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

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Executive Summary

Relative to the November 2017 SAFE report, the following substantive changes have been made in the assessment of Atka mackerel.

Summary of Changes in Assessment Input

1. The 2017 catch estimate was updated, and estimated total catch for 2018 was set equal to the TAC (71,000 t).
2. Estimated 2019 and 2020 catches are 58,900 t and 54,500 t, respectively.
3. The 2017 fishery age composition data were added.
4. The 2018 Aleutian Islands survey biomass estimates were added.
5. The estimated average selectivity for 2013-2017 was used for projections.
6. We assume that approximately 86% 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 2019 and 2020 maximum permissible ABCs, and those reduced amounts were assumed to be caught in order to estimate the 2019 and 2020 ABCs and OFL values.
7. As in 2017, the sample sizes specified for fishery age composition data were rescaled to have the same means as in the original baseline model (100), but varied relative to the number of hauls for the fishery. The 2017 data were added.
8. The 1986 survey age data were removed.

Summary of Changes in the Assessment Methodology

There were no changes in the model configuration.

Summary of Results

1. The addition of the 2017 fishery age composition information impacted the estimated magnitude of the 2011 year class which decreased 12%, relative to last year's assessment, and the magnitude of the 2013 year class which increased 12% relative to last year assessment. The 2011 and 2013 year classes are slightly below average and the 2012 year class remains slightly above average.
2. Estimated values of $B_{100\%}$, $B_{40\%}$, $B_{35\%}$ are 8% lower relative to last year's assessment.
3. Projected 2019 female spawning biomass (106,800 t) is 23% lower relative to last year's estimate of 2018 female spawning biomass, and 15% lower relative to last year's projection for 2019.
4. Projected 2019 female spawning biomass is below $B_{40\%}$ (113,510 t), thereby placing BSAI Atka mackerel in Tier 3b.
5. The current estimate of $F_{40\%\,adj}$= 0.44 is 16% higher relative to last year's estimate of $F_{40\%}$ due to changes in the fishery selectivity used for projections.
6. The projected 2019 yield at $maxF_{ABC} = F_{40\%adj}$ = 0.44 is 68,500 t, which is 26% lower relative to last year's estimate for 2018.
7. The projected 2019 overfishing level at $F_{35\%\,\mathrm{adj}}$ = 0.53 is 79,200 t, which is 27% lower than last year's estimate for 2018.

Quantity	As estimated or *specified last* year for: 2018	2019	As estimated or *recommended this* year for: 2019*	2020*
M (natural mortality rate)	0.30	0.30	0.30	0.30
Tier	3a	3a	3b	3b
Projected total (age 1+) biomass (t)	599,000	600,440	498,320	514,400
Projected Female spawning biomass	139,300	125,600	106,800	102,700
$B_{100\%}$	307,150	307,150	283,780	283,780
$B_{40\%}$	122,860	122,860	113,510	113,510
$B_{35\%}$	107,500	107,500	99,320	99,320
F_{OFL}	0.46	0.46	0.53	0.53
$maxF_{ABC}$	0.38	0.38	0.44	0.44
F_{ABC}	0.38	0.38	0.44	0.44
OFL (t)	108,600	97,200	79,200	73,400
maxABC (t)	92,000	84,400	68,500	63,400
ABC (t)	92,000	84,400	68,500	63,400
Status	As determined *this* year for: 2016	2017	As determined *this* year for: 2017	2018
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 58,900 t and 54,500 t in place of maximum permissible ABC for 2019 and 2020, respectively.

Area apportionment of ABC

The apportionments of the 2019 and 2020 recommended ABCs based on the most recent 4-survey weighted average:

	Survey Year				2019 & 2020 Apportionment	2019 ABC	2020 ABC
	2012	2014	2016	2018			
541+SBS	12%	42%	35%	38%	35%	23,970	22,190
542	39%	28%	30%	7%	21%	14,390	13,310
543	48%	30%	35%	55%	44%	30,140	27,900
Weights	8	12	18	27			
Total ABC						68,500	63,400

Responses to SSC and Plan Team Comments on Assessments in General

From the October 2017 SSC minutes: *"The SSC recommends that, for those sets of environmental and fisheries observations that support the inference of an impending severe decline in stock biomass, the issue of concern be brought to the SSC, with an integrated analysis of the indices in future stock assessment cycles. To be of greatest value, to the extent possible, this information should be presented at the October Council meeting so that there is sufficient time for the Plan Teams and industry to react to the possible reduction in fishing opportunity."*

There were no sets of environmental and fisheries observations that supported an inference of an impending severe decline in BSAI Atka mackerel stock biomass.

"The SSC also recommends explicit consideration and documentation of ecosystem and stock assessment status for each stock ... during the December Council meeting to aid in identifying stocks of concern." Note: This recommendation was clarified in December 2017 and June 18. *In these clarifications, the SSC noted that "Implementation of these stock and ecosystem determinations will be an iterative process and will require a dialogue between the stock assessment authors, Plan Teams, ecosystem modelers, ESR editors, and the SSC."*

The iterative process described above has not been developed, and no determinations of stock assessment and ecosystem status have been made specific to this recommendation. However, the ecosystem and stock status for BSAI Atka mackerel is documented and discussed at length in the current assessment. Also, a risk matrix table was completed for Atka mackerel that discussed ecosystem/environmental considerations. The conclusion from the risk matrix table was that "While data that could inform our assessment of ecosystem risks relevant to Atka are limited, indicators of Atka zooplankton prey and positive condition indices suggest that foraging conditions for Atka have been stable through the recent warm years, particularly in the Western Aleutians. Taken together. The limited ecosystem information suggest no immediate concerns and warrant a risk score of 1 at present".

From the December 2017 SSC minutes: *"The SSC reminds authors of the need to balance the desire to improve model fit with increased risk of model misspecification."* This recommendation was subsequently clarified in the minutes of the June 2018 SSC meeting as follows: *"In the absence of strict objective guidelines, the SSC recommends that thorough documentation of model evaluation and the logical basis for changes in model complexity be provided in all cases."*

Model evaluation is thoroughly documented in the Model Evaluation section and Appendix 17C. The logical basis for the recent changes in model complexity implemented last year (Model 16.0b), were provided in last year's stock assessment, presented at the September 2018 BSAI Plan Team meetings, and accepted by the SSC at the 2018 October meeting.

"Report a consistent metric (or set of metrics) to describe fish condition among assessments and ecosystem documents where possible.

The current BSAI Atka mackerel assessment does not report fish condition. However, a recommendation has been made to adopt the "weight-length residual" method currently used in the ESRs as the standard method. This index of fish condition will be reported in next year's assessment.

"Projections ... clearly illustrate the lack of uncertainty propagation in the 'proj' program used by assessment authors. The SSC encourages authors to investigate alternative methods for projection that incorporate uncertainty in model parameters in addition to recruitment deviations. Further, the SSC noted that projections made on the basis of fishing mortality rates (Fs) only will tend to underestimate the uncertainty (and perhaps introduce bias if the population distribution is skewed). Instead, a two-stage approach that first includes a projection using F to find the catch associated with that F and then a second projection using that fixed catch may produce differing results that may warrant consideration."

The BSAI Atka mackerel assessment uses the 'proj' program for projections. Modifications of the current standard projection code were not completed in time for the final 2018 stock assessments.

From the October SSC 2018 minutes: The SSC did not make any comments on assessments in general that were directed to authors. The general recommendations were for the Plan Teams.

From the November 2017 Joint and BSAI Plan Team minutes: The BSAI Plan Team did not make any comments on assessments in general.

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

From the December SSC 2017 minutes: *"For subsequent assessments, the SSC supports the following Plan Team recommendations:*

1. *Investigate which parameters (including derived quantities) are changing in the retrospective peels that might contribute the relationship between historical scale and number of peels.*
2. *Consider dropping the 1986 age composition from the analysis, to be consistent with the policy of not using pre-1991 survey data.*
3. *Improve documentation for the process of using Francis weights to tune the constraint governing the amount of time variability in fishery selectivity.*
4. *Continue to investigate fishery selectivity time blocks, with blocks linked to identifiable changes in the fishery.*
5. *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.*
6. *Investigate whether a larger number of survey otoliths can be collected in a representative fashion.* .
7. *Continue the investigation of age-dependent natural mortality.*
8. *Continue to include (and update) Figure 17.5."*

The authors have responded to all 8 SSC and Plan Team recommendations in the current assessment. Appendix 17C contains the evaluations and documentation requested for items 1-5 and 7, and are summarized in the Model Evaluation section of the main document. Random sampling was adopted for the 2018 Aleutian Islands survey, with a scheme to sample approximately 300 otoliths per area, with an overall target of otoliths from 1,000 Atka mackerel. The 2018 Aleutian Islands survey was able to randomly sample 1,078 Atka mackerel otoliths, a significantly higher number than has ever been collected in the Aleutian surveys. By area, the number of Atka mackerel otoliths collected were: Southern Bering Sea-75, Eastern Aleutians-219, Central Aleutians-369, and Western Aleutians- 415. Figure 17.5 is updated and included in the current assessment.

From the October SSC 2018 minutes: *"The SSC appreciates the many explorations by the author, but the SSC agrees with the authors and the PT that the base model should continue to be used (without the 1986 survey age data."*

This assessment uses Model 16.0b which is the accepted model from last year, with updated data and exclusion of the 1986 survey age data.

From the November 2017 BSAI Plan Team minutes: *"The Team recommend that the authors undertake the following during one or more future assessments (as this is a long list, the Team does not expect all items to be addressed by next September, and understands that the authors can prioritize the list as they see fit:*

1. *Investigate which parameters (including derived quantities) are changing in the retrospective peels that might contribute the relationship between historical scale and number of peels.*
2. *Consider dropping the 1986 age composition from the analysis, to be consistent with the policy of not using pre-1991 survey data.*
3. *Improve documentation for the process of using Francis weights to tune the constraint governing the amount of time variability in fishery selectivity.*

4. *Continue to investigate fishery selectivity time blocks, with blocks linked to identifiable changes in the fishery.*
5. *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.*
6. *Investigate whether a larger number of survey otoliths can be collected in a representative fashion.*
7. *Continue the investigation of age-dependent natural mortality.*
8. *Continue to include (and update) Figure 17.5."*

The authors have responded to all 8 SSC and Plan Team recommendations in the current assessment (see response above to December SSC 2017 minutes).

From the September 2018 BSAI Team minutes*: "The Team endorsed the author's proposal to exclude the 1986 survey age data from future assessments*."

The current assessment excludes the 1986 survey age data.

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 salmon during their time at the high seas, and has conducted standardized surveys of the upper pelagic layer in the EBS shelf using a surface trawl. 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. Leslie depletion analyses using historical AI and GOA fishery data suggest that catchability increased from one year to the next in the GOA fished areas, but remained the same in the AI areas (Lowe and Fritz 1996; 1997). 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 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 2017 and 2018 fishery operations are shown in Figure 17.1.

Fishing locations and CPUE for the 2015-2017 fisheries have been very similar (Figure 17.1, Figure 17. 1 in Lowe et al. 2016 and Lowe et al. 2017). 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. 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 2017 for BSAI Atka mackerel is included in Appendix 17B (Fissel 2018). The U.S. (Alaska), Japan and Russian are the major producers of Atka mackerel.[1] Approximately 90% of the Alaska caught Atka mackerel is processed as head-and-gut (H&G), while the remainder is mostly sold as whole fish (Fissel 2018, Table 17B-1). 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 (Fissel 2018. Table 17B-2). 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)

International production of Atka mackerel has been on the decline because of reductions in Japanese and Russian catch and production, which were particularly severe in 2015 and have continued. As a result, the U.S. has captured a larger share of global production and supplied 54% of the global market of Atka mackerel in 2016 (Fissel 2018, Table 17B-2). The recent opening of previously restricted areas off the Aleutians in Area 541 has given industry more access to larger fish which yield a higher price per pound in the market. The increased price of Atka mackerel in recent years has helped to maintain first-wholesale value despite reduced production volume (Fissel 2018).

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, an initial Atka mackerel TAC of 32,000 t was caught by March 11, almost entirely south of Seguam Island. This initial TAC release represented the amount of Atka mackerel that the Council thought could be appropriately harvested in the eastern portion of the AI subarea (based on the assessment for the 1993 fishery; Lowe 1992). In mid-1993, however, 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). On August 11, 1993, an additional 32,000 t of Atka mackerel TAC was released to the Central (27,000 t) and Western (5,000 t) districts. 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 TAC was

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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.

apportioned by applying the random effects model to AI survey biomass estimates. 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. Spatial dispersion was accomplished through a planned 4-year reduction in the maximum percentage of each seasonal allowance that could be caught within CH in the Central and Western AI. This was in addition to bans on trawling within 10 nm of all sea lion rookeries in the Aleutian district and within 20 nm of the rookeries on Seguam and Agligadak Islands (in area 541), which were instituted in 1992. 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 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 (BiOp) 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 (DPS) of Steller sea lions, and also likely to adversely modify the designated critical habitat of the western DPS of Steller sea lions. Because this BiOp 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 BiOp 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.

Subsequently, the U.S. District Court ordered NMFS to prepare an Environmental Impact Statement (EIS) on the interim final rule. The NPFMC preferred alternative in the draft EIS for the final EIS differed from the interim final rule, and a reinitiation of consultation was requested for the proposed action under the preferred alternative. The NMFS Section 7 Consultation BiOp determined that the proposed action is not likely to jeopardize the continued existence of the western DPS of Steller sea lions and is not likely to destroy or adversely modify designated critical habitat (NMFS 2014a). The final EIS was issued May, 2014 (NMFS 2014b). The modifications to the RPAs went in to effect for the 2015 fishing year.

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

RPAs from the 2010 Biological Opinion

In Area 543:

- 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 HLA.

In Area 542:

- 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 HLA.

In Area 541:

- 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.

In Bering Sea subarea:

- 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 BiOp, the interim final rule, and the 2014 BiOp are shown in the table below. The interim final rule changed the Atka mackerel trawl season dates to align the Atka mackerel seasons with the AI pollock and Pacific cod trawl fisheries and to temporally disperse catch. The Atka mackerel trawl fishery season dates are extended even further under the 2014 BiOp.

Atka mackerel trawl fishery season dates in 2010 Biological Opinion (BiOp), 2011–2014 Interim Final Rule, and the 2014 BiOp:

	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

In Area 543:

- 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 BiOp did not include an Area 543-specific Atka mackerel harvest limit and prohibited directed fishing for Atka mackerel and Pacific cod.

In Area 542:

- Close Stellar 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 BiOp 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.

In Area 541:

- 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 BiOp. Fishing for Atka mackerel has been prohibited in Steller sea lion CH in Area 541 since 2001.

In Bering Sea Subarea:

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 (MRA) 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 (AIHCA), 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). BSAI Atka mackerel is one of the groundfish species directly affected by Amendment 80. Participation in the Atka mackerel fishery is now limited as a result of Amendment 80. In addition, the Alaska Seafood Cooperative (AKSC) 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 not commonly 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 2000-2009 have been presented in previous assessments (Lowe *et al.* 2003 and Lowe *et al*. 2011, respectively). Bering Sea/Aleutian Islands Atka mackerel discard data from 2010 to the present are given below:

Year	Fishery	Discarded (t)	Retained (t)	Total (t)	Discard Rate (%)
2010	Atka mackerel	3,880	63,191	67,071	5.8
	All others	95	1,480	1,575	
	All	3,975	64,671	68,646	
2011	Atka mackerel	1,191	47,377	48,568	2.5
	All others	575	2,667	3,242	
	All	1,766	50,044	51,810	
2012	Atka mackerel	929	44,097	45,026	2.1
	All others	415	2,384	2,799	
	All	1,344	46,481	47,825	
2013	Atka mackerel	448	19,387	19,835	2.3
	All others	254	3,092	3,346	
	All	702	22,479	23,181	
2014	Atka mackerel	113	28,053	28,166	0.4
	All others	274	2,511	2,785	
	All	387	30,564	30,951	
2015	Atka mackerel	555	46,979	47,533	1.2
	All others	238	5,499	5,737	
	All	792	52,478	53,270	
2016	Atka mackerel	285	48,082	48,377	0.6
	All others	143	5,976	6,119	
	All	427	54,058	54,485	
2017	Atka mackerel	309	58,390	58,699	1.0
	All others	86	5,664	5,750	
	All	395	64,054	64,449	

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). In 2011, Steller sea lion protection measures were implemented which resulted in closures of the Western and Central Aleutian sub-areas (543, 542) to the Atka mackerel fishery and a reduction in the Atka mackerel TAC in the Central Aleutian sub-area (542). The large decrease in the 2011 discard rate likely reflects regulatory changes to the operation of the Atka mackerel fishery. More recently, the discard rate dropped significantly 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%.

Until 1998, discard rates of Atka mackerel by all fisheries have 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 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 the discard rates in the Central AI (542) have increased, reflecting a shift in effort of the Atka mackerel fishery. The 2011-2014 data from the Western AI (543) are minimal Atka mackerel catches from the rockfish fisheries; directed fishing for Atka mackerel in 543 was prohibited under Steller sea lion protection measures. 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.

		Aleutian Islands Subarea		
Year		**541**	**542**	**543**
2010	Retained (t)	23,073	24,035	17,460
	Discarded (t)	384	2,354	1,190
	Rate	***2%***	***9%***	***6%***
2011	Retained (t)	39,214	9,828	0.3
	Discarded (t)	467	886	205
	Rate	***2%***	***8%***	***100%***
2012	Retained (t)	36,034	9,599	0.2
	Discarded (t)	308	723	195
	Rate	***1%***	***7%***	***100%***
2013	Retained (t)	15,481	416	1.3
	Discarded (t)	149	6,867	119
	Rate	***1%***	***6%***	***99%***
2014	Retained (t)	21,011	9,434	2
	Discarded (t)	42	86	240
	Rate	***0.2%***	***0.9%***	***99%***
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	10,266
	Discarded (t)	115	143	65
	Rate	***0.4%***	***0.9%***	***0.6%***
2017	Retained (t)	23,844	17,618	12,322
	Discarded (t)	96	130	130
	Rate	***0.4%***	***0.7%***	***1.0%***

The top five species caught as bycatch in the Atka mackerel fishery are Pacific ocean perch, northern rockfish, Pacific cod, and pollock, and most of this bycatch is retained. Dusky rockfish in the BSAI are part of the other rockfish complex whose main component is shortspine thornyhead. Although relatively small amounts of dusky rockfish are caught in the Atka mackerel fishery, these levels of bycatch exceed the ABC levels for the non-shortspine thornyhead portion of the other rockfish complex (Conners et al. 2016). Bycatch of dusky rockfish is increasing and 218 t, 267 t, and 334 t were caught in the Atka mackerel fishery in 2015, 2016, and 2017, respectively. As of October 14, 2018, the catch of dusky rockfish in the Atka mackerel fishery is 400 t.

Steller sea lions and Atka mackerel fishery interactions

Since 1979, the Atka mackerel fishery has occurred largely within areas designated as Steller sea lion critical habitat (20 nm around rookeries and major haulouts). While total removals from critical habitat may be small in relation to estimates of total Atka mackerel biomass in the Aleutian region, past fishery harvest rates may have been high enough to affect prey availability of Steller sea lions in localized areas (Lowe and Fritz 1997). The localized pattern of fishing for Atka mackerel does not appear to affect fishing success from one year to the next because local populations in the Aleutian Islands are likely replenished by immigration and recruitment. However, temporary reductions in the size and density of localized Atka mackerel populations may have affected Steller sea lion foraging success during the time the fishery was operating in critical habitat, and this effect may have persisted for a period of unknown duration after the fishery was excluded from critical habitat. 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.

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 of Atka mackerel. Since 2000, the AFSC has released over 130,000 tagged fish and has recovered over 3,000 tagged fish. These studies are conducted to determine small scale changes in abundance and distribution of Atka mackerel around all of the major Steller sea lion rookeries along the Aleutian Island chain that are also targeted fishing areas for Atka mackerel. Mark- recapture methods have been successful for this species because the variance estimates obtained are unaffected by species patchiness, and tagging and handling mortality are very low (less than 4% in previous studies). In addition, the fishing industry has aided in the tag recovery process, substantially reducing the expense of chartering survey vessels.

The tagging studies conducted near Seguam Pass (in area 541) in August 2000, 2001 and 2002 indicated that the 20 nm trawl exclusion zones around the rookeries on Seguam and Agligadak Islands are effective in minimizing disturbance to prey fields within them (McDermott *et al*. 2005). The boundary of the 20 nm trawl exclusion zone at Seguam appears to occur at the approximate boundary of two naturally occurring assemblages. The movement rate between the two assemblages is small. Therefore, the results obtained in area 541 at Seguam regarding the efficacy of the trawl exclusion zone may not generally apply to other, smaller zones to the west. The tagging studies were expanded to management area 542, both inside and outside the 10 nm trawl exclusion zones in Tanaga Pass (in 2002), near Amchitka Island (in 2003) and off Kiska Island (in 2006). Movement rates at Tanaga pass and Kiska Island appear similar to those at Seguam with the trawl exclusion zones overlaying apparent natural boundaries to local aggregations. Movement rates at Amchitka were higher relative to Seguam. The boundaries at Amchitka bisect Atka mackerel habitat, unlike the boundaries at Seguam and Tanaga

After the release of the 2010 BiOp and implementation of the closure of area 543 to the Atka mackerel and Pacific cod fisheries, additional tagging studies were conducted with the primary objective of examining Atka mackerel populations near rookeries in all areas open to directed Atka mackerel fishing in the Aleutian Islands. Since 2006, NMFS has been working cooperatively with the North Pacific Fisheries Foundation (NPFF) to conduct field work. In May to June 2011 NMFS, in collaboration with

NPFF, released 8,500 tagged fish in the Eastern Aleutian Islands subarea (Seguam pass, area 541) and 19,000 fish in the Central Aleutian Islands subarea (Tanaga pass and Petrel bank, area 542). In May and June 2014, an additional 20,000 fish were tagged and released in the Western Aleutian Islands (Buldir Island, Western Aleutian Island Seamounts, Aggatu Island, and Ingenstrem Rocks, area 543) as well as Seguam Pass in the Eastern Aleutian Islands Aleutian Islands (area 541). Tag recovery surveys were conducted by a chartered fishing vessel and augmented with recoveries from the fishery.

Additionally, during the 2012 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.

These studies indicate that Atka mackerel exhibit very little large scale movement, with 98.5 % of tagged fish being recovered in the same study areas as they were released. The tagging model population and biomass estimates at the three study areas in the Eastern and Central Aleutian Islands showed large biomass estimates at Seguam Pass (541) and Petrel bank (542), both with approximately 190,000 t in the area open to fishing, and an estimated smaller biomass estimate (29,000 t) at Tanaga pass (542). In all three areas the local exploitation rate was below 10%, with 8% at Seguam pass, 4% at Petrel bank and 2% at Tanaga pass. These low exploitation rates indicated that there was little concern for localized depletion in the areas open to fishing in the Eastern and Central Aleutian Islands during 2011-2012 (McDermott *et al*. 2014). In 2015, several of the areas closed in 2010, including the Western Aleutians (area 543), were reopened to commercial fishing. Analysis of the local population biomass estimates from 2014 to 2015 in the Western Aleutian Islands is ongoing.

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
U.S. Atka mackerel trawl fisheries	Catch	1977-2018
	Age Composition	1977-2017

Fishery data

Fishery data consist of total catch biomass from 1977 to 2017 and projected end of year 2018 catch data (Table 17.1). Based on Atka mackerel catch levels as of mid-October, we project the 2018 end of year catch to be equal to the TAC (71,000 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 1 (e.g., removals due to scientific surveys, subsistence fishing, recreational fishing, and fisheries managed under other FMPs)

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 JV 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 R.O.K. fisheries personnel from their commercial landings. Data from the foreign fisheries are presented in Lowe and Fritz (1996).

Atka mackerel length distributions from the 2017 and preliminary 2018 fisheries by management area are shown in Figures 17.2 and 17.3, respectively. The modes at about 36-37 and 38-39 cm in the 2017 length distributions represent the 2012 year class. The available 2018 fishery data are presented and should be considered preliminary, but are similar to the 2017 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 1990-2017 (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 2009-2010 and 2015-2017 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, and the 2003 and 2004 fishery data showed the first appearance of large numbers from the 2000 and 2001 year classes, respectively. The 2012 fishery data are dominated by 5 and 6-year-olds of the 2007 and 2006 year classes, respectively, and continue to show the presence of the 2001 year class. Significant numbers of 4 year olds of the 2009 year class were observed in 2013, and the 2011 year class dominated the 2014 fishery catch-at-age data, which also showed the continued presence of large numbers of the 2009 year class. Most recently, the 2016 and 2017 catch data are mainly comprised of the 2012 year class, and no longer show a strong presence of the 2009 and 2011 year classes (Table 17.4).

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 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. Previous to this, the 2016 Central area biomass was down 35% relative to the 2014 survey. Biomass estimates in the Central area have ranged from 109,130 t to 204,868 t from 2010-2016 (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, contributing only 0.2% of the total 2000 Aleutian biomass and represented a 98% decline relative to the 1997 survey. The 2012 Eastern Aleutian biomass estimate of 33,149 t was down 91% relative the 2010 survey, and represented 12% of the total 2012 Aleutian biomass. The extremely low 2000 biomass estimate for the Eastern area has not been reconciled, but 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 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. During 2012, large catches of Atka mackerel were not observed in area 541 as they were during 2010, 2014, 2016 (to some extent), and in 2018. During the 2010, 2014, 2016, and 2018 surveys, the biomass from area 541 comprised 35 to 47% of the Aleutian Island biomass, but in 2012, only comprised 12% of the Atka mackerel biomass (Table 17.6b).

The variation in survey biomass and low estimates for 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 2012 survey in area 541 was 0.25 °C colder than average for the 100 to 200 m depth stratum where 99% of the Atka mackerel are caught in the surveys, and both 2012 and 2000 were years with colder than average temperatures and low abundances of Atka mackerel (Figure 17.5). However, this is in contrast to the large decrease in the Central area biomass in 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 the 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).

In 1994 for the first time since the initiation of the Aleutian triennial surveys, a significant concentration of biomass was detected in the southern Bering Sea area (66,603 t). This occurred again in 1997 (95,680 t), 2002 (59,883 t), 2004, (267,556 t), and in the 2010 survey (103,529 t, Table 17.6a,b). These biomass estimates are a result of large catches from a single haul encountered north of Akun Island in all five surveys. In addition, large catches of Atka mackerel in the 2004 survey were also encountered north of Unalaska Island, with a particularly large haul in the northwest corner of Unalaska Island. The 2004 southern Bering Sea strata biomass estimate of 267,556 t is the largest biomass encountered in this area in the survey time series. The *CV* of the 2004 southern Bering Sea estimate is 43%, much lower than previous years as several hauls contributed to the 2004 estimate. Most recently, the 2018 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).

Areas with large catches of Atka mackerel in the 2014 survey included Seguam Pass, Atka Island, Tanaga Island, Kiska Island, and Stalemate Bank (Figure 17.6). In the 2016 survey there were fewer large hauls, and more hauls that did not encounter Atka mackerel relative to previous surveys. Moderately large catches in the 2016 survey were observed at Seguam Pass, Buldir Island and Stalemate Bank (Figure 17.6). 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).

In the 2002, 2004, 2006, and 2010 surveys Atka mackerel were much less patchily distributed relative to previous surveys and were encountered in 55, 58, 52, and 56% of the hauls respectively, which are some of the highest rates of encounters in the survey time series. Although no extremely large catches of Atka mackerel were encountered in the 2012 survey, low to moderate catches were observed in areas consistent with previous surveys, and the percent occurrence of Atka mackerel in the 2012 survey was 48%. In the 2014 survey, Atka mackerel were encountered in 55% of the survey hauls, similar to surveys before 2012. The percent occurrence of Atka mackerel dropped to 38% in the 2016 survey, 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.

The average bottom temperatures measured in the 2000 and 2012 surveys were the lowest of any of the Aleutian surveys, particularly in depths less than 200 m where 99% of the Atka mackerel are caught in the surveys (Figure 17.5). 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. This was evident in the 2012, 2014, and 2016 surveys (Figure 17.7 in Lowe *et al.* 2012, Lowe *et al*. 2015, and Lowe et al. 2017). 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 2010 survey age composition was dominated by 3 and 4-year olds of the 2007 and 2006 year classes (Figure 17.8 in Lowe *et al*. 2011). The 2009-2013 fishery data confirm the strong presence of the 2006 and 2007 year classes in fishery catches. The 2012 survey age composition was dominated by 3 and 5-year olds of the 2009 and 2007 year classes, and the 2014 survey age composition was dominated by 3 and 4-year olds of the 2011 and 2010 year classes. Seven and eight year olds of the 2006 and 2007 year classes were still numerous in the 2014 survey age composition (Figure 17.5 in Lowe *et al*. 2015).

The 2016 survey age composition is mainly comprised of 3 and 4-year olds of the 2013 and 2012 year classes, respectively (Figure 17.8). These year classes comprise nearly 60% of 2016 age composition. The mean age in the 2016 survey age composition is 4.9 years, compared to 5.8 years in the 2014 survey. 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 (previous surveys used a length-stratified scheme). This year a 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 1,078 Atka mackerel otoliths, a significantly higher number than has ever been collected in the Aleutian surveys.

In previous assessments, biomass estimates from the U.S.-Japan cooperative trawl surveys were not utilized, but the survey age data from the 1986 U.S.-Japan cooperative trawl survey were used in the assessment model. The 1986 survey was most well-sampled survey in the cooperative survey time series, and the age data were thought to provide useful historical information for the assessment model. However, an analysis conducted previous to this assessment in response to Plan Team and SSC comments (see Appendix 17C for details), 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 this, and future assessments which was accepted by the BSAI Plan Team and SSC.

Survey abundance indices

A partial time series of relative indices from the 1980, 1983, 1986 Aleutian Islands surveys had been used in early assessments (Lowe *et al.* 2001). The relative indices of abundance excluded biomass from the 1-100 m depth strata of the Southwest Aleutian Islands region (west of 180°) due to the lack of sampling in this stratum in some years. Because the excluded area and depth stratum have consistently been found to be locations of high Atka mackerel biomass in later surveys, it was determined that the indices did not provide useful additional information to the model and have been omitted from the assessment since 2001. Analyses to determine the impact of omitting the relative time series showed that results without the relative index are more conservative (Lowe *et al*. 2002). In last year’s assessment we conducted a sensitivity analyses 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 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.

Analytic Approach

The 2002 BSAI Atka mackerel stock assessment introduced a new modeling approach implemented through the “Stock Assessment Toolbox“ (an initiative by the NOAA Fisheries Office of Science and Technology) that evaluated favorably with previous assessments (Lowe *et al.* 2002). This approach used 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) used for Aleutian Islands

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

Atka mackerel from 1991–2001, but allows for 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 1977-2018) 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	1977-2018	Lognormal	*CV*=5%
Fishery catch age composition	1977-2017	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	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	

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:

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

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

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

(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 last year's 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								
153	219	236	200								

The 2016 assessment (Model 16.0) used a similar approach for computing time-varying sample sizes for survey age compositions; sample sizes were scaled to have a mean of approximately 50 and varied with the number of Atka mackerel hauls. Model 16.0b introduced last year, scaled sample sizes 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
Ave.	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. One approach we took was to use the regression model of Hoenig (1983) which relates total mortality as a function of maximum age. Hoenig's (1983) equation is:

$$\ln(Z) = 1.46 - 1.01(\ln(Tmax)).$$

Where Z is total instantaneous mortality (the sum of natural and fishing mortality, $Z=M+F$), and $Tmax$ is the maximum age. The instantaneous total mortality rate can be considered an upper bound for the natural mortality rate if the fishing mortality rate is minimal. The catch-at-age data showed a 14-year-old fish in the 1990 fishery, and a 15-year-old in the 1994 fishery. Assuming a maximum age of 14 years and Hoenig's regression equation, Z was estimated to be 0.30 (Lowe 1992). Because fishing mortality was relatively low in 1990, natural mortality has been reasonably approximated by a value of 0.30 in past assessments.

An analysis was undertaken to explore alternative methods to estimate natural mortality for Atka mackerel (Lowe and Fritz, 1997). Several methods were employed 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). Atka mackerel appear to be segregated by size along the Aleutian chain. Thus, natural mortality estimates based on growth parameters would be sensitive to any sampling biases that could result in under- or over-estimation of the von Bertalanffy growth parameters. Fishery data collections are more likely to be biased as the fishery can be more size selective and concentrates harvests in specific areas as opposed to the surveys. Natural mortality estimates derived from fishery data ranged from 0.05 to 1.13 with a mean of 0.53. Natural mortality estimates, excluding those based on fishery data, ranged from 0.12 to 0.74 with a mean value of 0.34. The current assumed value of 0.3 is consistent with these values. Also, a value of 0.3 is consistent with values of *M* derived by the methods of Hoenig (1983) and Rikhter and Efanov (1976) which do not rely on growth parameters (Lowe and Fritz, 1997).

The 2003 assessment explored the use of priors on *M*, resulting in drastically higher biomass levels (Figure 17.11 in Lowe *et al.* 2003).

We previously 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 (see Appendix 17C). 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). 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). 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. The natural mortality estimate of 0.3 is a conservative assumption and based on a previous meta-analysis (Lowe and Fritz, 1997). This value seems to fit reasonably well with other key estimated parameters (e.g. survey catchability and selectivity). We suggested continuing with the current model (Model 16.0b) with the assumption of fixed constant *M*=0.3, which was accepted by the Plan Team and SSC.

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 for 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 2012, 2014, and 2016 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 2017, 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. 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.

Prior to the 2008 assessment, selectivity had been allowed to vary annually with a low constraint as described in the 2002 assessment (Lowe *et al*. 2002). As suggested by the 2008 CIE reviewers, we adopted a new model configuration with blocks of years with constant selectivity which corresponded approximately to the foreign fishery, the joint venture fishery, the domestic fishery prior to Steller sea lion regulations, and the domestic fishery post Steller sea lion regulations. This model configuration was used in the 2008-2012 assessments. In the 2013 assessment, a method to allow fishery selectivity to vary without having to subjectively specify an arbitrary degree of penalty was implemented based on an application developed at the Center for the Advancement of Population Assessment Methodology (CAPAM) workshop on selectivity. This method follows the procedure outlined in Annex 2.1.1 of the 2012 BSAI Pacific cod assessment (Thompson and Lauth 2012, p. 442-445), and was accepted by the SSC for the 2013 assessment (Lowe *et al*. 2013). This method for constraining fishery selectivity variability was used in the 2013-2016 assessments.

