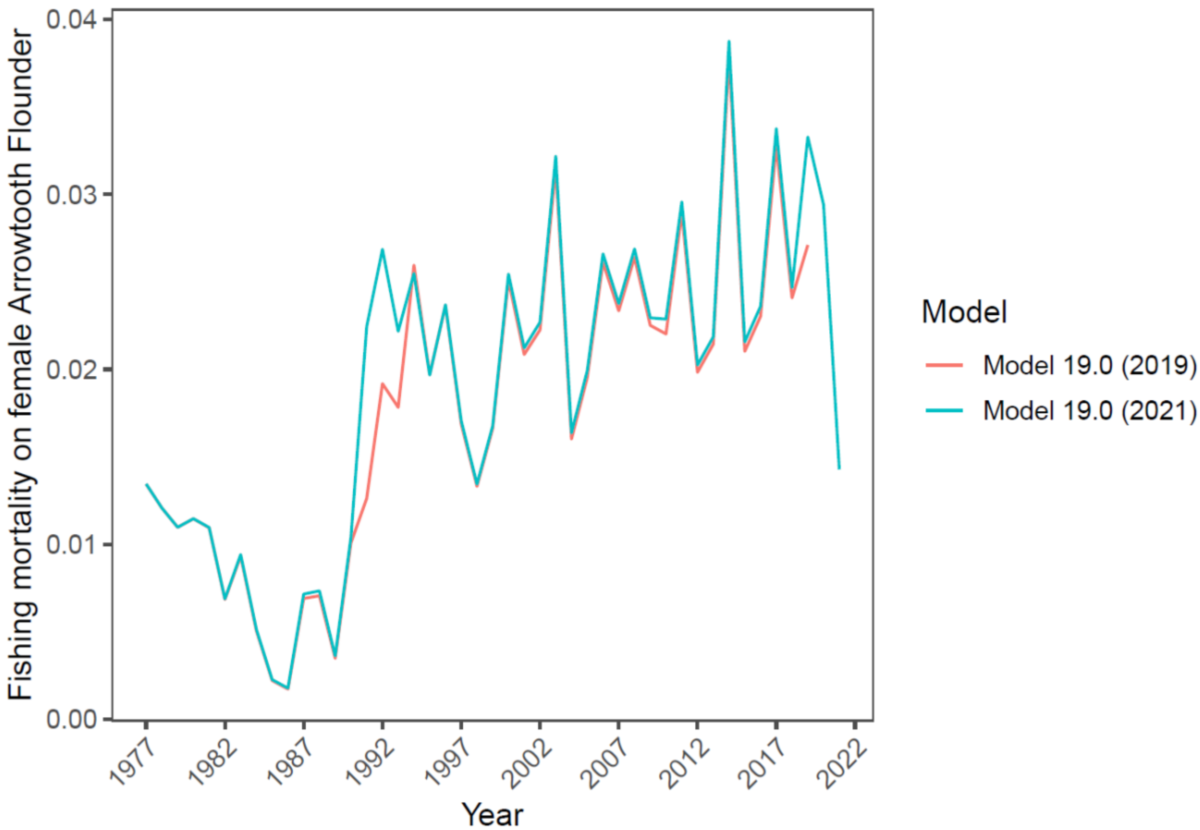

Figure 7.14: Fully-selected female fishing mortality estimated by the Model 19.0 (2019) and 19.0 (2021), 1977-2021.

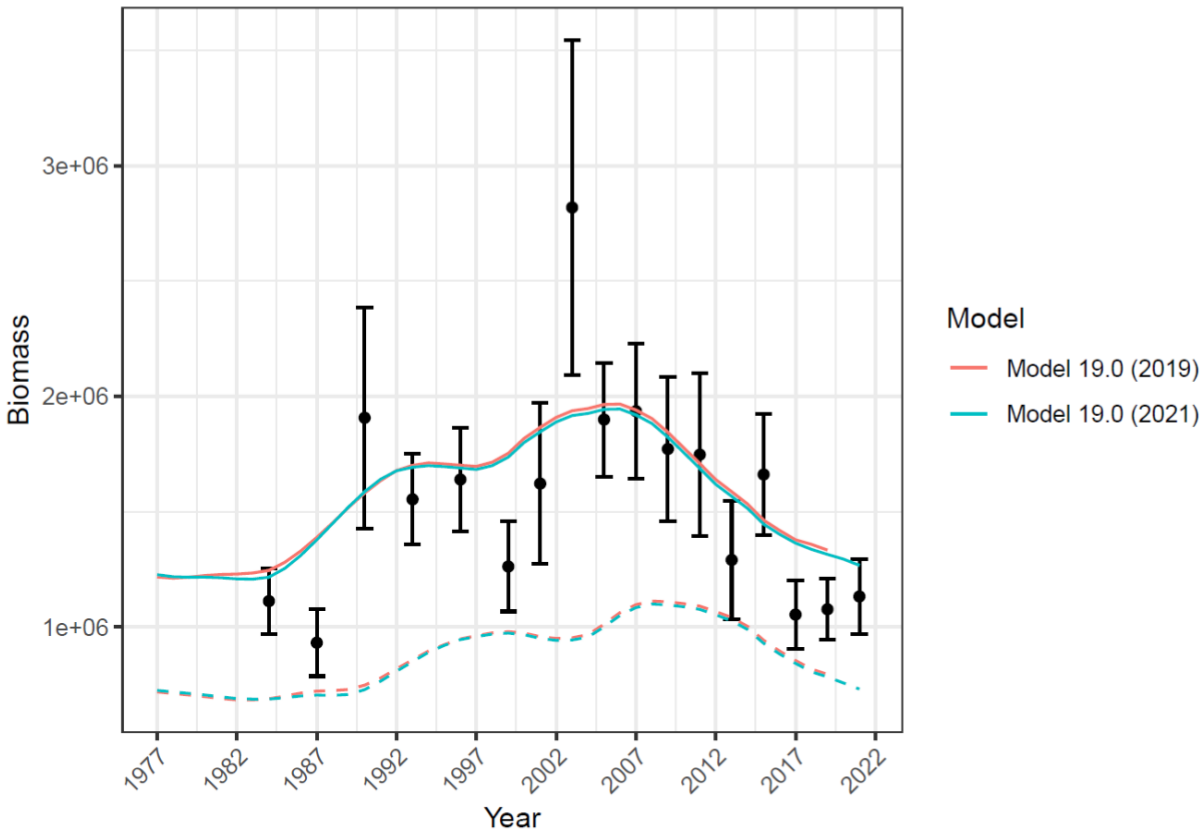

Figure 7.15: Estimated and observed survey biomass, 1977-2021 for Models 19.0 (2019), and 19.0 (2021). Dotted color lines show model estimates for female spawning biomass over the time series and solid color lines show total biomass over the time series.

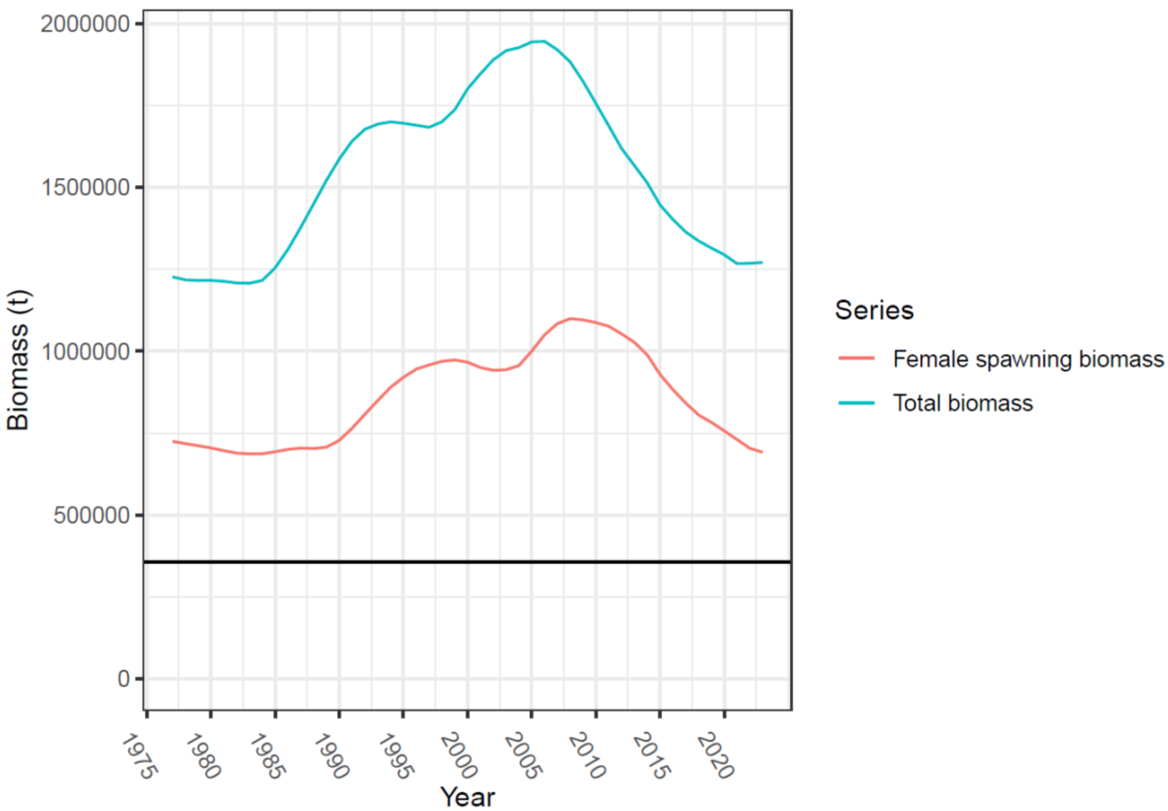

Figure 7.16: Estimated female spawning biomass and total biomass (age 1+) for Model 19.0 (2021), 1977-2023. Values for 2022 and 2023 were estimated using the projecion model. Horizontal line is B35%.

