17. Assessment of the Atka mackerel stock in the Bering Sea and Aleutian Islands

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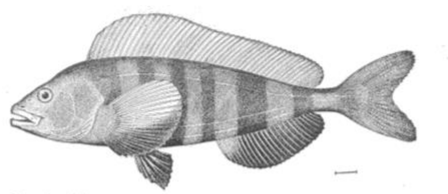

Executive Summary

Relative to the November 2020 SAFE report, the following substantive changes have been made in the assessment of Atka mackerel.

Summary of Changes in Assessment Input

1. The 2020 catch estimate was updated and estimated total catch for 2021 was set equal to the TAC (62,257 t).
2. Estimated 2022 and 2023 catches are 66,740 t and 61,320 t, respectively.
3. The 2020 fishery age composition data were added.
4. The estimated average selectivity for 2016-2020 was used for projections.
5. We assume that approximately 85% of the BSAI-wide ABC is likely to be taken under the revised Steller Sea Lion Reasonable and Prudent Alternatives (SSL RPAs) implemented in 2015. This percentage was applied to the 2022 and 2023 maximum permissible ABCs, and those reduced amounts were assumed to be caught in order to estimate the 2022 and 2023 ABCs and OFL values.

Summary of Changes in the Assessment Methodology

There were no changes in the model configuration.

Summary of Results

1. The addition of the 2020 fishery age composition information impacted the estimated magnitude of the 2012 and 2017 year classes which increased 4 and 33% respectively, relative to last year's assessment. The 2012 year class is estimated to be 59% above average. The 2017 year class increased 33% relative to last year's estimate, but remains just about equal to the long term average recruitment.
2. Estimated values of $B_{100\%}$, $B_{40\%}$, $B_{35\%}$ are slightly lower (-0.4%) relative to last year's assessment.
3. Projected 2022 female spawning biomass (109,360 t) is slightly higher (1.4%) relative to last year's estimate of 2021 female spawning biomass, and 6% higher relative to last year's projection for 2022.
4. Projected 2022 female spawning biomass is just below $B_{40\%}$ (111,470 t) at $B_{39\%}$, thereby placing BSAI Atka mackerel in Tier 3b.
5. The current estimate of $F_{40\%\ adj}$= 0.54 is 25% higher relative to last year's estimate of $F_{40\%\ adj}$ due to changes in the fishery selectivity used for projections.
6. The projected 2022 yield at $maxF_{ABC} = F_{40\%\ adj}$ = 0.54 is 78,510 t, which is 7% higher relative to last year's estimate for 2021.
7. The projected 2022 overfishing level at $F_{35\%\ adj}$ = 0.65 is 91,870 t, which is 7% higher than last year's estimate for 2021.

Quantity	As estimated or *specified last* year for: 2021	2022	As estimated or *recommended this* year for: 2022*	2023*
M (natural mortality rate)	0.30	0.30	0.30	0.30
Tier	3b	3b	3b	3b
Projected total (age 1+) biomass (t)	560,360	599,690	554,490	570,080
Projected Female spawning biomass	107,830	102,950	109,360	103,330
$B_{100\%}$	290,820	290,820	278,670	278,670
$B_{40\%}$	116,330	116,330	111,470	111,470
$B_{35\%}$	101,790	101,790	97,540	97,540
F_{OFL}	0.51	0.49	0.65	0.61
$maxF_{ABC}$	0.43	0.41	0.54	0.51
F_{ABC}	0.43	0.41	0.54	0.51
OFL (t)	85,580	79,660	91,870	84,440
maxABC (t)	73,590	68,220	78,510	71,990
ABC (t)	73,590	68,220	78,510	71,990
Status	As determined *this* 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 estimated total catch of 66,740 t and 61,320 t in place of maximum permissible ABC for 2022 and 2023, respectively.

Area apportionment of ABC

The apportionments of the 2021 and 2022 recommended ABCs based on the most recent 4-survey weighted average:

	Survey Year 2012	2014	2016	2018	2023 & 2023 Apportionment	2022 ABC	2023 ABC
541+SBS	12%	42%	35%	38%	0.35	27,260	25,000
542	39%	28%	30%	7%	0.21	16,880	15,470
543	48%	30%	35%	55%	0.44	34,370	31,520
Weights	8	12	18	27	1.00		
Total ABC						78,510	71,990

Responses to SSC and Plan Team Comments on Assessments in General

From the December 2020 SSC minutes:

There were no comments on assessments in general from the December 2020 SSC minutes that pertained to Atka mackerel. The comments were directed to the Council (reconstituting the spatial management working group, to assessments using VAST models (standardizing documentation), and to the Plan Teams regarding assessment frequency (be judicious in September in bringing forward full assessments outside of the cycle in place).

From the October SSC 2021 minutes:
There were no comments on assessments in general from the October 2021SSC minutes.

From the November 2020 Joint and BSAI Plan Team minutes:
There were no comments on assessments in general from the November 2020 Joint and BSAI Plan Team minutes.

From the September 2021 Joint and BSAI Plan Team minutes:
There were no comments on assessments in general from the September 2021 Joint and BSAI Plan Team minutes.

Responses to SSC and Plan Team Comments Specific to the Atka Mackerel Assessment

From the December SSC 2020 minutes*: “…the SSC requests reporting on other retrospective patterns in the next assessment as additional diagnostics. Other statistics that can be reported include Woods Hole rho, RMSE, and Hanselman’s phi.*

The current assessment reports Mohn’s rho and RSME. The authors plan to conduct an analysis of additional diagnostics and present plots of select estimated parameters related to scale at the September, 2022 Plan Team meeting.

From the November 2020 BSAI Plan Team minutes:
There were no comments specific to the Atka mackerel assessment.

From the September 2021 BSAI Team minutes*:*
An Atka mackerel document was not presented in September 2021.

Introduction

Native Names: In the Aleut languages, Atka mackerel are known as *tmadgi-{* among the Eastern and Atkan Aleuts and Atkan of Bering Island. They are also known as *tavyi-{* among the Attuan Aleuts (Sepez *et al.* 2003).

Distribution

Atka mackerel (*Pleurogrammus monopterygius*) are widely distributed along the continental shelf across the North Pacific Ocean and Bering Sea from Asia to North America. On the Asian side they extend from the Kuril Islands to Provideniya Bay (Rutenburg 1962); moving eastward, they are distributed throughout the Komandorskiye and Aleutian Islands (AI), north along the eastern Bering Sea (EBS) shelf, and through the Gulf of Alaska (GOA) to southeast Alaska.

Early life history

Atka mackerel are a substrate-spawning fish with male parental care. Single or multiple clumps of adhesive eggs are laid on rocky substrates in individual male territories within nesting colonies where males brood eggs for a protracted period. Nesting colonies are widespread across the continental shelf of the Aleutian Islands and western GOA down to bottom depths of 144 m (Lauth *et al*. 2007b). Historical data from ichthyoplankton tows done on the outer shelf and slope off Kodiak Island in the 1970’s and 1980’s (Kendall and Dunn 1985) suggest that nesting colonies may have existed at one time in the central GOA. Possible factors limiting the upper and lower depth limit of Atka mackerel nesting habitat include insufficient light penetration and the deleterious effects of unsuitable water temperatures, wave surge, or high densities of kelp and green sea urchins (Gorbunova 1962, Lauth *et al.* 2007b, Zolotov 1993).

In the eastern and central AI, larvae hatch from October to January with maximum hatching in late November (Lauth *et al.* 2007a). After hatching, larvae are neustonic and about 10 mm in length (Kendall and Dunn 1985). Along the outer shelf and slope of Kodiak Island, larvae caught in the fall were about 10.3 mm compared to larvae caught the following spring which were about 17.6 mm (Kendall and Dunn 1985). Larvae and fry have been observed in coastal areas and at great distances offshore (>500 km) in the Bering Sea and North Pacific Ocean (Gorbunova 1962, Materese *et al.* 2003, Mel'nikow and Efimkin 2003).

The Bering-Aleutian Salmon International Survey (BASIS) project studies the distribution and abundance of salmon during the ocean phase of their life cycle. BASIS conducted standardized surveys of the upper pelagic layer in the EBS shelf using a surface trawl in 2004-2006. In addition to collecting data pertaining to salmon species, BASIS also collected and recorded information for many other Alaskan fish species, including juvenile Atka mackerel. The EBS shelf was sampled during the mid-August through September from 2004 to 2006 and juvenile Atka mackerel with lengths ranging from 150-200 mm were distributed along the outer shelf in the southern EBS shelf and along the outer middle shelf between St. George and St. Matthew Islands (Appendix B in Lowe *et al*. 2007). The fate or ecological role of these juveniles is unknown since adult Atka mackerel are much less common or absent in annual standardized bottom trawl surveys in the EBS shelf (Lauth and Acuna 2009).

Reproductive ecology

The reproductive cycle consists of three phases: 1) establishing territories, 2) spawning, and 3) brooding (Lauth *et al*. 2007a). In early June, a fraction of the adult males end schooling and diurnal behavior and begin aggregating and establishing territories on rocky substrate in nesting colonies (Lauth *et al*. 2007a). The widespread distribution and broad depth range of nesting colonies suggests that previous conjecture of a concerted nearshore spawning migration by males in the AI is not accurate (Lauth *et al.* 2007b). Geologic, oceanographic, and biotic features vary considerably among nesting colonies, however, nesting habitat is invariably rocky and perfused with moderate or strong currents (Lauth *et al.* 2007b). Many nesting sites in the AI are inside fishery trawl exclusion zones which may serve as *de facto* marine reserves for protecting Atka mackerel (Cooper *et al*. 2010).

The spawning phase begins in late July, peaks in early September, and ends in mid-October (Lauth *et al*. 2007a). Mature females spawn an average of 4.6 separate batches of eggs during the 12-week spawning period or about one egg batch every 2.5 weeks (McDermott *et al*. 2007). After spawning ends, territorial males with nests continue to brood egg masses until hatching. Incubation times for developing eggs decrease logarithmically with an increase in water temperature and range from 39 days at a water temperature of 12.2° C to 169 days at 1.6 °C, however, an incubation water temperature of 15 °C was lethal to developing embryos *in situ* (Guthridge and Hillgruber 2008). Higher water temperatures in the range of water temperatures observed in nesting colonies, 3.9 °C to 10.5 °C (Gorbunova 1962, Lauth *et al*. 2007b), can result in long incubation times extending the male brooding phase into January or February (Lauth *et al*. 2007a).

Prey and predators

Adult Atka mackerel in the Aleutians consume a variety of prey, but principally calanoid copepods and euphausiids (Yang 1999), and are consumed by a variety of piscivores, including groundfish (e.g., Pacific cod and arrowtooth flounder, Livingston *et al.* unpubl. manuscr.), marine mammals (e.g., northern fur seals and Steller sea lions, Kajimura 1984, NMFS 1995, Sinclair and Zeppelin 2002, Sinclair *et al.* 2013), and seabirds (e.g., thick-billed murres, tufted puffins, and short-tailed shearwaters, Springer *et al.* 1999).

Predation on Atka mackerel eggs by cottids and other hexagrammids is prevalent during the spawning season as is cannibalism by other Atka mackerel of both sexes (heterocannibalism) and by males from their own nest (filial cannibalism; Canino *et al*. 2008, Yang 1999, Zolotov 1993). Filial egg cannibalism is a common phenomenon in species with extended paternal care.

Rand *et al*. (2010) analyzed Atka mackerel stomach data and determined that the east to west size cline in Atka mackerel sizes across the Aleutian Islands, was the result of food quality rather than food quantity or temperature, and may reflect local productivity. Atka mackerel near Amchitka Island (area 542) were eating more copepods and less euphausiids, whereas fish at Seguam pass (area 541) were eating more energy rich euphausiids and forage fish (Rand *et al*. 2010).

Nichol and Somerton (2002) examined the diurnal vertical migrations of Atka mackerel using archival tags and related these movements to light intensity and current velocity. Atka mackerel displayed strong diel behavior, with vertical movements away from the bottom occurring almost exclusively during daylight hours, presumably for feeding, and little to no movement at night (where they were closely associated with the bottom).

Stock structure

A morphological and meristic study suggests there may be separate populations in the GOA and the AI (Levada 1979). This study was based on comparisons of samples collected off Kodiak Island in the central Gulf, and the Rat Islands in the Aleutians. Lee (1985) also conducted a morphological study of Atka mackerel from the Bering Sea, AI, and GOA. The data showed some differences (although not consistent by area for each characteristic analyzed), suggesting a certain degree of reproductive isolation. Results from an allozyme genetics study comparing Atka mackerel samples from the western GOA with samples from the eastern, central, and western AI showed no evidence of discrete stocks (Lowe *et al.* 1998). A survey of genetic variation in Atka mackerel using microsatellite DNA markers provided little evidence of genetic structuring over the species range, although slight regional heterogeneity was evident in comparisons between some areas (Canino *et al*. 2010). Samples collected from the AI, Japan, and the GOA did not exhibit genetic isolation by distance or a consistent pattern of differentiation. Examination of these results over time (2004, 2006) showed temporal stability in Stalemate Bank, but not at Seguam Pass. These results indicate a lack of structuring in Atka mackerel over a large portion of the species range, perhaps reflecting high dispersal, a recent population expansion and large effective population size, or some combination of all these factors (Canino *et al*. 2010).

The question remains as to whether the Aleutian Island and Gulf of Alaska populations of Atka mackerel should be managed as a unit stock or separate populations given that there is a lack of consistent genetic stock structure over the species range. There are significant differences in population size, distribution, recruitment patterns, and resilience to fishing, suggesting that management as separate stocks is appropriate. Bottom trawl surveys and fishery data suggest that the Atka mackerel population in the GOA is smaller and much more patchily distributed than that in the AI, and composed almost entirely of fish >30 cm in length. There are also more areas of moderate Atka mackerel density in the AI than in the GOA. The lack of small fish in the GOA suggests that Atka mackerel recruit to that region differently than in the AI. Nesting sites have been located in the GOA in the Shumagin Islands (Lauth *et al.* 2007a), and historical ichthyoplankton data from the 1970's around Kodiak Island indicate there was a spawning and nesting population even further to the east (Kendall and Dunn 1985), but the source of these spawning populations is unknown. They may be migrant fish from strong year classes in the AI or a self-perpetuating population in the GOA, or some combination of the two. The idea that the western GOA is the eastern extent of their geographic range might also explain the greater sensitivity to fishing depletion in the GOA as reflected by the history of the GOA fishery since the early 1970s. Catches of Atka mackerel from the GOA peaked in 1975 at about 27,000 t. Recruitment to the AI population was low from 1980-1985, and catches in the GOA declined to 0 in 1986. Only after a series of large year classes recruited to the AI region in the late 1980s, did the population and fishery reestablish in the GOA beginning in the early 1990s. After passage of these year classes through the population, the GOA population, as sampled in the 1996 and 1999 GOA bottom trawl surveys, has declined and is very patchy in its distribution. More recently, the strong 1999, 2006, and 2007 year classes documented in the AI showed up in the GOA. These differences in population resilience, size, distribution, and recruitment support separate assessments and management of the GOA and AI stocks and a conservative approach to the management of the GOA portion of the population.

Management units

Amendment 28 to the Bering Sea/Aleutian Islands (BSAI) Fishery Management Plan became effective in mid-1993, and divided the Aleutian subarea into three districts at 177°W and 177°E for the purposes of spatially apportioning Total Allowable Catches (TAC). Since 1994, the BSAI Atka mackerel TAC has been allocated to the three regions (541 Eastern Aleutians, 542 Central Aleutians, and 543 Western Aleutians).

Fishery

Catch history

Atka mackerel became a reported species group in the BSAI Fishery Management Plan in 1978. Catches (including discards and community development quota [CDQ] catches), corresponding Acceptable Biological Catches (ABC), TAC, and Overfishing Levels (OFL) set by the North Pacific Fishery Management Council (NPFMC or Council) from 1978 to the present are given in Table 17.1. Non-commercial removals are presented in Appendix 17A. These supplemental catch data are estimates of total available removals that do not occur during directed groundfish fishing activities. These include removals incurred during research, subsistence, personal use, recreational, and exempted fishing permit activities.

From 1970-1979, Atka mackerel were landed off Alaska exclusively by the distant water fleets of the U.S.S.R., Japan and the Republic of Korea. U.S. joint venture fisheries began in 1980 and dominated the landings of Atka mackerel from 1982 through 1988. Total landings declined from 1980-1983 primarily due to changes in target species and allocations to various nations rather than changes in stock abundance. Catches increased quickly thereafter, and from 1985-1987 Atka mackerel catches averaged 34,000 t annually, dropping to a low of 18,000 t in 1989. The last joint venture allocation of Atka mackerel off Alaska was in 1989, and since 1990, all Atka mackerel landings have been made by U.S. fishermen. Beginning in 1992, TACs increased steadily in response to evidence of a large exploitable biomass, particularly in the central and western AI.

Description of the directed fishery

Fishery

The patterns of the Atka mackerel fishery generally reflect the behavior of the species: (1) the fishery is highly localized and usually occurs in the same few locations each year; (2) the schooling semi-pelagic nature of the species makes it particularly susceptible to trawl gear fished on the bottom; and (3) trawling occurs almost exclusively at depths less than 200 m. In the early 1970s, most Atka mackerel catches were in the western AI (west of 180°W longitude). In the late 1970s and through the 1980s, fishing effort moved eastward, with the majority of landings occurring near Seguam and Amlia Islands. In 1984 and 1985 the majority of landings came from a single 0.5° latitude by 1° longitude block bounded by 52° 30' N, 53° N, 172° W, and 173° W in Seguam Pass (73% in 1984, 52% in 1985). Areas fished by the Atka mackerel fishery from 1977 to 1992 are displayed in Fritz (1993). Areas of 2020 and 2021 fishery operations are shown in Figure 17.1.

Fishing locations and CPUE since 2015 have been very similar (Figure 17.1, Figure 17. 1 in Lowe *et al*. 2016, 2017, 2018, 2019). Of note are the fishery operations in the Central (542) area, particularly just preceding and during the AFSC bottom trawl surveys of the Central area during July 1-19, 2018. A total of 153 and 156 fishery hauls were observed July 1-19 in the Central area during the 2017 and 2018 fisheries, respectively. Fishery catch per unit effort (CPUE, extrapolated kg/haul) was also similar in 2017 and 2018, with fishery CPUE rates slightly higher in the 2018 Central area fishery during July 1-19, 2018. Also, fishing was more concentrated in 2018 relative to 2017 in the Central area during July 1-19 (unpublished data, S. Lowe, AFSC). It is unknown if the 2018 fishery had any impacts on the survey catch rates of Atka mackerel in the Central area during July 1-19, 2018. The 2018 survey catches of Atka mackerel in the Central area were significantly down, and the survey did not encounter any moderate to large catches of Atka mackerel as in previous years (See Survey data section below).

Atka mackerel are caught almost exclusively by the Amendment 80 Fleet. The fishery for Atka mackerel has been a catch share fishery since 2008 when Amendment 80 to the BSAI Groundfish FMP was implemented, rationalizing the fleet of catcher/processor vessels in the Bering Sea and Aleutian Islands region targeting flatfish, Atka mackerel and Pacific ocean perch.

Market

An economic performance report for 2020 for BSAI Atka mackerel is included in Appendix 17B (Fissel 2021). The U.S. (Alaska), Japan and Russian are the major producers of Atka mackerel.[1] Typically approximately 90% of the Alaska caught Atka mackerel is processed as head-and-gut (H&G) products, while the remainder is mostly sold as whole fish (Table 17B-1 in Appendix 17B). However, in 2019 and 2020 99% of the catch was processed as H&G as whole fish production dropped off. The domestic market for Atka mackerel is minimal, and data indicate U.S. imports are approximately 0.1% of global production. Virtually all of Alaska's Atka mackerel production is exported, mostly to Asian markets in Japan, South Korea, and northern China. In Asia it undergoes secondary processing into products like surimi, salted-and-split and other consumable product forms (Table 17B-2 in Appendix 17B). Based on U.S. export statistics, approximately 60% of Alaska's Atka mackerel is exported to Japanese markets where it is particularly popular in the northern Hokkaido region. Atka mackerel has a unique cultural significance and is a symbolic fish in the Hokkaido region (AFSC 2016).

COVID-19 had an unprecedented impact on fisheries in Alaska. 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, the economic performance report (Appendix 17B) focuses on catch, revenues, and effort and changes occurring during the most recent year. Atka mackerel 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 and Japan, which ultimately go to food service sectors. This includes Atka mackerel, which has significant end markets in Japan, China, and South Korea 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. Because of China's significance as an export market (approximately 25% of export volume), the tariffs between the U.S. and China which begun in 2018, may have put downward pressure on Atka mackerel prices which inhibited value growth in that market. The downward pressure on fish product prices in the first-wholesale market coupled with cost pressures from COVID-19 mitigation efforts likely resulted in negative impacts on net revenues.

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[1] Japan and Russia catch the distinct species Okhotsk Atka mackerel (*Pleurogrammus azonus*) which are substitutes as the markets treat the two species identically.

Atka mackerel was among the species to receive relief under the USDA Seafood Tariff Relief Program in 2019-2020.

As global production of Atka mackerel has dropped due to reductions in international supply, The U.S. has captured a larger share of global production in recent years. The U.S. supplied 49% of the global market of Atka mackerel in 2019.

Management history

Prior to 1992, ABCs were allocated to the entire Aleutian management district with no additional spatial management. However, because of increases in the ABC beginning in 1992, the Council recognized the need to disperse fishing effort throughout the range of the stock to minimize the likelihood of localized depletions. In 1993, Amendment 28 to the BSAI Fishery Management Plan became effective, dividing the Aleutian subarea into three districts at 177°W and 177°E for the purposes of spatially apportioning TACs (Figure 17.1). From 1994-2014, the BSAI Atka mackerel TAC was allocated to the three regions based on the average distribution of biomass estimated from the AI bottom trawl surveys. Beginning in 2015, The ABC was apportioned by applying the random effects model to AI survey biomass estimates from 2015 to 2018. Beginning in 2019, ABC has been apportioned by the average distribution of biomass estimated by the AI trawl surveys. Table 17.2 gives the time series of BSAI Atka mackerel catches, corresponding ABC, OFL, and TAC by region.

In June 1998, the Council passed a fishery regulatory amendment that proposed a four-year timetable to temporally and spatially disperse and reduce the level of Atka mackerel fishing within Steller sea lion critical habitat (CH) in the BSAI Islands. Temporal dispersion was accomplished by dividing the BSAI Atka mackerel TAC into two equal seasonal allowances, an A-season beginning January 1 and ending April 15, and a B-season from September 1 to November 1. The goal of spatial dispersion was to reduce the proportion of each seasonal allowance caught within CH to no more than 40% by the year 2002. No CH allowance was established in the Eastern subarea because of the year-round 20 nm trawl exclusion zone around the sea lion rookeries on Seguam and Agligadak Islands that minimized effort within CH. The regulations implementing this four-year phased-in change to Atka mackerel fishery management became effective on January 22, 1999 and lasted only 3 years (through 2001). In 2002, new regulations affecting the management of the Atka mackerel, pollock, and Pacific cod fisheries went into effect. Furthermore, all trawling was prohibited in CH from August 8, 2000 through November 30, 2000 by the Western District of the Federal Court because of violations of the Endangered Species Act (ESA).

As part of the plan to respond to the Court and comply with the ESA, NMFS and the NPFMC formulated new regulations for the management of Steller sea lion and groundfish fishery interactions that went into effect in 2002. The objectives of temporal and spatial fishery dispersion, cornerstones of the 1999 regulations, were retained. Season dates and allocations remained the same (A season: 50% of annual TAC from 20 January to 15 April; B season: 50% from 1 September to 1 November). However, the maximum seasonal catch percentage from CH was raised from the goal of 40% in the 1999 regulations to 60%. To compensate, effort within CH in the Central (542) and Western (543) Aleutian fisheries was limited by allowing access to each subarea to half the fleet at a time. Vessels fishing for Atka mackerel were randomly assigned to one of two teams, which started fishing in either area 542 or 543. Vessels were not permitted to switch areas until the other team had caught the CH allocation assigned to that area. In the 2002 regulations, trawling for Atka mackerel was prohibited within 10 nm of all rookeries in areas 542 and 543; this was extended to 15 nm around Buldir Island and 3 nm around all major sea lion haulouts. Steller sea lion CH east of 178° W in the Aleutian district, including all CH in subarea 541 and a 1° longitude-wide portion of subarea 542, was closed to directed Atka mackerel fishing.

The 2010 NMFS Biological Opinion found that the fisheries for Alaska groundfish in the Bering Sea and AI and GOA, and the cumulative effects of these fisheries, are likely to jeopardize the continued existence of the western distinct population segment of Steller sea lions, and also likely to adversely modify the designated critical habitat of the western Steller sea lions. Because this Biological Opinion found jeopardy and adverse modification of critical habitat, the agency was required to implement reasonable and prudent alternatives (RPAs) to the proposed actions (the fisheries). The 2010 Biological Opinion included RPAs which required changes in groundfish fishery management in Management Sub-areas 543, 542, and 541 in the AI Management Area. NOAA Fisheries implemented the RPAs via an interim final rule before the start of the 2011 fishery in January.

The RPAs from the 2010 Biological Opinion and the 2014 Section 7 Consultation Biological Opinion specific to Atka mackerel are listed below.

RPAs from the 2010 Biological Opinion

<u>In Area 543:</u>

- Prohibit retention by all federally permitted vessels of Atka mackerel and Pacific cod.
- Establish a TAC for Atka mackerel sufficient to support the incidental discarded catch that may occur in other targeted groundfish fisheries (e.g., Pacific ocean perch).
- Eliminate the Atka mackerel platoon management system in the harvest limitation area.

<u>In Area 542:</u>

- Close waters from 0–3 nm around Kanaga Island/Ship Rock to directed fishing for groundfish by federally permitted vessels.
- Set TAC for Area 542 to no more than 47 percent of the Area 543 ABC.
- Between 177° E to 179° W longitude and 178° W to 177° W longitude, close critical habitat from 0–20 nm to directed fishing for Atka mackerel by federally permitted vessels year round.
- Between 179° W to 178° W longitude, close critical habitat from 0-10 nm to directed fishing for Atka mackerel by federally permitted vessels year round. Between 179° W and 178° W longitude, close critical habitat from 10-20 nm to directed fishing for Atka mackerel by federally permitted vessels not participating in a harvest cooperative or fishing a CDQ allocation.
- Add a 50:50 seasonal apportionment to the CDQ allocation to mirror seasonal apportionments for Atka mackerel harvest cooperatives.
- Limit the amount of Atka mackerel harvest allowed inside critical habitat to no more than 10 percent of the annual allocation for each harvest cooperative or CDQ group. Evenly divide the annual critical habitat harvest limit between the A and B seasons.
- Change the Atka mackerel seasons to January 20, 12:00 noon to June 10, 12:00 noon for the A season and June 10, 12:00 noon to November 1, 12:00 noon for the B season.
- Eliminate the Atka mackerel platoon management system in the harvest limitation area.

<u>In Area 541:</u>

- Change the Bering Sea Area 541 Atka mackerel seasons to January 20, 12:00 noon to June 10, 12:00 noon for the A season and June 10,12:00 noon to November 1, 12:00 noon for the B season.

<u>In Bering Sea subarea:</u>

- Close the Bering Sea subarea year round to directed fishing for Atka mackerel.
- Prohibit trawling for Atka mackerel from 0 to 20 nm around all Steller sea lion rookeries and haulouts and in the Bogoslof Foraging Area.

Revised RPAs from the 2014 Biological Opinion

The season dates for the AI Atka mackerel trawl fishery are modified relative to the action analyzed in the 2010 Biological Opinion. The season dates from the action in the 2010 Biological Opinion, the interim final rule, and the 2014 Biological Opinion (BiOp) are shown in the table below.

	A Season		B Season	
	Start	End	Start	End
Action in 2010 BiOp	20-Jan	15-Apr	1-Sep	1-Nov
Interim Final Rule	20-Jan	10-Jun	10-Jun	1-Nov
Action in 2014 BiOp	20-Jan	10-Jun	10-Jun	31-Dec

<u>In Area 543:</u>

- Modify the closure around Buldir Island from a 0 to 15 nm closure to trawl fishing for Atka mackerel to a 0 to 10 nm closure.
- Limit the Area 543 Atka mackerel TAC to less than or equal to 65 percent of the ABC.

The action analyzed in the 2010 Biological Opinion did not include an Area 543-specific Atka mackerel harvest limit and prohibited directed fishing for Atka mackerel and Pacific cod.

<u>In Area 542:</u>

- Close Steller sea lion CH to Atka mackerel fishing between 178°E and 180° longitude.
- Increase 0 to 10 nm closures to 0 to 20 nm closures year-round at five rookeries (Ayugadak Point, Amchitka/Column Rocks, Amchitka Island/East Cape, Semisopochnoi/Petrel, and Semisopochnoi/Pochnoi)
- Increase 0 to 3 nm closures to 0 to 20 nm at six haulouts (Unalga and Dinkum Rocks, Amatignak Island/Nitrof Point, Amchitka Island/Cape Ivakin, Hawadax Island (formerly Rat Island), Little Sitkin Island, and Segula Island).

The action analyzed in the 2010 Biological Opinoin included an Area 542-specific Atka mackerel harvest limit which set TAC for Area 542 to no more than 47 percent of the Area 542 ABC. The revised action does not include an Area 542-specific Atka mackerel harvest limit.

<u>In Area 541:</u>

- Open a portion of CH in Area 541 from 12 to 20 nm southeast of Seguam Island.
- Beyond the 50 percent seasonal apportionments there is no limit on the amount of the Atka mackerel TAC that could be harvested inside this open area of CH.

All of CH in Area 541 was closed to Atka mackerel fishing under the action analyzed in the 2010 Biological Opinion. Fishing for Atka mackerel has been prohibited in Steller sea lion CH in Area 541 since 2001.

<u>In Bering Sea Subarea:</u>

Management of the Atka mackerel TAC in the AI Area 541 is combined with the Bering Sea subarea. In general, the harvest of Atka mackerel in the Bering Sea is incidental to harvest of other groundfish target species, and occurs in relatively small quantities in critical habitat areas closed to directed fishing for Atka mackerel.

- Modify maximum retainable amount regulations for Amendment 80 vessels and Western Alaska Community Development Quota (CDQ) entities operating in the Bering Sea subarea to revise the method for calculating the MRA.

The effect of the modifications in the Bering Sea subarea would provide for more of the combined Bering Sea/541 Atka mackerel TAC to be harvested in the Bering Sea subarea rather than the AI.

Amendment 78 to the BSAI Groundfish FMP closed a large portion of the AI subarea to nonpelagic trawling. The Amendment 78 closures to nonpelagic trawling include the AI Habitat Conservation Area, the AI Coral Habitat Protection Areas, and the Bowers Ridge Habitat Conservation Zone, located in the northern portion of Area 542 and 543. These closures were implemented on July 28, 2006. These closures are in addition to the Steller sea lion protection measures and, in combination, substantially limit the locations available for nonpelagic trawling in the AI subarea

Amendment 80 to the BSAI Groundfish FMP was adopted by the Council in June 2006 and implemented for the 2008 fishing year. This action allocated several BSAI non-pollock trawl groundfish species (including Atka mackerel) among trawl fishery sectors, facilitated the formation of harvesting cooperatives in the non-American Fisheries Act (non-AFA) trawl catcher/processor sector, and established a limited access privilege program (also referred to as a catch share program). The Alaska Seafood Cooperative formerly the Best Use Cooperative was formed under Amendment 80 which includes most of the participants in the BSAI Atka mackerel fishery.

Bycatch and discards

Atka mackerel are rarely caught as bycatch in other directed Aleutian Islands fisheries. The largest amounts of discards of Atka mackerel, which are likely under-size fish, occur in the directed Atka mackerel trawl fishery. Atka mackerel are also caught as bycatch in the trawl Pacific cod and rockfish fisheries. Discard data have been available for the groundfish fishery since 1990. Discards of Atka mackerel for 1990-1999 and 2000-2014 have been presented in previous assessments (Lowe *et al.* 2003 and Lowe *et al*. 2016, respectively). Bering Sea/Aleutian Islands fisheries Atka mackerel discard data from 2015 to the present in are given below:

		Atka mackerel retained and discarded catch in the directed Atka mackerel fisheries (Atka mackerel), and all other directed fisheries (All others)			
Year	Fishery	Discarded (t)	Retained (t)	Total (t)	Discard Rate (%)
2015	Atka mackerel	555	46,979	47,533	1.2
	All others	245	5,499	5,734	
	All	789	52,478	53,267	
2016	Atka mackerel	285	48,082	48,367	0.6
	All others	142	5,976	6,118	
	All	427	54,058	54,485	
2017	Atka mackerel	309	58,390	58,699	0.5
	All others	82	5,665	5,747	
	All	391	64,055	64,446	
2018	Atka mackerel	497	63,573	64,070	0.8
	All others	188	6,129	6,317	
	All	685	69,702	70,387	
2019	Atka mackerel	417	47,833	48,250	0.9
	All others	190	9,030	9,220	
	All	607	56,863	57,471	
2020	Atka mackerel	425	49,235	49,660	0.9
	All others	277	8,947	9,224	
	All	702	58,182	58,884	

Discard rates were 2-3% until 2009 when the discard rate increased to nearly 4% (Lowe *et al*. 2003, Lowe *et al*. 2011). The increases in 2009 and 2010 may have been due to large numbers of small fish from the 2006 and 2007 year classes (Lowe *et al*. 2011). The large decrease in the 2011 discard rate likely reflects regulatory changes to the operation of the Atka mackerel fishery. In 2014, the discard rate dropped to less than 1% in 2014. In 2015, the Western Aleutian sub-area (543) was re-opened to limited directed fishing for Atka mackerel, and the discard rate increased to slightly over 1%. Discard rates since 2015 have been under 1%.

Until 1998, discard rates of Atka mackerel by all fisheries had generally been greatest in the western AI (543) and lowest in the east (541, Lowe *et al.* 2003). In the 2004 fishery, the discard rates decreased in both the Central and Western Aleutians (542 & 543) while the Eastern AI rate increased (Lowe *et al.* 2011). Subsequently, the 2005 discard rates dropped significantly in all three areas, contributing to the large overall drop in the 2005 discard rate (Lowe *et al*. 2011). Discard rates have continued to decrease in Eastern AI (541) since 2005, and discard rates in the Central AI (542) have increased, reflecting a shift in effort of the Atka mackerel fishery. From 2011-2014 directed fishing for Atka mackerel in 543 was prohibited under Steller sea lion protection measures. Only minimal catches of Atka mackerel were taken during 2011-2014 from the Western AI (543) in the rockfish fisheries. The discard rates in the Eastern and Central AI dropped significantly in 2014 to less than 1%. In 2015 under the revised Steller sea lion RPAs, the TAC reduction in the Central AI was removed and the Western AI was re-opened to directed fishing for Atka mackerel. Since 2015, discard rates in all areas have been below 1.5%.

Year		Atka mackerel catch and discard in all Aleutian Islands fisheries by subarea 541	542	543
2015	Retained (t)	25,896	16,281	10,155
	Discarded (t)	182	391	98
	Rate	*0.7%*	*2.3%*	*1%*
2016	Retained (t)	27,885	15,652	10,265
	Discarded (t)	115	143	65
	Rate	*0.4%*	*0.9%*	*0.6%*
2017	Retained (t)	33,817	17,618	12,324
	Discarded (t)	129	130	109
	Rate	*0.4%*	*0.7%*	*0.9%*
2018	Retained (t)	34,646	20,744	13,287
	Discarded (t)	294	146	132
	Rate	*0.8%*	*0.7%*	*1.0%*
2019	Retained (t)	22,400	14,182	19,205
	Discarded (t)	134	139	236
	Rate	*0.6*	*1.0%*	*1.2%*
2020	Retained (t)	23,013	14,481	19,812
	Discarded (t)	214	115	185
	Rate	*0.9*	*0.8*	*0.9*

Data

The BSAI Atka mackerel assessment uses the following data in the assessment model:

Source	**Data**	**Years**
NMFS Aleutian Islands groundfish bottom trawl surveys	Survey biomass	1991, 1994, 1997, 2000, 2002 2004, 2006, 2010, 2012, 2014, 2016, 2018
	Age Composition	1991, 1994, 1997, 2000 2002, 2004, 2006, 2010, 2012, 2014, 2016, 2018
U.S. Atka mackerel trawl fisheries	Catch	1977-2021
	Age Composition	1977-2020

Fishery data

Fishery data consist of total catch biomass from 1977 to 2020 and projected end of year 2021 catch data (Table 17.1). Atka mackerel catch levels since 2015 have been 99% of the TAC each year. Thus, we project the 2021 end of year catch to be equal to the TAC (62,257 t). Appendix 17A contains Atka mackerel catches from sources other than those that are included in the Alaska Region's official estimate of catch listed in Table 17.1 (e.g., removals due to scientific surveys, subsistence fishing, recreational fishing, and fisheries managed under other FMPs). The only significant non-commercial catches of Atka mackerel are from the AFSC summer bottom trawl surveys in the Aleutian Islands Table 17A-1.

