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

Sandra Lowe, James Ianelli, and Wayne Palsson

Executive Summary

Relative to the November 2016 SAFE report, the following substantive changes have been made in the assessment of Atka mackerel.

Summary of Changes in Assessment Input

1. Total 2016 catch estimate was updated, and the projected total catch for 2017 was set to nearly equal the TAC (64,500 t), based on the catch amounts occurring after Oct. 1 in recent years.
2. The 2016 fishery age composition data were added.
3. The 2016 Aleutian Islands survey age composition estimates were added.
4. The estimated average selectivity for 2012-2016 was used for projections.
5. We assume that approximately 75% 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 2018 and 2019 maximum permissible ABCs, and those reduced amounts were assumed to be caught in order to estimate the 2018 and 2019 ABCs and OFL values.
6. As in 2016, the sample sizes specified for fishery age composition data were rescaled to have the same means as in the baseline model but varied relative to the number of hauls for the fishery. The 2016 data were added.
7. The survey age composition data were tuned using the Francis (2011) method. The 2016 data were added.
8. As requested, refinements to the time-varying fishery selectivity inputs were made using the statistical weighting method for the time-varying fishery selectivity variance term, as was used for the age composition data.

Summary of Changes in the Assessment Methodology

There were no changes in the model configuration. However, **the trade-offs between effective sample size and the extent selectivity is allowed to vary is evaluated using the existing model and previously computed "Francis weights".** Also, sensitivity to alternative fishery selectivity patterns over time were explored as requested.

Summary of Results

1. The addition of the 2016 fishery and survey age compositions information impacted the estimated magnitude of the 2011 year class which increased 14%, relative to last year's assessment, and the magnitude of the 2012 year class which increased 32% relative to last year assessment. The 2012 year class is now slightly above average.
2. Estimated values of $B_{100\%}$, $B_{40\%}$, $B_{35\%}$ are 2% lower relative to last year's assessment.
3. Projected 2018 female spawning biomass (139,300 t) is 4% lower relative to last year's estimate of 2017 female spawning biomass, but essentially equivalent to last year's projection for 2018 (<1% decrease).
4. Projected 2018 female spawning biomass is above $B_{40\%}$ (122,860 t), thereby placing BSAI Atka mackerel in Tier 3a.
5. The current estimate of $F_{40\%} = 0.38$ is 12% higher relative to last year's estimate of $F_{40\%}$ due to changes in the fishery selectivity used for projections.

6. The projected 2018 yield at $maxF_{ABC} = F_{40\%}$ = 0.38 is 92,000 t, which is 6% higher relative to last year's estimate for 2017.
7. The projected 2018 overfishing level at $F_{35\%}$ = 0.46 is 108,600 t, which is 6% higher than last year's estimate for 2017.

Quantity	As estimated or *specified last* year for: 2017	2018	As estimated or *recommended this* year for: 2018*	2019*
M (natural mortality rate)	0.30	0.30	0.30	0.30
Tier	3a	3a	3a	3a
Projected total (age 1+) biomass (t)	598,791	611,442	599,000	600,440
Projected Female spawning biomass				
Projected	145,258	138,791	139,300	125,600
$B_{100\%}$	313,220	313,220	307,150	307,150
$B_{40\%}$	125,288	125,288	122,860	122,860
$B_{35\%}$	109,627	109,627	107,500	107,500
F_{OFL}	0.40	0.40	0.46	0.46
$maxF_{ABC}$	0.34	0.34	0.38	0.38
F_{ABC}	0.34	0.34	0.38	0.38
OFL (t)	102,700	99,900	108,600	97,200
maxABC (t)	87,200	85,000	92,000	84,400
ABC (t)	87,200	85,000	92,000	84,400
Status	As determined *last* year for: 2015	2016	As determined *this* year for: 2016	2017
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 69,000 t and 65,000 t in place of maximum permissible ABC for 2018 and 2019, respectively.

Area apportionment of ABC

The apportionments of the 2018 and 2019 recommended ABCs based on the random effects model:

	2018 (t)	2019 (t)
Eastern (541+S.BSea)	36,820	33,780
Central (542)	32,000	29,350
Western (543)	23,180	21,270
Total	92,000	84,400

Responses to SSC and Plan Team Comments on Assessments in General

From the December 2016 SSC minutes: *"In an effort improve record keeping as assessment authors formulate various stock status evaluation models, the Plan Team has recommended a systematic cataloging convention. Any new model that diverges substantial from the currently accepted model will be marked with the two-digit year and a "0" version designation (e.g., 16.0 for a model from 2016). Variants that incorporate major changes are then distinguished by incremental increases in the version integer (e.g., 16.1 then 16.2), and minor changes are identified by the addition of a letter designation (e.g., 16.1a).* ***The SSC recommends this method of model naming and notes that it should reduce confusion and simplify issues associated with tracking model development over time."***

The BSAI Atka mackerel document is following the recommended naming convention.

From the December 2016 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 their December SSC 2016 minutes: "*While the authors did a very good job of recounting the management history relative to the Steller sea lion BIOP and RPAs, the ecosystem considerations section of the document provided very limited information on interactions between Atka mackerel and both marine mammal and seabird predators. The SSC recommends that the authors include information on how recent trends in Steller sea lion pup production correlate with Atka mackerel biomass and closure areas in the AI, and notes that the high biomass and low exploitation rates reported in areas 541 and 542 correspond with areas where Steller sea lion populations appear to be recovering, while the Steller sea lion population in area 543, which was recently reopened to fishing, continues to decline."*

The *Ecosystems considerations* section has been significantly expanded and updated. There is added discussion on marine mammal and seabird predators in the *Predator population trends* section. There is added discussion in the section on the Atka mackerel fishery and Steller sea lion interactions (see *Atka mackerel fishery effects on the ecosystem*). More specific information will become available in February 2018 when a final NPRB report is submitted for a comprehensive project that studied the fishery interactions of Atka mackerel and Steller sea lions in areas 541 and 543.

"For next year's assessment, the SSC supports the following Plan Team recommendations:

1. *Tuning compositional data sample sizes to the harmonic mean effective sample size, or using the "Francis method."*
2. *Turning off time-varying fishery selectivity.*
3. *Statistical estimation of the amount of time variability in selectivity.*
4. *Use of time blocks for fishery selectivity, in consultation with industry."*

See responses under November 2016 BSAI Plan Team minutes.

"The SSC appreciates the responses from authors on previous SSC comments and supports the continued comprehensive analysis of fishery and survey time-varying selectivity and estimation of M and Q. Additional explanation of why dome-shaped selectivity is appropriate for Atka mackerel would be helpful." The current assessment explores further aspects of time-varying fishery and survey selectivity (see *Model evaluation*). The current recommended model incorporates a new method for statistical estimation of the amount of time variability in fishery selectivity. The estimated dome-shaped selectivity patterns for the fishery and the survey are discussed under *Selectivity* in the *Time series results* section.

From the November 2016 BSAI Plan Team minutes: *"For next year's assessment, the Team recommends that the authors explore:*

1. *Tuning compositional data sample sizes to the harmonic mean effective sample size, or using the "Francis method."*
2. *Turning off time-varying fishery selectivity.*
3. *Statistical estimation of the amount of time variability in selectivity.*
4. *Use of time blocks for fishery selectivity, in consultation with industry."*

<u>Response to item 1</u>: In previous assessments (until 2016), we estimated the post 1989-fishery and all survey age composition data sample sizes as the harmonic mean of the estimated effective sample sizes based on the method described in Thompson and Dorn (2003). These estimates were scaled to have a mean of 100 (fishery) or 50 (survey); earlier years were set to constant values. In the 2016 assessment, the post-1989 fishery and survey age composition data sample sizes were scaled to have the same means as in the previous assessments, but varied relative to the number of hauls sampled. In the current assessment, the post-1989 fishery sample sizes varied relative to the number of hauls sample, but the survey age composition sample sizes were tuned using the "Francis method", (Francis 2011, equation TA1.8). For a discussion of these approaches, see *Input sample size* section.

<u>Response to items 2 and 4</u>: We addressed the requests to turn off time-varying selectivity and using time blocks for fishery selectivity together in a preliminary sensitivity analysis (Model 16.0c) using blocks of years with constant selectivity for the following time periods:

1977-1983 Foreign fishery
1984-1991 Joint venture fishery
1992-1998 Domestic fishery and 3-subarea split
1999-2010 Steller sea lion regulations
2011-2015 Steller sea lion RPAs
2015-2016 revised Steller sea lion RPAs

Results of the estimated selectivity patterns for the time blocks selected tended to obscure significant recruitment events, and or the selectivity for the block was based on a pattern that was only evident for a short time period (less than the number of years in the block). 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. Further discussion can be found in *Sensitivity analyses* in the *Model evaluation* section.

<u>Response to item 3</u>: In the current assessment, we implemented statistical estimation of the amount of time variability in fishery selectivity in Models 16.0a and 16.0b. We tuned the time-varying fishery selectivity variance (σ_{f_sel}) 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 sample sizes. See *Sensitivity analyses* in the *Model evaluation* section for further discussion.

"*It would be interesting to know how many fish are required to constitute a ton of catch in each area.*" Results of an analysis of the 2016 fishery data are given below:

	BSAI Area		
	541	542	543
Mean age	4.8	5.7	5.6
Minimum age	3	2	2
Maximum age	11	12	12
Mean weight (kg)	0.67	0.57	0.60
Number fish per metric ton	1492	1763	1657
Number of ages	386	856	570

"*Perhaps survey selectivity in the model should be time-varying*".

In the current assessment, we conducted a 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*), the 1980s survey biomass data are omitted, but the 1986 survey age composition are included. The 1986 survey age data 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. See *Survey selectivity and catchability* section for a discussion of previous explorations of time-varying survey selectivity including a random walk and time blocks. 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. Fishery and survey time-varying selectivity is an important topic and applications in this assessment will continue to be explored along with interactions with estimates of *M* and *q*

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 A. 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 2016 and 2017 fishery operations are shown in Fig. 17.1.

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. The most recent increase in the Atka mackerel TAC reflects the continued health of the stock and expanded fishing opportunities in the Aleutian Islands.

Market

An economic performance report for 2016 for BSAI Atka mackerel is included in Appendix 17B (Fissel 2017). The U.S. (Alaska), Japan and Russian are the major producers of Atka mackerel.[1] Approximately

---

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

90% of the Alaska caught Atka mackerel is processed as head-and-gut, while the remainder is mostly sold as whole fish (Fissel 2017, Table 1). The domestic market for Atka mackerel is minimal, and 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 2017). 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)

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 2017).

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 (Fig. 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 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

<u>In Area 543</u>:

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

<u>In Area 542</u>:

- Close waters from 0–3 nm around Kanaga Island/Ship Rock to directed fishing for groundfish by federally permitted vessels.
- Set TAC for Area 542 to no more than 47 percent of the Area 543 ABC.
- Between 177° E to 179° W longitude and 178° W to 177° W longitude, close critical habitat from 0–20 nm to directed fishing for Atka mackerel by federally permitted vessels year round.
- Between 179° W to 178° W longitude, close critical habitat from 0-10 nm to directed fishing for Atka mackerel by federally permitted vessels year round. Between 179° W and 178° W

longitude, close critical habitat from 10-20 nm to directed fishing for Atka mackerel by federally permitted vessels not participating in a harvest cooperative or fishing a CDQ allocation.
- Add a 50:50 seasonal apportionment to the CDQ allocation to mirror seasonal apportionments for Atka mackerel harvest cooperatives.
- Limit the amount of Atka mackerel harvest allowed inside critical habitat to no more than 10 percent of the annual allocation for each harvest cooperative or CDQ group. Evenly divide the annual critical habitat harvest limit between the A and B seasons.
- Change the Atka mackerel seasons to January 20, 12:00 noon to June 10, 12:00 noon for the A season and June 10, 12:00 noon to November 1, 12:00 noon for the B season.
- Eliminate the Atka mackerel platoon management system in the 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.

<u>In Area 541</u>:

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

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

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

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

- Modify maximum retainable amount (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	

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. Most 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.

Year		Aleutian Islands Subarea 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%***

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

Fishery data

Fishery data consist of total catch biomass from 1977 to 2016 and projected end of year 2017 catch data (Table 17.1).

Fishery Length Frequencies

From 1977 to 1988, commercial catches were sampled for length and age structures by the NMFS foreign fisheries observer program. There was no 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 2016 and preliminary 2017 fisheries by management area are shown in Figures 17.2 and 17.3, respectively. The modes at about 34-39 and 40-43 cm in the 2016 length distributions represent the 2012 year class. The available 2017 fishery data are presented and should be considered preliminary, but are similar to the 2016 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 1977-2015 (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 1990-2016 (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 2015-2016 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 catch data are mainly comprised of the 2012 year class, and no longer show a strong presence of the 2009 year class (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 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 trawl surveys conducted in 1980, 1983, 1986, and the 1991- 2016 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 2016 Aleutian Islands bottom trawl survey is 448,166 t, down 38% relative to the 2014 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 2016 survey is largely a result of the decrease in biomass observed in the Eastern Aleutian area, but all areas showed declines (Table 17.6b). Relative to the 2014 survey, the 2016 biomass estimates are down 27% in the Western area, 35% in the Central area, and 48% in the combined Southern Bering Sea/Eastern area (Fig. 17.4). The 95% confidence interval about the mean total 2016 Bering Sea/Aleutian Islands biomass estimate is 33-941,646 t. The coefficient of variation (*CV*) of the 2016 mean BSAI biomass is 31% (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 survey, and recently in the 2012 survey (Fig. 17.4). 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 2006, 2010, 2014, and to some extent in 2016. During the 2010, 2014, and 2016 surveys, the biomass from area 541 comprised 35 to 42% of the Aleutian Island biomass, but in 2012, only comprised 12% of the Atka mackerel biomass (Table 17.6b).

This variation in survey biomass and low estimates for 2012 may be 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 (Fig. 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. 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 2016 survey estimated only 186 t of biomass in the southern Bering Sea (*CV*=39%). Very little biomass has been observed in the southern Bering Sea since the 2010 survey.

Areas with large catches of Atka mackerel in the 2010 survey included north of Akun Island, northwest of the Islands of Four Mountains, Seguam Pass, Kiska Island, Buldir Island, and Stalemate Bank (Fig. 17.5 in Lowe *et al*. 2015). In the 2012 survey there were no extremely large catches observed as in previous surveys, and moderate catches were only observed south of Amchitka Island, Kiska Island, and Stalemate Bank (Fig. 17.6) In the 2014 survey, several large catches were observed at Seguam Pass, Atka Island, Tanaga Island, Kiska Island, and Stalemate Bank. 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 Islands and Stalemate Bank (Fig. 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 most recent 2016 survey.

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 (Fig. 17.5). Temperatures profiles from the 2014 and 2016 surveys were some of the warmest on record in the time series over all depth strata (Fig. 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 and 2014 surveys (Figure 17.7 in Lowe *et al.* 2012 and Lowe *et al*. 2015). The 2016 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 28-30 and 34-38 cm (Fig. 17.7). It is unclear why large numbers of 28-30 cm fish were only encountered in the Central Aleutians.

Survey age data

The 2010 survey age composition was dominated by 3 and 4-year olds of the 2007 and 2006 year classes (Fig. 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 (Fig. 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 (Fig. 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.

We note that although biomass estimates from the U.S.-Japan cooperative trawl surveys are not utilized, we do use the survey age data from the 1986 U.S.-Japan cooperative trawl survey as this was the most well-sampled survey in the cooperative survey time series, and the age data provide useful historical information for the assessment model.

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).

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 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 1977-2016) 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 17C Tables C-1 – C-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:

---

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

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

Data component	Years of data	Likelihood form	*CV* or sample size (*N*)
Catch biomass	1977-2017	Lognormal	*CV*=5%
Fishery catch age composition	1977-2016	Multinomial	Year specific *N*=2-236, Ave.=100
Survey biomass	1991, 1994, 1997, 2000, 2002 2004, 2006, 2010, 2012, 2014, 2016	Lognormal	Average *CV*=25%
Survey age composition	1986, 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:

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

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

In the 2016 assessment 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 (Fig. 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 last year's assessment) and Model 16.0b (introduced in the current assessment, see *Model Evaluation*), 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 Models 16.0 and 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									
153	219	236									

Last year's assessment used a similar approach for computing time-varying sample sizes for survey age compositions. As in the 2016 assessment, Model 16.0 scaled sample sizes to have a mean of approximately 50 but varied with the number of Atka mackerel hauls. For Model 16.0b, effective sample sizes for the survey age compositions were estimated following Francis (2011, equation TA1.8, Francis weights). The table below compares the survey sample sizes under Model 16.0 (last year's model with updated values) and the current Model 16.0b tuned using Francis weights.

Survey		
Year	Model 16.0	Model 16.0b
1986	31	16
1991	37	19
1994	36	19
1997	25	13
2000	38	20
2002	67	35
2004	72	37
2006	54	28
2010	69	36
2012	59	31
2014	66	34
2016	47	24
Ave.	52	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 (Fig. 17.11 in Lowe *et al.* 2003). We conducted preliminary explorations of alternative formulations of an age-dependent *M* selected outside the assessment model. 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]). Initial results showed higher natural mortality rates compared to the baseline assessment model. Values of recruitment were much greater relative to the baseline model and were reflected in higher spawning biomass levels and target fishing mortality rates. We found the effect of higher natural mortality generally is traded off with estimated patterns in selectivity, especially for the older ages. We will continue to explore the estimation of age-dependent *M* and the impacts on parameters of interest.

In the current assessment, a natural mortality value of 0.3 was used in the assessment model.

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 17.8). 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 17.8).

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 17.8 for 1990 to 2016, 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 17.8.

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 current assessment Model 16.0b, we tuned the time-varying fishery selectivity variance (σ_{f_sel}) using the Francis weighting method (Francis 2011, equation TA1.8) on the fishery age composition data for Model 16.0b. This is analogous to the tuning with Francis weights that were used to determine sample sizes. A key difference is that here, we consider that the mean input sample size for the fishery is reasonable (mean=100) and that the lack of fit (or potential overfitting as was the case here) could be adjusted by finding the appropriate level of interannual variability in selectivity. We argue that this provides a defensible statistical approach to setting the degree of selectivity variability (and thereby perhaps better track age-specific fishing mortality). Other approaches, e.g., constant or blocked selectivity specifications, would require downweighting the age composition data which may also miss age-specific targeting.

We conducted preliminary sensitivity analyses (Model 16.0c) using blocks of years with constant selectivity for the following time blocks:

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
2015-2016 Revised Steller sea lion RPAs

Results from Model 16.0c with time blocks for fishery selectivity (described below in *Sensitivity analyses* in the *Model evaluation* section), were deemed too preliminary for further consideration. We intend to pursue further analysis of fishery selectivity blocks, and the determination of the appropriate time frames for blocks.

Survey selectivity and catchability

For the bottom trawl survey, selectivity-at-age follows a parameterization similar to the fishery selectivity-at-age for the base Model 16.0, and used for the 2013-2016 assessments (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 the current 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.

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.

Fishery and survey time-varying selectivity is an important topic and applications in this assessment will continue to be explored along with interactions with estimates of M and q. Here we focused on the interaction of data weighting (and the assumptions for specified input sample sizes) and time-varying selectivity.

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 2016 assessment, we estimate this value.

Results

Model evaluation

Last year we introduced Model 16.0 with sample sizes varied relative to the number of hauls sampled. This year we again present Model 16.0 with updated data and conduct 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.

New data introduced in 2017

Model 16.0 (the selected model configuration used for the 2016 assessment and the 2017 ABC) was updated with new data. The 2016 fishery and survey age composition data were added. The 2016 fishery age data are mainly comprised of 4 year olds of the 2012 year class. The 2016 survey age data are also largely comprised the 2012 year class and 3 year olds of the 2013 year class. Figure 17.9 shows the time series of the current assessment estimated female spawning biomass and recruitment at age 1 from Model 16.0 with updated data, compared to last year's Model 16.0 estimates of age 1 recruitment (2016 assessment). Current estimated female spawning biomass is slightly lower over the time series relative to last year's assessment. This is attributed to changes in the recruitment estimates due to the addition of the 2016 fishery and survey age compositions.

Sensitivity analyses of changes in model inputs

In the current assessment we explore alternatives to the inputs for Model 16.0 for 4 different options:

- Fishery selectivity
- The variance term for time-varying fishery selectivity (σ_{f_sel})
- Weighting of fishery sample sizes
- Weighting of survey sample sizes.

The following table shows the alternative sub-models considered.

	Fishery selectivity	Variance of fishery selectivity σ_{f_sel}	Fishery sample sizes	Survey Sample sizes
Model 16.0	Time - varying	Varies as in 2016 assessment	Varied with # hauls	Varied with # hauls
Model 16.0a	Time - varying	Tuned using Francis weights	Varied with # hauls	Varied with # hauls
Model 16.0b	Time - varying	Tuned using Francis weights	Varied with # hauls	Tuned using Francis weights
Model 16.0c	Time blocks	NA	Tuned using Francis weights	Tuned using Francis weights

Model 16.0c with time blocks for fishery selectivity (decribed above in *Fishing mortality*), was deemed too preliminary for further consideration. Selectivity patterns for the time blocks selected tended to obscure significant recruitment events, and or the selectivity for the block was based on a pattern that was only evident for a short time period (less than the number of years in the block). As expected, the fits to the fishery age compositions were degraded. 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). Also, the 2013 assessment showed that incorporating an 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). We intend to pursue further analysis of fishery selectivity blocks, and statistical estimation of the appropriate time frames for blocks.