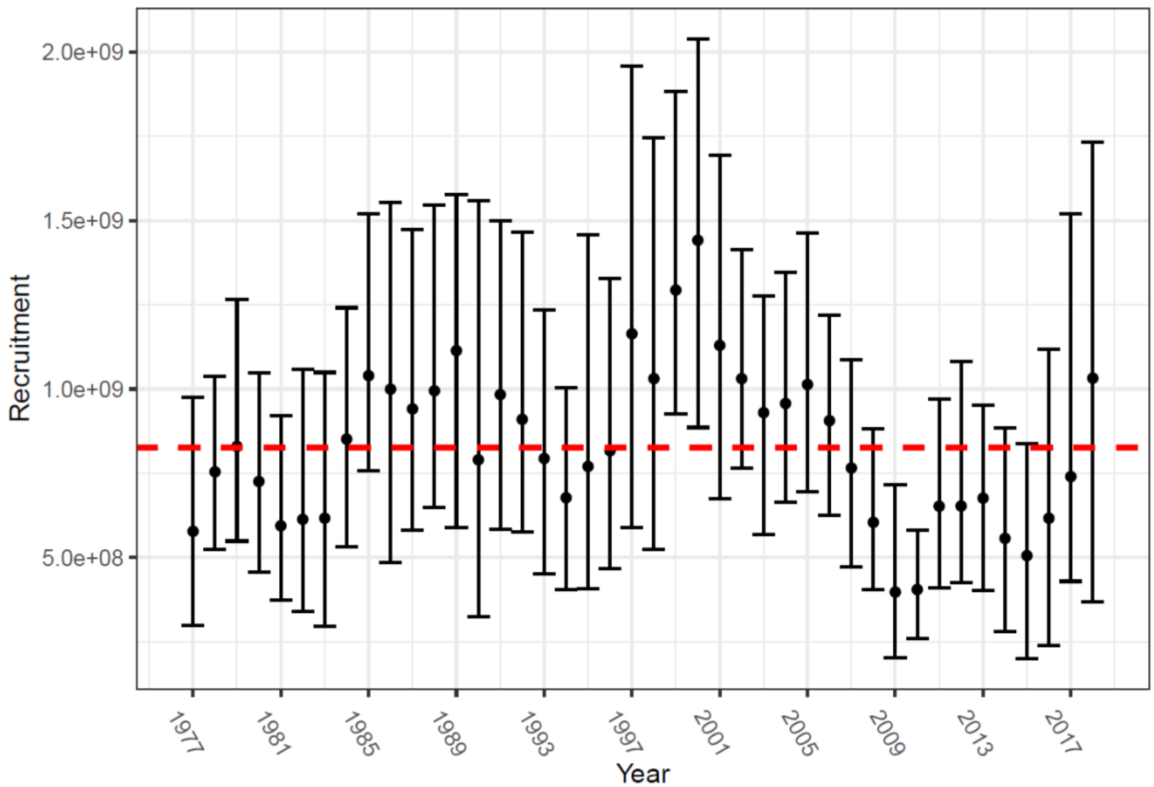

Figure 7.17: Age 1 estimated recruitments (male plus female) in numbers from 1977 to 2018. Data shown only through 2018 because recent recruitment estimates are not reliable as 50% maturity in Arrowtooth Flounder is estimated at age 7. with approximate 5% and 95% credible intervals. The dashed horizontal line indicates estimated mean recruitment from 1977-2017.

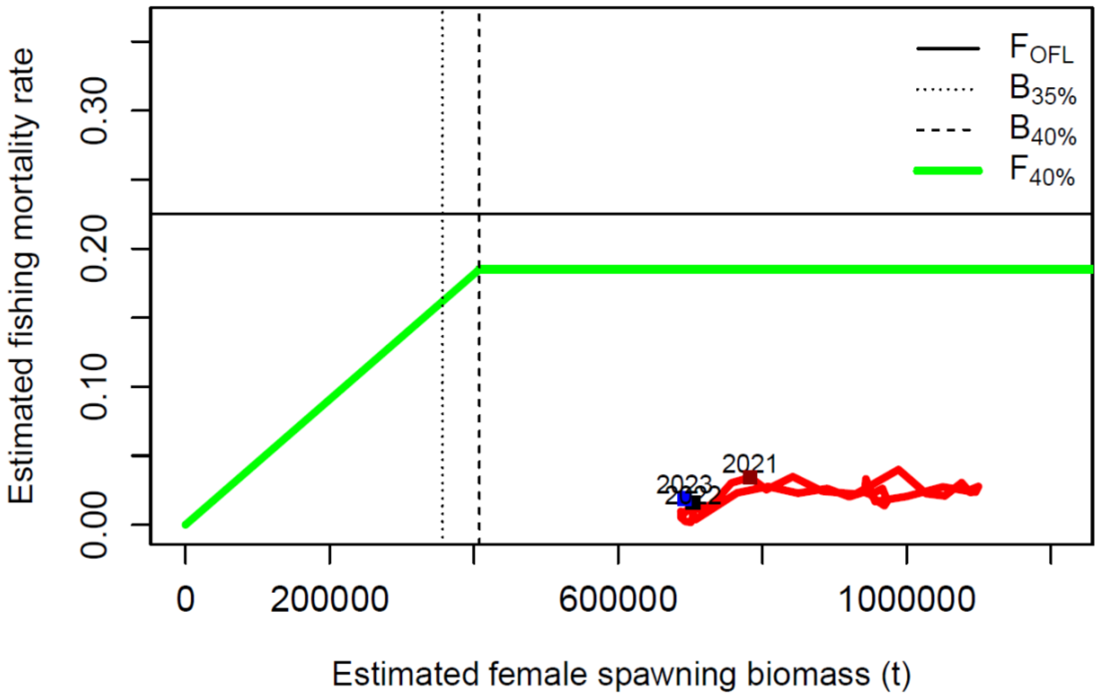

Figure 7.18: Fishing mortality rate and female spawning biomass from 1977 to 2021 compared to the F35% and F40% control rules. Vertical lines are B35% and B40%.

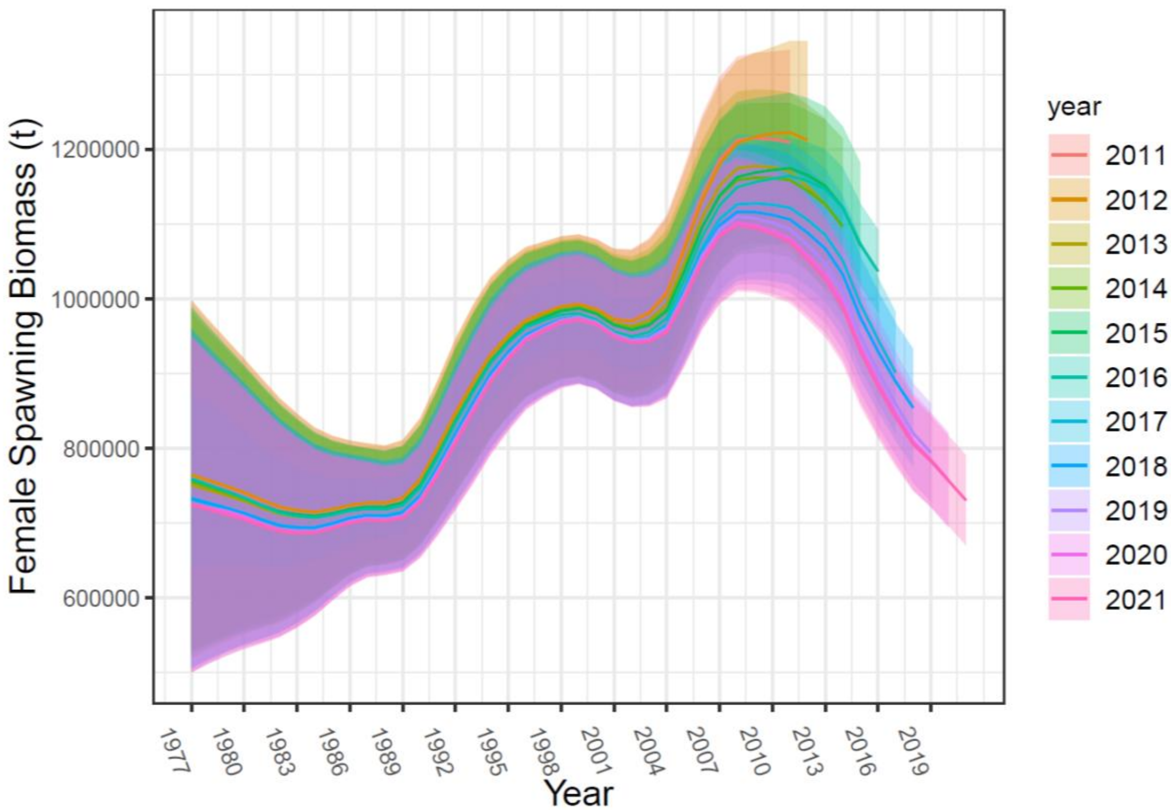

Figure 7.19: Retrospective plot of female spawning biomass. Estimates from the model 19.0 (2021) from 1977-2021 is shown, and data was sequentially removed through 2011.