Fishery Length Frequencies

From 1977 to 1988, commercial catches were sampled for length and age structures by the NMFS foreign fisheries observer program. There was no joint venture allocation of Atka mackerel in 1989, when the fishery became fully domestic. Since the domestic observer program was not in full operation until 1990, there was little opportunity to collect age and length data in 1989. Also, the 1980 and 1981 foreign observer samples were small, so these data were supplemented with length samples taken by Republic of Korea fisheries personnel from their commercial landings. Data from the foreign fisheries are presented in Lowe and Fritz (1996).

Atka mackerel length distributions from the 2020 and preliminary 2021 fisheries by management area are shown in Figure 17.2. The modes at about 39-40 cm (areas 542, 543) and 42 cm (area 541) in the 2020 length distributions represent the 2015 and 2017 year classes. The 2020 Bering Sea data (areas 517, 519) show a bimodal distribution. The second mode may represent the 2012 and 2013 year classes which dominated the 2019 fishery catches. The available 2021 fishery data are presented and should be considered preliminary, but are similar to the 2019 distributions.

Fishery Age Data

Length measurements collected by observers and otoliths read by the AFSC Age and Growth Lab (Table 17.3) were used to create age-length keys to determine the age composition of the catch from 1977-2017 (Table 17.4). In previous assessments (prior to 2008), the catch-at-age in numbers was compiled using total annual BSAI catches and global (Aleutian-wide) year-specific age-length keys. The formulas used are described by Kimura (1989). As with the length frequencies, the age data for 1980-1981 and 1989 presented problems. The commercial catches in 1980 and 1981 were not sampled for age structures, and there were too few age structures collected in 1989 to construct a reasonable age-length key. Kimura and Ronholt (1988) used the 1980 survey age-length key to estimate the 1980 commercial catch age distribution, and these data were further used to estimate the 1981 commercial catch age distribution with a mixture model (Kimura and Chikuni 1987). However, this method did not provide satisfactory results for the 1989 catch data and that year has been excluded from the analyses (Lowe *et al*. 2007).

An alternative approach to compiling the catch-at-age data was adopted in the 2008 assessment in response to issues raised during the 2008 Center for Independent Experts (CIE) review of the Aleutian Islands Atka mackerel and pollock assessments. This method uses stratified catch by region (Table 17.2) and compiles (to the extent possible) region-specific age-length keys stratified by sex. This method also accounts for the relative weights of the catch taken within strata in different years. This approach was applied to catch-at-age data after 1989 (the period when consistent observer data were available) and follows the methods described by Kimura (1989) and modified by Dorn (1992; Table 17.4). Briefly, length-stratified age data are used to construct age-length keys for each stratum and sex. These keys are then applied to randomly sampled catch length frequency data. The stratum-specific age composition estimates are then weighted by the catch within each stratum to arrive at an overall age composition for each year. In summary, estimates of the proportion of catch-at-age are derived from the mean of the bootstrap sampling of the revised catch-at-age estimates. The bootstrap method also allows evaluation of sample-size scaling that better reflect inter-annual differences in sampling and observer coverage. Since body mass is applied in this estimation, stratum-weighted mean weights-at-age are available with the estimates of catch-at-age. The three strata for the Atka mackerel coincide with the three management areas (eastern, central, and western regions of the Aleutian Islands). This method was used to derive the age compositions for 1990-2020 (the period for which all the necessary information is readily available). Prior to 1990, the catch-age composition estimates remain the same as in previous assessments.

The most notable features of the estimated catch-at-age data (Table 17.4) are the strong 1975, 1977, 1999, 2000, and 2001 year classes, and large numbers of the 2006 and 2012 year classes which showed up in the 2009-2012 and 2015-2019 fisheries, respectively. The 1975 year class appeared strong as 3 and 4-year-olds in 1978 and 1979. It is unclear why this year class did not continue to show up strongly after age 4. The 1977 year class appeared strong through 1987, after entering the fishery as 3-year-olds in 1980. The 2002 fishery age data showed the first appearance in the fishery of the exceptionally strong 1999 year class, followed by the first appearance of large numbers from the 2000 and 2001 year classes in the 2003 and 2004 fisheries, respectively. The 2012 fishery data are dominated by 5 and 6-year-olds of the 2007 and 2006 year classes, and continue to show the presence of the 2001 year class. More recently, the 2016-2019 catch data are mainly comprised of the 2012, 2013, and 2015 year classes (Table 17.4, Figure 17.3). The 2020 catch data show the first appearance of large numbers of 3 year olds from the 2017 year class (Figure 17.3).

Atka mackerel are a summer-fall spawning fish that do not appear to lay down an otolith annulus in the first year (Anderl *et al.*, 1996). The Alaska Fisheries Science Center Age and Growth Unit adds one year to the number of otolith hyaline zones determined for Atka mackerel otoliths. All age data presented in this report have been corrected in this way.

Survey data

Atka mackerel are a difficult species to survey because: (1) they do not have a swim bladder, making them poor targets for hydroacoustic surveys; (2) they prefer hard, rough and rocky bottom which makes sampling with survey bottom trawl gear difficult; (3) their diel schooling behavior and patchy distribution result in survey estimates associated with large variances; and 4) Atka mackerel are thought to be very responsive to tide cycles. During extremes in the tidal cycle, Atka mackerel may not be accessible which could affect their availability to the survey. Despite these shortcomings, the U.S.-Japan cooperative bottom trawl surveys conducted in 1980, 1983, 1986, and the 1991- 2018 domestic trawl surveys, provide the only direct estimates of population biomass from throughout the Aleutian Islands region. It is important to note that the biomass estimates from the early U.S-Japan cooperative surveys are not directly comparable with the biomass estimates obtained from the U.S. trawl surveys because of differences in the net, fishing power of the vessels and sampling design (Barbeaux *et al.* 2004). Due to differences in area and depth coverage of the U.S-Japan cooperative surveys, we present this historical data (Table 17.5), but these data are not used in the assessment model.

The 2020 Aleutian Islands survey was cancelled due Covid-19; the potential impacts due to increased uncertainty are discussed below for the risk table. The most recent Aleutian Islands biomass estimate from the 2018 Aleutian Islands bottom trawl survey is 355,213 t, down 21% relative to the 2016 survey estimate (Table 17.6b). The breakdown of the Aleutian biomass estimates by area corresponds to the management sub-districts (541-Eastern, 542-Central, and 543-Western). The decrease in biomass in the 2018 survey is essentially a result of the largest decrease in biomass observed in the Central Aleutian area (Table 17.6b). Relative to the 2016 survey, the 2018 biomass estimates are down 14% in the Western area, down 80% in the Central area, and up 6% in the Eastern area (Figure 17.4). The 95% confidence interval about the mean total 2018 Bering Sea/Aleutian Islands biomass estimate is 138,870-571,555 t. The coefficient of variation (*CV*) of the 2018 mean BSAI biomass is 30% (Table 17.6b).

The distribution of biomass in the Western, Central, and Eastern Aleutians and the southern Bering Sea has shifted between each of the surveys, most dramatically in area 541 in the 2000 and 2012 surveys, and recently in the Central area (542) in the 2018 survey (Figure 17.4). The 2018 Central Aleutian area biomass estimate of 26,615 t was the lowest in the survey time series, contributing only 7% of the total 2018 Aleutian biomass, and representing an 80% decline relative to the 2016 survey (Table 17.6b). The 2018 Central area survey biomass estimate represents an extreme unexplained decrease. Atka mackerel are thought to be very responsive to tide cycles and current patterns, and the catchability of Atka mackerel may be influenced by currents. However, there were no changes in survey protocols during 2018 that affected trawling operations with respect to tidal cycles. Gear temperatures in the 100 to 200 m depth stratum where 99% of Atka mackerel are caught in the surveys, were similar during the 2014, 2016, and 2018 surveys in area 542, and all three surveys were conducted in years with significantly warmer than average temperatures, especially in 2016 (Figure 17.5). The 2018 survey start date in the Central Aleutians was July 1, 2018 which is within a day or two of the start dates of the 2014 and 2016 surveys.

The 2000 Eastern Aleutian area biomass estimate (900 t) was the lowest of all surveys. There are several factors that may have had a significant impact on the distribution of Atka mackerel that were discussed in Lowe *et al.* (2001). The 2012 survey also did not observe large catches of Atka mackerel in the Eastern Aleutian area, resulting in the second lowest biomass estimate of the time series. The area specific variances for area 541 have always been high relative to 542 and 543; the distribution of Atka mackerel in 541 is patchier with episodic large catches often resulting from trawl samples in the major passes (Table 17.6b).

Variation in survey biomass and low estimates for 2000 and 2012 may have been affected by colder than average temperatures in the region and their effects on fish behavior. Gear temperature near the bottom during the 2000 and 2012 surveys in area 541 were colder than average for the 100 to 200 m depth stratum where 99% of the Atka mackerel are caught in the surveys (Figure 17.5). This is in contrast to the 2018 which was a significantly warm year (Figure 17.5).

Other factors could also affect survey catches. Sampling in area 541 includes passes with high currents that may affect towing success and catchability during daily tidal cycles and bi-weekly spring and neap tides. Atka mackerel are thought to be very responsive to tide cycles and current patterns, and catchability of Atka mackerel may be influenced by currents. However, there were no changes in survey protocols during 2012 that affected trawling operations with respect to tidal cycles and tows at stations were attempted with some failures through different current strengths. Three stations were resampled at the end of the cruise in area 541 in 2012 without any effect on the catch per unit effort of Atka mackerel. There is no evidence to suggest that the survey vessels were not sampling properly in 2012 and 2018. Appendix 1 in Lowe *et al*. (2001) examined the distribution of historical Atka mackerel survey data. Simulation results showed that it is very possible to underestimate the true biomass when the target organism has a very patchy distribution (E. Conners, Appendix 1 in Lowe *et al*. 2001).

Atka mackerel exhibit a very patchy distribution and biomass estimates are influenced by large isolated catches. In 2018, the survey estimated 25,654 t of biomass in the southern Bering Sea (*CV*=70%). Very little biomass has been observed in the southern Bering Sea since the 2010 survey, although the 2018 biomass estimate represented a large but highly uncertain increase in biomass relative to the previous three surveys (Table 17.6b).

In the 2018 survey, the largest haul occurred in the Eastern Aleutians off the Islands of Four Mountains (Figure 17.6). Moderately large hauls also occurred in Seguam Pass in the Eastern Aleutians. Moderate to large catches of Atka mackerel were completely absent in the Central Aleutian area (including Petral Bank) in significant contrast to previous surveys (Figure 17.6). Moderately large catches in the Western Aleutians were observed at Buldir Island, and no large catches were observed at Stalemate Bank as in previous surveys (Figure 17.6).

The percent occurrence of Atka mackerel in the Aleutian Islands surveys prior to 2016 ranged from 50-60%. The percent of occurrence of Atka mackerel in the 2016 survey dropped to 38%, and increased to 48% in the most recent 2018 survey. By area, the rates of encounter in the 2018 survey were 52% in the Western AI, 58% in the Central AI, and 39% in the Eastern AI area. Although biomass was the lowest in the Central area in the 2018 survey, the Central area had the highest rate of encounter of Atka mackerel. Very small catches of Atka mackerel were consistently found through much of the Central area.

Temperatures profiles from the 2014, 2016, and 2018 surveys were some of the warmest on record in the time series over all depth strata (Figure 17.5). Studies suggest that temperature affects the incubation period and potentially the occupation of nesting habitats by males (Lauth *et al*. 2007a). Recent studies of habitat-based definitions of essential fish habitat (EFH) in the Aleutian Islands demonstrate that water temperature can be an important determinant of EFH for many groundfish species (Laman *et al*. 2017).

The effect of temperature on survey catchability and fish behavior is unknown, but could affect the vertical or broad scale distribution of Atka mackerel to make them less available to the trawl during cold years.

Survey length frequencies

The bottom trawl surveys have consistently revealed a strong east-west gradient in Atka mackerel size similar to fishery data, with the smallest fish in the west and progressively larger fish to the east along the Aleutian Islands chain. The 2018 survey length frequency distributions also show a strong east-west gradient in Atka mackerel size, although the pattern is somewhat obscured in the Central Aleutians which showed a bimodal distribution with modes at 32-33 and 39-41 cm (Figure 17.7). A bimodal distribution in the Central area was also observed in the 2016 survey (Figure 17.7 in Lowe *et al*. 2017).

Survey age data

The 2018 survey age composition are mainly comprised of 5 and 6-year olds of the 2012 and 2013 year classes (40%), and 3-year olds of the 2015 year class (Figure 17.8). The 2009 year class is still prevalent. The mean age in the 2018 survey is 6 years. For comparison, the 2018 Aleutian Islands fishery age composition is shown and similar to the 2018 survey age data are comprised of 3, 5 and 6-year olds (Figure 17.8). Unlike the survey data, the 2009 year class are not prevalent in the fishery data. Table 17.7 gives estimated survey numbers at age of Atka mackerel from the Bering Sea/Aleutian Islands trawl surveys and numbers of Atka mackerel otoliths aged.

The 2018 Aleutian Islands survey adopted a random sampling scheme for otolith collections (previous surveys used a length-stratified scheme). The request was made to sample approximately 300 Atka mackerel otoliths per area, with an overall target of otoliths from 1,000 Atka mackerel. The 2018 Aleutian Islands survey was able to randomly sample and age 1,052 Atka mackerel otoliths, a significantly higher number than has ever been collected in the Aleutian surveys. A random sampling scheme will continue to be used for Aleutian Islands Atka mackerel.

An analysis conducted previous to this assessment in response to Plan Team and SSC comments (Appendix 17C, Lowe *et al*. 2018), concluded that there was no real benefit to including the 1986 survey age composition, and that including these data was inconsistent given that the model does not include the 1986 survey index. We proposed to exclude the 1986 survey age composition in the 2018 and future assessments which was accepted by the BSAI Plan Team and SSC.

Survey abundance indices

Previous assessments revealed that the partial time series of relative indices from the 1980, 1983, 1986 Aleutian Islands surveys did not provide useful additional information to the model and have been omitted from the assessment since 2001. In the 2018 assessment, we conducted a sensitivity analysis of time-varying selectivity for the survey as suggested by the BSAI Plan Team. Initial explorations allowed for a separate selectivity pattern for 1986 and included the 1986 survey biomass estimate (The 1986 survey was the most comprehensive of the 1980s surveys). The assumption was that different survey protocols during the 1980s may warrant allowing a selectivity change for that year. This was tested but failed to improve the model fit to the survey biomass and also had minimal impact on results (Appendix 17C, Lowe *et al*. 2018).

Analytic Approach

Since 2002 BSAI Atka mackerel stock assessment has been implemented using the Assessment Model for Alaska (AMAK)[2] from the Toolbox, which is similar to the stock synthesis application (Methot 1989, 1990; Fournier and Archibald 1982, Fournier 1998). The AMAK model allows increased flexibility in specifying models with uncertainty in changes in fishery selectivity and other parameters such as natural mortality and survey catchability (Lowe *et al.* 2002). This approach (AMAK) has also been adopted for the Aleutian Islands pollock stock assessment (Barbeaux *et al.* 2004).

Model structure

The AMAK models catch-at-age with the standard Baranov catch equation. The population dynamics follows numbers-at-age over the period of catch history (here 1977-2021) with natural and age-specific fishing mortality occurring throughout the 11-age-groups that are modeled (1-11+). Age 1 recruitment in each year is estimated as deviations from a mean value expected from an underlying stock-recruitment curve. Deviations between the observations and the expected values are quantified with a specified error model and cast in terms of a penalized log-likelihood. The overall log-likelihood (L) is the sum of the log-likelihoods for each data component and prior specification (e.g., for affecting the extent selectivity is allowed to vary). Appendix 17D Tables 17D-1 – 17D-3 provide a description of the variables used, and the basic equations describing the population dynamics of Atka mackerel as they relate to the available data. The quasi[3] likelihood components and the distribution assumption of the error structure are given below:

Data component	**Years of data**	**Likelihood form**	***CV* or sample size (*N*)**
Catch biomass	1977-2021	Lognormal	*CV*=5%
Fishery catch age composition	1977-2020	Multinomial	Year specific *N*=2-236, Ave.=100
Survey biomass	1991, 1994, 1997, 2000, 2002 2004, 2006, 2010, 2012, 2014, 2016, 2018	Lognormal	Average *CV*=26%
Survey age composition	1991, 1994, 1997, 2000 2002, 2004, 2006, 2010, 2012, 2014, 2016, 2018	Multinomial	*N*=13-37, Ave.=26
Recruitment deviations		Lognormal	
Stock recruitment curve		Lognormal	
Selectivity smoothness (in age-coefficients, survey and fishery)		Lognormal	
Selectivity change over time (fishery and survey)		Lognormal	
Priors (where applicable)		Lognormal	

[2] AMAK. 2015. A statistical catch at age model for Alaska, version 15.0. NOAA version available on request to authors.

[3] Quasi likelihood is used here because model penalties (not strictly relating to data) are included.

Input sample size

Model fitting and parameter estimation is affected by assumptions on effective sample size as inputs to reflect age-composition data (via the multinomial likelihood). In previous assessments, "effective sample sizes ($\dot{N}_{i,j}$) were estimated (where *i* indexes year, and *j* indexes age) as:

$$\dot{N}_{i,j} = \frac{p_{i,j}\left(1-p_{i,j}\right)}{\mathrm{var}\left(p_{i,j}\right)}$$

where $p_{i,j}$ is the proportion of Atka mackerel in age group *j* in year *i* plus an added constant of 0.01 to provide some robustness. The variance of $p_{i,j}$ was obtained from the estimates of variance in catch-at-age (Dorn 1992). Thompson and Dorn (2003, p. 137) and Thompson (AFSC pers. comm.) noted that the above is a random variable that has its own distribution. Thompson and Dorn (2003) show that the harmonic mean of this distribution is equal to the true sample size in the multinomial distribution. This property was used in the previous assessments to obtain sample size estimates for the (post 1989) fishery numbers-at-age estimates (scaled to have a mean of 100; earlier years were set to constant values).

In the 2016 assessment (Lowe *et al*. 2016), assumptions on sample sizes for age composition data were re-evaluated. For the fishery, the number of Atka mackerel lengths measured varied substantially as did the number of hauls from which hard-parts were sampled from fish for age-determinations. A comparison of values used in the 2015 assessment, and the scaled number of hauls shows differing patterns over time (Figure 17.10 in Lowe *et al*. 2016). Stewart and Hamel (2014) found the maximum realized sample sizes for fishery biological data to be related both to the number of hauls and individual fish sampled from those hauls, and that a relative measure proportional to the number of hauls sampled might be a better indicator of sampling intensity. Therefore, for Model 16.0 (introduced in the 2016 assessment) and Model 16.0b (introduced in the 2017 assessment, see *Model Evaluation* in Lowe *et al*. 2017), the post-1989 fishery sample sizes were scaled to have the same mean as the 2015 assessment model (N=100) but varied relative to the number of hauls sampled; earlier years were set to constant values.

The table below gives the fishery sample sizes for Model 16.0b.

1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
25	25	25	25	50	50	50	50	50	50	50	50
1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
47	6	3	2	28	23	22	5	27	74	94	66
2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
68	146	131	147	139	143	163	168	156	115	154	112
2014	2015	2016	2017	2018	2019	2020					
153	219	236	200	200	200	202					

Following Lowe *et al*. (2017) time-varying sample sizes for survey age compositions were scaled to have a mean of approximately 50 and varied with the number of Atka mackerel hauls, but effective sample sizes for the survey age compositions were estimated following Francis (2011, equation TA1.8, Francis weights). The table below gives the survey sample sizes for Model 16.0b tuned using Francis weights.

Survey	
Year	Sample Size
1986	16
1991	19
1994	19
1997	13
2000	20
2002	35
2004	37
2006	28
2010	36
2012	31
2014	34
2016	24
2018	25
Avg.	26

An ageing error conversion matrix is used in the assessment model to translate model population numbers at age to expected fishery catch at age. We estimated this matrix using an ageing error model fit to the observed percent agreement at ages 2 through 10. Mean percent agreement is close to 100% at age 2 and declines to 54% at age 10. Annual estimates of percent agreement are variable, but show no obvious trend, hence a single conversion matrix for all years in the assessment model was adopted. The model is based on a linear increase in the standard deviation of ageing error and the assumption that ageing error is normally distributed. The model predicts percent agreement by taking into account the probability that both readers are correct, both readers are off by one year in the same direction, and both readers are off by two years in the same direction. The probability that both readers agree and were off by more than two years was considered negligible.

Parameters estimated outside the assessment model

The following parameters were estimated independently of other parameters outside of the assessment model: natural mortality (*M*), length and weight at age parameters, and maturity at age and length parameters. A description of these parameters and how they were estimated follows.

Natural mortality

Natural mortality (*M*) is a difficult parameter to estimate reliably. Lowe et al. (1997) explored several methods based on correlations of *M* with life history parameters including growth parameters (Alverson and Carney 1975, Pauly 1980, Charnov 1993), longevity (Hoenig 1983), and reproductive potential (Roff 1986, Rikhter and Efanov 1976). Previous assessments explored the use of priors on *M*, resulting in drastically inflated biomass levels. This included the estimation of *M* and survey catchability (*q*) simultaneously with various combinations of priors, and a range of priors on *M* or *q*, while the other parameter was fixed (Lowe et al. 2003, Lowe et al. 2004). Results were unsatisfactory and difficult to interpret biologically.

More recently we conducted preliminary explorations of alternative formulations of age-specific natural mortality (*M*) specified outside the assessment model (Lowe and Ianelli 2016; unpublished data). Alternatives included the Lorenzen model (Lorenzen, 1996), and the *M*-at-age formulation suggested in the report of the Natural Mortality Workshop held in 2009 (the “best ad-hoc mortality model” in that report [see Brodziak *et al.* 2011]). In response to Plan Team and SSC requests to continue investigation of age-specific natural mortality, we included a third method (Gislason, 2010) in a further investigation of age-specific *M*, and use a rescaled average vector of *M* for model evaluation (Appendix 17C, Lowe *et al.*

2018). These three methods are initially based on theoretical life history and or ecological relationships that are then evaluated using meta-analysis, resulting in an empirical equation relating *M* to more easily measured quantities of length and weight.

Results of age-specific natural mortality estimates from the three methods described above were relatively consistent and suggested higher mortality rates for age classes younger than the age at maturity, particularly for ages 1-2 (Appendix 17C, Lowe *et al*. 2018). We used an ensemble approach and averaged the results for all three methods. We then used the method recommended by Clay Porch in Brodziak *et al*. (2011) to rescale the average age-specific values, and this rescaled average schedule was used to explore the impact of higher age-specific mortality for the younger ages.

In summary, the implementation of age-specific natural mortality improved model fits for some components, particularly the fishery age composition and stock recruitment components. The largest impacts of age-specific *M* is on the younger ages, particularly for ages 1 and 2 with estimated values of *M* of 1.04 and 0.56, respectively (Appendix 17C, Lowe *et al.* 2018). The assessment model has a lot of flexibility for age 1 recruitment, and the high estimated *M* for age 1 is accommodated by greatly inflated estimates of age 1 recruitment. Spawning biomass estimates were also scaled higher relative to the constant *M* assessment model. However, biological reference rates and ABC and OFL reflected only minor increases. Although estimates of age 1 recruitment differ greatly between the 2 models (constant *M* and age-specific *M*), age 1 recruits have low impact to stock dynamics given selectivity and maturity schedules for Atka mackerel. We concluded that the natural mortality estimate of 0.3 is a conservative assumption based on the previous meta-analysis by Lowe and Fritz (1997), and fits reasonably well with other key estimated parameters (e.g. survey catchability and selectivity). We recommended continuing with the assumption of fixed constant M=0.3 which was accepted by the Plan Team and SSC. This year's assessment assumes a fixed natural mortality rate of 0.3

Length and weight at age

Atka mackerel exhibit large annual and geographic variability in length at age. Because survey data provide the most uniform sampling of the Aleutian Islands region, data from these surveys were used to evaluate variability in growth (Kimura and Ronholt 1988, Lowe *et al.* 1998). Kimura and Ronholt (1988) conducted an analysis of variance on length-at-age data from the 1980, 1983, and 1986 U.S.-Japan surveys, and the U.S.-U.S.S.R. surveys in 1982 and 1985, stratified by six areas. Results showed that length at age did not differ significantly by sex, and was smallest in the west and largest in the east. Studies by Lowe *et al.* (1998), Rand *et al*. (2010), and McDermott *et al*. (2014) corroborated differential growth in three sub-areas of the Aleutian Islands and the Western GOA, and the east to west differential size cline. Based on the work of Kimura and Ronholt (1988), and annual examination of length and age data by sex which has found no differences, growth parameters are presented for combined sexes.

Parameters of the von Bertalanffy length-age equation and a weight-length equation have been calculated for (1) the combined 2010, 2012, 2014, and 2016 survey data for the entire Aleutians region, and for the Eastern (541), Central (542), and Western (543) subareas, and (2) the combined 2014-2016 fishery data for the same areas:

Data source	L_∞(cm)	K	t_0
2010, 2012, 2014, 2016 surveys			
Areas combined	43.23	0.384	-0.027
541	46.35	0.371	-0.374
542	42.76	0.377	-0.037
543	40.41	0.442	0.060
2014-2016 fishery			
Areas combined	41.52	0.318	-2.082
541	45.06	0.295	-2.188
542	39.52	0.466	-0.164
543	39.88	0.516	0.515

Length-age equation: Length (cm) = $L_\infty\{1\text{-exp}[-K(\text{age-}t_0)]\}$

Both the survey and fishery data show a clear east to west size cline in length at age with the largest fish found in the eastern Aleutians.

The weight-length relationship determined from the same data sets are as follows:

weight (kg) = 5.70E-06 × length (cm) $^{3.217}$ (2010, 2012, 2014, 2016 surveys; N = 1,784)
weight (kg) = 3.84E-05 × length (cm) $^{2.679}$ (2014-2016 fisheries; N = 6,610).

The observed differences in the weight-length relationships from the survey and fishery data, particularly in the exponent of length, probably reflect the differences in the timing of sample collection. The survey data were all collected in summer, the spawning period of Atka mackerel when gonad weight would contribute the most to total weight. The fishery data were collected primarily in winter, when gonad weight would be a smaller percentage of total weight than in summer.

Year-specific weight-at-age estimates are used in the model to scale fishery and survey catch-at-age (and the modeled numbers-at-age) to total catch biomass and are intended to represent the average weight-at-age of the catch. Separate annual survey weights-at-age are compiled by expanding modeled numbers into age-selected survey biomass levels (Table 17.8a). Specifically, survey estimates of length-at-age were obtained using year-specific age-length keys. Weights-at-age were estimated by multiplying the length distribution at age from the age-length key, by the mean weight-at-length from each year-specific data set (De Robertis and Williams 2008). In addition, a single vector of weight-at-age values based on the 2014, 2016, and 2018 surveys is used to derive population biomass from the modeled numbers-at-age in order to allow for better estimation of current biomass (Table 17.8a).

The fishery weight-at-age data presented in previous assessments (prior to 2008) were compiled based on unweighted, unstratified (Aleutian-wide) fishery catch-age samples to construct the year-specific age-length keys (see Table 17.8 in Lowe *et al.* 2007). Beginning with the 2008 assessment, the weights-at-age for the post 1989 fishery reflect stratum-weighted values based on the relative catches. The fishery weight-at-age data presented in Table 17.8b for 1990 to 2020, were compiled using the region-specific age-length key estimation scheme described above in the Fishery Data section. Prior to 1990, the fishery weight-at-age estimates are as in previous assessments and given in Table 17.8b.

Maturity at age and length

Female maturity at length and age were determined for Aleutian Islands Atka mackerel (McDermott and Lowe, 1997). The estimated female maturity at age is used in the assessment models. The age at 50% maturity is 3.6 years. Length at 50% maturity differs by area as the length at age differs by Aleutian Islands sub-areas:

	Length at 50% maturity (cm)
Eastern Aleutians (541)	35.91
Central Aleutians (542)	33.55
Western Aleutians (543)	33.64

The maturity schedules are given in Table 17.9. Cooper *et al*. (2010) examined spatial and temporal variation in Atka mackerel female maturity at length and age. Maturity at length data varied significantly between different geographic areas and years, while maturity at age data failed to indicate differences and corroborated the age at 50% maturity determined by McDermott and Lowe (1997).

Parameters estimated inside the assessment model

Deviations between the observations and the expected values are quantified with a specified error structure. Lognormal error is assumed for survey biomass estimates and fishery catch, and a multinomial error structure is assumed for survey and fishery age compositions. These error structures are used to estimate the following parameters conditionally within the model (fishing mortality, survey selectivity, survey catchability, age 1 recruitment). A description of these parameters and how they were estimated follows.

Fishing mortality

Fishing mortality is parameterized to be separable with a year component and an age (selectivity) component. The selectivity relationship is modeled with a smoothed non-parametric relationship that can take on any shape (with penalties controlling the degree of change over time, degree of declining selectivity at age (dome-shape, σ_d), and curvature as specified by the user; Table A-2). Selectivity is conditioned so that the mean value over all ages will be equal to one. To provide regularity in the age component, a moderate penalty was imposed on sharp shifts in selectivity between ages (curvature) using the sum of squared second differences (log-scale). In addition, the age component parameters are assumed constant for ages 10 and older. Asymptotic growth is reached at about age 9 to 10 years. Thus, it seemed reasonable to assume that selectivity of fish older than age 10 would be the same. We note that this assumption assumes there are no changes in behavior for the older fish. A moderate penalty was imposed to allow the model limited flexibility on degree of declining selectivity at age. In the 2012 assessment we evaluated a range of alternative values for the prior penalty of the parameter determining the degree of dome-shape (σ_d) for fishery selectivity. Based on these results, a value of 0.3 for σ_d was chosen for the selected model (Lowe *et al*. 2012) and is carried forward unchanged in this assessment.

Since the 2016 assessment, we tuned the time-varying fishery selectivity variance ($\sigma_{\text{f\_sel}}$) using the Francis weighting method (Francis 2011, equation TA1.8) on the fishery age composition data for Model 16.0b as described below. We consider that the mean input sample size for the fishery age composition is reasonable (mean=100) and that the lack of fit (or potential overfitting) could be adjusted by finding the appropriate level of inter-annual variability in selectivity. The procedure for tuning the degree of time-varying selectivity variability given input samples sizes was done iteratively by simply adjusting the variance term for selectivity variability (σ_{f_sel}) to achieve a “Francis weight” of 1.0 (or nearly). Typically, this was achieved in 3-4 iterations, and was done by manually editing the variance terms (which could differ by year, but for this case, were set to be the same for each year within a trial run). The original documentation for the smoothness (second differencing) penalty (L_2) was provided in Appendix Table 17D-3 of the 2017 (and previous) assessments as:

$$L_2 = \sum_l \lambda_2^l \sum_{j=1}^{A} \left(\eta_{j+2}^l + \eta_j^l - 2\eta_{j+1}^l \right)^2,$$

where λ is the weight for the prior on smoothness for selectivity. The index *l* is equal to *s* or *f* for survey or fishery selectivity respectively (in this case it is *f*). The index *j* denotes age with *A* being the maximum age modeled. The parameter η is the age effect for fishery selectivity.

However, in previous assessments we omitted discussion of how the σ_{f_sel} parameter relates to this equation. The relationship between σ_{f_sel} and λ_2^l is:

$$\lambda_2^l = \frac{1}{2\sigma_{f\_sel}^2}.$$

Regarding selectivity variability adjustments relative to results, we suggest that tuning by adjusting the σ_{f_sel} term provides a defensible statistical approach to setting the degree of selectivity variability (and thereby perhaps better track age-specific fishing mortality), assuming the effective sample size (to include overdispersion) is approximately correct. In contrast, other approaches, e.g., constant or blocked selectivity specifications, require downweighting the fishery age composition data, thereby implicitly accepting that the “model is correct” and the data are problematic. We consider the fishery age data to be the most robust of the data inputs. Model 16.0b, the current assessment model, uses Francis (2011) weights to tune the constraint governing the amount of time variability in fishery selectivity.

The current assessment model (Model 16.0b), incorporates time-varying fishery selectivity with constraints and penalties as described above.

Survey selectivity and catchability

In response to Plan Team and SSC requests, a sensitivity analysis of time-varying selectivity for the surveys was conducted in 2017 (Lowe *et al*. 2017) Based on the results of this analysis, the bottom trawl survey selectivity-at-age follows a parameterization similar to the fishery selectivity-at-age (except with no allowance for time-varying selectivity).

As in the past, we also restricted survey catchability and selectivity-at-age to average 1.0 over ages 4-10 (i.e., as a combination of non-parametric selectivity-at-age and the scalar (q). This was done to avoid situations where the product of selectivity-at-age and q results in unreasonable values, and to standardize the ages over which selectivity most reasonably applies. Since the 2004 assessment (Lowe *et al*. 2004), we have used a moderate prior on q (mean = 1.0, $\sigma^2 = 0.2^2$).

Recruitment

The Beverton-Holt form of stock recruitment relationship based on Francis (1992) was used (Table A-2). Values for the stock recruitment function parameters α and β are calculated from the values of R_0 (the number of 0-year-olds in the absence of exploitation and recruitment variability) and the “steepness” of the stock-recruit relationship (h, Table A-2). The “steepness” parameter is the fraction of R_0 to be expected (in the absence of recruitment variability) when the mature biomass is reduced to 20% of its pristine level (Francis 1992). Past assessments have assumed a value of 0.8. A value of $h = 0.8$ implies that at 20% of the unfished spawning stock size, an expected value of 80% of the unfished recruitment level will result. Model runs exploring other values of h and the use of a prior on h were explored in previous assessments (Lowe *et al.* 2002), but were found to have little or no bearing on the stock assessment results and were not carried forward for further evaluation at the time. As in past years, we assumed $h = 0.8$ for all model runs since previous work showed that assessment results were insensitive to this assumption (and given the Tier 3 status does not affect future projections). Prior to the 2012 assessment, the recruitment variance was fixed at a value 0.6. Since 2012, we estimate this value.

Results

Model evaluation

The 2016 assessment introduced Model 16.0 with sample sizes varied relative to the number of hauls sampled. The 2017 assessment introduced Model 16.0b which provided for statistical estimation of the amount of time variability in fishery selectivity through tuning of the time-varying selectivity term (σ_{f_sel}) with the Francis method (2011), and the survey age composition sample sizes were also tuned using the Francis method.

The 2018 assessment responded to BSAI Plan Team and the SSC requests for further evaluations of the Francis (2011) weights and selectivity changes implemented in Model 16.0b. These requests included:

1. Continue to investigate fishery selectivity time blocks, with blocks linked to identifiable changes in the fishery,
2. Evaluate the sensitivity of model results to an assumed average sample size of 100 for the fishery age composition data, or better yet (if possible), find a way to tune the sample size and the constraint governing the amount of time variability in fishery selectivity simultaneously and,
3. Investigate which parameters (including derived quantities) are changing in the retrospective peels that might contribute to the relationship between historical scale and number of peels.

The full evaluations of Model 16.0b are contained in Appendix 17C in Lowe *et al.* (2018).

New data introduced in 2020

Model 16.0b (the accepted model configuration used for the 2020 assessment) was updated with new data. The 2020 catch was updated, and the 2021 total year catch was assumed to equal the 2021 TAC of 62, 257 t. The 2020 fishery age compositions were added.

Retrospective analysis

Atka mackerel have a reasonable retrospective pattern for the last 6-7 years of predicting spawning biomass, with periods that are lower and higher (Figure 17.9). The revised Mohn's rho statistic was calculated to be 0.067. However, after data from 2012-2014 are dropped from the model, most subsequent retrospective runs resulted in biomass that was historically considerably higher. We concluded that the reason for the odd pattern can be attributed to the survey age compositions (Lowe *et al*. 2017). Given the assumed natural mortality as fixed (and constant over time), and the recent period of data with relatively large numbers of Atka mackerel in the survey "plus age group", the survey selectivity was fairly asymptotically shaped (see *Selectivity* section below). However, for the retrospectives which ignore those recent years of data, the survey selectivity becomes much more dome-shaped, hence the early period biomass estimates were estimated to be considerably higher.

The 2018 assessment investigated which parameters (including derived quantities) were changing in the retrospective peels that might contribute to the relationship between historical scale and number of peels. We concluded that the observed pattern is attributed to the addition of recent survey estimates, and suggested that the retrospective bias is a reflection of the data rather than issues with the model configuration (Lowe *et al*. 2018). In general, this type of retrospective pattern seems to be consistent with the uncertainty estimates of biomass for a species that is relatively patchily distributed, and trawl survey estimates that have a high level of variability. This interpretation still holds in the current assessment.