Models 16.0a and 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). In addition, for Model 16.0b the survey age composition sample sizes were tuned using the Francis method. Since the Francis method is well-established and in use for tuning compositional data sample sizes for several Alaska and West Coast groundfish assessments (e.g. Ianelli *et al*. 2016, and the west coast widow rockfish and rougheye and blackspotted rockfish assessments), we focus our evaluation on Models 16.0

and 16.0b. As noted above, the difference between model 16.0 and 16.0b was treatment of the input data and model specification (i.e., the degree of environmental variability). This was done in an effort to satisfy the request to arrive at a statistical approach for specifying the degree of time-varying selectivity. This assumes that the input fishery sample sizes have a mean value of 100 as a reasonable specification of overdispersion in fitting composition data. We argue that this is a defensible way to arrive at a balance between process and observation error (although more sensitivities to this assumption is certainly warranted). As such, Model 16.0b was selected as a refinement to account for these types of assessment model errors.

A summary of key results from the selected Model 16.0b is presented in Table 17.10. Results from the 2016 assessment model (16.0) with updated data and the explorations discussed above are presented for comparison.

Model fit

Key results from Model 16.0b are presented in Table 17.10. Tables of results for the 2016 Model 16.0 with updated data are presented in Appendix D. The coefficient of variation or *CV* (reflecting uncertainty) about the 2017 biomass estimate is 20% and the *CV*s on the strength of the 2006 and 2012 year classes at age 1 are 16 and 23%, respectively (Table 17.10). Recruitment variability (SigmaR) was moderate and estimated to be 0.46. 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 168 and survey data was 90. The overall residual root-mean square error (RMSE) for the survey biomass data was estimated at 0.244, 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 (Fig. 17.10). However, the declining trend in biomass indicated by the 2014 and 2016 surveys are 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 some 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 reflect large numbers of 4-year olds of the 2011 year class. 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 (Fig. 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% of the 2016 fishery age composition. 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" (Fig. 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 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 2016 fishery and survey catch- and weight-at-age values.

Time series results

Selectivity

For Atka mackerel, the estimated selectivity patterns are particularly important in describing their dynamics. Previous assessments focused on the transitions between ages and time-varying selectivity (Lowe *et al.* 2002, 2008, 2013). The current assessment allows for flexibility over time (fishery only) and age (Figures 17.13, 17.14, and 17.15; also Table 17.11). The current assessment's terminal year fishery selectivity estimate (2016) and the average selectivity used for projections (2012-2016) are fairly similar to, but differ slightly over some age ranges from the terminal year and average selectivity for projections used in the 2016 assessment, showing lower selectivity for ages 5-7 and higher selectivity after age 8 (Fig. 17.14). The current assessment's terminal year (2016) selectivity pattern shows a peak for 4-year olds and a drop in the selectivity for 5-year olds. Last year there was an unusually strong showing of 4-year olds of the 2012 year class in the 2016 fishery age data which was not evident in the 2015 fishery data. The 2016 fishery age composition showed less than expected number of 5-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 (1977-1983 and 1984-1991, respectively (Fig. 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 large shift occurred recently with the large number of 3-year olds dominating the 2014 fishery age composition. The age at 50% selectivity decreased to about 2.5 years. In the current assessment terminal year (2016), the age at 50% selectivity increased to about 5.5 years (Fig. 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 higher relative to the age at 50% selectivity for the average selectivity used for projections (2012-2016, Fig. 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 (Fig. 17.15), similar to the terminal year selectivity pattern for the fishery (Fig. 17.14). Both patterns show a peak at age 4. 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. Patterns in selectivity are traded off with assumptions about M. Analyses of age-dependent estimates of M found that the effect of higher natural mortality generally is traded off with estimated patterns in selectivity, especially for the older ages. We will continue to explore the estimation of age-dependent M and the impacts on selectivity and q.

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 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 (Fig. 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 16.0) results (Fig 17.16). The current assessment spawning biomass is higher in the early 1980s, and slightly lower over the time series from 2003 to 2011. After 2011, current estimates are slightly above the 2016 levels. Minor differences in spawning biomass levels are attributed to slightly revised estimates of recruitment levels (Fig. 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 (Figures 17.16 and 17.17). The 1999, 2000, and 2001 year classes are estimated to be three of the five largest recent year classes in the time series (approximately 1.9, 1.2, and 1.4 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 year classes (Fig. 17.17). The 1996 and 2008 year classes are the lowest in the time series, estimated at about 250 million recruits.

The average estimated recruitment from the time series 1978-2016 is 658 million fish and the median is 527 million fish (Table 17.14). The entire time series of recruitments (1977-2017) includes the 1976-2016 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 2017 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 2016 (1977-2015 year classes). Projections of biomass are based on estimated recruitments from 1978-2016 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 17.18. There are no estimates of female spawning biomass less than 140,000 t. The five largest year classes in the time series were all spawned from biomass levels ranging from 140,000-187,000 t. However, this range of female spawning biomass also spawned several years of low recruitment (Fig. 17.18).

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 17.19.

Retrospective analysis

A retrospective analysis was conducted by regressively eliminating the most current year of information extending back to 2007. 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 (Fig. 17.20). 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 2016 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" (Fig. 17.11), the survey selectivity was fairly asymptotically shaped (Fig 17.15). 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 summary still holds in this 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 0.0982.

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 1978-2016 (658 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:

$B_{100\%}$ = 307,151 t female spawning biomass

$B_{40\%}$ = 122,860 t female spawning biomass

$B_{35\%}$ = 107,503 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 (2012-2016) to reflect recent conditions for projections and computing ABC which gives:

Full selection *F*s	2017
F_{2017}	0.24
$F_{40\%}$	0.38
$F_{35\%}$	0.46
$F_{2017}/F_{40\%}$	0.63

For specification purposes to project the 2018 ABC, we assumed a total 2017 year end catch of 64,500 t nearly equal to the 2017 TAC, based on the amount of catch taken after Oct. 1 in recent years. For projecting to 2019, an expected catch in 2018 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 2017. 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. We estimated that about 75% of the BSAI-wide ABC is likely to be taken. This percentage was applied to the maximum permissible 2018 ABC and that amount was assumed to be caught in order to estimate the 2019 ABC and OFL values.

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 2018 female spawning biomass (SSB_{2018}) is estimated to be 139,300 t given assumed 2017 catch and a slightly reduced 2018 catch reflecting the RPA adjustment to the 2018 ABC.

The projected 2018 female spawning biomass estimate is above the $B_{40\%}$ value of 122,860 t, placing BSAI Atka mackerel in **Tier 3a**. The 2019 female spawning biomass estimate is also above $B_{40\%}$. The maximum permissible ABC and OFL values under **Tier 3a** are:

Year	Catch*	ABC	F_{ABC}	OFL	F_{OFL}	SSB	Tier
2018	69,000	92,000	0.38	108,600	0.46	139,300	3a
2019	65,000	84,400	0.38	97,200	0.46	125,600	3a

* Catches in 2018 and 2019 are less than the recommended ABC 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 2017 or 2018 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2030 using a fixed value of natural mortality of 0.3, the recent schedule of selectivity estimated in the assessment (in this case the average 2012-2016 selectivity), and the best available estimate of total (year-end) catch for 2017 (in this case assumed to be 64,500 t nearly equal to TAC). In addition, the 2018 and 2019 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 2018 and 2019, 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 2018 recommended in the assessment to the *max* F_{ABC} for 2018, and where catches for 2018 and 2019 are estimated at their most likely values given the 2018 and 2019 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, F 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 2019 or 2) above ½ of its MSY level in 2019 and above its MSY level in 2029 under this scenario, then the stock is not overfished.)

Scenario 7: In 2018 and 2019, 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 2019 or 2) above 1/2 of its MSY level in 2019 and expected to be above its MSY level in 2029 under this scenario, then the stock is not approaching an overfished condition.)

Status Determination

The projections of female spawning biomass, fishing mortality rate, and catch corresponding to the seven standard harvest scenarios are shown in Table 17.16. 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 2029 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

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

a) If the mean spawning biomass for 2019 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.
b) If the mean spawning biomass for 2019 is above $B_{35\%}$, the stock is not approaching an overfished condition.
c) If the mean spawning biomass for 2019 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2029. If the mean spawning biomass for 2029 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.

ABC Recommendation

Observations and characterizations of uncertainty in the Atka mackerel assessment are noted for ABC considerations.

1) 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 most recent 2016 survey indicated a 38% decrease in BSAI Atka mackerel biomass relative to the 2014 survey. It is noted that all areas in the Aleutian Islands showed decreases in the 2016 survey.
2) Under an $F_{40\%}$ harvest strategy and assuming SSL RPA catch reductions in 2018 and 2019 female spawning biomass is projected to drop below $B_{40\%}$ in 2020 but increase and remain above $B_{40\%}$ from 2022 through 2030 (Fig. 17.21 and Table 17.16 Scenarios 1 and 2). If SSL RPA catch reductions are in place beyond 2019, expected female spawning biomass levels would be higher than projected after 2019.
3) The 2016 fishery and survey data are dominated by the 2012 year class, and the 2016 survey data also shows significant numbers of 3 year olds of the 2013 year class (Fig. 17.8).

We believe the recommended model Model 16.0b provides an appropriate and improved assessment of BSAI Atka mackerel. Given the current moderate stock size, an above average 2012 year class, and that TACs are consistently set below ABC resulting in future catches below projected catches and more optimistic realizations of spawning biomass, the maximum permissible is acceptable for Atka mackerel.

We note that actual 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 17.22. 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 2018 yield associated with the Tier 3a maximum permissible F_{ABC} fishing mortality rate of 0.38 is 92,000 t, which is our 2018 ABC recommendation for BSAI Atka mackerel. The 2018 OFL is 102,700 t.

The 2019 yield associated with the Tier 3a maximum permissible F_{ABC} fishing mortality rate and assuming 2018 catch reductions, is 84,400 t, which is our 2019 ABC recommendation for BSAI Atka mackerel. The 2019 OFL is 97,200 t.

The 2018 ABC recommendation is 6% higher relative to the Council's 2017 ABC.

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 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 for the (Fig. 17.23), and then summing to get the overall BSAI biomass, the percentage apportionments for the Aleutian Islands subareas are shown below.

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

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

The apportionments of the 2018 and 2019 recommended ABCs based on the random effects model are:

	Random Effects Model	2018 (t)	2019 (t)
Eastern (541+S.Bsea)	**40.02%**	36,820	33,780
Central (542)	**34.78%**	32,000	29,350
Western (543)	**25.20%**	23,180	21,270
Total		92,000	84,400

Ecosystem Considerations

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 17.24 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 (Fig. 17.25a). It is noted that Figure 17.25a 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 2015 were warm across much of the North Pacific. The Copepod Community Size index saw negative anomalies for all three regions. 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 neutral or positive, 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 2016).

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 1988-2010 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 in 2015 to above average in 2016 (Zador and Yasumiishi 2016). 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 17.26. 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 (Fig. 17.25b), 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) indicate 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). 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. The population trends of seabirds are mixed, some increases, some decreases, and others stable. 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).

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 June 2015. 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 (Fig. 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 (Fig. 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. 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 (2015-2016) the Atka mackerel fishery has taken on average about 21 and 38% 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 316 t of non-target discards in the Aleutian Islands from 2015 to 2016. 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 320 t over 2015-2016.

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.

Acknowledgements

We thank the AFSC survey personnel for the collection of data and providing the biomass estimates. We are especially grateful to all the fishery observers working with the Fishery Monitoring and Analysis (FMA) Division who collect vital data for the stock assessments. We also thank the staff of the AFSC Age and Growth Unit for the ageing of otoliths used to determine the age compositions in the assessment. Thank you to Mike Levine of the AFSC RACE Division for providing updated von Bertalannfy growth parameters for the assessment.

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.

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.

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.

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, 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.

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.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.

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
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	64,500[b]	87,200	65,000	107,200

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

b) 2017 projected total year catch (the 2017 catch is assumed nearly equal to the 2017 TAC of 65,000 t, based on recent post Oct. 1 catches)

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	2006	Catch	7,422	39,836	14,638	61,896
	ABC	13,500	55,900	55,600	125,000		ABC	21,780	46,860	41,360	110,200
	TAC	13,500	50,000	16,500	80,000		TAC	7,500	40,000	15,500	63,000
1996	Catch	28,173	33,524	42,246	103,943	2007	Catch	22,943	26,723	9,097	58,763
	ABC	26,700	33,600	55,700	116,000		ABC	23,800	29,600	20,600	74,000
	TAC	26,700	33,600	45,857	10,657		TAC	23,800	29,600	9,600	63,000
1997	Catch	16,318	19,990	29,537	65,845	2008	Catch	19,112	22,926	16,045	58,083
	ABC	15,000	19,500	32,200	66,700		ABC	19,500	24,300	16,900	60,700
	TAC	15,000	19,500	32,200	66,700		TAC	19,500	24,300	16,900	60,700
1998	Catch	11,597	20,029	24,248	55,874	2009	Catch	26,417	30,137	16,253	72,807
	ABC	14,900	22,400	27,000	64,300		ABC	27,000	33,500	23,300	83,800
	TAC	14,900	22,400	27,000	64,300		TAC	27,000	32,500	16,900	76,400
1999	Catch	16,245	21,596	15,082	52,923	2010	Catch	23,608	26,388	18,650	68,646
	ABC	17,000	25,600	30,700	73,300		ABC	23,800	29,600	20,600	74,000
	TAC	17,000	22,400	27,000	66,400		TAC	23,800	29,600	20,600	74,000
2000	Catch	13,152	20,575	8,713	42,440	2011	Catch	40,891	10,713	205	51,809
	ABC	16,400	24,700	29,700	70,800		ABC	40,300	24,000	21,000	85,300
	TAC	16,400	24,700	29,700	70,800		TAC	40,300	11,280	1,500	53,080
2001	Catch	7,905	30,365	18,264	56,534	2012	Catch	37,308	10,323	195	47,826
	ABC	7,800	33,600	27,900	69,300		ABC	38,500	22,900	20,000	81,400
	TAC	7,800	33,600	27,900	69,300		TAC	38,500	10,763	1,500	50,763
2002	Catch	4,606	20,699	16,737	42,042	2013	Catch	15,777	7,284	120	23,181
	ABC	5,500	23,800	19,700	49,000		ABC	16,900	16,000	17,100	50,000
	TAC	5,500	23,800	19,700	49,000		TAC	16,900	7,520	1,500	25,920
2003	Catch	10,725	25,435	17,885	54,045	2014	Catch	21,185	9,520	242	30,947
	ABC	10,650	29,360	22,990	63,000		ABC	21,652	20,574	21,905	64,131
	TAC	10,650	29,360	19,990	60,000		TAC	21,652	9,670	1,000	32,322
2004	Catch	10,840	30,169	19,555	60,564	2015	Catch	26,343	16,672	10,253	53,268
	ABC	11,240	31,100	24,360	66,700		ABC	38,492	33,108	34,400	106,000
	TAC	11,240	31,100	20,660	63,000		TAC	27,000	17,000	10,500	54,500
2005	Catch	7,201	35,069	19,744	62,014	2016	Catch	28,360	15,795	10,330	54,485
	ABC	24,550	52,830	46,620	124,000		ABC	30,832	27,216	32,292	90,340
	TAC	7,500	35,500	20,000	63,000		TAC	28,500	16,000	10,500	55,500
						2017*	Catch	25,810	22,430	16,260	64,500
							ABC	34,890	30,330	21,980	87,200
							TAC	34,500	18,000	12,500	65,000

*2017 projected total year catches by region assumed nearly equal to the 2017 TACs, based on recent post Oct. 1 catches

Table 17.3. Numbers of Atka mackerel length-weight data, length frequency, and aged samples based on NMFS observer data 1990-2016.

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

Table 17.4. Estimated catch-in-numbers at age (in millions) of Atka mackerel from the BSAI region, 1977-2016. 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

[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 543	1-100	193	49,115	1,675
	101-200	692	124,806	40,675
	201-300		1,559	111
	301-500	0	164	0
	Total	885	175,644	42,461
Central 542	1-100	0	103,588	1,011,991
	101-200	58,666	1,488	20,582
	201-300	504	303	36
	301-500	0	0	10
	Total	59,170	105,379	1,032,619
Eastern 541	1-100		86,800	11
	101-200	3,018	120,962	45,835
	201-300	143	703	222
	301-500	0	0	0
	Total	3,161	208,465	46,068
Southern Bering Sea	1-100	6	0	429
	101-200	20,239	9	5
	201-300	2	0	1
	301-500		0	0
	Total	20,247	9	435

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

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

Table 17.6b. Aleutian Islands Atka mackerel survey biomass by bottom-depth category by region and subareas including area percentages of total (for each year) and coefficients of variation (*CV*) for 2000, 2002, 2004, 2006, 2010, 2012, 2014, and 2016.

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

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 2017 fishery weight-at-age values are the average of the last three years (2014-2016).

		Age										
	Year	1	2	3	4	5	6	7	8	9	10	11+
Fishery	1977	0.069	0.132	0.225	0.306	0.400	0.470	0.507	0.379	0.780	0.976	1.072
Foreign	1978	0.069	0.072	0.225	0.300	0.348	0.388	0.397	0.371	0.423	0.976	1.072
	1979	0.069	0.496	0.319	0.457	0.476	0.475	0.468	0.546	0.780	0.976	1.072
	1980	0.069	0.365	0.317	0.450	0.520	0.585	0.630	0.546	0.780	0.976	1.072
	1981	0.069	0.365	0.317	0.450	0.520	0.585	0.630	0.546	0.780	0.976	1.072
	1982	0.069	0.365	0.273	0.443	0.564	0.695	0.795	0.546	0.780	0.976	1.072
	1983	0.069	0.365	0.359	0.499	0.601	0.686	0.810	0.546	0.780	0.976	1.072
	1984	0.069	0.297	0.410	0.617	0.707	0.777	0.802	0.890	0.910	0.976	1.072
	1985	0.069	0.302	0.452	0.552	0.682	0.737	0.775	0.807	1.007	1.011	1.072
	1986	0.069	0.146	0.334	0.528	0.546	0.786	0.753	0.829	0.858	0.954	1.052
	1987	0.069	0.265	0.435	0.729	0.908	0.859	0.964	1.023	1.054	1.088	1.098
	1988	0.069	0.196	0.351	0.470	0.564	0.624	0.694	0.783	0.818	0.850	1.064
Domestic	1989	0.069	0.295	0.440	0.577	0.739	0.838	0.664	0.817	0.906	1.010	1.065
	1990	0.069	0.362	0.511	0.728	0.877	0.885	0.985	1.386	1.039	1.445	1.442
	1991	0.069	0.230	0.207	0.540	0.729	0.685	0.655	0.755	1.014	0.743	1.021
	1992	0.069	0.230	0.390	0.607	0.715	0.895	0.973	0.839	0.865	0.916	1.010
	1993	0.069	0.230	0.572	0.626	0.682	0.773	0.826	0.782	1.041	0.812	1.010
	1994	0.069	0.150	0.363	0.568	0.649	0.697	0.777	0.749	0.744	0.736	0.922
	1995	0.069	0.092	0.228	0.520	0.667	0.687	0.691	0.707	0.721	0.641	0.909
	1996	0.069	0.188	0.294	0.474	0.633	0.728	0.743	0.770	0.799	0.846	0.973
	1997	0.069	0.230	0.397	0.664	0.686	0.862	0.904	0.971	0.884	0.951	1.108
	1998	0.069	0.230	0.296	0.494	0.580	0.644	0.682	0.775	0.707	0.798	0.858
	1999	0.069	0.240	0.406	0.568	0.707	0.755	0.839	0.979	1.170	1.141	0.961
	2000	0.069	0.215	0.497	0.594	0.689	0.734	0.778	0.854	0.813	0.904	0.988
	2001	0.069	0.224	0.418	0.563	0.719	0.765	0.841	0.826	0.946	0.912	1.109
	2002	0.069	0.253	0.293	0.459	0.600	0.601	0.723	0.722	0.791	0.851	0.940
	2003	0.069	0.208	0.304	0.420	0.539	0.667	0.747	0.731	0.669	0.824	0.996
	2004	0.069	0.176	0.316	0.444	0.567	0.624	0.679	0.810	0.728	0.916	1.015
	2005	0.069	0.247	0.406	0.480	0.536	0.558	0.657	0.966	1.184	0.942	1.010
	2006	0.069	0.265	0.393	0.503	0.551	0.613	0.647	0.714	0.848	0.856	0.984
	2007	0.069	0.247	0.437	0.547	0.715	0.697	0.768	0.778	0.776	1.272	1.033
	2008	0.069	0.265	0.388	0.540	0.615	0.727	0.719	0.700	0.798	0.786	0.998
	2009	0.069	0.215	0.395	0.494	0.605	0.667	0.734	0.745	0.770	0.816	0.813
	2010	0.069	0.204	0.362	0.565	0.583	0.673	0.684	0.758	0.723	0.762	0.803
	2011	0.069	0.220	0.445	0.640	0.807	0.753	0.770	0.798	0.931	0.913	0.899
	2012	0.069	0.230	0.374	0.509	0.612	0.658	0.713	0.772	0.822	0.894	0.949
	2013	0.069	0.266	0.280	0.606	0.677	0.740	0.867	0.822	0.803	0.822	1.093
	2014	0.069	0.316	0.569	0.634	0.709	0.735	0.840	0.838	0.791	0.942	0.923
	2015	0.069	0.178	0.375	0.604	0.620	0.679	0.702	0.736	0.770	0.763	0.864
	2016	0.069	0.249	0.455	0.552	0.680	0.679	0.706	0.720	0.767	0.764	0.754
Ave. 2014-2016	2017	0.069	0.248	0.466	0.597	0.670	0.698	0.749	0.765	0.776	0.823	0.847

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 16.0. Results from last year's assessment (Last Year), last year's assessment model with updated data (Model 16.0), and the three refinements (Model 16.0a, 16.0b, and 16.0c) are given. Coefficients of variation (*CV*) for some key reference values are given, appearing directly below.