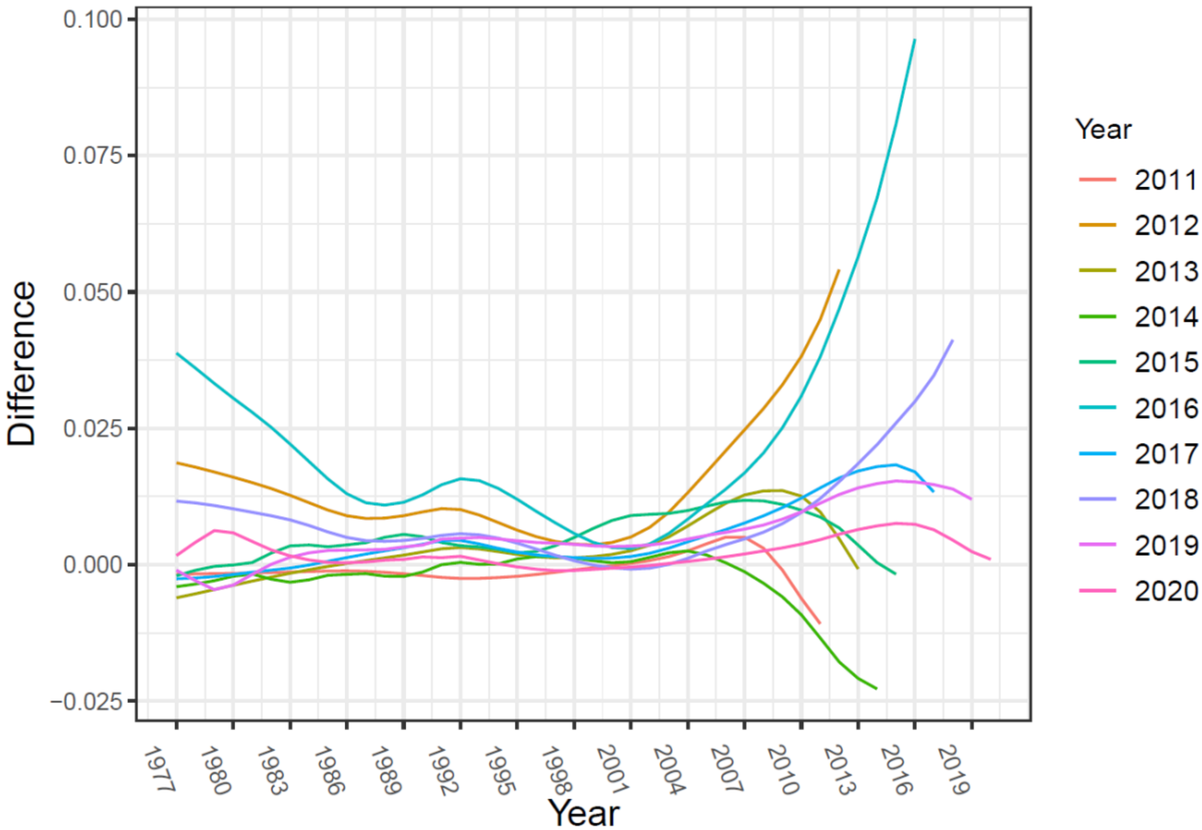

Figure 7.20: Relative differences (%) in estimates of spawning biomass between the preferred 2021 model and the retrospective model run from 1977 through 2021, and data was sequentially removed through 2011.

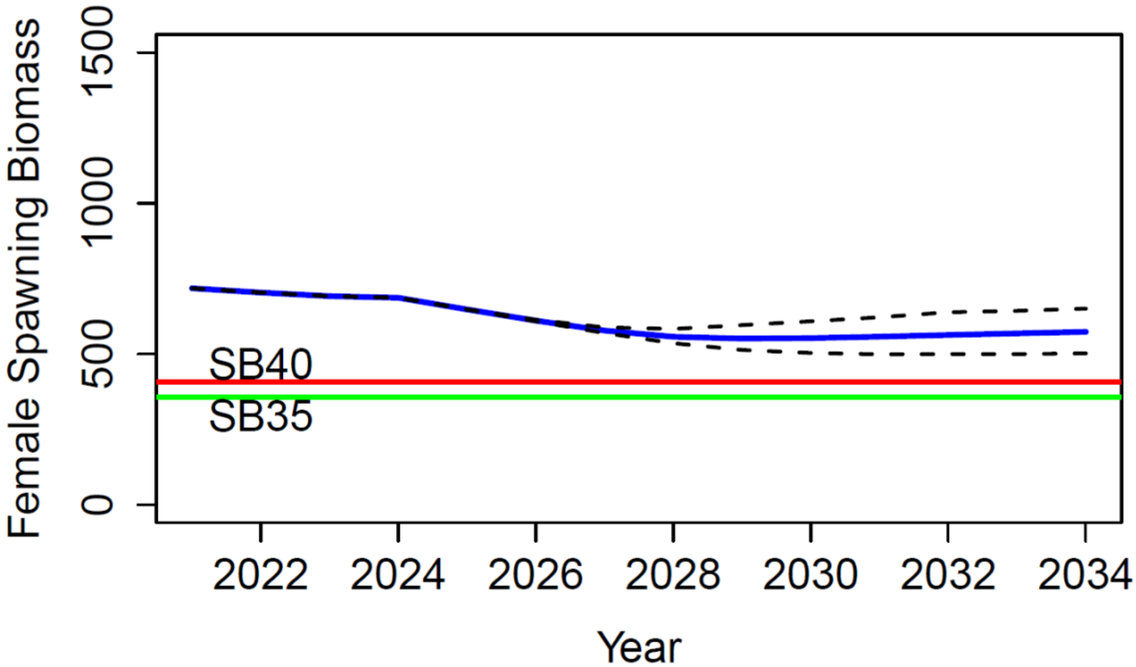

Figure 7.21: Projected female spawning biomass from 2021 to 2034 (blue line), with 5% and 95% confidence intervals, and fishing at the 5-year (2016-2020) average fishing mortality rate, F= 0.0298.

Appendix 7A

Table 7A1. Removals (kg) of Arrowtooth Flounder from the Gulf of Alaska (GOA) from sources other than those included in the Alaska Region's official estimate of catch, 1990-2020. Source NMFS Alaska Region: Sourced by the AKR.V_NONCOMMERCIAL_FISHERY_CATCH table, October 17, 2021. Abbreviations: IPHC (International Pacific Halibut Commission), ADFG (Alaska Department of Fish and Gam), NMFS (National Marine Fisheries Service).

Year	ADF&G	IPHC	NMFS	Total
1990	0	0	28,436	28,436
1991	63	0	26,500	26,563
1992	0	0	24,583	24,583
1993	79	0	32,112	32,191
1994	0	0	22,765	22,765
1995	0	0	39,303	39,303
1996	0	0	27,300	27,300
1997	0	0	47,365	47,365
1998	4,738	0	38,820	43,557
1999	16,905	0	51,625	68,531
2000	8,262	0	39,973	48,235
2001	13,567	0	35,726	49,293
2002	5,019	0	19,756	24,775
2003	15,835	0	22,772	38,607
2004	5,758	0	16,856	22,614
2005	15,754	0	22,218	37,972
2006	5,748	0	21,880	27,628
2007	8,956	0	29,565	38,521
2008	843	0	21,522	22,366
2009	6,685	0	24,590	31,275
2010	113,133	14,647	68,412	196,192
2011	99,341	11,946	136,058	247,345
2012	86,700	9,683	52,673	149,056
2013	50,707	7,565	99,461	157,733
2014	68,856	12,163	48,973	129,991
2015	122,416	8,887	137,274	268,577
2016	81,251	7,299	45,696	134,246
2017	79,861	4,422	69,105	153,387
2018	810,476	76,612	1,251,319	2,138,407
2019	108,928	8,295	76,595	193,818
2020	76,268	2,835	5,401	84,505

Appendix 7B Ecosystem Considerations

Arrowtooth Flounder are important predators of other groundfish in Alaskan ecosystems. In this section, we give an overview of diet data and ecosystem model results for Arrowtooth Flounder in the Gulf of Alaska (GOA). While Arrowtooth Flounder are present in the Aleutian Islands (AI) and Eastern Bering Sea (EBS or BS in figures), the density of Arrowtooth Flounder as measured in survey-estimated tons per square kilometer is by far the greatest in the GOA (Fig. B.1, left). Although the density of Arrowtooth differs between ecosystems, the relative effects of fishing and predation mortality as estimated within food web models constructed for each ecosystem (Aydin et al. in press) are similar between the AI, EBS, and GOA. Here, sources of mortality are compared against the total production of Arrowtooth as estimated in the BSAI and GOA Arrowtooth stock assessment models (see Background, "Production rates," for detailed methods). The "unknown" mortality in Figure B.1 (right) represents the difference between the stock assessment estimated Arrowtooth production and the known sources of fishing and predation mortality. Nearly half of Arrowtooth production as estimated by the stock assessment appears to be "unused" in the AI and GOA, which is consistent with results for other predator species such as Pacific cod and halibut. In the EBS, considerably more mortality is accounted for; please see the discussion of Arrowtooth mortality rates in the EBS in the BSAI Arrowtooth assessment (Wilderbuer et al. 2007). Of the accounted sources of mortality, fishing mortality is generally lower for Arrowtooth Flounder than predation mortality in all three ecosystems (Fig. B.1, right). This is consistent with the currently low fishing effort directed at this species.

To explore ecosystem relationships of Arrowtooth Flounder in more detail, we first examine the diet data collected for Arrowtooth. Diet data are collected aboard NMFS bottom trawl surveys in the GOA during the summer (May – August); this comparison uses diet data collected in the early 1990s. In the GOA a total of 1704 Arrowtooth stomachs were collected between the 1990 and 1993 bottom trawl surveys (n=654 and 1050, respectively) and used in this analysis and to build the GOA food web model. The diet compositions reported here reflect the size and spatial distribution of Arrowtooth in each survey (see Appendix A, "Diet calculations" for detailed methods). While the diet compositions summarized here most accurately reflect early 1990's conditions in the GOA, we also examine changes in Arrowtooth diets over time below.