In 2016, The SSC and BSAI Plan Team recommended the assessment explore statistical estimation of the amount of time variability in selectivity, and also re-examine the use of blocks for fishery selectivity. In the last year's assessment (and in the current 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 distinguish the tuning of the sample sizes given constant or other rigid selectivity/separable fishing mortality patterns, from the method introduced last year in which the allowance for time-varying selectivity variability (σ_{f_sel}) was tuned using the Francis weighting method (Francis 2011, equation TA1.8) on the fishery age composition data. This is analogous to the tuning with Francis weights that were used to determine samples sizes in Lowe *et al*. (2017). This was done in an effort to satisfy the request to arrive at a statistical approach for specifying the degree of time-varying selectivity. While this requires fixing the assumption that the input fishery sample sizes have a mean value of 100, we argue that this is a reasonable way to arrive at a balance between process and observation error. 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 selectivities. 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 accepted last year, 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

For 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). In response to the December 2010 SSC minutes which noted a lack of model fit to survey biomass estimates after 1999, the 2011 assessment explored the implementation of a random walk for a transition set of years in survey catchability and periods for survey selectivity, as one approach to help resolve the poor residual pattern identified (Lowe *et al*. 2011). Results were unsatisfactory and failed to significantly improve model fit to survey data. Using a random walk for catchability was therefore dropped, but two survey selectivity time blocks were retained which coincided with the break point in the lack of fit for the 2012-2013 assessments. Model explorations in the 2012-2013 assessments which constrained the degree of dome-shape for fishery selectivity and allowed for a greater degree of time-varying fishery selectivity, improved model fits to the survey by having survey catchability increase. In the 2014 assessment model a single survey selectivity-at-age vector was specified.

In last year's assessment, we conducted sensitivity analyses of time-varying survey selectivity as suggested by the BSAI Plan Team. Initial explorations allowed for a separate selectivity pattern for 1986. Because of inconsistencies in the 1980s survey data (see *Survey abundance indices*, above), the 1980s survey biomass data are omitted, but the 1986 survey age composition are included. The 1986 survey was the most comprehensive of the 1980s surveys, and otolith samples from approximately 700 Atka mackerel were used for estimating the 1986 age composition. Therefore, including the 1986 survey age data would seem to provide useful information on relative year-class strengths, but the 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.

In response to Plan Team and SSC requests to consider dropping the 1986 age composition data to be consistent with the policy of not using pre-1991 survey data, we conducted simulations with and without the 1986 survey age composition (Appendix 17C). The impact of dropping the 1986 survey age composition reduced recruitment estimates by nearly 3.6%, and the 2017 spawning biomass estimate was similarly affected with a slightly lower estimate when the 1986 survey age composition was excluded (Appendix 17C). Relative to survey fit, dropping the 1986 data degraded the fit to the data slightly. The estimate of survey catchability also differed, which explains some of the change in recruitment and spawning biomass levels In conclusion, we suggested that that there is no real benefit to including the 1986 survey age composition, and that including these data is inconsistent given that the model does not include the 1986 survey index. We proposed to exclude the 1986 survey age composition which was accepted by the Plan Team and SSC. The current assessment includes only post-1990 survey biomass and age information.

Other options to allow survey selectivity to change might be warranted, in particular to accommodate the change in survey tow duration and other changes in survey design over time. 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.

The 2002 assessment explored the estimation of M and survey catchability (q) simultaneously with various combinations of priors (Lowe *et al*. 2002). Preliminary results were unsatisfactory and difficult to interpret biologically. The 2003 assessment explored a range of priors on M or q, while the other parameter was fixed with mixed results that were also difficult to interpret and did not seem biologically reasonable (Lowe *et al.* 2003). In the 2004 assessment we presented a model (Model 4, Lowe *et al.* 2004), with a moderate prior on q (mean = 1.0, $\sigma^2 = 0.2^2$) which was accepted and used as the basis for the ABC and OFL specifications since 2004.

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. As in the 2017 assessment, 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. Last year we again presented Model 16.0 and conducted the model evaluation of 16.0 through sensitivity analyses of sub-models with changes in the fishery selectivity inputs and tuning the age composition data with the Francis (2011) method. Model 16.0b was the accepted model which provided for statistical estimation of the amount of time variability in fishery selectivity through tuning of the time-varying selectivity term ($\sigma_{\mathrm{f\_sel}}$) with the Francis method (2011), and the survey age composition sample sizes were also tuned using the Francis method.

Last year the BSAI Plan Team and the SSC requested 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 and summarized in this section. It is noted that the evaluations in Appendix 17C do not include the new data introduced in the current assessment.

New data introduced in 2018

Model 16.0b (the selected model configuration used for the 2017 assessment and the 2018 ABC) was updated with new data. In addition, the 1986 survey age data were excluded. The 2017 fishery age composition data and the 2018 Aleutian Islands bottom trawl survey biomass estimate were added. The 2017 fishery age data are mainly comprised of 5 year olds of the 2012 year class. The 2018 Aleutian

Islands survey biomass estimate is down 21% relative to the 2016 survey estimate, with most of this decrease attributed to the Central Aleutian area.

Sensitivity analyses of Model 16.0b to fishery selectivity variability

In Appendix 17C we evaluated the first two items listed above dealing with aspects of fishery selectivity. The results are summarized here.

Model 16.0b 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). Fishery selectivity is allowed to vary annually with constraints. The Plan Team and SSC requested examination of periods where fishery selectivity could reasonable assumed to be the same. We addressed previous SSC and Plan Team comments to turn off time-varying selectivity and apply time blocks for fishery selectivity together in a preliminary sensitivity analysis (Lowe *et al*. 2017, Model 16.0c), using blocks of years within which selectivity was time-invariant for the periods:

1977-1983 Foreign fishery
1984-1991 Joint venture fishery
1992-1998 Domestic fishery and 3-subarea split
1999-2010 Steller sea lion regulations
2011-2014 Steller sea lion RPAs
2015-2017 revised Steller sea lion RPAs

We continued the exploration of time blocks adding an additional time block within the 1999-2010 time period to account for changes in the fishery from Amendments 78 and 80 (Appendix 17C):

1999-2005 Steller sea lion regulations
2006-2010 Steller sea lion regulations, Amendments 78 and 80

As expected, the fits to the fishery age composition were degraded when time-varying selectivity was dropped and replaced with periods where selectivity was held constant for specific periods. Adding an additional “time block” to the blocked selectivity model resulted in only minor (negligible) improvements to the fit to the fishery age compositions (Appendix 17C). The fit to the survey was slightly worse and the spawning biomass and apical fishing mortality rates differed significantly compared to last year’s Model 16.0b with time-varying selectivity. The selectivity patterns can have a large impact on the reference fishing mortality rates, and Atka mackerel have been shown to be sensitive to assumptions about selectivity (Lowe *et al*. 2008, Lowe *et al*. 2013). For example, previous investigations incorporating annual time-varying approach for fishery selectivity allowed the model flexibility to better reflect the fishery age composition data and provided results consistent with fishery age distributions (Lowe *et al*. 2013). Also, it seems reasonable that some selectivity variability would occur given year-class variability (SigmaR= 45-50% in recent years), and the fact that the fishery may seek out higher catch-rate areas where such strong year-classes may be present. Therefore, we suggested that the time-varying selectivity option in Model 16.0b be retained, which was accepted by the Plan Team and SSC.

An evaluation of how tuning the selectivity variability affects results if a higher of lower sample size is assumed for the fishery age compositions is contained in Appendix 17C and summarized here. Model 16.0b assumes a mean sample size of 100 for the time period of observer data (1991-2017 in the current assessment and 1991-2016 in Appendix 17C). We rescaled all the input sample sizes to half (50) and double (200) that assumption. Tuning the selectivity variability parameter for these two new cases resulted in expected differences in the amount of selectivity variability in the fishery (i.e., increased variability with increased sample size). These runs also affected recruitment estimates i.e., when a higher sample size was specified, the selectivity varied more and interannual variability of recruitment increased.

For the most part, recruitment estimates for sample sizes of 50 and 100 were relatively similar, but increasing the sample size to 200 significantly lowered recruitment estimates. This is consistent with the expectation that greater "targetting" of specific year-classes results in higher values for the above-average year-classes compared to separable assumptions that selectivity/availability of cohorts are more even.

The relative impact expected in projections was explored in Appendix 17C by comparing the estimated recent 5-year average selectivities assuming mean fishery sample sizes equal to 50, 100, and 200. The tuned models under different fishery sample size assumptions resulted in different age-specific selectivity estimates, particularly for ages between 3 and 8 years. These differences impact the F_{SPR} estimates and consequently the ABC and OFL values. Higher sample sizes result in shifts in selectivity to the right, relative to maturity-at-age, which is associated with higher F_{SPR} reference rates. Comparing projections for these three scenarios show the spawning biomass as being highest for the low input sample size resulting in higher catches based on the ABC control rules (Appendix 17C).

A mean fishery sample size of 100 is the mean of the derived sample sizes from the 2015 assessment which was based on the numbers of Atka mackerel sampled for ages (Lowe et al. 2015). The 2016 assessment implented a new method whereby the samples sizes varied relative to the number of hauls, but were scaled to a mean of 100 as in previous assessments. 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. As such, we continue with Model 16.0b which varies the sample sizes relative to the number of hauls, with a mean sample size equal to 100 based on numbers of fish sampled for ages. This is consistent with the level of observer sampling.

Retrospective analysis

A retrospective analysis was conducted by regressively eliminating the most current year of information extending back to 2008. This allows judgment of the model performance as specified. Atka mackerel have a reasonable retrospective pattern for the last 5 years of predicting spawning biomass with periods that are lower and higher (Figure 17.9). However, after data from 2012-2016 are dropped from the model, most subsequent retrospective runs resulted in biomass that was historically considerably higher.

As noted in the 2017 assessment, the reason for the odd pattern can be attributed to the survey age compositions. 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. This interpretation still holds in the current assessment. In terms of impacts on ABC advice going forward, the fact that the present selectivity estimates suggest that the older ages are mostly observed in the survey, and recognizing the relatively broad confidence bounds for the current stock biomass estimates, further alternative model specifications to resolve this pattern may be unwarranted at this time. The revised Mohn's rho statistic was calculated to be 0.16.

Appendix 17C investigated which parameters (including derived quantities) are changing in the retrospective peels that might contribute to the relationship between historical scale and number of peels. Because there appears to be a scale shift in the biomass estimates, evaluations examined the survey catchability coefficient and the mean recruitment parameter. Extracting these values indicated that in more recent terminal-year assessment runs the value of the survey catchability was higher which, according to how the model is specified, scales the population to be lower, but only results in slightly lower mean recruitment estimates. Model fits to the survey data for these retrospective runs show that the 2 lowest survey estimates in time series before 2018 (2012 and 2016), likely dropped the overall biomass estimates (and increased values of catchability) following the three relatively high biomass estimates between 2002 and 2010. The 2002, 2004, and 2010 estimates represented the three highest survey biomass estimates in the time series. We also evaluated the impact of these survey data as they entered in to the retrospective assessments. For the survey index and survey age compositions, the negative log-likelihoods showed how historical biomass estimates become more or less consistent with model estimates with large jumps in cumulative negative log likelihood after the 2012 survey was included. The robust fishery age data which is generally well fit, prevents the model from fitting the 2012 and 2016 large drops in survey biomass. In conclusion, the observed pattern is attributed to the addition of recent survey estimates, and we suggest that the retrospective bias is a reflection of the data rather than issues with the model configuration. 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.

Choice of final model

The evaluations of Model 16.0b detailed in Appendix 17C and summarized above, did not find any substantial improvements. The only change recommended was to drop the 1986 survey age data (see *Survey age data* section above). The SSC agreed that the assessment should continue to use Model 16.0b without the 1986 survey age data (Oct. 2018 SSC minutes).

A summary of key results from the selected Model 16.0b is presented in Table 17.10. Results from the 2017 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 2018 biomass estimate is 20% and the *CV*s on the strength of the 2006 and 2012 year classes at age 1 are 15 and 19%, respectively (Table 17.10). Recruitment variability (SigmaR) 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 176 and survey data was 106. The overall residual root-mean square error (RMSE) for the survey biomass data was estimated at 0.246, 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). However, 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 2004, 2010, and 2014 observed bottom trawl survey biomass values, but fits the other survey years quite well (survey catchability is approximately equal to 1).

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 and 30% of the 2016 and 2017 fishery age compositions, respectively. The 2016 survey also showed a large number of 3-year olds from the 2013 year class. The 2013 and 2014 year classes combined made up approximately 60% of the 2016 survey age composition. We also note an unusual pattern in recent survey data (2010, 2012, and 2014) 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. Fits to recent fishery age composition data in Lowe *et al*. (2012) indicated a need for greater flexibility in selectivity. The 2013, and more recently the 2016 assessment 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 2017 fishery catch- and weight-at-age values, dropping the 1986 survey age composition, and the 2018 survey biomass estimates.

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 (2017) and the average selectivity used for projections (2013-2017) are fairly similar to, but differ slightly over some age ranges from the terminal year and average selectivity for projections used in the 2017 assessment, showing lower selectivity for ages 3-7 and higher selectivity after age 8 (Figure 17.14). The current assessment’s terminal year (2017) selectivity pattern shows a peak for 5-year olds and a drop in the selectivity for 6-year olds. In the previous assessment, the unusually strong showing of 4-year olds of the 2011 year class in the 2015 fishery age data was not evident in the 2016 fishery data. Similarly, the 2017 fishery age composition showed less than expected number of 6-year olds from the 2011 year class.

The fishery catches essentially consist of fish 3-11 years old, although a 15-year-old fish were found in the 2013 and 2014 fishery catches. 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 (2017) is about 4 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 slightly lower relative to the age at 50% selectivity for the average selectivity used for projections (2013-2017). Maturity-at-age is much lower relative to recent average selectivity over ages 4-6 (Figure 17.14).

Survey catches are mostly comprised of fish 3-9 years old. The 2016 survey is dominated by 3- and 4-year olds of the 2012 and 2013 year classes, and shows larger than expected numbers of 9 and 10 year olds of the 2006 and 2007 year classes. 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), similar to the terminal year selectivity pattern for the fishery (Figure 17.14). Both the survey and fishery show a dip in selectivity at ages 5 and 6, respectively, reflecting the 2011 year class which showed up strongly in the 2014 fishery and survey and disappeared thereafter. 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). 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). The current assessment spawning biomass is slightly lower over the time series after 1985. Differences in spawning biomass levels are attributed to slightly revised estimates of recruitment levels (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 (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 1.8, 1.1, and 1.3 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, and 2012 year classes (Figure 17.16, Table 17.14). The 1996 and 2008 year classes are the lowest in the time series, estimated at about 210 and 240 million recruits, respectively.

The average estimated recruitment from the time series 1978-2017 is 609 million fish and the median is 493 million fish (Table 17.14). The entire time series of recruitments (1977-2018) includes the 1976-2017 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 2018 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 2017 (1977-2016 year classes). Projections of biomass are based on estimated recruitments from 1978-2017 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 120,000 t. The five largest year classes in the time series were all spawned from biomass levels ranging from 155,000-180,000 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 1978-2017 (609 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:

$B_{100\%}$ = 283,776 t female spawning biomass
$B_{40\%}$ = 113,510 t female spawning biomass
$B_{35\%}$ = 99,322 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 (2013-2017) to reflect recent conditions for projections and computing ABC which gives:

Full selection Fs	2018
F_{2018}	0.37
$F_{40\%\ adj}$	0.44
$F_{35\%\ adj}$	0.53
$F_{2018}/F_{40\%adj}$	0.84

For specification purposes to project the 2019 ABC, we assumed a total 2018 year end catch of 71,000 t equal to the 2018 TAC. For projecting to 2020, an expected catch in 2019 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 2019. 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 2019 ABC estimate, and that amount was summed with the maximum permissible ABC estimates for the Eastern and Central Aleutian areas for a total estimated 2019 catch. The total estimated 2019 catch was assumed to be caught in order to estimate the 2020 ABC and OFL values. We estimated that about 86% of the BSAI-wide 2019 ABC is likely to be taken.

We note that in previous years we estimated 75% of the BSAI-wide ABC would be taken. Recent ABCs since 2015 have been in the order of about 90,000 t (the 2018 ABC was 92,000 t), and are decreasing. Also, the Atka mackerel directed fishery is expected to take the full BSAI TAC in 2018. The combination of lower ABC levels and catches equal to TAC result in a higher percentage of the total catch to BSAI ABC ratio.

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 2019 female spawning biomass (SSB_{2019}) is estimated to be 106,800 t given assumed 2018 catch and a slightly reduced 2019 catch reflecting the Steller sea lion RPA adjustment to the 2019 ABC.

The projected 2019 female spawning biomass estimate is below the $B_{40\%}$ value of 113,510 t, placing BSAI Atka mackerel in **Tier 3b**. The 2020 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
2019	58,910	68,500	0.44	79,200	0.53	106,800	3b
2020	54,524	63,400	0.44	73,400	0.53	102,714	3b

* Catches in 2019 and 2020 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 2018 or 2019 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2031 using a fixed value of natural mortality of 0.3, the recent schedule of selectivity estimated in the assessment (in this case the average 2013-2017 selectivity), and the best available estimate of total (year-end) catch for 2018 (in this case assumed to be 71,000 equal to TAC). In addition, the 2019 and 2020 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 2019 and 2020, 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 2019 recommended in the assessment to the *max* F_{ABC} for 2019, and where catches for 2019 and 2020 are estimated at their most likely values given the 2019 and 2020 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 2018 or 2) above ½ of its MSY level in 2018 and above its MSY level in 2028 under this scenario, then the stock is not overfished.)

Scenario 7: In 2019 and 2020, 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 2020 or 2) above 1/2 of its MSY level in 2020 and expected to be above its MSY level in 2030 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 (2017) is 64,451 t. This is less than the 2017 OFL of 107,200 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 2018:

a) If spawning biomass for 2018 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b) If spawning biomass for 2018 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c) If spawning biomass for 2018 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 2028 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 2020 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

b) If the mean spawning biomass for 2020 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c) If the mean spawning biomass for 2020 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2030. If the mean spawning biomass for 2030 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 recommended in their October 2018 minutes that assessment authors and Plan Teams use the risk matrix table below when determining whether to recommend an ABC lower than the maximum permissible.

	Assessment-related considerations	Population dynamics considerations	Environmental/ecosystem considerations
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
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 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, and/or b) up or down trophic levels (i.e., predators and prey of stock)
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

The table is applied by evaluating the severity of three 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, and environmental/ecosystem considerations. Examples of the types of concerns that might be relevant include the following:

1. Assessment considerations—
    a. Data-inputs: biased ages, skipped surveys, lack of fishery-independent trend data
    b. Model fits: poor fits to fits to fishery or survey data, inability to simultaneously fit multiple data inputs.
    c. Model performance: poor model convergence, multiple minima in the likelihood surface, parameters hitting bounds.
    d. Estimation uncertainty: poorly-estimated but influential year classes.
    e. 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.

<u>Assessment considerations</u>. 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 2012-2016 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). 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 is attributed to the addition of recent survey estimates, and we suggest that the retrospective bias is a reflection of the data rather than issues with the model configuration. 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). However, the overall BSAI 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 two moderately strong year classes (2006 and 2007 year classes), and the most recent slightly above average 2012 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 a slightly above average year class (2012 year class) following the 2006 and 2007 strong year classes which were 54% above average is unusual. As the 2006 and 2007 year classes have aged and moved through the population, there has been no strong recruitment to slow down or stop the declining trend in spawning biomass. However, we note that the 2016 and 2017 fisheries were dominated by the 2012 year class. The 2016 survey data are dominated by 3- and 4-year olds, of the 2013 and 2012 year classes, respectively (Figure 17.8). These year classes comprised nearly 60% of 2016 survey age composition. Atka mackerel have been in Tier 3a until this year, when the 2019 female spawning biomass is projected to drop just below $B_{40\%}$ thereby placing Atka mackerel in Tier 3b. Under the Tier 3b $F_{40\%\mathrm{adj}}$ harvest strategy and assuming SSL RPA catch reductions in 2019 and 2020, female spawning biomass is projected to drop below $B_{40\%}$ in 2019 but increase and remain above $B_{40\%}$ from 2024 through 2031 (Figure 17.19 and Table 17.16 Scenarios 1 and 2). If SSL RPA catch reductions are in place beyond 2020, expected female spawning biomass levels would be higher than projected after 2020. 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.

Environmental/Ecosystem considerations. It is possible the reduced recruitment since 2007 is due to changing environmental factors such as water temperature which is known to affect Atka mackerel eggs, larvae, and hatching times; however, this has not yet been evaluated fully. Ecosystem indicators suggest no clear concern for prey supply for Atka mackerel, although we have limited data on zooplankton abundance. Data from Continuous Plankton Recorders that sample near the Aleutians have shown anomalously small copepod taxa, but average to above average biomass during the recent warm years of 2015-2017. Planktivorous auklets that nest in the Western Aleutians at Buldir Island have had good reproductive success 2016-2018, suggesting that zooplankton have been sufficiently abundant during these years to support successful production of chicks. Assessing Atka mackerel condition through length-weight regressions can indicate how well Atka mackerel have been meeting their energetic requirements. Condition was slightly below average in 2018 across the entire Aleutians. However, when assessed at smaller spatial scales, condition was above average in the Western Aleutians, providing further support that zooplankton prey were abundant there. In contrast, condition was below average in the Eastern Aleutians. There was a similar spatial pattern in Atka mackerel condition in 2016, where condition was positive in the Western Aleutians, but decreased to the east. Interestingly, the reproductive success of piscivorous tufted puffins at Buldir was very high in 2013 and 2014, which were also years when they fed chicks more age-0 Atka mackerel than usual. Whether there is a positive relationship between the abundance of age-0 Atka mackerel in tufted puffin chick diets and the abundance of age-0 Atka mackerel in the waters around Buldir is currently unknown but may be worth investigating more closely. Regarding abundance of Atka mackerel as sampled in the bottom trawl survey, the large drop in the Central area biomass was inconsistent with Atka mackerel biomass changes in the other Aleutian Islands areas (Eastern and Western Aleutians), and reported fishing conditions in the region. The lack of any moderate to large catches of Atka mackerel by the survey in only one area may have been due to a combination of environmental factors that could have affected catchability, Atka mackerel availability, and fish movement and behavior. Steller sea lion populations have continued to decline in the Aleutians, suggesting that their predatory impact on Atka has not increased. While data that could inform our assessment of ecosystem risks relevant to Atka are limited, indicators of Atka zooplankton prey and positive condition indices suggest that foraging conditions for Atka have been stable through the recent warm years, particularly in the Western Aleutians. Taken together. The limited ecosystem information suggest no immediate concerns and warrant a risk score of 1 at present.

These results are summarized in the table below:

Considerations			
Assessment-related	Population dynamics	Environmental / ecosystem	Overall (max)
Level 1: Typical to moderately increased concerns	Level 1: Stock trends are typical for the stock and expected given stock dynamics; recent recruitment is within the lower end of the normal range.	Level 1: No apparent environmental/ ecosystem concerns	Level 1: Normal

The overall score of level 1 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. 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 assessment model estimates indicate a declining trend dropping below $B_{40\%}$ from 2019 through 2023. However, since the maximum permissible F_{ABC} will be adjusted downwards (since in 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 2019 recommended ABC based on the Tier 3b F_{ABC} rate (0.44) is 68,500 t. The 2019 OFL is 79,200 t.

The 2020 recommended ABC associated with the Tier 3b F_{ABC} is 63,400 t and the 2020 OFL is 73,400 t. Note that these calculations assume 2019 catches were equal to 86% of the 2019 ABC.

The recommended 2019 ABC is 26% lower than 2018 ABC specified last year (and adopted into regulation by NMFS).

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 are shown below.

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

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

Apportionments of the 2019 and 2020 recommended ABCs based on the 2018 RE model are:

	Random Effects Model	2019 (t)	2020 (t)
Eastern (541+S.Bsea)	**50%**	34,250	31,700
Central (542)	**10%**	6,850	6,340
Western (543)	**40%**	27,400	25,360
Total		68,500	63,400

The apportionments from the 2018 RE model reflect the large drop in the 2018 Central area survey biomass estimate relative to the 2016 estimate. For comparison, the apportionments from the 2017 RE model without the 2018 survey data are shown below.

	2017 Random Effects Model
541[1]	**40.01%**
542	**34.78%**
543	**25.20%**

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. This is unusual (see fishery CPUE map Figure 17.1), and as noted above, inconsistent with reported fishing conditions in the region. Linton and Bence (2008) noted that observation errors within statistical catch-at-age analysis (SCAA) commonly take the form of differences between observed and true fishery catch or survey indices of abundance. Process errors within SCAA generally take the form of annual deviations in recruitment, catchability, or fishery selectivity. Errors within SCAA also can be combinations of observation and process error (Linton and Bence). Several aspects relating to observation error were evaluated for the 2014, 2016, and 2018 surveys (e.g., station location, timing, haul performance, etc.) and very little differences were noted. In addition, the survey protocols for the 2000 and 2018 surveys were compared (years of lowest EAI and CAI survey biomass estimates, respectively), and the only notable differences were the extreme low survey temperatures in 2000 in contrast to the high survey temperatures in 2018. It is puzzling that in the 2000 and 2018 surveys, the (low and high) temperatures were consistently observed across all areas in the Aleutian Islands, but only one area experienced an extreme decrease in biomass (EAI in 2000, CAI in 2018). As such, we suggest that environmental effects and process errors in the forms of catchability, Atka mackerel availability, and fish movement and behavior could have greatly impacted the 2018 survey. Furthermore, we suggest that the process error estimates for the RE model may have been too high, particularly for the CAI. The process error variance term was freely estimated and treated independently among areas. Further research on the estimation of process error variance is needed, including an evaluation of whether it is better to link process error variances between areas and take spatial patterns into account. We also intend to explore the utility of spatial temporal models (e.g., Vector-autoregressive spatio-temporal [VAST] model estimation methods) as an alternative to design-based estimates of survey biomass.

In the interim until further research and evaluations can be done, we recommend applying the 4-survey weighted average for ABC apportionments for 2019 and 2020. This provides values that are intermediate from the two recent RE model results and dampens the change between assessments. Thus, the 4-survey weighted average apportionments from the 2012, 2014, 2016, and 2018 surveys are shown below with the **recommended ABC apportionments for 2019 and 2020**.

	Survey Year				2019 & 2020 Apportionment	2019 ABC	2020 ABC
	2012	2014	2016	2018			
541+SBS	12%	42%	35%	38%	35%	23,970	22,190
542	39%	28%	30%	7%	21%	14,390	13,310
543	48%	30%	35%	55%	44%	30,140	27,900
Weights	8	12	18	27			
Total ABC						68,500	63,400

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

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. It is notable that in the last two years (2016-2017) the Atka mackerel fishery has taken on average about 54 and 23% respectively, of the total Aleutian Islands sponge and coral catches. 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 Pacifc cod, Pacifc 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 370 t of non-target discards in the Aleutian Islands from 2016 to 2017. 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 297 t over 2016-2017.

Data Gaps and Research Priorities

More information on 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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Literature Cited

Alaska Fisheries Science Center. 2016. Wholesale market profiles for Alaska groundfish and crab fisheries. 134 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA98115

Aydin, K., S. Gaichas, I. Ortiz, D. Kinzey, and N. Friday. 2007. A comparison of the Bering Sea, Gulf of Alaska, and Aleutian Islands large marine ecosystems through food web modeling. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-178, 298 p.

Alverson, D.L., and M.J. Carney. 1975. A graphic review of the growth and decay of population cohorts. J. Cons. Int. Explor. Mer 36:133-143.

Anderl, D.M., A. Nishimura, and S.A. Lowe. 1996. Is the first annulus on the otolith of the Atka mackerel, *Pleurogrammus monopterygius*, missing? Fish. Bull. 94:163-169.

Bailey, K.M., J.F. Piatt, T.C. Royer, S.A. Macklin, R.K. Reed, M. Shima, R.C. Francis, A.B. Hollowed, D.A. Somerton, R.D. Brodeur, W.J. Ingraham, P.J. Anderson, and W.S. Wooster. 1995. ENSO events in the northern Gulf of Alaska, and effects on selected marine fisheries. Calif. Coop. Oceanic Fish. Invest. Rep. 36:78-96.

Barbeaux, S., J. Ianelli, and E. Brown. 2004. Stock assessment of Aleutian Islands region pollock. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Batten, S. 2016. Continuous plankton recorder data from the Northeast Pacific: lower trophic level in 2015. In S. Zador and E. Yasumiishi (Eds.) Ecosystem Considerations 2016, Status of the Aleutian Islands Marine Ecosystem. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Batten, S. 2018. Continuous plankton recorder data from the Aleutian Islands and southern Bering Sea through 2017. In S. Zador and I. Ortiz (Eds.) Ecosystem Status Report 2016 Aleutian Islands. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Boldt, J.L. (Ed). 2005. Ecosystem indicators for the North Pacific and their implications for stock assessment: Proceedings of first annual meeting of NOAA's Ecological Indicators research program. AFSC Processed Rep.2005-04, Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115.

Bond, N. 2018. North Pacific climate overview. In S. Zador and I. Ortiz (Eds.) Ecosystem Status Report 2016 Aleutian Islands. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Brodziak, J., Ianelli, J., Lorenzen, K., and Methot R.D. Jr. (eds) (2011) Estimating natural mortality in stock assessment applications. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-119, 38 p.

Canino, M.F, I.B. Spies, M.M. Hollowed, and J.L. Guthridge. 2008. Mating behavior of Atka mackerel inferred from genetic analysis of egg masses in the wild and in captivity. Marine and Coastal Fisheries.

Canino, M.F., I.B. Spies, S.A. Lowe, and W.S. Grant. 2010. Highly discordant nuclear and mitochondrial DNA diversities in Atka mackerel. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science. 2:388–398, 2010 DOI: 10.1577/C09-24.1

Center for the Advancement of Population Assessment Methodology (CAPAM), NOAA/NMFS. 2013. P. Crone, M. Maunder, J. Valero, J. McDaniel, and B. Semmens, *eds*. Selectivity: theory, estimation, and application in fishery stock assessment models. Workshop Series Report, June 2013.

Charnov, E.L. 1993. Life history invariants some explorations of symmetry in evolutionary ecology. Oxford University Press Inc., New York. 167p.

Cooper, D. W., S. F. McDermott and J. N. Ianelli. 2010. Spatial and temporal variability in Atka mackerel female maturity at length and age. Marine and Coastal Fisheries, 2:329-338.

http://www.tandfonline.com/doi/abs/10.1577/C09-45.1

DeRobertis, A. and K. Williams. 2008. Length –weight relationships in fisheries studies: the standard allometric model should be applied with caution. Trans. Amer. Fish. Soc. 137:707-719, 2008.

Dorn, M.W. 1992. Detecting environmental covariates of Pacific whiting *Merluccius productus* growth using a growth-increment regression model. Fish. Bull. 90:260-275.

Dragoo, D.E., G.V. Byrd, and D.B. Irons. 2001. Breeding status, population trends, and diets of seabirds in Alaska, 2000. U.S. Fish and Wildl. Serv. Report AMNWR 01/07.

Fournier, D. 1998. An Introduction to AD model builder for use in nonlinear modeling and statistics. Otter Research Ltd. PO Box 2040, Sidney BC V8L3S3, Canada, 53p.

Fournier, D., and C. P. Archibald. 1982. A general theory for analyzing catch at age data. Can. J. Fish. Aquat. Sci. 39:1195-1207.

Francis, R.C., and S.R. Hare. 1994. Decadal scale regime shifts in the large marine ecosystems of the northeast Pacific: A case for historical science. Fish. Oceanogr. 3(1):279-291.

Francis, R.I.C.C. 1992. Use of risk analysis to assess fishery management strategies: a case study using orange roughy (*Hoplostethus atlanticus*) on the Chatham Rise, New Zealand. Can. J. Fish. Aquat. Sci. 49: 922-930.

Francis, R.I.C.C 2011. Data weighting in statistical fisheries stock assessment models. Can. Journ. Fish. Aquat. Sci. 1138: 1124-1138.

Fritz, L.W. 1993. Trawl locations of walleye pollock and Atka mackerel fisheries in the Bering Sea, Aleutian Islands, and Gulf of Alaska from 1977-1992. AFSC Processed Report 93-08, NMFS, 7600 Sand Point Way, NE, Seattle, WA 98115. 162 pp.

Fritz, L.W. and S.A. Lowe. 1998. Seasonal distributions of Atka mackerel (*Pleurogrammus monopterygius*) in commercially-fished areas of the Aleutian Islands and Gulf of Alaska. NOAA Tech. Memo. NMFS-AFSC-92. 29p.

Gorbunova, N.N. 1962. Razmnozhenie I razvite ryb semeistva terpugovykh (Hexagrammidae) (Spawning and development of greenlings (family Hexagrammidae)). Tr. Inst. Okeanol., Akad. Nauk SSSR 59:118-182. In Russian. (Trans. By Isr. Program Sci. Trans., 1970, p. 121-185 in T.S. Rass (editor), Greenlings: taxonomy, biology, interoceanic transplantation; available from the U.S. Dep. Commer., Natl. Tech. Inf. Serv., Springfield, VA., as TT 69-55097).

Guthridge, J.L. and N. Hillgruber. 2008. Embryonic development of Atka mackerel (*Pleurogrammus monopterygius*) and the effect of temperature. Pages 43-65 *in* S. F. McDermott, M. Canino, N. Hillgruber, D. W. Cooper, I. Spies, J. Guthridge, J. N. Ianelli, P. Woods. 2008. Atka mackerel *Pleurogrammus monopterygius* reproductive ecology in Alaska. North Pacific Research Board Final report, 163p.

Hare, S.R., and N.J. Mantua. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Prog. Oceanogr. 47:103-145.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. 82: 898-903.