Assessment Model	**Last Year (16.0)**	**Model 16.0**	**Model 16.0a**	**Model 16.0b**	**Model 16.0c**
Model setup					
Survey catchability	1.20	1.27	1.13	1.17	0.94
Steepness	0.8	0.8	0.8	0.8	0.8
SigmaR	0.44	0.44	0.47	0.46	0.38
Natural mortality	0.3	0.3	0.3	0.3	0.3
Fishery Average Effective *N*	250	252	170	168	85
Survey Average Effective *N*	112	122	106	90	78
RMSE Survey	0.236	0.243	0.241	0.244	0.249
-log Likelihoods					
Number of Parameters	506	518	518	518	178
Survey index	7.20	7.88	7.97	8.18	8.24
Catch biomass	0.02	0.02	0.02	0.02	0.01
Fishery age comp	84.0	89.8	132.1	130.8	87.5
Survey age comp	40.07	40.2	44.21	27.54	27.24
Sub total	131.31	137.91	184.29	166.56	122.96
-log Penalties					
Recruitment	-8.5	-8.2	-2.7	-4.9	-20.2
Selectivity constraint	86.29	92.73	98.67	95.35	22.15
Prior	0.41	0.7	0.19	0.3	0.05
	78.2	85.2	96.1	90.8	2.0
Total	209.48	223.10	280.42	257.34	124.96
Fishing mortalities (full selection)					
F_{2015}	0.13	0.13	0.11	0.11	0.09
$F_{2017}/F_{40\%}$	0.58	0.52	0.48	0.47	0.37
Stock abundance					
Initial Biomass (t, 1977)	688,517	629206	670882	717242	961583
CV	20%	20%	21%	21%	20%
Assessment year total biomass (t)	588,326	578996	622424	630597	827785
CV	19%	20%	19%	20%	20%
2006 year class (millions at age 1)	959	969	1034	1007	1124
CV	15%	15%	15%	16%	17%
2012 year class (millions at age 1)	541	674	699	715	982
CV	27%	22%	22%	23%	23%

Table 17.11. Estimates of Atka mackerel fishery (over time, 1977-2016) and survey selectivity at age (normalized to have a maximum of 1.0). The average selectivity over 2012-2016 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	0.018	0.170	0.479	0.366	0.625	0.803	1.000	0.918	0.326	0.326
Ave. 2012-2016	0.003	0.030	0.355	0.519	0.648	0.850	0.906	0.946	0.845	0.570	0.570
Survey	0.015	0.144	0.604	0.836	0.751	0.784	0.982	1.000	0.814	0.694	0.694

Table 17.12. Estimated BSAI Atka mackerel begin-year numbers at age in millions, 1977-2017.

	Age										
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11+**
1977	388	614	392	142	111	65	58	49	39	30	103
1978	2177	287	450	270	91	72	45	41	35	28	97
1979	568	1611	210	307	176	59	49	31	29	26	91
1980	354	421	1189	151	209	120	41	35	23	21	86
1981	398	262	311	863	106	146	85	30	25	17	79
1982	267	294	194	227	619	75	104	60	22	19	70
1983	364	198	218	142	164	439	54	75	44	16	66
1984	418	269	147	160	104	119	316	39	55	33	60
1985	596	310	199	106	112	71	81	218	28	40	68
1986	506	441	228	140	72	75	47	54	151	20	78
1987	678	374	325	161	95	48	50	32	37	106	70
1988	527	502	276	232	111	65	33	35	22	26	127
1989	1292	390	370	198	158	76	46	23	25	16	111
1990	625	957	288	269	139	111	55	33	17	18	92
1991	367	463	707	210	190	99	80	39	24	12	81
1992	565	272	342	513	146	131	69	56	28	17	67
1993	951	418	200	247	355	98	89	47	39	20	60
1994	384	704	308	144	168	230	63	58	32	27	56
1995	382	285	519	221	97	106	142	40	37	21	56
1996	991	282	209	367	141	57	60	80	23	23	50
1997	232	733	207	146	225	77	29	30	41	13	45
1998	359	172	540	148	97	138	46	17	18	26	39
1999	843	266	126	385	96	58	80	26	10	11	42
2000	1907	624	196	91	254	61	36	49	16	6	36
2001	1242	1412	460	140	61	164	38	22	30	11	29
2002	1393	919	1041	326	91	37	97	22	13	19	27
2003	304	1032	678	749	219	59	24	59	14	9	32
2004	409	225	762	487	510	143	38	15	38	10	29
2005	554	303	166	547	333	339	95	25	10	27	27
2006	383	410	223	119	374	223	225	63	17	7	38
2007	1007	284	301	155	81	249	147	147	42	12	32
2008	838	746	208	209	105	54	166	96	98	29	31
2009	250	620	548	145	139	69	35	106	62	65	42
2010	541	185	455	379	92	86	42	21	64	39	71
2011	349	400	136	321	243	57	52	26	13	40	74
2012	634	259	295	98	221	161	37	34	17	9	77
2013	715	469	191	212	68	146	102	23	22	11	56
2014	441	530	347	138	150	48	102	71	16	15	47
2015	390	327	391	243	98	104	33	71	49	11	44
2016	459	288	241	275	166	64	66	20	42	31	38
2017	499	340	213	171	181	112	41	40	12	24	47
Average	647	485	361	257	175	115	76	50	34	23	60

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 1977-2018).

	Age 1+ biomass (t)			Female spawning biomass (t)		
Year	Estimate	LCI	UCI	Estimate	LCI	UCI
1977	717,240	418,540	1,015,940	182,530	100,936	264,124
1978	793,380	454,480	1,132,280	186,760	98,968	274,552
1979	898,990	506,310	1,291,670	199,490	101,844	297,136
1980	1,046,100	585,320	1,506,880	230,930	119,826	342,034
1981	1,003,400	559,620	1,447,180	290,990	154,686	427,294
1982	955,230	531,150	1,379,310	319,730	169,398	470,062
1983	857,260	477,920	1,236,600	294,730	156,836	432,624
1984	777,440	439,880	1,115,000	259,240	136,882	381,598
1985	718,210	405,630	1,030,790	224,750	115,522	333,978
1986	673,060	381,480	964,640	194,370	97,954	290,786
1987	659,510	381,110	937,910	178,530	91,206	265,854
1988	676,510	402,370	950,650	181,100	95,298	266,902
1989	729,190	455,270	1,003,110	187,540	103,138	271,942
1990	804,830	530,250	1,079,410	198,910	115,510	282,310
1991	886,520	605,080	1,167,960	218,110	134,336	301,884
1992	866,050	598,490	1,133,610	243,210	156,638	329,782
1993	845,080	588,460	1,101,700	243,960	156,894	331,026
1994	815,100	567,460	1,062,740	215,640	134,880	296,400
1995	777,350	536,310	1,018,390	192,160	115,862	268,458
1996	702,810	470,050	935,570	174,060	98,462	249,658
1997	637,110	405,990	868,230	156,730	84,332	229,128
1998	625,930	395,910	855,950	146,020	76,846	215,194
1999	577,780	356,240	799,320	152,040	80,952	223,128
2000	653,040	411,800	894,280	147,980	77,498	218,462
2001	822,170	539,550	1,104,790	140,000	72,078	207,922
2002	1,035,500	697,220	1,373,780	175,740	98,880	252,600
2003	1,147,300	782,620	1,511,980	249,320	151,758	346,882
2004	1,159,400	790,980	1,527,820	307,530	193,566	421,494
2005	1,038,400	699,520	1,377,280	322,500	204,326	440,674
2006	934,990	619,670	1,250,310	294,990	182,570	407,410
2007	849,450	554,890	1,144,010	251,920	151,282	352,558
2008	820,800	535,620	1,105,980	218,990	127,886	310,094
2009	822,330	535,550	1,109,110	195,710	110,426	280,994
2010	761,210	483,430	1,038,990	193,710	107,824	279,596
2011	681,750	419,870	943,630	197,350	109,854	284,846
2012	656,560	401,940	911,180	183,730	99,990	267,470
2013	628,870	379,930	877,810	172,530	94,624	250,436
2014	667,680	407,940	927,420	172,960	97,280	248,640
2015	676,970	410,370	943,570	171,710	94,552	248,868
2016	630,600	366,860	894,340	170,470	89,138	251,802
2017	595,460	332,940	857,980	159,027	77,822	244,178
2018	569,490	302,030	836,950	139,297	65,292	226,828

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 (1977-2018) compared to last year's (2016) assessment results.

	Age 3+ biomass (t)		Female spawning biomass (t)	
Year	Current	2016	Current	2016
1977	595,230	600,325	182,530	194,135
1978	646,900	604,684	186,760	187,696
1979	598,920	545,585	199,490	184,824
1980	958,510	783,585	230,930	198,180
1981	940,860	794,704	290,990	245,803
1982	893,040	738,223	319,730	257,912
1983	807,190	693,872	294,730	243,375
1984	712,730	653,539	259,240	227,795
1985	638,650	606,376	224,750	204,616
1986	575,160	573,316	194,370	185,122
1987	565,320	575,154	178,530	180,099
1988	567,310	578,463	181,100	186,380
1989	604,750	606,970	187,540	191,005
1990	613,780	609,609	198,910	201,256
1991	791,200	785,368	218,110	216,924
1992	794,400	804,875	243,210	245,262
1993	731,130	733,085	243,960	242,320
1994	677,850	671,131	215,640	213,464
1995	711,710	698,388	192,160	190,682
1996	610,240	607,462	174,060	169,352
1997	501,800	489,281	156,730	149,411
1998	580,570	566,426	146,020	141,020
1999	494,730	497,421	152,040	151,702
2000	461,170	447,096	147,980	143,116
2001	525,760	543,336	140,000	138,829
2002	816,310	882,832	175,740	187,098
2003	957,790	1,050,846	249,320	275,350
2004	1,102,700	1,190,008	307,530	333,747
2005	961,930	1,057,734	322,500	354,805
2006	847,890	928,604	294,990	326,248
2007	755,930	833,231	251,920	282,022
2008	656,110	725,049	218,990	245,929
2009	705,360	745,900	195,710	214,408
2010	705,420	730,883	193,710	208,870
2011	597,850	612,418	197,350	204,269
2012	584,030	574,538	183,730	182,981
2013	516,780	515,011	172,530	172,271
2014	557,630	539,387	172,960	170,225
2015	603,830	553,053	171,710	162,615
2016	560,830	510,847	170,470	154,396
2017	515,150	487,620	159,027	145,258
2018	484,150		139,297	

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 (2016) are shown for comparison.

	Age 1 recruitment		
Year	Current	Std. dev	2016 assessment
1977	387	104	340
1978	2,175	507	1,623
1979	568	145	489
1980	354	95	359
1981	397	103	445
1982	267	73	318
1983	364	93	421
1984	418	104	491
1985	596	142	574
1986	505	130	473
1987	678	163	635
1988	527	130	463
1989	1,291	243	1,282
1990	624	144	610
1991	367	94	374
1992	565	121	525
1993	951	168	860
1994	384	86	398
1995	382	81	380
1996	990	167	948
1997	232	53	220
1998	359	74	341
1999	842	150	952
2000	1,906	292	2,048
2001	1,241	193	1,273
2002	1,393	206	1,467
2003	304	59	321
2004	409	73	419
2005	554	93	563
2006	383	68	376
2007	1,007	158	959
2008	838	138	750
2009	250	51	238
2010	540	103	486
2011	349	75	338
2012	634	135	558
2013	715	163	541
2014	441	124	423
2015	389	120	467
2016	459	188	484
2017	499	212	
Average 78-16	658		638
Median 78-16	527		486

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	0.141	0.037
1978	0.136	0.037
1979	0.083	0.039
1980	0.061	0.021
1981	0.044	0.021
1982	0.044	0.022
1983	0.028	0.015
1984	0.090	0.051
1985	0.111	0.059
1986	0.104	0.056
1987	0.076	0.053
1988	0.087	0.039
1989	0.051	0.030
1990	0.047	0.036
1991	0.073	0.034
1992	0.096	0.061
1993	0.143	0.090
1994	0.183	0.096
1995	0.275	0.115
1996	0.394	0.170
1997	0.227	0.131
1998	0.269	0.098
1999	0.197	0.114
2000	0.189	0.102
2001	0.255	0.117
2002	0.195	0.055
2003	0.154	0.056
2004	0.115	0.055
2005	0.114	0.064
2006	0.125	0.073
2007	0.126	0.078
2008	0.154	0.089
2009	0.231	0.103
2010	0.203	0.097
2011	0.138	0.087
2012	0.153	0.082
2013	0.065	0.045
2014	0.069	0.056
2015	0.234	0.088
2016	0.250	0.097
2017	0.282	0.125

[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 307,151 t, 122,860 t, and 107,503 t, respectively.

Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2017	64,500	64,500	64,500	64,500	64,500	64,500	64,500
2018	69,000	69,000	69,000	69,000	69,000	108,563	92,155
2019	65,000	65,000	65,000	65,000	65,000	80,739	75,694
2020	83,075	83,075	16,343	23,502	0	77,052	84,373
2021	81,594	81,594	18,877	26,755	0	83,223	86,109
2022	83,906	83,906	21,275	29,827	0	88,998	89,988
2023	87,160	87,160	23,550	32,728	0	93,392	93,681
2024	89,469	89,469	25,375	35,020	0	95,968	96,025
2025	89,697	89,697	26,490	36,355	0	95,858	95,859
2026	89,423	89,423	27,146	37,109	0	95,230	95,232
2027	89,188	89,188	27,475	37,464	0	94,802	94,808
2028	88,698	88,698	27,644	37,622	0	94,307	94,310
2029	89,183	89,183	27,894	37,921	0	95,004	95,006
2030	89,362	89,362	28,045	38,094	0	95,235	95,235
Fishing M.	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2017	0.238	0.238	0.238	0.238	0.238	0.238	0.238
2018	0.278	0.278	0.278	0.278	0.278	0.464	0.384
2019	0.283	0.283	0.283	0.283	0.283	0.402	0.357
2020	0.366	0.366	0.066	0.096	0	0.383	0.403
2021	0.355	0.355	0.066	0.096	0	0.393	0.401
2022	0.355	0.355	0.066	0.096	0	0.404	0.406
2023	0.358	0.358	0.066	0.096	0	0.410	0.411
2024	0.359	0.359	0.066	0.096	0	0.413	0.414
2025	0.360	0.360	0.066	0.096	0	0.413	0.414
2026	0.359	0.359	0.066	0.096	0	0.412	0.412
2027	0.359	0.359	0.066	0.096	0	0.412	0.412
2028	0.359	0.359	0.066	0.096	0	0.412	0.412
2029	0.359	0.359	0.066	0.096	0	0.412	0.412
2030	0.358	0.358	0.066	0.096	0	0.411	0.411
Spawning biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2017	159,027	159,027	159,027	159,027	159,027	159,027	159,027
2018	139,297	139,297	139,297	139,297	139,297	128,922	133,272
2019	125,587	125,587	125,587	125,587	125,587	107,324	114,495
2020	118,779	118,779	133,815	132,233	137,396	102,660	107,705
2021	119,215	119,215	156,726	152,393	166,847	106,911	109,145
2022	123,280	123,280	180,662	173,546	197,746	112,218	113,086
2023	125,992	125,992	199,874	190,180	223,731	114,922	115,253
2024	127,752	127,752	214,905	202,931	245,045	116,364	116,494
2025	128,542	128,542	226,195	212,262	261,966	116,826	116,884
2026	128,014	128,014	233,181	217,703	273,601	116,150	116,184
2027	127,343	127,343	237,482	220,866	281,481	115,521	115,540
2028	127,080	127,080	240,993	223,463	287,957	115,309	115,318
2029	127,170	127,170	243,610	225,412	292,828	115,431	115,435
2030	127,838	127,838	246,142	227,446	297,084	116,066	116,068

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 western and central 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	Stable, some increasing some decreasing	Affects young-of-year mortality	No concern
Fish (Pacific cod, arrowtooth flounder)	Arrowtooth abundance trends are stabilizing, possibly slight declining trend	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	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 2015-2016, the Atka mackerel fishery contributed an average of 316 and 320 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, 2010-2016. 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
Bairdi Tanner Crab	53	682	0	87	0	254	0
Blue King Crab	0	0	0	0	0	0	0
Chinook Salmon	241	285	161	0	299	136	535
Golden (Brown) King Crab	3,180	33,855	6,662	3,402	2,571	1,321	2,898
Halibut	73	150	232	99	107	126	121
Herring	0	0	0	0	0	0	0
Non-Chinook Salmon	839	152	1,155	705	514	1,687	1,162
Opilio Tanner (Snow) Crab	0	0	64	131	0	38	0
Red King Crab	1,258	1,790	1,782	362	795	4,956	348
Grand Total	**5,644**	**36,914**	**10,056**	**4,786**	**4,286**	**8,517**	**5,064**

Figures

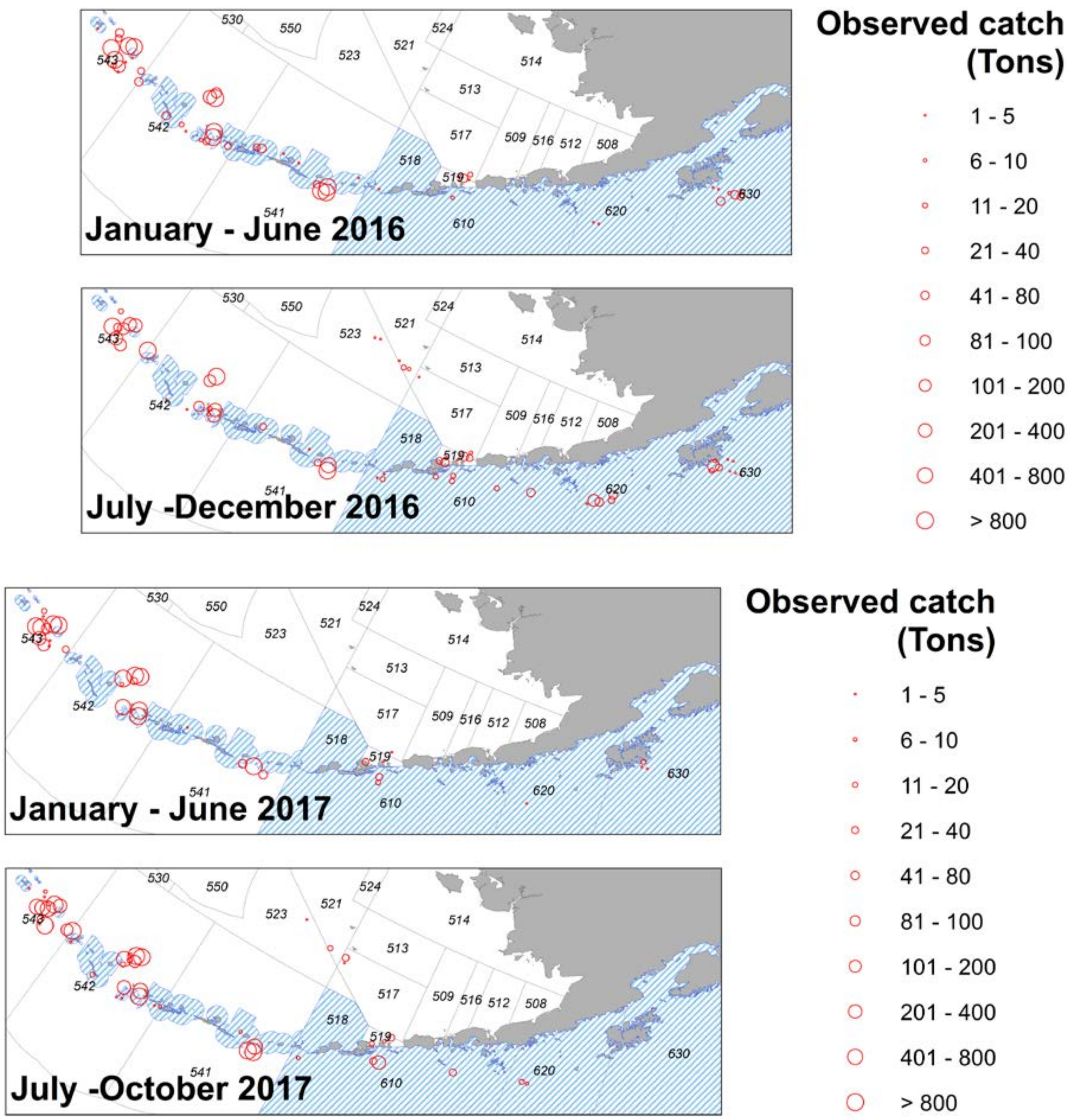


Figure 17.1. Observed catches of Atka mackerel summed for 20 km^2 cells for 2016 and 2017 where observed catch per haul was greater than 1 t. Shaded areas represent areas closed to directed Atka mackerel fishing.