Arrowtooth Flounder have a varied diet comprised of zooplankton, fish, and benthic invertebrates as both juveniles (0-20 cm TL fish) and adults (>20 cm TL; Fig. B.2). Capelin, euphausiids, adult and juvenile pollock, Pandalid shrimp, herring, and other forage fish comprise the majority of adult Arrowtooth Flounder diet, but none of these prey account for more than 22% of diet. As juveniles, Arrowtooth prey mainly on euphausiids, which make up nearly 60% of diet, followed by capelin at 24% (Fig. B.2). When the uncertainty in food web model parameters is included (see Aydin et al in press for Ecosense methods), we estimate fairly high annual consumption of these prey by Arrowtooth Flounder. For example, estimated consumption of all forage fish (capelin, sandlance, eulachon, etc.) by adult Arrowtooth ranges from 300,000 to 1.2 million metric tons, and estimated consumption of pollock by adult Arrowtooth ranges from 400,000 to 800,000 metric tons annually (Fig. B.3, upper panel). Consumption of euphausiids by adult Arrowtooth is estimated to range from 100,000 to 800,000 tons annually, with another 60,000 to 490,000 tons consumed annually by juvenile Arrowtooth Flounder (Fig. B.3, upper and lower).

Using diet data for all predators of Arrowtooth Flounder and consumption estimates for those predators, as well as fishery catch data, we next estimate the sources of Arrowtooth mortality in the GOA (see detailed methods in Background section). As described above, sources of mortality are compared against the total production of Arrowtooth as estimated in the GOA stock assessment model for the early 1990s. There are few sources of mortality for Arrowtooth Flounder in the GOA as both adults and juveniles, as indicated by the large proportion of unexplained mortality (76% for adults, 88% for juveniles) in Figure B.4. Predators explain more mortality than fisheries for Arrowtooth Flounder (at least in this model based on early 1990s data where the fishery for Arrowtooth Flounder was extremely limited). Pacific halibut, Steller sea lions, and Pacific cod together explain about 10% of adult Arrowtooth mortality, while the flatfish trawl fishery accounts for 2% (Fig. B.4, upper panel). Juvenile Arrowtooth Flounder mortality is caused by adult Arrowtooth Flounder, and both adult and juvenile pollock in the GOA, but the total of these mortality sources is less than 7% of juvenile Arrowtooth production (Fig. B.4, lower panel). The total tonnage consumed by predators of Arrowtooth Flounder is low relative to their biomass for both adults and juveniles: the most important predators of Arrowtooth, pinnipeds and halibut, are each estimated to consume between 13,000 and 30,000 or 20,000 tons of Arrowtooth annually, respectively (Fig. B.5, upper panel). Adult Arrowtooth Flounder are estimated to consume 4,000 to 12,000 tons of juvenile Arrowtooth Flounder annually, with pollock consuming nearly the same small amount (Fig. B.5, lower panel). Few mortality sources for Arrowtooth Flounder are consistent with an increasing population, which has been observed in the Gulf of Alaska since the 1960s.

After comparing the different diet compositions and mortality sources of Arrowtooth Flounder, we shift focus slightly to view them within the context of the larger GOA food webs (Fig. B.6). Arrowtooth Flounder occupy a relatively high trophic level in the GOA, and represent the highest biomass single species group at that high trophic level. The green boxes represent direct prey of Arrowtooth, the dark blue boxes the direct predators of Arrowtooth, and light blue boxes represent groups that are both predators and prey of Arrowtooth. Visually, it is apparent that Arrowtooth's direct trophic relationships in each ecosystem include a majority of species groups. In the GOA, the significant predators of Arrowtooth (blue boxes joined by blue lines) include the halibut, sea lions, sharks, and fisheries. Significant prey of Arrowtooth (green boxes joined by green lines) include several fish groups, Euphausiids, and Pandalid shrimp. The most interesting interaction may be with pollock, which are both prey of adult Arrowtooth, and predators on juvenile ar- rowtooth. This situation is also observed in the EBS, but there the biomass of pollock overwhelms that of Arrowtooth so the impact of this interaction on the two populations is very different between ecosystems. We next use the diet and mortality results integrated with information on uncertainty in the food web using the Sense routines (Aydin et al. in press) and a perturbation analysis with each model food web to explore the ecosystem relationships of Arrowtooth Flounder further. Two questions are important in determining the ecosystem role of Arrowtooth Flounder: which species groups are Arrowtooth important to, and which species groups are important to Arrowtooth? First, the importance of Arrowtooth to other groups within the GOA ecosystem was assessed using a model simulation analysis where Arrowtooth survival was decreased (mortality was increased) by a small amount, 10%, over 30 years to determine the potential effects on other living groups. This analysis also incorporated the uncertainty in model parameters using the Sense routines, resulting in ranges of possible outcomes which are portrayed as 50% confidence intervals (boxes in Figure B.7) and 95% confidence intervals (error bars in Figure B.7). Species showing the largest median changes from baseline conditions are presented in descending order from left to right. Therefore, the largest change resulting from a 10% decrease in Arrowtooth survival is a highly uncertain increase in herring biomass, and an accompanying increase in herring catches in the fishery (Fig. B.7). A more certain outcome of the per- turbation is the expected direct effect, a decrease in adult Arrowtooth biomass, which has a smaller median change than the herring change. Similarly, sleeper sharks decrease with some certainty, while sablefish and pollock are predicted to increase but with nearly as much uncertainty as herring. In general, the effects of a small change in Arrowtooth survival result in a large amount of uncertainty in the ecosystem, with potentially large effects on multiple species due to Arrowtooth's ecosystem interactions.

To determine which groups were most important to Arrowtooth in each ecosystem, we conducted the inverse of the analysis presented above. In this simulation, each species group in the ecosystem had survival reduced by 10% and the system was allowed to adjust over 30 years. The strongest median effects on GOA Arrowtooth are presented in Figure B.8. Here the largest impacts on Arrowtooth biomass are the direct effects through changes in Arrowtooth survival and juvenile Arrowtooth survival, but the next largest impacts are more in- teresting ecologically. Arrowtooth biomass appears strongly influenced by changes in bottom up production, with decreases in survival for large and small phytoplankton and euphausiids having similar biomass effects as direct effects from Arrowtooth and juvenile Arrowtooth (Fig. B.8). While euphausiids are direct prey of Arrowtooth, phytoplankton are not. Smaller effects on Arrowtooth biomass are seen due to decreased survival of capelin (direct prey), but these are uncertain compared with those due to phytoplankton and euphausiids. There are more unequivocal bottom up effects related to Arrowtooth Flounder in these simulations than top down effects of Arrowtooth on other species.

Finally, we summarize the available food habits collections for Arrowtooth Flounder in the GOA in Table 1, and make preliminary consumption estimates from this data in Figures B.9 and B.10 for juvenile and adult Arrowtooth. In general, while changes in the amount of consumption have been noted, the Arrowtooth diet remains diverse and focused on euphausiids, pollock, capelin, and other fish throughout the time series (Fig. B.9). Further analysis of this data will be presented in an upcoming assessment.

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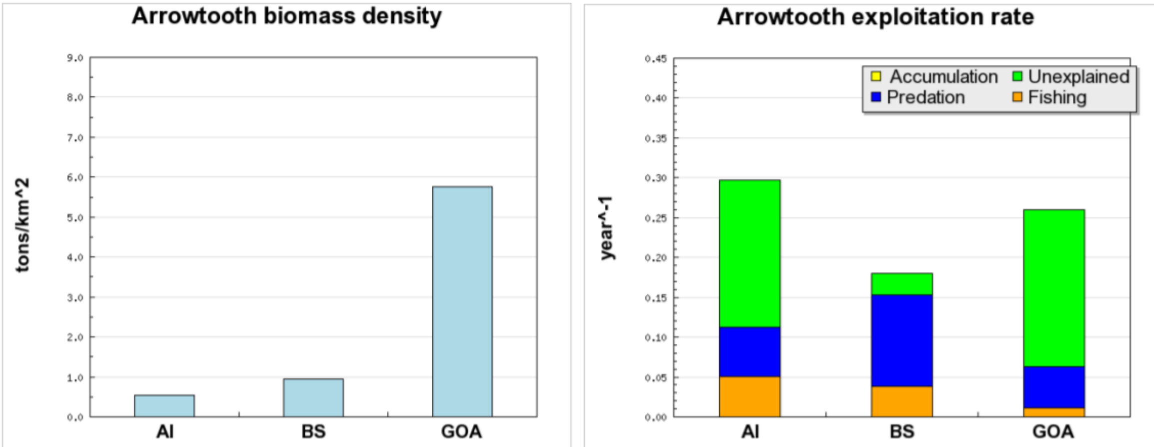


Figure 7B.1: Comparative biomass density (left) and mortality sources (right) for Arrowtooth flounder in the AI, EBS, and GOA ecosystems. Biomass density (left) is the average biomass from early 1990s NMFS bottom trawl surveys divided by the total area surveyed. Total arrowtooth production (right) is derived from stock assessments for the early 1990's, and partitioned according to fishery catch data and predation mortality estimated from cod predator diet data (Aydin et al. 2007). See Background section for detailed methods.