Hollowed, A.B., S.R. Hare, and W.S. Wooster. 2001. Pacific Basin climate variability and patterns of Northeast Pacific marine fish production. Prog. Oceanogr. 49:257-282.

Hunt, G.L. Jr., H. Kato, and S.M. McKinnell [eds.] 2000. Predation by marine birds and mammals in the subarctic north Pacific Ocean. North Pacific Marine Science Organization (PICES) Scientific Report #25. 165 p.

Ianelli, J.N, T. Honkalehto, S. Barbeaux, B. Fissel, and S. Kotowicki. 2016. Assessment of the walleye pollock stock in the Eastern Bering Sea. *In* Stock Assessment and Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, Alaska, 99510.

Kajimura, H. 1984. Opportunistic feeding of the northern fur seal *Callorhinus ursinus*, in the eastern north Pacific Ocean and eastern Bering Sea. NOAA Tech. Rept. NMFS SSRF-779. USDOC, NOAA, NMFS, 49 pp.

Kendall, A.W., and J.R. Dunn. 1985. Ichthyoplankton of the continental shelf near Kodiak Island, Alaska. U.S. Department of Commerce, NOAA Technical Report NMFS 20, 89 p.

Kimura, D.K. 1989. Variability in estimating catch-in-numbers-at-age and its impact on cohort analysis. P.57-66, In Effects of ocean variability on recruitment and evaluation of parameters used in stock assessment models, R.J. Beamish and G.A. McFarlane (editors), Can. Spec. Pub. Fish. Aquat. 108.

Kimura D.K. and L.L. Ronholt. 1988. In R.G. Bakkala (editor), Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1987, p. 143-171. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-139.

Kimura, D.K., and S. Chikuni. 1987. Mixtures of empirical distributions: an iterative application of the age-length key. Biometrics 43: 23-35.

Ladd, C. 2016. Eddies in the Aleutian Islands. In S. Zador and E. Yasumiishi (Eds.) Ecosystem Considerations 2016, Status of the Aleutian Islands Marine Ecosystem. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Ladd, C. 2018. Eddies in the Aleutian Islands. In S. Zador and I. Ortiz (Eds.) Ecosystem Status Report 2016 Aleutian Islands. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Laman, N. 2016. Water temperature data collections – Aleutian Islands trawl surveys. In S. Zador and E. Yasumiishi (Eds.) Ecosystem Considerations 2016, Status of the Aleutian Islands Marine Ecosystem. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Laman, N. 2018. Aleutian Islands trawl survey water temperature analysis. In S. Zador and I. Ortiz (Eds.) Ecosystem Status Report 2016 Aleutian Islands. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Laman, E.A., C.N. Rooper, K. Turner, S. Rooney, D.W. Cooper, and M. Zimmerman. 2017. Using species distribution models to describe essential fish habitat in Alaska. Can. J. Fish. Aquat. Sci. Published on the web 29 September 2017, https://doi.org/10.1139/cjfas-2017-0181

Lauth, R.R., and E. Acuna. 2009. Results of the 2008 eastern Bering Sea continental shelf bottom trawl survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo., NMFS-AFSC-195, 229 p.

Lauth, R.R., J. Guthridge, D. Nichol, S.W. Mcentire, and N. Hillgruber. 2007a. Timing and duration of mating and brooding periods of Atka mackerel (*Pleurogrammus monopterygius*) in the North Pacific Ocean. Fish. Bull., U.S. 105:560-570. http://fishbull.noaa.gov/1054/lauth.pdf

Lauth, R.R., S.W. Mcentire, and H.H. Zenger, Jr. 2007b. Geographic distribution, depth range, and description of Atka mackerel *Pleurogrammus monopterygius* nesting habitat in Alaska. Alaska Fish. Res. Bull. 12:165-186. http://www.adfg.state.ak.us/pubs/afrb/vol12_n2/lautv12n2.pdf

Lee, J.U. 1985. Studies on the fishery biology of the Atka mackerel *Pleurogrammus monopterygius* (Pallas) in the north Pacific Ocean. Bull. Fish. Res. Dev. Agency, 34, pp.65-125.

Levada, T.P. 1979. Comparative morphological study of Atka mackerel. Pac. Sci. Res. Inst. Fish. Oceanogr. (TINRO), Vladivostok, U.S.S.R., Unpublished manuscript.

Linton, B.C and J.R. Bence. 2008. Evaluating methods for estimating process and observation error variances in statistical catch-at-age analysis. Fish. Res. 94(2008) 26-35. dx.doi.org/10.1016/j.fishres.2008.06.014

Livingston, P.A., M-S. Yang, and G.M. Lang. Unpublished manuscript. Comparison of the role of walleye pollock in groundfish food webs of the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska. NMFS. Alaska Fisheries Science Center, 7600 Sand Point Way NE., Seattle, WA 98115.

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. Journal of Fish Biology. 49:627-647.

Lowe, S.A. 1992. Atka mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions as Projected for 1993. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Lowe, S.A., D.M. Van Doornik, and G.A. Winans. 1998. Geographic variation in genetic and growth patterns of Atka mackerel, *Pleurogrammus monopterygius* (Hexagrammidae), in the Aleutian archipelago. Fish. Bull. U.S. 96:502-515.

Lowe, S., J. Ianelli, H. Zenger, and R. Lauth. 2003. Atka mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Lowe, S., J. Ianelli, H. Zenger, K. Aydim, and R. Lauth. 2004. Stock assessment of Aleutian Islands Atka mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Lowe, S., J. Ianelli, H. Zenger, and R. Reuter. 2002. Atka mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Lowe, S., J. Ianelli, M. Wilkins, K. Aydin, R. Lauth, and I. Spies. 2007. Stock assessment of Aleutian Islands Atka mackerel. *In* Stock Assessment and Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, Alaska, 99510.

Lowe, S., J. Ianelli, M. Wilkins, K. Aydin, R. Lauth, and I. Spies. 2008. Stock assessment of Aleutian Islands Atka mackerel. *In* Stock Assessment and Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, Alaska, 99510.

Lowe, S., J. Ianelli, M. Wilkins, K. Aydin, R. Lauth, and I. Spies. 2011. Stock assessment of Aleutian Islands Atka mackerel. *In* Stock Assessment and Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, Alaska, 99510.

Lowe, S., J. Ianelli, and W. Palsson. 2012. Stock assessment of Aleutian Islands Atka mackerel. *In* Stock Assessment and Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, Alaska, 99510.

Lowe, S., J. Ianelli, W. Palsson. 2013. Stock assessment of Aleutian Islands Atka mackerel. *In* Stock Assessment and Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, Alaska, 99510.

Lowe, S., J. Ianelli, W. Palsson. 2015. Stock assessment of Aleutian Islands Atka mackerel. *In* Stock Assessment and Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, Alaska, 99510.

Lowe, S., J. Ianelli, W. Palsson. 2016. Stock assessment of Aleutian Islands Atka mackerel. *In* Stock Assessment and Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, Alaska, 99510.

Lowe, S., J. Ianelli, W. Palsson. 2017. Stock assessment of Aleutian Islands Atka mackerel. *In* Stock Assessment and Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, Alaska, 99510.

Lowe, S.A. and L.W. Fritz. 1996. Atka mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions as Projected for 1997. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Lowe, S.A. and L.W. Fritz. 1997. Atka mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions as Projected for 1999. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Lowe, S.A., R.F. Reuter and H. Zenger. 2001. Atka mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Malecha, P.W., R.P. Stone, and J. Heifetz. 2005. Living substrate in Alaska: Distribution, abundance, and species associations. Pages 289-299 *in* P.W. Barnes and J.P. Thomas, editors. Benthic habitats and the effects of fishing. American Fisheries Society, Symposium 41, Bethesda, Maryland.

Materese, A.C., D. M. Blood, S. J. Piquelle, and J. L. Benson. 2003. Atlas of abundance and distribution patterns of ichthyoplankton from the Northeast Pacific Ocean and Bering Sea ecosystems based on research conducted by the Alaska Fisheries Science Center (1972-1996). U.S. Dep. Commer., NOAA Professional Paper, NMFS-1, 281 p.

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

McDermott, S.F. 2003. Improving abundance estimation of a patchily distributed fish, Atka mackerel (*Pleurogrammus monopterygius*). Dissertation, University of Washington, 150 p.

McDermott, S.F., K.E. Pearson and D.R. Gunderson. 2007. Annual fecundity, batch fecundity, and oocyte atresia of Atka mackerel (*Pleurogrammus monopterygius*) in Alaskan waters. Fish Bull. 105:19-29.

McDermott, S., K. Rand, M. Levine, J. Ianelli, and E. Logerwell. 2014. Small-scale Atka mackerel population abundance and movement in the central Aleutian Islands, an area of continuing Steller sea lion decline. North Pacific Research Board Final Report:109.

McDermott, S. F., L. W. Fritz, and V. Haist. 2005. Estimating movement and abundance of Atka mackerel (*Pleurogrammus monopterygius*) with tag-release data. Fish. Oceanogr. 14:113-130. http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2419.2005.00380.x/pdf

McDermott, S.F. and S.A. Lowe. 1997. The reproductive cycle of Atka mackerel, *Pleurogrammus monopterygius*, in Alaska waters. Fish. Bull. U.S. 95:231-333.

Mel'nikov, I.V. and A. YA. Efimkin. 2003. The young of the northern Atka mackerel Pleurogrammus monopterygius in the epipelagic zone over deep-sea areas of the northern Pacific Ocean. J. Ichthyol. 43: 424-437.

Merrick, R.L., M.K. Chumbley, and G.V. Byrd. 1997. Diet diversity of Steller sea lions (*Eumetopias jubatus*) and their population decline in Alaska: a potential relationship. Can. J. Fish. Aquat. Sci.54:1342-1348.

Methot, R.D. 1989. Synthetic estimates of historical abundance and mortality for northern anchovy. In E. Edwards and B. Megrey (eds.) Mathematical analysis of fish stock dynamics: reviews and current applications. Amer. Fish. Soc. Symposium 6:66-82.

Methot, R.D. 1990. Synthesis model: An adaptable framework for analysis of diverse stock assessment data. INPFC Bull. 50:259-277.

Mordy, C. W., P. J. Stabeno, C. Ladd, S. Zeeman, D. P. Wisegarver, S. A. Salo, and G. L. Hunt. 2005. Nutrients and primary production along the eastern Aleutian Island Archipelago. Fisheries Oceanography 14:55-76.

Nichol D.G., Somerton D.A. 2002. Diurnal vertical migration of the Atka mackerel *Pleurogrammus monopterygius* as shown by archival tags. Mar Ecol Prog Ser 239: 193-207.

NMFS. 1995. Status review of the Unites States Steller sea lion (*Eumetopias jubatus*) population. National Marine Mammal Laboratory, Alaska Fishery Science Center, National Marine Fisheries Service, 7600 Sand Point Way, NE, Seattle, WA 98115.

NMFS. 2014a. Endangered Species Act – Section 7 Consultation Biological Opinion: Authorization of the Alaska groundfish fisheries under the proposed revised Steller Sea Lion protection measures. NMFS, Alaska Region. P. O. Box 21668, Juneau, AK 99802. Available from: http://alaskafisheries.noaa.gov/protectedresources/stellers/section7.htm

NMFS. 2014b. Final Environmental Impact Statement Steller Sea Lion Protection Measures for Groundfish Fisheries in the Bering Sea and Aleutian Islands Management. NMFS, Alaska

Region. P. O. Box 21668, Juneau, AK 99802. Available from: http://alaskafisheries.noaa.gov/sustainablefisheries/sslpm/eis/default.htm

Okkonen, S. R. 1996. The influence of an Alaskan Stream eddy on flow through Amchitka Pass. Journal of Geophysical Research-Oceans 101:8839-8851.

Olson, J. Observed fishing effort in the Eastern Bering Sea, Aleutian Islands, and Gulf of Alaska. In S. Zador. (ed) Ecosystem considerations 2015 Status of the Alaska's marine ecosystems. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Ortiz, I. 2007. Ecosystem Dynamics of the Aleutian Islands. Ph.D. Thesis. University of Washington, Seattle.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. Int. Explor. Mer 39(2):175-192.

Rand, K. M., D. A. Beauchamp, and S. A. Lowe. 2010. Longitudinal growth differences and the influence of diet quality on Atka mackerel of the Aleutian Islands, Alaska: using a bioenergetics model to explore underlying mechanisms. Marine and Coastal Fisheries 2:362-374.

Renner, H. and N. Rojek. 2018. Seabird monitoring summary from Alaska Maritime National Wildlife Refuge. In S. Zador and I. Ortiz (Eds.) Ecosystem Status Report 2016 Aleutian Islands. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Rikhter, V.A., and V.N. Efanov. 1976. On one of the approaches to estimation of natural mortality of fish populations. ICNAF Res. Doc. 76/VI/8. Serial N. 3777. 13p.

Roff, D.A. 1986. The evolution of life history parameters in teleosts. Can. J. Fish. Aquat. Sci. 41:989-1000.

Rutenberg, E.P. 1962. Survey of the fishes family Hexagrammidae. Trudy Instituta Okeanologii Akademiya Nauk SSSR 59:3-100. In Russian. (Translated by the Israel Program for Scientific Translations, 1970. Pages 1-103 in T.S. Rass (editor), Greenlings: taxonomy, biology, interoceanic transplantation; available from the U.S. Department of Commerce, National Technical Information Services, Springfield, Virginia, as TT 69-55097).

Sepez, J., C. Package, J. Isaacs, and K. Nixon. 2003. NOAA Fisheries TEK Database: A Compilation of Written Source Material Documenting the Traditional Ecological Knowledge of Alaska Natives, With a Focus on Marine Resources. Report prepared for National Marine Fisheries Service, Alaska Fisheries Science Center, Seattle, WA.

Sinclair, E.H., D.S. Johnson, T.K. Zeppelin, and T.S. Gelatt. 2013. Decadal variation in the diet of western stock Steller sea lions (*Eumetopias jubatus*). U.S. Dep. Commer., NOAA Tech. Memo., NMFS-AFSC-248, 67 p.

Sinclair E.H. and T.K. Zeppelin. 2002. Seasonal and spatial differences in diet in the western stock of Steller sea lions (*Eumetopias jubatus*). Journal of Mammalogy 83(4):973-990.

Springer, A.M., J.F. Piatt, V.P. Shuntov, G.B. Van Vliet, V.L. Vladimirov, A.E. Kuzin, A.S. Perlov. 1999. Prog. In Oceanogr. 43(1999)443-487.

Stabeno, P. J., D. G. Kachel, N. B. Kachel, and M. E. Sullivan. 2005. Observations from moorings in the Aleutian Passes: temperature, salinity and transport. Fisheries Oceanography 14:39-54.

Stewart, I. J. and O. S. Hamel. (2014). Bootstrapping of sample sizes for length- or age-composition data used in stock assessments, Can. J. Fish. Aquat. Sci. 71:581–588.

Stone, R.P. 2006. Coral habitat in the Aleutian Islands of Alaska: depth distribution, fine-scale species associations, and fisheries interactions. Coral Reefs 25:229-238.

Thompson, G.G., and M.W. Dorn. 2003. Assessment of the Pacific cod stock in the Eastern Bering Sea and Aleutian Islands Area. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Yang, M-S. 1996. Diets of the important groundfishes in the Aleutian Islands in summer 1991. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-60. 105 p.

Yang, M-S. 1999. The trophic role of Atka mackerel, *Pleurogrammus monopterygius*, in the Aleutian Islands area. Fishery Bulletin 97(4):1047-1057.

Yang, M-S. 2003. Food habits of the important groundfishes in the Aleutian Islands in 1994 and 1997. AFSC Processed Rep.2003-07, Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115. P. 233.

Zador, S. (ed.), 2015. Ecosystem considerations for 2016 Status of the Alaska's marine ecosystems. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Zolotov, O.G. 1993. Notes on the reproductive biology of *Pleurogrammus monopterygius* in Kamchatkan waters. J. of Ichthy. 33(4), pp. 25-37.

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) 2018 projected total year catch (the 2018 catch is assumed equal to the 2018 TAC of 71,000 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	71,000[b]	92,000	71,000	108,600

a) Atka mackerel was not a reported species group until 1978.

b) 2018 projected total year catch (the 2018 catch is assumed equal to the 2018 TAC of 71,000 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 1995 are available in Lowe *et al*. (2013). Catches, ABCs, and TACs are in metric tons.

Year		Eastern (541)	Central (542)	Western (543)	Total	Year		Eastern (541)	Central (542)	Western (543)	Total
1995	Catch	14,199	50,387	16,966	81,552	2007	Catch	22,943	26,723	9,097	58,763
	ABC	13,500	55,900	55,600	125,000		ABC	23,800	29,600	20,600	74,000
	TAC	13,500	50,000	16,500	80,000		TAC	23,800	29,600	9,600	63,000
1996	Catch	28,173	33,524	42,246	103,943	2008	Catch	19,112	22,926	16,045	58,083
	ABC	26,700	33,600	55,700	116,000		ABC	19,500	24,300	16,900	60,700
	TAC	26,700	33,600	45,857	10,657		TAC	19,500	24,300	16,900	60,700
1997	Catch	16,318	19,990	29,537	65,845	2009	Catch	26,417	30,137	16,253	72,807
	ABC	15,000	19,500	32,200	66,700		ABC	27,000	33,500	23,300	83,800
	TAC	15,000	19,500	32,200	66,700		TAC	27,000	32,500	16,900	76,400
1998	Catch	11,597	20,029	24,248	55,874	2010	Catch	23,608	26,388	18,650	68,646
	ABC	14,900	22,400	27,000	64,300		ABC	23,800	29,600	20,600	74,000
	TAC	14,900	22,400	27,000	64,300		TAC	23,800	29,600	20,600	74,000
1999	Catch	16,245	21,596	15,082	52,923	2011	Catch	40,891	10,713	205	51,809
	ABC	17,000	25,600	30,700	73,300		ABC	40,300	24,000	21,000	85,300
	TAC	17,000	22,400	27,000	66,400		TAC	40,300	11,280	1,500	53,080
2000	Catch	13,152	20,575	8,713	42,440	2012	Catch	37,308	10,323	195	47,826
	ABC	16,400	24,700	29,700	70,800		ABC	38,500	22,900	20,000	81,400
	TAC	16,400	24,700	29,700	70,800		TAC	38,500	10,763	1,500	50,763
2001	Catch	7,905	30,365	18,264	56,534	2013	Catch	15,777	7,284	120	23,181
	ABC	7,800	33,600	27,900	69,300		ABC	16,900	16,000	17,100	50,000
	TAC	7,800	33,600	27,900	69,300		TAC	16,900	7,520	1,500	25,920
2002	Catch	4,606	20,699	16,737	42,042	2014	Catch	21,185	9,520	242	30,947
	ABC	5,500	23,800	19,700	49,000		ABC	21,652	20,574	21,905	64,131
	TAC	5,500	23,800	19,700	49,000		TAC	21,652	9,670	1,000	32,322
2003	Catch	10,725	25,435	17,885	54,045	2015	Catch	26,343	16,672	10,253	53,268
	ABC	10,650	29,360	22,990	63,000		ABC	38,492	33,108	34,400	106,000
	TAC	10,650	29,360	19,990	60,000		TAC	27,000	17,000	10,500	54,500
2004	Catch	10,840	30,169	19,555	60,564	2016	Catch	28,360	15,795	10,330	54,485
	ABC	11,240	31,100	24,360	66,700		ABC	30,832	27,216	32,292	90,340
	TAC	11,240	31,100	20,660	63,000		TAC	28,500	16,000	10,500	55,500
2005	Catch	7,201	35,069	19,744	62,014	2017	Catch	34,269	17,860	12,322	64,451
	ABC	24,550	52,830	46,620	124,000		ABC	34,890	30,330	21,980	87,200
	TAC	7,500	35,500	20,000	63,000		TAC	34,500	18,000	12,500	65,000
2006	Catch	7,422	39,836	14,638	61,896	2018*	Catch	36,500	21,000	13,500	71,000
	ABC	21,780	46,860	41,360	110,200		ABC	36,820	32,000	23,180	92,000
	TAC	7,500	40,000	15,500	63,000		TAC	36,500	21,000	13,500	71,000

*2018 projected total year catches by region assumed equal to the 2018 TACs

Table 17.3. Numbers of Atka mackerel length-weight data, length frequency, and aged samples based on NMFS observer data 1990-2017.

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
2018	4,921	26,472	1,318

Table 17.4. Estimated catch-in-numbers at age (in millions) of Atka mackerel from the BSAI region, 1977-2017. 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

[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 subregion, 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	1-100	193	49,115	1,675
543	101-200	692	124,806	40,675
	201-300		1,559	111
	301-500	0	164	0
	Total	885	175,644	42,461
Central	1-100	0	103,588	1,011,991
542	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	1-100		86,800	11
541	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	1-100	6	0	429
Bering Sea	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 survey was conducted in 2008.

		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

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 2012, 2014, and 2016.

		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
Avg 2012, 2014, 2016		0.045	0.171	0.398	0.507	0.662	0.719	0.792	0.888	0.898	0.845	0.951

Table 17.8b. Year-specific fishery weight-at-age (kg) values used to obtain expected fishery catch biomass. The 2018 fishery weight-at-age values are the average of the last three years (2015-2017).

		Age										
	Year	1	2	3	4	5	6	7	8	9	10	11+
Fishery Foreign	1977	0.069	0.132	0.225	0.306	0.400	0.470	0.507	0.379	0.780	0.976	1.072
	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
Ave. 2015-2017	2018	0.069	0.228	0.429	0.594	0.649	0.705	0.730	0.751	0.792	0.779	0.825

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 and excluding the 1986 survey age composition 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	1.17	1.35
Steepness	0.8	0.8
SigmaR	0.46	0.48
Natural mortality	0.3	0.3
Fishery Average Effective *N*	168	176
Survey Average Effective *N*	90	106
RMSE Survey	0.244	0.246
-log Likelihoods		
Number of Parameters	518	530
Survey index	8.18	8.67
Catch biomass	0.02	0.02
Fishery age comp	130.8	132.19
Survey age comp	27.54	21.58
Sub total	166.56	162.46
-log Penalties		
Recruitment	-4.9	-1.94
Selectivity constraint	95.35	91.99
Prior	0.3	1.11
Sub Total	90.8	91.2
Total	257.34	253.62
Fishing mortalities (full selection)		
F_{2018}	0.278	0.367
$F_{2018}/F_{40\%}$	0.73	.83
Stock abundance		
Initial Biomass (t, 1977)	717,242	695,240
CV	21%	20%
Assessment year total biomass (t)	569,490	505,730
CV	20%	20%
2006 year class (millions at age 1)	1007	938
CV	16%	15%
2012 year class (millions at age 1)	715	745
CV	23%	19%

Table 17.11. Estimates of Atka mackerel fishery (over time, 1977-2017) and survey selectivity at age (normalized to have a maximum of 1.0). The average selectivity over 2013-2017 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	0.074	0.532	1.000	0.952	0.575	0.349	0.210	0.128	0.091	0.091
1978	0.007	0.072	0.614	0.928	1.000	0.670	0.413	0.240	0.141	0.099	0.099
1979	0.007	0.052	0.383	1.000	0.960	0.668	0.448	0.249	0.140	0.097	0.097
1980	0.007	0.052	0.334	0.894	1.000	0.769	0.606	0.303	0.157	0.107	0.107
1981	0.008	0.056	0.347	0.724	0.937	0.955	1.000	0.375	0.184	0.125	0.125
1982	0.006	0.041	0.206	0.500	1.000	0.907	0.592	0.288	0.156	0.107	0.107
1983	0.006	0.041	0.227	0.513	0.818	1.000	0.656	0.310	0.174	0.119	0.119
1984	0.006	0.045	0.254	0.606	0.861	1.000	0.797	0.412	0.232	0.152	0.152
1985	0.007	0.056	0.447	0.816	0.961	1.000	0.853	0.582	0.356	0.217	0.217
1986	0.007	0.061	0.475	0.841	0.986	1.000	0.962	0.794	0.547	0.304	0.304
1987	0.007	0.061	0.464	0.958	1.000	0.915	0.885	0.767	0.551	0.379	0.379
1988	0.005	0.046	0.371	1.000	0.810	0.637	0.600	0.507	0.381	0.264	0.264
1989	0.006	0.053	0.377	1.000	0.950	0.731	0.635	0.529	0.401	0.299	0.299
1990	0.006	0.049	0.387	1.000	0.919	0.694	0.606	0.502	0.389	0.297	0.297
1991	0.006	0.047	0.286	0.833	1.000	0.866	0.721	0.573	0.438	0.348	0.348
1992	0.006	0.043	0.238	0.723	1.000	0.947	0.796	0.636	0.488	0.392	0.392
1993	0.006	0.038	0.202	0.596	0.929	1.000	0.852	0.693	0.531	0.422	0.422
1994	0.005	0.032	0.174	0.515	0.880	1.000	0.881	0.762	0.580	0.443	0.443
1995	0.005	0.031	0.164	0.536	0.832	0.994	1.000	0.854	0.647	0.496	0.496
1996	0.004	0.028	0.144	0.481	0.769	0.939	1.000	0.907	0.641	0.484	0.484
1997	0.004	0.026	0.147	0.484	0.836	0.939	1.000	0.911	0.672	0.501	0.501
1998	0.004	0.025	0.139	0.519	0.818	0.920	1.000	0.939	0.689	0.495	0.495
1999	0.003	0.024	0.153	0.595	0.768	0.890	0.966	1.000	0.687	0.461	0.461
2000	0.003	0.021	0.191	0.525	0.727	0.858	0.953	1.000	0.629	0.399	0.399
2001	0.002	0.019	0.180	0.520	0.743	0.872	1.000	0.903	0.580	0.364	0.364
2002	0.002	0.020	0.153	0.500	0.701	0.823	1.000	0.811	0.511	0.332	0.332
2003	0.003	0.024	0.210	0.549	0.805	0.906	1.000	0.874	0.524	0.345	0.345
2004	0.004	0.035	0.267	0.686	0.933	0.981	1.000	0.854	0.557	0.366	0.366
2005	0.004	0.046	0.315	0.707	0.909	0.963	1.000	0.766	0.518	0.353	0.353
2006	0.004	0.061	0.515	0.695	0.870	0.922	1.000	0.767	0.544	0.370	0.370
2007	0.004	0.062	0.525	0.743	0.737	0.817	1.000	0.825	0.587	0.377	0.377
2008	0.004	0.055	0.429	0.685	0.716	0.854	1.000	0.895	0.740	0.410	0.410
2009	0.004	0.044	0.298	0.640	0.803	0.848	1.000	0.897	0.704	0.458	0.458
2010	0.004	0.040	0.245	0.704	0.890	1.000	0.993	0.893	0.762	0.508	0.508
2011	0.004	0.034	0.206	0.511	0.824	1.000	0.940	0.815	0.798	0.672	0.672
2012	0.003	0.033	0.214	0.468	0.744	1.000	0.992	0.862	0.840	0.828	0.828
2013	0.003	0.037	0.353	0.720	0.763	0.943	1.000	0.902	0.815	0.705	0.705
2014	0.003	0.040	0.816	0.587	0.853	1.000	0.914	0.966	0.900	0.634	0.634
2015	0.002	0.022	0.220	0.341	0.515	0.681	0.820	1.000	0.753	0.358	0.358
2016	0.002	0.018	0.170	0.479	0.366	0.625	0.803	1.000	0.918	0.326	0.326
2017	0.002	0.017	0.110	0.471	0.657	0.617	1.000	0.944	0.898	0.519	0.519
Ave. 2013-2017	0.002	0.025	0.321	0.509	0.636	0.770	0.925	0.975	0.916	0.605	0.605
Survey	0.014	0.127	0.511	0.717	0.656	0.690	0.894	1.000	0.888	0.766	0.766

Table 17.12. Estimated BSAI Atka mackerel begin-year numbers at age in millions, 1977-2018.

	Age										
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11+**
1977	376	618	393	138	108	61	55	46	37	28	95
1978	2184	278	453	269	89	69	42	38	33	27	90
1979	545	1616	204	308	176	57	47	29	28	24	85
1980	321	404	1192	146	210	120	40	33	21	20	80
1981	351	238	298	865	103	146	85	29	24	16	74
1982	225	260	176	217	621	73	104	60	21	18	66
1983	307	167	192	129	157	440	52	75	44	15	62
1984	333	227	123	141	94	114	317	38	55	32	57
1985	533	247	168	89	99	64	77	218	27	40	65
1986	459	394	181	117	59	64	42	51	151	19	76
1987	625	340	290	127	78	39	42	28	35	106	68
1988	493	462	250	206	86	53	26	29	19	25	125
1989	1234	365	341	179	138	58	36	18	20	14	108
1990	589	914	270	247	125	97	41	26	13	15	89
1991	343	436	676	196	174	88	69	30	19	10	76
1992	535	254	322	490	136	119	61	48	21	13	61
1993	899	396	188	233	337	91	80	41	33	15	53
1994	358	665	292	135	158	216	57	51	27	23	47
1995	354	265	490	209	90	98	131	36	33	18	47
1996	921	262	195	346	133	52	54	72	20	20	41
1997	213	681	192	136	209	71	26	26	35	11	35
1998	330	157	501	137	89	126	41	15	15	22	30
1999	776	244	116	357	87	52	71	23	8	9	32
2000	1762	574	180	83	233	55	32	42	13	5	27
2001	1147	1305	424	128	55	148	34	19	25	8	22
2002	1287	849	961	299	82	33	86	19	11	15	20
2003	278	953	626	689	199	52	20	51	11	7	24
2004	374	206	703	448	466	128	33	13	32	8	21
2005	507	277	152	504	305	307	84	21	8	22	20
2006	352	375	204	108	342	201	201	54	14	6	30
2007	938	261	276	141	73	225	131	129	36	10	25
2008	796	695	192	190	94	49	149	84	85	24	24
2009	239	589	510	132	125	62	31	93	53	55	33
2010	492	177	432	351	83	75	37	18	54	33	57
2011	337	364	130	304	223	50	44	21	11	33	59
2012	556	250	269	93	209	146	32	28	14	7	61
2013	745	412	184	192	64	137	91	20	18	9	42
2014	494	552	304	133	135	45	95	63	14	12	36
2015	238	366	408	212	94	94	31	66	43	9	33
2016	424	177	270	287	143	61	58	19	38	26	28
2017	445	314	130	193	190	95	38	34	11	22	36
2018	471	330	232	93	124	116	59	21	19	6	37
Average	600	450	335	238	162	106	69	45	30	20	52

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 1977-2019).

	Age 1+ biomass (t)			Female spawning biomass (t)		
Year	Estimate	LCI	UCI	Estimate	LCI	UCI
1977	695,240	424,956	965,524	173,470	100,664	246,276
1978	775,990	466,702	1,085,278	179,580	100,386	258,774
1979	884,110	523,627	1,244,593	193,950	104,827	283,073
1980	1,032,000	606,425	1,457,575	226,480	124,491	328,469
1981	984,740	576,590	1,392,890	287,140	161,210	413,070
1982	930,330	542,701	1,317,959	315,310	176,119	454,501
1983	824,020	481,608	1,166,432	288,260	161,517	415,003
1984	734,510	434,924	1,034,096	250,110	138,984	361,236
1985	663,860	392,086	935,634	212,840	115,081	310,599
1986	608,540	360,463	856,617	179,140	94,674	263,606
1987	589,250	355,755	822,745	159,460	85,035	233,885
1988	603,750	375,312	832,188	159,390	87,407	231,373
1989	655,650	428,780	882,520	164,890	94,542	235,238
1990	732,230	506,399	958,061	176,110	106,840	245,380
1991	814,830	584,354	1,045,306	195,520	126,316	264,724
1992	798,760	580,710	1,016,810	220,990	149,871	292,109
1993	781,300	573,285	989,315	222,530	151,245	293,815
1994	753,480	553,952	953,008	195,780	130,059	261,501
1995	717,400	523,587	911,213	173,340	111,671	235,009
1996	644,330	457,234	831,426	155,420	94,564	216,276
1997	578,320	392,171	764,469	138,780	80,625	196,935
1998	567,000	380,835	753,165	128,550	72,886	184,214
1999	520,170	340,320	700,020	133,930	76,459	191,401
2000	588,620	391,914	785,326	129,910	72,651	187,169
2001	744,740	513,499	975,981	122,190	66,804	177,576
2002	940,940	664,188	1,217,692	155,000	92,074	217,926
2003	1,043,300	745,831	1,340,769	222,450	142,386	302,514
2004	1,052,700	752,977	1,352,423	275,460	182,158	368,762
2005	938,780	663,576	1,213,984	288,490	192,178	384,802
2006	840,990	585,171	1,096,809	262,130	170,759	353,501
2007	761,080	521,646	1,000,514	222,040	140,373	303,707
2008	736,870	503,532	970,208	191,570	117,654	265,486
2009	741,780	504,816	978,744	170,050	100,584	239,516
2010	686,860	455,678	918,042	168,860	98,182	239,538
2011	613,700	395,493	831,907	173,700	100,892	246,508
2012	590,810	379,914	801,706	162,100	92,054	232,146
2013	568,400	363,913	772,887	152,750	87,815	217,685
2014	614,110	401,842	826,378	153,960	91,446	216,474
2015	633,790	415,230	852,350	153,640	90,636	216,644
2016	586,570	372,244	800,896	156,060	89,653	222,467
2017	540,280	332,402	748,158	147,140	78,646	215,634
2018	505,730	296,892	714,568	123,188	56,392	188,088
2019	498,320	253,368	688,252	106,800	42,517	166,243

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 (1977-2019) compared to last year's (2017) assessment results.