Choice of final model

This year simply updated Model 16.0b detailed in Lowe *et al.* (2019). A summary of key results from the selected Model 16.0b is presented in Table 17.10. Results from the 2020 assessment model (16.0b) with updated data are presented for comparison.

Model fit

Key results from Model 16.0b are presented in Table 17.10. The coefficient of variation or *CV* (reflecting uncertainty) about the 2020 biomass estimate is 23% and the *CV*s on the strength of the 2006 and 2012 year classes at age 1 are 14 and 15%, respectively (Table 17.10). Recruitment variability (Sigma*R*) was moderate and estimated to be 0.48. Sample size values (using McAllister and Ianelli 1997 method) were calculated for the fishery data and the bottom trawl survey data as a diagnostic. This gave effective sample size estimates (relative to model fit) for the fishery of 202 and survey data of 104. The overall residual root-mean square error (RMSE) for the survey biomass data was estimated at 0.278, which is in line with estimates of sampling-error *CV*s for the survey which range from 14-35% and average 26% over the time series (Table 17.6).

Figure 17.10 compares the observed and estimated survey biomass abundance values for the BSAI for Model 16.0b. The decreases in biomass indicated by the 1994 and 1997 surveys followed by the large increases in biomass from the 2002 and 2004 surveys appear to be consistent with recruitment patterns. However, the large increase observed in the 2004 survey was not fit as well by the model compared to the 2000, 2002, and 2006 surveys. In the 2004 survey, an unusually high biomass (268,000 t) was estimated for the southern Bering Sea area. This value represented 23% of the entire 2004 BSAI survey biomass estimate. The 2006 survey indicates a downward trend which is consistent with the population age composition at the time. The 2010 survey biomass estimate indicated a large increase that was not predicted by the assessment model. The 2010 survey biomass estimate for the southern Bering Sea was also unusually high (103,500 t) and represented a 741% increase over the 2006 southern Bering Sea estimate. The 2012 survey biomass estimate is the lowest value and associated with the lowest variance in the time series, but is not fit by the model (Figure 17.10). The declining trend in biomass indicated by the three most recent surveys is consistent with the population age composition. Population biomass would be expected to decline as the most recent strong year class (2006 year class) is aging and past peak cohort biomass. We note that the model’s predicted survey biomass trend is very conservative relative to the 2002, 2004, 2010, and 2014 observed bottom trawl survey biomass values, but fits the other survey years quite well.

The fits to the survey and fishery age compositions for Model 16.0b are depicted in Figures 17.11 and 17.12, respectively. The model fits the fishery age composition data well particularly after 1997, and the survey age composition data less so. This reflects the fact that the sample sizes for age and length composition data are higher for the fishery in most years than the survey. It is interesting to note that the 2014 survey observed significantly fewer 3-year olds (2011 year class) than predicted, whereas the 2014 fishery catch was comprised of a larger proportion of 3-year olds than predicted. The 2015 fishery age composition did not show large numbers of 4-year olds of the 2011 year class (Figure 17.12). The 2016 fishery data showed slightly lower proportions of 5-year olds of the 2011 year class than predicted, in contrast to the 2016 survey which showed much lower than expected numbers of the 2011 year class (Figure 17.11). The 2016 fishery and survey data showed large numbers of 4-year olds of the 2012 year class. The 2012 year class comprised 35, 30, 29, and 24% of the 2016, 2017, 2018, and 2019 fishery age compositions, respectively. The 2016 survey also showed a large number of 3-year olds from the 2013 year class which showed up in the 2017-2019 fishery data. Both the 2018 survey and fishery age data show a lack of 4-year olds from the 2014 year class. The 2018 fishery and survey age data show some similarities, but for the most part the 2018 survey age data are very poorly fit in contrast to the 2018 fishery age data. The 2016-2019 fishery age data show the progression of the 2012 and 2013 year classes. We also note an unusual pattern in recent survey data (2010, 2012, 2014, and 2018) of relatively large numbers of Atka mackerel in the “plus group” (Figure 17.11).

These figures highlight the patterns in changing age compositions over time. Note that the older age groups in the fishery age data are largely absent until around 1985 when the 1977 year class appears. This also coincides with the peak of the joint venture fisheries and may be related to changes in selectivity of the fisheries. Fits to recent fishery age composition data in Lowe *et al*. (2012) and Lowe *et al*. (2016)

indicated a need for greater flexibility in selectivity. The assessments allowed for more flexibility to estimate time-varying fishery selectivity, which improved fits to the fishery age compositions.

The results discussed below are based on the recommended Model 16.0b with updated 2020 fishery catch- and weight-at-age values.

Time series results

Selectivity

For Atka mackerel, the estimated selectivity patterns are particularly important in describing their dynamics. Previous assessments focused on the transitions between ages and time-varying selectivity (Lowe *et al.* 2002, 2008, 2013). The current assessment allows for flexibility over time (fishery only) and age (Figures 17.13, 17.14, and 17.15; also Table 17.11). The current assessment's terminal year fishery selectivity estimate (2020) and the average selectivity used for projections (2016-2020) have shifted to the left showing lower selectivity for ages 3-8, relative to the terminal year and average selectivity for projections used in the 2020 assessment (Figure 17.14). The current assessment's terminal year (2020) selectivity pattern shows a peak for 8-year olds (2012 year class) and similar selectivity for 9-10 year olds (Figures 17.13 and 17.14). The 2014 selectivity pattern initially showed an unusual large numbers of 3-year olds of the 2011 year class which have not persisted in the fishery data (Figure 17.13).

The fishery catches generally consist of fish 3-11 years old. The fishery exhibits a dome-shaped selectivity pattern which is more pronounced prior to 1992 during the foreign and joint venture fisheries conducted during 1977-1983 and 1984-1991, respectively (Figure 17.13). After 1991, fishery selectivity patterns are relatively consistent but do show differences at ages 3-7 and more notable differences at age 8 and older. Fish older than age 9 make up a very small percentage of the population each year, and the differences in the selectivity assumptions for the older ages are not likely to have a large impact. However, differences in selectivity for ages 3-8 can have a significant impact. The recent patterns since 2000 reflect the large numbers of fish from the 1999, 2000, 2001, 2006, 2007, and 2012 year classes (Table 17.4). The age at 50% selectivity is estimated at about ages 3-4 in 2006-2013 as the large year classes moved through the population. A shift occurred recently with a large number of 3-year olds dominating the 2014 fishery age composition, and the age at 50% selectivity decreased to about 2.5 years. However, this year class did not continue to show up after 2014. The age at 50% selectivity of the current assessment's terminal year (2020) is about 5.5 years, compared to last year's assessment terminal year's age at 50% selectivity of 4.5 years (Figure 17.14). It is important to note the maturity-at-age vector relative to the current selectivity patterns (age at 50% maturity is 3.6 years). The age at 50% maturity is lower relative to the age at 50% selectivity for the average selectivity used for projections (2016-2020). Maturity-at-age is much higher relative to recent average selectivity over ages 3-7 (Figure 17.14).

Survey catches are mostly comprised of fish 3-9 years old. The 2018 survey is dominated by 5- and 6-year olds of the 2012 and 2013 year classes which is similar to the 2018 fishery data (Figure 17.8). A 17-year old fish was found in the 2012 survey and 3, 16-year old fish were caught in the 2014 survey. The current model configuration estimates a moderately dome-shape selectivity pattern (Figure 17.15). It is interesting to note that the survey tends to catch higher numbers of young fish (<3 years) and older fish (>10 years) relative to the fishery.

Both the fishery and survey show dome-shaped selectivity. The dome-shaped patterns reflect the age compositions fairly well, but the mechanisms responsible for dome-shaped selectivity are uncertain and several factors likely contribute. As discussed above, the foreign and joint venture fisheries catches show a distinct lack of older fish in fishery catches. The decline in older age selectivity occurs after about 8 years old, which also corresponds with asymptotic growth and full maturity. Large, older fish may be less available to the fishery and survey. Mature fish may be aggregated and unavailable to the summer surveys which can occur during the spawning season. Temperature may also affect recruitment of Atka mackerel and availability to the bottom trawl survey.

Abundance trend

The estimated time series of total numbers at age are given in Table 17.12. The estimated time series of total biomass (ages 1+) and female spawning biomass with approximate upper and lower 95% confidence limits are given in Table 17.13a. A comparison of the age 3+ biomass and spawning biomass trends from the current and previous assessments (Table 17.13b and Figure 17.16 top panel) indicates consistent trends throughout the time series, i.e., biomass increased during the early 80s and again in the late 80s to early 90s. After the estimated peak spawning biomass in 1992, spawning biomass declined for nearly 10 years until 2001 (Figure 17.16 top panel). Thereafter, spawning biomass began a steep increase which continued to 2005. The abundance trend has been declining since the most recent peak in 2005 which represented a build-up of biomass from the exceptionally strong 1999-2001 year classes. Estimates from the current assessment (Model 16.0b) are very similar to last year's assessment (Model 16.0b) results (Figure 17.16). However, the current assessment spawning biomass shows an increasing trend and higher biomass levels after 2020. Differences in spawning biomass levels are attributed to revised estimates of recent recruitment levels of the 2012, 2013year classes, and in particular, the 2017 year class (Figure 17.16).

Recruitment trend

The estimated time series of age 1 recruits indicates the strong 1977 year class as the most notable in the current assessment, followed by the 1999, 2001, 1988 and 2000 year classes (Table 17.14, Figure 17.16). The 1999, 2000, and 2001 year classes are estimated to be three of the five largest recent year classes in the time series (approximately 1.7, 1.1, and 1.2 billion recruits, respectively) due to the persistent observations of these year classes in the fishery and survey catches. The current assessment estimates above average (greater than 20% of the mean) recruitment from the 1977, 1988, 1992, 1995, 1998, 1999, 2000, 2001, 2006, 2007, and 2012 year classes (Figure 17.16, Table 17.14). The 2014, 1996, 2008, and 2002 year classes are the lowest in the time series, estimated at 173, 200, 227, and 259 million recruits, respectively. It is interesting to note that these low recruitments occur just after particularly strong recruitment.

The average estimated recruitment from the time series 1978-2020 is 560 million fish and the median is 468 million fish (Table 17.14). The entire time series of recruitments (years 1977-2021) includes the 1976-2020 year classes. The Alaska Fisheries Science Center has recognized that an environmental "regime shift" affecting the long-term productive capacity of the groundfish stocks in the BSAI occurred during the period 1976-1977, and the 2021 estimate is only based on one year of data. Thus, the average recruitment value presented in the assessment is based on year classes spawned after 1976 through 2020 (1977-2019) year classes). Projections of biomass are based on estimated recruitments from the years 1978-2020 using a stochastic projection model described below.

Estimated age 1 recruits versus female spawning biomass with the Beverton-Holt stock recruitment curve plotted is shown in Figure 17.17. There are no estimates of female spawning biomass less than 109,000 t. The five largest year classes in the time series were all spawned from biomass levels ranging from 115,000-180,000 t. However, this range of female spawning biomass also spawned several years of low recruitment (Figure 17.17).

Trend in exploitation

The estimated time series of fishing mortalities on fully selected age groups and the catch-to-biomass (age 3+) ratios are given in Table 17.15 and shown in Figure 17.18.

Projections and harvest recommendations

Results and recommendations in this section pertain to the authors' recommended Model 16.0b.

Amendment 56 Reference Points

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC (*max* F_{ABC}). The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. The overfishing and maximum allowable ABC fishing mortality rates are given in terms of percentages of unfished female spawning biomass ($F_{SPR\%}$), on fully selected age groups. The associated long-term average female spawning biomass that would be expected under average estimated recruitment from 1978-2020 (569 million age-1 recruits) and F equal to $F_{40\%}$ and $F_{35\%}$ are denoted $B_{40\%}$ and $B_{35\%}$, respectively. The Tiers require reference point estimates for biomass level determinations. We present the following reference points for BSAI Atka mackerel for Tier 3 of Amendment 56. For our analyses, we computed the following values from Model 16.0b results based on recruitment from post-1976 spawning events:

$B_{100\%}$ = 278,670 t female spawning biomass

$B_{40\%}$ = 111,470 t female spawning biomass

$B_{35\%}$ = 97,540 t female spawning biomass

Specification of OFL and Maximum Permissible ABC

In the current assessment, Model 16.0b is configured with time-varying selectivity. We use a 5-year average (2016-2020) to reflect recent conditions for projections and computing ABC which gives:

Full selection *F*s	2021
F_{2021}	0.50
$F_{40\%\ adj}$	0.54 (Tier 3b)
$F_{40\%}$	0.57 (Tier 3a
$F_{35\%\ adj}$	0.65 (Tier 3b)
$F_{35\%}$	0.70 (Tier 3a)
$F_{2021}/F_{40\%adj}$	0.93

For specification purposes to project the 2022 ABC, we assumed a total 2021 year end catch of 62,357 t equal to the 2021 TAC. For projecting to 2023, an expected catch in 2022 is also required. Recognizing that the modified Steller sea lion RPAs implemented in 2015 require a TAC reduction in Area 543, we assume a stock-wide catch based on a reduced overall BSAI-wide Atka mackerel catch for 2022. Under the modified Steller sea lion RPAs, the Area 543 Atka mackerel TAC is set less than or equal to 65 percent of the Area 543 ABC. This percentage (65%) was applied to the Western Aleutian Islands maximum permissible 2022 ABC estimate, and that amount was summed with the maximum permissible ABC estimates for the Eastern and Central Aleutian areas for a total estimated 2022 catch. The total estimated 2022 catch was assumed to be caught in order to estimate the 2023 ABC and OFL values. We estimated that about 85% of the BSAI-wide 2022 ABC is likely to be taken.

It is important to note that for BSAI Atka mackerel, projected female spawning biomass calculations depend on the harvest strategy because spawning biomass is estimated at peak spawning (August). Thus, projections incorporate 7 months of the specified fishing mortality rate. The projected 2022 female spawning biomass (SSB_{2022}) is estimated to be 109,360 t given assumed 2021 catch and 7 months of the estimated 2022 catch reflecting the Steller sea lion RPA adjustment to the 2022 ABC.

The projected 2022 female spawning biomass estimate is just below the $B_{40\%}$ value of 111,470 t, placing BSAI Atka mackerel in **Tier 3b**. The 2023 female spawning biomass estimate is also below $B_{40\%}$. The maximum permissible ABC and OFL values under **Tier 3b** are:

Year	Catch*	ABC	F_{ABC}	OFL	F_{OFL}	SSB	Tier
2022	66,740	78,510	0.54	91,870	0.65	109,360	3b
2023	61,320	71,990	0.51	84,440	0.61	103,330	3b

* Catches in 2022 and 2023 are less than the recommended maximum permissible ABCs to reflect expected catch reductions under Steller sea lion RPAs.

Standard Harvest Scenarios and Projection Methodology

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

For each scenario, the projections begin with the vector of 2021 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2034 using a fixed value of natural mortality of 0.3, the recent schedule of selectivity estimated in the assessment (in this case the average 2016-2020 selectivity), and the best available estimate of total (year-end) catch for 2021 (in this case assumed to be 62,257 t equal to TAC). In addition, the 2022 and 2023 catches are reduced to accommodate Steller sea lion RPA TAC reductions for Scenarios 1 and 2. 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 (August) and the maturity and population weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years, except that in the first two years of the projection, a lower catch may be specified for stocks where catch is typically below ABC (as is the case for Atka mackerel). This projection scheme is run 500 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios are designed to provide a range of harvest alternatives that are likely to bracket the final TACs for 2022 and 2023, 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 2022 recommended in the assessment to the *max* F_{ABC} for 2022, and where catches for 2022 and 2023 are estimated at their most likely values given the 2022 and 2023 maximum permissible ABSs under this scenario. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment).

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

Scenario 4: In all future years, the upper bound on F_{ABC} is set equal to $F_{60\%}$. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels).

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

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

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in 2021 or 2) above ½ of its MSY level in 2021 and above its MSY level in 2031 under this scenario, then the stock is not overfished.)

Scenario 7: In 2022 and 2023, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is 1) above its MSY level in 2023 or 2) above 1/2 of its MSY level in 2023 and expected to be above its MSY level in 2033 under this scenario, then the stock is not approaching an overfished condition.).

The projections of female spawning biomass, fishing mortality rate, and catch corresponding to the seven standard harvest scenarios are shown in Table 17.16

Status Determination

Under the MSFCMA, the Secretary of Commerce is required to report on the status of each U.S. fishery with respect to overfishing. This assessment reports the answer 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 approaching an overfished condition? The official catch estimate for the most recent complete year (2020) is 58,975 t. This is less than the 2020 OFL of 81,200 t. Therefore, the BSAI Atka mackerel stock is not being subject 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 overfished? This depends on the stock's estimated spawning biomass in 2021:

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 17.16). 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 (Table 17.16):

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 2033. If the mean spawning biomass for 2033 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 17.16, the BSAI Atka mackerel stock is not overfished and is not approaching an overfished condition.

Should the ABC be reduced below the maximum permissible ABC?

The SSC in its December 2019 minutes recommended that all assessment authors use the risk table when determining whether to recommend an ABC lower than the maximum permissible. The SSC also requested the addition of a fourth column on fishery performance, which has been included in the table below.

	Assessment-related considerations	*Population dynamics considerations*	*Environmental/ecosystem considerations*	*Fishery Performance*
Level 1: Normal	Typical to moderately increased uncertainty/minor unresolved issues in assessment.	Stock trends are typical for the stock; recent recruitment is within normal range.	No apparent environmental/ecosystem concerns	No apparent fishery/resource-use performance and/or behavior concerns
Level 2: Substantially increased concerns	Substantially increased assessment uncertainty/ unresolved issues.	Stock trends are unusual; abundance increasing or decreasing faster than has been seen recently, or recruitment pattern is atypical.	Some indicators showing an adverse signals relevant to the stock but the pattern is not consistent across all indicators.	Some indicators showing adverse signals but the pattern is not consistent across all indicators
Level 3: Major Concern	Major problems with the stock assessment; very poor fits to data; high level of uncertainty; strong retrospective bias.	Stock trends are highly unusual; very rapid changes in stock abundance, or highly atypical recruitment patterns.	Multiple indicators showing consistent adverse signals a) across the same trophic level as the stock, and/or b) up or down trophic levels (i.e., predators and prey of the stock)	Multiple indicators showing consistent adverse signals a) across different sectors, and/or b) different gear types
Level 4: Extreme concern	Severe problems with the stock assessment; severe retrospective bias. Assessment considered unreliable.	Stock trends are unprecedented; More rapid changes in stock abundance than have ever been seen previously, or a very long stretch of poor recruitment compared to previous patterns.	Extreme anomalies in multiple ecosystem indicators that are highly likely to impact the stock; Potential for cascading effects on other ecosystem components	Extreme anomalies in multiple performance indicators that are highly likely to impact the stock

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

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

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

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

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

Assessment considerations: The BSAI Atka mackerel assessment has a reasonable retrospective pattern for the last 5 years of predicting spawning biomass, with periods that are lower and higher. However, after data from 2012-2014 are dropped from the model, most subsequent retrospective runs resulted in biomass that was historically considerably higher (Figure 17.9). The 2018 assessment investigated which parameters (including derived quantities) were changing in the retrospective peels that might contribute to the relationship between historical scale and number of peels (Appendix 17C, Lowe *et al*. 2018). The robust fishery age data which is generally well fit, prevents the model from fitting the 2012 and 2016 extremely large drops in Atka mackerel survey biomass. In conclusion, the observed retrospective pattern seems attributable to survey estimate variability. We suggest that the retrospective pattern reflects an interaction between the model configuration data variability. In general, this type of retrospective pattern seems to be consistent with the uncertainty estimates of biomass for a species that is relatively patchily distributed, and trawl survey estimates that have a high level of variability. As noted, the fishery age data is generally well fit, and the survey age data is fit less so. Trawl survey estimates of Aleutian Islands biomass are highly variable. The 2012 survey decreased 70% relative to the 2010 survey, the 2014 survey increased 161% relative to the 2012 survey, and the 2016 survey decreased 38% relative to the 2014 survey. The most recent survey showed a 21% decrease in Atka mackerel biomass relative to the 2016 estimate (Figure 17.10). Most of this decrease is attributed to the Central Aleutians area where biomass declined 80% relative to the 2016 Central area Atka mackerel biomass (Figure 17.4).

The cancellation of the 2020 Aleutian Islands survey was problematic in that there was no new data to inform the 2018 survey biomass estimate for the assessment, as well as no new survey composition data. Bryan *et al*. 2020 conducted a retrospective analysis looking at the loss of survey data (index and composition data) for several groundfish and crab species to quantify uncertainty in assessment model quantities and management advice. The Atka mackerel stock assessment relies on the biennial Aleutian Islands bottom trawl survey as a primary source of fisheries-independent information. The distributions of the spawning stock biomass CV in the terminal year for Atka mackerel indicated that the uncertainty is greater (CV is larger) when the model does not have the most recent survey information. The assessment models become more positively biased (i.e., overestimates biomass) and uncertainty in terminal year estimates of biomass is greater, when the most recent survey data are removed from the assessment as compared to the standard retrospective. The assessment model did not capture the potential added uncertainty due to the lack of the 2020 survey. However, the overall 2018 BSAI survey data point was fit fairly well by the assessment model (Figure 17.10), and supported by recent estimates of below average recruitment and only one slightly above average recruitment (2012 year class, Figure 17.16). We rated the assessment-related concern as Level 1. We have typical to moderately increased concerns about assessment-related uncertainty, particularly in regard to the survey data.

Population dynamics considerations: The BSAI Atka mackerel assessment shows a decline in female spawning biomass since peak biomass in 2005. The peak biomass in 2005 is the result of 3 back-to-back very strong year classes (1999, 2000, 2001 year classes; Figure 17.16). Since these year classes entered the population, there have only been three moderately strong year classes (2006, 2007, and 2012 year classes), and the most recent slightly above average 2017 year class. Gaps of about 4-6 years between strong year classes seems to be typical for Atka mackerel throughout the time series of estimated recruitments (Figure 17.16). However, the appearance of only an average year class (2017 year class) following the 2012 year class which was 59% above average is unusual. We note that the 2016-2019 fisheries were dominated by the 2012 year class. The 2018 survey and fishery age data are dominated by the 2012, and 2013 year classes (Figure 17.8). These year classes comprised nearly 40% of 2018 survey age composition, and 60% of the 2018 fishery age composition. Most recently, a large number of 3 year olds showed up in the 2020 fishery catches representing 17% of the 2020 fishery age composition. Atka mackerel have been Tier 3b since the 2019 assessment. Under the Tier 3b $F_{40\%\mathrm{adj}}$ harvest strategy and assuming SSL RPA catch reductions in 2022 and 2023, female spawning biomass is projected to be just below $B_{40\%}$ in 2022 but increase and remain above $B_{40\%}$ from 2027 through 2034 (Figure 17.19 and Table 17.16 Scenarios 1 and 2). If SSL RPA catch reductions are in place beyond 2023, expected female spawning biomass levels would be higher than projected after 2023. We rated the population dynamics-related concern as Level 1. Stock trends are typical for the stock and expected given the stock dynamics; recent recruitment is within the lower end of the normal range and the magnitude of the 2012, 2013, and 2015 year classes has increased in recent assessments.

Environmental/Ecosystem considerations: The Aleutian Islands Ecosystem Status Report was updated in 2021, so the indicators noted here largely reflect conditions in 2021. However, the most recent bottom trawl survey was conducted in 2018, so indicators based on those data have not been updated since that time. In general, water temperatures have trended warmer than the long-term average since 2013, including the highest sea surface temperature (SST) on record during August–September this year. Temperatures observed at both mid-depth (100–300m) during the longline survey and water column temperature (surface to bottom) during the bottom trawl survey (through 2018) have remained warmer than the long term average since 2013. However, the 2021 longline survey sampled the eastern Aleutians from 164°W to 170°W and recorded temperatures that were cooler than in 2019 and similar to those in 2020. Overall, SST has been above the mean since 2013, and the number of days per season where SST has been above the heatwave threshold has been higher than the long term average since 2013–2014. The SST throughout the Aleutians during 2021 was slightly above average overall with noticeably increased temperatures during August-September when the warmest temperatures on the satellite SST time series were recorded, but the number of heatwave days is lower so far in 2021 (less than 50 days) compared to 2020 (~150 days) and 2019 (>300 days), which was a record warm year in the eastern AI. In general, higher ambient temperatures incur bioenergetic costs for ectothermic fish such that, all else being equal, consumption must increase to maintain fish condition. Thus, the persistent higher temperatures may be considered a negative indicator for Atka mackerel. Higher temperatures that increase consumption demands beyond what is available may impact body conditions.

Atka mackerel showed a declining trend in condition (defined as mean weight-length residuals) from 2010 to 2018, which are the most recent data available, indicating that insufficient prey was available to promote optimal growth during that time. Condition was also below the time series mean (1984–2018) in the eastern Aleutians and southern Bering Sea when analyzed at smaller spatial scales, indicating that suboptimal foraging conditions were widespread throughout the eastern portion of their distribution along the Aleutian chain.

Although we don't have direct abundance estimates of copepods, which comprise 76% of small (<20 cm) and 54% of large Atka mackerel diet, we can infer that copepods experienced higher predation pressure this year based on the biannual cycle and high abundance of Kamchatka pink salmon during 2021. The biannual cycle and cascading effects of pink salmon predation on copepods has been documented before by Springer 2014, Batten et al. 2018. Estimated catch in numbers at age of Atka mackerel age-2 shows a biennial pattern from ~2011 onwards, with higher catches shown in odd years when pink abundances are high. This pattern is suggestive of some interaction between pink salmon and Atka mackerel, particularly in the absence of alternative hypotheses for the pattern in catches. The biennial pattern is not seen in other ages. Other inferences we can make about zooplankton prey availability are from seabird reproductive success. Planktivorous auklets that nest in the western Aleutians at Buldir Island had above average reproductive success in 2021, suggesting that zooplankton were sufficiently abundant to support successful production of chicks and possibly indicative of abundant zooplankton prey in that area. Data from the Continuous Plankton Recorders showed copepod community size was anomalously smaller from 2016–2018, but larger in 2019, and small again in 2020, which may indicate overall smaller zooplankton prey available to Atka mackerel. A study by Matta et al. 2020 failed to detect any significant relationships between Atka mackerel body conditions and prey abundance, suggesting that other measures of fish health and fitness should be explored. This may explain why there are mixed recent signals for availability of Atka mackerel prey.

Atka mackerel are a key prey for Steller sea lions, Pacific cod, arrowtooth flounder, and Pacific halibut (AFSC Groundfish Food Habits database). Recent data suggest that Steller sea lion populations have continued to decline in the western Aleutians (AI Ecosystem Status Report), suggesting that their predatory impact on Atka has not increased. However, Pacific cod has been consistently increasing after a steady decline from 2000 to 2012 with higher abundances in the eastern Aleutians. While Pacific cod diets recently (2016, 2018) changed from sculpins to Atka mackerel in NMFS area 541. codswitched from Atka mackerel to other prey in NMFS areas 542 and 543. Arrowtooth flounder biomass peaked in 2006 and has been decreasing since, as has Pacific halibut since 1997 based on AI survey biomass estimates. There are no clear signs of changes in predation pressure that would be influencing Atka mackerel.

Taken together, recent higher temperature trends and high abundance of pink salmon this year, along with the poor body condition during 2010–2018, indicate the potential for some negative ecosystem impacts on Atka mackerel. In contrast, the above normal reproductive success of seabirds in the western Aleutians may be considered a positive indicator for Atka mackerel prey availability in 2021.Taken together, the ecosystem information which includes some mixed signals, suggest no immediate concerns and warrant a risk score of 1 at present.

Fishery performance considerations: Catches since 2015 have been relatively consistent and ranged from 53,000-70,000 t. Fishery catches of BSAI Atka mackerel have not shown any unusual trends in location, timing and catch levels. There are no apparent fishery/resource-use performance and/or behavior concerns therefore, we rated the fishery performance-related concern as Level 1.

These results are summarized in the table below:

Assessment-related considerations	*Population dynamics considerations*	*Environmental/ ecosystem considerations*	*Fishery Performance considerations*
Level 1: Typical to moderately increased concerns	Level 1: Stock trends are typical for the stock; recent recruitment is within normal range.	Level 1: No apparent environmental/ ecosystem concerns	Level 1: No apparent fishery/resource-use performance and/or behavior concerns

There are no changes to the risk table scores relative to last year, and the scores suggests that setting the ABC below the maximum permissible is not warranted.

ABC Recommendation

The recommended model (Model 16.0b) provides reasonable fits to the available data and previously has been selected as appropriate for providing advice on BSAI Atka mackerel catch levels. We note that the survey data remain highly uncertain and the 2018 survey biomass estimate decrease was mainly due to poor catch rates in the Central area. The 2018 survey biomass trends were inconsistent throughout the Aleutians: the EAI increased 6% and the WAI decreased 14% in contrast to an 80% drop in the CAI relative to the 2016 survey estimates. This pattern conflicts with fishery observations and observed catch fishery catch rates. The 2012 year class estimate was above average and has increased in recent assessments. The 2017 year class showed up as an average year class in the 2020 fishery as 3 year olds. The assessment model estimates indicate a slight declining trend in spawning biomass below $B_{40\%}$ from 2021 through 2024, and then an increasing trend to just above $B_{40\%}$ *by* 2027. However, since the maximum permissible F_{ABC} will be adjusted downwards (Tier 3b, below $B_{40\%}$), the maximum permissible Tier 3b F_{ABC} is appropriately precautionary (for Atka mackerel). Recent fishing mortality rates have been below F_{ABC}. For perspective, a plot of relative harvest rate ($F_t / F_{35\%}$) versus relative female spawning biomass ($B_t/B_{35\%}$) is shown in Figure 17.20. For all of the time series the current assessment estimates that relative harvest rates have been below 1, and the relative spawning biomass rates have been greater than 1.0.

The 2022 recommended ABC based on the Tier 3b F_{ABC} rate (0.54) is 78,510 t. The 2022 OFL is 91,870 t.

The 2023 recommended ABC associated with the Tier 3b F_{ABC} is 71,990 t and the 2023 OFL is 84,440 t. Note that these calculations assume 2022 catches were equal to 85% of the 2022 ABC.

The recommended 2022 ABC is 7% higher than 2021 ABC specified last year.

Area Allocation of Harvests

Amendment 28 of the BSAI Fishery Management Plan divided the Aleutian subarea into 3 districts at 177° E and 177° W longitude, providing the mechanism to apportion the Aleutian Atka mackerel ABCs and TACs. Previous to 2016, the Council used a 4-survey weighted average to apportion the BSAI Atka mackerel ABC. The rationale for the weighting scheme was described in Lowe *et al.* (2001). The SSC requested that the Atka mackerel assessment use the random effects (RE) model for setting subarea ABC allocations (Dec. 2015 SSC minutes). This method has been applied since the 2015 assessment. Based on applying this method to each area separately (Figure 17.21), and then summing to get the overall BSAI biomass, the percentage apportionments for the Aleutian Islands subareas based on the 2018 RE model are shown below:

	2018 Random Effects Model
541[1]	50%
542	10%
543	40%

[1]Includes eastern Aleutian Islands and southern Bering Sea areas.

The apportionments from the 2018 RE model reflected the large drop in the 2018 Central area survey biomass estimate relative to the 2016 estimate. The 2018 RE Central area apportionment represents a 71% decrease relative to the 2017 RE Central area apportionment.

The 2018 bottom trawl survey tows conducted July 1-19, 2018 in the Central Aleutian area did not encounter any moderate to large catches of Atka mackerel and were inconsistent with reported fishing conditions in the region. Therefore, we recommended applying the 4-survey weighted average for ABC apportionments for 2019, 2020, and 2021 until further research and evaluations could be conducted (Lowe *et al*. 2018). A next step would be to apply the vector-autoregressive spatio-temporal (VAST) modeling framework. There are some issues using VAST for the Aleutian Islands (Atka mackerel are problematic), and research is ongoing.

Appendix 17C in Lowe et al. (2019), presented an investigation of an alternative area apportionment method incorporating available NMFS observer data from the fishery. We incorporated auxiliary population information in the random effects model (in that case nominal fishery CPUE). We applied the same survey data as for the random effects model in Lowe *et al*. (2018), but added the information on nominal CPUE from the fishery. The model was applied with varying relative weights according to the indices.

Although the application of nominal fishery CPUE data for abundance trends is problematic—for example data are unavailable for search time, and selectivity and catchability can differ—the relative patterns between regions may be a reasonable proxy for relative abundances. However, the Plan Team and SSC correctly noted that "The choice of weightings between the indices is likely to be a subjective decision". A working group has been convened to evaluate the use of fishery CPUE, and we will continue to evaluate this approach.

Due to the cancelled 2020 Aleutian survey and no new data in which to inform apportionment methodology, we again recommend apportionments by Aleutian Islands management areas for the 4-survey weighted average (recommended last year and again this year):

Weighted Average (Recommended)

	Survey Year				2022 & 2023 Apportionment	**2021 ABC**	**2022 ABC**
	2012	2014	2016	2018			
541+SBS	12%	42%	35%	38%	0.35	**27,260**	**25,000**
542	39%	28%	30%	7%	0.21	**16,880**	**15,470**
543	48%	30%	35%	55%	0.44	**34,370**	**31,520**
Weights	8	12	18	27	1.00		
Total ABC						**78,510**	**71,990**

To fulfill reporting requirements for the Species Information System, each model was used to reverse-engineer the fishing mortality rate corresponding to the specified OFL for the last complete year (2020). The reverse-engineered F_{OFL} values (*RE* F_{OFL}) for this year's model is 0.37 for BSAI Atka mackerel.

Ecosystem Considerations

Overall, the Aleutian ecosystem has shown a response to the recent warm years that has similar characteristics to those in the Gulf of Alaska. As the water column and surface temperatures shifted to anomalously warm in 2013/2014, the mean size of the copepod community became smaller than the long term mean, indicating that smaller-bodied copepod species became relatively abundant as is expected (Zador and Ortiz 2018). In general, planktivorous seabirds have had fewer reproductive failures during these warm years relative to piscivorous seabirds, indicating that zooplankton resources were largely sufficient while forage fish were periodically lacking. The zooplankton community in the Aleutians is largely dominated by copepods, and the ecosystem itself is oceanic in nature. There is a consistent long term trend whereby the proportion of rockfish biomass (Pacific ocean perch and northern rockfish) has been consistently increasing compared to that of Atka mackerel and pollock combined (Zador and Ortiz 2018). Since the early 1990s the Aleutian Islands ecosystem has changed from a system where two thirds of the pelagic foragers biomass was made up of Atka mackerel and pollock, to a system composed of half or even two thirds composed by rockfish (Zador and Ortiz 2018).

Ecosystem effects on BSAI Atka mackerel *Note: This section was not updated and will be removed in next year's assessment and included in the 2021 planned ESP.*

Prey availability/abundance trends

Adult Atka mackerel in the Aleutians consume a variety of prey, but are primarily zooplanktivors, consuming mainly euphausiids and calanoid copepods (Yang 1996, Yang 2003). Other zooplankton prey include larvaceans, gastropods, jellyfish, pteropods, amphipods, isopods, and shrimp (Yang and Nelson 2000, Yang 2003, Yang *et al.* 2006). Atka mackerel also consume fish, such as sculpins, juvenile Pacific halibut, eulachon, Pacific sand lance, juvenile Kamchatka flounder, juvenile pollock, and eelpouts, in small proportions relative to zooplankton (Yang and Nelson 2000, Yang *et al.* 2006, Aydin *et al.* 2007). The proportions of these various prey groups consumed by Atka mackerel vary with year and location (Yang and Nelson 2000). Atka mackerel diet data also shows a longitudinal gradient, with euphausiids dominating diets in the east and copepods and other zooplankton dominating in the west. Greater piscivory, especially on myctophids, occurs in the island passes (Ortiz, 2007). Rand *et al*. (2010) found that Atka mackerel near Amchitka Island (area 542) were eating more copepods and less euphausiids, whereas fish at Seguam pass (area 541) were eating more energy rich euphausiids and forage fish.

Figure 17.22 shows the food web of the Aleutian Islands summer survey region, based on trawl survey and food habits data, with an emphasis on the predators and prey of Atka mackerel (see the current Ecosystem Assessment's ecosystem modeling results section for a description of the methodology for constructing the food web). Food habits data from 1990-1994 indicate that Atka mackerel feed on calanoid copepods (40%) and euphausiids (25%) followed by squids (10%), juvenile pollock (6%), and finally a range of zooplankton including fish larvae, benthic amphipods, and gelatinous filter feeders (Figure 17.23a). It is noted that Figure 17.23a shows an aggregate diet for the Aleutian Islands based on data collected from 1990-1994; the diet of Atka mackerel varies temporally and spatially (Yang and Nelson 2000, Ortiz 2007, Rand *et al*. 2010).