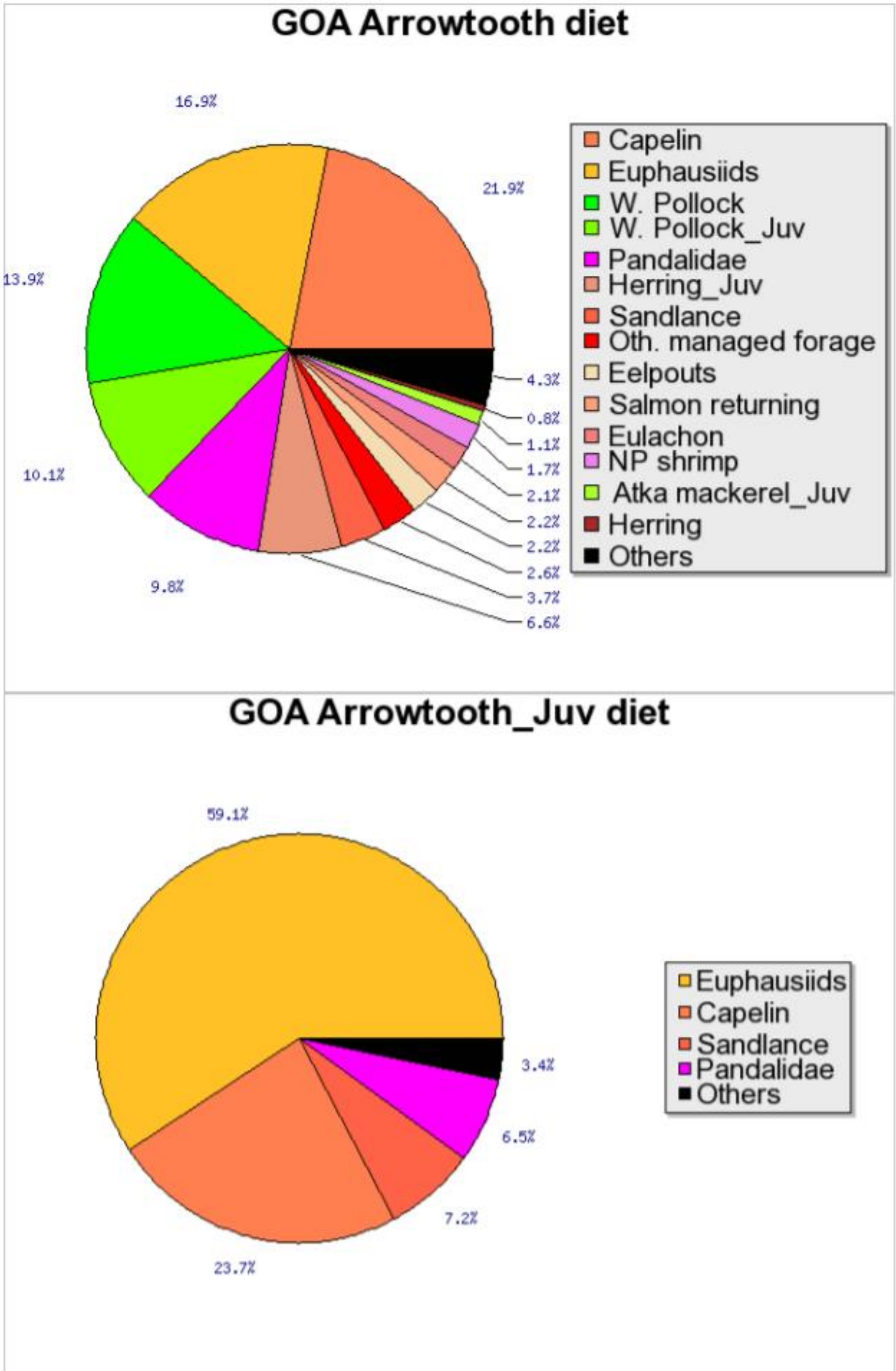


Figure 7B.2: Arrowtooth flounder diet compositions for the GOA ecosystem, for adults > 20cm (top) and juveniles 0-20 cm in length (bottom). Diets are estimated from stomach collections taken aboard NMFS bottom trawl surveys in 1990-1993. See Background section for detailed methods.

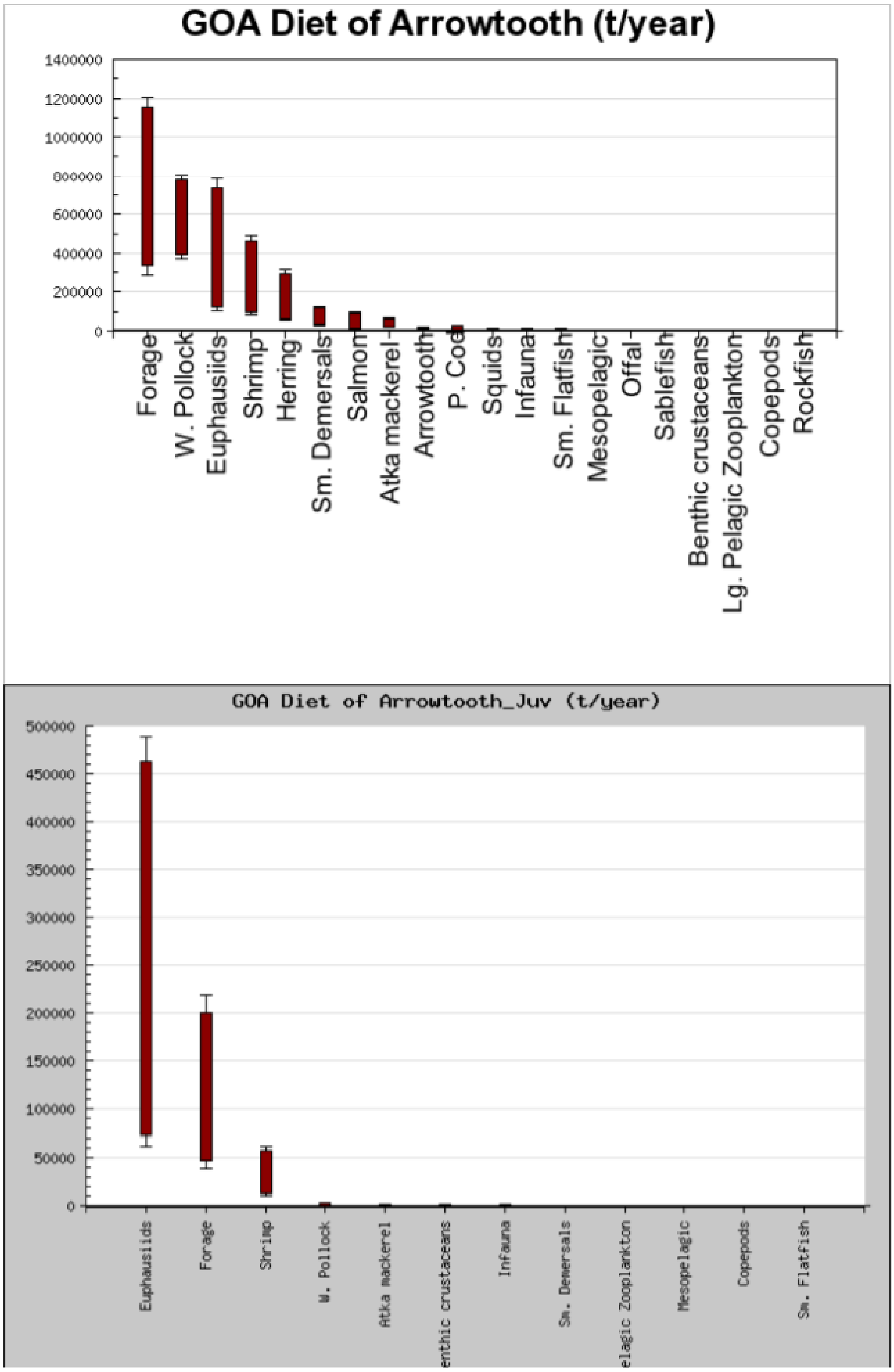
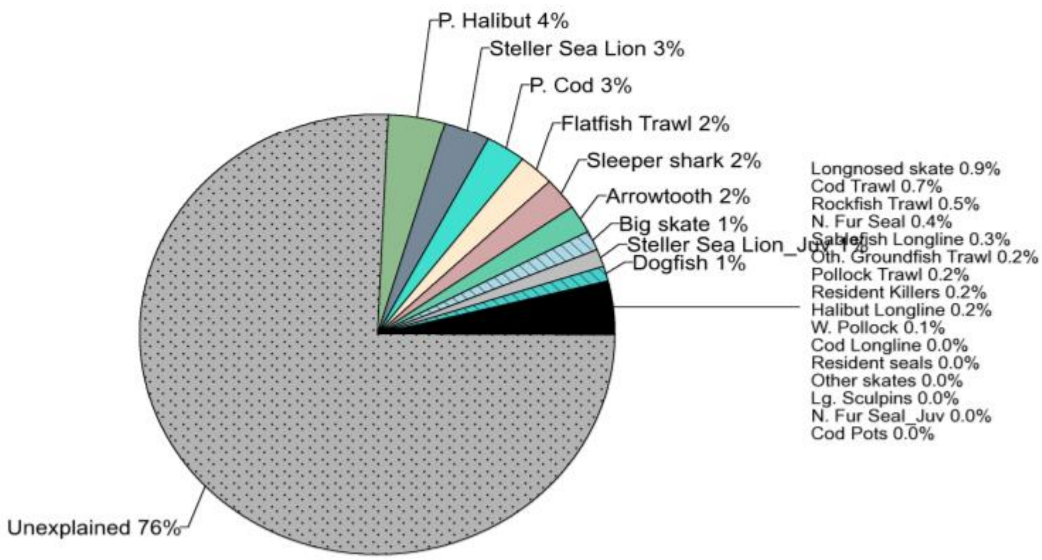


Figure 7B.3: Estimated annual tons of each prey type consumed by GOA Arrowtooth flounder adults >20 cm (top) and juveniles 0-20 cm (bottom), based on diets in Fig. B.2. “Forage” is all forage fish together, including capelin, sand lance, eulachon, and other managed forage.