	Age 3+ biomass (t)		Female spawning biomass (t)	
Year	Current	2017	Current	2017
1977	573,030	595,230	173,470	182,530
1978	630,570	646,900	179,580	186,760
1979	583,970	598,920	193,950	199,490
1980	948,720	958,510	226,480	230,930
1981	928,400	940,860	287,140	290,990
1982	875,880	893,040	315,310	319,730
1983	781,840	807,190	288,260	294,730
1984	680,800	712,730	250,110	259,240
1985	597,890	638,650	212,840	224,750
1986	520,690	575,160	179,140	194,370
1987	503,300	565,320	159,460	178,530
1988	502,770	567,310	159,390	181,100
1989	538,020	604,750	164,890	187,540
1990	549,900	613,780	176,110	198,910
1991	725,070	791,200	195,520	218,110
1992	731,380	794,400	220,990	243,210
1993	673,380	731,130	222,530	243,960
1994	623,980	677,850	195,780	215,640
1995	656,300	711,710	173,340	192,160
1996	558,280	610,240	155,420	174,060
1997	452,610	501,800	138,780	156,730
1998	525,380	580,570	128,550	146,020
1999	443,750	494,730	133,930	152,040
2000	411,610	461,170	129,910	147,980
2001	470,780	525,760	122,190	140,000
2002	738,390	816,310	155,000	175,740
2003	868,280	957,790	222,450	249,320
2004	1,000,800	1,102,700	275,460	307,530
2005	868,770	961,930	288,490	322,500
2006	761,130	847,890	262,130	294,990
2007	674,490	755,930	222,040	251,920
2008	582,700	656,110	191,570	218,990
2009	630,560	705,360	170,050	195,710
2010	634,620	705,420	168,860	193,710
2011	536,420	597,850	173,700	197,350
2012	523,260	584,030	162,100	183,730
2013	464,750	516,780	152,750	172,530
2014	497,830	557,630	153,960	172,960
2015	560,710	603,830	153,640	171,710
2016	537,410	560,830	156,060	170,470
2017	466,700	515,150	147,140	159,027
2018	428,390	484,150	123,188	139,297
2019	390,270		106,805	

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 (2017) are shown for comparison.

Year	Current	Std. dev	2017 assessment
1977	376	99	387
1978	2,184	494	2,175
1979	545	137	568
1980	321	85	354
1981	351	90	397
1982	225	62	267
1983	307	79	364
1984	333	84	418
1985	533	126	596
1986	459	115	505
1987	625	146	678
1988	493	119	527
1989	1,234	219	1,291
1990	589	132	624
1991	343	87	367
1992	535	111	565
1993	899	149	951
1994	358	77	384
1995	354	72	382
1996	921	145	990
1997	213	47	232
1998	330	66	359
1999	776	130	842
2000	1,762	250	1,906
2001	1,147	164	1,241
2002	1,287	174	1,393
2003	278	52	304
2004	374	63	409
2005	507	80	554
2006	352	59	383
2007	938	138	1,007
2008	796	124	838
2009	239	46	250
2010	492	84	540
2011	337	63	349
2012	556	103	634
2013	745	143	715
2014	494	114	441
2015	238	76	389
2016	424	128	459
2017	445	186	499
2018	471	202	
Average 78-17	609		658
Median 78-17	493		527

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	0.145	0.038
1978	0.139	0.038
1979	0.083	0.040
1980	0.062	0.022
1981	0.043	0.021
1982	0.044	0.023
1983	0.028	0.015
1984	0.095	0.053
1985	0.123	0.063
1986	0.123	0.061
1987	0.094	0.060
1988	0.101	0.044
1989	0.057	0.033
1990	0.051	0.040
1991	0.081	0.037
1992	0.105	0.066
1993	0.157	0.098
1994	0.198	0.105
1995	0.305	0.124
1996	0.442	0.186
1997	0.256	0.145
1998	0.306	0.109
1999	0.233	0.127
2000	0.223	0.115
2001	0.294	0.131
2002	0.225	0.061
2003	0.179	0.062
2004	0.133	0.061
2005	0.130	0.071
2006	0.141	0.081
2007	0.142	0.087
2008	0.173	0.100
2009	0.264	0.115
2010	0.236	0.108
2011	0.157	0.097
2012	0.177	0.091
2013	0.073	0.050
2014	0.077	0.062
2015	0.252	0.095
2016	0.255	0.101
2017	0.292	0.138
2018	0.367	0.166

[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 283,776 t, 113,510 t, and 99,322 t, respectively.

Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2018	71,000	71,000	71,000	71,000	71,000	71,000	71,000
2019	58,900	58,900	58,900	58,900	58,900	79,197	68,478
2020	54,500	54,500	54,500	54,500	54,500	65,238	59,854
2021	66,315	66,315	56,770	19,283	0	66,141	71,795
2022	70,467	70,467	60,927	22,799	0	74,293	76,572
2023	74,833	74,833	65,109	26,138	0	80,426	81,235
2024	78,185	78,185	68,510	29,025	0	84,175	84,423
2025	80,575	80,575	71,151	31,332	0	86,601	86,643
2026	81,156	81,156	72,274	32,772	0	86,825	86,823
2027	80,820	80,820	72,522	33,561	0	86,082	86,082
2028	80,491	80,491	72,429	33,888	0	85,561	85,565
2029	79,943	79,943	72,180	34,074	0	84,954	84,956
2030	79,935	79,935	72,234	34,229	0	85,059	85,060
2031	80,310	80,310	72,528	34,425	0	85,543	85,544
Fishing M.	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2018	0.367	0.367	0.367	0.367	0.367	0.367	0.367
2019	0.337	0.337	0.337	0.337	0.337	0.471	0.399
2020	0.325	0.325	0.325	0.325	0.325	0.427	0.373
2021	0.391	0.391	0.331	0.106	0.000	0.428	0.446
2022	0.394	0.394	0.331	0.106	0.000	0.446	0.454
2023	0.399	0.399	0.331	0.106	0.000	0.460	0.462
2024	0.404	0.404	0.331	0.106	0.000	0.467	0.468
2025	0.406	0.406	0.331	0.106	0.000	0.471	0.471
2026	0.407	0.407	0.331	0.106	0.000	0.471	0.471
2027	0.406	0.406	0.331	0.106	0.000	0.469	0.469
2028	0.406	0.406	0.331	0.106	0.000	0.468	0.468
2029	0.405	0.405	0.331	0.106	0.000	0.467	0.467
2030	0.404	0.404	0.331	0.106	0.000	0.467	0.467
2031	0.404	0.404	0.331	0.106	0.000	0.466	0.466
Spawning biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2018	123,188	123,188	123,188	123,188	123,188	123,188	123,188
2019	106,805	106,805	106,805	106,805	106,805	101,416	104,278
2020	102,714	102,714	102,714	102,714	102,714	92,423	97,770
2021	102,732	102,732	104,946	113,675	118,051	92,607	96,522
2022	107,389	107,389	112,946	135,540	148,006	98,352	100,071
2023	112,857	112,857	121,598	157,173	178,491	103,594	104,258
2024	115,906	115,906	127,226	173,628	203,569	106,038	106,277
2025	117,830	117,830	131,082	186,070	223,912	107,407	107,493
2026	118,801	118,801	133,464	195,339	240,331	107,935	107,975
2027	118,330	118,330	133,828	200,683	251,571	107,269	107,293
2028	117,681	117,681	133,580	203,740	259,147	106,640	106,654
2029	117,260	117,260	133,381	206,045	265,176	106,264	106,271
2030	117,152	117,152	133,314	207,586	269,493	106,217	106,220
2031	117,794	117,794	133,976	209,371	273,355	106,863	106,864

Table 17.17. Ecosystem effects.

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, 2010-2017. Estimates are reported in metric tons for halibut and herring, and counts of fish for crab and salmon.

Species group name	2010	2011	2012	2013	2014	2015	2016	2017
Bairdi Tanner Crab	53	682	0	87	0	254	0	44
Blue King Crab	0	0	0	0	0	0	0	0
Chinook Salmon	241	285	161	0	299	136	535	1,109
Golden (Brown) King Crab	3,180	33,855	6,662	3,402	2,571	1,321	2,898	1,409
Halibut	73	150	232	99	107	126	121	99
Herring	0	0	0	0	0	0	0	0
Non-Chinook Salmon	839	152	1,155	705	514	1,687	1,162	1,611
Opilio Tanner (Snow) Crab	0	0	64	131	0	38	0	0
Red King Crab	1,258	1,790	1,782	362	795	4,956	348	239
Grand Total Halibut and Herring (t)	73	150	232	99	107	126	121	112
Grand Total Numbers of Crab and Salmon	5,571	36,764	9,824	4,687	4,179	8,392	4,943	4,943

Figures

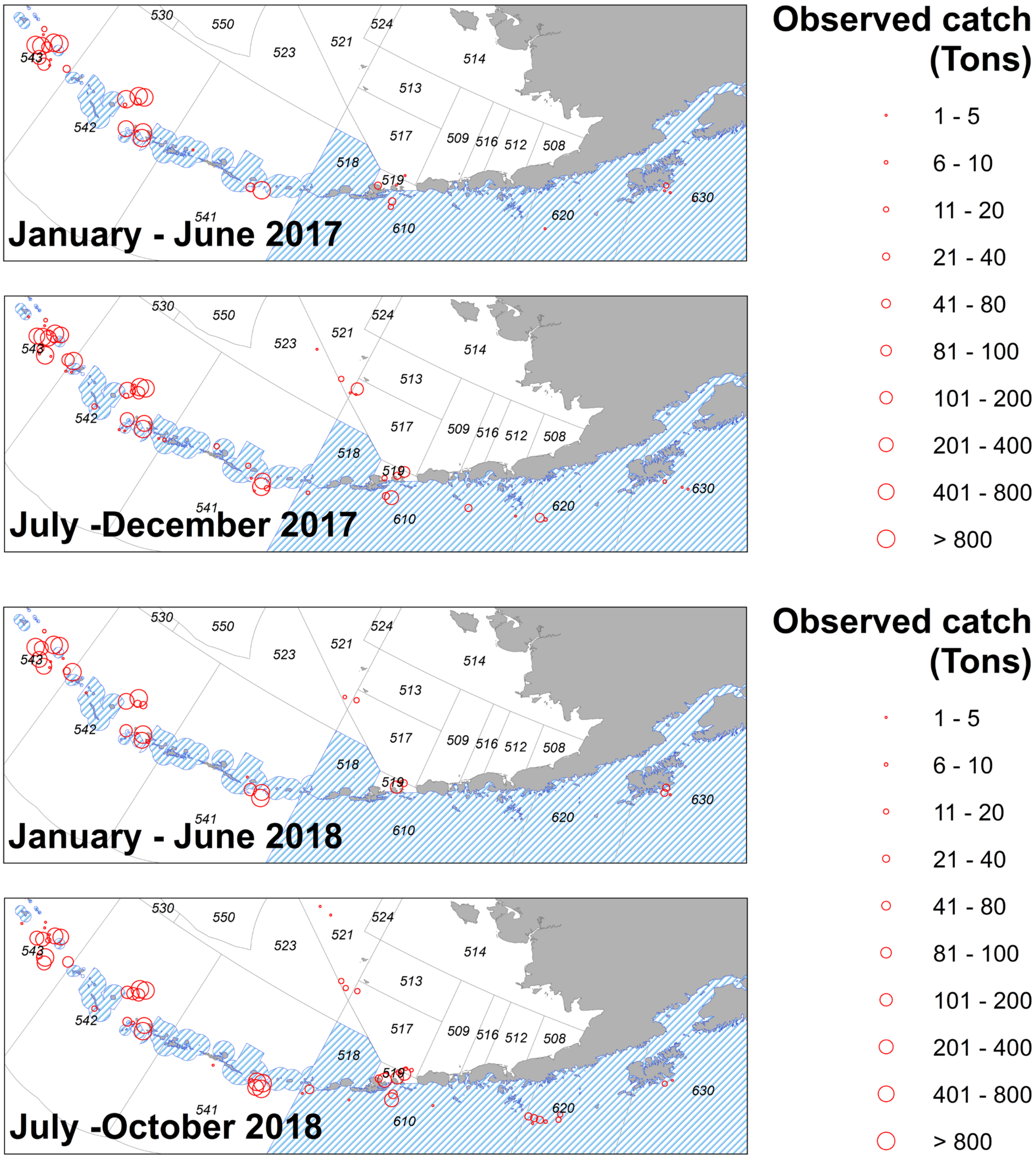


Figure 17.1. Observed catches of Atka mackerel summed for 20 km^2 cells for 2017 and 2018 where observed catch per haul was greater than 1 t. Shaded areas represent areas closed to directed Atka mackerel fishing.

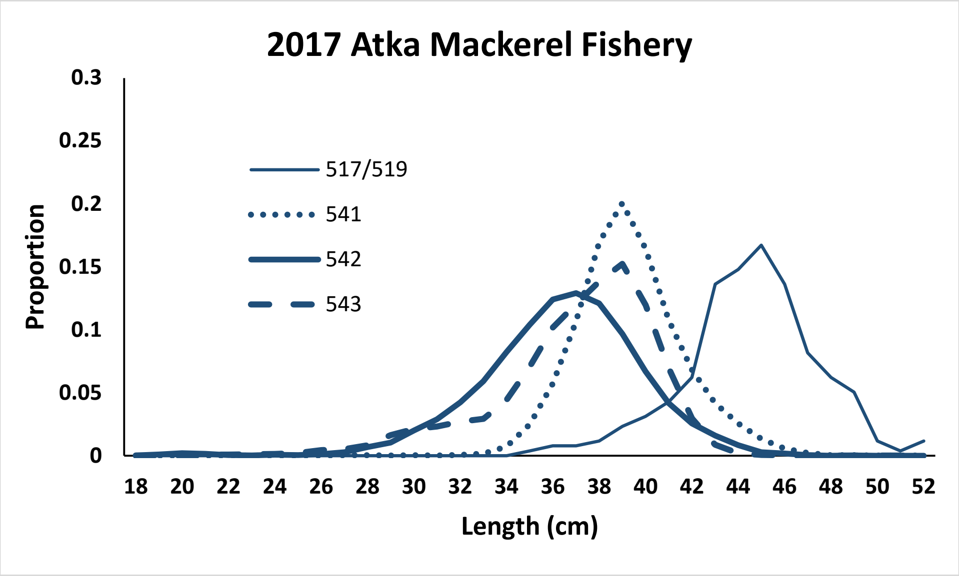


Figure 17.2. 2017 Atka mackerel fishery length-frequency data by area fished (see Figure 17.1). Numbers refer to management areas.

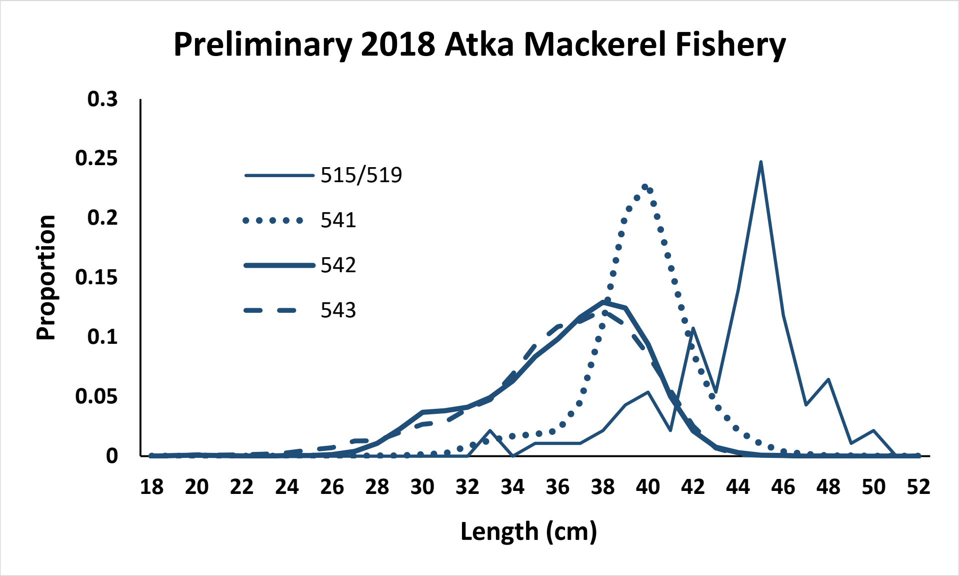


Figure 17.3. Preliminary 2018 Atka mackerel fishery length-frequency data by area fished (see Figure 17.1). Numbers refer to management areas.

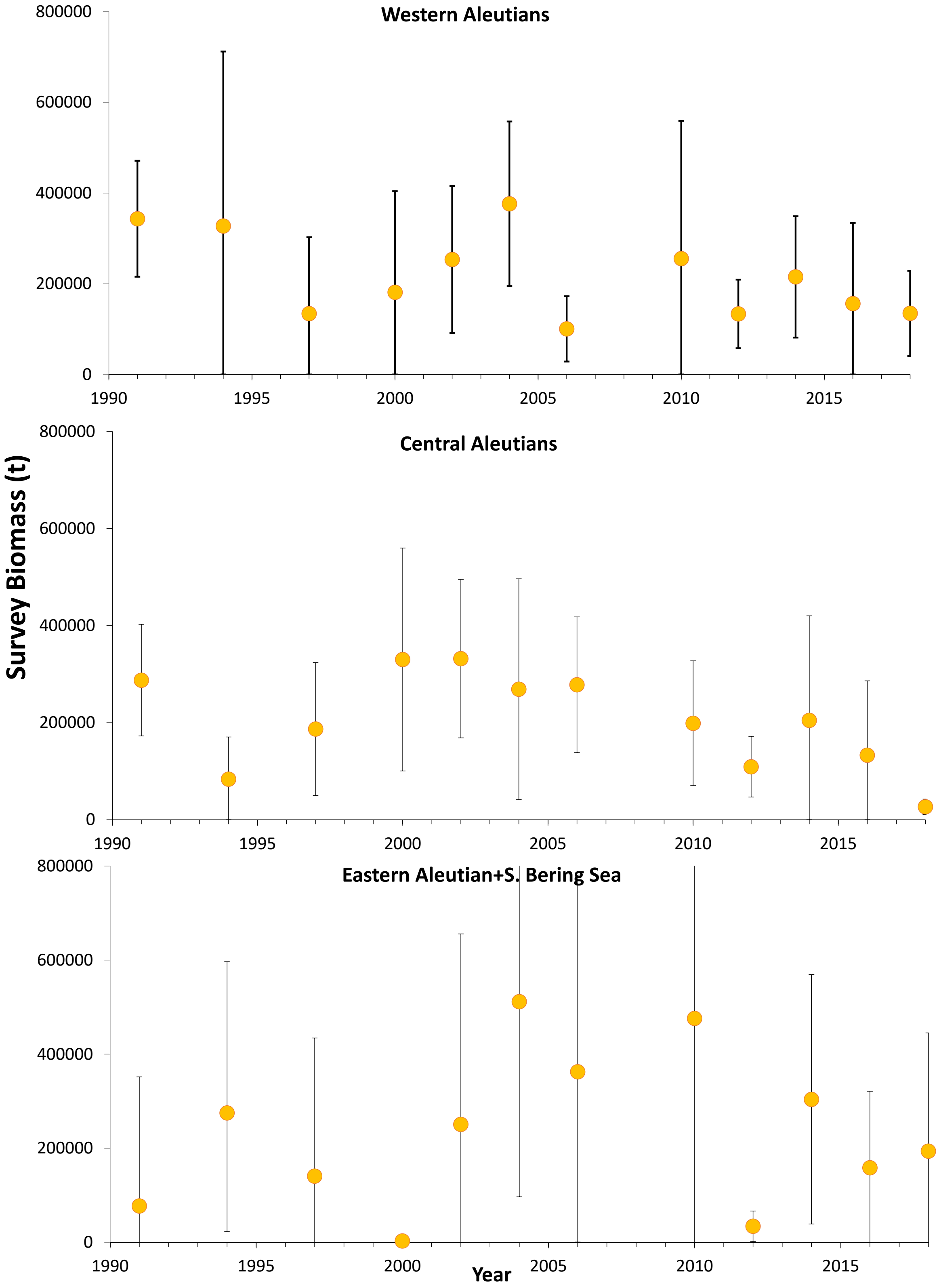


Figure 17.4. Atka mackerel Aleutian Islands survey biomass estimates by area and survey year. Bars represent 95% confidence intervals based on sampling error.

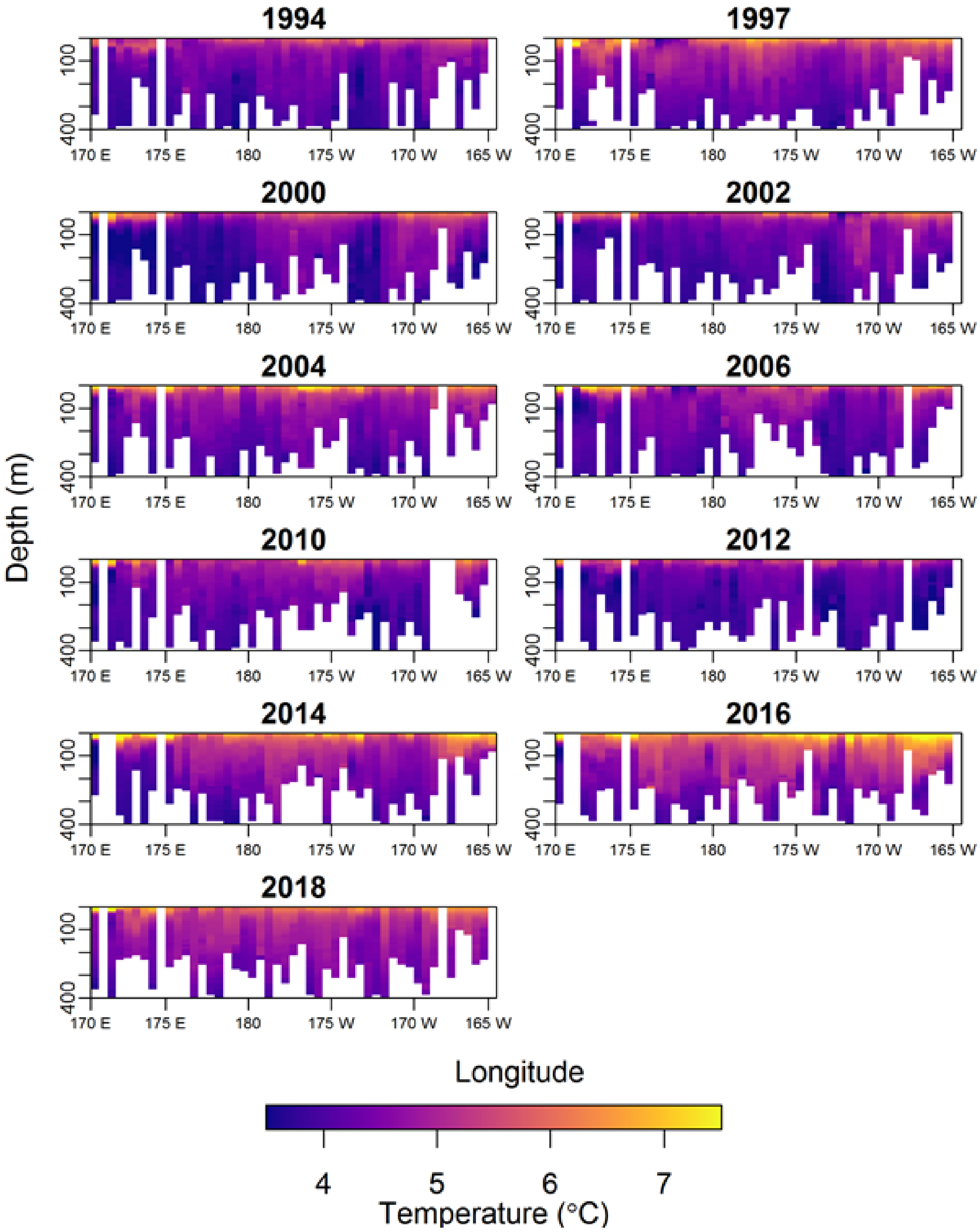
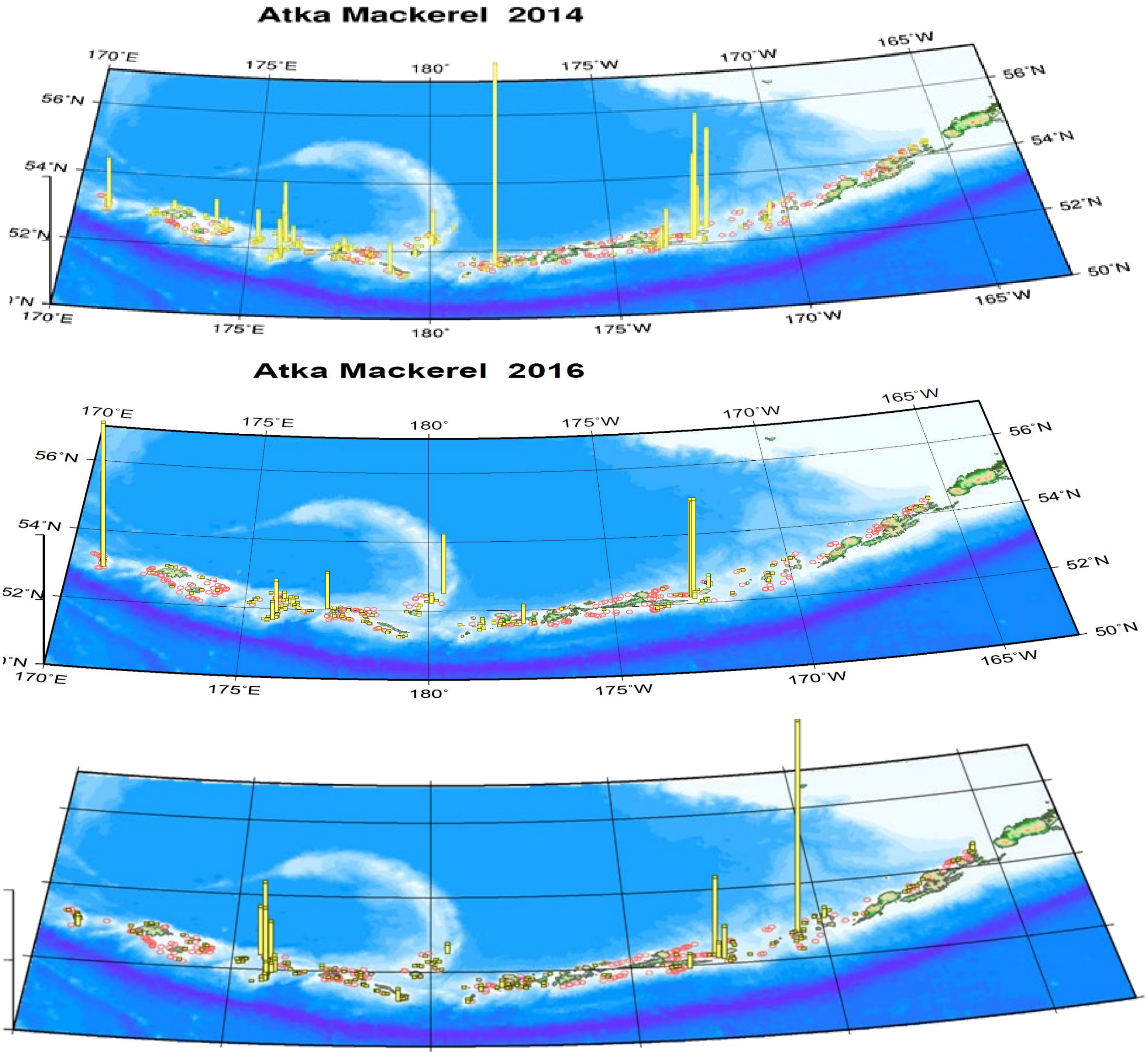


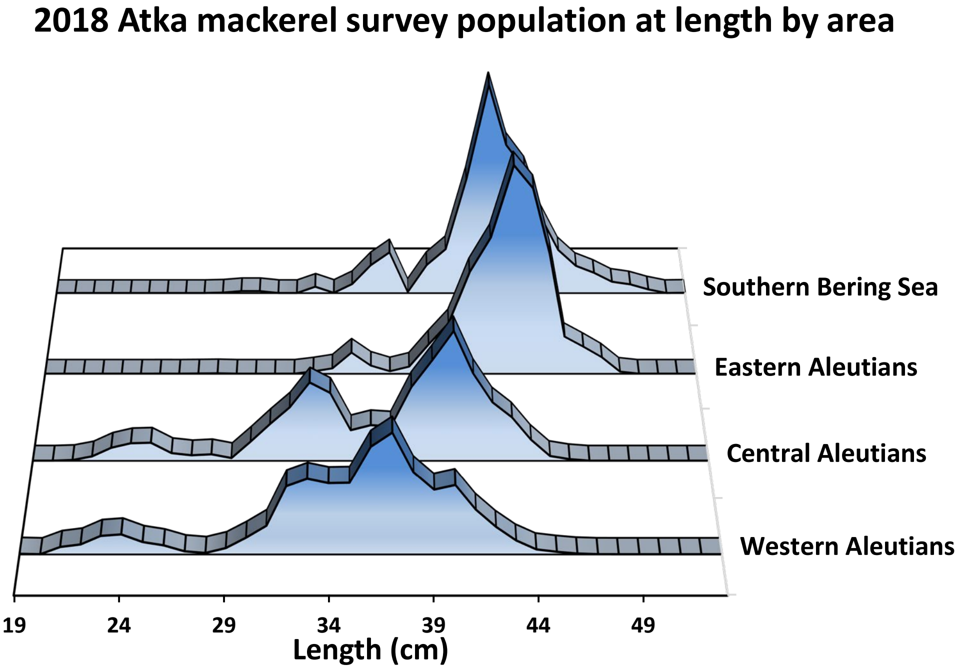
Figure 17.5. Median-survey-date-standardized, generalized additive model (GAM) predicted thermal (°C) anomaly profiles from water temperature measurements collected on Aleutian Islands bottom trawl surveys (1994-2018); to visually enhance near-surface temperature changes, values ≤ 3.5°C or ≥ 7.5°C were 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).



Atka Mackerel 2014

Atka Mackerel 2016

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



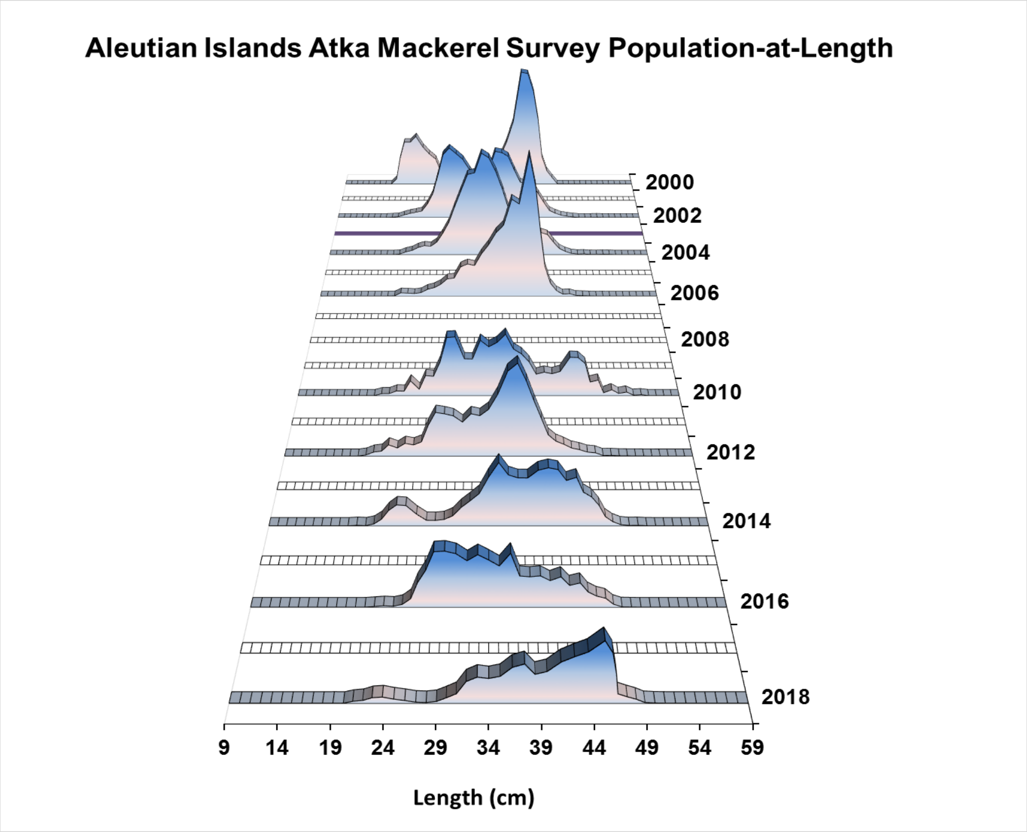


Figure 17.7. Atka mackerel bottom trawl survey length frequency data by subarea in 2018 (top) and for all areas, 2000-2018 (bottom). Vertical scales are proportional for a given area or year.

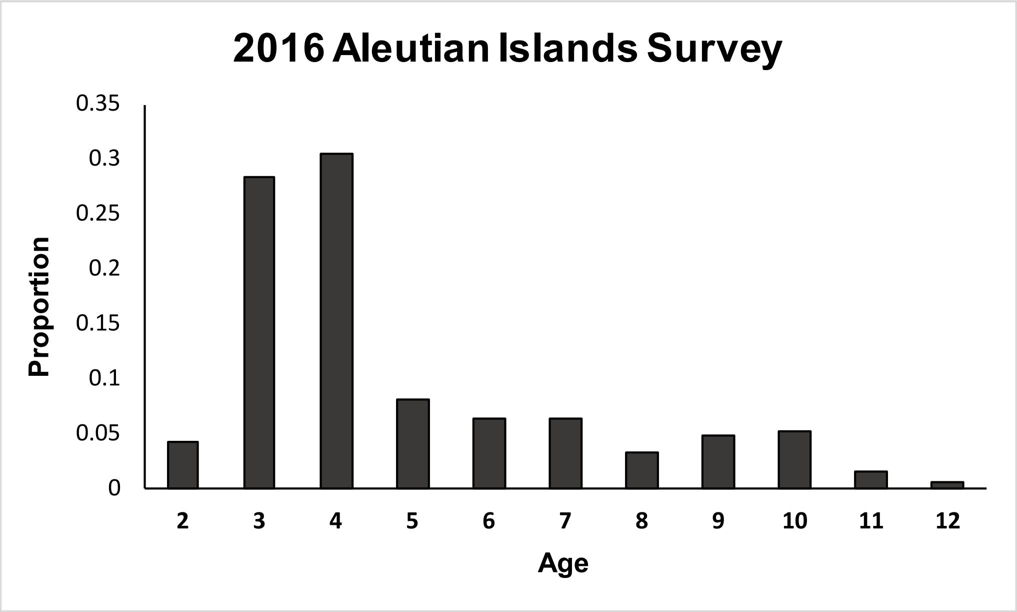


Figure 17.8. Atka mackerel age distribution from the 2016 Aleutian Islands bottom trawl survey. A total of 300 otoliths were aged; mean age from the 2016 survey is 4.9 years.