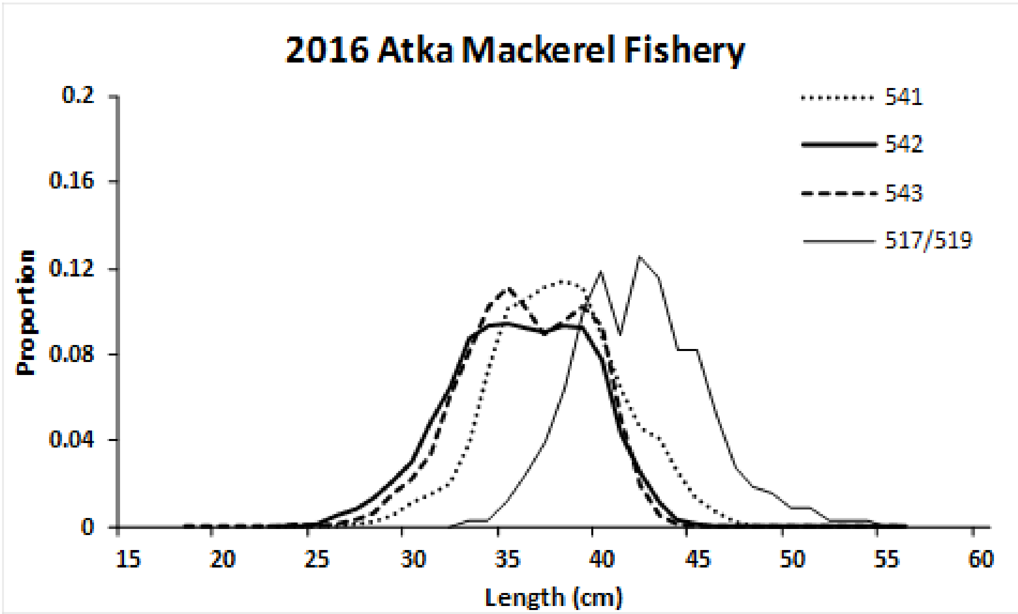


Figure 17.2. 2016 Atka mackerel fishery length-frequency data by area fished (see Figure 17.1). Numbers refer to management areas.

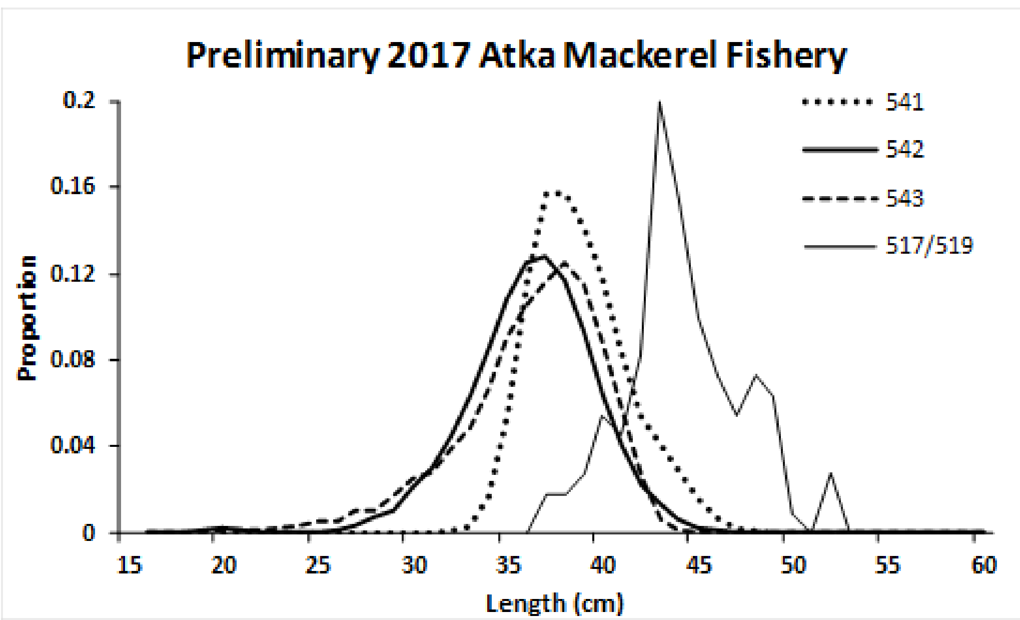


Figure 17.3. Preliminary 2017 Atka mackerel fishery length-frequency data by area fished (see Figure 17.1). Numbers refer to management areas.

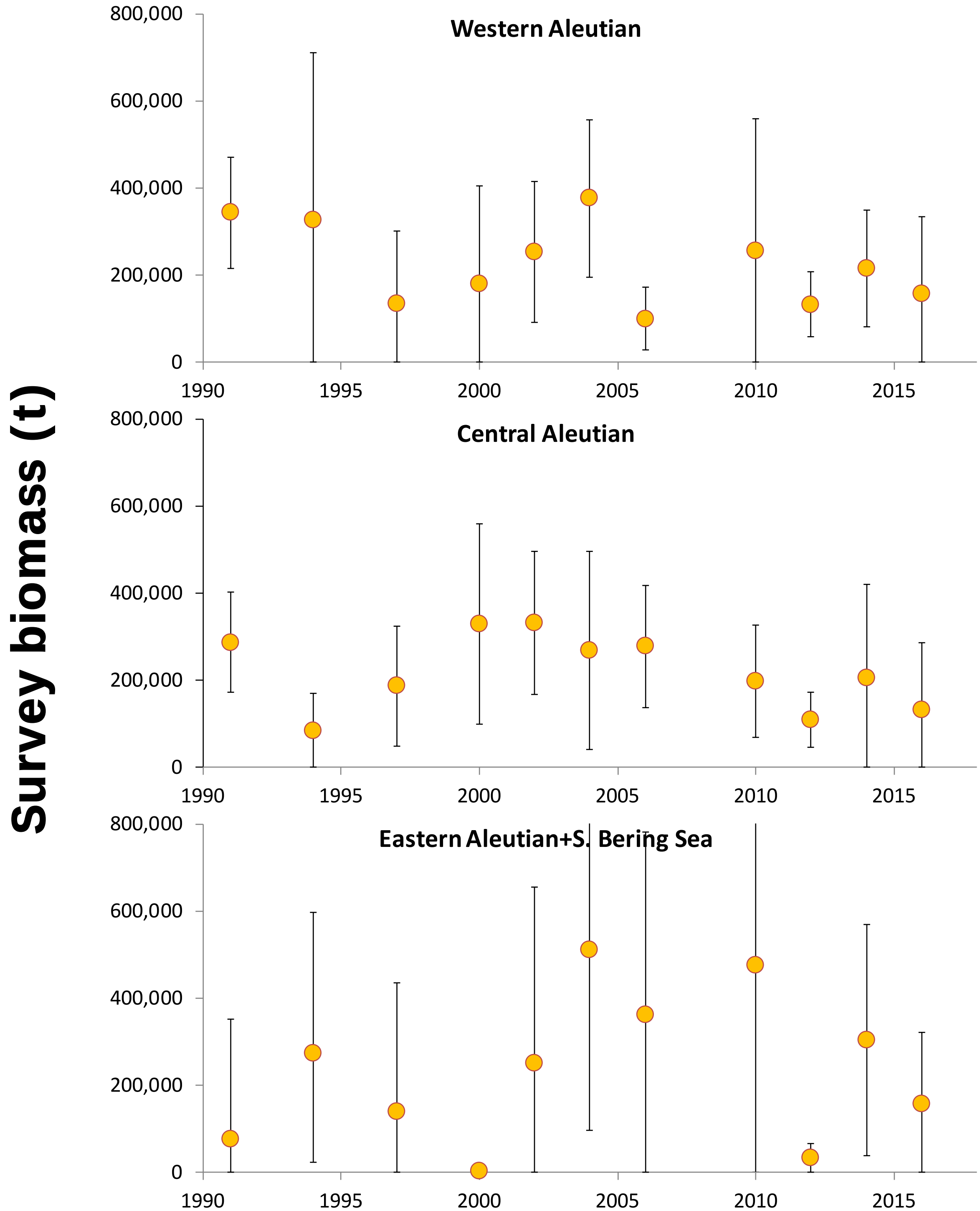


Figure 17.4. Atka mackerel Aleutian Islands survey biomass estimates by area and survey year. Bars represent 95% confidence intervals based on sampling error.

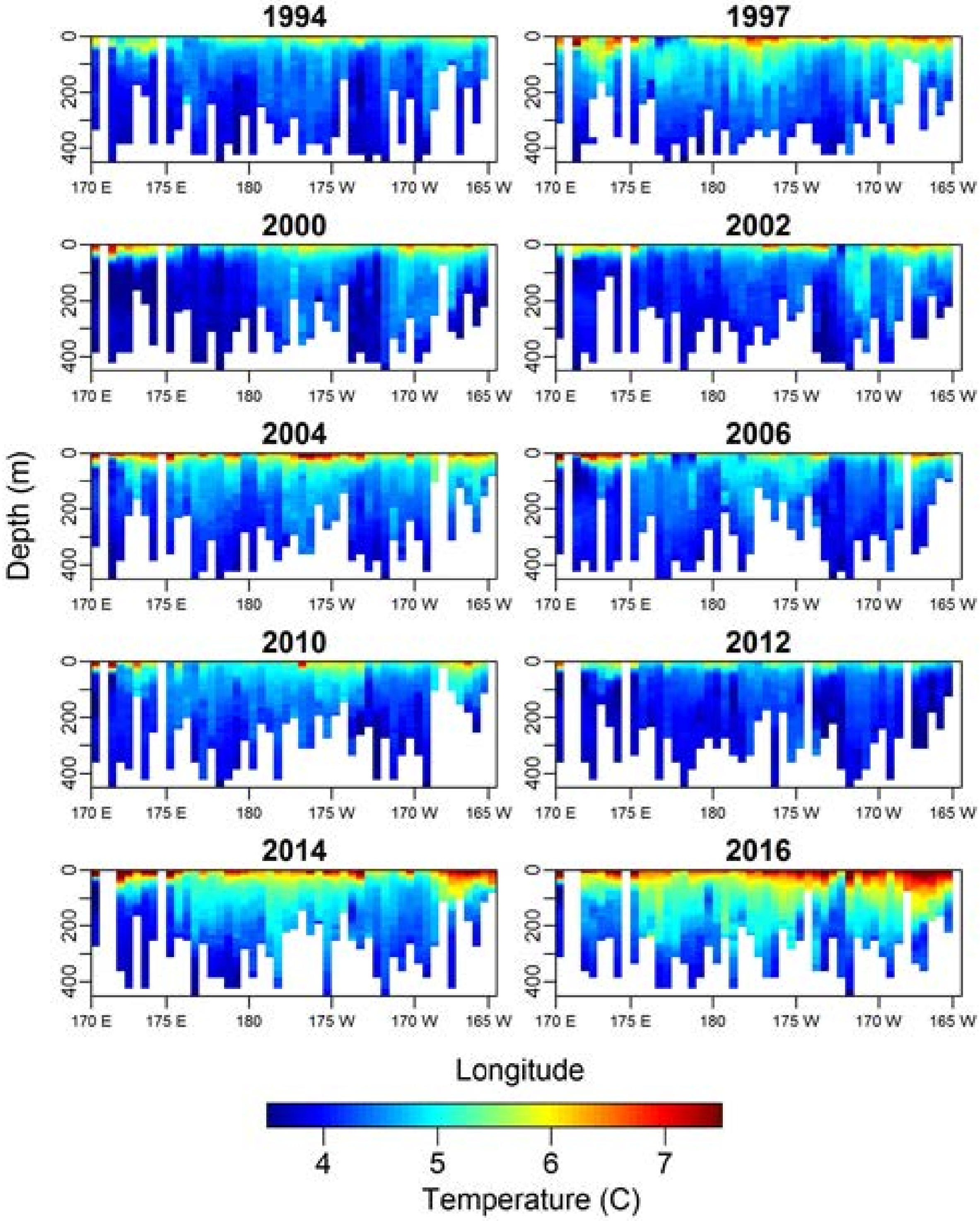


Figure 17.5. Date-standardized temperature (°C) anomaly profiles predicted by a generalized additive model (GAM) at systematic depth increments and ½-degree longitude intervals for Aleutian Islands bottom trawl survey years 1994-2016 (Laman 2016).

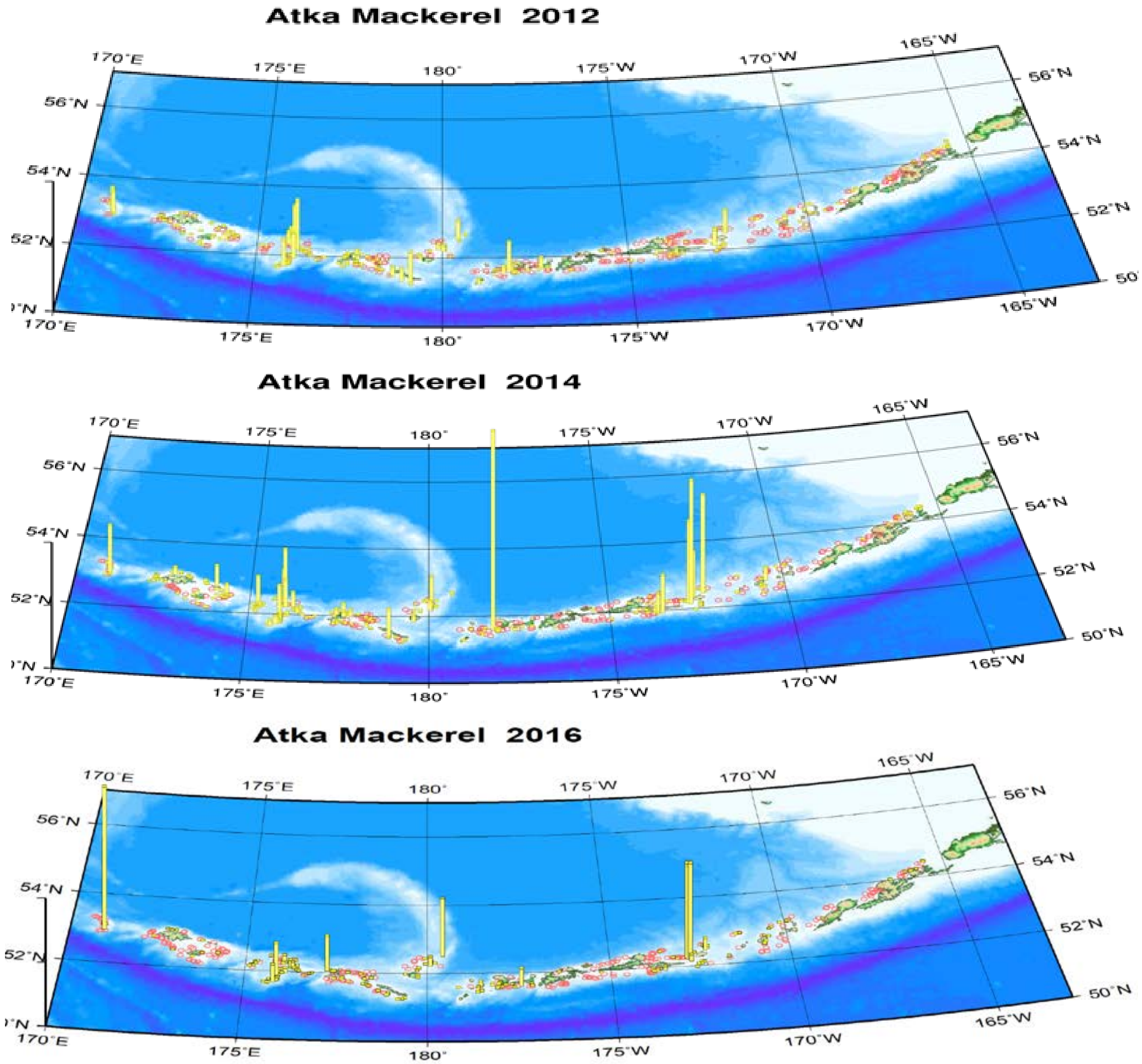
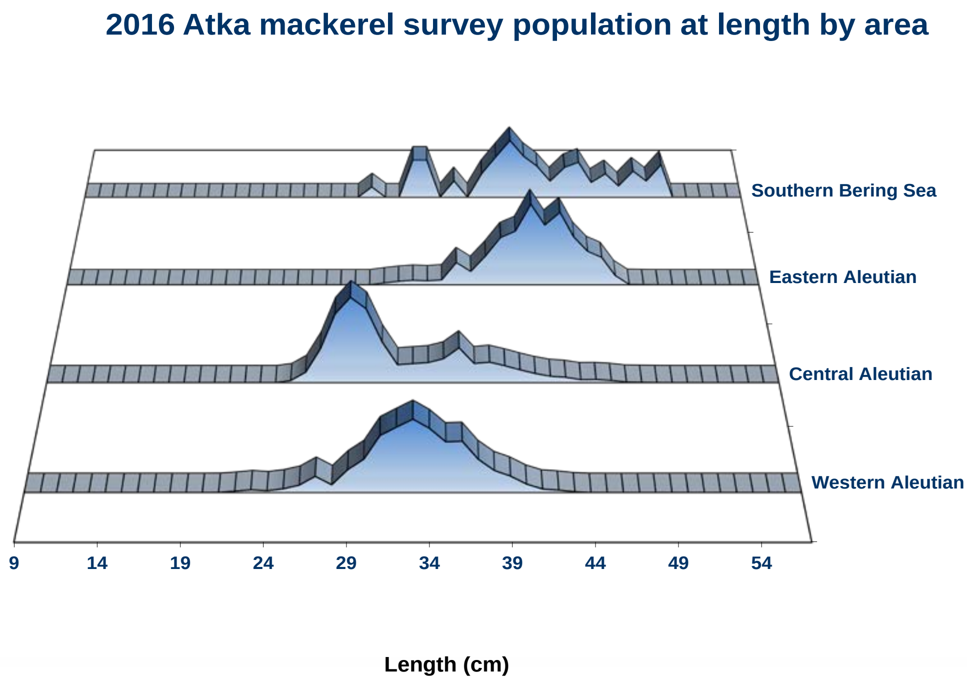


Figure 17.6. Bottom-trawl survey CPUE distributions of Atka mackerel catches during the summers of 2012, 2014, and 2016.



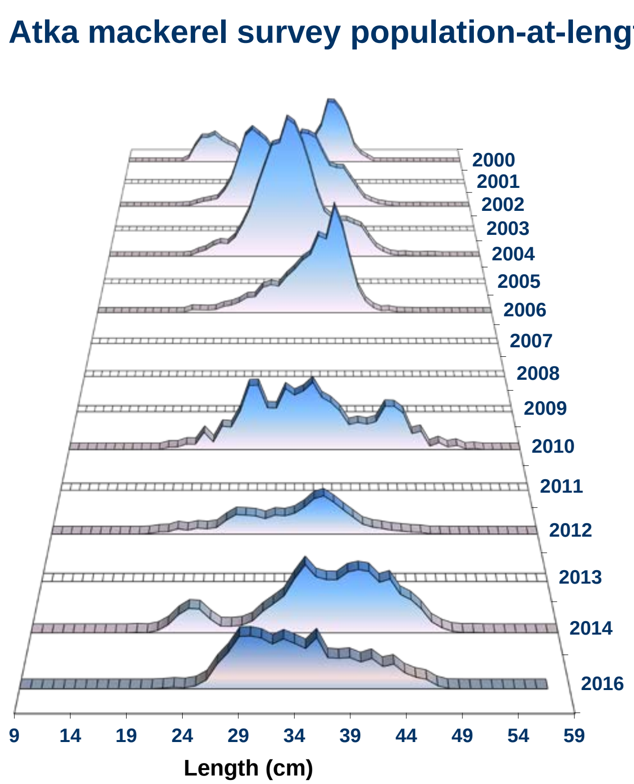


Figure 17.7. Atka mackerel bottom trawl survey length frequency data by subarea in 2016 (top) and for all areas, 2000-2016 (bottom). Vertical scale is proportion in top panel and estimated absolute numbers at age bottom panel.