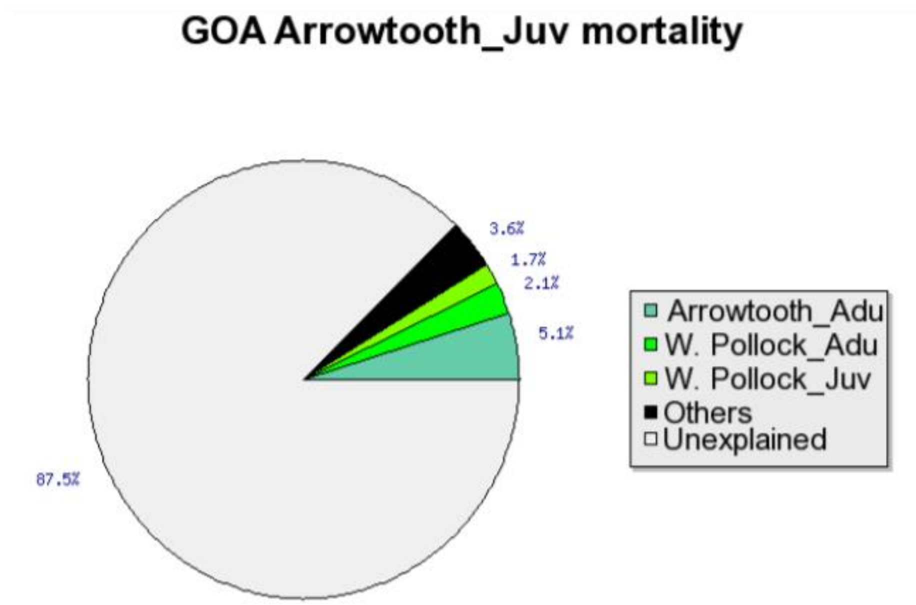


Figure 7B.4: Arrowtooth flounder mortality sources for the GOA ecosystem, for adults > 20cm (top) and juveniles 0-20 cm in length (bottom). Mortality sources reflect arrowtooth flounder predator diets estimated from stomach collections taken aboard NMFS bottom trawl surveys in 1990-1993, arrowtooth predator consumption rates estimated from stock assessments and other studies, and catch of arrowtooth by all fisheries in the same time periods (Aydin et al. 2007). See Background section for detailed methods.

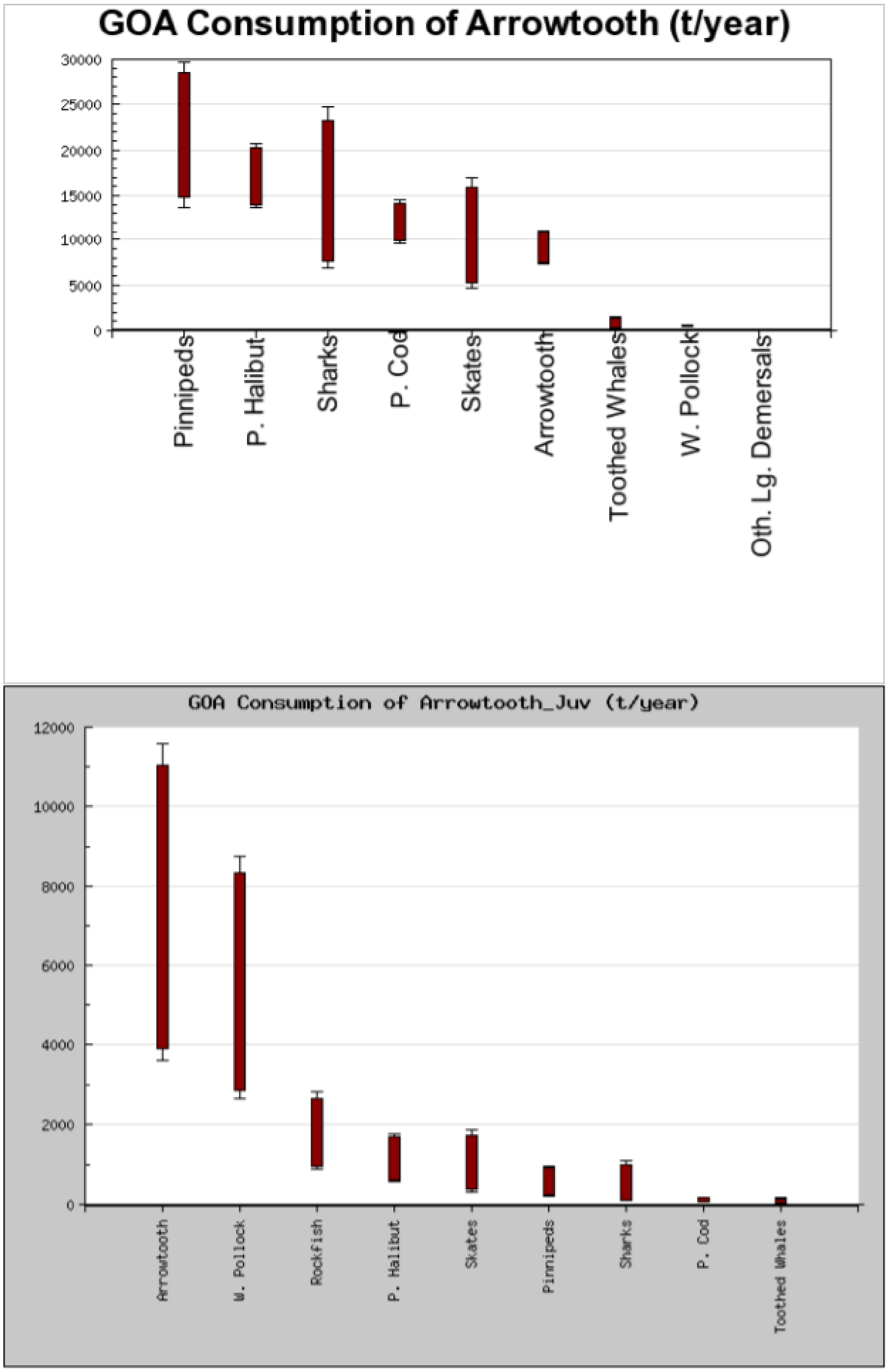


Figure 7B.5: Estimated annual tons of arrowtooth flounder consumed by predators in the GOA. Consumption of adult arrowtooth 20 cm (top) and juveniles 0-20 cm (bottom), based on mortality estimates in Fig. B.4. “Forage” is all forage fish together, including capelin, sand lance, eulachon, and other managed forage.

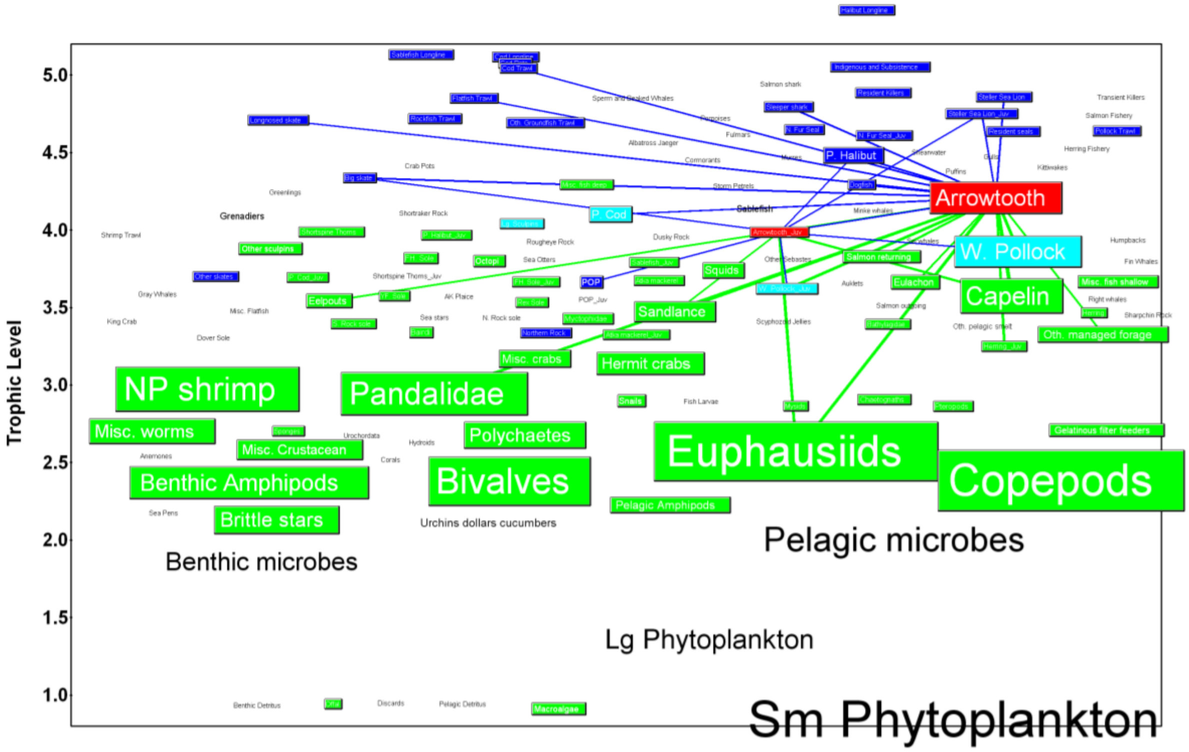


Figure 7B.6: Adult and juvenile arrowtooth flounder in the GOA food web. Box size is proportional to biomass, and lines between boxes represent the most significant energy flows. Predators of arrowtooth are dark blue, prey of arrowtooth are green, and species that are both predators and prey of arrowtooth are light blue.