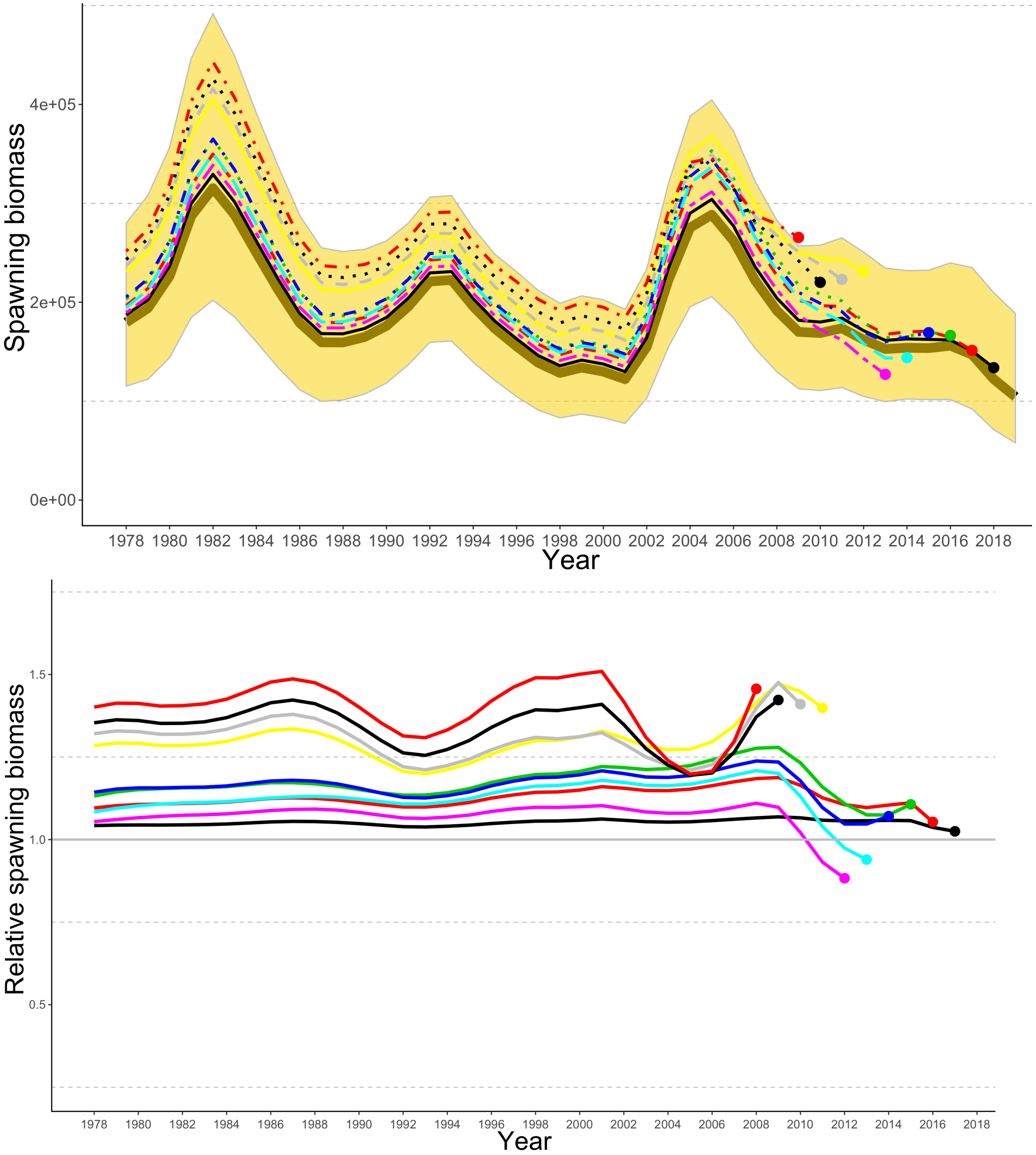


Figure 17.9. Retrospective plots showing the BSAI Atka mackerel spawning biomass over time (top) and the relative difference (bottom) over 10 different “peels”. Mohn’s rho was 0.16.

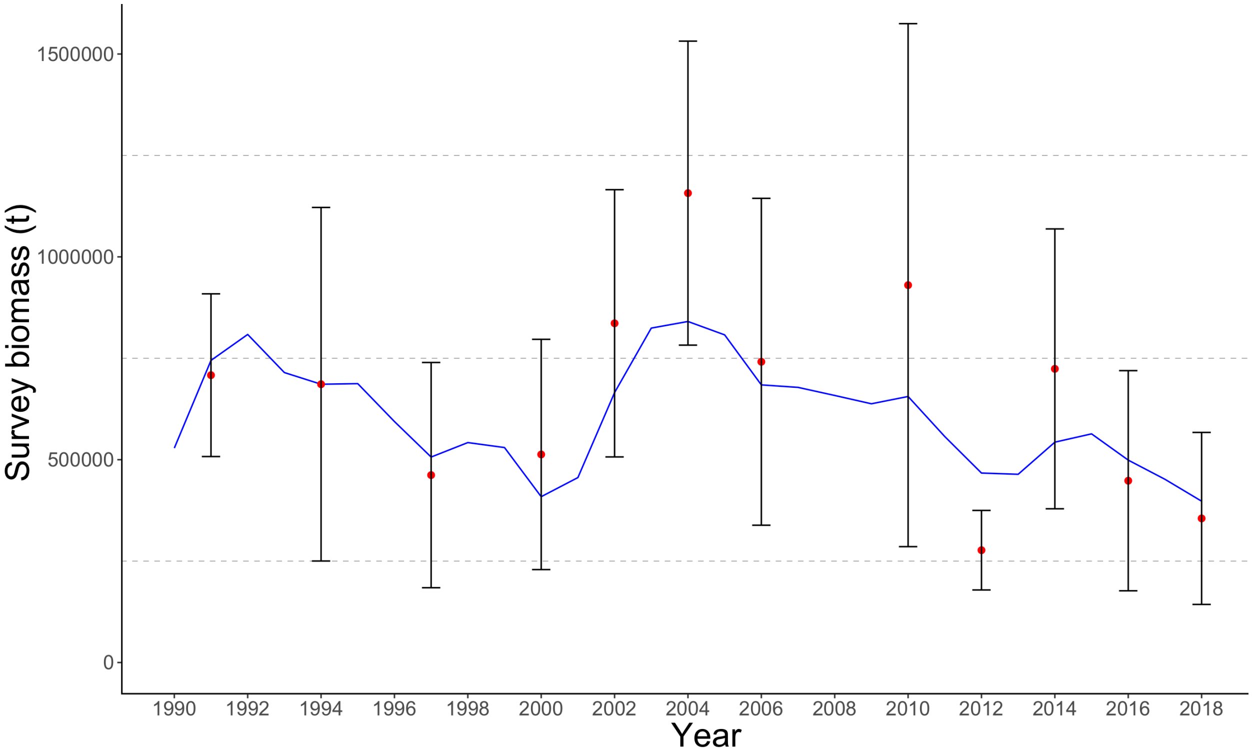


Figure 17.10. Observed (dots) and predicted (trend line) survey biomass estimates (t) for Bering Sea/Aleutian Islands Atka mackerel. Error bars represent two standard errors (based on sampling) from the survey estimates.

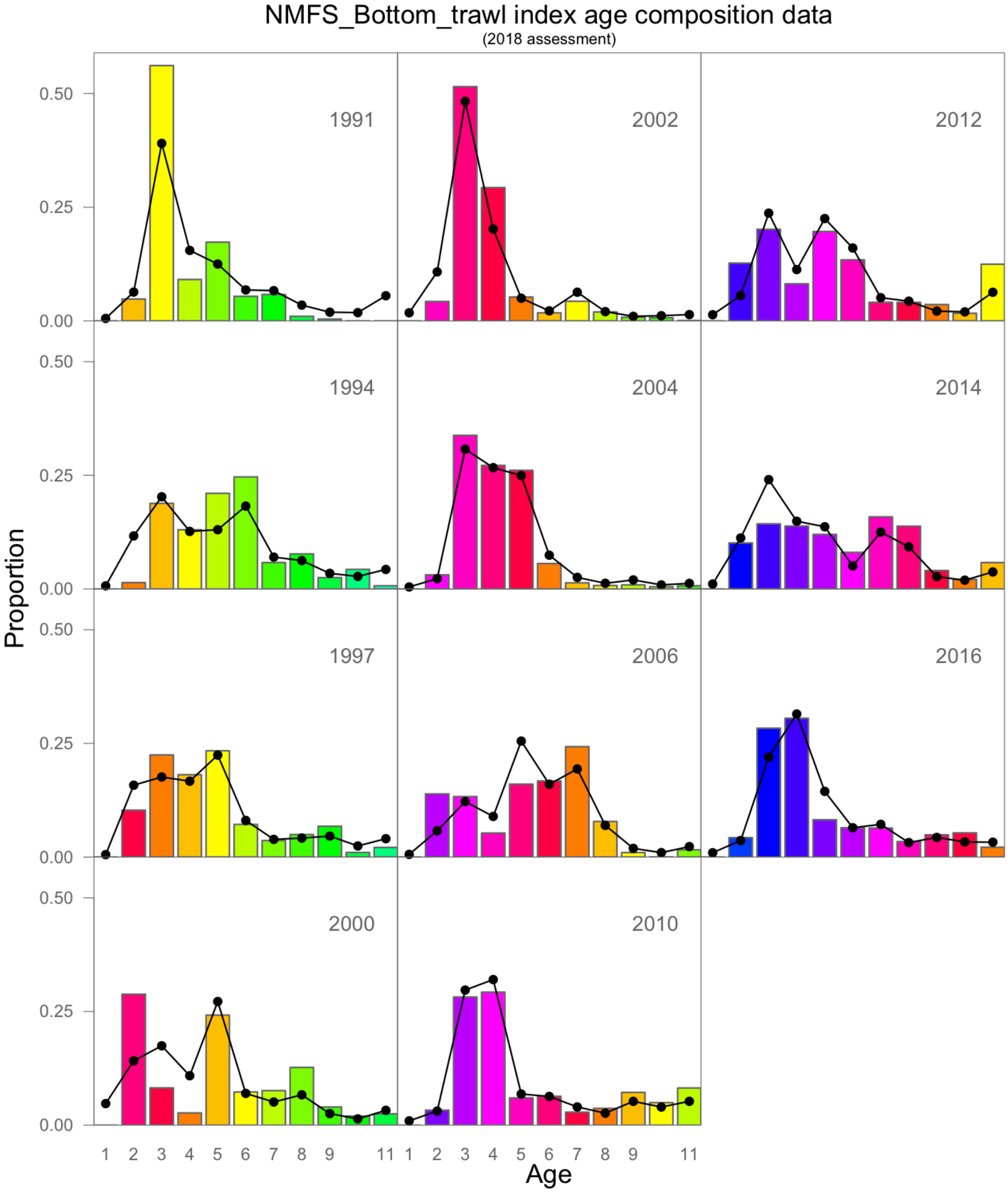


Figure 17.11. Observed and predicted **survey** proportions-at-age for BSAI Atka mackerel. Lines with "•" symbol are the model predictions and columns are the observed proportions at age.

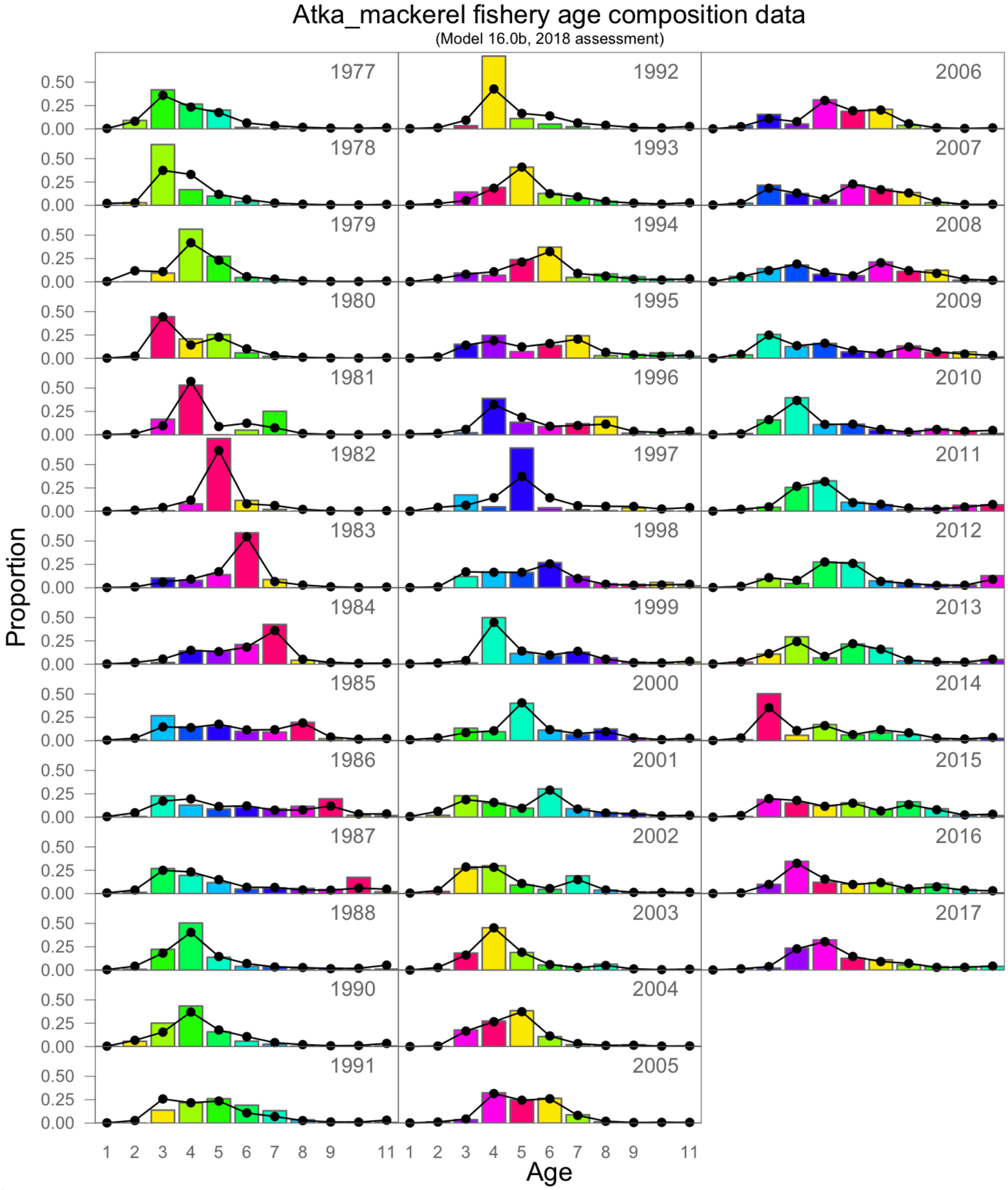


Figure 17.12. Observed and predicted Atka mackerel **fishery** proportions-at-age for BSAI Atka mackerel. Lines with "•" symbol are the model predictions and columns are the observed proportions at age (with colors corresponding to cohorts).

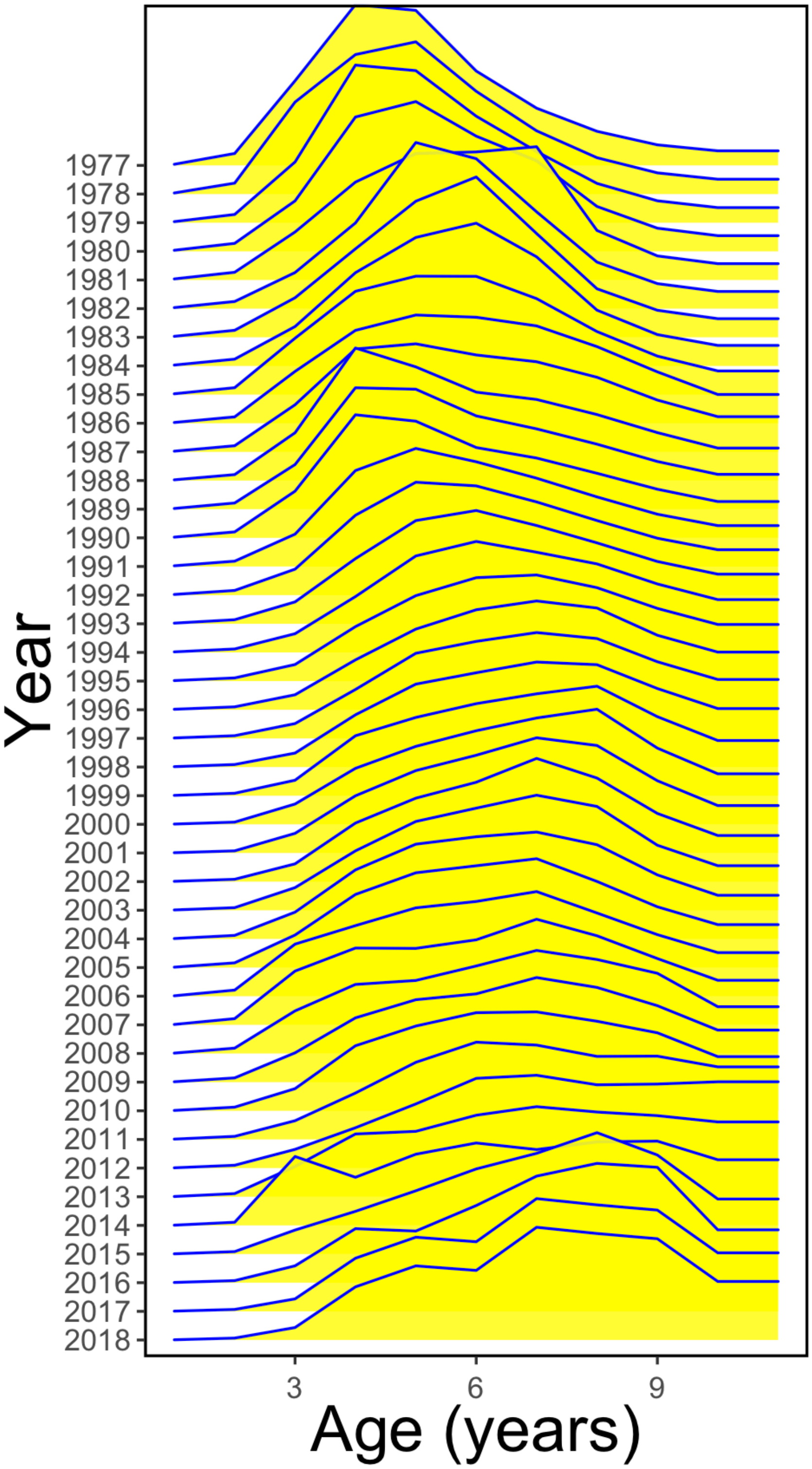


Figure 17.13. Fishery selectivity estimates over time for BSAI Atka mackerel.

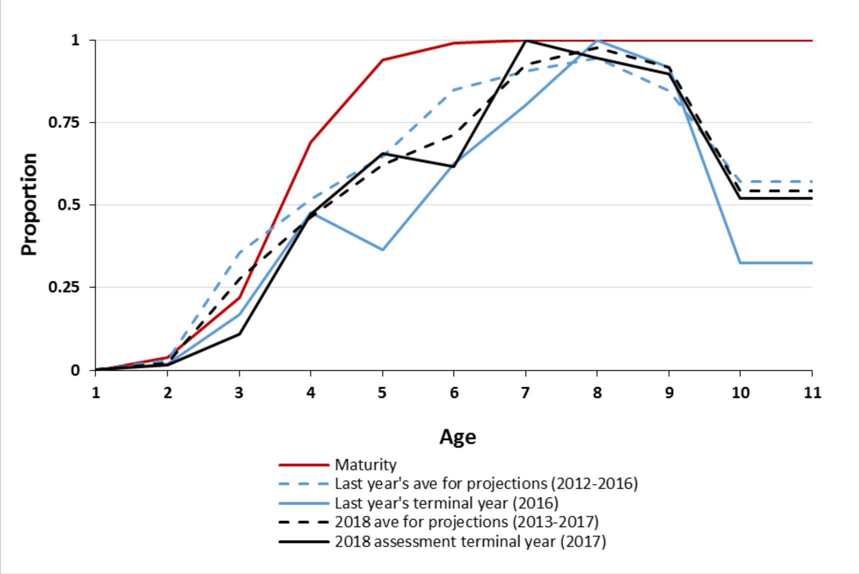


Figure 17.14. Estimated fishery selectivity patterns in the current assessment with a) last year's average for projections (2012-2016), b) the 2018 assessment average selectivity used for projections (2013-2017), c) last year's assessment terminal year (2016), and d) the 2018 assessment terminal year (2017) compared with the maturity-at-age estimates for BSAI Atka mackerel.

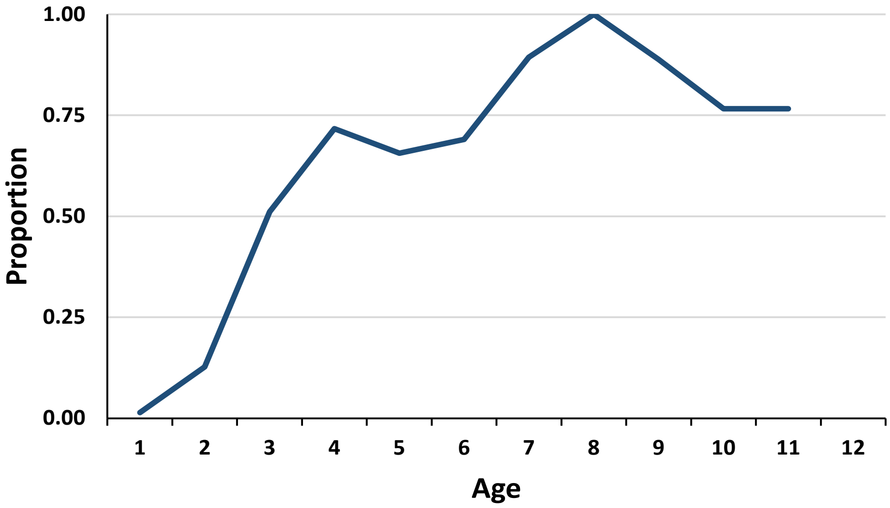
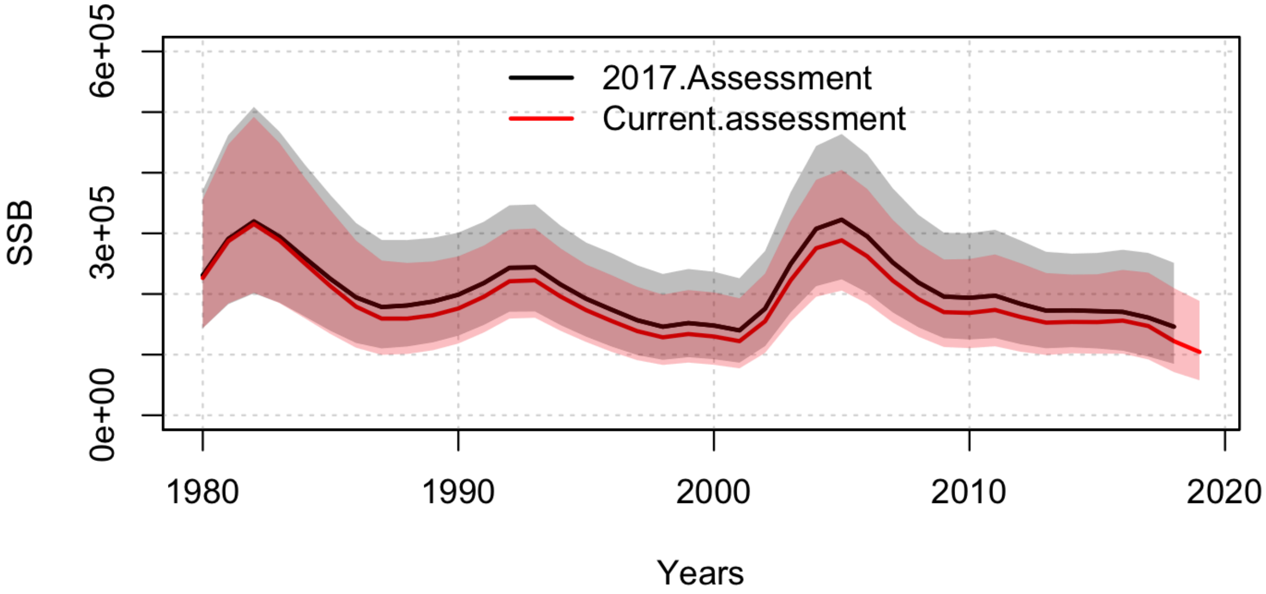


Figure 17.15. Estimated BSAI Atka mackerel survey selectivity-at-age from the current assessment (Model 16.0b). Selectivity estimates have been normalized to a maximum value of 1.0 for presentation.



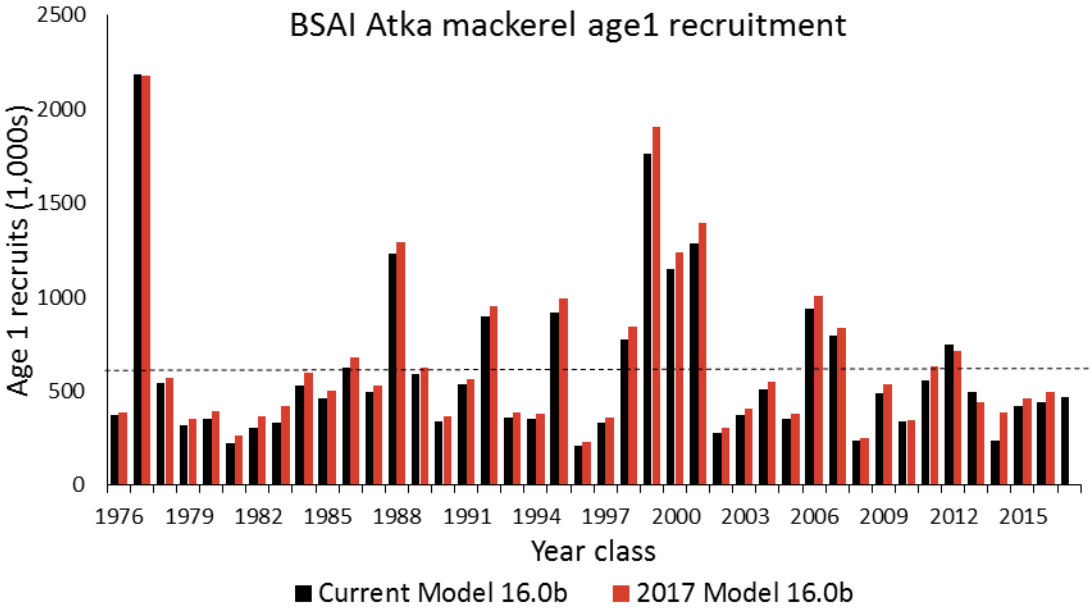


Figure 17.16. Time series of estimated Aleutian Islands Atka mackerel spawning biomass with approximate 95% confidence bounds (in t top), and recruitment at age 1 (thousands, bottom) from the current assessment (Model 16.0b) compared to last year's 2017 assessment results (Model 16.0b). Dashed line represents average recruitment over the time series from the current assessment (609 million recruits).

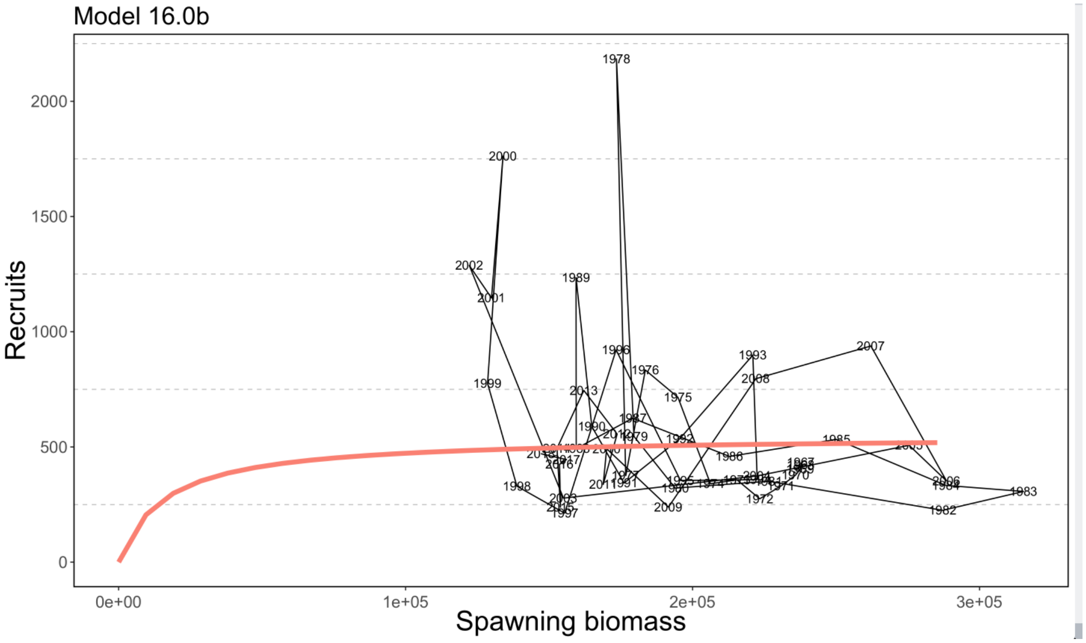


Figure 17.17 Estimated age 1 recruits (millions) versus female spawning biomass (t) for BSAI Atka mackerel. Solid line indicates Beverton-Holt stock recruitment curve (with steepness *h*=0.8).

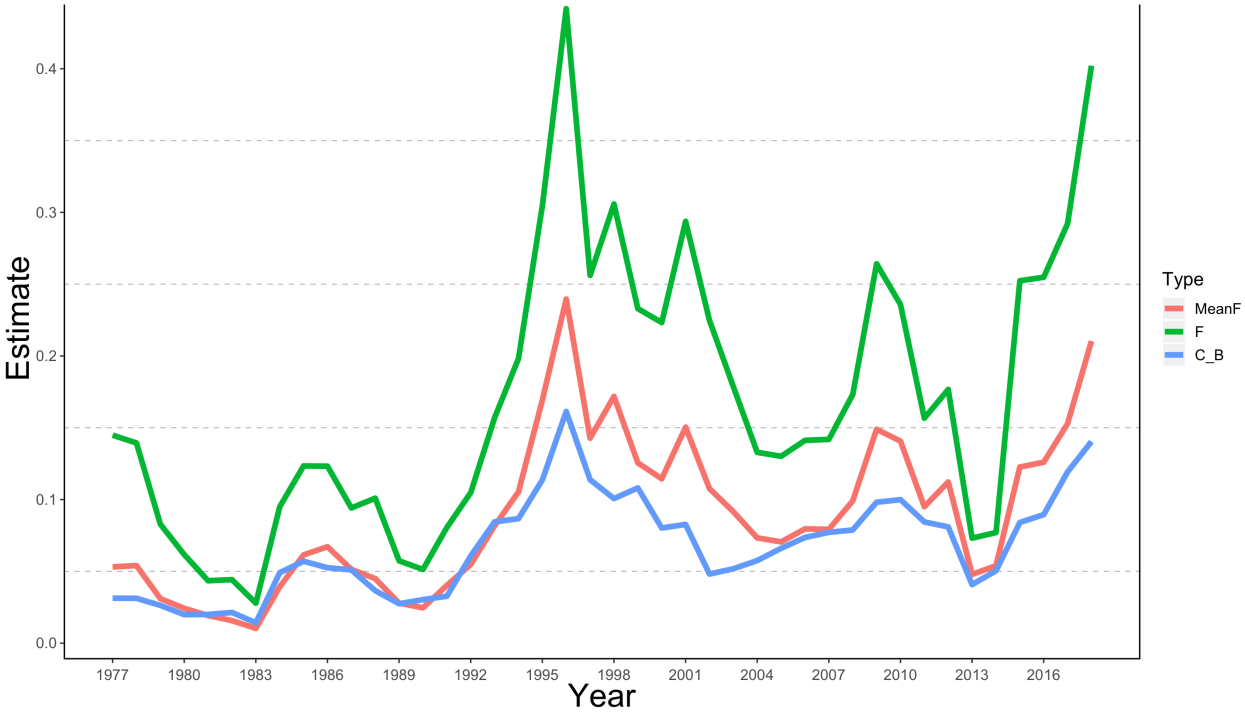


Figure 17.18 Estimated time series of Model 16.0 mean and full-selection fishing mortality and catch/biomass (C_B) exploitation rates of Atka mackerel, 1977-2018. Catch/biomass rates are the ratios of catch to beginning year age 3+ biomass.