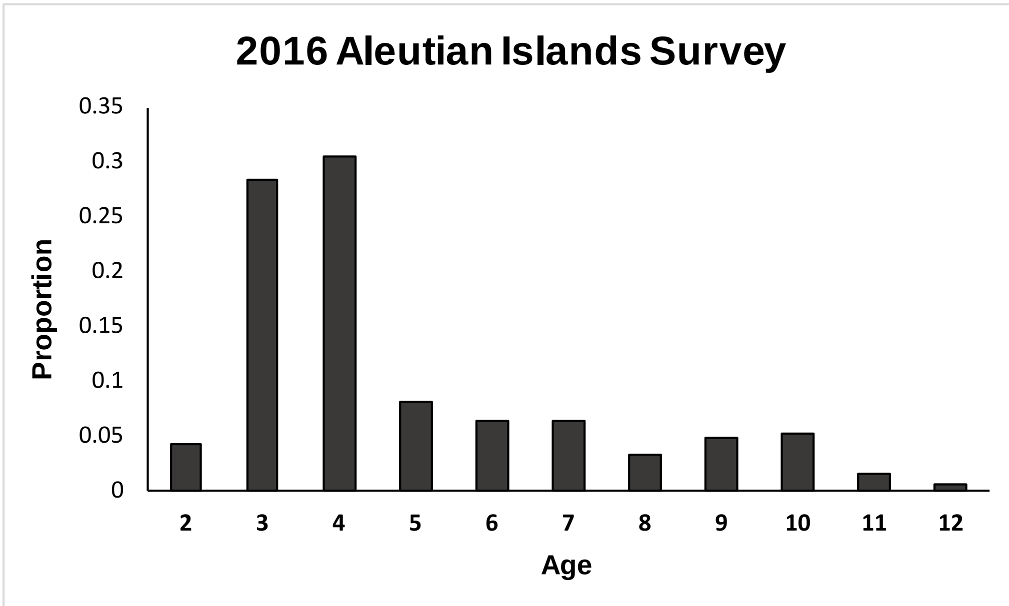
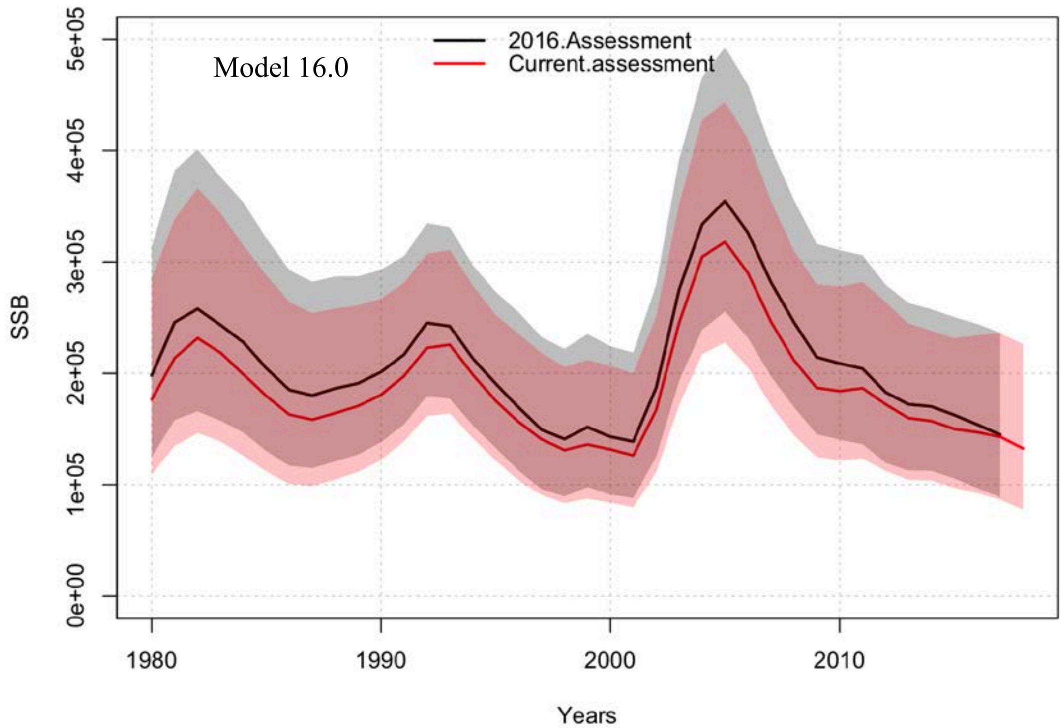


Figure 17.8. Atka mackerel age distribution from the 2016 Aleutian Islands bottom trawl survey. A total of 300 otoliths were aged; mean age from the 2016 survey is 4.9 years.



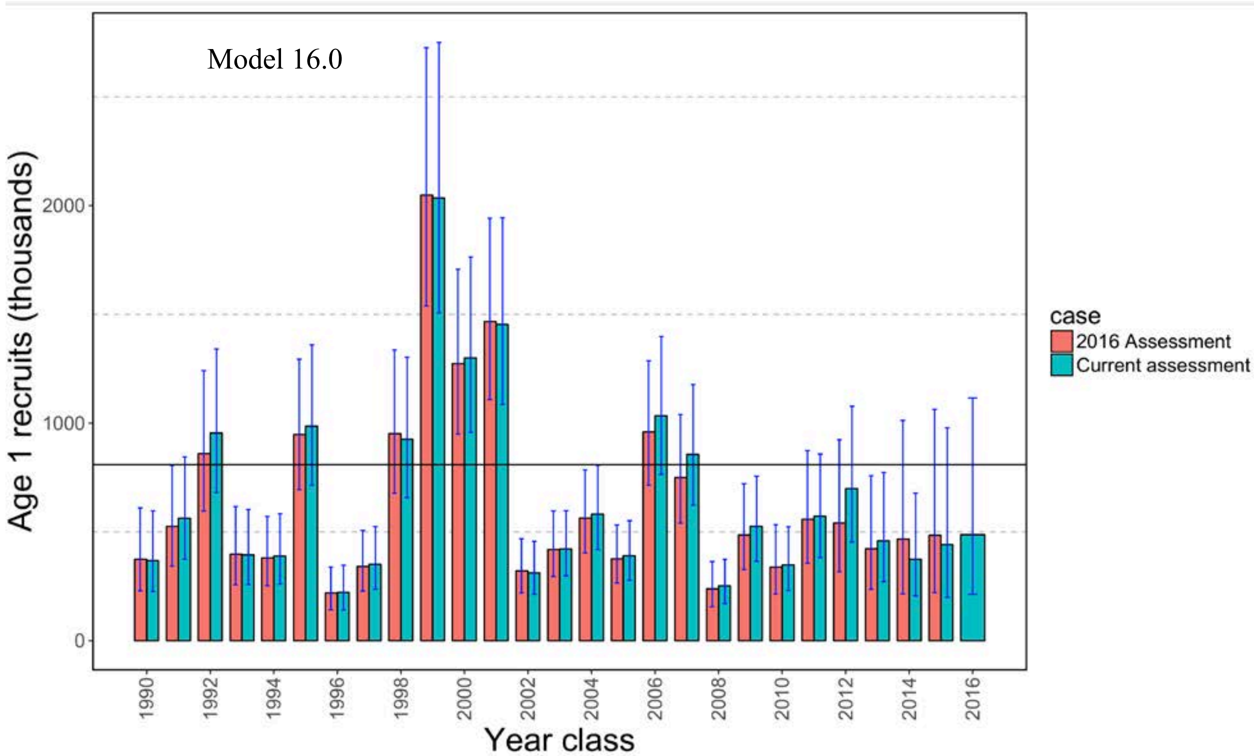


Figure 17.9 Time series of the current assessment (Model 16.0) estimated Aleutian Islands Atka mackerel spawning biomass (in t, top) and recruitment at age 1 (bottom) with approximate 95% confidence bounds, compared to last year's Model 16.0 estimates (2016 assessment). The only change in these figures are the new data available in 2017.

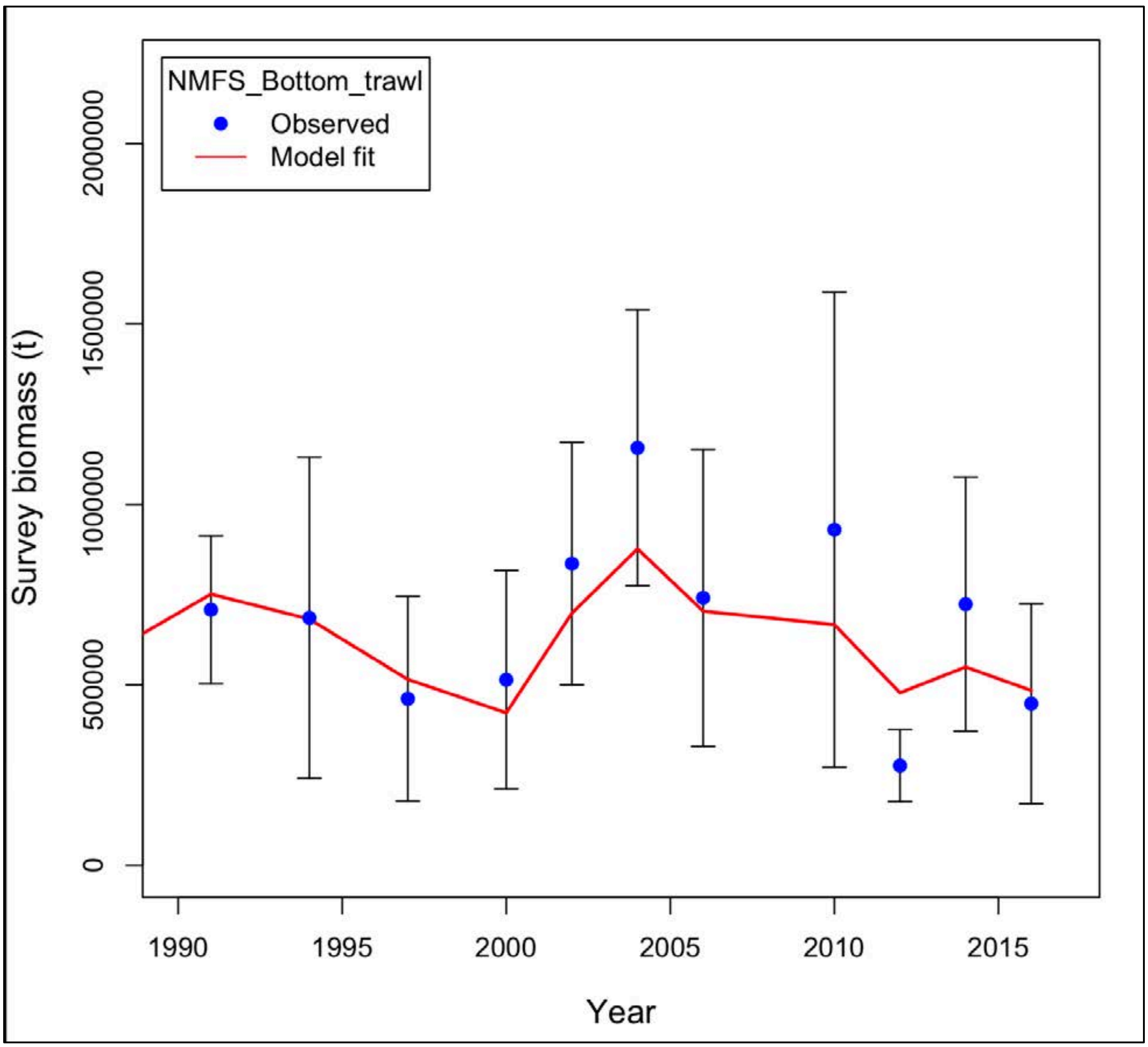


Figure 17.10. Observed (dots) and predicted (trend line) survey biomass estimates (t) for Bering Sea/Aleutian Islands Atka mackerel. Error bars represent two standard errors (based on sampling) from the survey estimates.

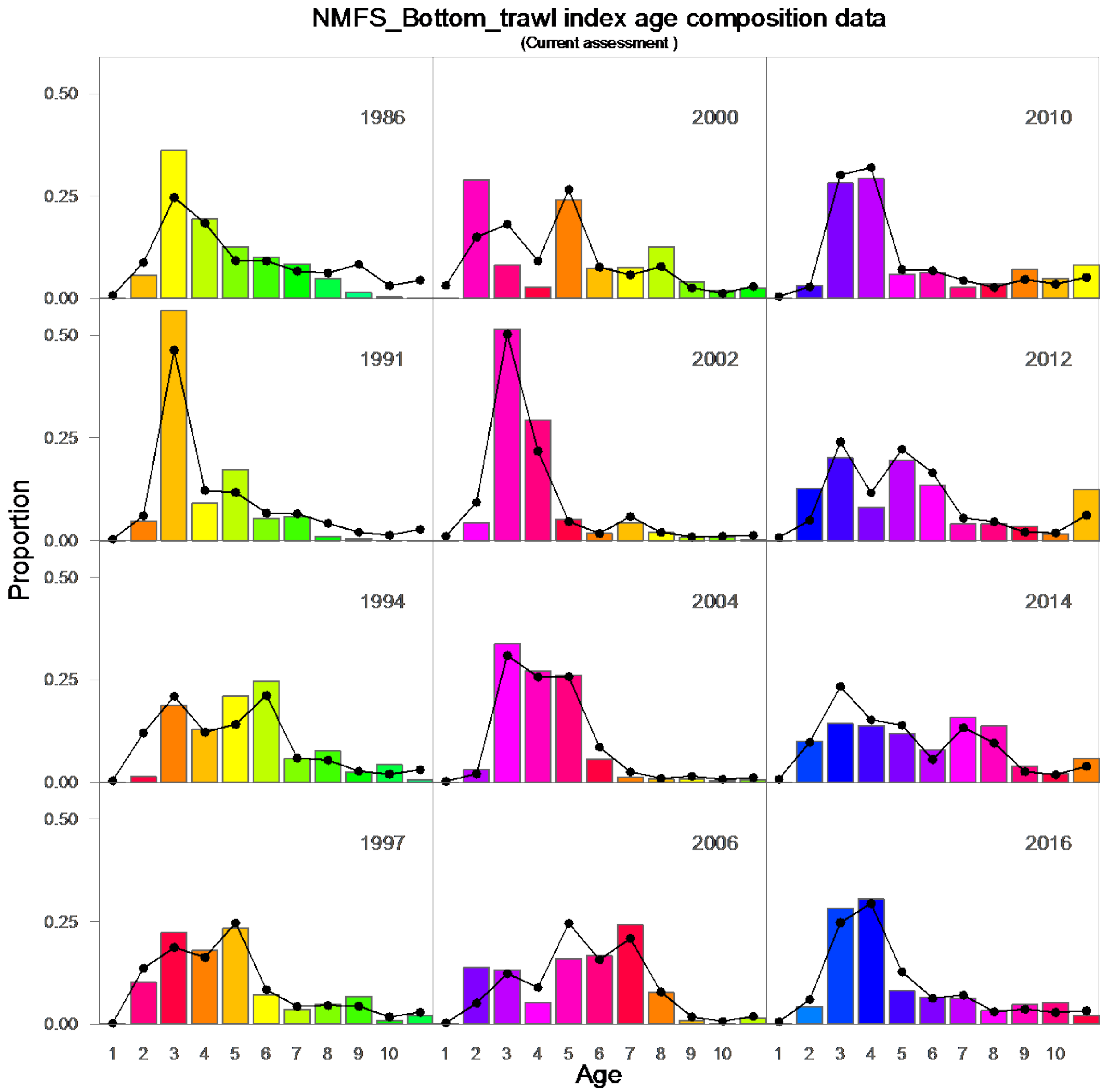


Figure 17.11. Observed and predicted **survey** proportions-at-age for BSAI Atka mackerel. Lines with "•" symbol are the model predictions and columns are the observed proportions at age.

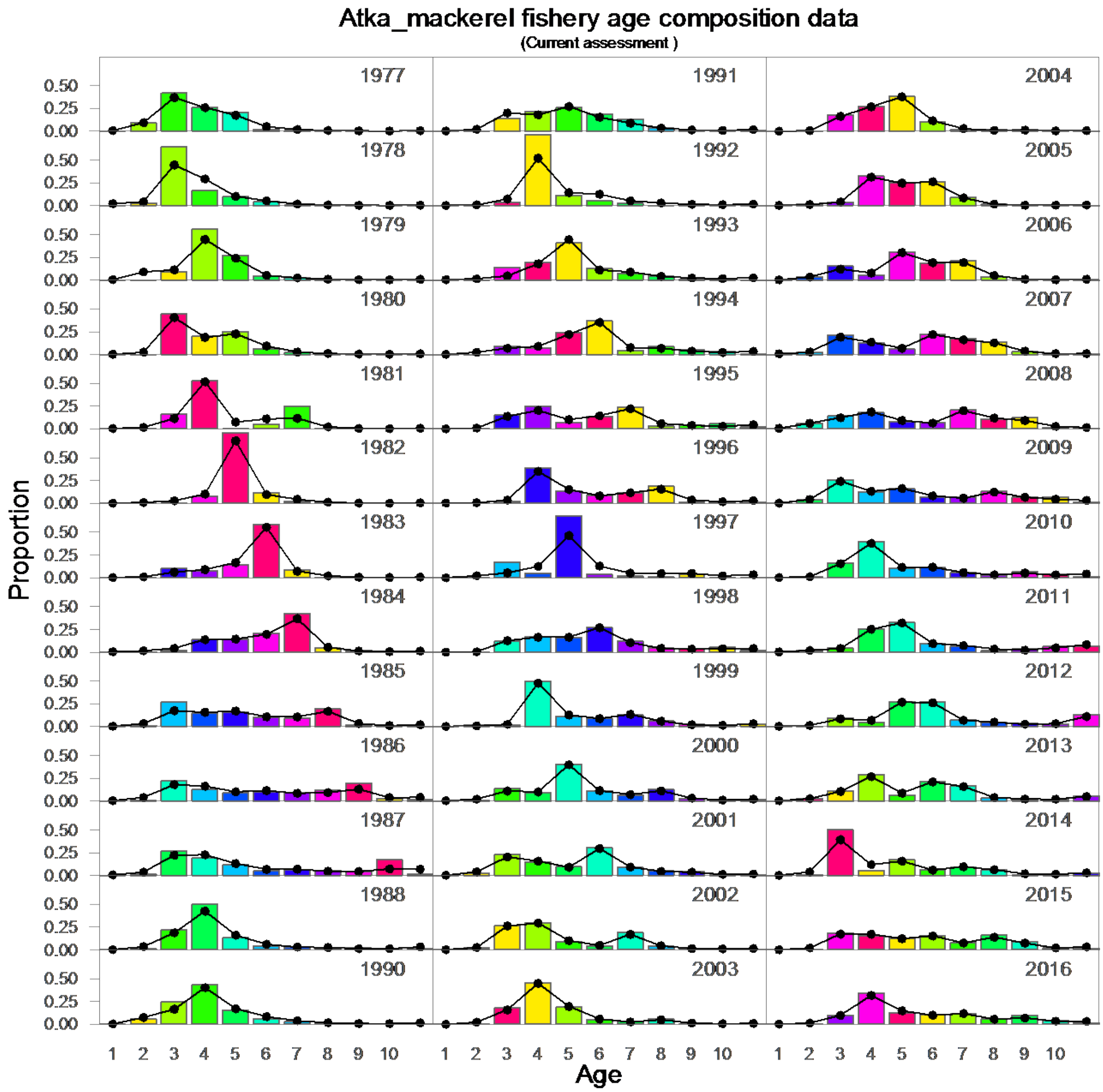


Figure 17.12. Observed and predicted Atka mackerel **fishery** proportions-at-age for BSAI Atka mackerel. Lines with "•" symbol are the model predictions and columns are the observed proportions at age (with colors corresponding to cohorts).

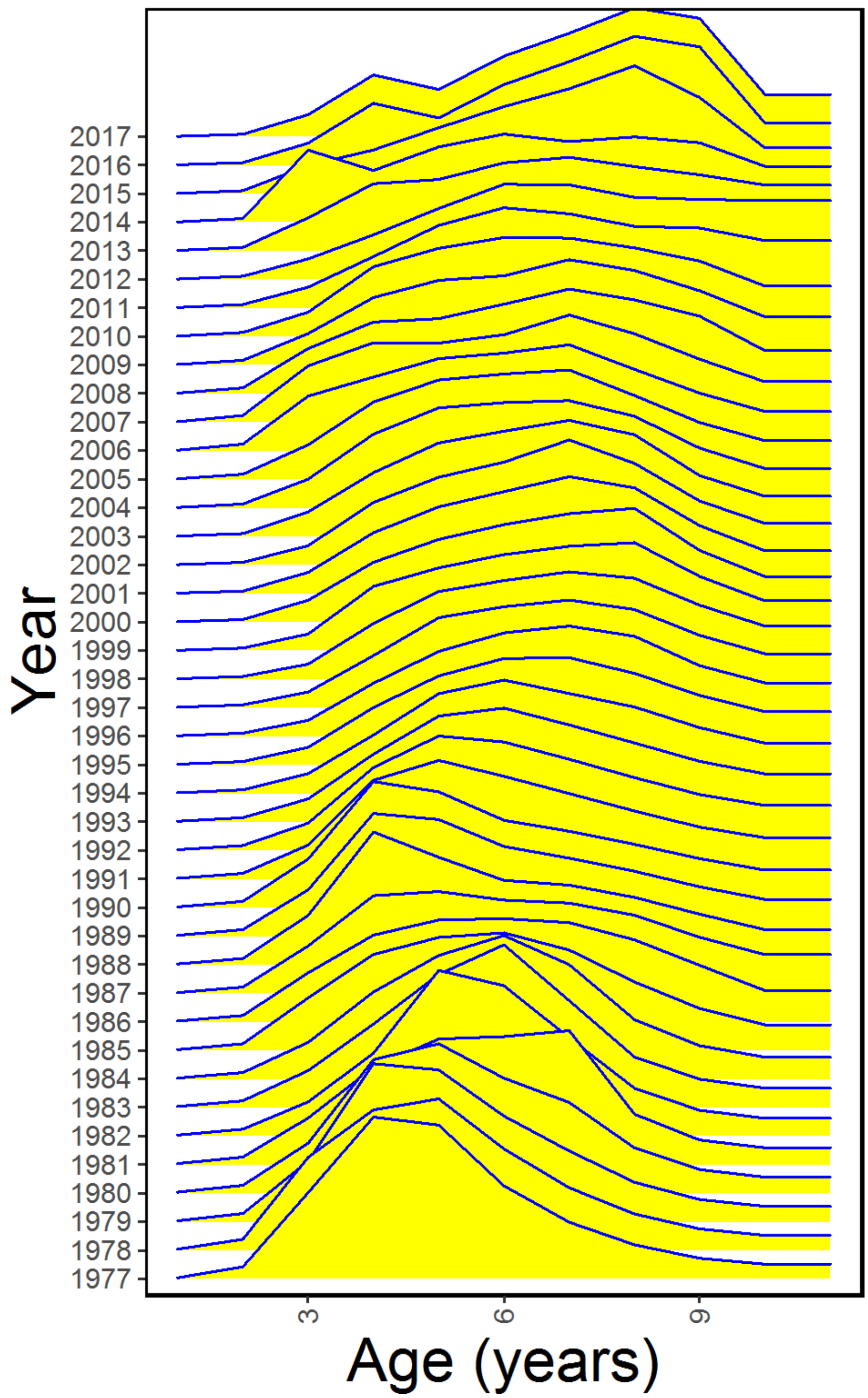


Figure 17.13. Fishery selectivity estimates over time for BSAI Atka mackerel.