Monitoring trends in Atka mackerel prey populations may, in the future, help elucidate Atka mackerel population trends. There are no long-term continuous time series of zooplankton biomass information available for the AI. However, Continuous Plankton Recorders (CPRs) have been deployed in the North Pacific routinely since 2000. An index of Copepod Community Size is derived from the CPR data and calculated for three regions: the oceanic North-East Pacific, the Alaskan shelf SE of Cook Inlet, and the deep waters of the southern Bering Sea (Batten 2016). Ocean conditions in 2014-2016 were warm across much of the North Pacific. The Copepod Community Size index saw strong negative anomalies for all three regions indicating a community biased toward smaller species than typical for May (Batten 2018). The Bering Sea data are only represented by the fall sampling, but 2015 values were the smallest since 2009 at this time of year (Batten 2016). In the Bering Sea region north of the Western and Central Aleutian Islands that is sampled by the continuous plankton recorder, spring diatom abundances and mesozooplankton biomass anomalies were near neutral in 2015. Changes in abundance or biomass, together with size, influence availability of prey to predators. Prey size as indexed by mean Copepod Community Size index may reflect changes in the nutritional quality of the organism to their predators. While mesozooplankton biomass anomalies remained positive during the last 3 years, the reduced average size of the copepod community suggests numerous, smaller prey items, which may require more work by predators to obtain their nutritional needs (Batten 2018).

Least auklets (*Aethia pusilla*) and crested auklets (*A. cristatella*) are small, abundant seabirds that nest in the Aleutian Islands. The USFWS stations field biologists to monitor auklet chick diets and reproductive success annually at Buldir Island and less frequently at other islands on which they occur. Crested auklet chick diets consist of mainly euphausiids and copepods. Due to the lack of time series of direct measurements of zooplankton in the Aleutian Islands, biologists monitor reproductive anomalies of least and crested auklets to serve as indicators of copepod and euphausiid abundance. Reproductive anomalies were selected as the metric of interest instead of chick diets because reproductive success is an integrative indictor of ecosystem productivity and forage for planktivorous commercially-fished species (Zador 2015).

Reproductive success is defined as the ratio of number of nest sites with a fledged chick to the number of nest sites with eggs. In the Western AI ecoregion, reproductive success of least and crested auklets were recorded annually at Buldir Island from 1988-2018 with the exception of 1989 and 1999. In the Central ecoregion, reproductive success was monitored annually at Kasatochi Island from 1996-2007. In 2008 a volcanic eruption covered the monitored colony in ash, disrupting breeding. It is unknown when auklets will nest there again and if so, whether observations will continue (Zador 2015).

In the Western ecoregion, the reproductive success of planktivorous auklets, serving as indicators of zooplankton production, increased from low values prior to 2015, to above average from 2015-2018 (Zador and Ortiz 2018). The increase was seen in both crested auklets, which feed their chicks mainly euphausiids and copepods, and least auklets, which focus on copepods. Thus, it is suggested that sufficient zooplankton were available to support reproductive success. Recent trends in auklet reproductive success in the Central ecoregion are unknown due to the disruption of the monitored colony in 2008, when the volcano on Kasatochi Island erupted. A suitable replacement indicator has not yet been identified. Planktivorous auklets are not as numerous in the Eastern ecoregion as in the Central and Western ecoregions and are not monitored in the Eastern ecoregion (Zador 2015).

Predator population trends

Atka mackerel are consumed by a variety of piscivores, including groundfish (e.g., Pacific cod, Pacific halibut, and arrowtooth flounder, Livingston *et al.* unpubl. manuscr.), marine mammals (e.g., northern fur seals and Steller sea lions, Kajimura 1984, NMFS 1995, Sinclair and Zeppelin 2002, Sinclair *et al.* 2013), skates, and seabirds (e.g., thick-billed murres, tufted puffins, and short-tailed shearwaters, Springer *et al.* 1999).

Apportionment of Atka mackerel mortality between fishing, predation, and unexplained mortality, based on the consumption rates and food habits of predators averaged over 1990-1994 is shown in Figure 17.24. During these years, approximately 20% of the Atka mackerel exploitation rate (as calculated by stock assessment) was due to the fishery, 62% due to predation, and 18% "unexplained", where "unexplained" is the difference between the stock assessment total mortality and the sum of fisheries exploitation and quantified predation. This unexplained mortality may be due to data uncertainty, or Atka mackerel mortality due to disease, migration, senescence, etc. Of the 62% of mortality due to predation, a little less than half (25% of total) is due to Pacific cod predation, and one quarter (15% of total) due to Steller sea lion predation, with the remainder spread across a range of predators (Figure 17.23b), based on Steller sea lion diets published by Merrick *et al.* (1997) and summer fish food habits data from the Resource Ecology and Ecosystem (REEM) food habits database.

If converted to tonnages, the food habits data translates to 100,000-120,000 t/year of Atka mackerel consumed by predatory fish (of which approximately 60,000 t is consumed by Pacific cod), and 40,000-80,000 t/year consumed by Steller sea lions during the early 1990s. Estimating the consumption of Atka mackerel by birds is more difficult to quantify due to data limitations: based on colony counts and residency times, predation by birds, primarily kittiwakes, fulmars, and puffins, on all forage and rockfish combined in the Aleutian Islands is at most 70,000 t/year (Hunt *et al.* 2000). However, colony specific diet studies, for example for Buldir Island, indicate that the vast majority of prey found in these birds is sandlance, myctophids, and other smaller forage fish, with Atka mackerel never specifically identified as prey items, and "unidentified greenlings" occurring infrequently (Dragoo *et al.* 2001). The food web model's estimate, based on foraging overlap between species, estimates the total Atka mackerel consumption by birds to be less than 2,000 t/year. While this might be an underestimate, it should be noted that most predation would occur on juveniles (<1year old) which is not counted in the stock assessment's total exploitation rates.

Analysis of reproductive effort data (mean hatch date and reproductive success) indicated that 2015 was a poor reproductive year for many seabirds. The North Pacific experienced the second warm year after several sequential cold years. These oceanographic changes have influenced biological components of the ecosystem, which appears to have negative influences on seabird reproductive activity (Zador 2015). Black-legged kittiwakes had moderate reproductive success in 2016 at the Semidi Islands, in contrast to the complete failure in 2015 for kittiwakes as well as other seabird species (Zador 2015). In general, seabirds in the Aleutians did not experience widespread failures like the Gulf of Alaska did during the marine heat wave of the past few years. However many seabirds did poorly in 2018 at Buldir and had mixed success at Aiktak (Renner and Rojek 2018). Tufted puffins completely failed at Buldir only one other time, in 2011. In general, tufted puffins can adapt their foraging to what is available, so their failure suggests a potentially broad lack of prey that includes forage fish and squid (Renner and Rojek 2018). Seabird population trends could potentially affect juvenile Atka mackerel mortality, but this has not been quantified in the AI.

Steller sea lion food habits data (from analysis of scats) from the Aleutian Islands indicate that Atka mackerel is the most common prey item throughout the year (NMFS 1995, Sinclair and Zeppelin 2002, Sinclair *et al*. 2013). The prevalence of Atka mackerel and walleye pollock in sea lion scats reflected the distributions of each fish species in the Aleutian Islands region. The percentage occurrence of Atka mackerel was progressively greater in samples taken in the central and western Aleutian Islands, where most of the Atka mackerel biomass in the Aleutian Islands is located. Conversely, the percentage occurrence of pollock was greatest in the eastern Aleutian Islands. Steller sea lions and Pacific cod are a significant source of mortality of Atka mackerel in the AI, and predation events by these predators, may increase or decrease the degree of predator control due to the changing size of their populations.

During the 2012 NMFS Atka mackerel tag recovery survey, there was an opportunity to study the prey distribution of a Steller sea lion adult female that was tagged with a satellite-tracking tag in November 2011 by the AFSC Marine Mammal Laboratory. A hydroacoustic transect was conducted, species composition data was collected from trawl hauls, and camera tows were conducted in the area where the sea lion was feeding (South Petrel Bank). This provided a unique opportunity to investigate possible prey species availability during the same time and in the same location where the tagged female sea lion was diving. The Steller sea lion appeared to be diving in an area with high prey diversity: 5 spatially close trawl hauls each a captured a different predominant prey species (including Pacific ocean perch, northern rockfish, walleye pollock, Pacific cod, and Atka mackerel (McDermott *et al*. 2014); http://www.afsc.noaa.gov/REFM/Stocks/fit/FITcruiserpts.htm).

The abundance trends of Aleutian Islands Pacific cod has been quite variable, alternating between increases and decreases in recent surveys, and Aleutian Islands arrowtooth flounder has been increasing. Northern fur seals are showing declines, and Steller sea lions have shown some slight increases except in the Western Aleutians where the adult population decreased rapidly at approximately -7% per year. Sub-area Steller sea lion adult population trends improved to the east through the western Gulf of Alaska, where the annual trend was approximately +4% per year. Regional trends in pup production are similar to trends in non-pup counts, with continued steep declines in the western Aleutians, a less steep decline in the central Aleutians, and improvement in the eastern Aleutians. The population trends of seabirds are mixed, some increases, some decreases, and others stable. However, many seabirds did poorly in 2018 at Buldir and tufted puffins completely failed at Buldir. Seabird population trends could potentially affect juvenile Atka mackerel mortality. Declining trends in predator abundance could lead to possible decreases in Atka mackerel mortality, while increases in predator biomass could potentially increase the mortality.

Changes in habitat quality

Atka mackerel habitat associations

Another objective of the NMFS tagging studies (described in the *Fishery* section above), was to characterize Atka mackerel habitat by conducting underwater camera tows in each area where fish were recaptured. Underwater camera tows were used to explore habitat characteristics in areas of high Atka mackerel abundance. In camera tows from the Central and Eastern Aleutian Islands, Atka mackerel were associated almost exclusively with coarse-grained and rocky substrates. At Seguam and Petrel, greater than 60% of substrate identified during camera tows was rock (largely bedrock and boulders), while the remainder was largely gravel and cobble. At Tanaga, gravel and cobble composed 75% of all substrate. In all three study areas, fine-grained substrates (sand and mud) composed less than 1% of the substrate. At Seguam, nearly all substrate had between 26%-75% biocover (sponges and corals). Biocover at Tanaga and Petrel ranged from nearly bare to almost 100% (McDermott *et al*. 2014). Impacts to these habitats could potentially affect Atka mackerel, but at this time only associations to these habitat types have been established.

Climate

Interestingly, strong year classes of AI Atka mackerel have occurred in years of hypothesized climate regime shifts 1977, 1988, and 1999, as indicated by indices such as the Pacific Decadal Oscillation (Francis and Hare 1994, Hare and Mantua 2000, Boldt 2005). Bailey *et al.* (1995) noted that some fish species show strong recruitment at the beginning of climate regime shifts and suggested that it was due to a disruption of the community structure providing a temporary release from predation and competition. It is unclear if this is the mechanism that influences Atka mackerel year class strength in the Aleutian Islands. El Niño Southern Oscillation (ENSO) events are another source of climate forcing that influences the North Pacific. Hollowed *et al.* (2001) found that gadids in the GOA have a higher proportion of strong year classes in ENSO years. There was, however, no relationship between strong year classes of AI Atka mackerel and ENSO events (Hollowed *et al.* 2001). The state of the North Pacific atmosphere-ocean system during 2015-2016 featured the continuance of warm sea surface temperature anomalies that became prominent late in 2013. A strong El Niño developed during winter 2015-2016 (Zador and Yasumiishi 2016). The North Pacific atmospheric-ocean climate system during fall 2017 to summer 2018 was similar to that during 2016-2017. A weak La Nina developed during winter 2017-2018 along with a weaker than normal Aleutian Low, similar to the previous year (Bond 2018).

Eddies in the Alaskan Stream south of the Aleutian Islands have been shown to influence flow into the Bering Sea through the Aleutian Passes (Okkonen, 1996). By influencing flow through the passes, eddies could impact flow in the Aleutian North Slope Current and Bering Slope Current as well as inuencing the transports of heat, salt and nutrients (Mordy *et al*., 2005; Stabeno *et al*., 2005) into the Bering Sea.

Average eddy kinetic energy (EKE, $cm^2\ s^{-2}$) from south of Amutka Pass in the Aleutian Islands was examined and found to be potentially informative (S. Lowe unpubl. Data). Particularly strong eddies were observed south of Amukta Pass in 1997, 1999, 2004, 2006/2007, 2009/2010, and summer 2012 (Ladd 2016). The 1999-2001 and the 2006 Atka mackerel year classes were strong, the 2012 year class is slightly above average. Eddy energy in the region has been low from the fall 2012 through 2018 (Ladd 2018). In early 2016, a small eddy was present in the region, resulting in slightly above average EKE (Ladd 2016). These trends indicate that higher than average volume, heat, salt, and nutrient fluxes to the Bering Sea through Amukta Pass may have occurred in 1997/1998, 1999, 2004, 2006/2007, 2009/2010, and summer 2012. These fluxes were likely smaller during the period from fall 2012 until early 2015 and may have been slightly enhanced in early 2016 (Ladd 2016). The role of eddies may be the transport of larva which hatch in the fall, and or the increase in nutrients and favorable environment conditions. Further research is needed to determine the effects of climate on growth and year class strength, and the temporal and spatial scales over which these effects occur.

Bottom temperature

The distribution of Atka mackerel spawning and nesting sites are thought to be limited by water temperature (Gorbunova 1962). Temperatures below 3 °C and above 15 °C are lethal to eggs or unfavorable for embryonic development depending on the exposure time (Gorbunova 1962). Temperatures recorded at Alaskan nesting sites, 3.9 – 10.7 ºC, do not appear to be limiting, as they were within this range (Lauth *et al.* 2007b). The 2000 and 2012 Aleutian Islands summer bottom temperatures indicated that these were the coldest years followed by summer bottom temperatures from the 2002 survey, which indicated the second coldest year (Figure 17.5). The 2004 AI summer bottom temperatures indicated that 2004 was an average year, while the 2006 and 2010 bottom temperatures were slightly below average. The average bottom temperatures measured in the 2014 survey were the third highest of the Aleutian surveys, significantly higher than the 2000 and 2012 surveys and very similar to the 1991 and 1997 surveys. The 2016 survey bottom temperatures were the highest in the Aleutian survey time series.

The temperature anomaly profiles from the 2016 AI survey data appear to be some of the warmest on record (Figure 17.5). These warm anomalies were also some of the most pervasive (vertically and longitudinally) recorded to date. The profiles from 2016 are similar to those of 2014 and share the characteristics of widely distributed warm surface waters along with greater thermal stratification although the 2016 anomalies are more broadly dispersed and penetrate deeper (Laman 2016). By contrast, the 2000 AI survey remains one of the coldest years in the record. The last three survey years in the AI have generally been warmer than previous years with the exception of 1997 which was comparable with the thermal anomalies observed in 2014 and 2016 (Laman 2018). The 2018 AI profile suggests a return to slightly cooler conditions relative to 2016, but is still amongst the warmer years from the records with warm anomalies penetrating deeper and distributed more extensively across the Aleutian archipelago than in 2014 (Laman 2018). These differences among survey years illustrate the highly variable and dynamic oceanographic environment found in the Aleutian archipelago. Recent phenomena of the resilient ridge of atmospheric high pressure that helped to establish the warm water “Blob” in the Northeast Pacific influenced water temperatures in the Aleutian Islands. The formation and intensification of the warm blob in 2014 and 2015 followed by the ENSO in 2015-16 almost certainly influenced the temperatures observed during the 2016 AI bottom trawl survey (Laman 2016). Phenomena like these influence both Aleutian Islands and Bering Sea ecosystems and fish populations.

Thermal regime and mixed-layer-depth differences are known to influence regional biological processes and impact fish populations. In the AI, the magnitude of primary production depends on mixed-layer-depth (Mordy *et al*., 2005) while ontogenesis of Atka mackerel eggs and larvae is temperature dependent (Lauth *et al*., 2007a). Recent studies of habitat-based definitions of essential fish habitat (EFH) in the Aleutian Islands demonstrate that water temperature can be an important determinant of EFH for many groundfish species (Laman *et al*. 2017). The effect of temperature on survey catchability and fish behavior is unknown, but could affect the vertical or broad scale distribution of Atka mackerel to make them less available to the trawl during cold years. It is unclear what effect the recent warm temperatures may have on Atka mackerel nesting sites that are within this depth range, or on adult fish distributions in response to water temperatures.

Atka mackerel fishery effects on the ecosystem

Atka mackerel fishery contribution to bycatch

The levels of bycatch in the Atka mackerel fishery of prohibited species, forage fish, Habitat Areas of Particular Concern (HAPC) biota, marine mammals, birds, and other sensitive non-target species is relatively low except for the species which are noted in Table 17.17 and 17.18 and discussed below.

The Atka mackerel fishery has very low bycatch levels of some species of HAPC biota, e.g. seapens and whips. The bycatch of sponges and coral in the Atka mackerel fishery is highly variable. During 2017 to

2019, the directed Atka mackerel fishery took 150-170 t of sponges and about 13 t of corals. It is unknown if the absolute levels of sponge and coral bycatch in the Atka mackerel fishery are of concern.

Fishing gear effects on spawning and nesting habitat

Bottom contact fisheries could have direct negative impacts on Atka mackerel by destroying egg nests and/or removing the males that are guarding nests (Lauth *et al.* 2007b); however, this has not been examined quantitatively. It was previously thought that all Atka mackerel migrated to shallow, nearshore areas for spawning and nesting sites. When nearshore bottom trawl exclusion zones near Steller sea lion rookeries were implemented this was hypothesized to eliminate much of the overlap between bottom trawl fisheries and Atka mackerel nesting areas (Fritz and Lowe 1998). Lauth *et al.* (2007b), however found that nesting sites in Alaska were "…widespread across the continental shelf and found over a much broader depth range…". The use of bottom contact fishing gear, such as bottom trawls, pot gear, and longline gear, utilized in July to January could, therefore, still potentially affect Atka mackerel nesting areas, despite trawl closures in nearshore areas around Steller sea lion rookeries.

Management measures for the Atka mackerel fishery have an impact on the fishery interactions with Steller sea lions and on Atka mackerel habitat. Substantial parts of the Aleutian Islands were closed to trawling for Atka mackerel and Pacific cod (the predominant target species) as well as longlining for Pacific cod in early 2011 as part of mitigation measures for Steller sea lions. Management area 543 and large sections of 542 were included in this closure. The western and central Aleutian Islands were subsequently reopened to trawling in 2015.

Observed fishing effort is used as an indicator of total fishing effort (Olson 2015), and can be used as an indicator of potential habitat disturbance. For the period 2005-2014 there were 23,499 observed bottom trawl tows in the Aleutian Islands (Olson 2015). During 2014, the amount of observed bottom trawl effort was 1,789 tows, which is almost 24 percent below average for the 10-year period. It represents a decrease over 2013. Patterns of high and low fishing effort are dispersed throughout the Aleutian Islands. The primary catches in these areas are Pacific cod, Pacific ocean perch, and Atka mackerel. In 2014, areas of anomalous fishing effort were minimal but scattered throughout the region, with higher than average observed effort east of Agattu Island and on Petrel Bank. Some areas that were closed in 2011 due to Steller sea lion management measures were reopened to varying degrees in 2015. In 2006, the Aleutian Islands Habitat Conservation Area (AIHCA) closed approximately 279,114 nm^2 to bottom trawl fishing in the three AI management areas (Olson 2015). Changes in management regulations and the amount of Atka mackerel fishing effort is likely to have ecosystem impacts.

NMFS has conducted ongoing tagging studies to determine the efficacy of trawl exclusion zones as a fishery-Steller sea lion management tool and to determine the local movement rates and abundance of Atka mackerel. A comprehensive report funded through the North Pacific Fishery Research Board (NPRB) that examined local scale fishery interactions of Atka mackerel and Steller sea lions in areas 541 and 543, will be forthcoming in 2018.

Indirect effects of bottom contact fishing gear, such as effects on fish habitat, may also have implications for Atka mackerel. Living substrate that is susceptible to fishing gear includes sponges, seapens, sea anemones, ascidians, and bryozoans (Malecha *et al.* 2005). Of these, Atka mackerel sampled in the NMFS bottom trawl survey are primarily associated with emergent epifauna such as sponges and corals (Malecha *et al.* 2005, Stone 2006). Effects of fishing gear on these living substrates could, in turn, affect fish species that are associated with them.

Concentration of Atka mackerel catches in time and space

Analyses of historic fishery CPUE revealed that the fishery may create temporary localized depletions of Atka mackerel, and historic fishery harvest rates in localized areas may have been high enough to affect prey availability of Steller sea lions (Section 12.2.2 of Lowe and Fritz 1997). The localized pattern of fishing for Atka mackerel could have created temporary reductions in the size and density of localized Atka mackerel populations which may have affected Steller sea lion foraging success during the time the fishery was operating and for a period of unknown duration after the fishery closed. As a precautionary measure, the NPFMC passed regulations in 1998 and 2001 (described above) to disperse fishing effort temporally and spatially as well as reduce effort within Steller sea lion critical habitat.

Steller sea lion protection measures have spread out Atka mackerel harvests in time and space through the implementation of seasonal and area-specific TACs and harvest limits within sea lion critical habitat. Most recently, RPAs from the 2010 BiOp closed the entire Western Aleutians (Area 543) to directed fishing for Atka mackerel, and several closures were implemented in critical habitat in the Central Aleutians (Area 542) and the TAC for Area 542 was reduced to no more than 47 percent of the Area 543 ABC. These measures were in place from 2011 to 2014. Revised RPAs were implemented in 2015. For the 2015 fishery, the Area 543 Atka mackerel TAC was set to less than or equal to 65 percent of the Area 543 ABC. In Area 542, there are expanded area closures and no requirement for a TAC reduction. Concentration of catches in time and space is still an issue of possible concern and research efforts continue to monitor and assess the availability of Atka mackerel biomass in areas of concern. Also, in some cases the sea lion protection measures have forced the fishery to concentrate in areas outside of critical habitat that had previously experienced lower levels of exploitation. The impact of the fishery in these areas outside of critical habitat is unknown.

Atka mackerel fishery effects on amount of large size Atka mackerel

The numbers of large size Atka mackerel are largely impacted by highly variable year class strength rather than by the directed fishery. Year to year differences are attributed to natural fluctuations.

Atka mackerel fishery effects on Atka mackerel age-at-maturity and fecundity

The effects of the fishery on the age-at-maturity and fecundity of Atka mackerel are unknown. Studies were conducted to determine age-at-maturity (McDermott and Lowe 1997, Cooper *et al*. 2010) and fecundity (McDermott 2003, McDermott *et al*. 2007) of Atka mackerel. These are recent studies and there are no earlier studies for comparison on fish from an unexploited population. Further studies would be needed to determine if there have been changes over time and whether changes could be attributed to the fishery.

Atka mackerel fishery contribution to discards and offal production

There is no time series of the offal production from the Atka mackerel fishery. The Atka mackerel fishery has taken on average, about 400 t of non-target discards in the Aleutian Islands from 2015 to 2019. Most of the Atka mackerel fishery discards of target species are comprised of small Atka mackerel. The average discards of Atka mackerel in the Atka mackerel fishery have been about 412 t over 2015-2019.

Data Gaps and Research Priorities

More information on the spatial and temporal aspects of Atka mackerel habitat preferences would be useful to improve our understanding of Essential Fish Habitat (EFH), and improve our assessment of the impacts to habitat due to fishing. Better habitat mapping of the Aleutian Islands would provide information for survey stratification and the extent of trawlable and untrawlable habitat.

The high variability in survey abundance and trend estimates is a major source of uncertainty in the assessment. Other approaches for analyzing the survey data such as spatial models, incorporating spatial covariates, especially those that are habitat related, into predictive estimates are research priorities. Changes in survey tow duration starting in 2002 may have resulted in a higher encounter rate for this species and may have resulted in an inconsistency in estimating the biomass over the complete time series. An evaluation of the survey data in terms of tow duration changes, survey design and the development of alternate estimation approaches possibly incorporating habitat information are research priorities.

Studies to determine the impacts of environmental indicators such as temperature regime on Atka mackerel are needed. Further studies to determine whether there have been any changes in life history parameters over time (e.g. fecundity, and weight- and length-at-age) would be informative.

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Tables

Table 17.1. Time series of Bering Sea/Aleutian Islands Atka mackerel catches (including discards and CDQ catches), corresponding Acceptable Biological Catches (ABC), Total Allowable Catches (TAC), and Overfishing Levels (OFL) set by the North Pacific Fishery Management Council from 1978 to the present. Catches, ABCs, TACs, and OFLs are in metric tons.

Year	Catch	ABC	TAC	OFL
1977	21,763	a	a	
1978	24,249	24,800	24,800	
1979	23,264	24,800	24,800	
1980	20,488	24,800	24,800	
1981	19,688	24,800	24,800	
1982	19,874	24,800	24,800	
1983	11,726	25,500	24,800	
1984	36,055	25,500	35,000	
1985	37,860	37,700	37,700	
1986	31,990	30,800	30,800	
1987	30,061	30,800	30,800	
1988	22,084	21,000	21,000	
1989	17,994	24,000	20,285	
1990	22,206	24,000	21,000	
1991	26,626	24,000	24,000	
1992	48,532	43,000	43,000	435,000
1993	66,006	117,100	32,000	771,100
1994	65,360	122,500	68,000	484,000
1995	81,554	125,000	80,000	335,000
1996	103,942	116,000	106,157	164,000
1997	65,842	66,700	66,700	81,600
1998	57,097	64,300	64,300	134,000
1999	56,237	73,300	66,400	148,000

a) Atka mackerel was not a reported species group until 1978.
b) 2021 projected total year catch (the 2021 catch is assumed equal to the 2021 TAC of 62,257 t).
Sources: compiled from NMFS Regional Office web site and various NPFMC reports.

Table 17.1.cont.Time series of Bering Sea/Aleutian Islands Atka mackerel catches (including discards and CDQ catches), corresponding Acceptable Biological Catches (ABC), Total Allowable Catches (TAC), and Overfishing Levels (OFL) set by the North Pacific Fishery Management Council from 1978 to the present. Catches, ABCs, TACs, and OFLs are in metric tons.

Year	Catch	ABC	TAC	OFL
2000	47,230	70,800	70,800	119,000
2001	61,563	69,300	69,300	138,000
2002	45,288	49,000	49,000	82,300
2003	54,045	63,000	60,000	99,700
2004	60,562	66,700	63,000	78,500
2005	62,012	124,000	63,000	147,000
2006	61,894	110,000	63,000	130,000
2007	58,763	74,000	63,000	86,900
2008	58,090	60,700	60,700	71,400
2009	72,806	83,800	76,400	99,400
2010	68,619	74,000	74,000	88,200
2011	51,818	85,300	53,080	101,000
2012	47,826	81,400	50,763	96,500
2013	23,180	50,000	25,920	57,700
2014	30,951	64,131	32,322	74,492
2015	53,268	106,000	54,500	125,297
2016	54,485	90,340	55,000	104,749
2017	64,451	87,200	65,000	107,200
2018	70,394	92,000	71,000	108,600
2019	57,206	68,500	57,951	79,200
2020	58,975	70,100	59,305	81,200
2021[b]	62,257	73,590	62,257	85,580

a) Atka mackerel was not a reported species group until 1978.
b) 2021 projected total year catch (the 2021 catch is assumed equal to the 2021 TAC of 62,257 t).

Sources: compiled from NMFS Regional Office web site and various NPFMC reports.

Table 17.2. Time series of Bering Sea/Aleutian Islands Atka mackerel catches (including discards and CDQ catches) by region, corresponding Acceptable Biological Catches (ABC), and Total Allowable Catches (TAC) set by the North Pacific Fishery Management Council from 1995 to the present. Apportioned catches prior to 2000 are available in Lowe *et al*. (2013) and Lowe *et al*. 2018. Catches, ABCs, and TACs are in metric tons.

Year		Eastern (541)	Central (542)	Western (543)	Total	Year		Eastern (541)	Central (542)	Western (543)	Total
2000	Catch	13,152	20,575	8,713	42,440	2011	Catch	40,891	10,713	205	51,809
	ABC	16,400	24,700	29,700	70,800		ABC	40,300	24,000	21,000	85,300
	TAC	16,400	24,700	29,700	70,800		TAC	40,300	11,280	1,500	53,080
2001	Catch	7,905	30,365	18,264	56,534	2012	Catch	37,308	10,323	195	47,826
	ABC	7,800	33,600	27,900	69,300		ABC	38,500	22,900	20,000	81,400
	TAC	7,800	33,600	27,900	69,300		TAC	38,500	10,763	1,500	50,763
2002	Catch	4,606	20,699	16,737	42,042	2013	Catch	15,777	7,284	120	23,181
	ABC	5,500	23,800	19,700	49,000		ABC	16,900	16,000	17,100	50,000
	TAC	5,500	23,800	19,700	49,000		TAC	16,900	7,520	1,500	25,920
2003	Catch	10,725	25,435	17,885	54,045	2014	Catch	21,185	9,520	242	30,947
	ABC	10,650	29,360	22,990	63,000		ABC	21,652	20,574	21,905	64,131
	TAC	10,650	29,360	19,990	60,000		TAC	21,652	9,670	1,000	32,322
2004	Catch	10,840	30,169	19,555	60,564	2015	Catch	26,343	16,672	10,253	53,268
	ABC	11,240	31,100	24,360	66,700		ABC	38,492	33,108	34,400	106,000
	TAC	11,240	31,100	20,660	63,000		TAC	27,000	17,000	10,500	54,500
2005	Catch	7,201	35,069	19,744	62,014	2016	Catch	28,360	15,795	10,330	54,485
	ABC	24,550	52,830	46,620	124,000		ABC	30,832	27,216	32,292	90,340
	TAC	7,500	35,500	20,000	63,000		TAC	28,500	16,000	10,500	55,500
2006	Catch	7,422	39,836	14,638	61,896	2017	Catch	34,269	17,860	12,322	64,451
	ABC	21,780	46,860	41,360	110,200		ABC	34,890	30,330	21,980	87,200
	TAC	7,500	40,000	15,500	63,000		TAC	34,500	18,000	12,500	65,000
2007	Catch	22,943	26,723	9,097	58,763	2018	Catch	30,086	20,915	13,395	70,394
	ABC	23,800	29,600	20,600	74,000		ABC	36,820	32,000	23,180	92,000
	TAC	23,800	29,600	9,600	63,000		TAC	36,500	21,000	13,500	71,000
2008	Catch	19,112	22,926	16,045	58,083	2019	Catch	23,655	14,129	19,422	57,206
	ABC	19,500	24,300	16,900	60,700		ABC	23,970	14,390	30,140	68,500
	TAC	19,500	24,300	16,900	60,700		TAC	23,970	14,390	19,591	57,951
2009	Catch	26,417	30,137	16,253	72,807	2020	Catch	24,382	14,628	19,965	58,975
	ABC	27,000	33,500	23,300	83,800		ABC	24,535	14,721	30,844	70,100
	TAC	27,000	32,500	16,900	76,400		TAC	24,535	14,721	20,049	59,305
2010	Catch	23,608	26,388	18,650	68,646	2021*	Catch	25,760	15,450	21,047	62,257
	ABC	23,800	29,600	20,600	74,000		ABC	25,760	15,450	32,380	73,590
	TAC	23,800	29,600	20,600	74,000		TAC	25,760	15,450	21,047	62,257

*2021 projected total year catches by region assumed equal to the 2021 TAC.

Table 17.3. Numbers of Atka mackerel length-weight data, length frequency, and aged samples based on NMFS observer data 1990-2020.

Year	Number of length-weight samples	Length frequency records	Number of aged samples
1990	731	8,618	718
1991	356	7,423	349
1992	90	13,532	86
1993	58	12,476	58
1994	913	13,384	837
1995	1,054	19,653	972
1996	1,039	24,758	680
1997	126	13,412	123
1998	733	15,060	705
1999	1,633	12,349	1,444
2000	2,697	9,207	1,659
2001	3,332	11,600	935
2002	3,135	12,418	820
2003	4,083	13,740	1,008
2004	4,205	14,239	870
2005	4,494	13,142	1,024
2006	4,194	13,598	980
2007	2,100	11,841	884
2008	1,882	19,831	922
2009	2,374	15,207	971
2010	2,462	16,347	879
2011	1,976	11,814	720
2012	1,495	13,794	1,012
2013	1,178	13,327	642
2014	1,301	14,210	1,061
2015	2,493	15,959	1,687
2016	2,819	29,095	1,868
2017	4,921	26,472	1,318
2018	3,745	63,084	1,581
2019	2,699	47,745	1,510
2020	2,797	51,285	2,111

Table 17.4. Estimated catch-in-numbers at age (in millions) of Atka mackerel from the BSAI region, 1977-2020. These data were used in fitting the age-structured model.

Age	2	3	4	5	6	7	8	9	10	11+
1977	6.83	31.52	20.06	15.11	1.22	0.39	0.20	---	---	---
1978	2.70	60.16	15.57	9.22	3.75	0.59	0.34	0.11	---	---
1979	0.01	4.48	26.78	13.00	2.20	1.11	---	---	---	---
1980	---	12.68	5.92	7.22	1.67	0.59	0.24	0.13	---	---
1981	---	5.39	17.11	0.00	1.61	8.10	---	---	---	---
1982	---	0.19	2.63	25.83	3.86	0.68	---	---	---	---
1983	---	1.90	1.43	2.54	10.60	1.59	---	---	---	---
1984	0.09	0.98	7.30	7.07	10.79	21.78	2.21	0.96	---	---
1985	0.63	15.97	8.79	9.43	6.01	5.45	11.69	1.26	0.27	---
1986	0.37	11.45	6.46	4.42	5.34	4.53	5.84	9.91	1.04	0.85
1987	0.56	10.44	7.60	4.58	1.89	2.37	2.19	1.71	6.78	0.75
1988	0.40	9.97	22.49	6.15	1.80	1.54	0.63	0.96	0.20	0.48
1989[a]										
1990	1.74	7.62	13.15	4.78	1.77	0.81	0.11	0.09	0.03	0.17
1991	0.00	4.15	6.49	7.78	5.71	3.94	1.04	0.18	0.35	0.22
1992	0.00	0.93	20.82	2.97	1.40	0.62	0.00	0.00	0.00	0.00
1993	0.00	13.55	18.33	38.88	12.16	6.76	4.17	0.61	0.59	0.00
1994	0.05	9.16	6.83	23.13	36.00	4.64	8.21	5.27	3.04	0.61
1995	0.13	20.65	33.67	9.81	18.78	33.09	4.01	5.84	7.90	2.98
1996	0.02	3.65	63.55	21.94	14.14	19.44	31.59	2.85	3.37	2.53
1997	0.00	17.11	4.66	66.28	3.72	1.56	0.67	3.56	0.36	0.00
1998	0.00	11.15	15.73	15.24	25.07	11.21	4.02	3.55	5.28	1.85
1999	1.17	1.08	38.31	8.85	7.09	9.93	5.24	1.80	1.49	1.79
2000	0.54	8.91	6.40	26.59	7.53	4.33	8.33	1.93	0.78	1.01
2001	1.87	20.59	13.57	8.68	27.20	8.16	4.60	3.86	0.78	0.50
2002	1.94	22.68	25.37	7.88	3.89	16.20	3.23	1.56	1.67	0.53
2003	0.78	19.96	49.54	20.63	5.95	3.27	7.02	0.78	0.49	0.85
2004	0.09	20.44	31.49	44.20	12.32	2.40	1.56	2.21	0.00	0.39
2005	1.43	3.96	35.31	27.23	28.97	9.68	1.54	0.25	0.85	0.00
2006	3.56	16.74	5.66	33.56	20.27	22.62	4.12	0.56	0.36	0.26
2007	2.25	19.63	11.63	5.39	19.94	15.90	12.46	2.69	0.77	0.08
2008	5.49	13.29	16.90	7.61	6.29	20.04	10.53	11.63	1.64	0.54
2009	4.69	31.92	15.73	20.00	8.81	8.56	16.59	8.24	8.71	1.79
2010	1.67	19.00	47.22	13.06	13.59	6.46	3.82	7.90	4.66	1.75
2011	1.05	3.02	17.61	22.41	6.68	4.89	1.16	2.73	4.44	4.82
2012	0.18	7.41	3.54	21.16	20.78	5.69	3.21	2.69	2.36	9.96
2013	1.56	7.42	19.99	4.59	14.75	11.71	2.52	1.32	0.85	3.44
2014	0.48	23.50	2.71	8.10	2.87	4.02	2.86	0.44	0.59	1.27
2015	0.58	16.21	13.06	10.55	13.24	6.86	14.11	7.73	1.98	1.42
2016	0.12	8.30	28.76	10.13	8.66	9.81	4.69	8.43	3.59	0.74
2017	1.01	2.05	21.83	29.96	11.81	10.18	5.27	3.45	3.45	3.69
2018	0.67	10.84	3.81	28.18	31.16	8.74	6.40	4.20	1.78	2.30
2019	1.30	3.42	13.90	6.60	19.32	20.23	6.08	3.03	1.89	1.20
2020	0.72	13.50	10.08	13.43	6.41	14.50	15.14	4.09	2.00	1.28

[a] Too few fish were sampled for age structures in 1989 to construct an age-length key.