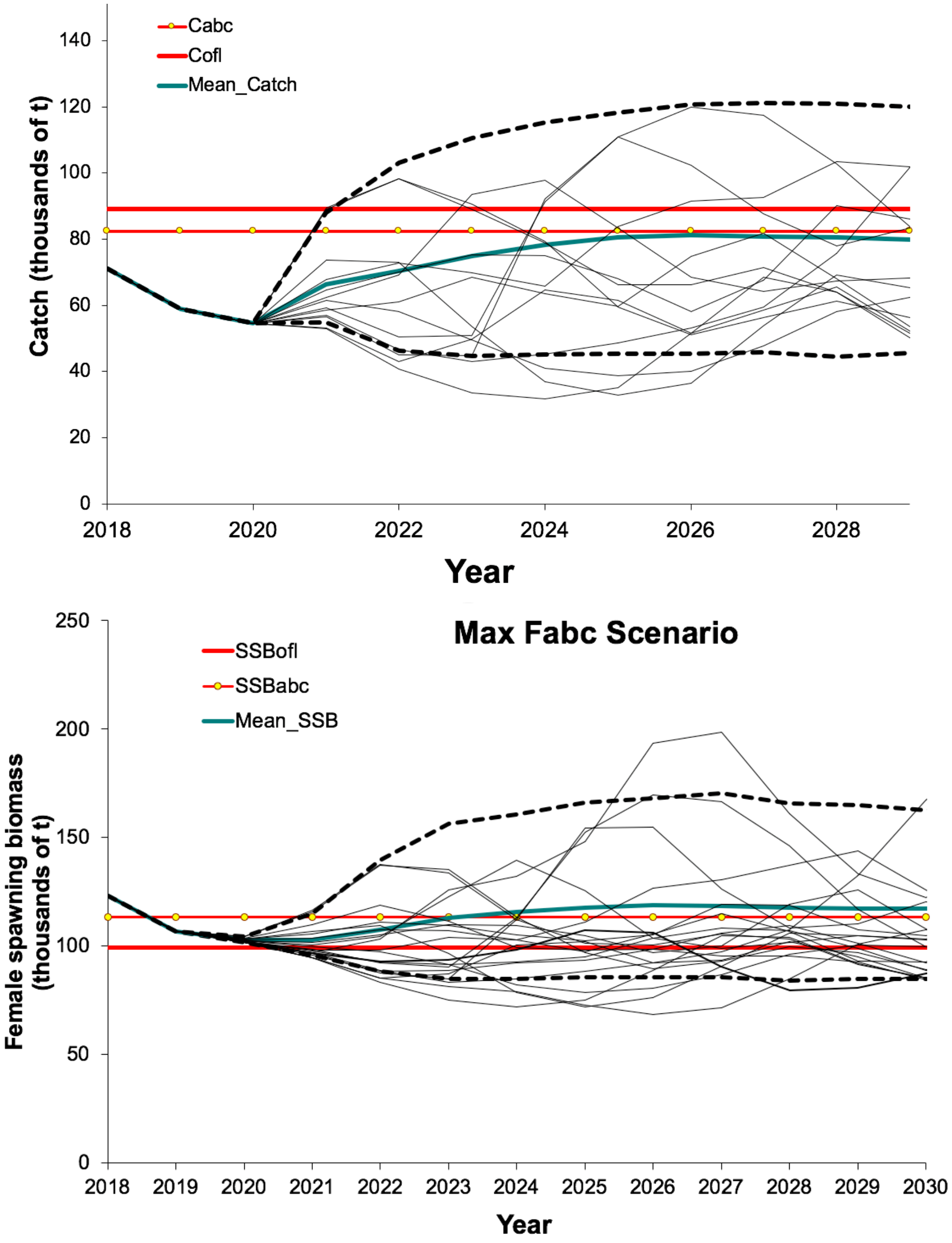


Figure 17.19. Projected Atka mackerel catch (assuming TAC taken in 2018 and reduced catches in 2019 and 2020; top) and spawning biomass (bottom) in thousands of metric tons under maximum permissible harvest control rule specifications after 2020. The individual thin lines represent samples of simulated trajectories.

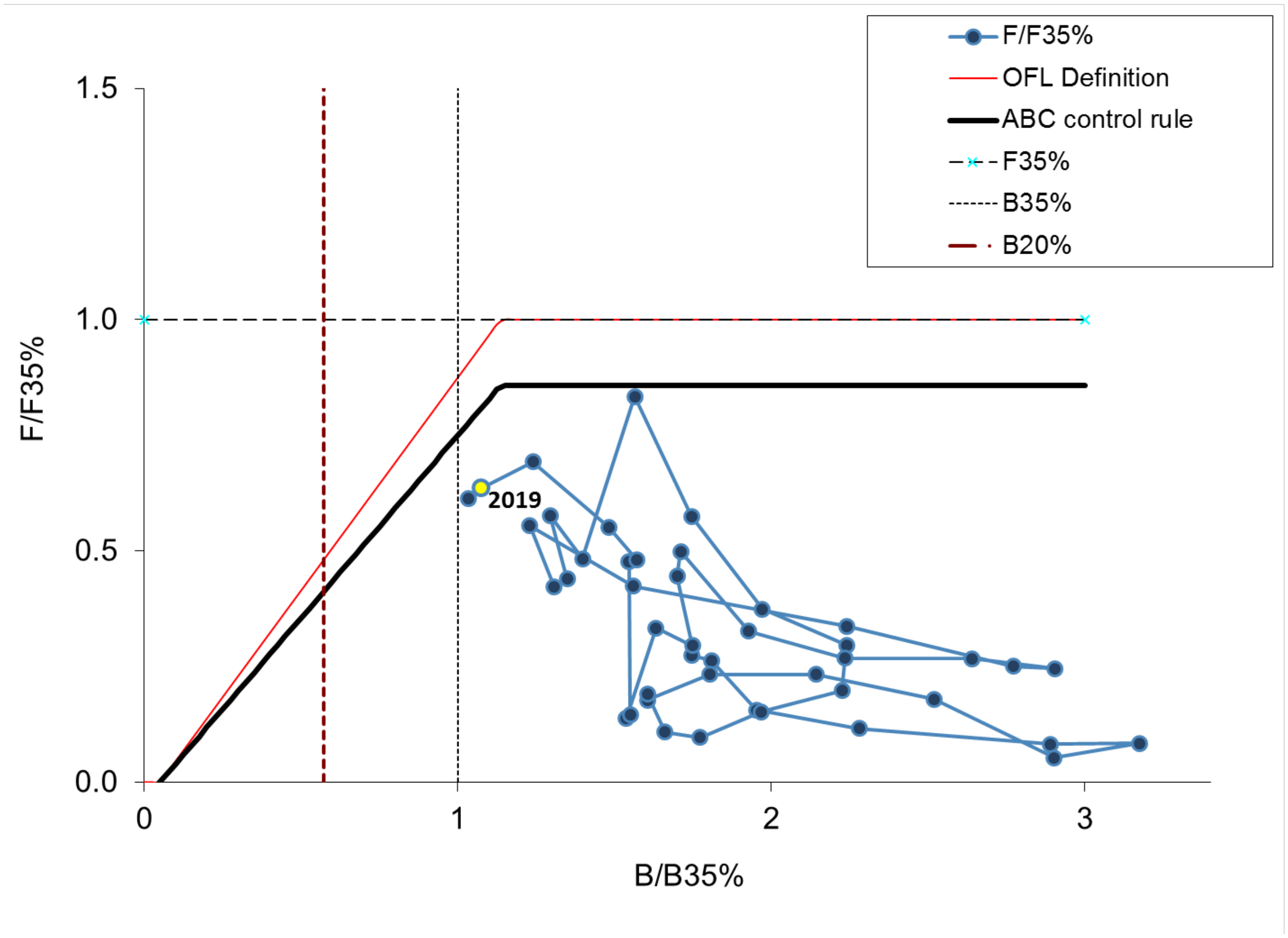


Figure 17.20. Aleutian Islands Atka mackerel spawning biomass relative to $B_{35\%}$ and fishing mortality relative to F_{OFL} (1977-2020). The ratio of fishing mortality to F_{OFL} is calculated using the estimated selectivity pattern in that year. Estimates of spawning biomass and $B_{35\%}$ are based 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.

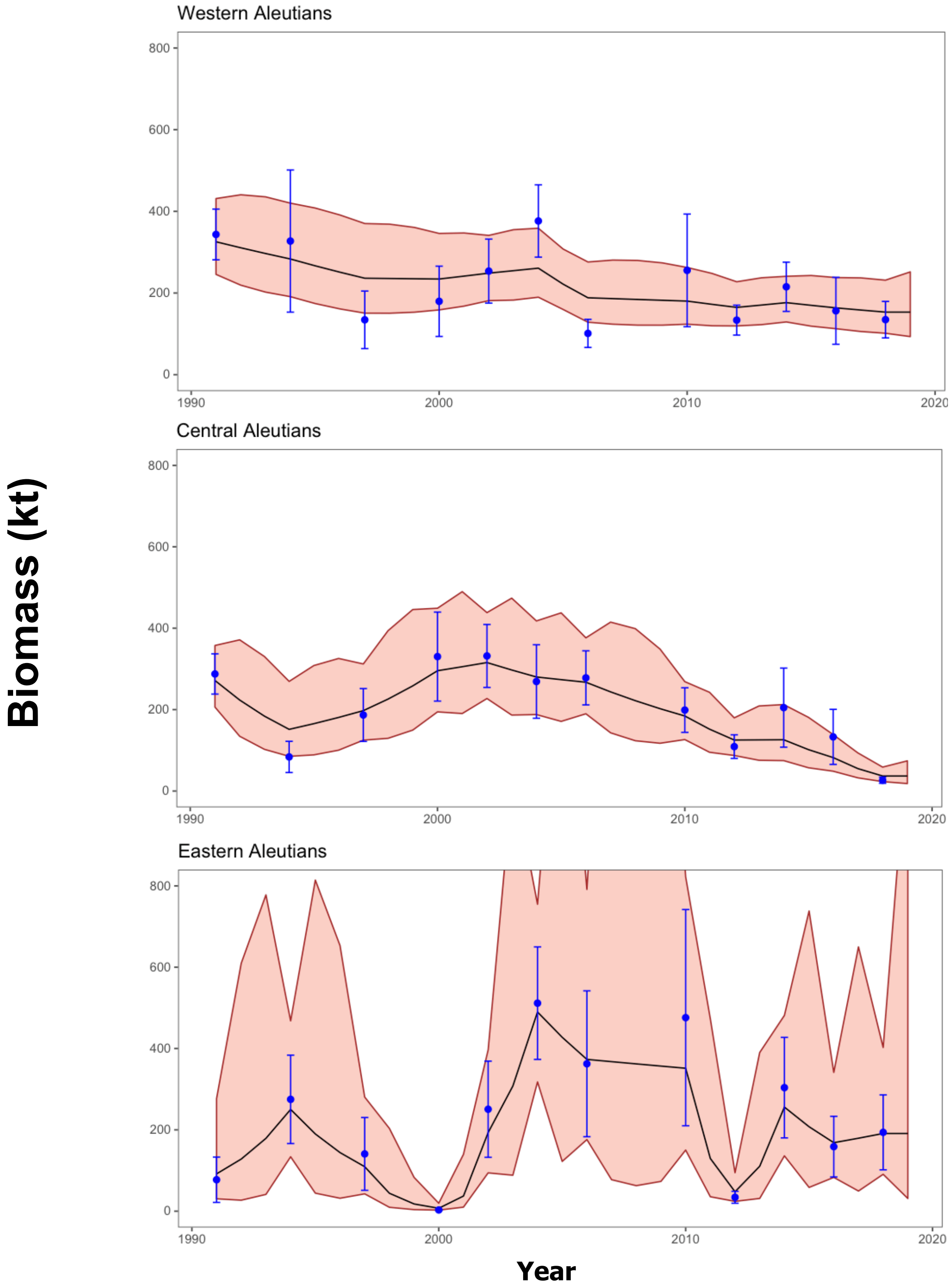


Figure 17.21. Atka mackerel bottom trawl survey biomass by subarea 1991-2018 with random effects model fitting for area apportionment purposes. The random effects biomass estimates for 2019 in Eastern Aleutians is 191 thousand t, Central Aleutians is 37 thousand t, and Western Aleutians is 153 thousand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

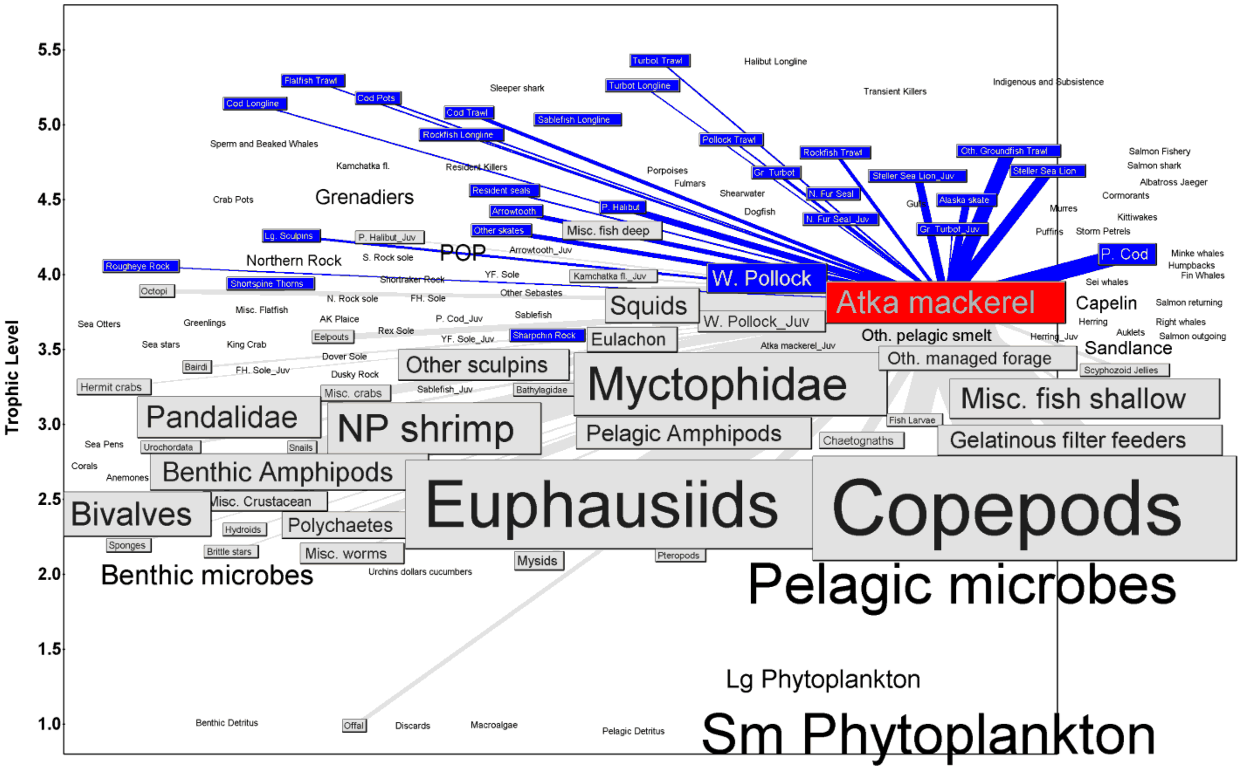


Figure 17.22. The food web of the Aleutian Islands survey region, 1990-1994, emphasizing the position of age 1+ Atka mackerel. Outlined species represent predators of Atka mackerel (dark boxed with light text) and prey of Atka mackerel (light boxes with dark text). Box and text size are proportional 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.

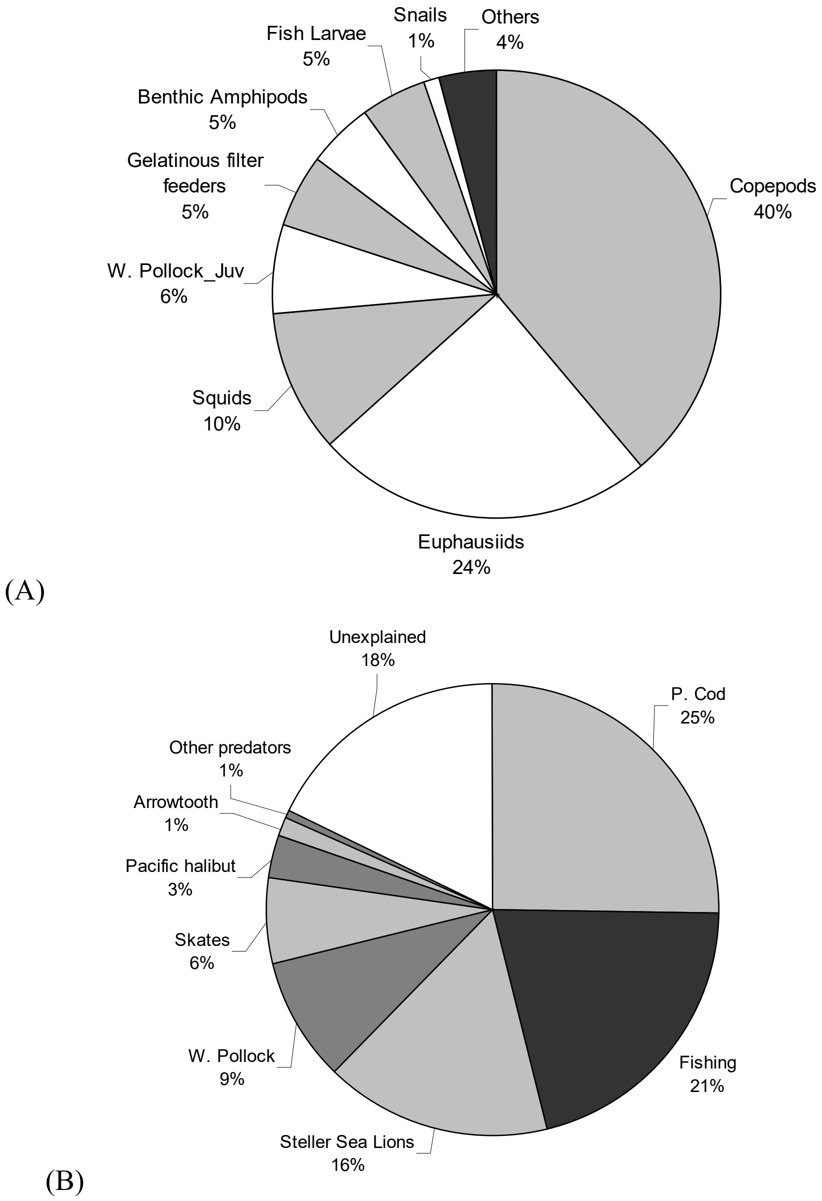


Figure 17.23. (A) Diet of age 1+ Atka mackerel, 1990-1994, by percentage wet weight in diet weighted by age-specific consumption rates. (B) Percentage mortality of Atka mackerel by mortality source, 1990-1994. “Unexplained” mortality is the difference between the stock assessment total exploitation rate 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.

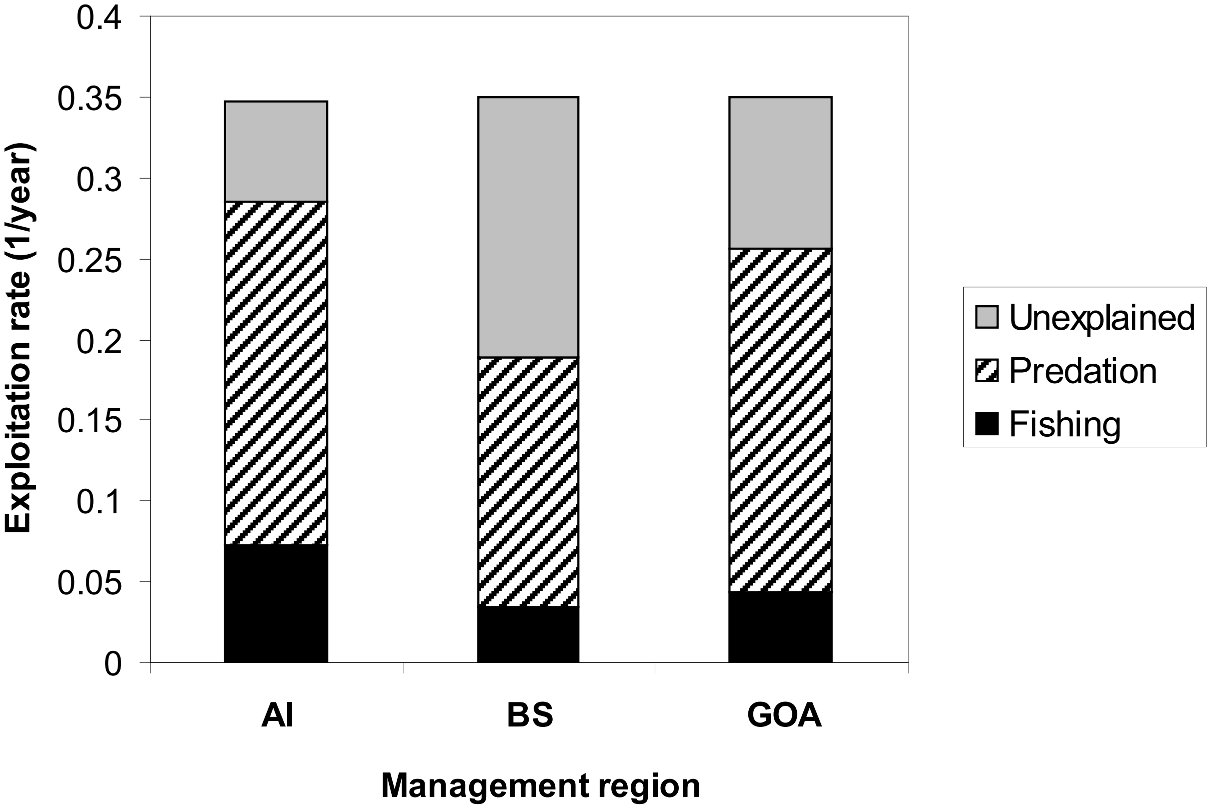


Figure 17.24. Total exploitation rate of age 1+ Atka mackerel, 1990-1994, proportioned into exploitation by fishing (black), predation (striped) and "unexplained" mortality (grey). "Unexplained" mortality is the difference between the stock assessment total exploitation rate averaged for 1990-1994, and 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 1977-2017 in Table 17A-1. Recent removals from activities other than directed fishing totaled <1 t in 2013, 111 t in 2014, <1 t in 2015, 78 t in 2016, and 2 t in 2017. This is approximately <0.1 % of the 2013, 2015, 2016, and 2017 ABCs, and 2% of the 2014 ABC. These low levels of non-commercial catch represent a very low 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 2019 and 2020 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	0				0
2016	AFSC	78				78
2017	AFSC	2				2

Appendix 17B

Atka mackerel (BSAI) Economic Performance Report for 2017

By
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Alaska Fishery Science Center, Resource Ecology and Fishery Management Division,
Economic and Social Sciences Research Division

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 2017 Atka mackerel total catch increased to 65.5 thousand t and retained catch increased to 64.7 thousand t. Catch levels in 2017 were comparable to the high catch levels in 2009 and 2010 prior to the significant reductions in the TAC in 2012 and 2013 when catch levels dropped to approximately 40% of the 2001-2010 average (Table 17B-1). The lower catch through 2012 and 2013 was due to area closures to protect endangered Steller sea lions and survey-based changes in the spatial apportionment of TAC. Recent increases in TAC reflect the continued health of the stock and expanded fishing opportunities in the Aleutian Islands. Commensurate with the change in catch, first-wholesale production increased. First-wholesale revenue grew to $125.2 million, with an increase in the price to $1.39/lb. The 2017 price rebounded after dipping in 2015 and is above pre-2012 levels.

The U.S. (Alaska), Japan and Russian are the major producers of Atka mackerel.[5] Approximately 90% of the Alaska caught Atka mackerel production volume is processed as head-and-gut (H&G), while the remainder is mostly sold as whole fish (Table 17B-1). 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 17B-2). Industry reports that the domestic market is minimal and data indicate U.S. imports are approximately 0.1% of global production. The upward trend in first-wholesale and export prices have been influenced by international factors. In particular, global supply of Atka mackerel has been in decline because of substantial decreases in catch volume both in the U.S. and Japan. Global production dropped from an average of 226 thousand t between 2008-2012 to102 thousand t in 2016 (Table 17B-2). The reductions in international supply mean that the U.S. has captured a larger share of global production in recent years relative to the 2008-2012 average (Table 2). The global supply reductions have upward pressure on the price which is reflected in the higher price after 2011. Additionally, the recent opening of previously restricted areas off the Aleutians has given industry more access to larger fish which yield a higher price per pound in the market. The increased price of Atka mackerel in recent years has helped to increase first-wholesale value (Table 17B-1). International production of Atka mackerel has been on the decline because of reductions in Japanese, and Russian catch and production which were particularly severe 2015 and have continued. As a result the U.S. supplied 54% of the global market of Atka mackerel in 2016 (Table 17B-2). There has been increased demand for U.S. Atka mackerel in Japan where it is used to make surimi. Because

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[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.

Atka mackerel is primarily exported to Japan, which constitutes roughly 70% of the export value, the U.S. exchange rate can influence first-wholesale prices, the value of the Dollar increased over the Yen in 2017 but and remained fairly stable since 2016 (Table 17B-2).

Table 17B-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; 2008-2012 average and 2013-2017.

	2008-2012 Average	**2013**	**2014**	**2015**	**2016**	**2017**
Total catch K mt	61.7	24.5	32.0	54.5	55.6	65.5
Retained catch K mt	56.2	21.6	28.8	53.3	54.8	64.7
Vessels #	12	14	11	14	15	17
First-wholesale production K mt	35.4	14.6	20.9	32.9	33.1	40.9
First-wholesale value M US$	$68.2	$39.5	$63.3	$74.3	$74.9	$125.2
First-wholesale price/lb US$	$0.87	$1.23	$1.37	$1.03	$1.03	$1.39
H&G share of value	94%	87%	93%	95%	95%	90%

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 17B-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; 2008-2012 average and 2013-2018.

	2008-2012 Average	**2013**	**2014**	**2015**	**2016**	**2017**	**2018 (thru July)**
Global production K mt	226.2	130.4	120.2	110.2	102.4	-	-
US share global production	26%	18%	26%	48%	54%	-	-
Export quantity K mt	21.0	12.7	19.5	30.1	30.2	37.1	20.7
Export value M US$	$31.0	$34.7	$53.2	$84.1	$83.8	$103.4	$56.9
Export price/lb US$	$0.67	$1.24	$1.24	$1.27	$1.26	$1.26	$1.24
Japan's share of export value	64%	62%	66%	73%	74%	72%	63%
Exchange rate, Yen/Dollar	88.9	97.6	105.9	121.0	108.8	112.2	109.1

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

Evaluation of aspects of the Bering Sea/Aleutian Islands Atka mackerel stock assessment model and data

Presented in September, 2018

Sandra Lowe and James Ianelli

Introduction

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

The Bering Sea/Aleutian Islands (BSAI) Plan Team recommended a list of items to be addressed in future assessments at their November, 2017 meeting. The SSC agreed (December, 2017 SSC minutes) with the Plan Team recommendations listed below. The elements in bold are addressed in this document. Items 6 and 8 will be addressed in the final (November, 2018) assessment.

From the November 2017 Plan Team minutes: *The Team recommends that the authors undertake the following during one or more future assessments (as this is a long list, the Team does not expect all items to be addressed by next September, and understands that the authors can prioritize the list as they see fit):*

1. **Investigate which parameters (including derived quantities) are changing in the retrospective peels that might contribute the relationship between historical scale and number of peels.**
2. **Consider dropping the 1986 age composition from the analysis, to be consistent with the policy of not using pre-1991 survey data.**
3. **Improve documentation for the process of using Francis weights to tune the constraint governing the amount of time variability in fishery selectivity.**
4. **Continue to investigate fishery selectivity time blocks, with blocks linked to identifiable changes in the fishery.**
5. **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.**
6. Investigate whether a larger number of survey otoliths can be collected in a representative fashion.
   Note: Random sampling was adopted for the 2018 AI survey, with a scheme to sample approximately 300 otoliths per area, with an overall target of otoliths from 1,000 Atka mackerel.
7. **Continue the investigation of age-dependent natural mortality.**
8. Continue to include (and update) Figure 17.5.
   This will be included in the November, 2018 assessment.

Evaluations

Data used for these evaluations were identical to those used in the 2017 assessment. References to last year's (2017) assessment are based on model runs with last year's accepted model (Model 16.0b, Lowe *et al*. 2017).

Retrospective pattern investigations

The Plan Team requested investigation of which parameters might be causing the apparent downward shift in biomass for retrospective "assessments" after about 2013 (Figure 1). Because there appears to be a scale shift in the biomass estimates, initial evaluations examined the survey catchability coefficient and the mean recruitment parameter. Extracting these values indicates that in more recent terminal-year assessment runs the value of the survey catchability was higher which, according to how the model is specified, scales the population to be lower (Figure 1), but only results in slightly lower mean recruitment estimates (Figure 2). Model fits to the survey data for these retrospective runs show that the 2 lowest survey estimates in time series (2012 and 2016), likely dropped the overall biomass estimates (and increased values of catchability) following the three relatively high biomass estimates between 2002 and 2010 (Figure 3). The 2002, 2004, and 2010 estimates represented the three highest survey biomass estimates in the time series. We also evaluated the impact of these survey data as they entered in to the retrospective assessments. For the survey index, the negative log-likelihood shows how historical biomass estimates become more or less consistent with model estimates with a large jump in cumulative negative log likelihood after the 2012 survey was included (Figure 4). Figure 4 also shows the relative impact of adding survey age compositions. The retrospective peels are fairly consistent with expected jumps after the recent 2012 and 2014 survey age compositions were added. Although jumps in the cumulative survey age negative log likelihoods occurred after the 2012 and 2014 survey data were added, these increases were much less than the survey index, and are comparable with adding in past years of survey age compositions (Figure 4). The robust fishery age data which is generally well fit, prevents the model from fitting the 2012 and 2016 large drops in survey biomass. In conclusion, the observed pattern reflects the addition of recent survey estimates, and in general, 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.

Dropping the 1986 survey age compositions

Because of inconsistencies in the 1980s survey data (see *Survey abundance indices* in Lowe *et al*. 2017), the 1980s survey biomass data are omitted, but the 1986 survey age composition are included. The 1986 survey age data were thought to provide useful information on relative year-class strengths. We explored this further with simulations with and without the 1986 survey age composition. The impact of dropping the 1986 survey age composition reduced recruitment estimates by nearly 3.6% (mean recruitment is 658 million with those data included compared to 634 million without; Figure 5). The 2017 spawning biomass estimate was similarly affected with a slightly lower estimate when the 1986 survey age composition was excluded. Relative to survey fit, dropping the 1986 data degraded the fit to the data slightly (negative log likelihood for the survey index of 8.18 versus 8.32 without the 1986 age compositions). Between these two models runs, the estimate of survey catchability also differed, which explains some of the change in recruitment and spawning biomass levels (1.17 for Model 16.0b and 1.29 for the same model without the 1986 survey age composition).

In last year's assessment we also conducted a sensitivity analyses 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). Although the 1986 survey age data may provide useful information on relative year-class strengths, the 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.

In conclusion, we suggest that that there is no real benefit to including the 1986 survey age composition, and that including these data is inconsistent given that the model does not include the 1986 survey index. We propose to exclude the 1986 survey age composition in future assessments.

Further evaluations of the Francis weights and selectivity changes

In this section we attempt to address SSC and Plan Team requests 3, 4, and 5 (above) all dealing with aspects of fishery selectivity variability. For item 3 (documenting the procedure for tuning the time-varying selectivity variability), we distinguish the tuning of the sample sizes given constant or other rigid selectivity/separable fishing mortality patterns, from the method introduced last year in which the allowance for time-varying selectivity variability (σ_{f_sel}) was tuned using the Francis weighting method (Francis 2011, equation TA1.8) on the fishery age composition data. This is analogous to the tuning with Francis weights that were used to determine samples sizes in Lowe *et al*. (2017). This was done in an effort to satisfy the request to arrive at a statistical approach for specifying the degree of time-varying selectivity. While this requires fixing the assumption that the input fishery sample sizes have a mean value of 100, we argue that this is a reasonable way to arrive at a balance between process and observation error. 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 interannual 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 C-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 selectivities. 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, would 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.

Item 4, (request to continue to examine periods where fishery selectivity could reasonably assumed to be the same) was initially explored in the 2017 assessment. We addressed previous SSC and Plan Team comments to turn off time-varying selectivity and apply time blocks for fishery selectivity together in a preliminary sensitivity analysis (Lowe *et al*. 2017, Model 16.0c), using blocks of years within which selectivity was time-invariant for the periods:

1977-1983 Foreign fishery
1984-1991 Joint venture fishery
1992-1998 Domestic fishery and 3-subarea split
1999-2011 Steller sea lion regulations
2011-2014 Steller sea lion RPAs
2015-2017 revised Steller sea lion RPAs

These periods were identified as ones having different management measures and spatial closures. However, the model performance was relatively low given model fits (e.g., to survey data) and assumptions about the level of observer sampling. Results from preliminary investigations implementing blocked selectivity were unsatisfactory and appeared to miss age-specific targeting and recruitment events (Lowe *et al*. 2017). Results of the estimated selectivity patterns for the time blocks selected tended to obscure confirmed significant recruitment events, and or the selectivity for the block was based on a pattern that was only evident in the fishery catches for a short time period (less than the number of years in the block). We continued the exploration of time blocks adding an additional time block within the 1999-2010 time period to account for changes in the fishery from Amendments 78 and 80:

1999-2005 Steller sea lion regulations
2006-2010 Steller sea lion regulations, Amendments 78 and 80

Amendment 78 to the BSAI Groundfish FMP closed a large portion of the Aleutian Islands (AI) subarea to nonpelagic trawling. The Amendment 78 closures to nonpelagic trawling included the AI Habitat Conservation Area (AIHCA), 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 were in addition to the Steller sea lion protection measures and, in combination, substantially limited 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). BSAI Atka mackerel is one of the groundfish species directly affected by Amendment 80.

As expected, the fits to the fishery age composition were degraded when time-varying selectivity was dropped and replaced with periods where selectivity was held constant for specific periods. Adding an additional “time block” to the blocked selectivity model resulted in only minor (negligible) improvements to the fit to the fishery age compositions (Figure 6 compared to Figure 7). The fit to the survey was slightly worse and the spawning biomass and apical fishing mortality rates differed significantly compared to last year’s model (Model 16.0b) with time-varying selectivity (Figure 8). The selectivity patterns can have a large impact on the reference fishing mortality rates, and Atka mackerel have been shown to be sensitive to assumptions about selectivity (Lowe *et al*. 2008, Lowe *et al*. 2013). For example, previous investigations incorporating annual time-varying approach for fishery selectivity allowed the model flexibility to better reflect the fishery age composition data and provided results consistent with fishery age distributions (Lowe *et al*. 2013). Also, it seems reasonable that some selectivity variability would occur given year-class variability (SigmaR= 45-50% in recent years), and the fact that the fishery may seek out higher catch-rate areas where such strong year-classes may be present (and hence have higher peak fishing mortalities as shown in Figure 8). Therefore, we suggest that the time varying selectivity option be retained. Further explorations of statistical aspects of tuning the time-varying selectivity variance term ($\sigma_{\mathrm{f\_sel}}$) with the Francis (2011) method are provided below.