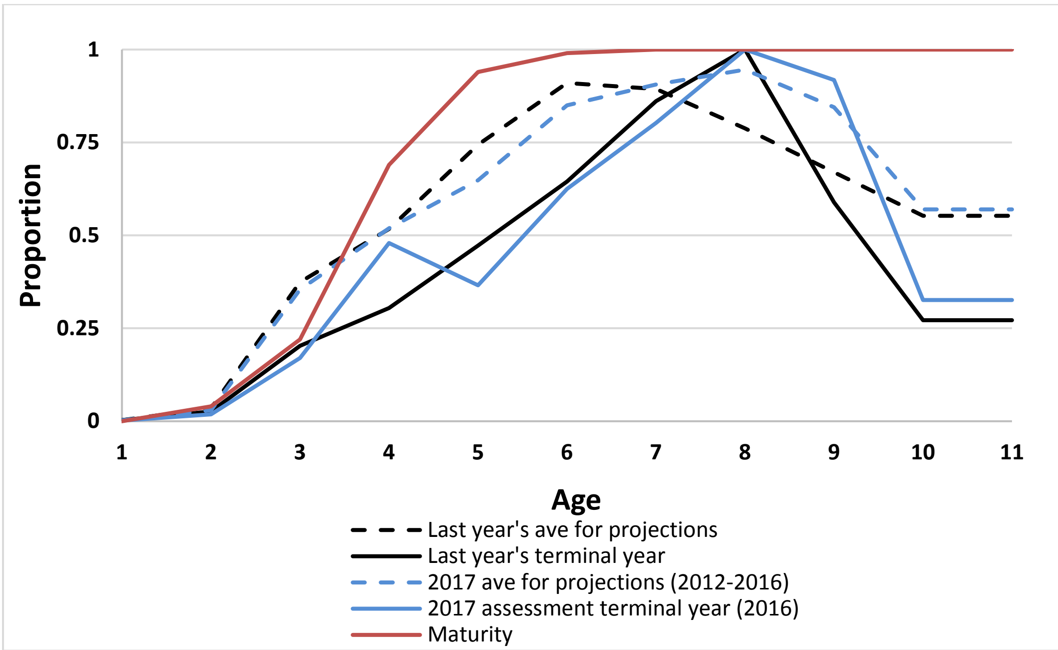


Figure 17.14. Estimated fishery selectivity patterns in the current assessment with a) last year's average for projections, b) the 2017 assessment average selectivity used for projections (2012-2016), c) last year's assessment terminal year, and d) the 2017 assessment terminal year (2016) compared with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

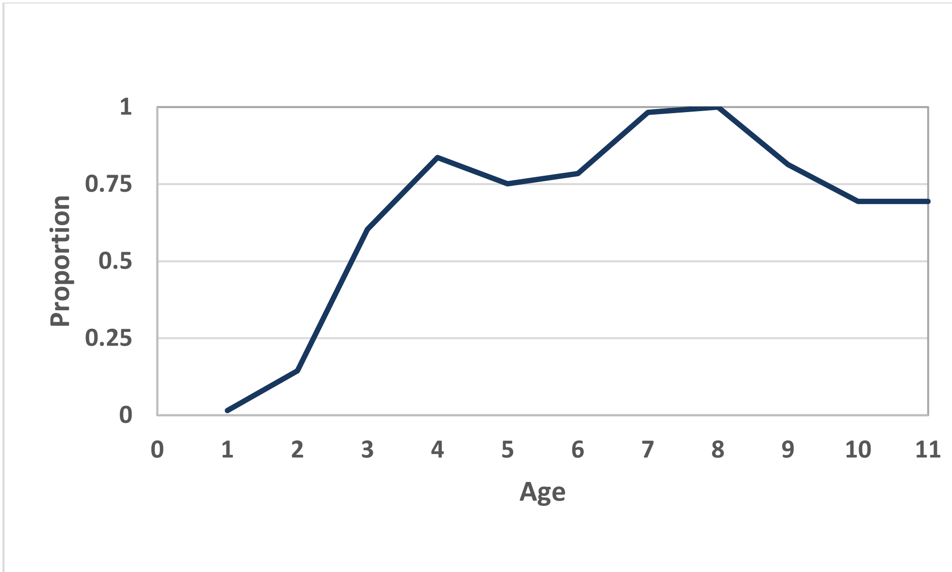
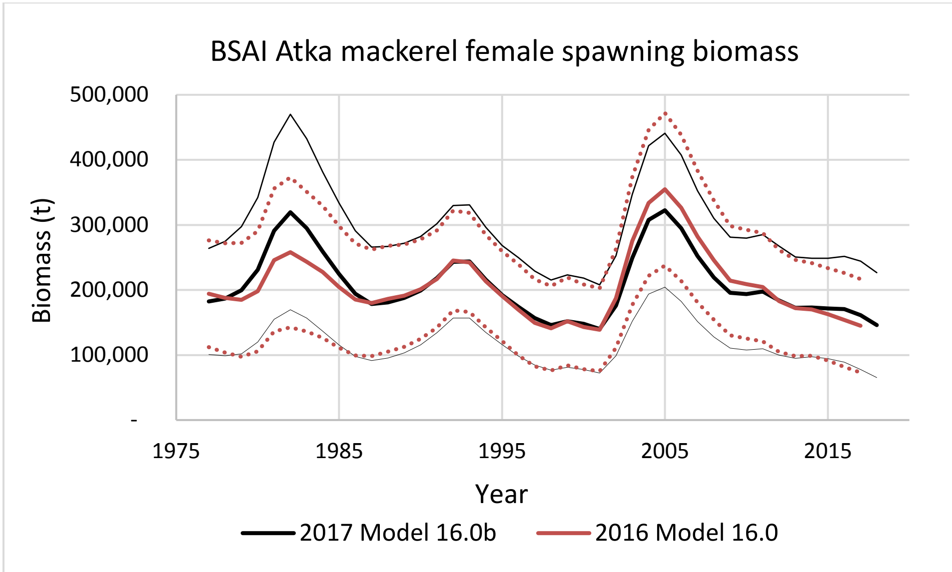


Figure 17.15. Estimated BSAI Atka mackerel survey selectivity-at-age from the current assessment (Model 16.0b). Selectivity estimates have been normalized to a maximum value of 1.0 for presentation.



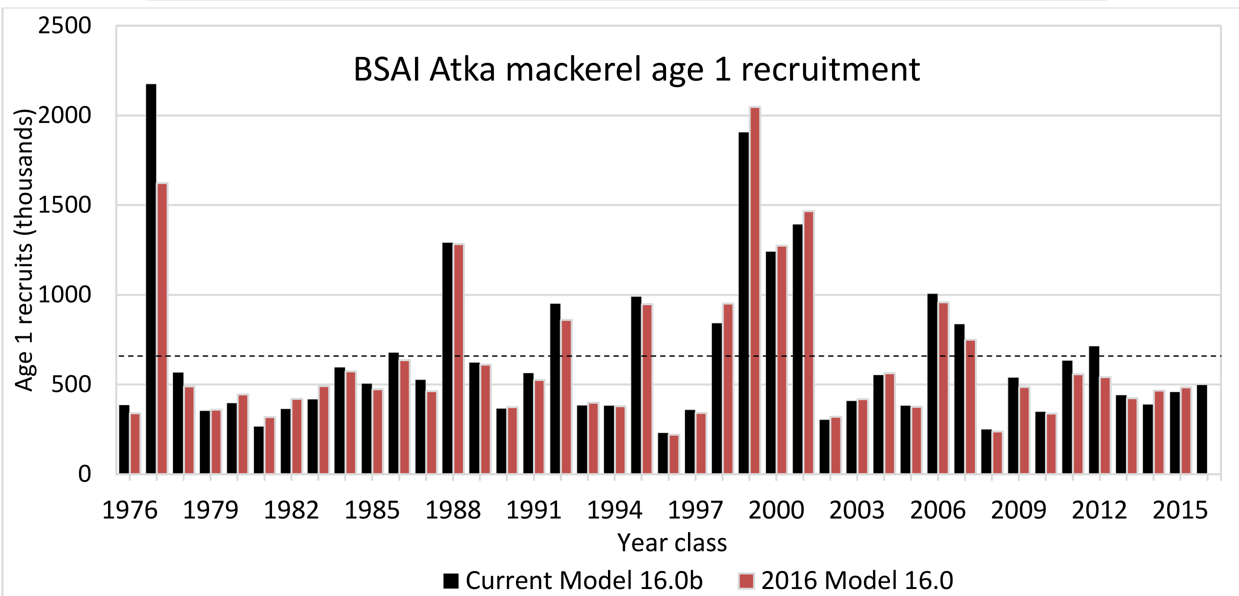


Figure 17.16. Time series of estimated Aleutian Islands Atka mackerel spawning biomass with approximate 95% confidence bounds (in t, top), and recruitment at age 1 (thousands, bottom) from the current assessment (Model 16.0b) compared to last year's 2016 assessment results (Model 16.0). Dashed line represents average recruitment over the time series from the current assessment (658 million recruits).

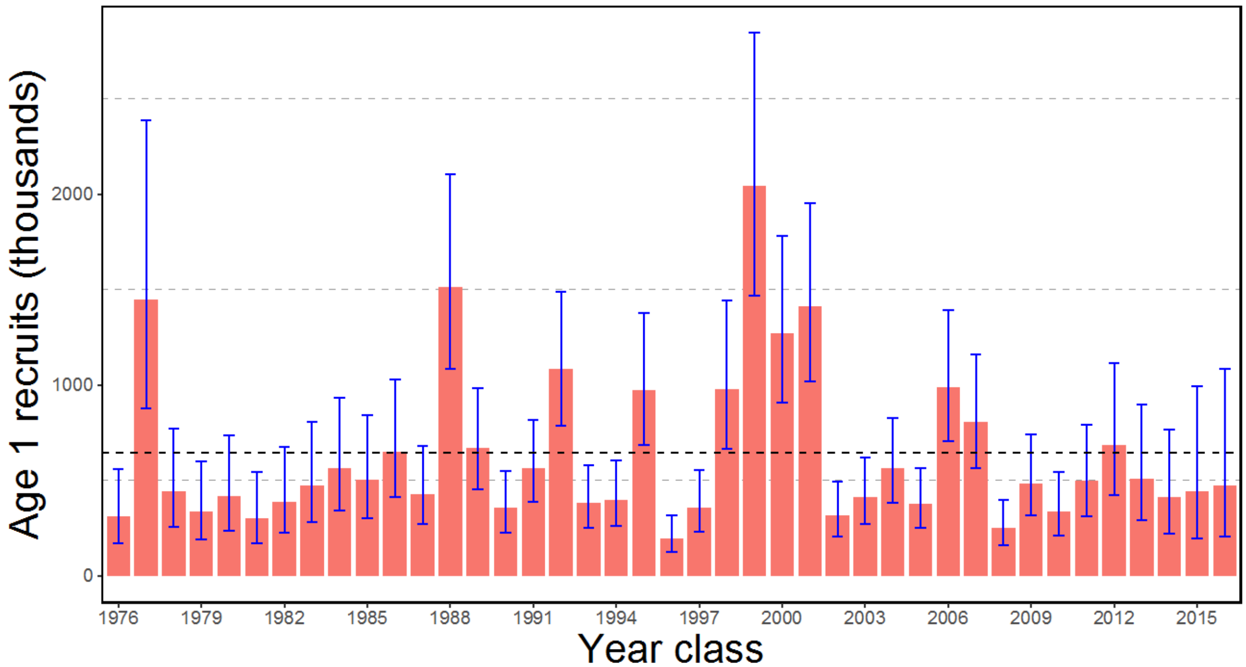


Figure 17.17. Age 1 recruitment from the current assessment (Model 16.0b). Average recruitment for the 1977-2015 year classes is 658 million recruits.

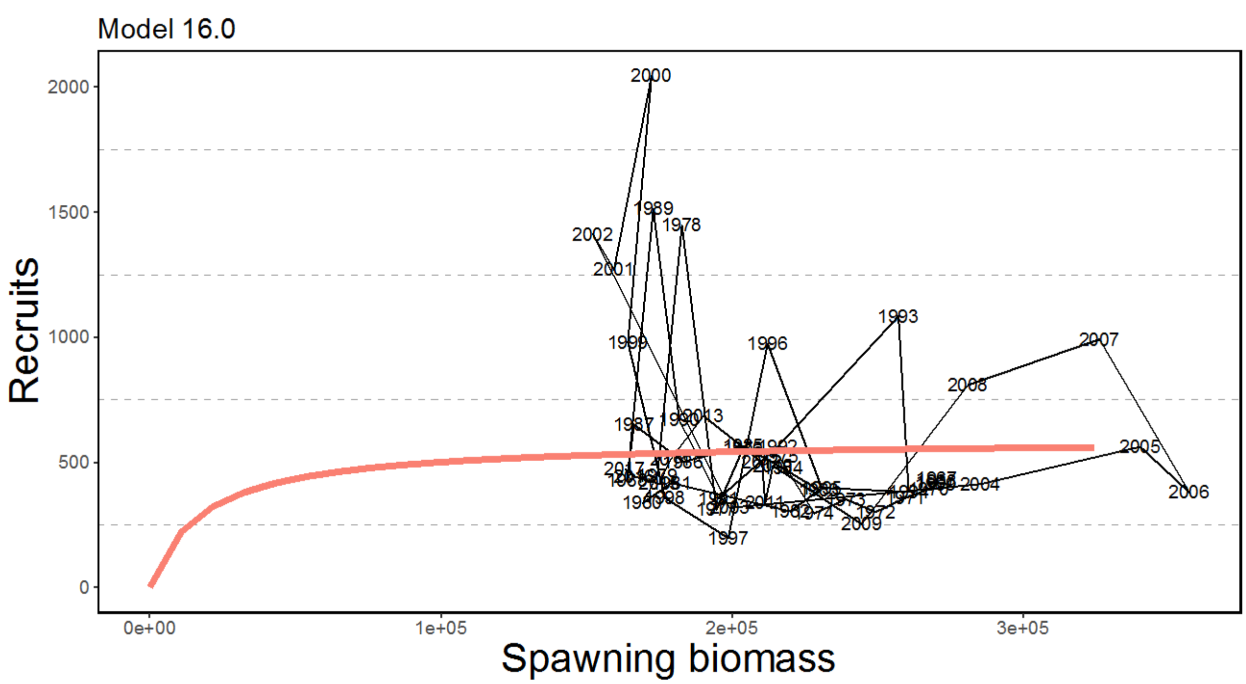


Figure 17.18 Estimated age 1 recruits (millions) versus female spawning biomass (t) for BSAI Atka mackerel. Solid line indicates Beverton-Holt stock recruitment curve (with steepness *h*=0.8).

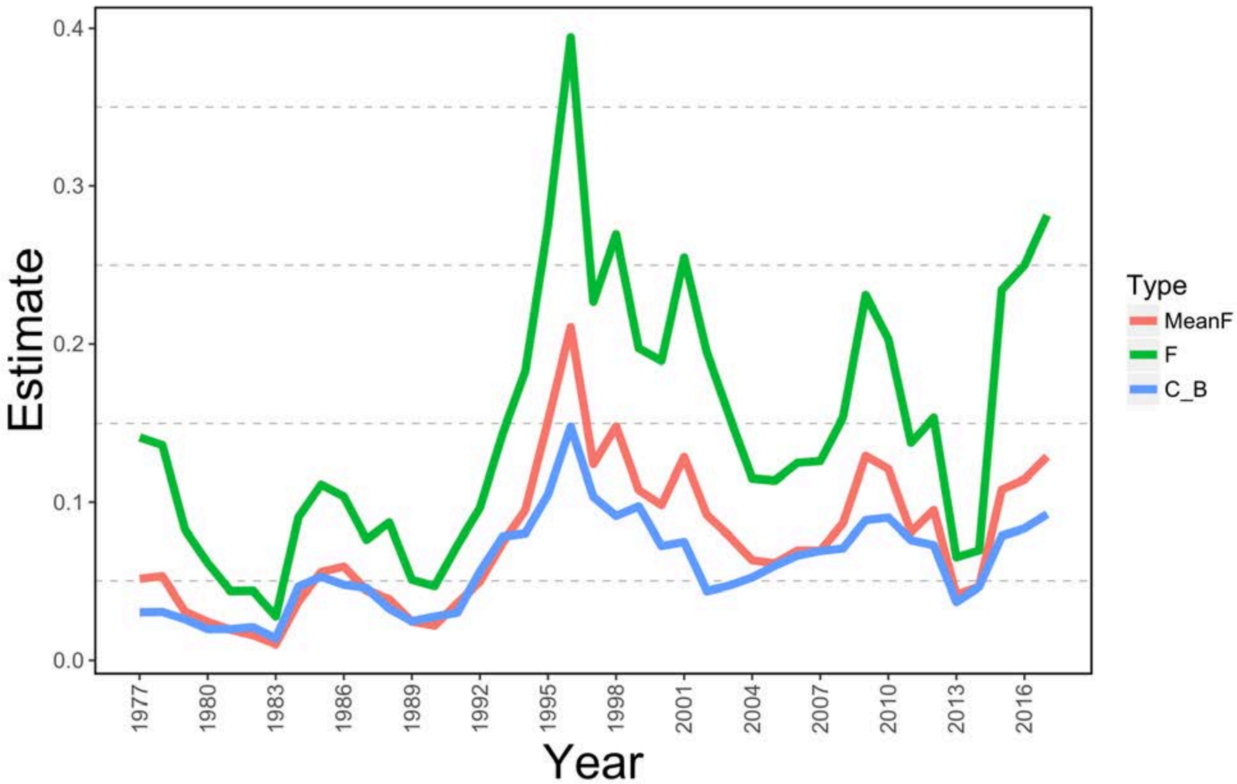
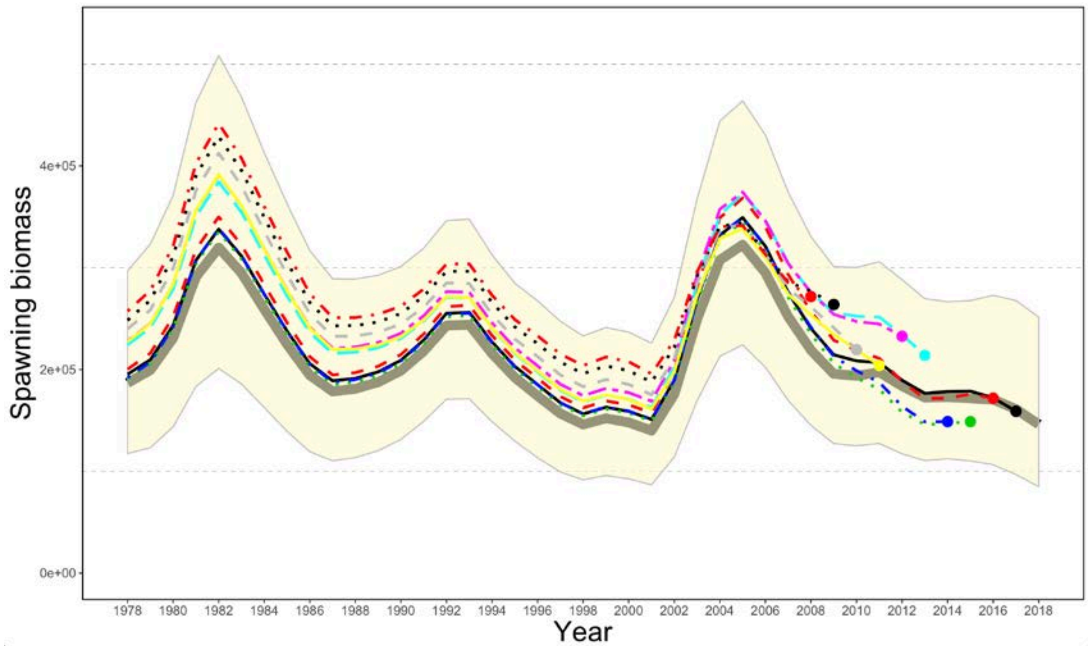


Figure 17.19 Estimated time series of Model 16.0 mean and full-selection fishing mortality and catch/biomass (C_B) exploitation rates of Atka mackerel, 1977-2017. Catch/biomass rates are the ratios of catch to beginning year age 3+ biomass.