Table 17.5. Atka mackerel estimated biomass in metric tons from the U.S.-Japan cooperative bottom trawl surveys, by sub-region, depth interval, and survey year, with the corresponding Aleutian-wide coefficients of variation (*CV*). These historical data are presented, but are not used in the assessment model.

		Biomass		
Area	Depth (m)	1980	1983	1986
Aleutian	1-100	193	239,502	1,013,678
	101-200	62,376	247,256	107,092
	201-300	646	2,565	368
	301-500	0	164	10
	Total	63,215	489,487	1,121,148
	CV	0.80	0.24	0.80
Western 543	1-100	193	49,115	1,675
	101-200	692	124,806	40,675
	201-300		1,559	111
	301-500	0	164	0
	Total	885	175,644	42,461
Central 542	1-100	0	103,588	1,011,991
	101-200	58,666	1,488	20,582
	201-300	504	303	36
	301-500	0	0	10
	Total	59,170	105,379	1,032,619
Eastern 541	1-100		86,800	11
	101-200	3,018	120,962	45,835
	201-300	143	703	222
	301-500	0	0	0
	Total	3,161	208,465	46,068
Southern Bering Sea	1-100	6	0	429
	101-200	20,239	9	5
	201-300	2	0	1
	301-500		0	0
	Total	20,247	9	435

Table 17.6a. Aleutian Islands Atka mackerel survey biomass by bottom-depth category by region and subareas including area percentages of total (for each year) and coefficients of variation (*CV*) for 1991, 1994, and 1997.

		Biomass		
Area	**Depth (m)**	**1991**	**1994**	**1997**
Aleutian Islands + S. BS	1-100	429,873	211,562	284,176
	101-200	277,907	472,725	177,672
	201-300	520	1,691	130
	301-500	0	30	20
	Total	708,299	686,007	461,997
Regional area % of Total		100%	100%	100%
	CV	*14%*	*32%*	*31%*
Western 543	1-100	168,968	93,847	90,824
	101-200	174,182	231,733	43,478
	201-300	276	1,656	66
	301-500	-	6	-
	Total	343,426	327,242	134,367
Regional area % of Total		48%	48%	29%
	CV	*18%*	*57%*	*56%*
Central 542	1-100	187,194	50,513	70,458
	101-200	100,329	33,255	116,295
	201-300	70	13	53
	301-500	0	2.9	8
	Total	287,594	83,784	186,813
Regional area % of Total		41%	12%	40%
	CV	*17%*	*48%*	*36%*
Eastern 541	1-100	73,663	641	27,222
	101-200	3,392	207,707	17,890
	201-300	163	19	11
	301-500	0	12	14
	Total	77,218	208,379	45,137
Regional area % of Total		11%	30%	10%
	CV	*83%*	*44%*	*68%*
Bering Sea	1-100	47	66,562	95,672
	101-200	3	30	9
	201-300	11	3	0
	301-500	0	8	0
	Total	61	66,603	95,680
Regional area % of Total		0%	10%	21%
	CV	*37%*	*99%*	*99%*

Table 17.6b. Aleutian Islands Atka mackerel survey biomass by bottom-depth category by region and subareas including area percentages of total (for each year) and coefficients of variation (*CV*) for 2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016, and 2018. No surveys were conducted in 2008 and 2020.

		Biomass (t)								
Area	**Depth (m)**	**2000**	**2002**	**2004**	**2006**	**2010**	**2012**	**2014**	**2016**	**2018**
Aleutian Islands + S. BS	1-100	146,851	394,092	518,232	374,774	304,909	130,616	286,064	143,338	110,823
	101-200	357,325	393,159	631,150	326,716	624,294	145,351	436,506	302,604	198,050
	201-300	8,636	48,723	7,410	40,091	1,008	886	716	2,093	46,180
	301-500	82	221	292	67	41	23	642	130	160
	Total	512,897	836,195	1,157,084	741,648	930,252	276,877	723,928	448,166	355,213
Regional area % of Total		100%	100%	100%	100%	100%	100%	100%	100%	100%
	CV	*28%*	*20%*	*17%*	*28%*	*35%*	*18%*	*24%*	*31%*	*30%*
Western 543	1-100	106,168	50,481	140,669	64,429	59,449	62,247	115,359	16,808	71,728
	101-200	65,600	154,820	229,675	36,331	195,819	70,983	99,102	139,608	62,922
	201-300	7,912	48,362	6,033	318	134	350	172	17	116
	301-500	-	8	36	21	17	8	602	0	0
	Total	179,680	253,671	376,414	101,098	255,419	133,588	215,235	156,433	134,766
Regional area % of Total		35%	30%	33%	14%	27%	48%	30%	35%	38%
	CV	*51%*	*32%*	*24%*	*35%*	*58%*	*28%*	*29%*	*56%*	*34%*
Central 542	1-100	38,805	131,770	198,243	192,832	102,211	62,238	86,097	122,628	19,613
	101-200	290,766	199,743	70,267	85,102	96,457	46,861	118,612	10,338	6,843
	201-300	674	168.9	367.1	103	207	16.2	119.7	37	79
	301-500	9	142.5	194.1	0	0	15.1	39.8	18	80
	Total	330,255	331,824	269,071	278,036	198,874	109,130	204,868	133,022	26,615
Regional area % of Total		64%	40%	23%	37%	21%	39%	28%	30%	7%
	CV	*34%*	*24%*	*35%*	*24%*	*28%*	*27%*	*50%*	*54%*	*29%*
Eastern 541	1-100	25	152,159	54,424	107,230	44,981	6,029	84,252	3,802	12,815
	101-200	772	38,492	188,592	205,108	327,105	26,685	217,748	152,623	109,439
	201-300	48	94	971	37,829	339	435	382	1,989	45,903
	301-500	73	71	57	40	5	0	0	112	31
	Total	919	190,817	244,043	350,206	372,429	33,149	302,383	158,525	168,188
Regional area % of Total		0%	23%	21%	47%	40%	12%	42%	35%	47%
	CV	*74%*	*58%*	*33%*	*55%*	*74%*	*46%*	*43%*	*50%*	*57%*
Bering Sea	1-100	1,853	59,682	124,896	10,284	98,268	103	356	100	6,668
	101-200	187	103	142,616	176	4,914	822	1,044	35	18,847
	201-300	4	98	39	1,842	327	85	42	50	82
	301-500	0	0	3.8	6	19	0	0	0	49
	Total	2,044	59,883	267,556	12,308	103,529	1,010	1,443	186	25,645
Regional area % of Total		0%	7%	23%	2%	11%	0%	0%	0%	7%
	CV	*88%*	*99%*	*43%*	*44%*	*86%*	*77%*	*73%*	*39%*	*70%*

Table 17.7. Estimated survey numbers at age (in millions) of Atka mackerel from the Aleutian Islands trawl surveys and numbers of Atka mackerel otoliths aged (*n*).

Age	*n*	2	3	4	5	6	7	8	9	10	11+
1986	712	157.53	985.94	532.35	344.94	274.32	230.87	135.80	40.74	10.86	2.72
1991	478	72.44	846.64	137.33	261.09	81.49	87.53	15.09	6.04	0.00	0.00
1994	745	12.37	166.06	114.83	185.49	217.29	51.23	68.01	22.08	37.98	6.18
1997	433	65.67	142.93	115.25	148.73	45.71	23.18	31.55	43.14	6.44	13.52
2000	831	269.32	76.68	25.25	226.30	68.26	71.07	118.76	37.41	18.70	23.38
2002	789	77.33	933.52	531.22	95.13	32.08	78.05	35.78	14.47	12.71	1.53
2004	598	66.94	726.25	584.22	560.93	120.42	29.00	16.47	19.23	10.67	15.32
2006	525	166.24	159.26	63.30	192.03	200.48	290.68	93.74	11.92	0.27	19.16
2010	560	45.18	386.11	400.88	82.19	86.99	39.26	50.56	98.85	67.84	112.04
2012	417	63.17	100.11	40.52	97.73	66.74	20.26	20.26	17.88	8.34	61.98
2014	478	109.92	155.54	150.30	130.30	87.45	172.27	149.99	44.11	22.87	63.07
2016	300	34.99	231.82	249.68	67.08	52.74	52.15	27.88	40.06	43.59	17.76
2018	1,052	23.95	76.78	17.35	82.19	107.58	55.42	29.23	43.57	12.93	30.33

Table 17.8a. Year-specific survey and the population weight-at-age (kg) values used to obtain expected survey catch biomass and population biomass. The population weight-at-age values are derived from the Aleutian trawl surveys as the average of years 2014, 2016, and 2018.

		Age										
	Year	1	2	3	4	5	6	7	8	9	10	11+
Survey	1991	0.045	0.185	0.449	0.637	0.652	0.751	0.811	0.693	1.053	1.764	0.878
	1994	0.045	0.177	0.450	0.653	0.738	0.846	0.941	0.988	0.906	0.907	0.516
	1997	0.045	0.191	0.486	0.686	0.753	0.805	0.887	0.970	0.919	1.375	0.935
	2000	0.045	0.130	0.387	0.623	0.699	0.730	0.789	0.810	0.792	0.864	0.871
	2002	0.045	0.139	0.342	0.615	0.720	0.837	0.877	0.773	0.897	0.955	1.084
	2004	0.045	0.138	0.333	0.497	0.609	0.739	0.816	0.956	0.928	0.745	0.824
	2006	0.045	0.158	0.332	0.523	0.516	0.675	0.764	0.719	0.855	1.653	0.991
	2010	0.045	0.161	0.369	0.633	0.667	0.744	0.974	1.075	0.981	1.041	1.244
	2012	0.045	0.161	0.360	0.517	0.627	0.705	0.762	0.820	0.863	0.809	0.949
	2014	0.045	0.162	0.465	0.524	0.662	0.709	0.856	0.951	0.920	0.808	1.017
	2016	0.045	0.189	0.370	0.480	0.696	0.744	0.759	0.892	0.910	0.917	0.887
	2018	0.069	0.161	0.481	0.593	0.751	0.771	0.891	0.896	0.971	0.973	0.981
Avg 2014, 2016, 2018		0.053	0.171	0.439	0.532	0.703	0.741	0.835	0.913	0.934	0.899	0.962

Table 17.8b. Year-specific fishery weight-at-age (kg) values used to obtain expected fishery catch biomass. The 2021 fishery weight-at-age values are the average of the last three years (2018-2020).

		Age										
	Year	1	2	3	4	5	6	7	8	9	10	11+
Fishery	1977	0.069	0.132	0.225	0.306	0.400	0.470	0.507	0.379	0.780	0.976	1.072
Foreign	1978	0.069	0.072	0.225	0.300	0.348	0.388	0.397	0.371	0.423	0.976	1.072
	1979	0.069	0.496	0.319	0.457	0.476	0.475	0.468	0.546	0.780	0.976	1.072
	1980	0.069	0.365	0.317	0.450	0.520	0.585	0.630	0.546	0.780	0.976	1.072
	1981	0.069	0.365	0.317	0.450	0.520	0.585	0.630	0.546	0.780	0.976	1.072
	1982	0.069	0.365	0.273	0.443	0.564	0.695	0.795	0.546	0.780	0.976	1.072
	1983	0.069	0.365	0.359	0.499	0.601	0.686	0.810	0.546	0.780	0.976	1.072
	1984	0.069	0.297	0.410	0.617	0.707	0.777	0.802	0.890	0.910	0.976	1.072
	1985	0.069	0.302	0.452	0.552	0.682	0.737	0.775	0.807	1.007	1.011	1.072
	1986	0.069	0.146	0.334	0.528	0.546	0.786	0.753	0.829	0.858	0.954	1.052
	1987	0.069	0.265	0.435	0.729	0.908	0.859	0.964	1.023	1.054	1.088	1.098
	1988	0.069	0.196	0.351	0.470	0.564	0.624	0.694	0.783	0.818	0.850	1.064
Domestic	1989	0.069	0.295	0.440	0.577	0.739	0.838	0.664	0.817	0.906	1.010	1.065
	1990	0.069	0.362	0.511	0.728	0.877	0.885	0.985	1.386	1.039	1.445	1.442
	1991	0.069	0.230	0.207	0.540	0.729	0.685	0.655	0.755	1.014	0.743	1.021
	1992	0.069	0.230	0.390	0.607	0.715	0.895	0.973	0.839	0.865	0.916	1.010
	1993	0.069	0.230	0.572	0.626	0.682	0.773	0.826	0.782	1.041	0.812	1.010
	1994	0.069	0.150	0.363	0.568	0.649	0.697	0.777	0.749	0.744	0.736	0.922
	1995	0.069	0.092	0.228	0.520	0.667	0.687	0.691	0.707	0.721	0.641	0.909
	1996	0.069	0.188	0.294	0.474	0.633	0.728	0.743	0.770	0.799	0.846	0.973
	1997	0.069	0.230	0.397	0.664	0.686	0.862	0.904	0.971	0.884	0.951	1.108
	1998	0.069	0.230	0.296	0.494	0.580	0.644	0.682	0.775	0.707	0.798	0.858
	1999	0.069	0.240	0.406	0.568	0.707	0.755	0.839	0.979	1.170	1.141	0.961
	2000	0.069	0.215	0.497	0.594	0.689	0.734	0.778	0.854	0.813	0.904	0.988
	2001	0.069	0.224	0.418	0.563	0.719	0.765	0.841	0.826	0.946	0.912	1.109
	2002	0.069	0.253	0.293	0.459	0.600	0.601	0.723	0.722	0.791	0.851	0.940
	2003	0.069	0.208	0.304	0.420	0.539	0.667	0.747	0.731	0.669	0.824	0.996
	2004	0.069	0.176	0.316	0.444	0.567	0.624	0.679	0.810	0.728	0.916	1.015
	2005	0.069	0.247	0.406	0.480	0.536	0.558	0.657	0.966	1.184	0.942	1.010
	2006	0.069	0.265	0.393	0.503	0.551	0.613	0.647	0.714	0.848	0.856	0.984
	2007	0.069	0.247	0.437	0.547	0.715	0.697	0.768	0.778	0.776	1.272	1.033
	2008	0.069	0.265	0.388	0.540	0.615	0.727	0.719	0.700	0.798	0.786	0.998
	2009	0.069	0.215	0.395	0.494	0.605	0.667	0.734	0.745	0.770	0.816	0.813
	2010	0.069	0.204	0.362	0.565	0.583	0.673	0.684	0.758	0.723	0.762	0.803
	2011	0.069	0.220	0.445	0.640	0.807	0.753	0.770	0.798	0.931	0.913	0.899
	2012	0.069	0.230	0.374	0.509	0.612	0.658	0.713	0.772	0.822	0.894	0.949
	2013	0.069	0.266	0.280	0.606	0.677	0.740	0.867	0.822	0.803	0.822	1.093
	2014	0.069	0.316	0.569	0.634	0.709	0.735	0.840	0.838	0.791	0.942	0.923
	2015	0.069	0.178	0.375	0.604	0.620	0.679	0.702	0.736	0.770	0.763	0.864
	2016	0.069	0.249	0.455	0.552	0.680	0.679	0.706	0.720	0.767	0.764	0.754
	2017	0.069	0.257	0.458	0.627	0.646	0.756	0.783	0.796	0.838	0.809	0.857
	2018	0.069	0.292	0.511	0.695	0.744	0.708	0.783	0.819	0.839	0.852	0.835
	2019	0.069	0.426	0.595	0.665	0.769	0.783	0.746	0.847	0.811	0.818	0.862
	2020	0.069	0.391	0.555	0.599	0.73	0.793	0.824	0.81	0.833	0.815	0.88
Ave. 2018-2020		0.069	0.369	0.554	0.653	0.748	0.761	0.784	0.825	0.827	0.828	0.859

Table 17.9. Schedules of age and length specific maturity of Atka mackerel from McDermott and Lowe (1997) by Aleutian Islands subareas. Eastern - 541, Central - 542, and Western - 543.

	INPFC Area				
Length (cm)	541	542	543	Age	Proportion mature
25	0	0	0	1	0
26	0	0	0	2	0.04
27	0	0.01	0.01	3	0.22
28	0	0.02	0.02	4	0.69
29	0.01	0.04	0.04	5	0.94
30	0.01	0.07	0.07	6	0.99
31	0.03	0.14	0.13	7	1
32	0.06	0.25	0.24	8	1
33	0.11	0.4	0.39	9	1
34	0.2	0.58	0.56	10	1
35	0.34	0.73	0.72		
36	0.51	0.85	0.84		
37	0.68	0.92	0.92		
38	0.81	0.96	0.96		
39	0.9	0.98	0.98		
40	0.95	0.99	0.99		
41	0.97	0.99	0.99		
42	0.99	1	1		
43	0.99	1	1		
44	1	1	1		
45	1	1	1		
46	1	1	1		
47	1	1	1		
48	1	1	1		
49	1	1	1		
50	1	1	1		

Table 17.10. Estimates of key results from AMAK for Bering Sea/Aleutian Islands Atka mackerel from Model 16.0b. Results from last year's assessment (Last Year), and last year's assessment model with updated data (Current Year Model 16.0b) are given. Coefficients of variation (*CV*) for some key reference values are given, appearing directly below.

Assessment Model	**Last Year (Model 16.0b)**	**Current Year Model 16.0b**
Model setup		
Survey catchability	1.5	1.5
Steepness	0.8	0.8
SigmaR	0.48	0.48
Natural mortality	0.3	0.3
Fishery Average Effective *N*	194	202
Survey Average Effective *N*	103	104
RMSE Survey	0.276	0.278
Number of Parameters	554	565
-log Likelihoods		
Survey index	10.01	9.96
Catch biomass	0.03	0.03
Fishery age comp	136.87	139.61
Survey age comp	23.63	23.62
Sub total	170.54	173.22
-log Penalties		
Recruitment	-1.09	-0.48
Selectivity constraint	94.9	97.33
Prior	1.8	2.19
Sub Total	95.6	103.44
Total	266.15	276.66
Fishing mortalities (full selection)		
F_{2020}	0.312	0.427
$F_{2020}/F_{40\%}$	0.73	0.79
Stock abundance		
Initial Biomass (t, 1977)	689,610	704,315
CV	20%	19%
Assessment year total biomass (t)	491,250	467,034
CV	25%	23%
2006 year class (millions at age 1)	893	865
CV	14%	14%
2012 year class (millions at age 1)	872	904
CV	16%	15%

Table 17.11. Estimates of Atka mackerel fishery (over time, 1977-2020) and survey selectivity at age (normalized to have a maximum of 1.0). The average selectivity over 2016-2020 listed below, is used for projections and computation of ABC.

	Age										
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11+**
1977	0.007	0.075	0.540	1.000	0.942	0.561	0.339	0.203	0.123	0.088	0.088
1978	0.007	0.073	0.626	0.939	1.000	0.663	0.405	0.233	0.137	0.096	0.096
1979	0.007	0.052	0.384	1.000	0.953	0.656	0.435	0.239	0.134	0.092	0.092
1980	0.007	0.053	0.333	0.891	1.000	0.762	0.593	0.292	0.150	0.102	0.102
1981	0.008	0.057	0.356	0.727	0.947	0.968	1.000	0.367	0.177	0.120	0.120
1982	0.006	0.043	0.216	0.513	1.000	0.910	0.590	0.281	0.150	0.102	0.102
1983	0.006	0.043	0.244	0.546	0.843	1.000	0.651	0.304	0.168	0.114	0.114
1984	0.006	0.047	0.273	0.648	0.896	1.000	0.768	0.393	0.220	0.143	0.143
1985	0.007	0.057	0.470	0.866	0.998	1.000	0.815	0.536	0.326	0.199	0.199
1986	0.007	0.057	0.472	0.853	1.000	0.984	0.907	0.716	0.479	0.267	0.267
1987	0.006	0.055	0.428	0.943	1.000	0.903	0.845	0.702	0.487	0.331	0.331
1988	0.005	0.044	0.357	1.000	0.867	0.681	0.629	0.514	0.374	0.253	0.253
1989	0.006	0.050	0.363	0.999	1.000	0.786	0.683	0.557	0.411	0.300	0.300
1990	0.006	0.047	0.375	1.000	0.960	0.752	0.672	0.549	0.417	0.313	0.313
1991	0.006	0.044	0.268	0.803	1.000	0.899	0.768	0.613	0.466	0.367	0.367
1992	0.006	0.041	0.226	0.699	1.000	0.981	0.849	0.691	0.536	0.432	0.432
1993	0.005	0.035	0.188	0.562	0.898	1.000	0.882	0.741	0.582	0.470	0.470
1994	0.005	0.030	0.165	0.495	0.861	1.000	0.920	0.832	0.660	0.518	0.518
1995	0.005	0.028	0.151	0.497	0.785	0.959	1.000	0.905	0.726	0.578	0.578
1996	0.004	0.025	0.133	0.443	0.722	0.904	1.000	0.961	0.729	0.579	0.579
1997	0.004	0.024	0.135	0.447	0.782	0.900	1.000	0.972	0.775	0.614	0.614
1998	0.003	0.023	0.128	0.480	0.765	0.877	0.995	1.000	0.799	0.616	0.616
1999	0.003	0.020	0.132	0.513	0.675	0.803	0.902	1.000	0.754	0.547	0.547
2000	0.002	0.018	0.165	0.457	0.640	0.778	0.899	1.000	0.693	0.479	0.479
2001	0.002	0.017	0.163	0.478	0.694	0.830	1.000	0.959	0.672	0.459	0.459
2002	0.002	0.018	0.137	0.456	0.658	0.793	1.000	0.867	0.594	0.416	0.416
2003	0.003	0.021	0.187	0.492	0.745	0.872	1.000	0.928	0.605	0.429	0.429
2004	0.003	0.031	0.238	0.614	0.851	0.935	1.000	0.906	0.639	0.450	0.450
2005	0.003	0.041	0.286	0.643	0.840	0.913	1.000	0.814	0.596	0.435	0.435
2006	0.004	0.056	0.484	0.657	0.823	0.891	1.000	0.820	0.631	0.463	0.463
2007	0.004	0.057	0.499	0.717	0.712	0.795	1.000	0.861	0.667	0.467	0.467
2008	0.004	0.050	0.405	0.663	0.705	0.845	1.000	0.928	0.815	0.498	0.498
2009	0.003	0.038	0.269	0.599	0.780	0.843	1.000	0.911	0.755	0.535	0.535
2010	0.003	0.033	0.207	0.620	0.828	0.982	1.000	0.909	0.803	0.578	0.578
2011	0.003	0.028	0.176	0.448	0.768	1.000	0.996	0.888	0.906	0.809	0.809
2012	0.003	0.026	0.172	0.384	0.634	0.922	0.990	0.915	0.948	1.000	1.000
2013	0.002	0.030	0.291	0.610	0.662	0.864	1.000	0.983	0.989	0.952	0.952
2014	0.002	0.027	0.658	0.446	0.668	0.813	0.786	0.920	1.000	0.828	0.828
2015	0.002	0.016	0.151	0.316	0.456	0.627	0.778	1.000	0.882	0.532	0.532
2016	0.001	0.014	0.107	0.331	0.386	0.570	0.785	0.944	1.000	0.504	0.504
2017	0.002	0.016	0.117	0.372	0.549	0.689	0.958	0.975	1.000	0.646	0.646
2018	0.002	0.016	0.132	0.315	0.654	0.812	0.840	1.000	0.884	0.561	0.561
2019	0.002	0.015	0.106	0.328	0.574	0.849	1.000	0.956	0.777	0.482	0.482
2020	0.001	0.012	0.108	0.266	0.390	0.666	0.886	1.000	0.638	0.382	0.382
2021	0.001	0.012	0.108	0.266	0.390	0.666	0.886	1.000	0.638	0.382	0.382
Ave. 2016-2020	0.002	0.015	0.114	0.322	0.511	0.717	0.894	0.975	0.860	0.515	0.515
Survey	0.011	0.107	0.434	0.613	0.585	0.643	0.855	1.000	0.929	0.815	0.815

Table 17.12. Estimated BSAI Atka mackerel begin-year numbers at age in millions, 1977-2021.

					Age						
Year	1	2	3	4	5	6	7	8	9	10	11+
1977	350	560	361	136	107	66	57	47	36	28	90
1978	2,023	259	410	247	87	69	45	40	33	26	86
1979	507	1,497	190	277	159	56	46	31	29	24	82
1980	299	375	1,104	136	188	108	39	33	23	21	78
1981	327	221	277	799	95	130	76	28	24	17	73
1982	209	242	163	202	572	67	92	54	20	18	66
1983	285	155	179	120	146	404	48	66	39	15	62
1984	310	211	115	131	87	105	290	35	49	29	56
1985	497	229	156	83	91	59	70	199	25	35	62
1986	430	368	169	108	54	59	38	47	137	17	70
1987	589	318	270	117	72	35	38	25	31	95	63
1988	471	436	234	192	79	48	24	26	17	22	113
1989	1,190	349	321	167	127	53	33	16	18	12	97
1990	565	881	257	233	116	89	37	23	12	13	80
1991	330	419	651	187	163	82	63	27	17	9	68
1992	515	244	309	471	129	111	56	44	19	12	55
1993	862	382	180	223	323	86	74	38	30	13	47
1994	341	638	281	129	151	206	54	47	25	20	41
1995	336	253	470	201	86	93	124	33	29	16	41
1996	871	249	185	331	127	49	50	66	18	17	35
1997	200	644	182	129	198	66	24	23	31	9	29
1998	310	148	474	130	84	118	38	13	13	18	24
1999	728	229	109	336	82	48	65	20	7	7	26
2000	1,652	539	169	78	217	51	29	38	12	4	21
2001	1,075	1,223	397	120	51	137	31	17	22	7	17
2002	1,207	796	901	279	76	30	77	16	9	13	15
2003	259	893	587	645	184	48	18	44	10	6	19
2004	347	192	659	419	433	117	30	11	27	6	17
2005	468	257	141	471	283	282	76	19	7	18	16
2006	325	347	189	100	318	186	183	48	12	5	24
2007	865	241	255	130	67	207	120	116	32	8	20
2008	739	641	177	174	86	44	135	76	75	21	19
2009	227	547	470	121	114	56	28	83	47	48	27
2010	492	168	401	321	75	67	32	15	47	28	47
2011	348	364	124	281	201	44	38	18	9	28	47
2012	522	258	269	89	192	130	27	23	11	6	48
2013	904	386	190	192	61	124	79	16	14	7	32
2014	616	670	285	137	135	42	86	54	11	10	27
2015	173	457	495	198	97	94	29	59	36	8	25
2016	428	128	337	351	134	63	58	17	33	21	21
2017	283	317	95	242	236	89	40	34	10	18	27
2018	564	209	234	68	161	150	54	22	19	5	28
2019	360	418	154	166	45	97	85	31	12	11	20
2020	423	266	308	111	111	28	55	47	17	7	20
2021	447	313	196	218	73	70	16	28	23	10	17
Average	562	421	313	222	148	97	62	40	26	18	44

Table 17.13a. Estimates of Atka mackerel biomass in metric tons with approximate lower and upper 95% confidence bounds for age 1+ biomass and female spawning biomass (labeled as LCI and UCI; computed for period 1977-2022).

	Age 1+ biomass (t)			Female spawning biomass (t)		
Year	Estimate	LCI	UCI	Estimate	LCI	UCI
1977	704,315	487,332	1,017,910	179,048	120,780	265,427
Valu es				181,731	119,749	275,797
1978	786,605	537,859	1,150,390			
1979	861,068	581,017	1,276,100	191,783	123,738	297,249
1980	1,026,170	687,154	1,532,460	222,642	144,412	343,250
1981	961,214	641,501	1,440,270	278,422	181,759	426,491
1982	907,060	602,929	1,364,600	306,112	198,689	471,614
1983	795,038	528,690	1,195,570	275,930	179,234	424,794
1984	711,723	476,062	1,064,040	240,462	155,078	372,856
1985	640,036	427,071	959,201	202,268	128,241	319,027
1986	584,692	390,180	876,172	169,387	105,801	271,186
1987	572,777	386,645	848,513	151,720	95,038	242,206
1988	583,120	401,200	847,531	150,512	95,750	236,595
1989	645,376	460,930	903,629	156,934	102,548	240,164
1990	716,732	532,354	964,969	168,672	114,268	248,979
1991	814,960	623,346	1,065,470	190,228	134,781	268,486
1992	796,303	616,251	1,028,960	216,050	158,710	294,106
1993	780,620	609,309	1,000,100	218,587	161,227	296,354
1994	746,590	584,174	954,163	190,761	138,853	262,073
1995	718,285	559,977	921,346	168,911	120,889	236,010
1996	640,234	489,417	837,527	149,778	103,602	216,536
1997	563,965	417,238	762,291	133,006	89,542	197,568
1998	561,499	412,434	764,442	122,843	81,398	185,390
1999	508,271	366,281	705,305	127,471	84,548	192,183
2000	578,937	421,598	794,994	123,495	80,760	188,843
2001	725,256	539,515	974,941	115,105	74,056	178,907
2002	933,549	706,542	1,233,490	148,831	100,450	220,515
2003	1,019,980	778,972	1,335,550	213,798	151,159	302,395
2004	1,036,650	793,025	1,355,110	265,870	192,228	367,722
2005	908,751	688,778	1,198,980	275,686	200,350	379,352
2006	809,863	606,897	1,080,710	249,185	178,463	347,934
2007	730,150	540,919	985,580	207,979	145,879	296,515
2008	702,001	517,394	952,476	178,556	122,728	259,779
2009	709,073	519,786	967,291	157,100	105,125	234,773
2010	658,975	473,355	917,385	154,911	102,122	234,988
2011	585,146	410,685	833,721	159,664	104,784	243,286
2012	573,644	401,828	818,926	149,231	96,346	231,144
2013	565,554	396,372	806,946	143,182	93,044	220,337
2014	637,114	456,956	888,302	148,613	98,736	223,686
2015	689,994	501,038	950,211	153,318	102,419	229,512
2016	653,847	468,383	912,747	167,030	112,320	248,389
2017	586,897	411,669	836,712	166,154	109,917	251,164
2018	543,030	368,971	799,199	140,553	88,162	224,076
2019	489,195	319,045	750,087	118,736	70,199	200,834
2020	490,993	311,526	773,848	109,326	61,305	194,965
2021	553,233	287,901	757,626	113,529	55,982	195,220
2022	554,486	277,510	772,385	109,358	52,943	197,754

Table 17.13b. Estimates of Atka mackerel age 3+ biomass and female spawning biomass in metric tons from the current recommended assessment model, Model 16.0b (1977-2022) compared to last year's (2020) assessment results.

	Age 3+ biomass (t)		Female spawning biomass (t)	
Year	Current	2020	Current	2020
1977	590,216	570,710	179,048	169,746
1978	635,185	628,310	181,731	175,673
1979	578,960	576,890	191,783	189,492
1980	946,379	958,600	222,642	223,495
1981	906,178	920,610	278,422	282,113
1982	854,731	870,590	306,112	311,707
1983	753,483	768,580	275,930	281,459
1984	659,280	672,990	240,462	245,658
1985	574,580	587,430	202,268	207,040
1986	499,195	511,220	169,387	173,734
1987	487,347	499,640	151,720	155,805
1988	483,822	496,150	150,512	154,669
1989	522,874	535,970	156,934	161,220
1990	536,501	549,360	168,672	173,081
1991	726,107	741,730	190,228	194,926
1992	727,344	742,060	216,050	221,099
1993	669,875	683,280	218,587	223,655
1994	619,715	632,220	190,761	195,349
1995	657,406	670,480	168,911	173,271
1996	551,678	563,720	149,778	154,109
1997	443,523	454,900	133,006	137,148
1998	519,839	533,110	122,843	126,898
1999	430,651	442,710	127,471	131,735
2000	399,573	411,490	123,495	127,801
2001	459,762	473,560	115,105	119,414
2002	733,873	755,220	148,831	154,160
2003	853,934	878,510	213,798	220,997
2004	985,550	1,014,000	265,870	274,681
2005	840,104	865,710	275,686	285,030
2006	733,522	757,470	249,185	258,229
2007	643,250	665,870	207,979	216,172
2008	553,592	574,400	178,556	186,205
2009	603,722	627,320	157,100	164,588
2010	604,181	630,010	154,911	162,905
2011	504,579	528,460	159,664	168,236
2012	502,068	526,580	149,231	157,716
2013	451,773	473,690	143,182	151,209
2014	490,284	510,490	148,613	156,092
2015	602,955	611,580	153,318	159,154
2016	609,287	612,160	167,030	170,133
2017	517,907	517,900	166,154	166,971
2018	477,427	492,130	140,553	141,957
2019	398,904	425,790	118,736	123,350
2020	423,148	414,250	109,326	116,934
2021	389,897	395,400	113,529	107,831
2022	382,867		109,358	

Table 17.14. Estimates of age-1 Atka mackerel recruitment (millions of recruits) and standard deviation (Std. dev.). Estimates of age-1 recruitment from last year's assessment (2020) are shown for comparison.

Year	Current	Std.dev	2020 assessment
1977	350	91	356
1978	2,023	446	2,073
1979	507	125	518
1980	299	78	305
1981	327	83	334
1982	209	57	214
1983	285	73	291
1984	310	77	317
1985	497	115	508
1986	430	106	438
1987	589	135	601
1988	471	112	479
1989	1,190	202	1,210
1990	565	123	572
1991	330	82	333
1992	515	104	522
1993	862	137	874
1994	341	72	346
1995	336	66	342
1996	871	130	888
1997	200	43	204
1998	310	60	317
1999	728	117	745
2000	1,652	220	1,692
2001	1,075	144	1,100
2002	1,207	150	1,235
2003	259	46	265
2004	347	56	356
2005	468	70	481
2006	325	53	335
2007	865	122	893
2008	739	112	766
2009	227	43	235
2010	492	81	511
2011	348	60	356
2012	522	84	530
2013	904	131	872
2014	616	101	603
2015	173	39	171
2016	428	99	492
2017	283	78	342
2018	564	157	424
2019	360	137	422
2020	423	178	447
2021	447	192	
Average 78-20	569		580
Median 78-20	468		479

Table 17.15. Estimates of full-selection fishing mortality rates and exploitation rates (Catch/Biomass) for BSAI Atka mackerel.

Year	*F*	Catch/Biomass Rate[a]
1977	0.150	0.037
1978	0.147	0.038
1979	0.091	0.040
1980	0.068	0.022
1981	0.048	0.022
1982	0.048	0.023
1983	0.030	0.016
1984	0.103	0.055
1985	0.135	0.066
1986	0.135	0.064
1987	0.103	0.062
1988	0.109	0.046
1989	0.062	0.034
1990	0.055	0.041
1991	0.086	0.037
1992	0.111	0.067
1993	0.167	0.099
1994	0.209	0.105
1995	0.327	0.124
1996	0.479	0.188
1997	0.280	0.148
1998	0.338	0.110
1999	0.265	0.131
2000	0.254	0.118
2001	0.328	0.134
2002	0.252	0.062
2003	0.201	0.063
2004	0.150	0.061
2005	0.146	0.074
2006	0.157	0.084
2007	0.157	0.091
2008	0.192	0.105
2009	0.298	0.121
2010	0.274	0.114
2011	0.180	0.103
2012	0.211	0.095
2013	0.084	0.051
2014	0.098	0.063
2015	0.285	0.088
2016	0.289	0.089
2017	0.288	0.124
2018	0.323	0.147
2019	0.303	0.143
2020	0.427	0.139
2021	0.502	0.160

[a]Catch/Biomass rate is the ratio of catch to beginning year age 3+ biomass.

Table 17.16. Projections of female spawning biomass in metric tons, full-selection fishing mortality rates (F) and catch in metric tons for Atka mackerel for the 7 scenarios. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 278,674 t, 111,469 t, and 97,536 t, respectively.

Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2021	62,257	62,257	62,257	62,257	62,257	62,257	62,257
2022	66,739	66,739	66,739	66,739	66,739	91,871	78,510
2023	61,318	61,318	61,318	61,318	61,318	73,592	67,468
2024	74,211	74,211	66,374	20,019	0	73,073	80,367
2025	76,062	76,062	69,269	23,832	0	80,101	82,724
2026	80,162	80,162	73,157	27,431	0	86,604	87,402
2027	83,694	83,694	76,536	30,428	0	90,660	90,843
2028	86,311	86,311	79,269	32,965	0	93,165	93,191
2029	87,237	87,237	80,664	34,643	0	93,705	93,706
2030	86,881	86,881	80,835	35,501	0	92,926	92,930
2031	86,412	86,412	80,563	35,847	0	92,215	92,219
2032	85,795	85,795	80,192	36,028	0	91,568	91,571
2033	85,541	85,541	80,039	36,135	0	91,419	91,420
2034	85,885	85,885	80,256	36,264	0	91,872	91,873
Fishing M.	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2021	0.394	0.394	0.394	0.394	0.394	0.394	0.394
2022	0.446	0.446	0.446	0.446	0.446	0.646	0.538
2023	0.423	0.423	0.423	0.423	0.423	0.572	0.492
2024	0.512	0.512	0.453	0.125	0.000	0.569	0.595
2025	0.511	0.511	0.453	0.125	0.000	0.590	0.599
2026	0.515	0.515	0.453	0.125	0.000	0.606	0.609
2027	0.520	0.520	0.453	0.125	0.000	0.616	0.616
2028	0.524	0.524	0.453	0.125	0.000	0.621	0.621
2029	0.524	0.524	0.453	0.125	0.000	0.620	0.620
2030	0.523	0.523	0.453	0.125	0.000	0.618	0.618
2031	0.523	0.523	0.453	0.125	0.000	0.616	0.616
2032	0.522	0.522	0.453	0.125	0.000	0.615	0.615
2033	0.521	0.521	0.453	0.125	0.000	0.614	0.614
2034	0.521	0.521	0.453	0.125	0.000	0.614	0.614
Spawning biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2021	113,529	113,529	113,529	113,529	113,529	113,529	113,529
2022	109,358	109,358	109,358	109,358	109,358	102,758	106,290
2023	103,327	103,327	103,327	103,327	103,327	91,521	97,674
2024	102,254	102,254	104,151	115,342	120,020	91,302	95,317
2025	106,016	106,016	110,212	137,361	150,258	96,621	98,131
2026	111,234	111,234	117,399	158,152	179,643	101,722	102,221
2027	114,045	114,045	121,814	173,443	203,137	103,934	104,091
2028	116,010	116,010	125,043	185,540	223,048	105,316	105,374
2029	116,807	116,807	126,701	193,988	238,417	105,738	105,766
2030	116,235	116,235	126,594	198,811	249,037	105,016	105,031
2031	115,428	115,428	125,957	201,382	256,097	104,273	104,281
2032	115,004	115,004	125,588	203,322	261,645	103,917	103,921
2033	114,876	114,876	125,395	204,526	265,526	103,866	103,867
2034	115,555	115,555	126,027	206,101	269,097	104,567	104,567

Table 17.17. Ecosystem effects. *Note: this table has not been updated; it will be updated in the final version.*

Ecosystem effects on Atka mackerel			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Zooplankton	Data limited, Copepod Community Size index has declined, negative anomalies since 2012, bias towards smaller species	Trends could affect nutritional quality of prey, influence availability of prey	Unknown
Predator population trends			
Marine mammals	Northern fur seals: Pribilof Island rookeries declining, Bogoslof breeding rookery increasing. Steller sea lions remain below their long-term mean in the WAI and CA AI, non-pup counts in the EAI remain high.	Mixed potential impact, possibly increased or decreased mortality on Atka mackerel depending on region	No concern
Birds	Some increasing some decreasing. Many seabirds did poorly in 2018 at Buldir.	Affects young-of-year mortality	No concern
Fish (Pacific cod, arrowtooth flounder)	Variable, arrowtooth abundance increasing	Possible changes in predation on Atka mackerel	No concern
Changes in habitat quality			
Temperature regime	2016 AI summer bottom trawl survey temperature was highest in the time series. 2014, 2016, and 2018 3 highest in time series	Could possibly affect vertical and broad scale distribution of Atka mackerel. Could possibly affect nesting sites and habitat.	Unknown
***The Atka mackerel* effects on ecosystem**			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	Variable, heavily monitored. See Table 17.18	Likely to be a minor contribution to mortality	Unknown
Forage (including herring, Atka mackerel, cod, and pollock)	Stable, heavily monitored	Bycatch levels small relative to forage biomass	Unknown
HAPC biota (seapens/whips, corals, sponges, anemones)	Low bycatch levels of seapens/whips, sponge and coral catches are variable	Unknown	Possible concern for sponges and corals
Marine mammals and birds	Very minor direct-take	Likely to be very minor contribution to mortality	No concern
Fishery concentration in space and time	Steller sea lion protection measures spread out Atka mackerel catches in time and space. Western Aleutians (WAI) closed to directed Atka mackerel fishery (2011-2014); Atka mackerel TAC reduced in Central Aleutians (≤47% CAI ABC). WAI opened to directed fishing 2015; WAI TAC reduced to ≤65% WAI ABC. Fishery has become highly concentrated in areas outside of critical habitat	Mixed potential impact (fur seals vs Steller sea lions). Areas outside of critical habitat may be experiencing higher exploitation rates.	Possible concern
Fishery effects on amount of large size target fish	Depends on highly variable year-class strength	Natural fluctuation (environmental)	Probably no concern
Fishery contribution to discards and offal production	Offal production—unknown From 2016-2017, the Atka mackerel fishery contributed an average of 318 and 421 t of the total AI trawl non-target and Atka mackerel discards, respectively.	The Atka mackerel fishery is one of the few trawl fisheries operating in the AI. Numbers and rates should be interpreted in this context.	Unknown
Fishery effects on age-at-maturity and fecundity	Unknown	Unknown	Unknown

Table 17.18. Prohibited species catch in the Atka mackerel fishery, 2015-2020. Estimates are reported in metric tons for halibut and herring, and counts of fish for crab and salmon.

Species group name	2015	2016	2017	2018	2019	2020
Bairdi Tanner Crab	254	0	44	0	0	0
Blue King Crab	0	0	0	0	0	0
Chinook Salmon	136	535	1,109	652	432	680
Golden (Brown) King Crab	1,321	2,898	1,409	7,074	14,237	2,107
Halibut	126	121	171	203	110	69
Herring	0	0	0	0	0	0
Non-Chinook Salmon	1,687	1,162	1,611	1,506	3,640	1,194
Opilio Tanner (Snow) Crab	38	0	0	0	40	9
Red King Crab	4,956	348	239	239	149	131
Grand Total Halibut and Herring (t)	126	121	171	203	110	69
Grand Total Numbers of Crab and Salmon	8,392	4,943	4,94	9,472	18,598	4,121

Figures

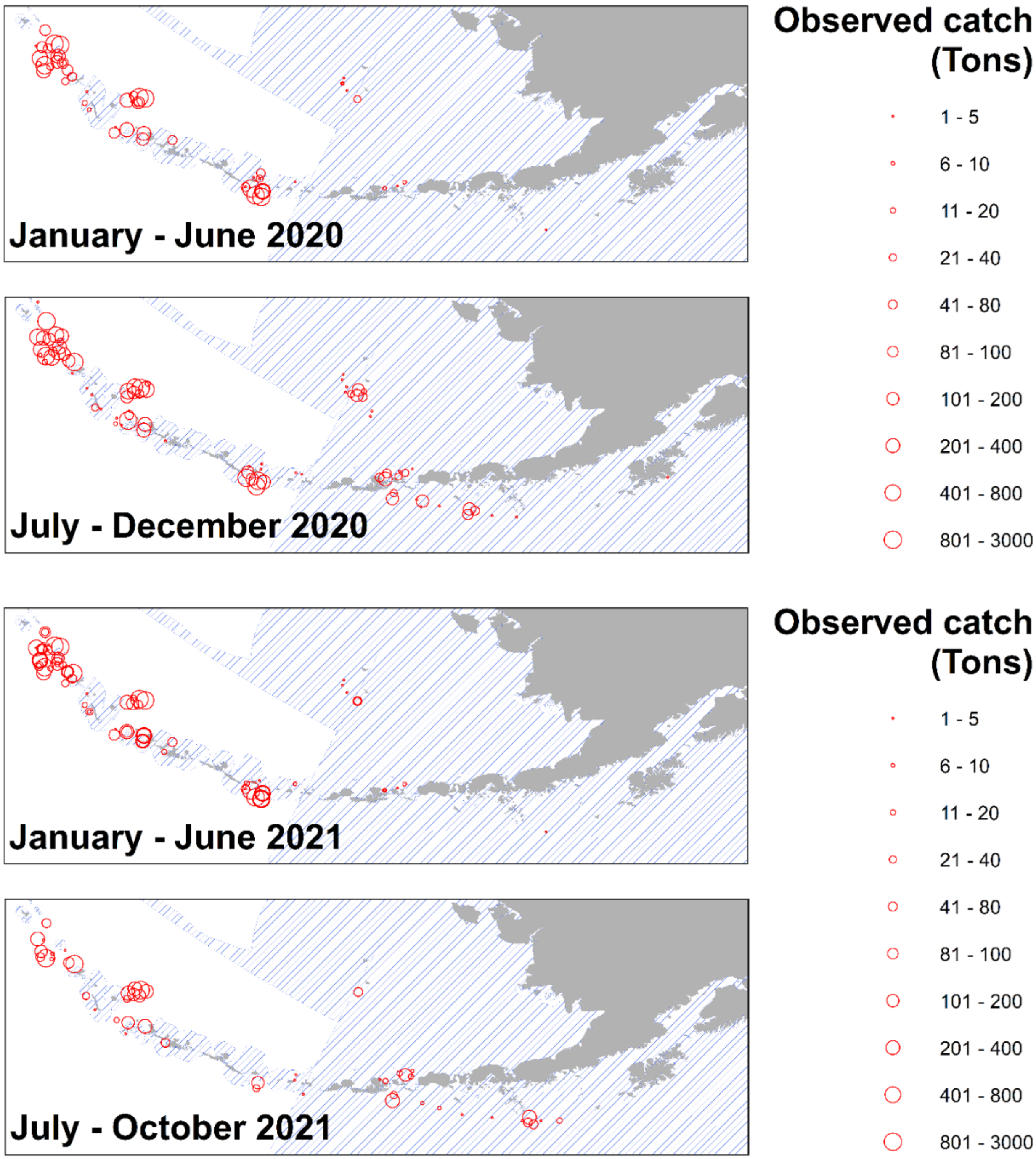


Figure 17.1. Observed catches of Atka mackerel summed for 20 km^2 cells for 2020 and 2021 where observed catch per haul was greater than 1 t. Shaded areas represent areas closed to directed Atka mackerel fishing.

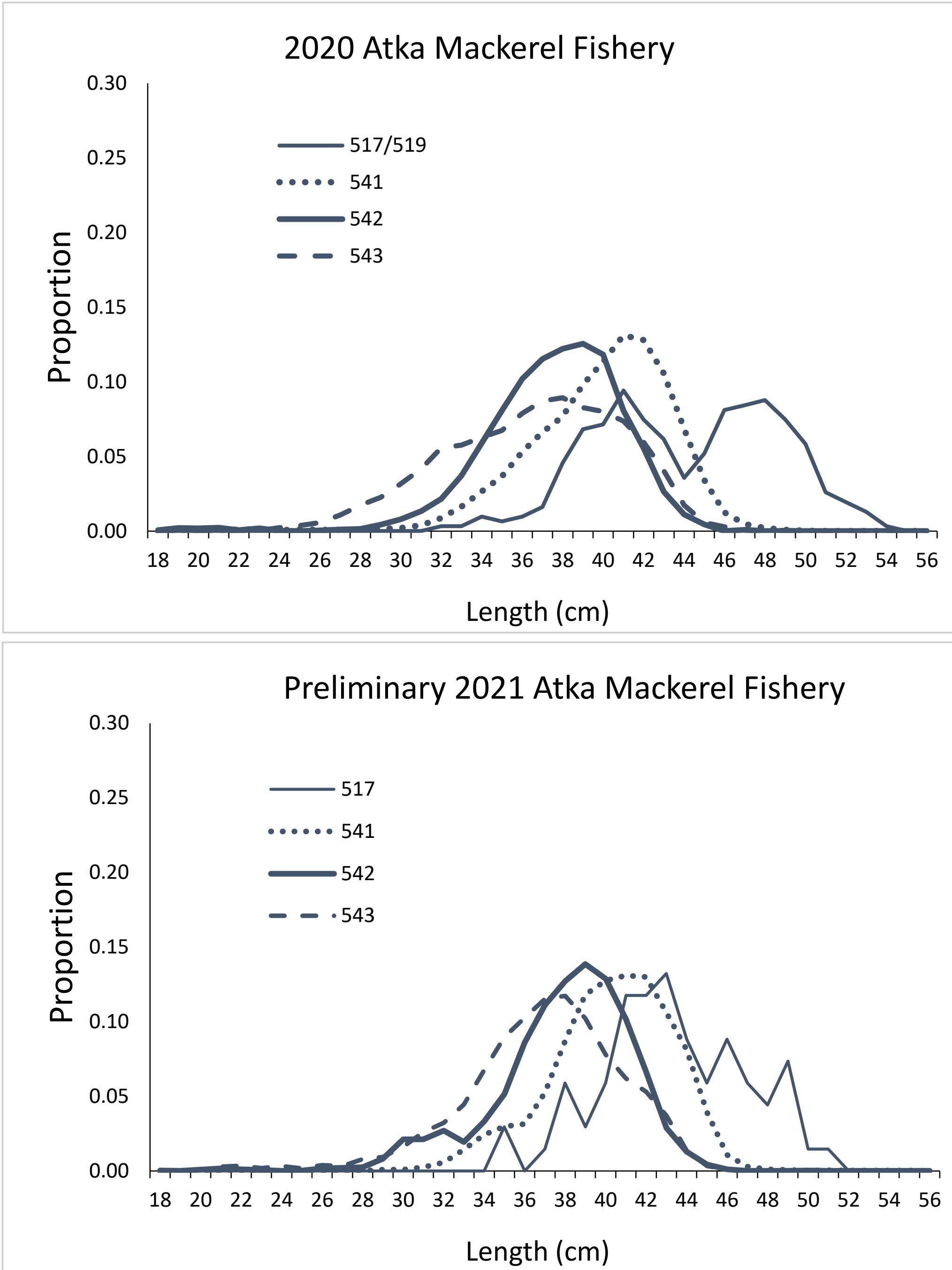


Figure 17.2 2020 and preliminary 2021 Atka mackerel fishery length-frequency data by area fished (see Figure 17.1). Numbers refer to management areas.

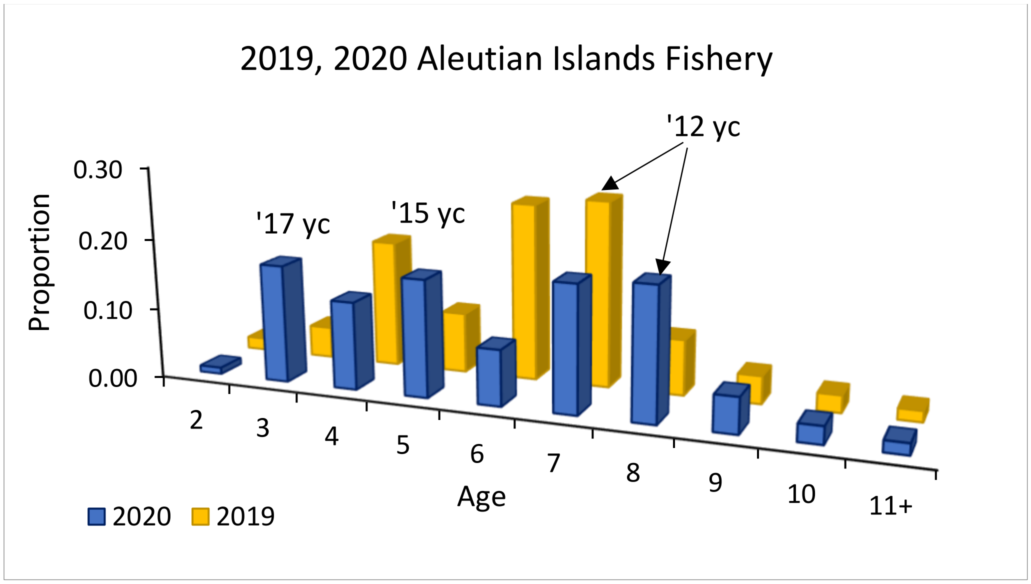


Figure 17.3. Atka mackerel age distributions from the 2019 and 2020 Aleutian Islands fisheries. A total of 1,510 and 2,111otoliths were aged from the 2019 and 2020 fisheries, respectively; mean age from the 2019 fishery is 6.1 years, and mean age from the 2020 fishery is 5.9 years.

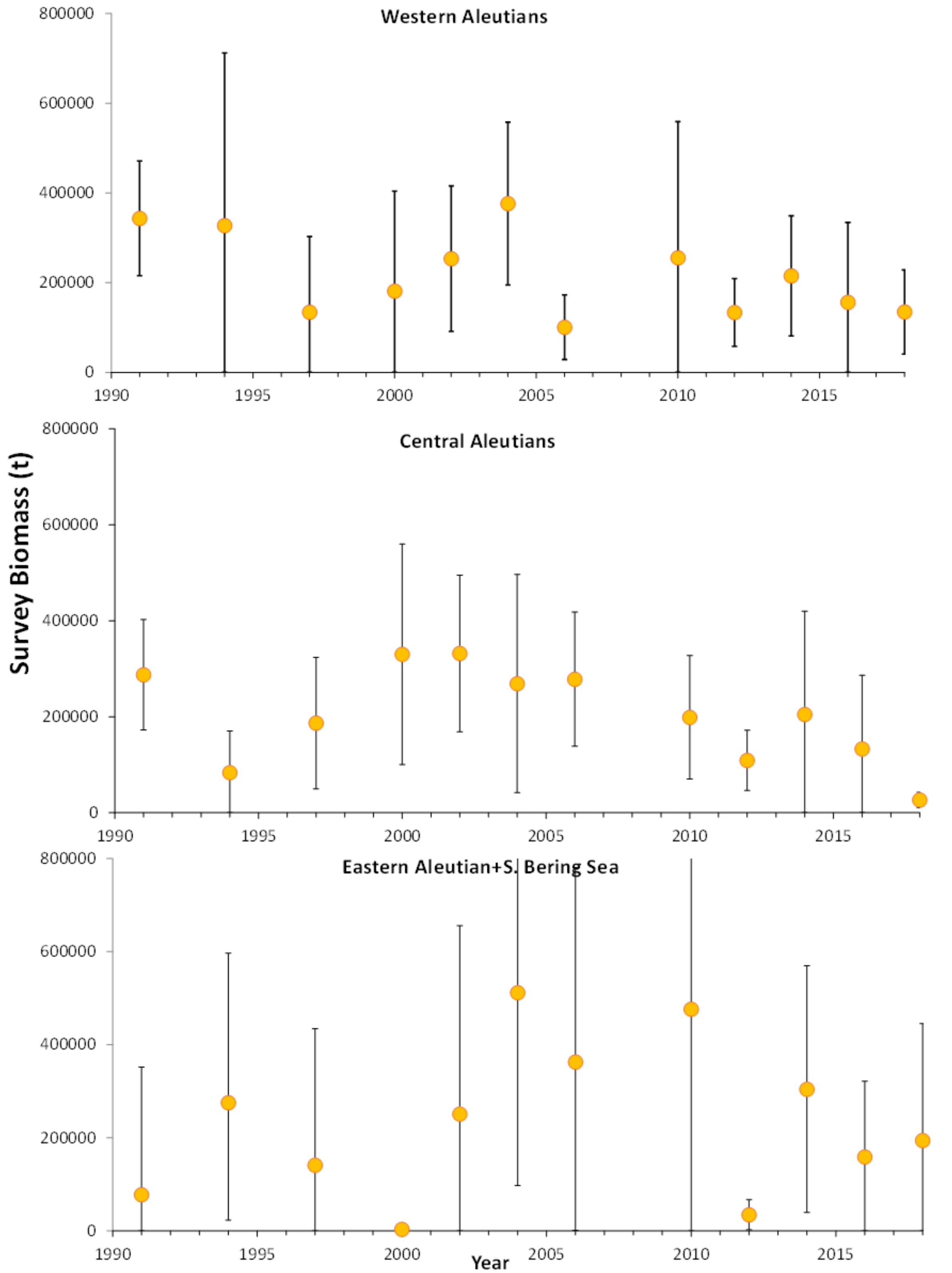


Figure 17.4. Atka mackerel Aleutian Islands survey biomass estimates by area and survey year. Bars represent ±2 standard errors.

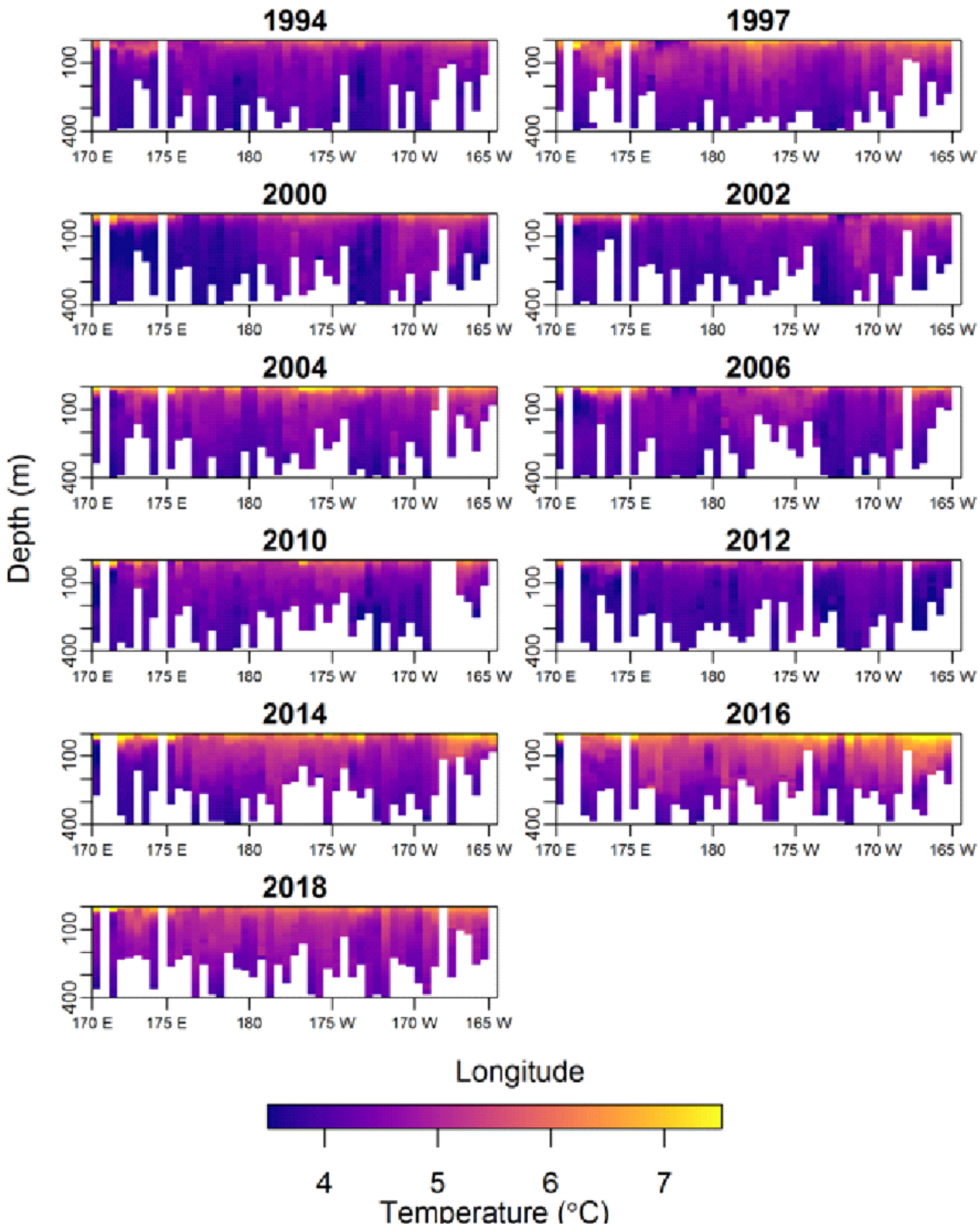


Figure 17.5. Median-survey-date-standardized, generalized additive model (GAM) predicted thermal (°C) anomaly profiles from water temperature measurements collected on Aleutian Islands bottom trawl surveys (1994-2018); to visually enhance near-surface temperature changes, values ≤ 3.5°C or ≥ 7.5°C were fixed at 3.5 or 7.5°C and the y-axis (depth) was truncated at 400 m though maximum collection depth was ca. 500 m. (Laman 2018).

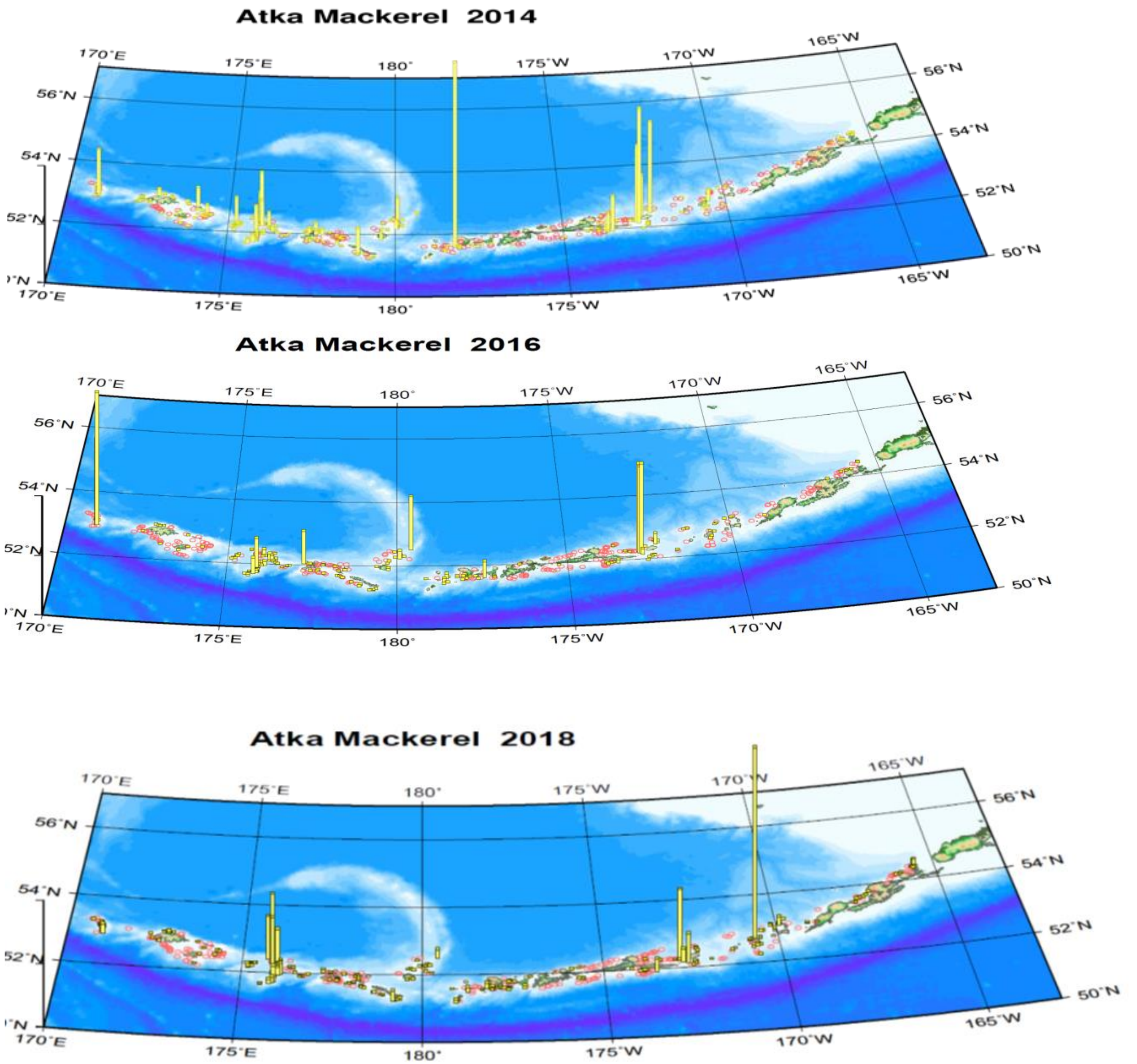
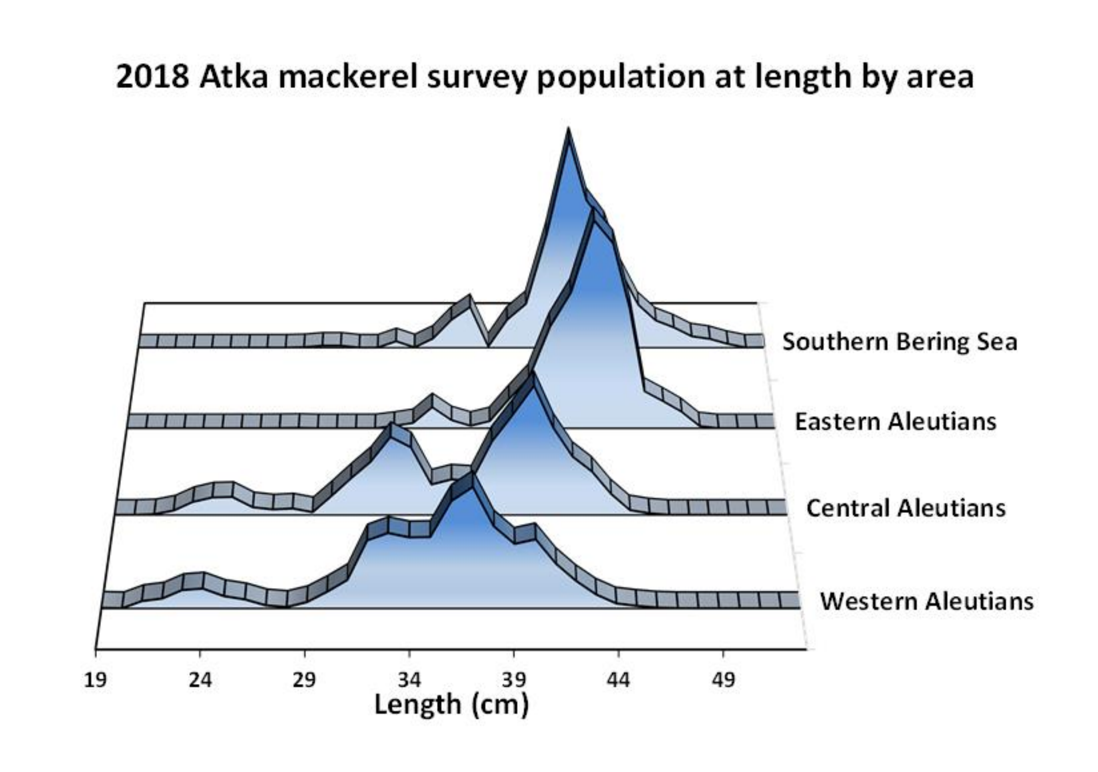


Figure 17.6. Bottom-trawl survey CPUE distributions of Atka mackerel catches during the summers of 2014, 2016, and 2018.



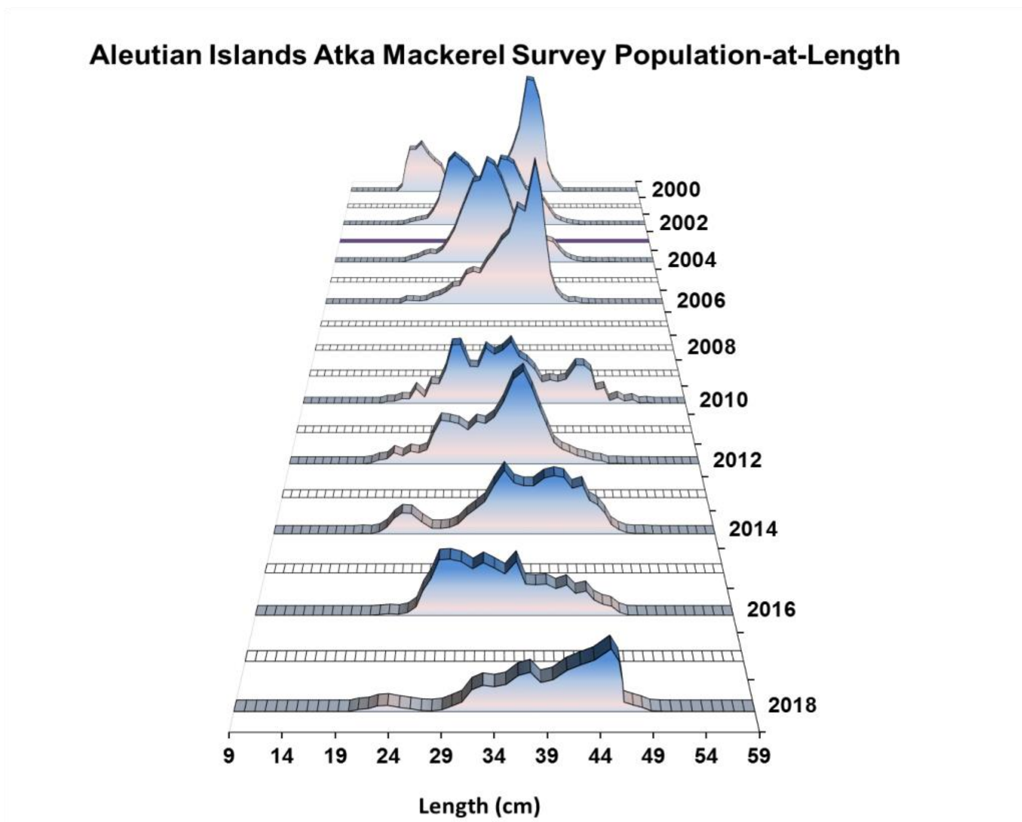


Figure 17.7. Atka mackerel bottom trawl survey length frequency data by subarea in 2018 (top) and for all areas, 2000-2018 (bottom). Vertical scales are proportional for a given area or year.

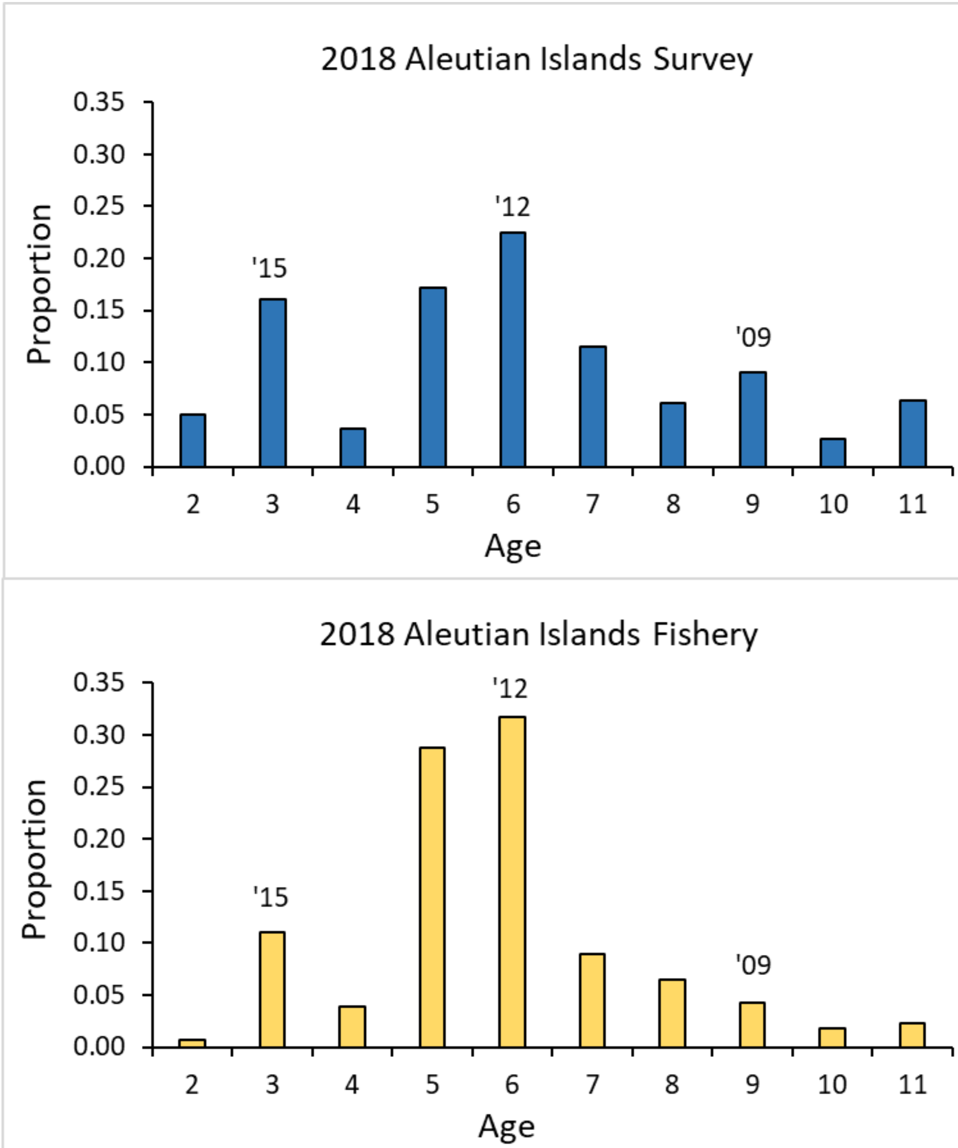


Figure 17.8. Atka mackerel age distributions from the 2018 Aleutian Islands bottom trawl survey (top) and the 2018 Aleutian Islands fishery (bottom). A total of 1,052 otoliths were aged from the survey; mean age from the 2018 survey is 6 years. A total of 1,581 otoliths were aged from the fishery; mean age from the 2018 fishery is 5.8 years.