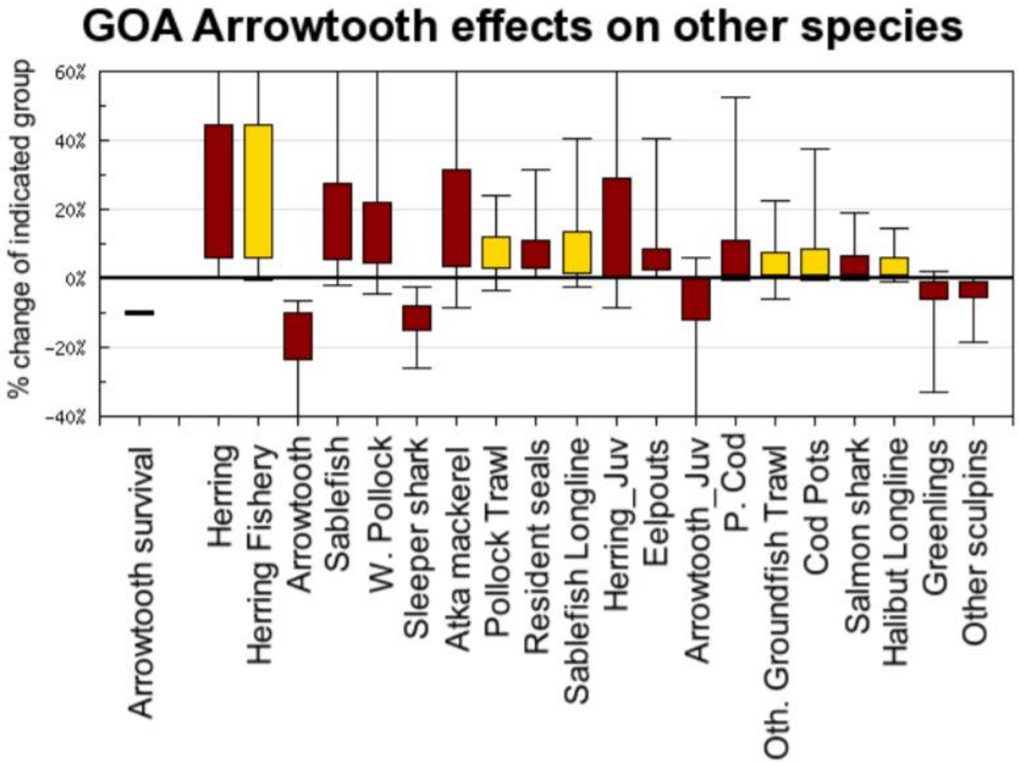


Figure 7B.7: Effect of changing arrowtooth > 20 cm survival on fishery catch (yellow) and biomass of other species (dark red) in the GOA, from a simulation analysis where arrowtooth survival was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting percent change in the biomass of each species on the x axis after 30 years for 50% of feasible ecosystems, error bars show results for 95% of feasible ecosystems (see Aydin et al. 2007, for detailed methods).

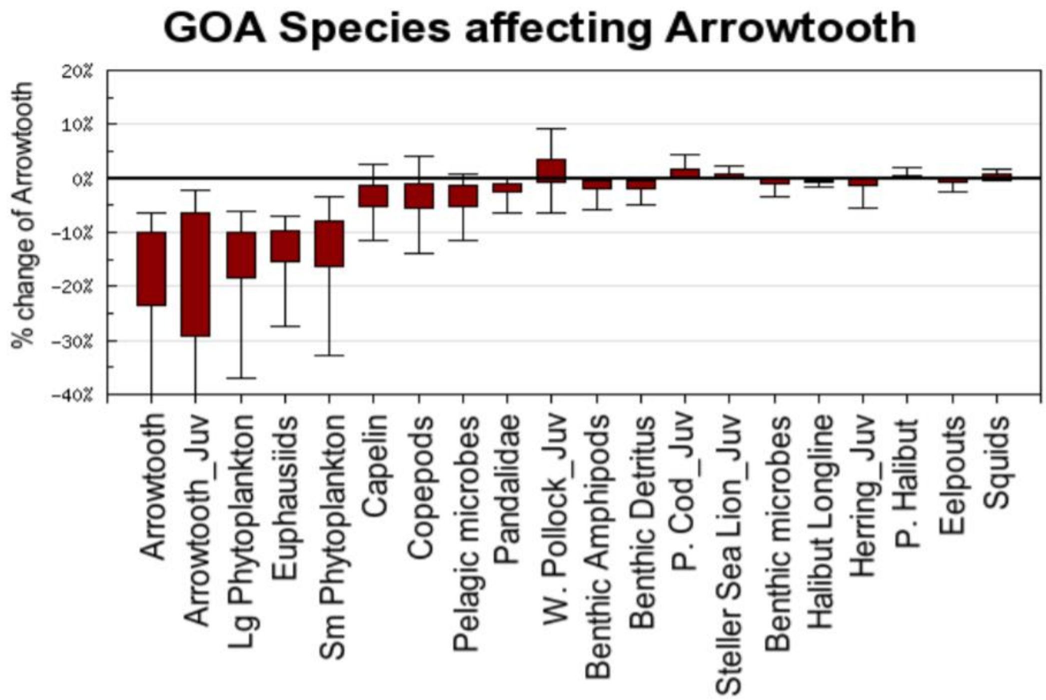


Figure 7B.8: Effect of reducing fisheries catch (yellow) and other species survival (dark red) on arrowtooth > 20 cm biomass, from a simulation analysis where survival of each X axis species group was decreased by 10% and the rest of the ecosystem adjusted to this decrease for 30 years. Boxes show resulting percent change in the biomass of adult arrowtooth after 30 years for 50% of feasible ecosystems, error bars show results for 95% of feasible ecosystems (see Aydin et al. 2007 for detailed methods).

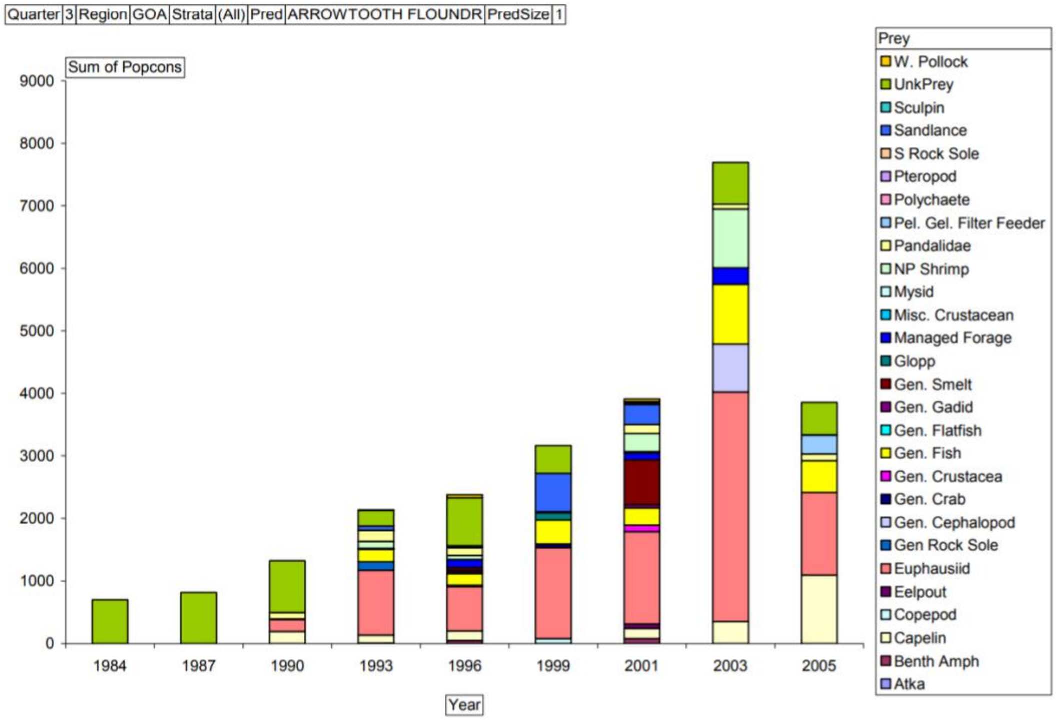


Figure 7B.9: Juvenile (<20 cm) arrowtooth estimated consumption of prey by survey year in the GOA.

Appendix 7C: Economic Performance Report for the Flatfish Fisheries in the Gulf of Alaska

Ben Fissel

Alaska Fisheries Science Center
National Marine Fisheries Service

November 2021

Flatfish total catch in the Gulf of Alaska was 29 thousand tons in 2020, down 10% from 2019 (Table 1). Retained catch decreased to 24.4 thousand t in 2020, with decreases in arrowtooth flounder, flathead sole and rex sole. Catches in the shallow-water flatfish complex, which is largely comprised of rock sole, increased 65% to 4 thousand tons, however, it only accounts for 17% of the total GOA flatfish catch. The retention rate, which was roughly 75% in 2009-2013 has been 85% or greater since 2017. Flatfish are an important component of the catch portfolio of GOA trawl fisheries. There were 22 vessels targeting flatfish in 2019, which is less than typical in recent years but not unprecedented. Ex-vessel value of flatfish was down 19% from 2019 to $5 million in 2020, which was the result of a decrease in the ex-vessel price in addition to reduced catch levels. The average ex-vessel price decreased 14% to $0.084/lb and prices decreased for most species (complexes). First-wholesale value was down 20% to $14.5 million with analogous decreases in production and prices (Table 2).

COVID-19 had an unprecedented impact on fisheries in Alaska. Undoubtedly, one of the significant economic impacts experienced by the industry were the mitigation costs experienced by the fishing and processing industries to continue to supply national and global markets for seafood. Existing data collections do not adequately capture these costs, and as such, this report focuses on catch, revenues, and effort and changes occurring during the most recent year. GOA flatfish catch levels relative to TAC were within a typical range suggesting that COVID-19 did not have a significant impact on catch levels. In contrast to changes in landings, however, there was a notable decrease in prices for many of the products with significant exports to China for reprocessing. This includes GOA flatfish, which has significant end markets in North America, Japan, and Europe in both foodservice and retail. The downward pressure on these prices is likely the result of COVID-19 related logistical difficulties in international shipping and inspections, as well as foodservice closures, and compounded the downward pressure on prices from tariffs. This downward pressure on fish product prices in the first-wholesale market coupled with cost pressure from COVID-19 mitigation efforts likely had upstream impacts on ex-vessel prices that decreased significantly.