For request 5 listed above, the Plan Team suggested looking at how tuning the selectivity variability parameter affects results if a higher or lower sample size was assumed for the fishery. The 2017 model assumed a mean sample size of 100 for the time period of observer data 1991-2016 (scaled based on the number of tows sampled). To fulfill this request we rescaled all the input sample sizes to half (50) and double (200) that assumption. Tuning the selectivity variability parameter for these two new cases resulted in expected differences in the amount of selectivity variability in the fishery (Figures 9, 10, and 11). These runs also affected recruitment estimates i.e., when a higher sample size was specified, the selectivity varied more (Figure 11) and interannual variability of recruitment increased (Figure 12). For the most part, recruitment estimates for sample sizes of 50 and 100 were relatively similar, but increasing the sample size to 200 significantly lowered recruitment estimates (Figure 12). This is consistent with the expectation that greater “targetting” of specific year-classes results in higher values for the above-average year-classes compared to separable assumptions that selectivity/availability of cohorts are more even.

The relative impact expected in projections is explored by comparing the estimated recent 5-year average selectivities assuming mean fishery sample sizes equal to 50, 100, and 200. Figure 13 shows that the tuned models under different fishery sample size assumptions result in different age-specific selectivity estimates, particularly for ages between 3 and 8 years. The fishery catches essentially consist of fish 3-11 years old. Fish older than age 9 make up a very small percentage of the population each year, and the differences in the selectivity assumptions for older ages are not likely to have a large impact. However, differences in selectivity for ages 3-8 can have a significant impact. These differences will impact the F_{SPR} estimates and consequently the ABC and OFL values. Higher sample size result in shifts in selectivity to the right, relative to maturity-at-age, which is associated with higher F_{SPR} reference rates. For example, the $F_{40\%}$ value for the higher input sample size was 0.43 compared to 0.42 and 0.40 for input mean sample sizes of 100 and 50, respectively. Comparing projections for these three scenarios show the spawning biomass as being highest for the low input sample size resulting in higher catches based on the ABC control rules (Figure 14).

Age-specific natural mortality

We previously 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 request 7 (continue investigation of age-specific natural mortality), we include a third method (Gislason, 2010) in a further investigation of age-specific *M*, and use a rescaled average vector of *M* for model evaluation. 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. The three methods used in this analysis are:

Brodziak et al. (2011)—Age–specific *M* is given by

$$M(a) = \begin{cases} M_c \dfrac{L_{mat}}{L(a)} & for \quad a < a_{mat} \\ M_c & for \quad a \geq a_{mat} \end{cases}$$

where L_{mat} is the length at maturity = 36.77 cm (age 5, 90% maturity), $M_c = 0.30$ is the specified natural mortality at L_{mat}, L(a) is mean length at age for the 2010-2016 Aleutian Islands summer bottom trawl surveys.

Lorenzen (1996)—Age-specific M for ocean ecosystems is given by

$$M\,(\mathrm{a}) = 3.69\ W^{-0.305},$$

where W is the mean weight at age from the 2010-2016 Aleutian Islands summer bottom trawl surveys.

Gislason et al. (2010)—Age specific M is given by

$$\ln(M) = 0.55 - 1.61\ \ln(L) + 1.44\ \ln(L_\infty) + \ln(K),$$

where $L_\infty = 43.23$ cm, and $K = 0.384$ were estimated by fitting the von Bertalanffy growth curve using age data from the 2010-2016 Aleutian Islands summer bottom trawl surveys.

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 (Table 1). To obtain an age-specific natural mortality schedule for further investigation, 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 so that the average M for a range of ages equals a specified value (Porch, 2011). The average age-specific values were rescaled so that natural mortality for fish greater than or equal to age 4.5, the age at 90% maturity, was equal to 0.3, the value of natural mortality used in previous Atka mackerel assessments (Table 1). This rescaled average schedule was used to explore the impact of higher age-specific mortality for the younger ages.

Spawning biomass for the age-specific natural mortality shows a shift to higher totals relative to the 2017 assessment model (Figure 15). Projections from the age-specific natural mortality model run showed minor increases in ABC (<3%), which on investigation, was consistent with the relatively minor differences in natural mortality between the two models for the “most” selected age groups (Figure 16). Notably, the biggest difference was for age-1 recruits which are impacted by higher values of M but have low impact to stock dynamics given selectivity and maturity schedules (Figure 17).

The following table of negative log-likelihood values compares components between last year’s assessment model and one modified with age-specific natural mortality.

	2017Assessment	Age-specific natural mortality
Fishery age composition	160.38	127.14
Selectivity regularity	140.08	99.09
Survey index	8.43	8.2
Survey age composition	28.29	27.87
Stock recruitment	4.15	-5.77
Prior on survey q	1.47	0.44

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 (Table 1). The 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 (Figure 17). Although spawning biomass estimates are scaled higher relative the the 2017 assessment with constant *M*, biological reference rates and the associated ABC and OFL reflect only minor increases. The age at 50% selectivity for both models is about age 4.5, natural mortality and selectivity schedules are nearly indentical for ages greater than age 4 (Figure 16). Although estimates of age 1 recruitment differ greatly between the 2 models, age 1 recruits have low impact to stock dynamics given selectivity and maturity schedules for Atka mackerel (Figure 16). As such, we are not clear that a model configuration with age-specific mortality is an improved representation for Atka mackerel stock dynamics than the currently accepted model with constant *M*=0.3. The natural mortality estimate of 0.3 is a conservative assumption and based on a previous meta-analysis (Lowe and Fritz, 1997). This value seems to fit reasonably well with other key estimated parameters (e.g. survey catchability and selectivity). We suggest continuing with the current accepted model (Model 16.0b) with the assumption of fixed constant *M*=0.3, and to focus our efforts on other aspects of the Atka mackerel assessment model.

Literature Cited

Brodziak, J., Ianelli, J., Lorenzen, K., and Methot R.D. Jr. (eds) (2011) Estimating natural mortality in stock assessment applications. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-119, 38 p.

Francis, R.I.C.C 2011. Data weighting in statistical fisheries stock assessment models. Can. Journ. Fish. Aquat. Sci. 1138: 1124-1138.

Gislason, H., N. Daan, J. C. Rice and J. G. Pope. 2010. Size, growth, temperature and natural mortality of marine fish. Fish and Fisheries 11:149-158.

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. Journal of Fish Biology 49:627-647.

Lowe, S. and J. Ianelli. 2016. *Unpublished report*. Assessment evaluations for the Atka mackerel stock in the Bering Sea/Aleutian Islands. Alaska Fisheries Science Center, 7600 Sand Point Way NE, Building 4, REFM, Seattle, WA 98115

Lowe, S., J. Ianelli, M. Wilkins, K. Aydin, R. Lauth, and I. Spies. 2008. Stock assessment of Aleutian Islands Atka mackerel. *In* Stock Assessment and Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, Alaska, 99510.

Lowe, S., J. Ianelli, W. Palsson. 2013. Stock assessment of Aleutian Islands Atka mackerel. *In* Stock Assessment and Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, Alaska, 99510.

Lowe, S., J. Ianelli, W. Palsson. 2017. Stock assessment of Aleutian Islands Atka mackerel. *In* Stock Assessment and Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, Alaska, 99510.

Lowe, S.A. and L.W. Fritz. 1997. Atka mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions as Projected for 1999. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Porch, C. 2011. Abstract #12: Rescaling the Lorenzen natural mortality curve: issues from the Southeast Data Assessment and Review. *In* Brodziak, J., Ianelli, J., Lorenzen, K., and Methot R.D. Jr. (eds) (2011) Estimating natural mortality in stock assessment applications. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-119, 38 p.

Tables

Table 17C-1. Schedule of alternative approaches to specifying specific natural mortality rates-at-age. The "Rescaled Average" was used for evaluations.

Age	Length (cm)	Weight (g)	Brodziak *et al*. (2011)	Lorenzen (1996)	Gislason *et al*. (2010)	Average	Rescaled Ave.
1	14.09	45	0.76	1.00	2.13	1.30	1.04
2	23.38	168.25	0.46	0.69	0.94	0.70	0.56
3	29.71	391	0.36	0.54	0.64	0.51	0.41
4	34.02	538.5	0.31	0.49	0.52	0.44	0.35
5	36.96	663	0.30	0.46	0.45	0.40	0.32
6	38.96	725.5	0.30	0.45	0.41	0.39	0.31
7	40.32	837.75	0.30	0.43	0.39	0.37	0.30
8	41.25	934.5	0.30	0.42	0.38	0.37	0.29
9	41.88	918.5	0.30	0.42	0.37	0.36	0.29
10	42.31	893.75	0.30	0.42	0.36	0.36	0.29
11+	42.60	1024.25	0.30	0.41	0.36	0.36	0.29

Figures

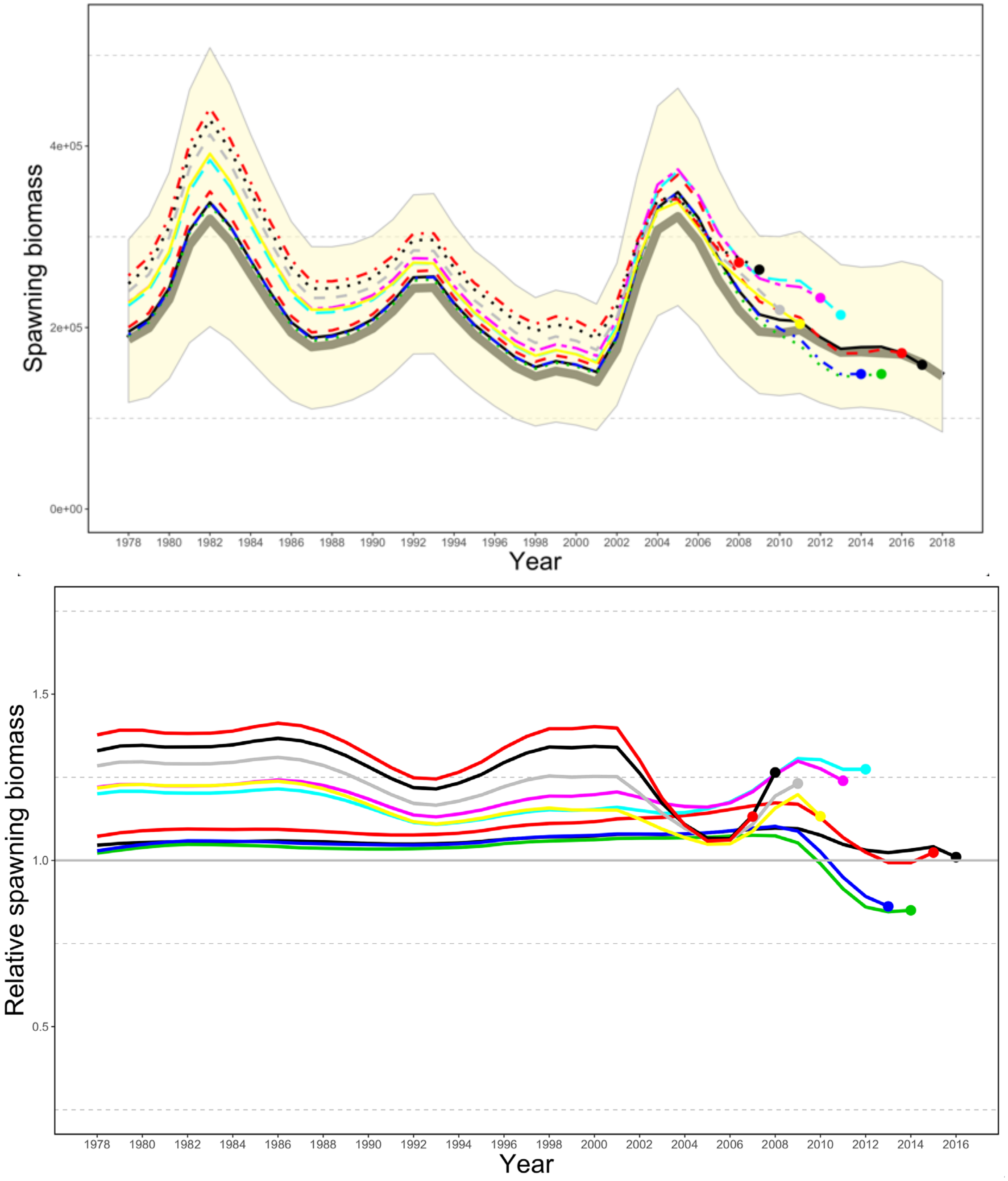

Figure 17C-1. Retrospective plots showing the BSAI Atka mackerel spawning biomass over time (top) and the relative difference (bottom) over 10 different "peels".

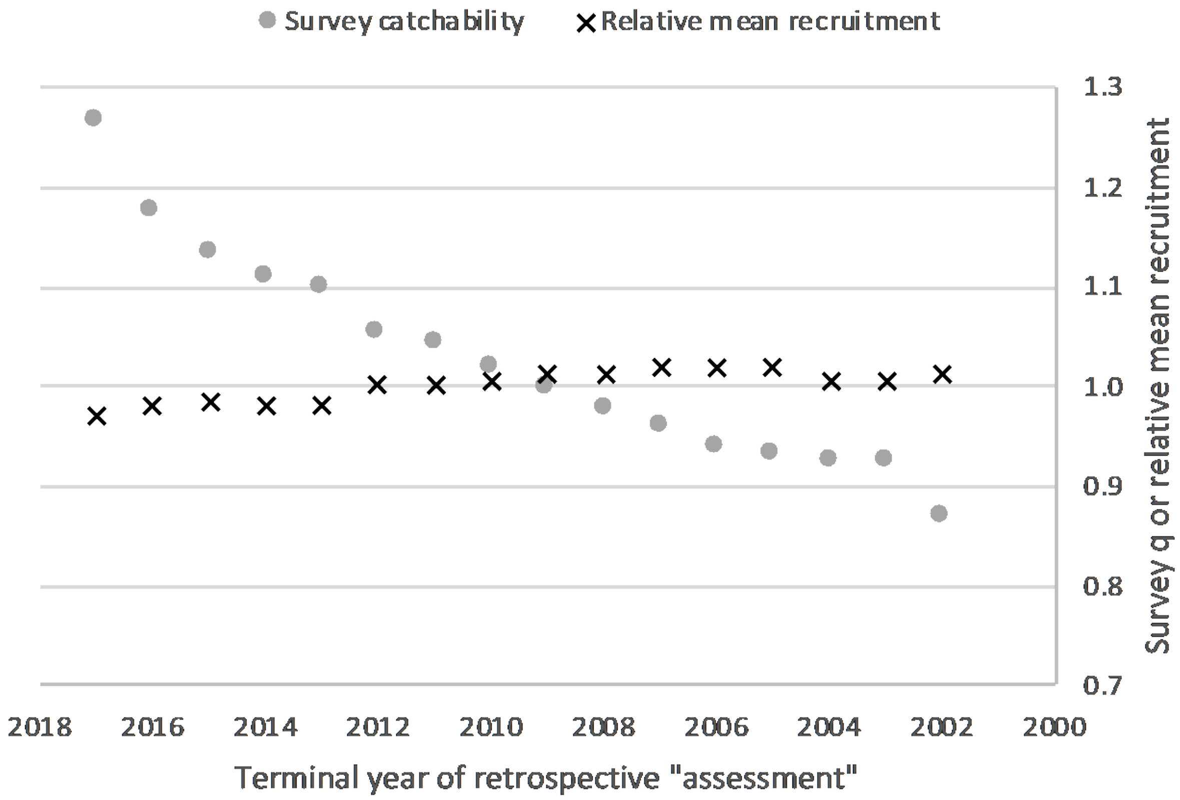

Figure 17C-2. Atka mackerel Aleutian Islands bottom trawl survey catchability (*q*) and mean recruitment (rescaled to have mean of 1.0) over different retrospective model runs. Horizontal axis (in reverse order) represents the terminal year of the retrospective model run.

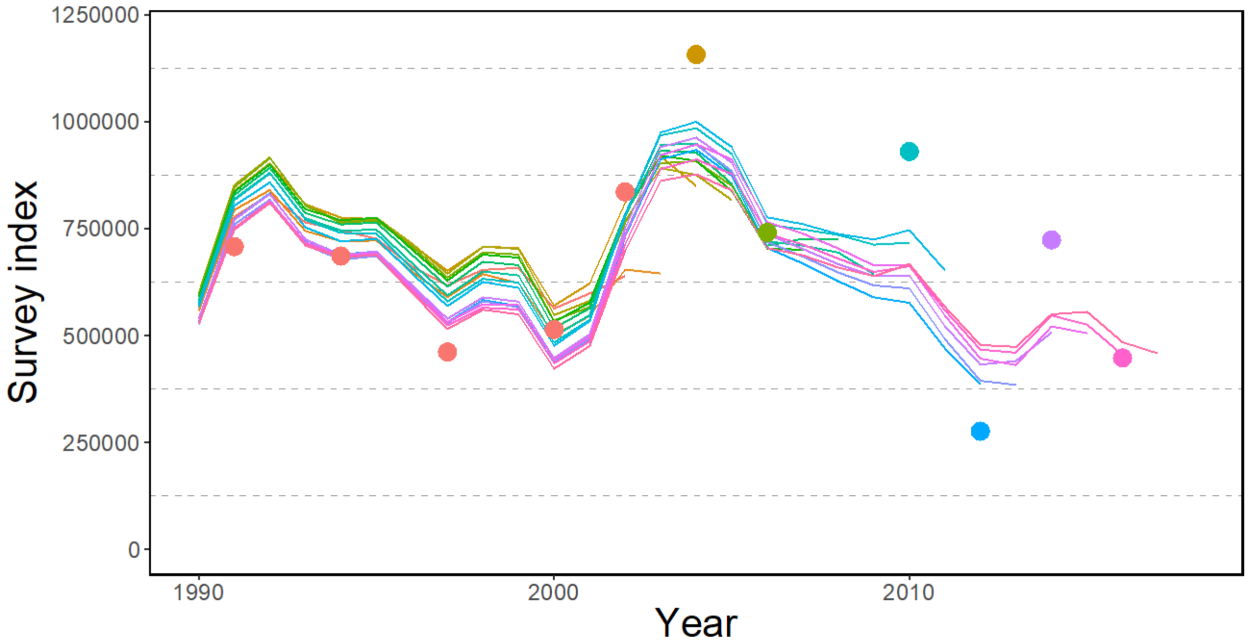

Figure 17C-3. Fit to survey data (dots) relative to retrospective run model fits (lines). Note that each run estimates survey catchability (and age-specific selectivity) independently, hence the pattern may or may not reflect changes in absolute biomass estimates.

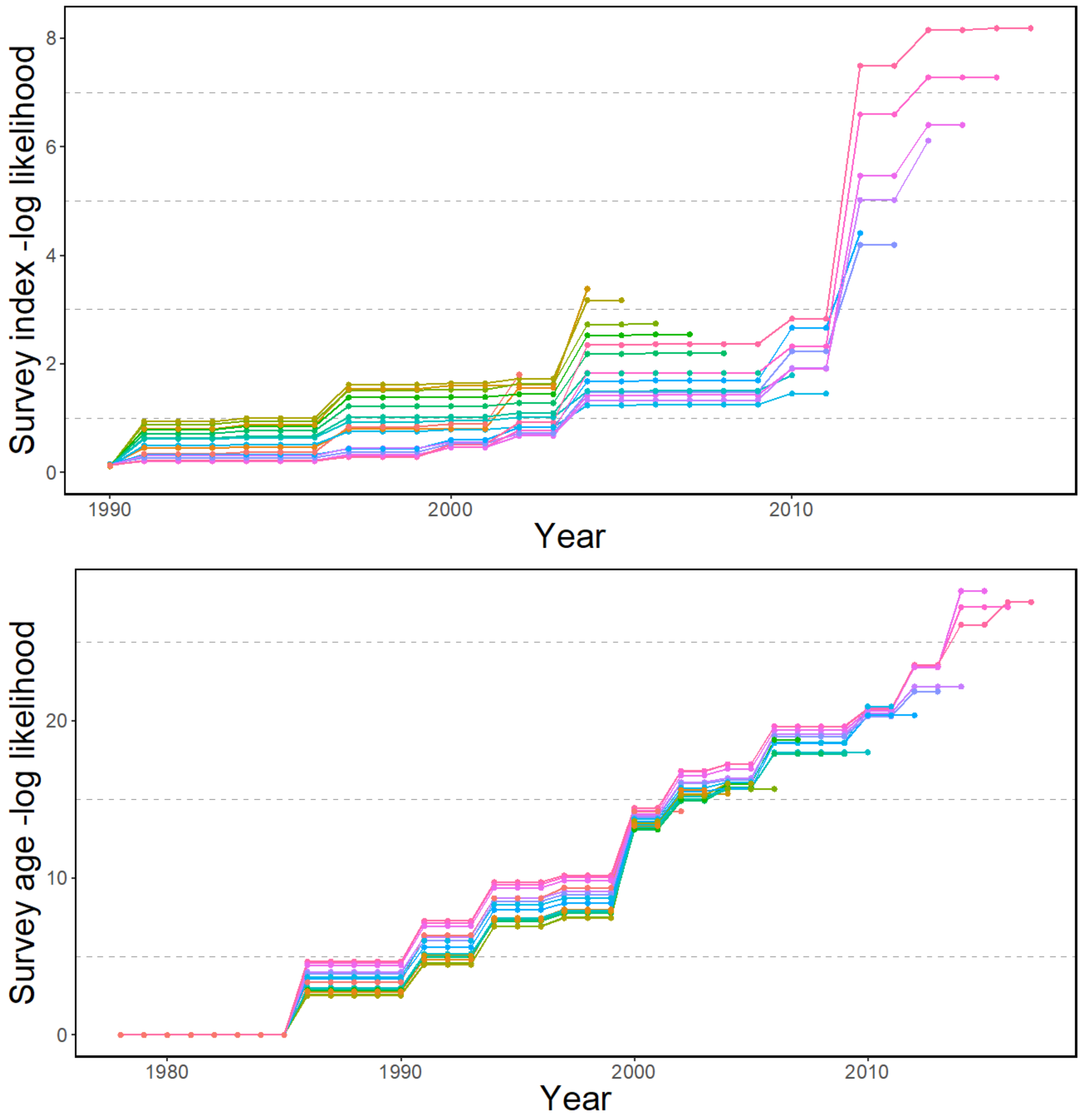

Figure 17C-4. Cumulative negative log-likelihood for survey index data (top), and survey age composition (bottom) for retrospective model runs.

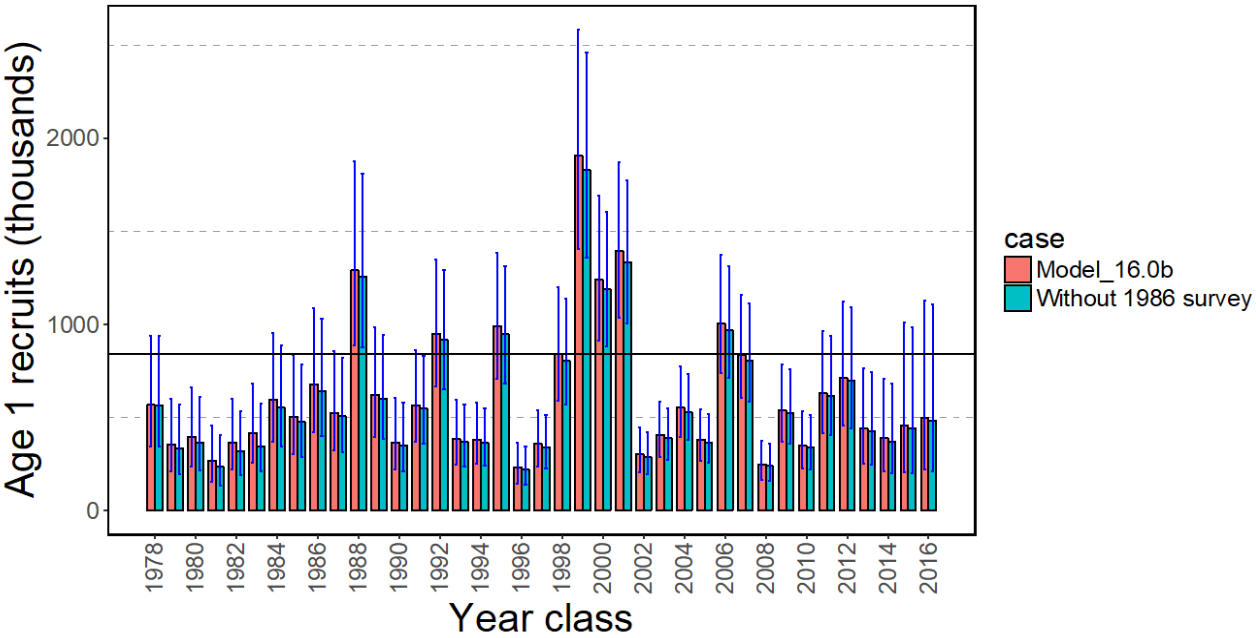

Figure 17C-5. Recruitment estimates (age 1) with, and without the 1986 survey age composition included. Model 16.0b is last year's model configuration including the 1986 survey age composition. The solid line is the mean recruitment estimate for Model 16.0b.

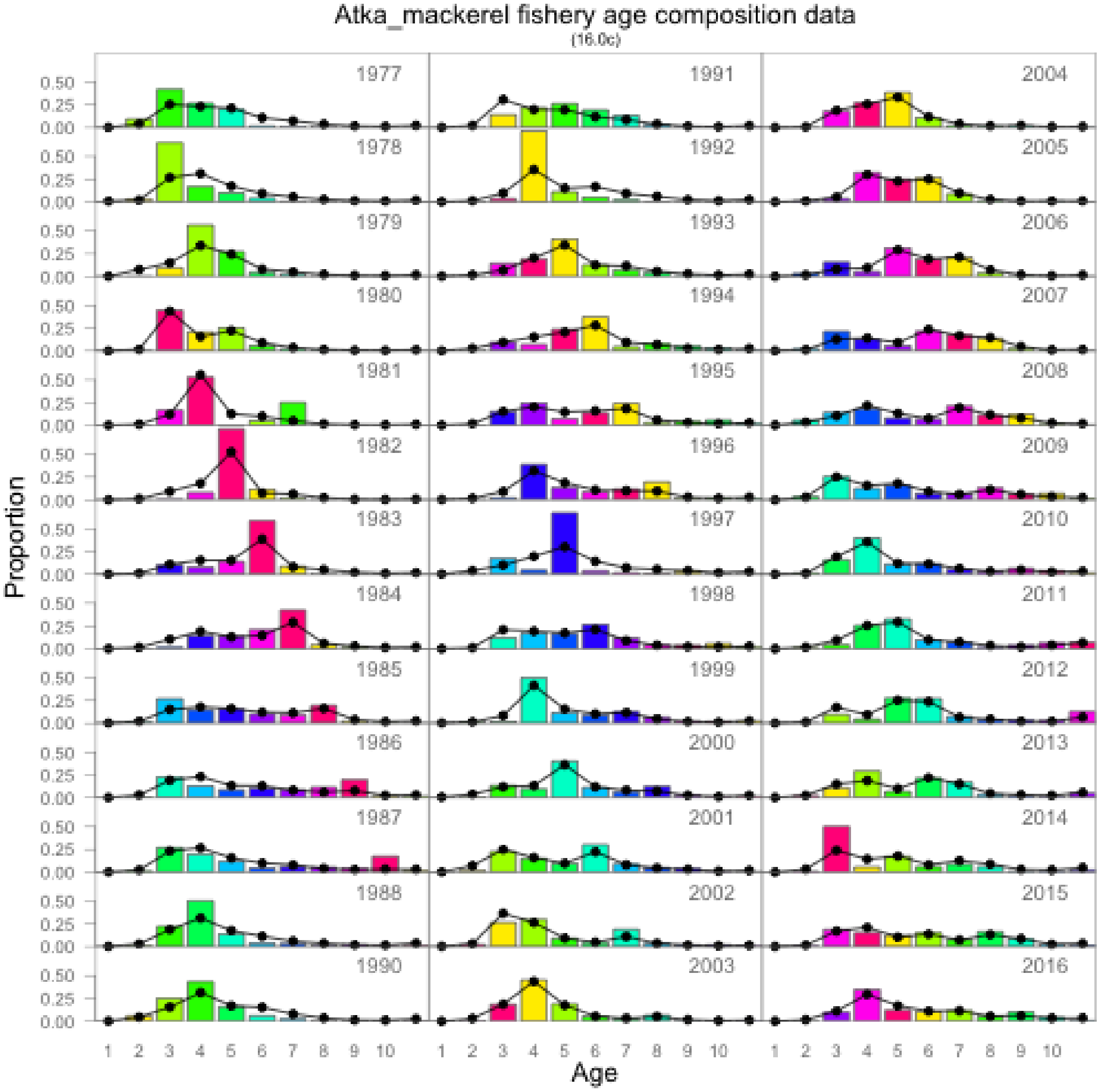

Figure 17C-6. Model fits for configuration 16.0c as in the 2017 assessment, without an added block of selectivity in 2000-2005 period for BSAI Atka mackerel.

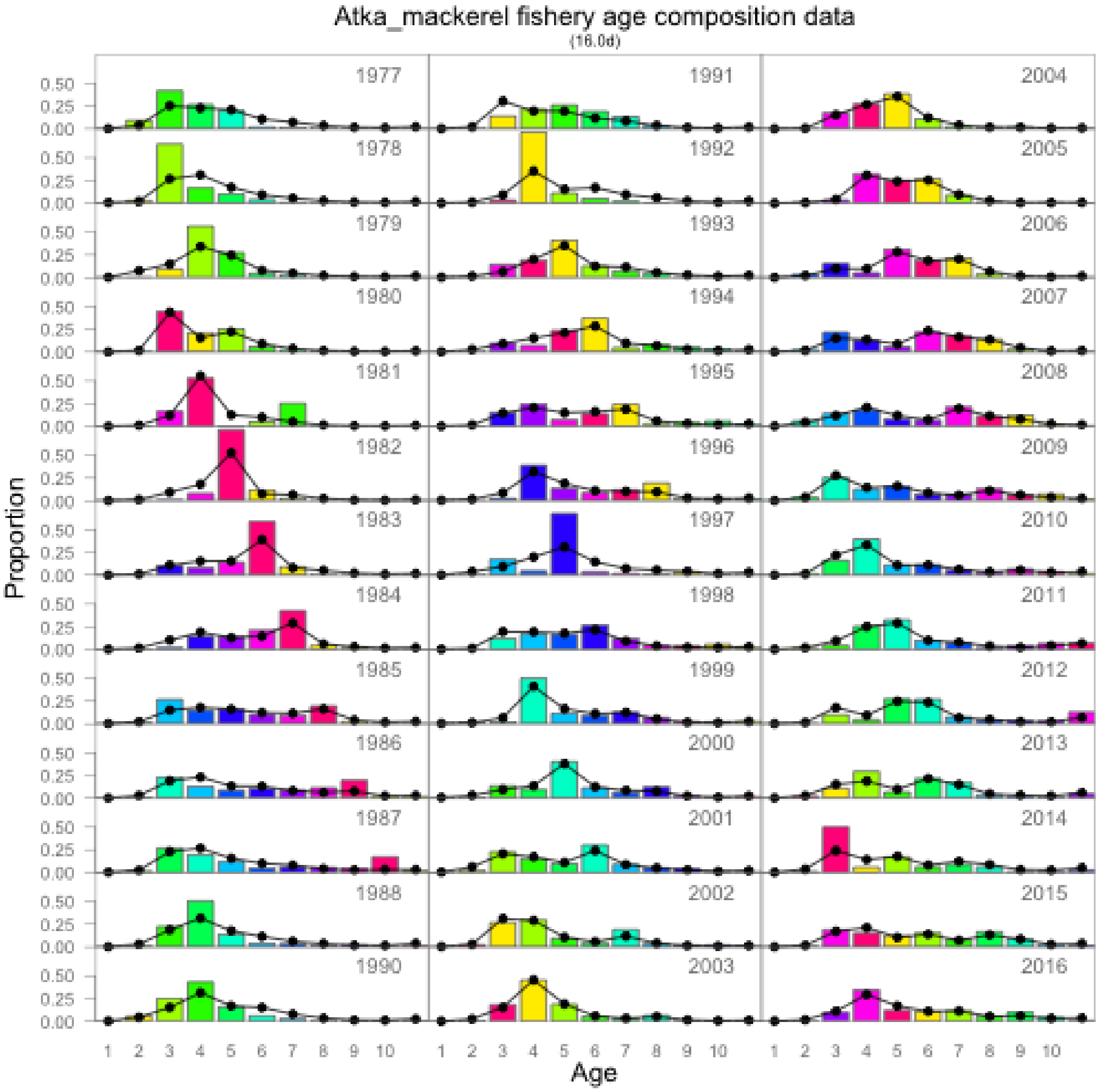

Figure 17C-7. Model fits for configuration 16.0d with an added block of selectivity in the 2000-2005 period for BSAI Atka mackerel.