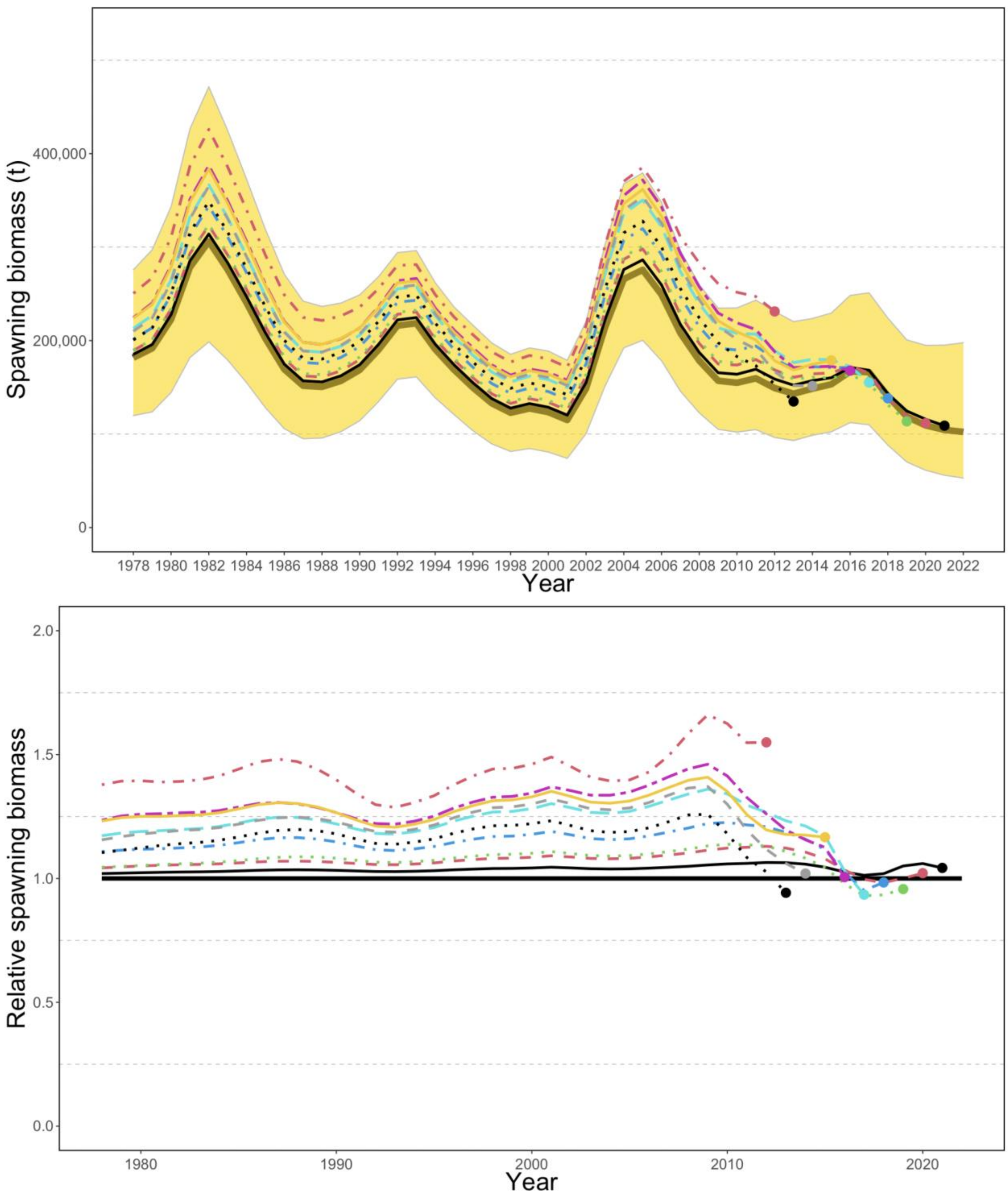


Figure 17.9. Retrospective plots showing the BSAI Atka mackerel spawning biomass over time (top) and the relative difference (bottom) over 10 different "peels". Mohn's rho was 0.062.

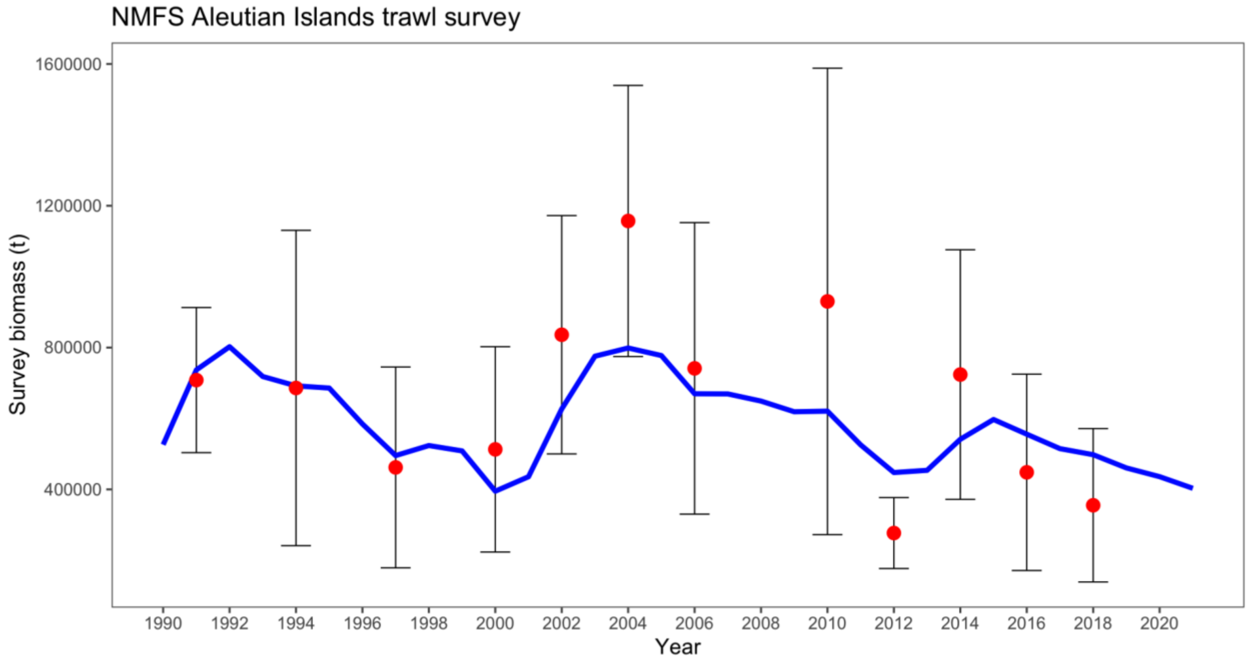


Figure 17.10. Observed (dots) and predicted (trend line) survey biomass estimates (t) for Bering Sea/Aleutian Islands Atka mackerel. Error bars represent two standard errors (based on sampling) from the survey estimates.

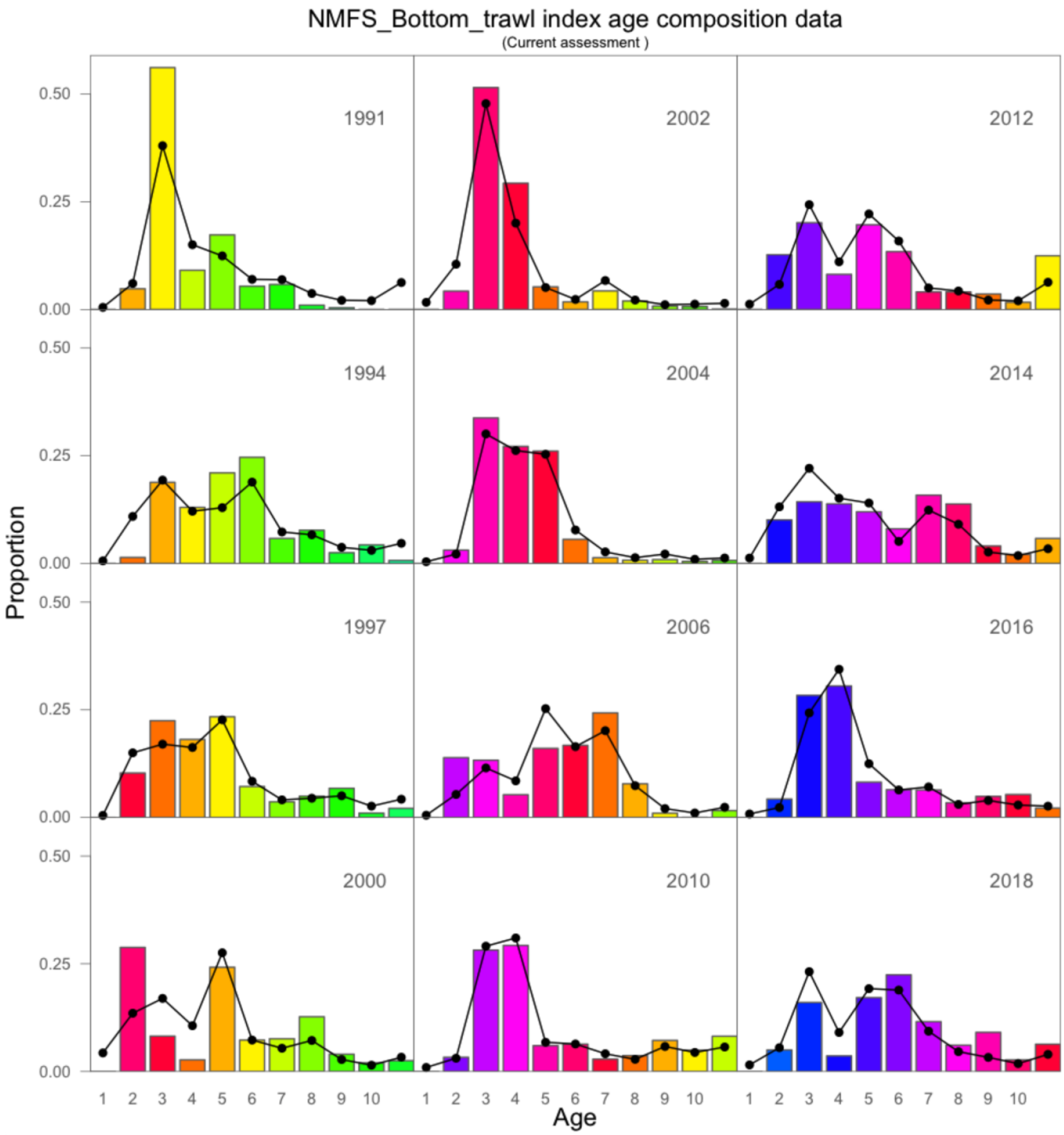


Figure 17.11. Observed and predicted **survey** proportions-at-age for BSAI Atka mackerel. Lines with "●" symbol are the model predictions and columns are the observed proportions at age.

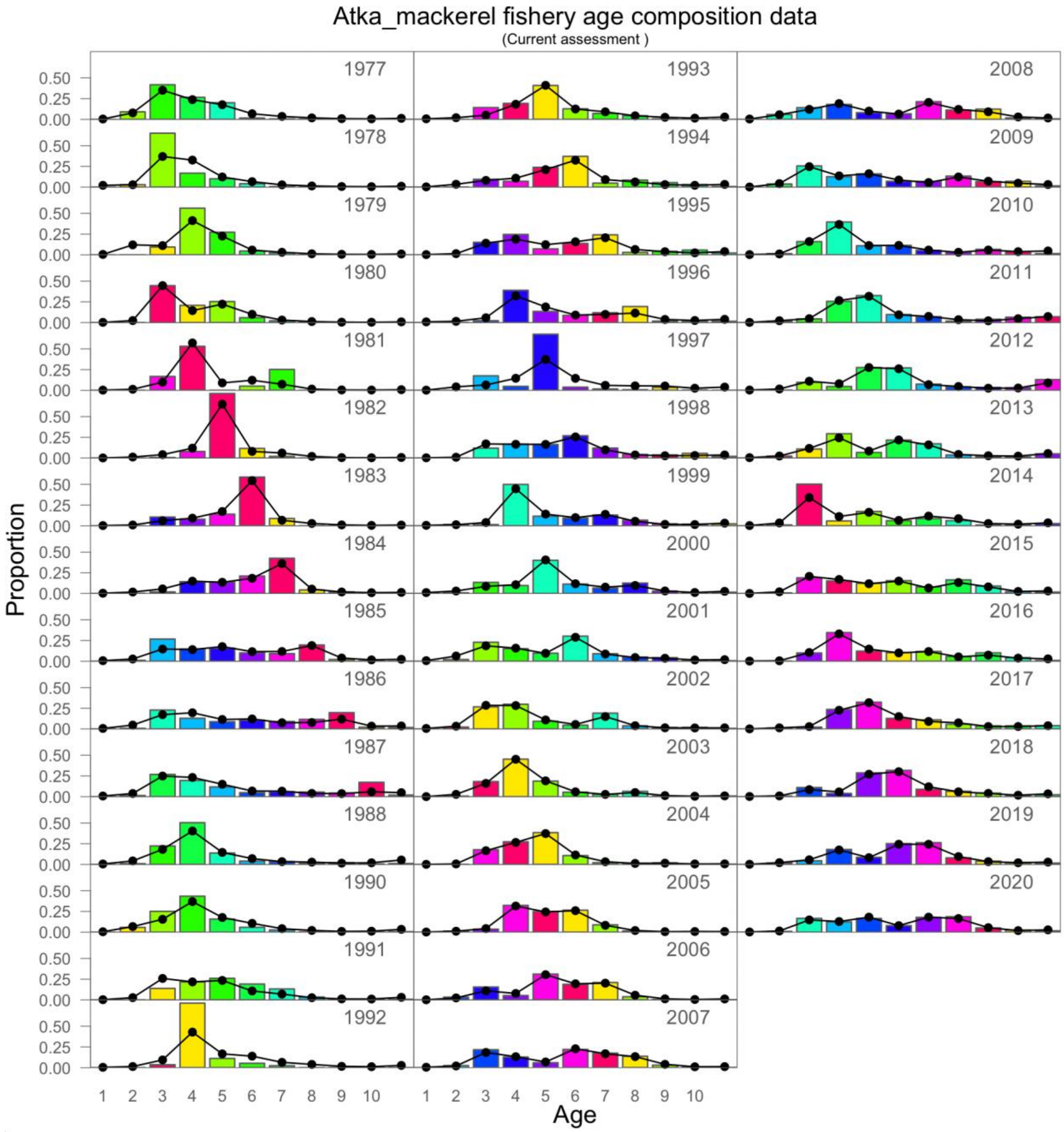


Figure 17.12. Observed and predicted Atka mackerel **fishery** proportions-at-age for BSAI Atka mackerel. Lines with "●" symbol are the model predictions and columns are the observed proportions at age (with colors corresponding to cohorts).

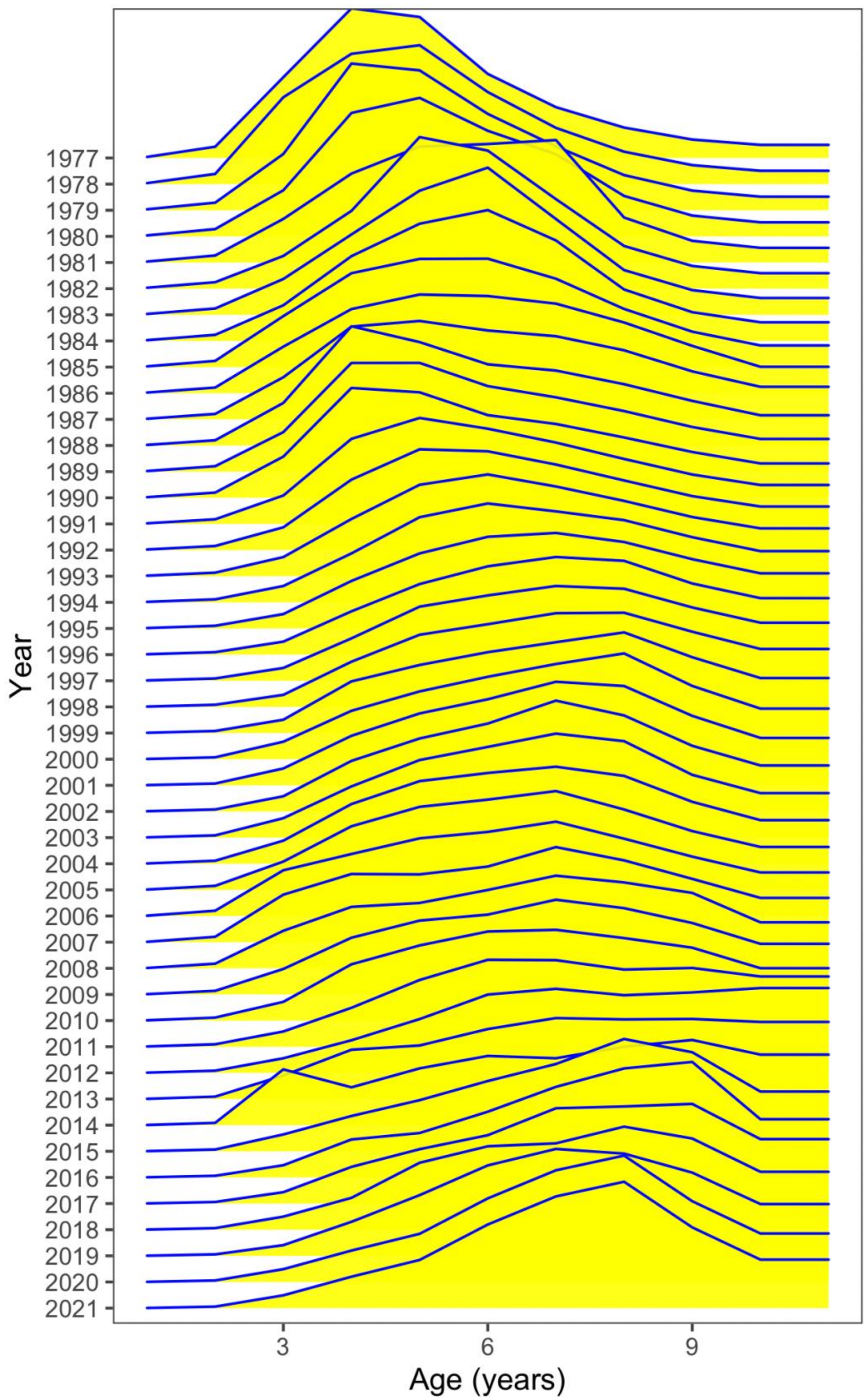


Figure 17.13. Fishery selectivity estimates over time for BSAI Atka mackerel.

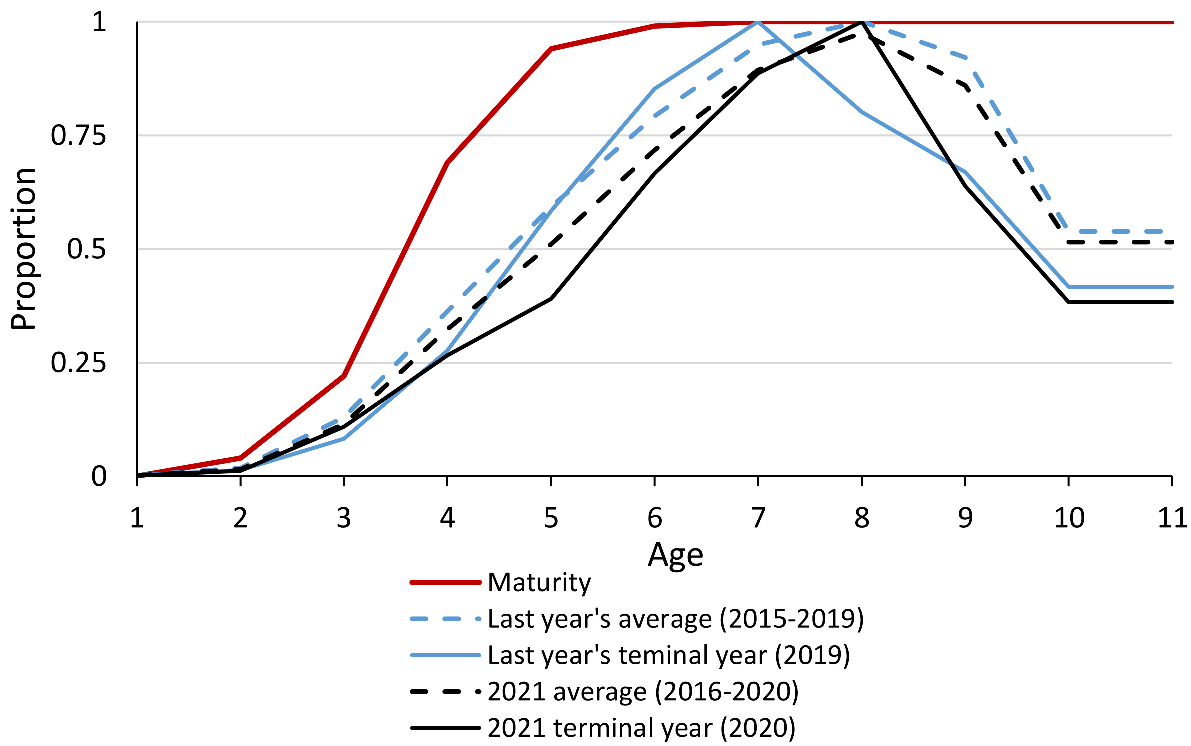


Figure 17.14. Estimated fishery selectivity patterns in the current assessment with a) last year's average for projections (2015-2019), b) the 2021 assessment average selectivity used for projections (2016-2020), c) last year's assessment terminal year (2019), and d) the 2021 assessment terminal year (2020) compared with the maturity-at-age estimates for BSAI Atka mackerel.

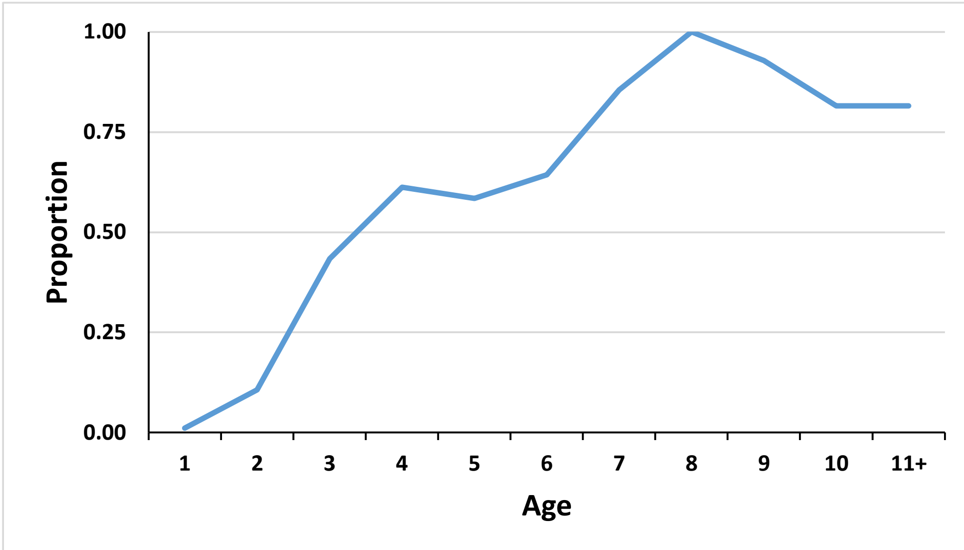


Figure 17.15. Estimated BSAI Atka mackerel survey selectivity-at-age (Model 16.0b). Selectivity estimates have been normalized to a maximum value of 1.0 for presentation.

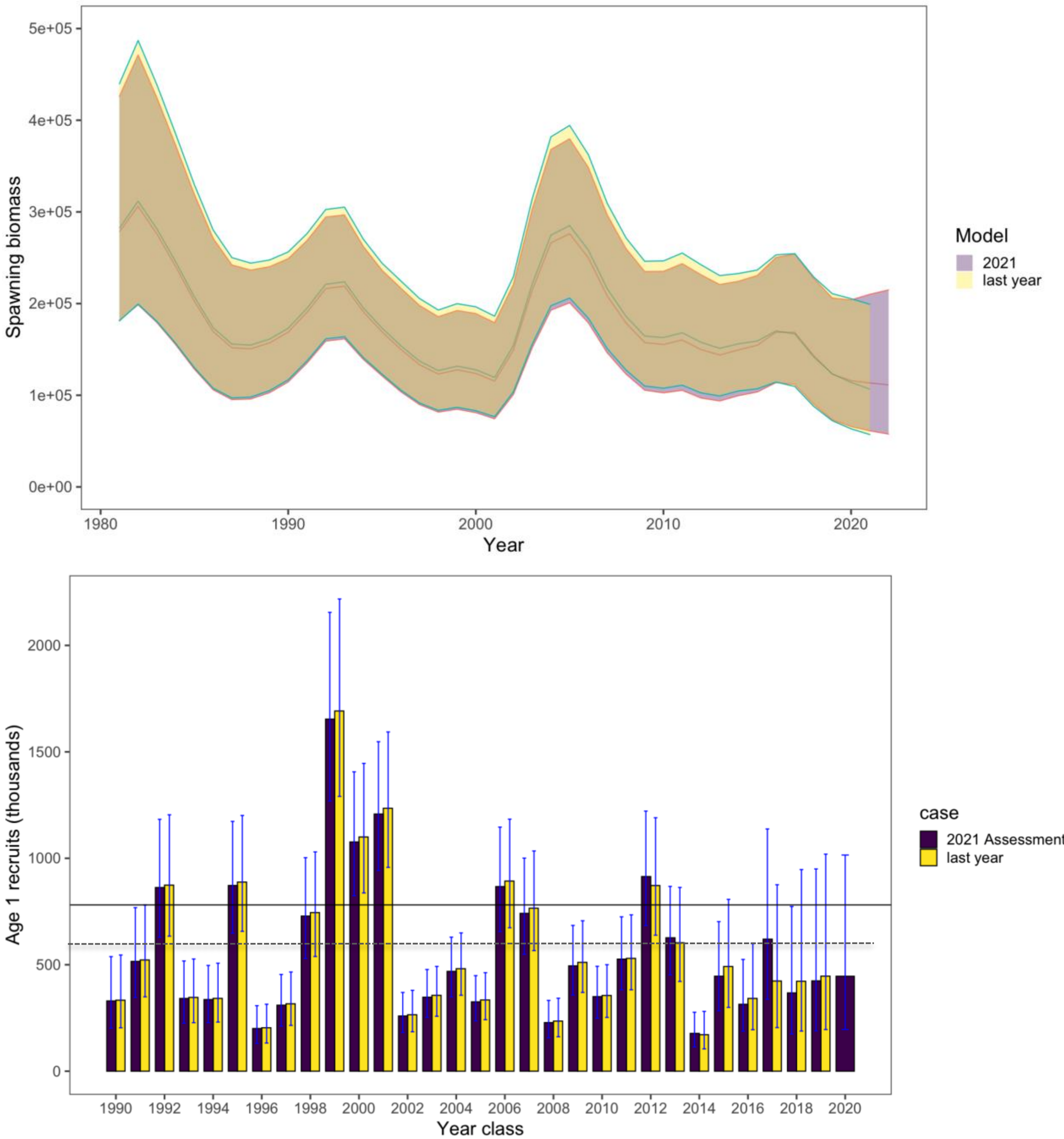


Figure 17.16. Time series of estimated Aleutian Islands Atka mackerel spawning biomass with approximate 95% confidence bounds (in t top), and recruitment at age 1 (thousands, bottom) from the current assessment (Model 16.0b) compared to last year's 2020 assessment results (Model 16.0b). Dashed line represents average recruitment over the time series from the current assessment (1978-2020, 569 million recruits).

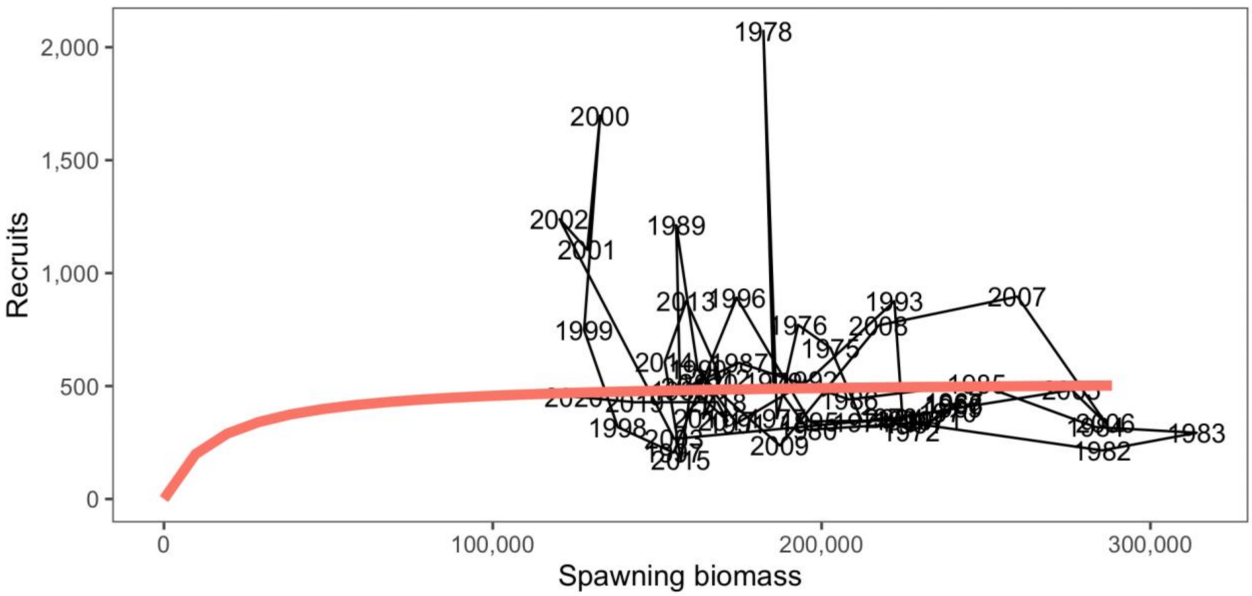


Figure 17.17 Estimated age 1 recruits (millions) versus female spawning biomass (t) for BSAI Atka mackerel. Solid line indicates Beverton-Holt stock recruitment curve (with steepness *h*=0.8).

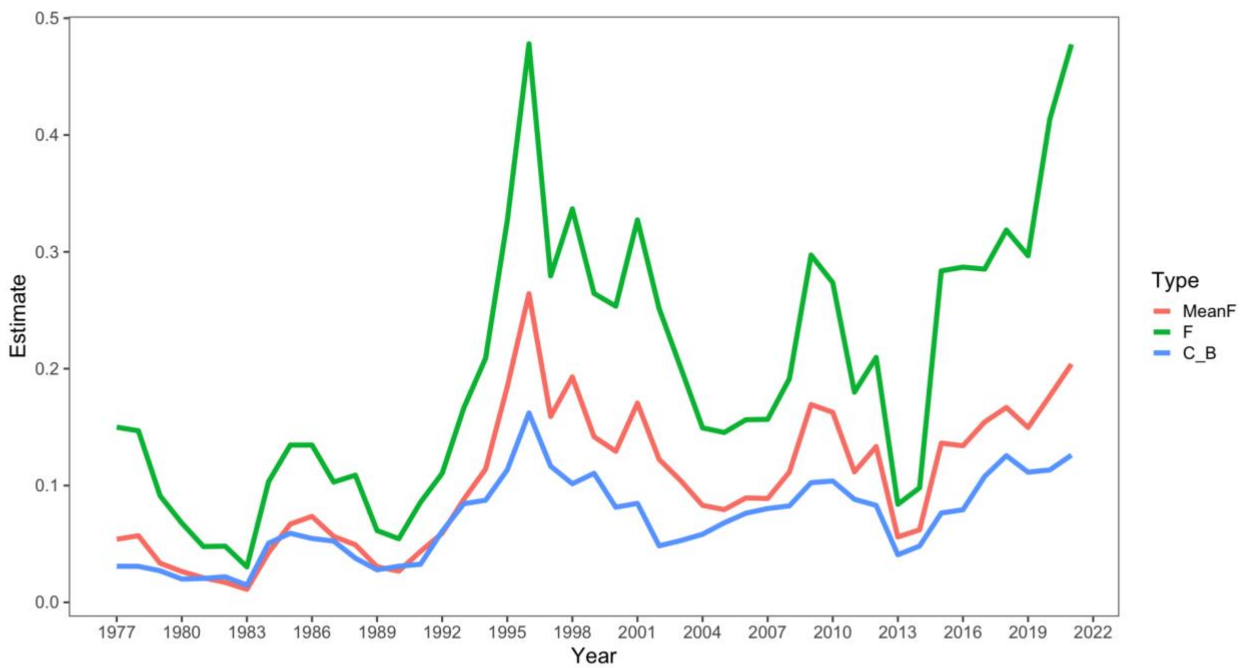
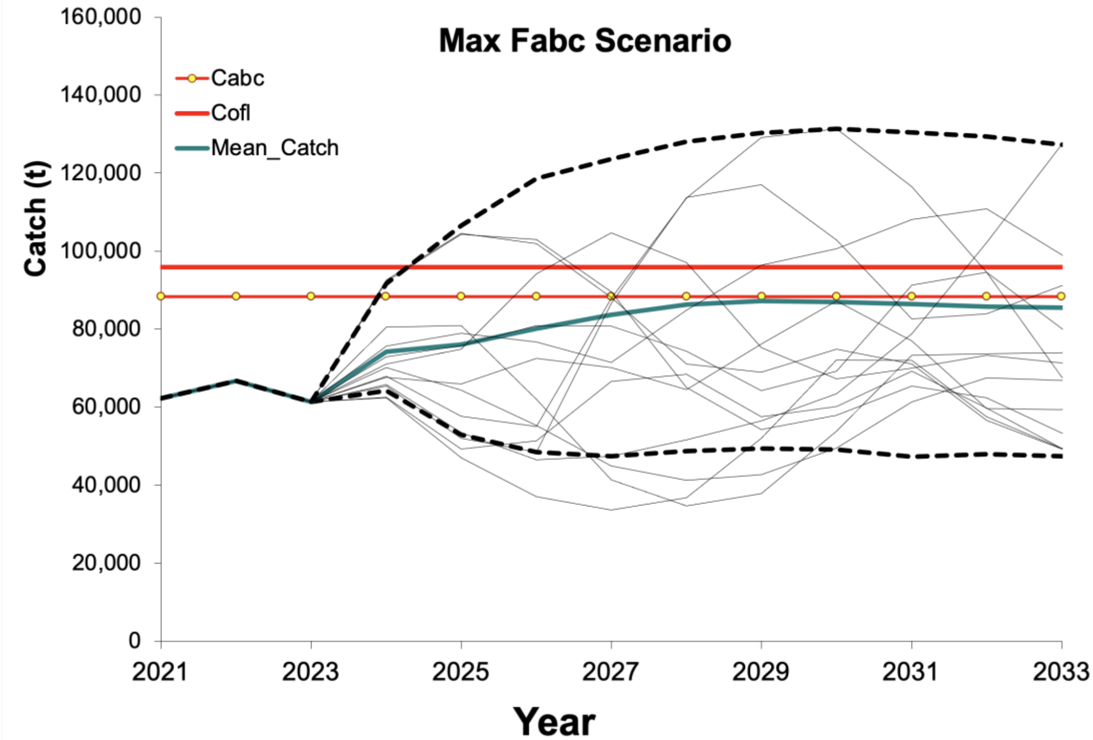


Figure 17.18 Estimated time series of Model 16.0b mean and full-selection fishing mortality and catch/biomass (C_B) exploitation rates of Atka mackerel, 1977-2021. Catch/biomass rates are the ratios of catch to beginning year age 3+ biomass.