Arrowtooth flounder is the most significant flatfish species in the GOA in terms of market value and volume. In 2020 it accounted for 81% of the retained GOA flatfish catch and 65% of the ex-vessel value (Table 1). Flathead sole, and rex sole are also caught in significant quantities accounting for 7% and 4% of the retained catch in 2020. The remainder of the catch volume is mostly of species in the shallow-water flatfish complex, which is comprised of number of different species. Rock sole, butter sole are the most frequently caught shallow-water flatfish typically accounting for 70-80% and 10-20% of the catch, respectively. Deep-water flatfish catches are comprised primarily of Dover sole.

Flatfish are targeted using trawl gear and are caught both as a target species and in fisheries targeting other groundfish. Catcher processors and catcher vessels participate in the fishery, though catcher processors primarily catch arrowtooth. Significant quantities of arrowtooth are also caught in the BSAI, however, the GOA has accounted for more than of 60% of the total Alaska catch of arrowtooth catch in recent years and 67% in 2020. Catcher vessels typically account for approximately 50-80% of the retained catch, though this can vary significantly year over year depending on how heavily catcher processors prosecute arrowtooth fishing. In 2020 catcher vessels accounted for 78% of the flatfish catch. GOA flatfish catches can be constrained by halibut interactions and halibut avoidance can influence seasonal fishing patterns. In 2014, Amendment 95 (regulations to reduce GOA halibut PSC limits) implemented changes to the accounting of halibut PSC sideboard limits for Amendment 80 vessels that allowed the fleet to increase their groundfish catch, mostly arrowtooth flounder. Also, Amendment 95 revised halibut PSC limit apportionments used by trawl catcher vessels from May 15 through June 30 that extended the deep-water species fishery allowing for an increase in arrowtooth flounder catch for this fleet.[a] The GOA flatfish undergo relatively low fishing pressure and harvests are routinely 10-30% of the TAC in recent years. Flathead sole and shallow-water flatfish abundance increased significantly starting in 2012 and arrowtooth and rex sole abundances have remained stable, although abundance appears to have little influence on retained catch.

In the Central Gulf where the majority (>95%) of flatfish fisheries occur, flatfish comprised 10%-14% of the Central Gulf's total retained catch on average from 2015-2018 as pollock catches were high. In 2019 and 2020 the Central Gulf's total retained catch increased to 19% as pollock catches were reduced and pacific cod catches are low. Flatfish are typically only 5-10% of the Central Gulf's ex-vessel value because they are a comparatively lower priced species.

First-wholesale value of GOA flatfish in 2020 was $14.5 million, which was down slightly from 2019 and below the 2011-2015 average of $24.5 million (Table 2). Commensurate with the decrease in catch, production volume fell 7% to 14.1 thousand t. Most flatfish species are primarily processed as headed-and-gutted (H&G) with the exception of rex sole which is primarily sold as whole fish. Because of the minimal processing, changes in production largely reflect changes in catch levels. Before 2010 a significant share of shallow-water flatfish were processed as fillets, however this share has declined over time. The average first-wholesale price decreased 14% to $0.47 per pound in 2020 and was below the 2011-2015 average of $0.59 per pound. The decrease was largely due to a decrease in the rex sole, shallow-water, and flathead sole prices, which fell to $0.63, $0.47, and $0.40 per pound in 2020, respectively. Relative to other flatfish, rex sole tends to be the higher priced species. H&G and whole fish prices for other flatfish typically range from $0.60-$0.75 per pound.

The majority of flatfish produced in the U.S. are exported, primarily to Asia. The U.S. accounted for approximately 27% of global flatfish production in 2019 and Gulf of Alaska flatfish represent approximately 10% of the U.S. flatfish production (Table 3). U.S. trade data encodes the primary GOA flatfish (arrowtooth, rex sole and flathead sole) species with other flatfish exported from the U.S. in a non-specific general flatfish category which limits how informative it is for GOA flatfish specifically. The Alaska flatfish fishery became MSC certified in 2010 and received the Responsible Fishery Management (RFM) certification in 2014. Certification provides access to some markets and may enhance value. For flatfish in general, the majority are exported to China and some share of this product is re-processed into fillets and re-exported. Some arrowtooth exported to China is eaten as a less expensive flounder-type fish and has served as a substitute for more expensive fish. Previous reports indicated growing demand in China through 2016. Export quantities of NSPF[b] flatfish increased in 2020 and average export prices fell 15% to $0.71 per pound and were below the 2011-2015 average (Table 3). Because of China's significance as a re-processor of flatfish products, the tariffs between the U.S. and China, which begun in 2018, have put downward pressure on flatfish prices which has inhibited value growth in flatfish markets. Flatfish were among the species to receive relief under the USDA Seafood Tariff Relief Program in 2019-2020. Industry lacks immediate alternative reprocessing options to China on a large scale. Export quantities of flatfish increased in 2020 from 2019 and the share of exports to China was within a typical range (Table 3). The COVID-19 pandemic created supply chain logistical

[a] For details see http://alaskafisheries.noaa.gov/frules/79fr9625.pdf

[b] NSPF (not specifically provided for) Flatfish is a non-specific flatfish category for U.S. exports.

difficulties, particularly in China, which put downward pressure on prices. In addition, foodservice closures in major markets also likely impacted prices negatively for flatfish finished goods.

Table 1. GOA flatfish ex-vessel market data. Total and retained catch (thousand metric tons), number of vessel, catcher vessel share of retained catch, value (million US$), price (US$ per pound), arrowtooth flounder share of GOA flatfish retained catch, and GOA share of arrowtooth retained catch; 2011-2015 average and 2016-2020.

	2011-2015 Average	2016	2017	2018	2019	2020
Total catch K mt	35.74	28.1	33.3	25.8	31.9	28.8
Retained catch K mt	28.8	23.6	29.3	22.6	28.2	24.4
Catcher Processors #	5.4	5	4	4	4	5
Catcher Vessels #	28	27	19	34	30	22
Catcher Vessel Share of Retained	56%	75%	50%	78%	76%	78%
Ex-vessel value M US$	$8.6	$6.3	$7.9	$6.4	$6.2	$5.0
Ex-vessel price US$/lb	$0.135	$0.114	$0.119	$0.132	$0.098	$0.084
Arrowtooth Share of Retained[1]	73%	75%	85%	72%	80%	81%
Rex Sole Share of Retained	10%	7%	4%	5%	4%	4%
Shallow Flatfish Share of Retained	14%	15%	7%	11%	9%	17%
GOA share of AK Arrowtooth catch	57%	66%	82%	73%	72%	67%

Source: NMFS Alaska Region Blend and Catch-accounting System estimates; and ADF&G Commercial Operators Annual Reports (COAR). Data compiled and provided by the Alaska Fisheries Information Network (AKFIN).

Table 2. GOA flatfish first-wholesale market data. Production (thousand metric tons), value (million US$), price (US$ per pound), arrowtooth flounder, rex sole and flathead sole share of GOA flatfish value and price (US$ per pound), and head-and-gut share of value; 2011-2015 average and 2016-2020.

	2011-2015 Average	2016	2017	2018	2019	2020
First-wholesale production K mt	15.7	12.6	17.8	12.8	15.2	14.1
First-wholesale value M US$	$24.5	$21.0	$37.1	$18.3	$18.1	$14.5
First-wholesale price/lb US$	$0.71	$0.76	$0.95	$0.65	$0.54	$0.47
Arrowtooth share of value	52%	63%	85%	59%	65%	65%
Arrowtooth price/lb US$	$0.59	$0.73	$0.99	$0.57	$0.48	$0.46
Rex sole share of value	24%	16%	8%	19%	18%	10%
Rex sole price/lb US$	$1.04	$1.02	$0.99	$0.98	$0.98	$0.63
Shallow flatfish share of value	15%	13%	4%	13%	10%	18%
Shallow flatfish price/lb US$	$0.82	$0.77	$0.63	$0.73	$0.60	$0.47
H&G share of value	61%	70%	75%	61%	69%	63%

Source: NMFS Alaska Region At-sea Production Reports; and ADF&G Commercial Operators Annual Reports (COAR). Data compiled and provided by the Alaska Fisheries Information Network (AKFIN).

Table 3. Flatfish U.S. trade and global market data. Global production (thousand metric tons), U.S. share of global production, GOA share of U.S. production, U.S. NSPF[2] export volume (thousand metric tons), U.S. export value (million US$), U.S. export price (US$ per pound), China's share of U.S. exports of generic (NSPF) frozen flatfish and the Chinese Yuan/U.S. Dollar exchange rate; 2011-2015 average and 2016-2020.

	2011-2015 Average	2016	2017	2018	2019	2020
Global production of flounder, halibut, and sole K mt	1,013.9	989.3	975.5	973.7	946.4	-
US share global production	31.8%	27.1%	26.7%	25.5%	26.9%	-
GOA FMP flatfish share of U.S.[1]	9.0%	8.8%	11.2%	9.1%	11.1%	-
Export quantity of NSPF Frozen Flatfish K mt	14.6	18.3	22.9	14.1	17.1	22.2
Export value of NSPF Frozen Flatfish M US$	$24.7	$31.7	$44.0	$26.5	$31.6	$34.8
Export price/.b of NSPF Frozen Flatfish US$	$0.77	$0.78	$0.87	$0.85	$0.84	$0.71
Share of U.S. exports of NSPF Frozen Flatfish to China[2]	64.1%	61.9%	77.1%	81.1%	80.3%	78.5%
Exchange rate, Yuan/Dollar	6.42	6.61	6.75	6.64	6.90	6.75

Source: FAO Fisheries & Aquaculture Dept. Statistics http://www.fao.org/fishery/statistics/en. U.S. Department of Agriculture http://www.ers.usda.gov/data-products/agricultural-exchange-rate-data-set.aspx.

1 - The GOA FMP share of U.S. production is calculated as the GOA retained catch divided by the FAO's U.S. production of flounder, halibut and sole.
2 - NSPF (not specifically provided for) Flatfish is a non-specific flatfish category for U.S. exports.