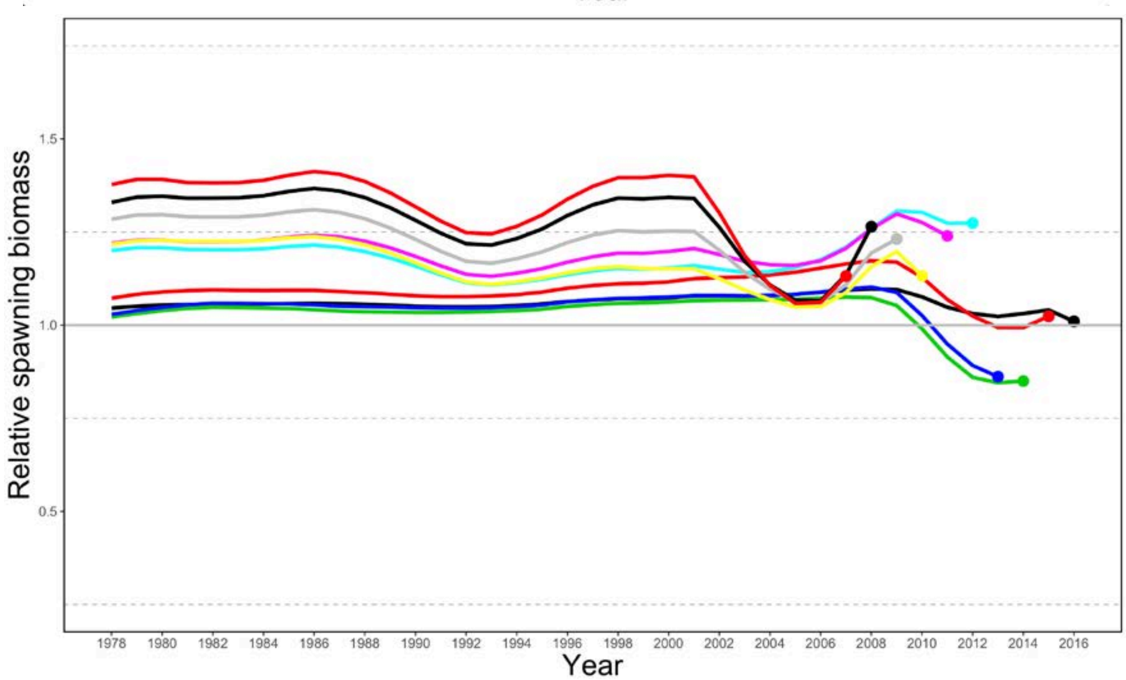
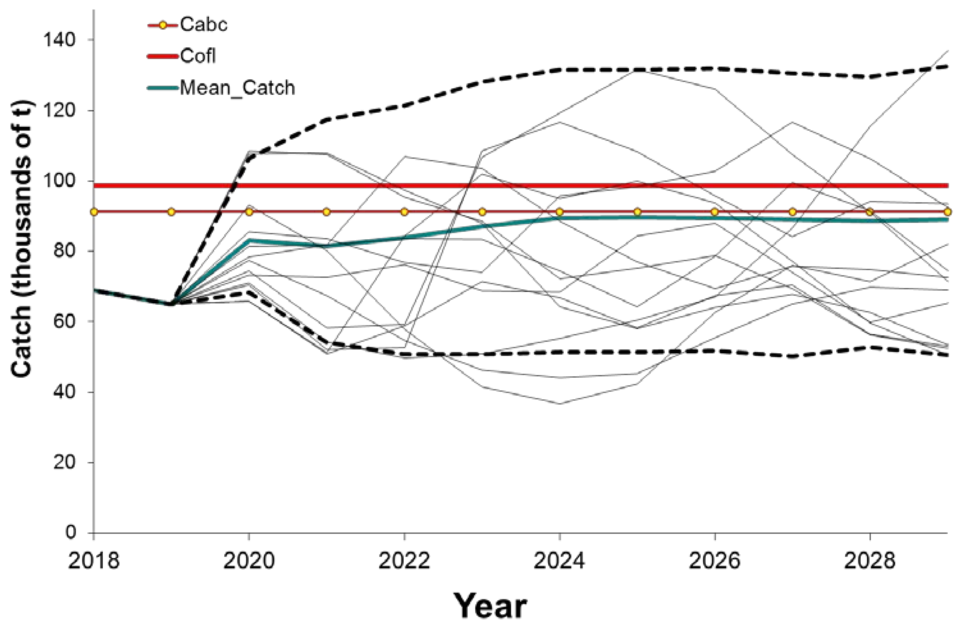


Figure 17.20. Retrospective plots showing the BSAI Atka mackerel spawning biomass over time (top) and the relative difference (bottom) over 10 different “peels”.



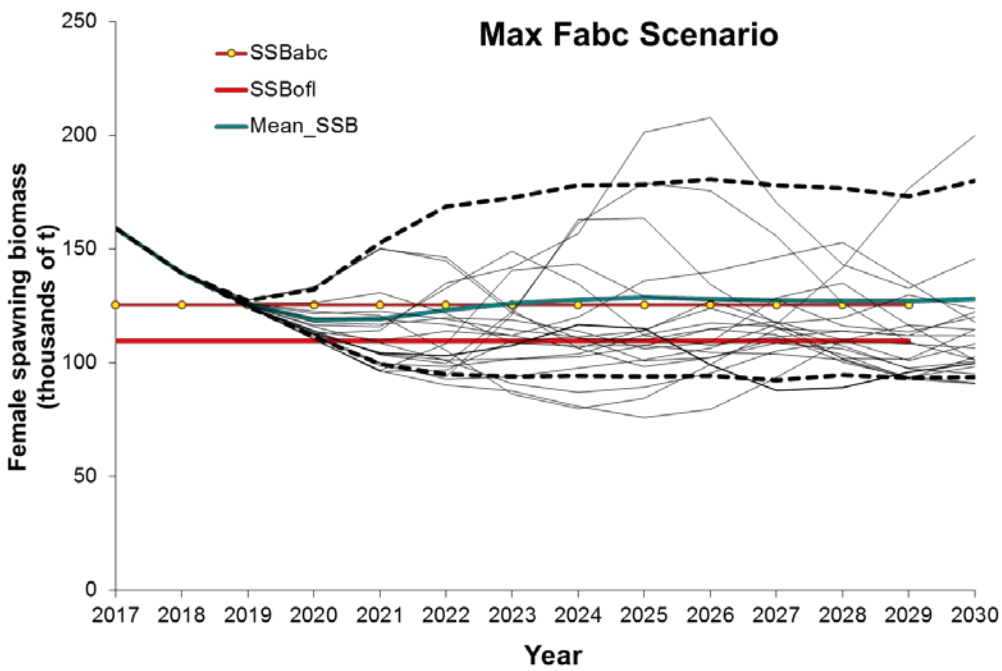


Figure 17.21. Projected Atka mackerel catch (assuming TAC taken in 2017 and reduced 2018 and 2019 catches; top) and spawning biomass (bottom) in thousands of metric tons under maximum permissible Tier 3a harvest specification. The individual thin lines represent samples of simulated trajectories.

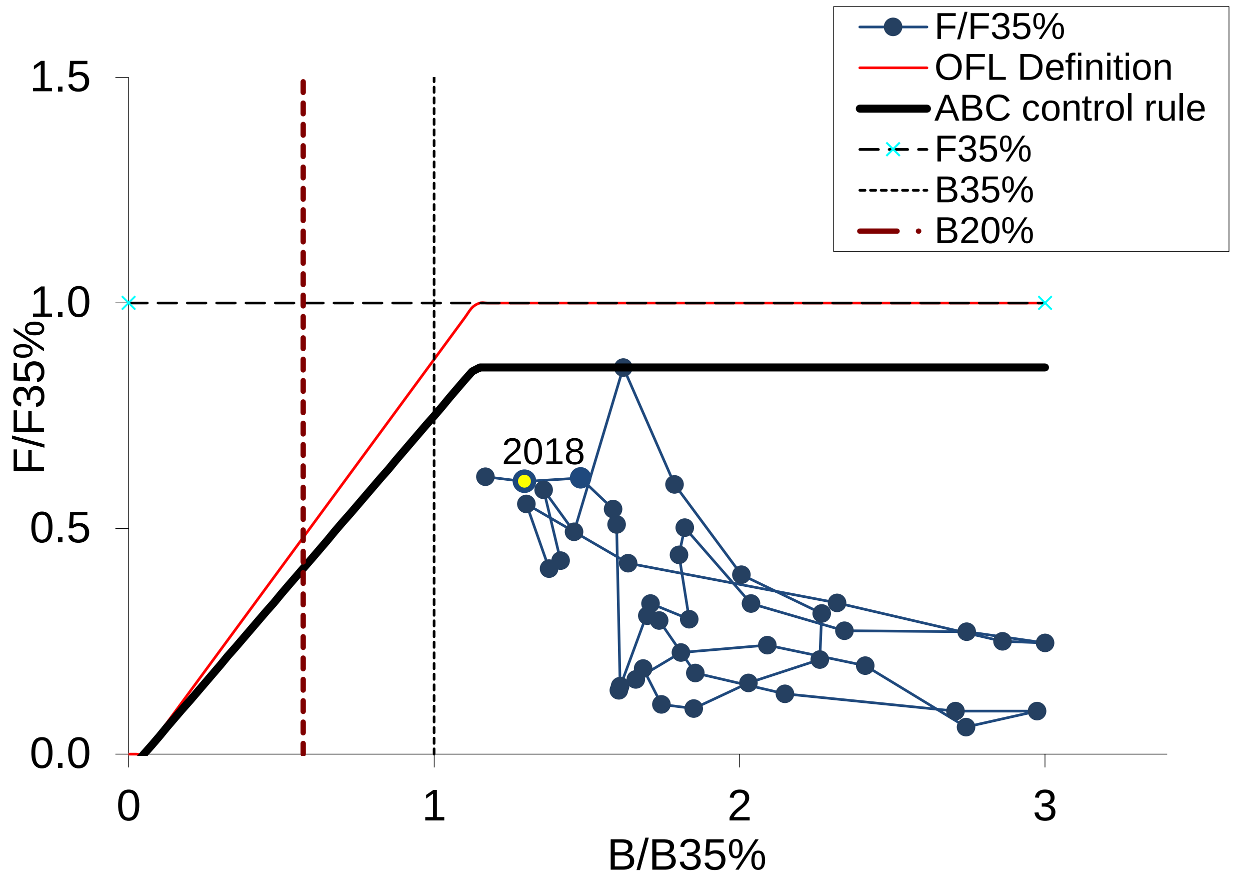


Figure 17.22. Aleutian Islands Atka mackerel spawning biomass relative to $B_{35\%}$ and fishing mortality relative to F_{OFL} (1977-2019). The ratio of fishing mortality to F_{OFL} is calculated using the estimated selectivity pattern in that year. Estimates of spawning biomass and $B_{35\%}$ are based 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.

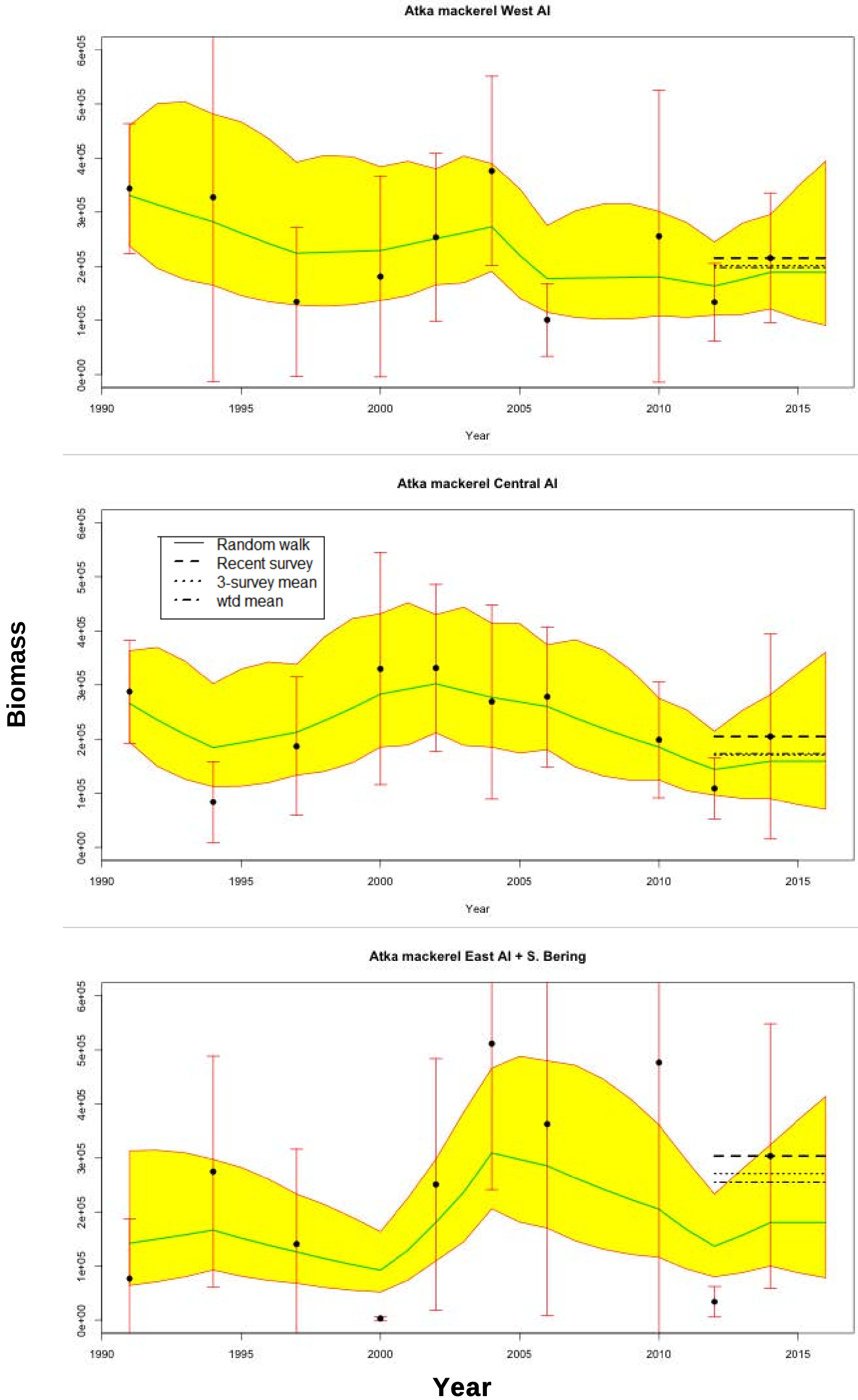


Figure 17.23. Atka mackerel bottom trawl survey biomass by subarea 1991-2016 with random effects model fitting for area apportionment purposes. Dashed lines represent alternative methods for averaging surveys.

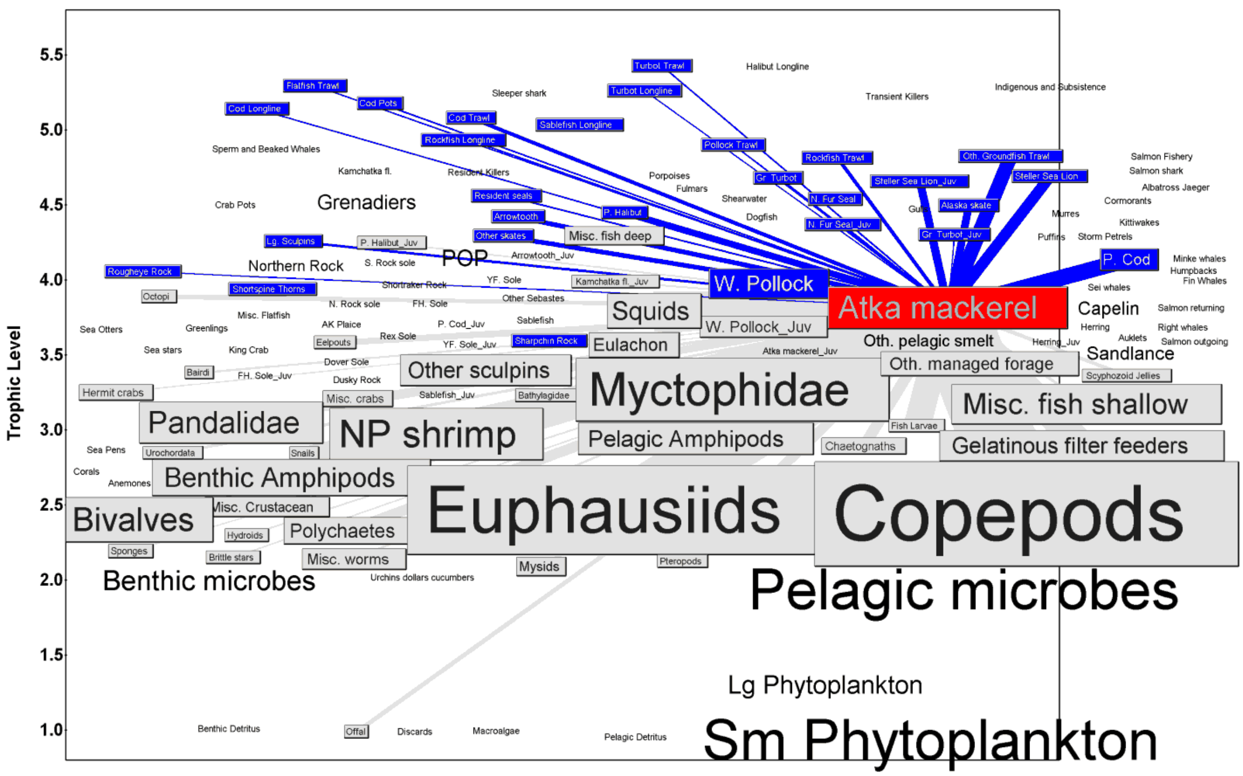
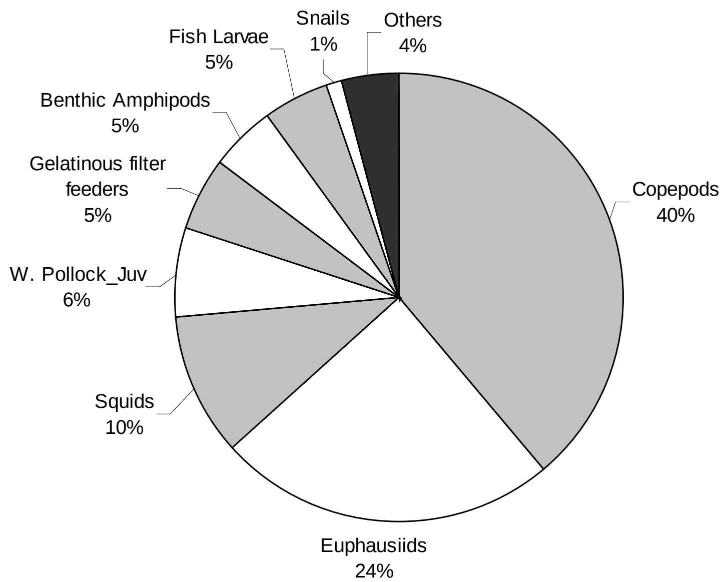
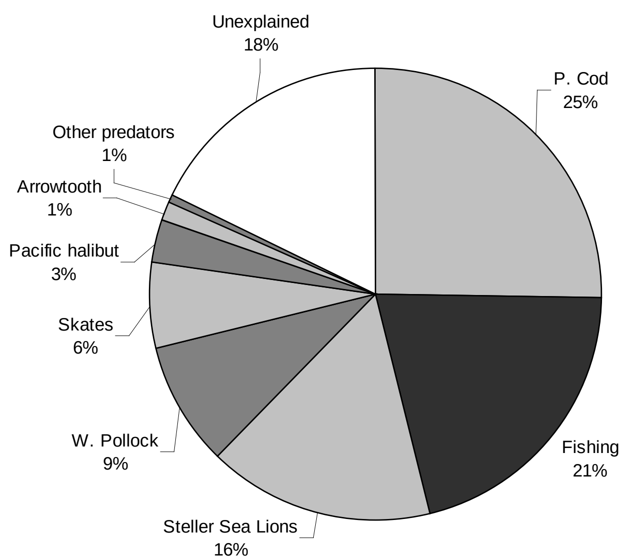


Figure 17.24. The food web of the Aleutian Islands survey region, 1990-1994, emphasizing the position of age 1+ Atka mackerel. Outlined species represent predators of Atka mackerel (dark boxed with light text) and prey of Atka mackerel (light boxes with dark text). Box and text size are proportional to each species' standing stock biomass, while line widths are proportional to the consumption between boxes (t/year). Trophic levels of individual species may be staggered up to +/-0.5 of a trophic level for visibility.



(A)



(B)

Figure 17.25. (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.

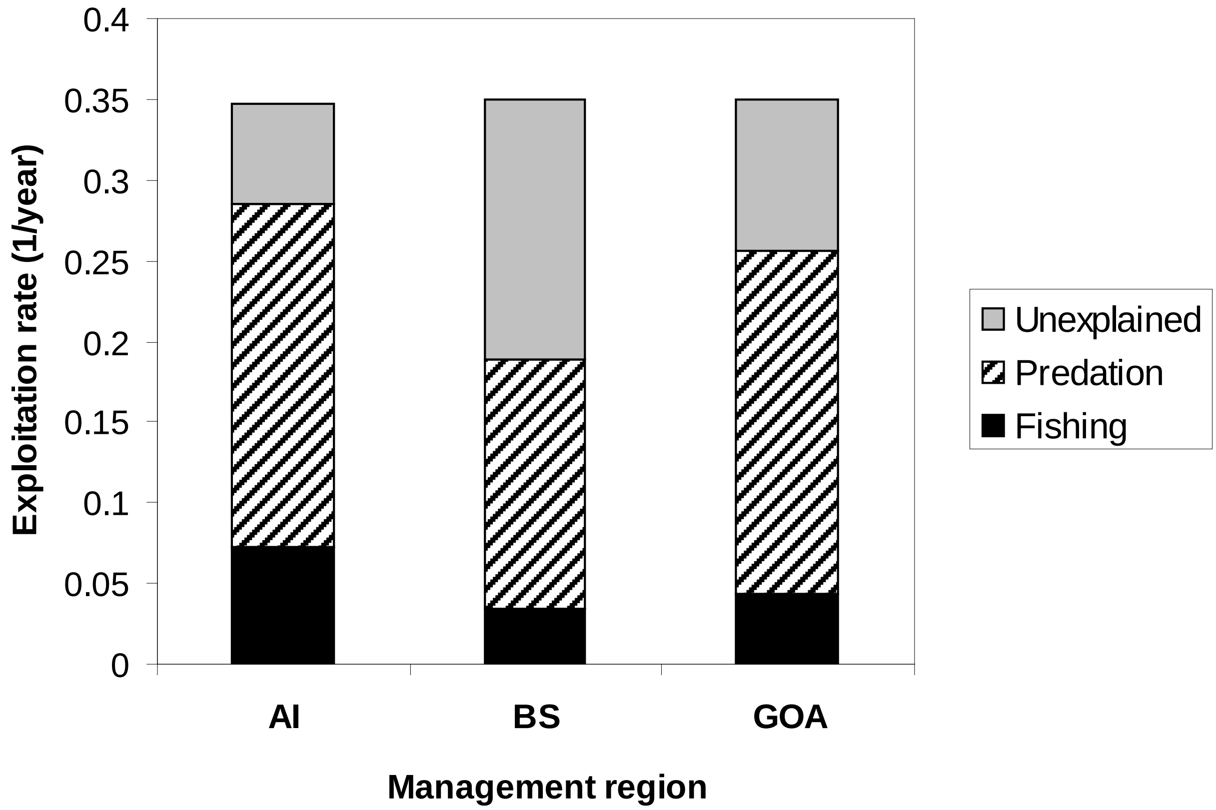


Figure 17.26. Total exploitation rate of age 1+ Atka mackerel, 1990-1994, proportioned into exploitation by fishing (black), predation (striped) and "unexplained" mortality (grey). "Unexplained" mortality is the difference between the stock assessment total exploitation rate averaged for 1990-1994, and 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 have been 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 1977-2015 in Table 17B-1. Recent removals from activities other than directed fishing totaled 140 t in 2010, 1,529 t in 2011, 62 t in 2012, <1 t in 2013, 111 t in 2014, and 58 t in 2015. This is approximately 0.2, 2.0, <0.1, <0.1, 0.2, and <0.1% of the 2011, 2012, 2013, 2014, and 2015 ABCs respectively, and 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 2017 and 2018 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

Appendix 17B

Atka mackerel (BSAI) Economic Performance Report for 2016

By
Ben Fissel

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] In 2015 Atka mackerel total catch increased to 54 thousand t bringing it back to roughly 2011 catch levels after significant reductions in the TAC in 2012 and 2013 when catch levels dropped to approximately 40% of the 2001-2010 average (Table 1). The lower catch 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. The result was a 17.4% growth in first-wholesale revenue to $74 million, despite a 25.4% decrease in the wholesale price.