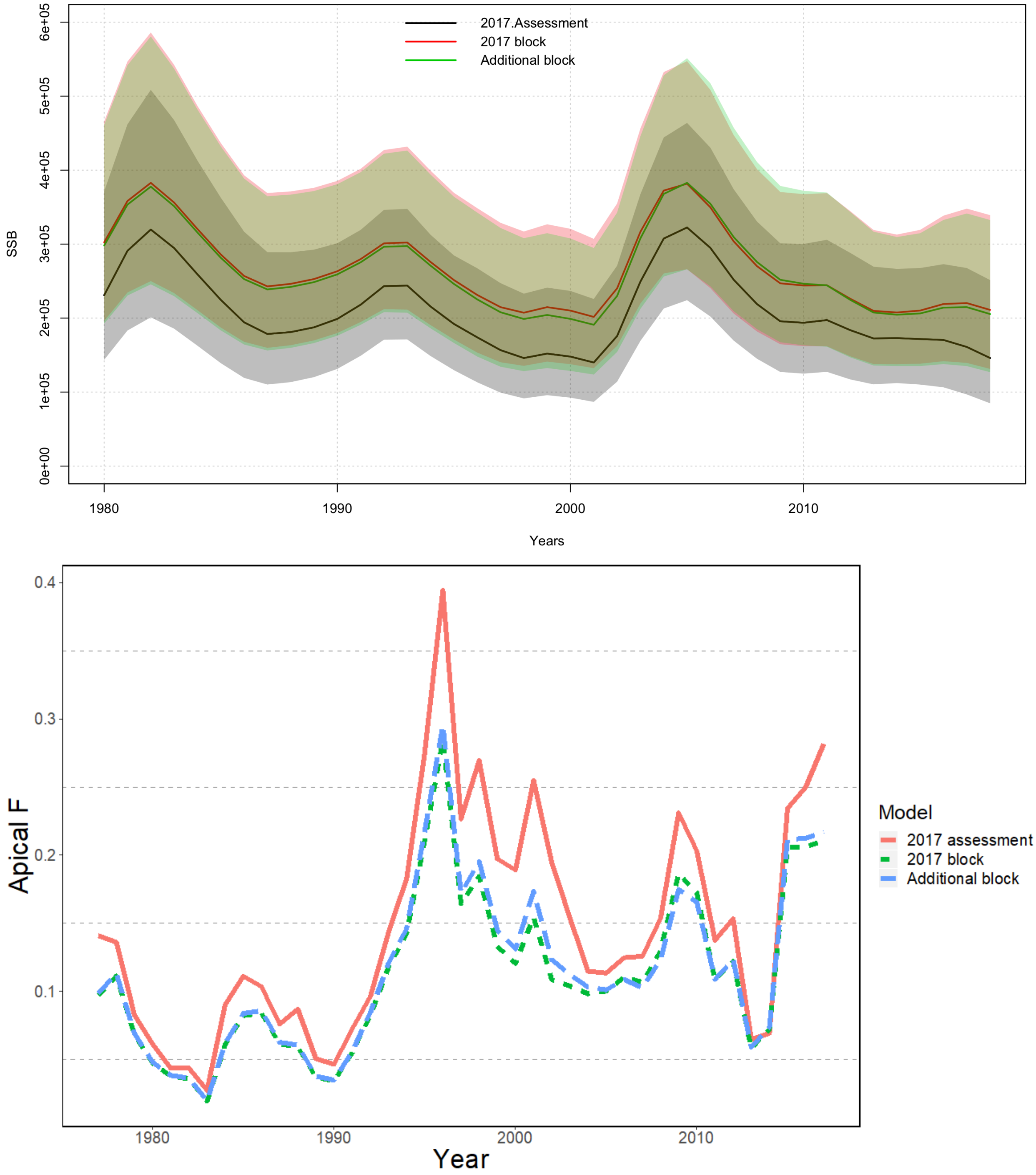

Figure 17C-8. Spawning biomass (top) and apical fishing mortality (bottom) for the 2017 selected assessment model configuration (Model 16.0b) with time-varying fishery selectivity, and alternative selectivity blocking schemes.

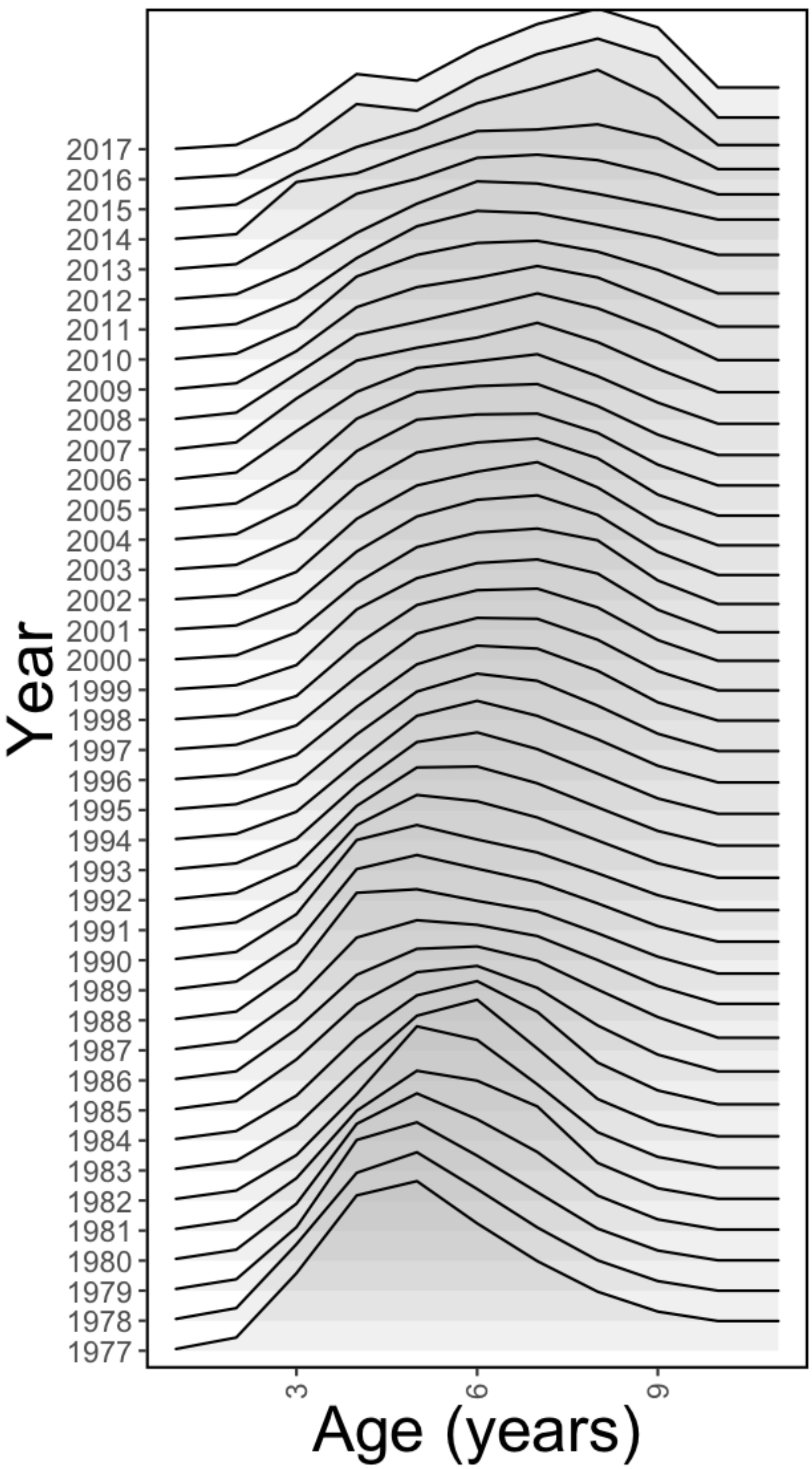

Figure 17C-9. Selectivity estimates for Model 16.0b, with mean 1991-2016 sample size equal to 50 and Francis (2011) weights tuned to approximately 1.0.

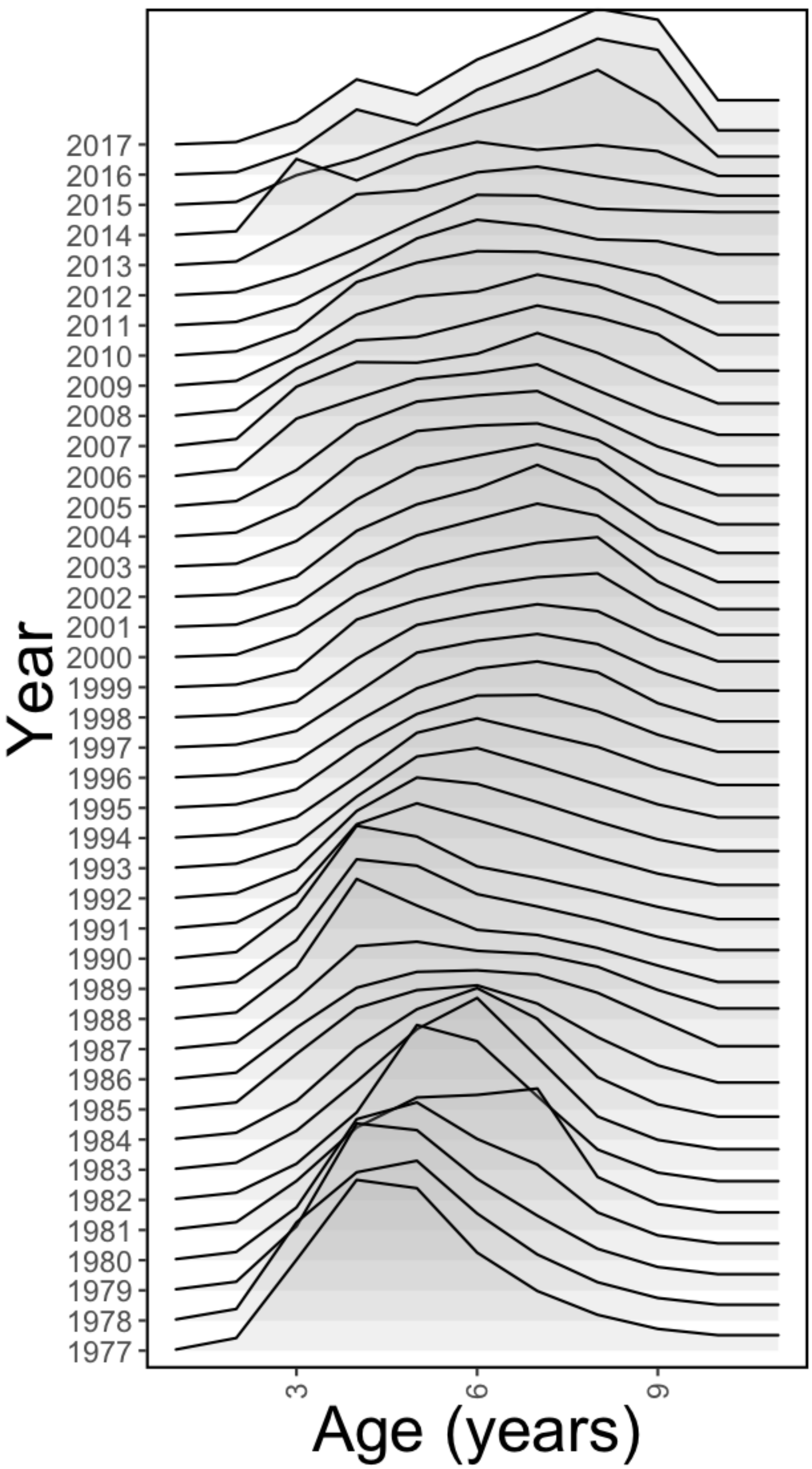

Figure 17C-10. Selectivity estimates for Model 16.0b, with mean 1991-2016 sample size equal to 100 and Francis (2011) weights tuned to approximately 1.0 (Model 16.0b used in 2017 assessment).

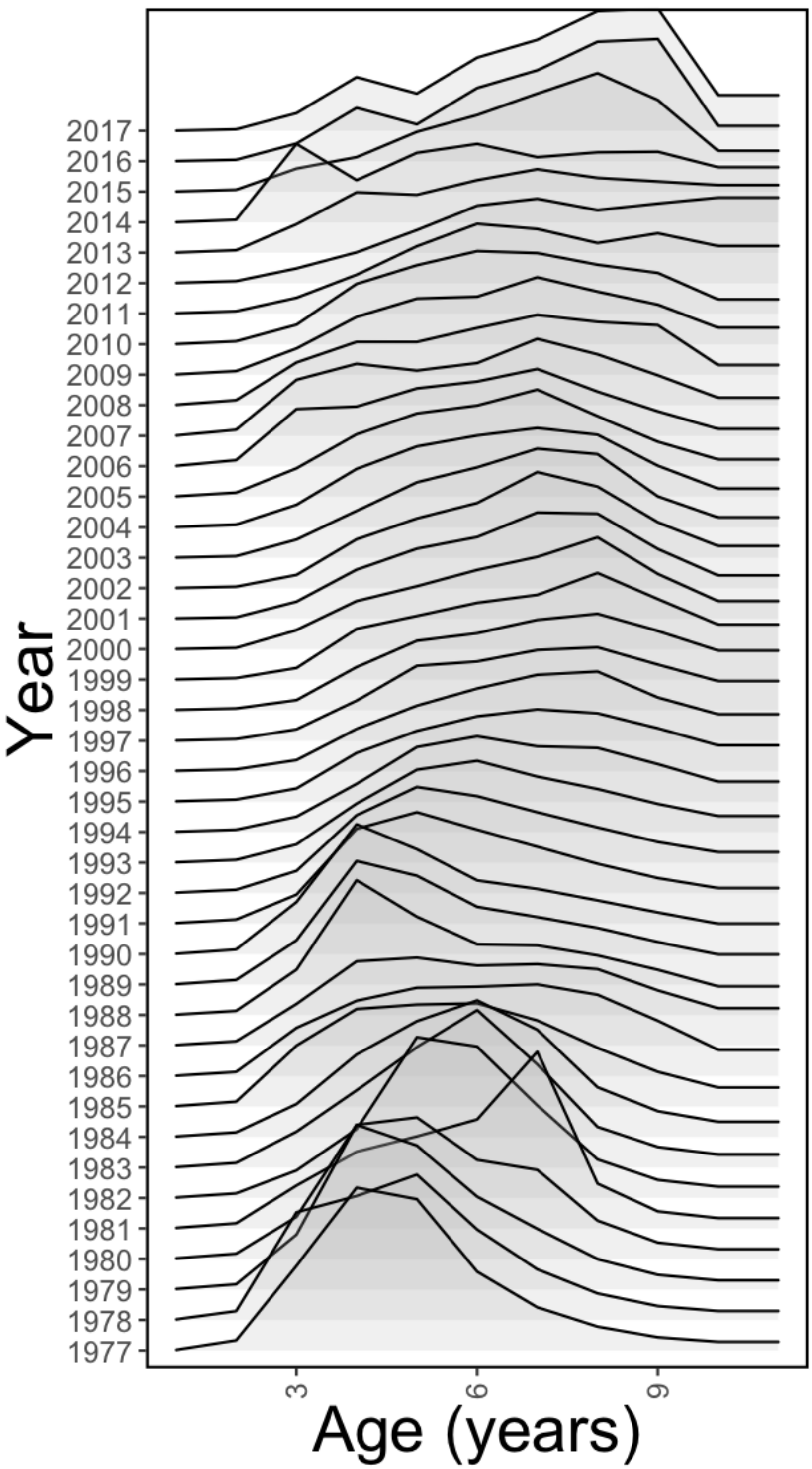

Figure 17C-11. Selectivity estimates for Model 16.0b, with mean 1991-2016 sample size equal to 200 and Francis (2011) weights tuned to approximately 1.0.

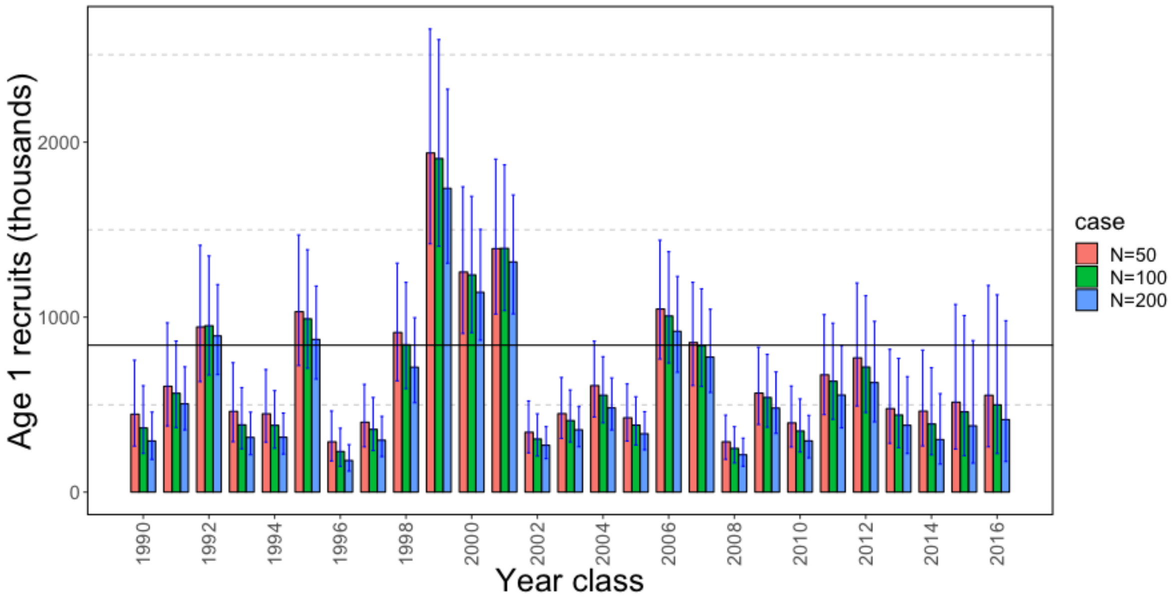

Figure 17C-12. Estimated BSAI Atka mackerel age 1 recruitment under different assumptions about mean 1991-2016 fishery sample sizes comparing values of 100 (used in the 2017 assessment), and alternative mean 1991-2016 sample sizes equal to 50 and 200, and Francis weights tuned to approximately 1.0

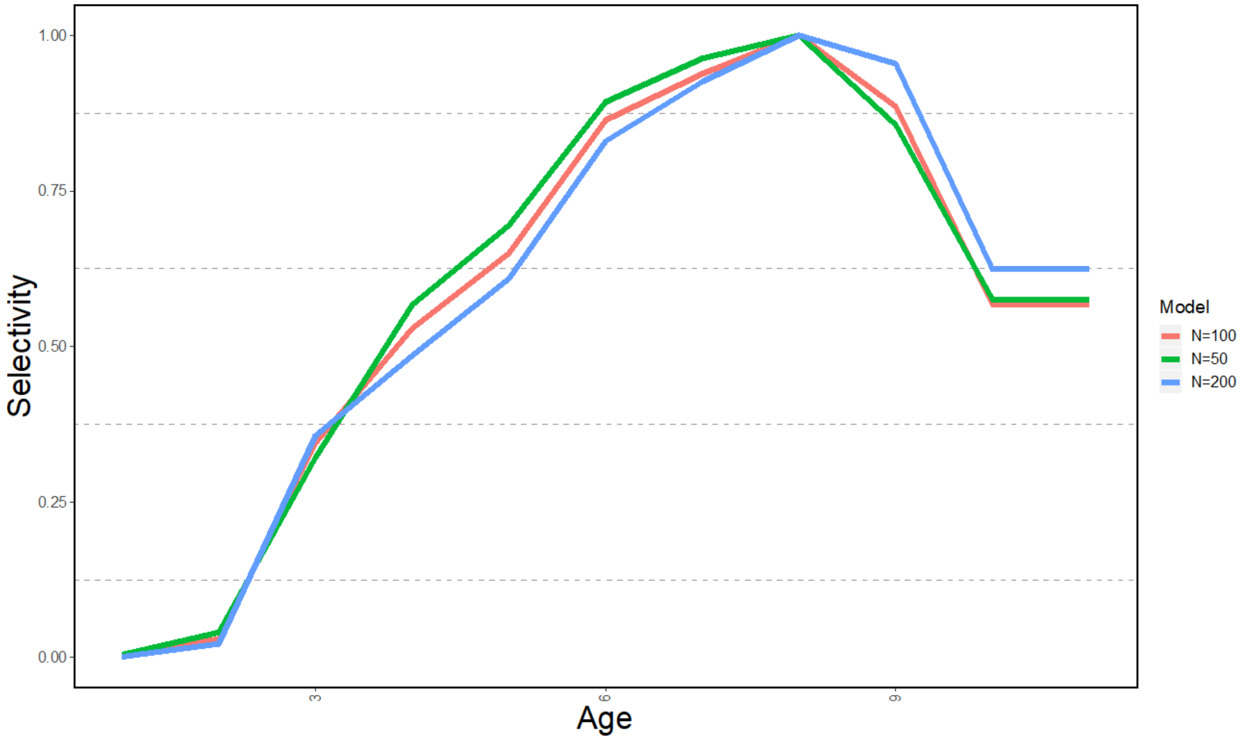

Figure 17C-13. Average (2012-2016) selectivity at age estimates for different tuned model runs with mean 1991-2016 fishery sample sizes equal to 100 (used in the 2017 assessment), and alternatives with selectivity variability tuned to mean 1991-2016 fishery sample sizes equal to 50 and 200.

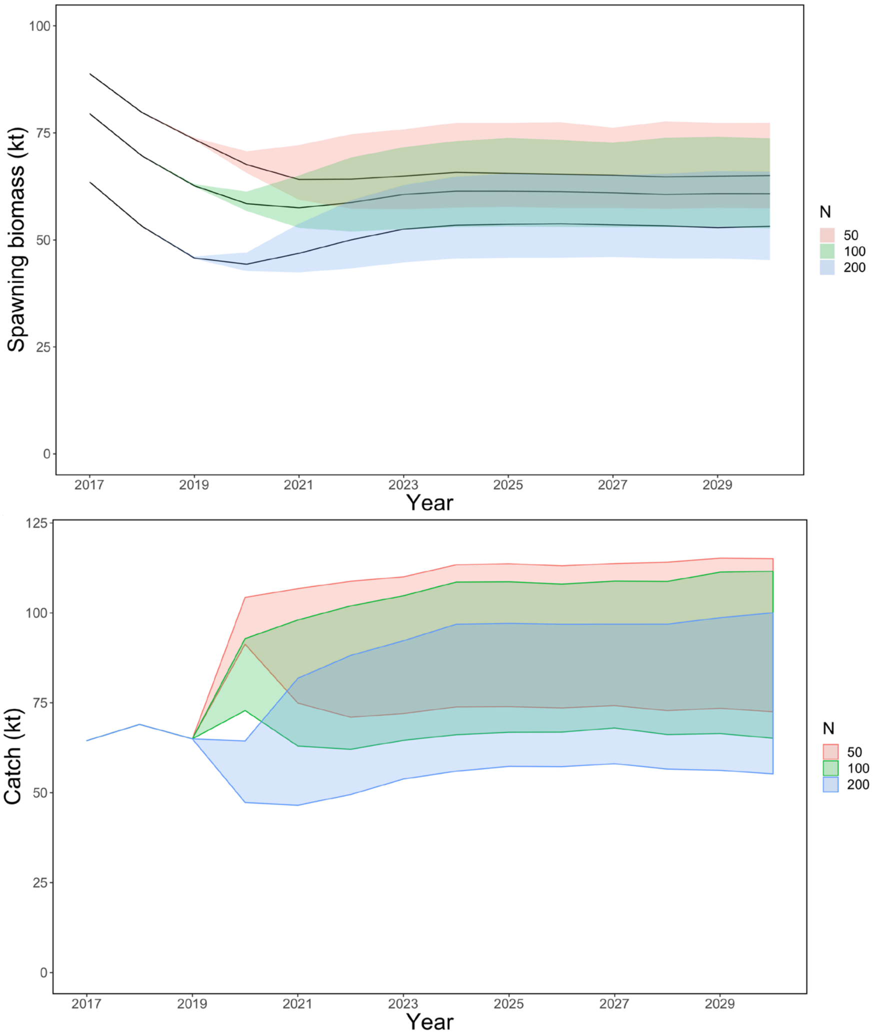

Figure 17C-14. Projections of spawning biomass (top) and fishery catch (bottom) for different tuned model runs with mean 1991-2016 fishery sample sizes N=100 (used in 2017 assessment) and alternatives with time-varying selectivity variability tuned to mean fishery sample sizes of N=50 and N=200.

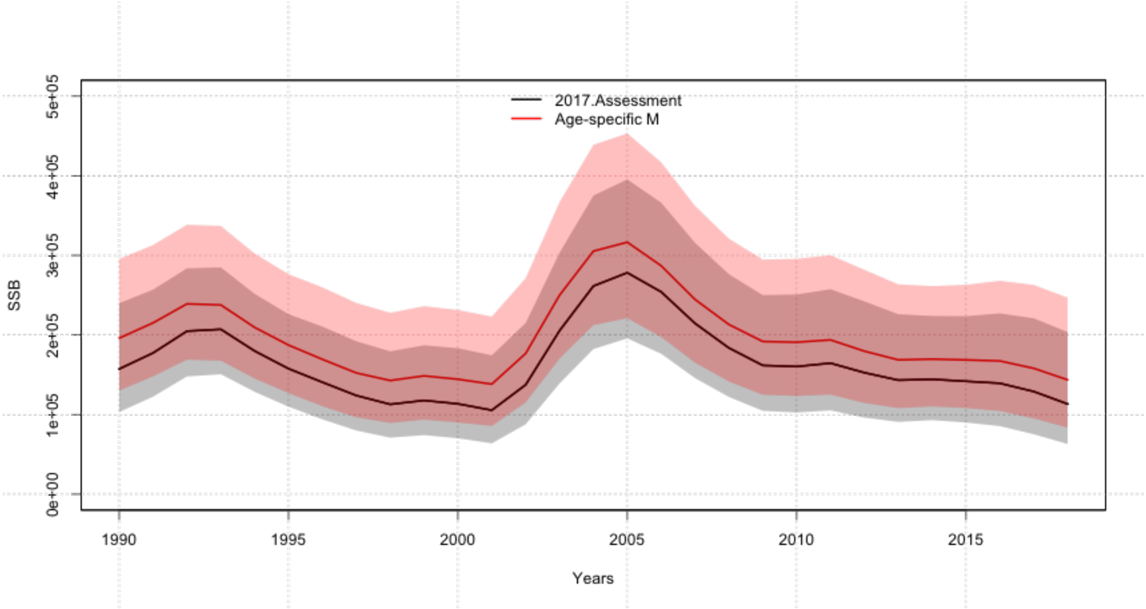

Figure 17C-15. Comparison of Atka mackerel spawning biomass for last year's Model 16.0b (2017 assessment) and one with age-specific natural mortality (*M*) specified.

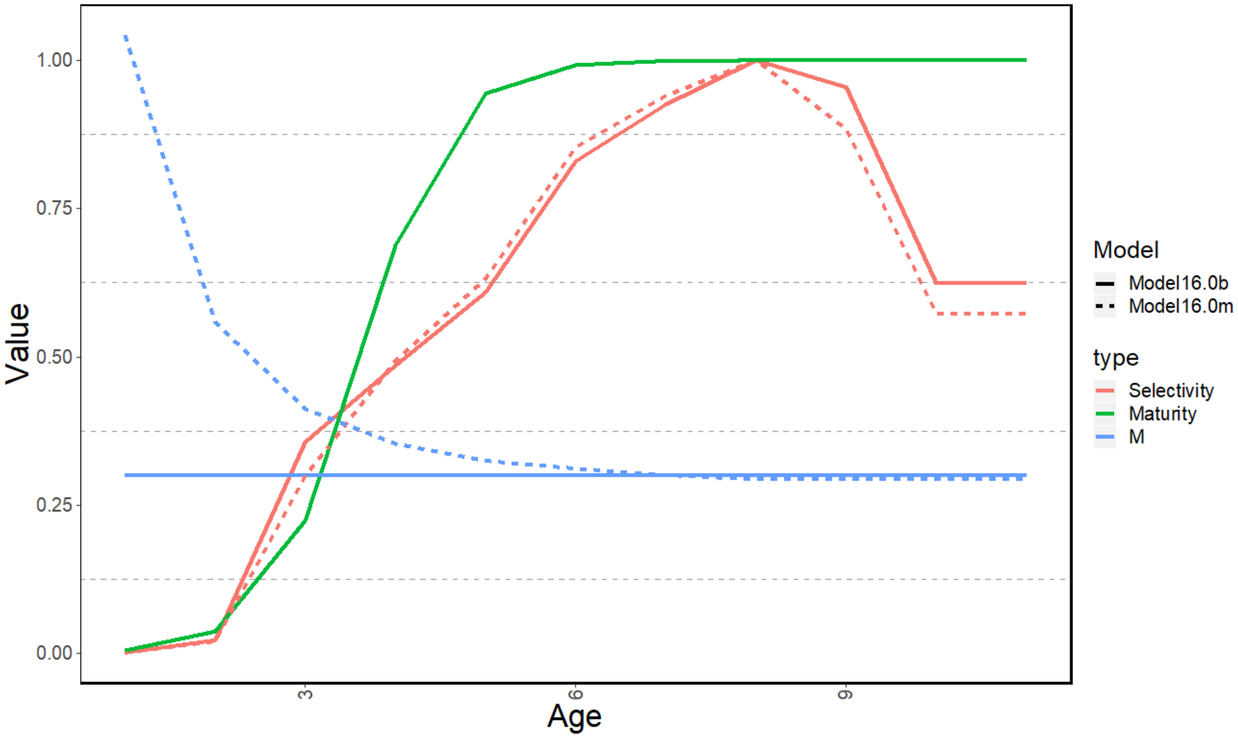

Figure 17C-16. Age-specific schedules for Atka mackerel for the 2017 assessment model (Model 16.0b) and the one with age-specific natural mortality (Model 16.0m).

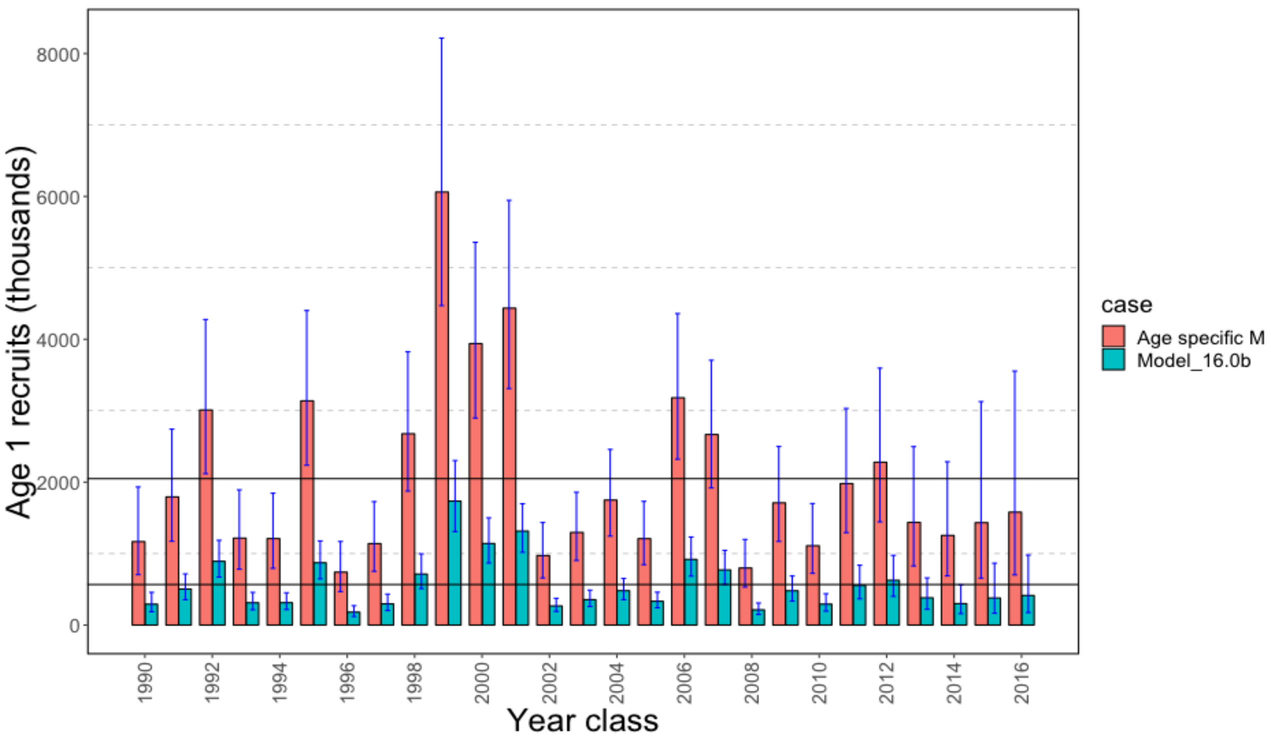

Figure 17C-17. Age 1 recruitment estimates for BSAI Atka mackerel from the 2017 assessment (Model 16.0b, constant *M* =0.3, and the one with age-specific natural mortality (Model 16.0m).

Appendix 17D

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

General Definitions	Symbol/Value	Use in Catch at Age Model
Year index: *i* = {1977, …., 2018}	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 17D-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	$\varepsilon_i, \sum_i \varepsilon_i = 0$	$N_{i,1} = e^{\mu_R + \varepsilon_i}$
Index catchability Mean effect	μ^s, μ^f	$q_i^s = e^{\mu^s}$
Age effect	$\eta_j^s, \sum_{j=1}^{A} \eta_j^s = 0$	$s_j^s = e^{\eta_j^s}$ $j \leq$ maxage
		$s_j^s = e^{\eta_{\text{maxage}}^s}$ $j >$ maxage
Instantaneous fishing mortality		$F_{ij} = e^{\mu_f + \eta_j^f + \phi_i}$
mean fishing effect Annual effect of fishing in year *i*	μ_f $\phi_i, \sum_i \phi_i = 0$	
Age effect of fishing (regularized) in year time variation allowed	$\eta_{ij}^f, \sum_{j=1}^{A} \eta_{ij} = 0$	$s_{ij}^f = e^{\eta_j^f}$, $j \leq$ maxage $s_{ij}^f = e^{\eta_{\text{maxage}}^f}$ $j >$ maxage
In years where selectivity is constant over time	$\eta_{i,j}^f = \eta_{i-1,j}^f$	$i \neq$ 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 17D-3. Specification of objective function that is minimized (i.e., the penalized negative of the log-likelihood).

Likelihood /penalty component		Description / notes
Biomass indices	$L_1 = \lambda_1 \sum_i \ln\left(Y_i^s \middle/ \hat{Y}_i^s \right)^2 \frac{1}{2\sigma_i^2}$	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	$L_4 = \lambda_4 \sum_i \varepsilon_i^2 + \sum_i \left(lnR_i - ln\hat{R}_i \right)^2 / \sigma_R^2$	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	$L \quad = \lambda \quad \sum_i \ \phi_i^2$	(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	$\dot{L} = \sum_{i=1}^{7} L_i$	