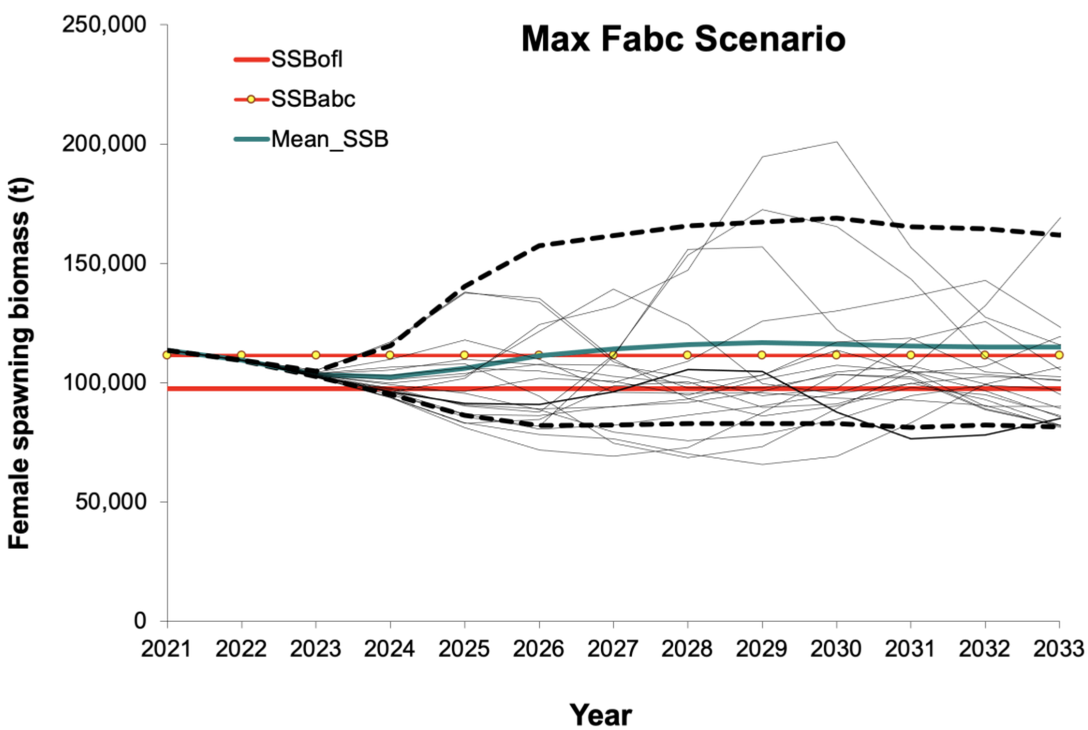


Figure 17.19. Projected Atka mackerel catch (assuming TAC taken in 2021 and reduced catches in 2022 and 2023; top) and spawning biomass (bottom) in thousands of metric tons under maximum permissible harvest control rule specifications after 2023. The individual thin lines represent samples of simulated trajectories.

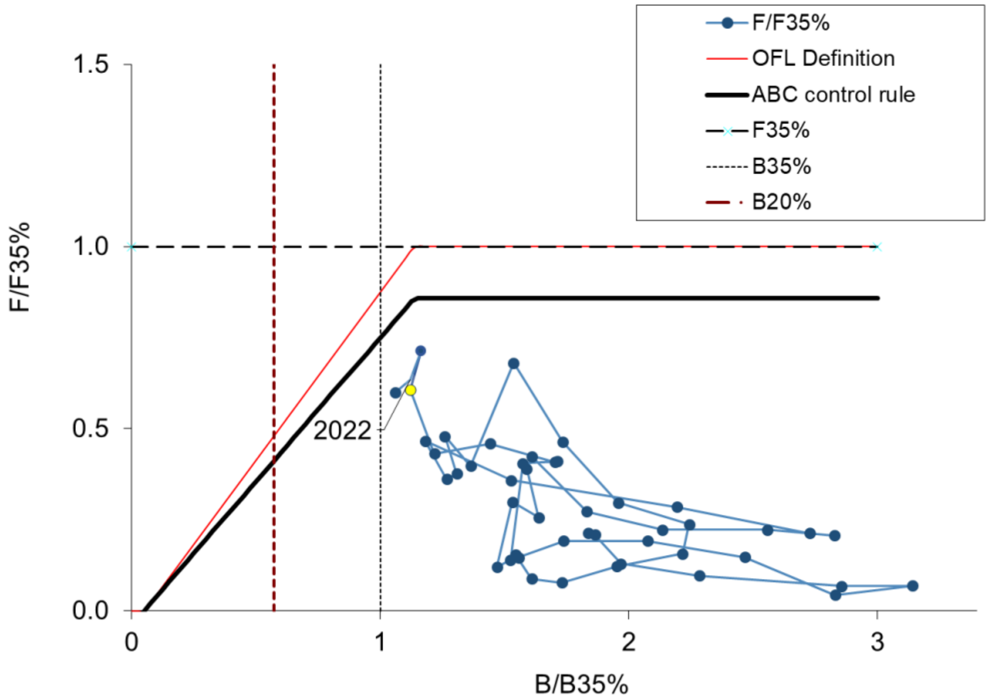


Figure 17.20. Aleutian Islands Atka mackerel spawning biomass relative to $B_{35\%}$ and fishing mortality relative to F_{OFL} (1977-2023). The ratio of fishing mortality to F_{OFL} is calculated using the estimated selectivity pattern in that year. Estimates of spawning biomass and $B_{35\%}$ are based on current estimates of weight-at-age and mean recruitment. Because these estimates change as new data become available, this figure can only be used in a general way to evaluate management performance relative to biomass and fishing mortality reference levels.

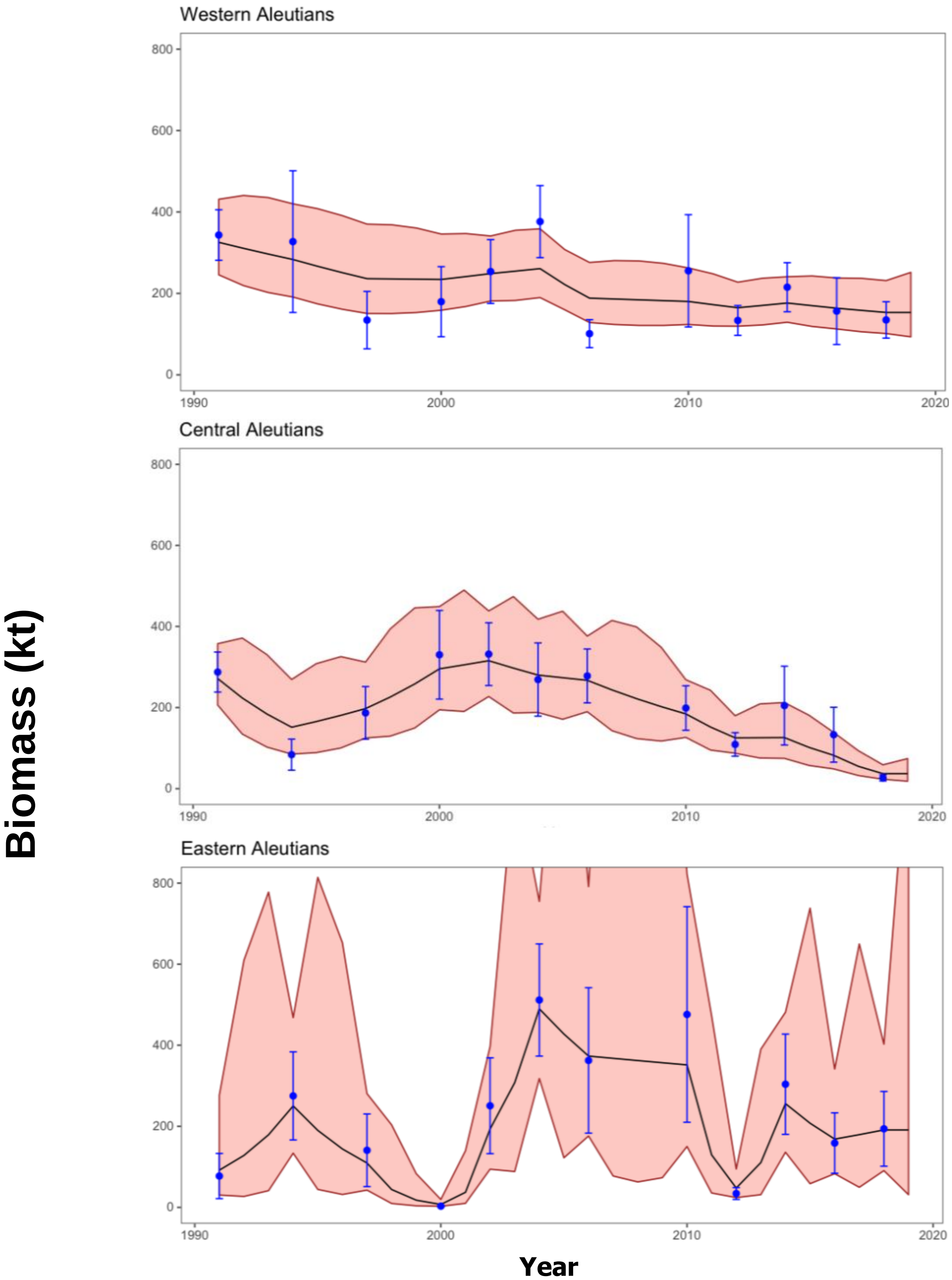


Figure 17.21. Atka mackerel bottom trawl survey biomass by subarea 1991-2018 with random effects model fitting for area apportionment purposes. The random effects biomass estimates for 2019 in Eastern Aleutians is 191 thousand t, Central Aleutians is 37 thousand t, and Western Aleutians is 153 thousand t.

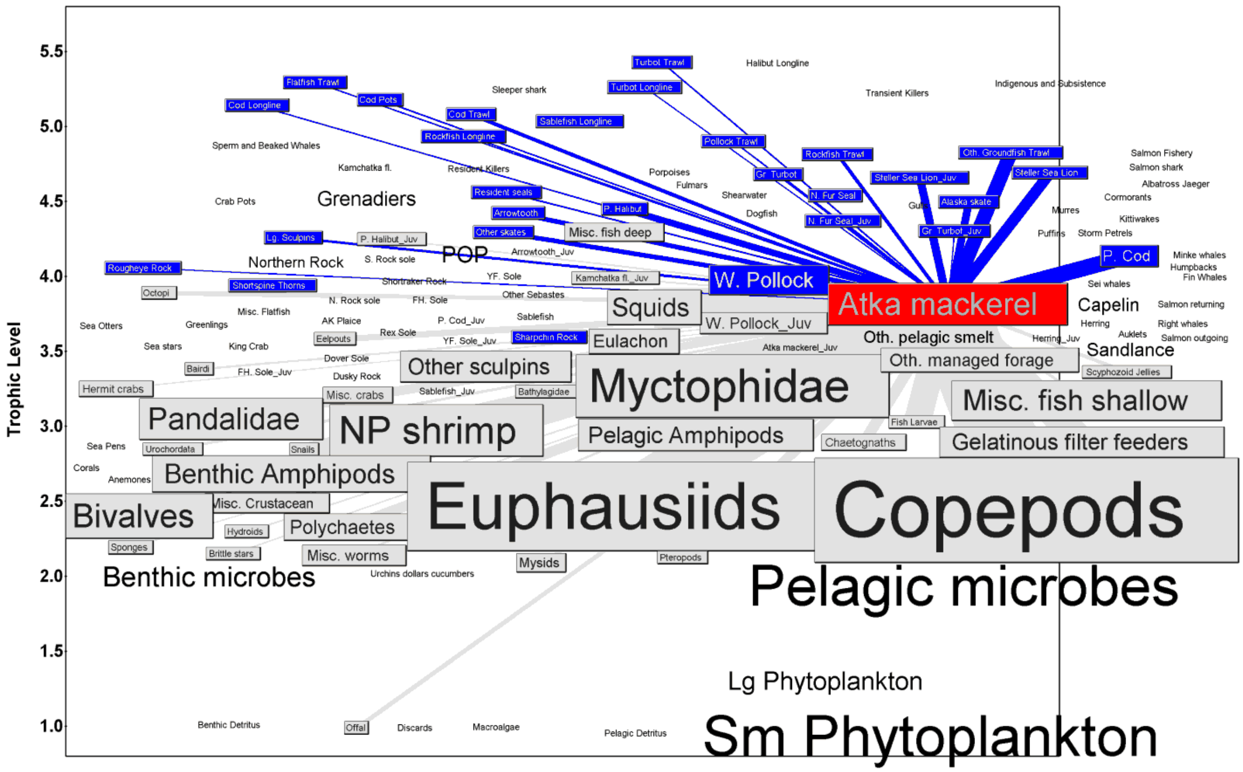
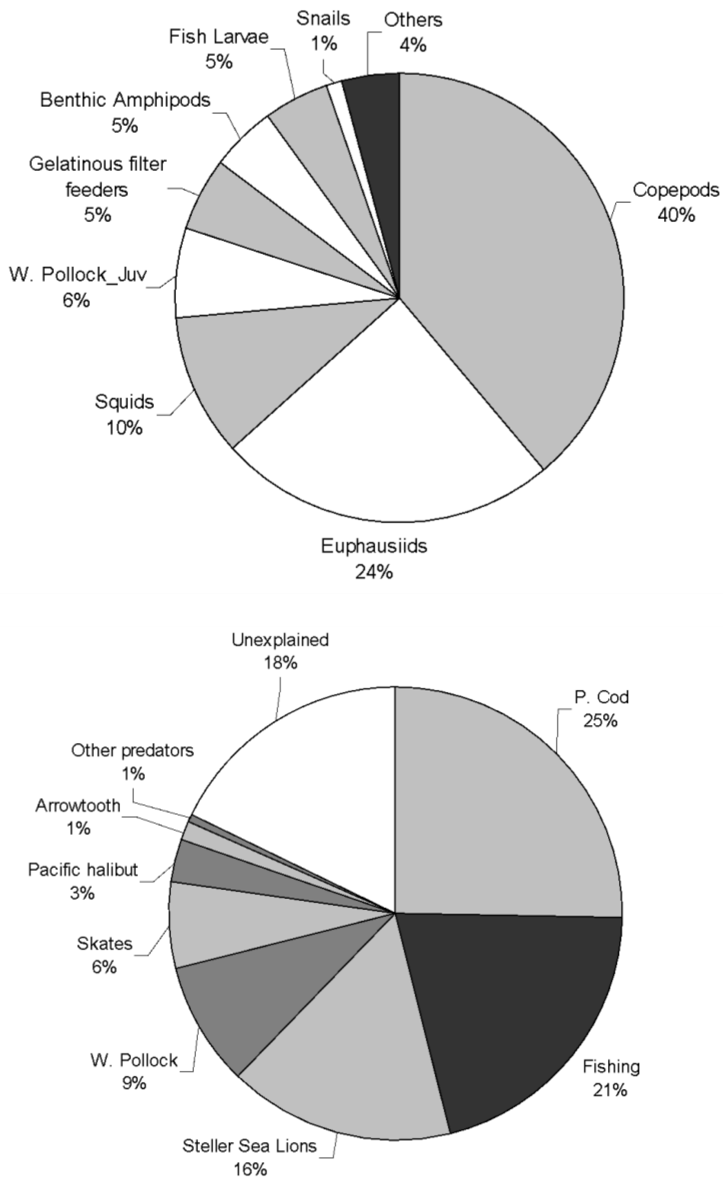


Figure 17.22. The food web of the Aleutian Islands survey region, 1990-1994, emphasizing the position of age 1+ Atka mackerel. Outlined species represent predators of Atka mackerel (dark boxed with light text) and prey of Atka mackerel (light boxes with dark text). Box and text size are proportional to each species' standing stock biomass, while line widths are proportional to the consumption between boxes (t/year). Trophic levels of individual species may be staggered up to +/-0.5 of a trophic level for visibility.



(A)

(B)

Figure 17.23. (A) Diet of age 1+ Atka mackerel, 1990-1994, by percentage wet weight in diet weighted by age-specific consumption rates. (B) Percentage mortality of Atka mackerel by mortality source, 1990-1994. “Unexplained” mortality is the difference between the stock assessment total exploitation rate averaged for 1990-1994, and the predation and fishing mortality, which are calculated independently of the assessment using predator diets, consumption rates, and fisheries catch.

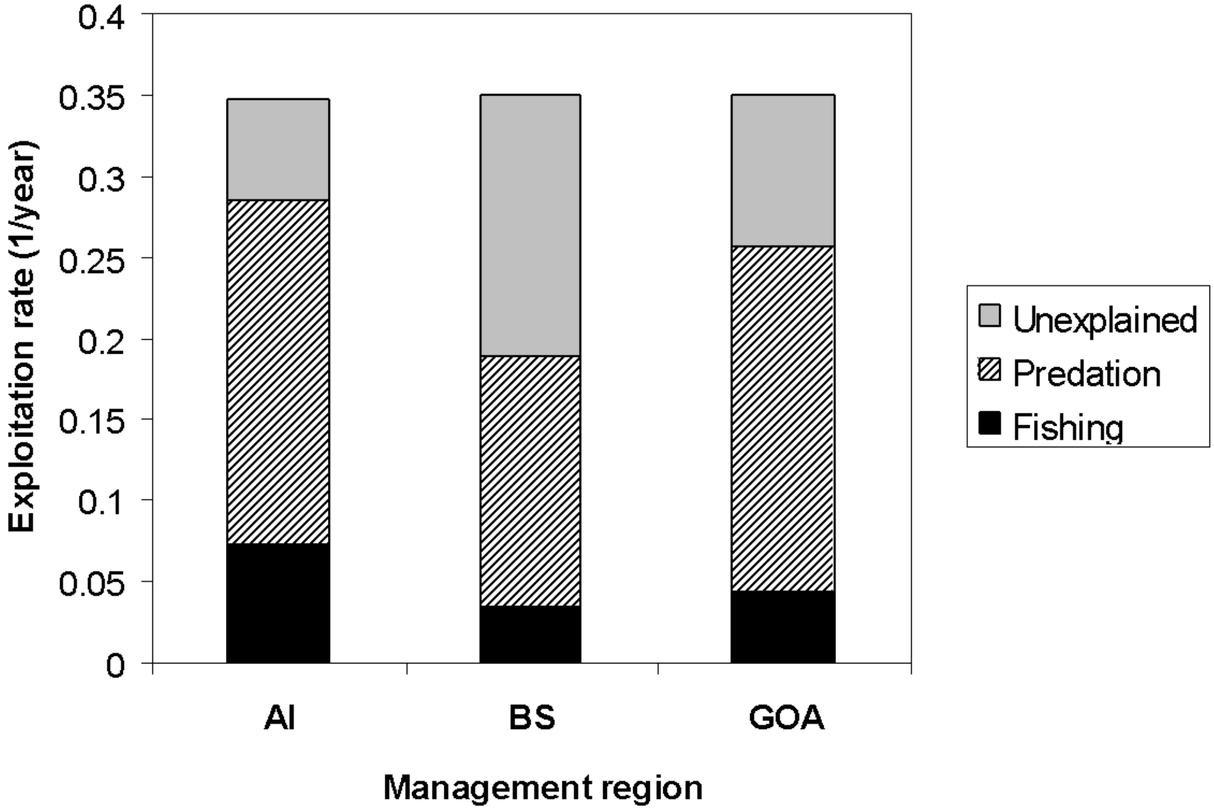


Figure 17.24. Total exploitation rate of age 1+ Atka mackerel, 1990-1994, proportioned into exploitation by fishing (black), predation (striped) and “unexplained” mortality (grey). “Unexplained” mortality is the difference between the stock assessment total exploitation rate averaged for 1990-1994, and the predation and fishing mortality, which are calculated independently of the assessment using predator diets, consumption rates, and fisheries catch.

Appendix 17A Supplemental catch data

In order to comply with the Annual Catch Limit (ACL) requirements, two new datasets were generated to help estimate total catch and removals from NMFS stocks in Alaska.

The first dataset, non-commercial removals, estimates total available removals that do not occur during directed groundfish fishing activities. These include removals incurred during research, subsistence, personal use, recreational, and exempted fishing permit activities, but do not include removals taken in fisheries other than those managed under the groundfish FMP. These estimates represent additional sources of removals to the existing Catch Accounting System (CAS) estimates. Estimates for Atka mackerel from this dataset are shown along with trawl survey removals from 1977-2020 in Table 17A-1. Recent removals from activities other than directed fishing totaled 71 t in 2018, <1 t 2019, and <1 t in 2020. This is approximately <0.1 % of the 2018-2020 ABCs. These low levels of non-commercial catch represent a negligible risk to the stock. These removals were not incorporated in the stocks assessment. If these removals were accounted for in the stock assessment model, the recommended ABCs for 2022 and 2023 would likely change very little.

The second dataset, Halibut Fishery Incidental Catch Estimation (HFICE), is an estimate of the incidental catch of groundfish in the halibut IFQ fishery in Alaska, which is currently unobserved. To estimate removals in the halibut fishery, methods were developed by the HFICE working group and approved by the Gulf of Alaska and Bering Sea/Aleutian Islands Groundfish Plan Teams and the Scientific and Statistical Committee of the North Pacific Fishery Management Council. A detailed description of the methods is available in Tribuzio et al. (2011). There are no reported catches >0.5 t of BSAI Atka mackerel from this dataset.

References

Cahalan J., J. Mondragon., and J. Gasper. 2010. Catch Sampling and Estimation in the Federal Groundfish Fisheries off Alaska. NOAA Technical Memorandum NMFS-AFSC-205. 42 p.

Tribuzio, C.A., S. Gaichas, J. Gasper, H. Gilroy, T. Kong, O. Ormseth, J. Cahalan, J. DiCosimo, M. Furuness, H. Shen, and K. Green. 2011. Methods for the estimation of non-target species catch in the unobserved halibut IFQ fleet. August Plan Team document. Presented to the Joint Plan Teams of the North Pacific Fishery Management Council.

Table 17A-1. Total removals of BSAI Atka mackerel (t) from activities not related to directed fishing, since 1977. "Trawl" refers to a combination of the NMFS echo-integration; small-mesh; large-mesh; and Aleutian Islands bottom trawl surveys; and occasional short-term research projects involving trawl gear. "Longline" refers to either the NMFS or IPHC longline survey. "Other" refers to recreational, personal use, and subsistence harvest.

			Longline			
Year	Source	Trawl	NMFS	IPHC	Other	Total
1977	AFSC	0				0
1978	AFSC	0				0
1979	AFSC	0				0
1980	AFSC	48				48
1981	AFSC	0				0
1982	AFSC	1				1
1983	AFSC	151				151
1984	AFSC	0				0
1985	AFSC	0				0
1986	AFSC	130				130
1987	AFSC	0				0
1988	AFSC	0				0
1989	AFSC	0				0
1990	AFSC	0				0
1991	AFSC	77				77
1992	AFSC	0				0
1993	AFSC	0				0
1994	AFSC	147				147
1995	AFSC	0				0
1996	AFSC	0				0
1997	AFSC	85				85
1998	AFSC	0				0
1999	AFSC	0				0

Table 17A-1cont. Total removals of BSAI Atka mackerel (t) from activities not related to directed fishing, since 1977. “Trawl” refers to a combination of the NMFS echo-integration; small-mesh; large-mesh; and Aleutian Islands bottom trawl surveys; and occasional short-term research projects involving trawl gear. “Longline” refers to either the NMFS or IPHC longline survey. “Other” refers to recreational, personal use, and subsistence harvest.

			Longline			
Year	Source	Trawl	NMFS	IPHC	Other	Total
2000	AFSC	105				105
2001	AFSC	0				0
2002	AFSC	171				171
2003	AFSC	0				0
2004	AFSC	240				240
2005	AFSC	0				0
2006	AFSC	99				99
2007	AFSC	0				0
2008	AFSC	0				0
2009	AFSC	0				0
2010	AFSC	140				140
2011	AFSC	1,529				1,529
2012	AFSC	62				62
2013	AFSC	0				0
2014	AFSC	111				111
2015	AFSC	4				4
2016	AFSC	78				78
2017	AFSC	2				2
2018	AFSC	71				71
2019	AFSC	0				0
2020	AFSC	0				0

Appendix 17B

Atka mackerel (BSAI) Economic Performance Report for 2020

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Atka mackerel is predominantly caught in the Aleutian Islands, and almost exclusively by the Amendment 80 Fleet. The fishery for Atka mackerel has been a catch share fishery since 2008 when Amendment 80 was implemented rationalizing the fleet of catcher/processor vessels in the Bering Sea and Aleutian Islands region targeting flatfish, Atka mackerel and Pacific ocean perch.[4] Atka mackerel is an important source of revenue for the Amendment 80 fleet because of its comparatively high price relative to other species. In 2020 Atka mackerel total catch increased to 59.5 thousand t and retained catch increased to 58.6 thousand t. Catch levels peaked in 2018 after significant reductions in the TAC in 2012 and 2013 when catch levels were low due to area closures to protect endangered Steller sea lions, and survey-based changes in the spatial apportionment of TAC. The 2019 increase in the catch is a result of an increase in the Allowable Biological Catch and TAC. Commensurate with the change in catch, first-wholesale production increased to 34.2 thousand tons. The increase in production was offset by a 9.4% decrease in price to $1.05 per pound resulted in an 8.7% drop in first-wholesale revenue to $79.1 million.

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. Atka mackerel 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 and Japan, which ultimately go to food service sectors. This includes Atka mackerel, which has significant end markets in Japan, China, and South Korea 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 resulted in negative impacts on net revenues.

The U.S. (Alaska), Japan and Russian are the major producers of Atka mackerel.[5] Typically, approximately 90% of the Alaska caught Atka mackerel production value is processed as head-and-gut (H&G) products, the remainder is mostly sold as whole fish (Table 1). In 2019 and 2020 99% of the catch was processed as H&G as whole fish production dropped off. Virtually all of Alaska's Atka mackerel production is exported, mostly to Asian markets. In Asia it undergoes secondary processing into products like surimi, salted-and-split and other consumable product forms (Table 2). Industry reports that the domestic market is minimal and data indicate U.S. imports are approximately 0.1% of global production.

[4] Because Atka mackerel is only targeted by at-sea catcher/processor vessel there is not an effective ex-vessel market for it. Though ex-vessel statistics are computed for national reporting purposes.
[5] Japan and Russia catch the distinct species Okhotsk Atka mackerel which are substitutes as the markets treat the two species identically.

The upward trend in first-wholesale and export prices through 2018 have been influenced by international factors. In particular, global supply of Atka mackerel was in decline because of substantial decreases in catch volume in Japan. In 2018 catch volumes in Japan began to increase, coupled with increasing supply from the U.S. in 2018, which may be putting downward pressure on first-wholesale prices that carried through into 2019. Atka mackerel first wholesale prices in 2020 dropped to approximately 2016 levels (Table 1). Because Atka is primarily exported to Japan, which constitutes roughly 70% of the export value, the U.S. exchange rate can influence first-wholesale prices. The exchange rate has remained stable since 2016, though the U.S. dollar weakened somewhat against the Yen in 2020 it was within its historical range (Table 2). Because of China's significance as an export market (approximately 25% of export volume), the tariffs between the U.S. and China which begun in 2018, may have put downward pressure Atka mackerel prices which has inhibited value growth in that market. Atka mackerel was among the species to receive relief under the USDA Seafood Tariff Relief Program in 2019-2020. The COVID-19 pandemic created supply chain logistical difficulties, which may have put downward pressure on prices. In addition, foodservice closures in major markets for Atka mackerel finished goods, also likely impacted prices negatively.

Global production dropped from an average of 145 thousand t between 2011-2015 to an average of 115 thousand t between 2016-2019 (Table 2). The reductions in international supply meant that the U.S. has captured a larger share of global production in recent years relative to the 2011-2015 average. The U.S. supplied 49% of the global market of Atka mackerel in 2019.

Table 1. Atka mackerel catch and first-wholesale market data. Total and retained catch (thousand metric tons), number of vessel, first-wholesale production (thousand metric tons), value (million US$), price (US$ per pound), and head and gut share of production; 2011-2015 average and 2016-2020.

	2011-2015 Average	2016	2017	2018	2019	2020
Total catch K mt	42.7	55.6	65.5	71.8	58.7	59.5
Retained catch K mt	39.6	54.9	64.7	70.8	57.8	58.6
Vessels #	14	15	17	21	18	16
First-wholesale production K mt	26.3	33.1	42.2	43.9	33.9	34.2
First-wholesale value M US$	$65.4	$74.9	$127.8	$130.6	$86.6	$79.1
First-wholesale price/lb US$	$1.13	$1.03	$1.37	$1.35	$1.16	$1.05
H&G share of value	92%	95%	91%	88%	99%	99%

Source: NMFS Alaska Region Blend and Catch-accounting System estimates; 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 2. Atka mackerel U.S. trade and global market data. Global production (thousand metric tons), U.S. share of global production, U.S. export volume (thousand metric tons), U.S. export value (million US$), U.S. export price (US$ per pound) and the share of U.S. export value from Japan; 2011-2015 average and 2016-2020.

	2011-2015 Average	2016	2017	2018	2019	2020
Global production K mt	145.3	102.4	112.3	128.1	118.2	-
US share global production	28%	54%	58%	55%	49%	-
Export quantity K mt	20.9	30.2	37.1	38.9	28.1	29.7
Export value M US$	$48.5	$83.8	$103.4	$106.7	$77.3	$81.6
Export price/lb US$	$1.05	$1.26	$1.26	$1.24	$1.25	$1.25
Japan's share of export value	66%	74%	72%	66%	63%	68%
Exchange rate, Yen/Dollar	97.2	110.3	115.6	115.5	115.5	114.5

Source: FAO Fisheries & Aquaculture Dept. Statistics http://www.fao.org/fishery/statistics/en. NOAA Fisheries, Fisheries Statistics Division, Foreign Trade Division of the U.S. Census Bureau, http://www.st.nmfs.noaa.gov/commercial-fisheries/foreign-trade/index. U.S. Department of Agriculture http://www.ers.usda.gov/data-products/agricultural-exchange-rate-data-set.aspx

Appendix 17C

Table 17C-1. Variable descriptions and model specification.

General Definitions	Symbol/Value	Use in Catch at Age Model
Year index: i = {1977, …., 2021}	i	
Age index: j = {1, 2, 3, …, A}	j	
Mean weight by age j	W_j	
Maximum age beyond which selectivity is constant	*Maxage*	Selectivity parameterization
	σ_d^2	Dome-shape penalty variance term
Instantaneous Natural Mortality	M	Fixed M=0.30, constant over all ages
Proportion females mature at age j	p_j	Definition of spawning biomass
Sample size for proportion at age j in year i	T_i	Scales multinomial assumption about estimates of proportion at age
Survey catchability coefficient	q^s	Prior distribution = lognormal(1.0 , σ_q^2)
Stock-recruitment parameters	R_0	Unfished equilibrium recruitment
	h	Stock-recruitment steepness
	σ_R^2	Recruitment variance
Estimated parameters		
$\phi_i(37),\ R_0,\ \varepsilon_i(47), \sigma_R^2,\ \mu^f,\ \mu^s,\ M,\ \eta_j^s(10),\ \eta_j^f(10), F_{50\%}, F_{40\%}, F_{30\%}, q^s$		

Note that the number of selectivity parameters estimated depends on the model configuration.

Table 17C-2. Variables and equations describing implementation of the Assessment Model for Alaska (AMAK).

Description	Symbol/Constraints	Key Equation(s)
Survey abundance index (*s*) by year	Y_i^s	$\hat{Y}_i^s = q_i^s \sum_{j=1}^{A} s_j^s W_{ij} e^{Z_{i,j}\frac{7}{12}} N_{ij}$
Catch-at-age by year	C_{ij}	$\hat{C}_{ij} = N_{ij} \frac{F_{ij}}{Z_{ij}} \left(1-e^{-Z_{ij}}\right)$
Catch biomass	$\hat{C}_i^B$	$\hat{C}_i^B = \sum_j W_{ij} \hat{C}_{ij}$
Initial numbers at age	*j = 1*	$N_{1977,1} = e^{\mu_R+\varepsilon_{1977}}$
	A *1 < j < A*	$N_{1977,j} = e^{\mu_R+\varepsilon_{1978-j}} \prod_{j=1}^{j} e^{-M}$
Maximum age	*j = A*	$N_{1977,A} = N_{1977,A-1}\left(1-e^{-M}\right)^{-1}$
Subsequent years (*i >1977*)	*j = 1*	$N_{i,1} = e^{\mu_R+\varepsilon_i}$
	1 < j < A	$N_{i,j} = N_{i-1,j-1} e^{-Z_{i-1,j-1}}$
	j = A	$N_{i,15^+} = N_{i-1,14}\, e^{-Z_{i-1,14}} + N_{i-1,15}\, e^{-Z_{i-1,15}}$
Year effect, *i* = 1967, …, 2018	$\sum \varepsilon_i = 0$	$N_{i,1} = e^{\mu_R+\varepsilon_i}$
Index catchability Mean effect	$\mu^s,\ \mu^f$	$q_i^s = e^{\mu^s}$
Age effect	$\eta_j^s,\ \sum_{j=1}^{A} \eta_j^s = 0$	$s_j^s = e^{\eta_j^s}$ $j \le \text{maxage}$ $s_j^s = e^{\eta_{\text{maxage}}^s}$ $j > \text{maxage}$
Instantaneous fishing mortality		$F_{ij} = e^{\mu_f+\eta_j^f+\phi_i}$
mean fishing effect	μ_f	
Annual effect of fishing in year *i*	$\sum_i \phi_i = 0$	
Age effect of fishing (regularized) in year time variation allowed	$\eta_{ij}^f,\ \sum_{j=1}^{A} \eta_{ij} = 0$	$s_{ij}^f = e^{\eta_j^f}$, $j \le \text{maxage}$ $s_{ij}^f = e^{\eta_{\text{maxage}}^f}$ $j > \text{maxage}$
In years where selectivity is constant over time	$\eta_{i,j}^f = \eta_{i-1,j}^f$	$i \ne \text{change year}$
Natural Mortality Total mortality	*M*	$Z_{ij} = F_{ij} + M$
Recruitment Beverton-Holt form	$\tilde{R}_i$	$\tilde{R}_i = \frac{\alpha B_i}{\beta + B_i}$, $\alpha = \frac{4hR_0}{5h-1}$ and $\beta = \frac{B_0(1-h)}{5h-1}$ where $B_0 = \tilde{R}_0 \varphi$ $\varphi = \frac{e^{-AM} W_A p_A}{1-e^{-M}} + \sum_{j=1}^{A} e^{-M(j-1)} W_j p_j$

Table 17C-3. Specification of objective function that is minimized (i.e., the penalized negative of the log-likelihood).

Likelihood /penalty component		Description / notes
Biomass indices	$L_1 = \lambda_1 \sum_i \ln\left(Y_i^s / \hat{Y}_i^s \right)^2 \frac{1}{2\sigma_i^2}$	Survey biomass
Prior on smoothness for selectivities	$L_2 = \sum_l \lambda_2^l \sum_{j=1}^{A} \left(\eta_{j+2}^l + \eta_j^l - 2\eta_{j+1}^l \right)^2$ $\lambda_2^l = \frac{1}{2\sigma_{f\_sel}^2}$	Smoothness (second differencing), Note: $l=\{s$, or $f\}$ for survey and fishery selectivity
Prior on extent of dome-shape for fishery selectivity	$L_3 = \sum_l \lambda_3^l \sum_{j=5}^{A} \left(I_j d_j \right)^2$ $d_j = \left(\ln\left(s_j^f\right) - \ln\left(s_{j-1}^f\right) \right)$ $I_j = \begin{cases} 1 \text{ if } d_j > 0 \\ 0 \text{ if } d_j \le 0 \end{cases}$	Allows model some flexibility on degree of declining selectivity at age
Prior on recruitment regularity	$L_4 = \lambda_4 \sum_i \varepsilon_i^2 + \sum_i \frac{\left(lnR_i - ln\hat{R}_i\right)^2}{\sigma_R^2}$	Influences estimates where data are lacking (e.g., if no signal of recruitment strength is available, then the recruitment estimate will converge to median value).
Catch biomass likelihood	$L_5 = \lambda_5 \sum_i \left(lnC_i - ln\hat{C}_i\right)^2$	Fit to catch biomass
Proportion at age likelihood	$L_6 = -\sum_{l,i,j} T_{ij}^l P_{ij}^l \ln\left(\hat{P}_{ij}^l \cdot P_{ij}^l \right)$	$l=\{s, f\}$ for survey and fishery age composition observations
Fishing mortality regularity	$L_\phi = \lambda \sum_i \phi_i^2$	(removed in final phases of estimation)
Priors	$L_7 = \left[\lambda_7 \frac{\ln\left(M/\hat{M}\right)^2}{2\sigma_M^2} + \lambda_8 \frac{\ln\left(q/\hat{q}\right)^2}{2\sigma_q^2} \right]$	Prior on natural mortality, and survey catchability (reference case assumption that *M is* precisely known at 0.3).
Overall objective function to be minimized	$L = \sum_{i=1}^{7} L_i$	