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 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 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 US and Japan. Global production dropped from an average of 265 thousand t between 2001-2010 to 154 thousand tons in between 2011 and 2014 (Table 2). The reductions in international supply mean that the U.S. has captured a larger share of global production global production in recent years relative to the 2001-2010 average (Table 2). The global supply reductions have upward pressure on the price. 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 had the effect of actually increasing first-wholesale value (excluding 2013) above the 2001-2010 average despite the reduced production volume (Table 1). International production of Atka mackerel has been on the decline primarily because of reductions in Japanese catch and production which persisted through 2015. The U.S. exchange rate was a likely factor in the 2015 first-wholesale price decrease as the value of the Dollar increased 12.5% over the Yen between 2014 and 2015 and Japan constitutes roughly 70% of the export value (Table 2). Additionally, industry reports that the

[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.

price in 2014 may have overshot a level that the market can sustain and buyers may be anticipating future harvest increases.

Table 1. Atka mackerel catch and first-wholesale market data. Total and retained catch (thousand metric tons), number of vessel, first-wholesale production (thousand metric tons), value (million US$), price (US$ per pound), and head and gut share of production; 2001-2010 average and 2011-2015.

	2001-2010 Average	2011	2012	2013	2014	2015
Total catch K mt	62.0	53.4	49	24.5	32	54.5
Retained catch K mt	55.9	51.1	47.2	23.4	31.5	53.4
Vessels #	15	14	14	14	11	14
First-wholesale production K mt	32.92	32.74	30.17	14.57	20.88	32.87
First-wholesale value M US$	$42.89	$74.90	$74.80	$39.40	$63.30	$74.30
First-wholesale price/lb US$	$0.59	$1.04	$1.12	$1.23	$1.38	$1.03
H&G share of value	90%	93%	90%	87%	93%	95%

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

Table 2. Atka mackerel U.S. trade and global market data. Global production (thousand metric tons), U.S. share of global production, U.S. export volume (thousand metric tons), U.S. export value (million US$), U.S. export price (US$ per pound) and the share of U.S. export value from Japan; 2001-2010 average and 2011-2016.

	2001-2010 Average	2011	2012	2013	2014	2015	2016 (thru June)
Global production K mt	256.98	179.85	186.01	130.42	120.17	-	-
US share global production	22%	28%	25%	18%	26%	-	-
Export value M US$	$34.38	$29.88	$40.45	$34.75	$53.18	$84.10	$35.98
Export quantity K mt	22.235	21.85	20.1	12.73	19.53	30.13	13.05
Export price/lb US$	$0.69	$0.62	$0.91	$1.24	$1.24	$1.27	$1.25
Japan's share of export value	73%	56%	61%	62%	66%	73%	73%
Exchange rate, Yen/Dollar	110.00	79.81	79.79	97.60	105.94	121.04	107.32

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

Appendix 17C

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

General Definitions	Symbol/Value	Use in Catch at Age Model
Year index: i = {1977, …., 2016}	i	
Age index: j = {1, 2, 3, …, A}	j	
Mean weight by age j	W_j	
Maximum age beyond which selectivity is constant	*Maxage*	Selectivity parameterization
	σ_d^2	Dome-shape penalty variance term
Instantaneous Natural Mortality	M	Fixed M=0.30, constant over all ages
Proportion females mature at age j	p_j	Definition of spawning biomass
Sample size for proportion at age j in year i	T_i	Scales multinomial assumption about estimates of proportion at age
Survey catchability coefficient	q^s	Prior distribution = lognormal(1.0 , σ_q^2)
Stock-recruitment parameters	R_0	Unfished equilibrium recruitment
	h	Stock-recruitment steepness
	σ_R^2	Recruitment variance
Estimated parameters		
$\phi_i(37),\ R_0,\ \varepsilon_i(47), \sigma_R^2,\ \mu^f, \mu^s,\ M,\ \eta_j^s(10),\ \eta_j^f(10), F_{50\%}, F_{40\%}, F_{30\%}, q^s$		

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

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

Description	Symbol/Constraints	Key Equation(s)
Survey abundance index (s) by year	Y_i^s	$\hat{Y}_i^s = q_i^s \sum_{j=1}^{A} s_j^s W_{ij} e^{Z_{i,j}\frac{7}{12}} N_{ij}$
Catch-at-age by year	C_{ij}	$\hat{C}_{ij} = N_{ij} \frac{F_{ij}}{Z_{ij}}\left(1-e^{-Z_{ij}}\right)$
Catch biomass	$\hat{C}_i^B$	$\hat{C}_i^B = \sum_j W_{ij} \hat{C}_{ij}$
Initial numbers at age	$j = 1$	$N_{1977,1} = e^{\mu_R+\varepsilon_{1977}}$
	A $1 < j < A$	$N_{1977,j} = e^{\mu_R+\varepsilon_{1978-j}} \prod_{j=1}^{j} e^{-M}$
Maximum age	$j = A$	$N_{1977,A} = N_{1977,A-1}\left(1-e^{-M}\right)^{-1}$
Subsequent years ($i > 1977$)	$j = 1$	$N_{i,1} = e^{\mu_R+\varepsilon_i}$
	$1 < j < A$	$N_{i,j} = N_{i-1,j-1} e^{-Z_{i-1,j-1}}$
	$j = A$	$N_{i,15^+} = N_{i-1,14}\, e^{-Z_{i-1,14}} + N_{i-1,15}\, e^{-Z_{i-1,15}}$
Year effect, i = 1967, …, 2016	$\varepsilon_i, \sum_{i=1967}^{2015} \varepsilon_i = 0$	$N_{i,1} = e^{\mu_R+\varepsilon_i}$
Index catchability Mean effect	μ^s, μ^f	$q_i^s = e^{\mu^s}$
Age effect	$\eta_j^s, \sum_{j=1}^{A} \eta_j^s = 0$	$s_j^s = e^{\eta_j^s}$ $\quad j \le \text{maxage}$ $s_j^s = e^{\eta_{\text{maxage}}^s}$ $\quad j > \text{maxage}$
Instantaneous fishing mortality		$F_{ij} = e^{\mu_f+\eta_j^f+\phi_i}$
mean fishing effect	μ_f	
Annual effect of fishing in year i	$\phi_i, \sum_{i=1977}^{2015} \phi_i = 0$	
Age effect of fishing (regularized) in year time variation allowed	$\eta_{ij}^f, \sum_{j=1}^{A} \eta_{ij} = 0$	$s_{ij}^f = e^{\eta_j^f}$, $j \le \text{maxage}$ $s_{ij}^f = e^{\eta_{\text{maxage}}^f}$ $\quad j > \text{maxage}$
In years where selectivity is constant over time	$\eta_{i,j}^f = \eta_{i-1,j}^f$	$i \ne \text{change year}$
Natural Mortality Total mortality	M	$Z_{ij} = F_{ij} + M$
Recruitment Beverton-Holt form	$\tilde{R}_i$	$\tilde{R}_i = \frac{\alpha B_i}{\beta + B_i}$, $\alpha = \frac{4hR_0}{5h-1}$ and $\beta = \frac{B_0(1-h)}{5h-1}$ where $B_0 = \tilde{R}_0 \varphi$ $\varphi = \frac{e^{-AM} W_A p_A}{1-e^{-M}} + \sum_{j=1}^{A} e^{-M(j-1)} W_j p_j$

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

Likelihood /penalty component		Description / notes
Abundance indices	$L_1 = \lambda_1 \sum_i \ln\left(Y_i^s \big/ \hat{Y}_i^s \right)^2 \frac{1}{2\sigma_i^2}$	Survey abundance
Prior on smoothness for selectivities	$L_2 = \sum_l \lambda_2^l \sum_{j=1}^{A} \left(\eta_{j+2}^l + \eta_j^l - 2\eta_{j+1}^l \right)^2$	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	$L_4 = \lambda_4 \sum_{i=1967}^{2015} \varepsilon_i^2 +$ $0.5 \sum_{t=1977}^{2015} \left(\ln R_t - \ln \hat{R}_t \right) / \sigma_R^2$	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	$L_5 = \lambda_5 \sum_{i=1977}^{2015} \ln\left(C_i^B \big/ \hat{C}_i^B \right)^2$	Fit to survey
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	$L_{.} = \lambda_6 \sum_{i=1978}^{2015} \phi_i^2$	(relaxed in final phases of estimation)
Priors	$L_7 = \left[\lambda_7 \frac{\ln\left(M \big/ \hat{M} \right)^2}{2\sigma_M^2} + \lambda_8 \frac{\ln\left(q / \hat{q} \right)^2}{2\sigma_q^2} \right]$	Prior on natural mortality, and survey catchability (reference case assumption that *M is* precisely known at 0.3).
Overall objective function to be minimized	$\dot{L} = \sum_{i=1}^{7} L_i$	

Appendix 17D Model 16.0 results

Projections

Results discussed below are for Model 16.0 with updated 2016 fishery and survey catch- and weight-at-age values. Results for Model 16.0 are given in Tables 17D-1 to 17D-6 and Figure 17D-1.

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 1978-2016 (617 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 16.0 results based on recruitment from post-1976 spawning events:

$B_{100\%}$ = 297,954 t female spawning biomass

$B_{40\%}$ = 115,182 t female spawning biomass

$B_{35\%}$ = 100,784 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 (2012-2016) to reflect recent conditions for projections and computing ABC which gives:

Full selection Fs	2017
F_{2017}	0.28
$F_{40\%}$	0.39
$F_{35\%}$	0.47
$F_{2017}/F_{40\%}$	0.72

For specification purposes to project the 2018 ABC, we assumed a total 2017 year end catch of 64,500 t nearly equal to the 2017 TAC, based on the amount of catch taken after Oct. 1 in recent years. For projecting to 2019, an expected catch in 2018 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 2017. 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. We estimated that about 75% of the BSAI-wide ABC is likely to be taken. This percentage was applied to the maximum permissible 2018 ABC and that amount was assumed to be caught in order to estimate the 2019 ABC and OFL values.

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 2018 female spawning biomass (SSB_{2018}) is estimated to be 126,700 t given assumed 2017 catch and a slightly reduced 2018 catch reflecting the RPA adjustment to the 2018 ABC.

The projected 2018 female spawning biomass estimate is above the $B_{40\%}$ value of 115,180 t, placing BSAI Atka mackerel in **Tier 3a**. The 2019 female spawning biomass estimate is also above $B_{40\%}$. The maximum permissible ABC and OFL values under **Tier 3a** are:

Year	Catch*	ABC	F_{ABC}	OFL	F_{OFL}	SSB	Tier
2018	69,000	82,100	0.39	96,500	0.47	126,700	3a
2019	65,000	75,000	0.39	86,200	0.47	113,800	3a

* Catches in 2018 and 2019 are less than the recommended ABC 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 2017 or 2018 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2030 using a fixed value of natural mortality of 0.3, the recent schedule of selectivity estimated in the assessment (in this case the average 2012-2016 selectivity), and the best available estimate of total (year-end) catch for 2017 (in this case assumed to be 64,500 t nearly equal to TAC). In addition, the 2018 and 2019 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 2018 and 2019, 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 2018 recommended in the assessment to the *max* F_{ABC} for 2018, and where catches for 2018 and 2019 are estimated at their most likely values given the 2018 and 2019 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, F 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 2019 or 2) above ½ of its MSY level in 2019 and above its MSY level in 2029 under this scenario, then the stock is not overfished.)

Scenario 7: In 2018 and 2019, 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 2019 or 2) above 1/2 of its MSY level in 2019 and expected to be above its MSY level in 2029 under this scenario, then the stock is not approaching an overfished condition.)

Status Determination

The projections of female spawning biomass, fishing mortality rate, and catch corresponding to the seven standard harvest scenarios are shown in Table 17.16. 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 2029 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

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

a) If the mean spawning biomass for 2019 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

b) If the mean spawning biomass for 2019 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c) If the mean spawning biomass for 2019 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2029. If the mean spawning biomass for 2029 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 17D-6, the BSAI Atka mackerel stock is not overfished and is not approaching an overfished condition.

The apportionments of the 2018 and 2019 maximum permissible ABCs that would result from Model 16.0 and based on the random effects model are:

	Rand. Effects model	2018 (t)	2019 (t)
Eastern (541+S.Bsea)	**40.02%**	32,860	30,020
Central (542)	**34.78%**	28,550	26,080
Western (543)	**25.20%**	20,690	18,900
Total		82,100	75,000

Table 17D-1. Estimates of Model 16.0 Atka mackerel fishery (over time, 1977-2016) and survey selectivity at age (normalized to have a maximum of 1.0). The average selectivity over 2012-2016 listed below, is used for projections and computation of ABC.

	Age										
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11+**
1977	0.010	0.096	0.568	1.000	0.751	0.315	0.140	0.073	0.044	0.033	0.033
1978	0.009	0.117	0.969	1.000	0.906	0.495	0.227	0.111	0.063	0.045	0.045
1979	0.005	0.033	0.272	1.000	0.848	0.443	0.215	0.103	0.055	0.037	0.037
1980	0.005	0.038	0.260	0.832	1.000	0.623	0.397	0.186	0.082	0.048	0.048
1981	0.004	0.030	0.200	0.386	0.395	0.600	1.000	0.283	0.086	0.044	0.044
1982	0.004	0.021	0.093	0.335	1.000	0.906	0.458	0.196	0.089	0.053	0.053
1983	0.004	0.023	0.133	0.333	0.639	1.000	0.621	0.235	0.105	0.064	0.064
1984	0.004	0.025	0.124	0.387	0.690	1.000	0.925	0.428	0.188	0.103	0.103
1985	0.006	0.055	0.484	0.786	0.864	0.961	1.000	0.826	0.434	0.231	0.231
1986	0.005	0.043	0.314	0.489	0.562	0.656	0.848	1.000	0.767	0.366	0.366
1987	0.008	0.068	0.483	0.823	0.825	0.763	0.858	1.000	0.970	0.871	0.871
1988	0.004	0.040	0.360	1.000	0.628	0.404	0.365	0.337	0.306	0.247	0.247
1989	0.007	0.062	0.377	0.969	1.000	0.698	0.494	0.386	0.325	0.289	0.289
1990	0.006	0.052	0.453	1.000	0.794	0.492	0.355	0.277	0.235	0.208	0.208
1991	0.008	0.048	0.234	0.714	1.000	0.920	0.685	0.485	0.375	0.327	0.327
1992	0.009	0.046	0.203	0.640	1.000	0.989	0.820	0.643	0.521	0.459	0.459
1993	0.008	0.037	0.160	0.443	0.784	1.000	0.901	0.747	0.617	0.543	0.543
1994	0.006	0.029	0.146	0.420	0.821	1.000	0.947	0.922	0.772	0.603	0.603
1995	0.005	0.028	0.144	0.487	0.713	0.887	1.000	0.979	0.886	0.760	0.760
1996	0.004	0.021	0.103	0.363	0.592	0.799	0.966	1.000	0.805	0.671	0.671
1997	0.004	0.023	0.123	0.389	0.761	0.890	0.984	1.000	0.933	0.861	0.861
1998	0.003	0.020	0.109	0.428	0.728	0.834	0.963	1.000	0.936	0.837	0.837
1999	0.002	0.018	0.125	0.566	0.667	0.739	0.831	1.000	0.851	0.659	0.659
2000	0.001	0.015	0.199	0.508	0.693	0.762	0.839	1.000	0.708	0.488	0.488
2001	0.001	0.013	0.157	0.505	0.768	0.901	1.000	0.899	0.625	0.419	0.419
2002	0.001	0.014	0.107	0.375	0.590	0.774	1.000	0.789	0.516	0.358	0.358
2003	0.002	0.017	0.177	0.436	0.631	0.826	1.000	0.922	0.528	0.349	0.349
2004	0.004	0.037	0.282	0.744	0.953	0.961	1.000	0.931	0.642	0.407	0.407
2005	0.006	0.053	0.298	0.765	1.000	0.996	0.991	0.701	0.461	0.332	0.332
2006	0.007	0.092	0.657	0.716	0.939	1.000	0.990	0.631	0.421	0.312	0.312
2007	0.005	0.078	0.581	0.787	0.688	0.785	1.000	0.755	0.451	0.292	0.292
2008	0.005	0.060	0.462	0.701	0.695	0.840	1.000	0.917	0.748	0.351	0.351
2009	0.005	0.041	0.279	0.616	0.804	0.820	1.000	0.881	0.651	0.429	0.429
2010	0.004	0.038	0.218	0.673	0.888	1.000	0.960	0.859	0.686	0.369	0.369
2011	0.004	0.028	0.162	0.444	0.776	1.000	0.904	0.763	0.818	0.687	0.687
2012	0.003	0.026	0.167	0.344	0.652	0.933	1.000	0.879	0.926	0.969	0.969
2013	0.003	0.039	0.342	0.842	0.744	0.887	1.000	0.846	0.715	0.663	0.663
2014	0.002	0.039	1.000	0.512	0.749	0.756	0.608	0.577	0.513	0.444	0.444
2015	0.001	0.016	0.181	0.359	0.532	0.697	0.886	1.000	0.674	0.296	0.296
2016	0.001	0.011	0.118	0.436	0.393	0.601	0.803	1.000	0.896	0.267	0.267
2017	0.001	0.011	0.118	0.436	0.393	0.601	0.803	1.000	0.896	0.267	0.267
Ave. 2012-2016	0.002	0.026	0.361	0.499	0.614	0.775	0.859	0.860	0.745	0.528	0.528
Survey	0.010	0.127	0.552	0.733	0.666	0.708	0.923	1.000	0.807	0.680	0.680

Table 17D-2. Estimated Model 16.0 BSAI Atka mackerel begin-year numbers at age in millions, 1977-2017.

	Age										
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11+**
1977	320	426	296	124	109	69	60	48	37	28	97
1978	1520	236	309	196	75	69	48	43	35	27	93
1979	460	1124	172	195	123	48	47	34	31	26	88
1980	340	341	829	122	125	80	33	34	25	23	84
1981	421	251	251	597	83	83	56	24	25	18	79
1982	301	312	186	182	424	59	58	37	17	18	72
1983	396	223	230	137	132	293	41	41	27	12	66
1984	463	293	165	170	100	95	208	30	30	20	58
1985	550	343	216	120	120	68	62	138	21	22	57
1986	462	407	252	152	81	80	45	41	93	15	57
1987	617	342	300	179	105	56	54	30	27	62	51
1988	439	457	252	215	125	73	39	38	20	18	78
1989	1275	325	337	180	143	87	52	28	27	15	70
1990	606	944	240	244	126	100	62	38	20	20	61
1991	353	449	697	173	171	89	72	45	27	15	59
1992	524	261	331	506	121	116	61	50	32	20	53
1993	883	388	192	240	350	80	77	41	35	22	52
1994	375	653	286	139	165	227	50	49	27	23	50
1995	370	277	481	206	95	104	139	31	30	17	48
1996	901	274	204	342	132	57	59	76	17	17	39
1997	210	666	201	144	213	74	29	28	35	9	30
1998	328	155	491	144	97	131	44	17	16	21	23
1999	903	243	114	352	94	57	75	24	9	9	25
2000	1952	668	179	82	229	60	36	46	14	6	22
2001	1201	1446	494	127	55	146	37	22	27	9	18
2002	1359	889	1067	350	82	33	84	21	13	17	18
2003	301	1006	657	770	237	52	20	49	13	8	24
2004	386	223	743	471	526	156	33	12	30	9	22
2005	527	286	165	534	321	351	104	22	8	21	22
2006	360	390	211	118	364	213	233	69	15	6	31
2007	969	266	286	144	80	241	140	153	47	11	26
2008	809	717	195	196	96	54	161	91	103	33	26
2009	242	599	526	134	130	64	35	102	58	68	41
2010	474	179	439	364	85	79	38	20	60	37	72
2011	321	351	131	309	231	51	46	23	12	38	74
2012	473	238	259	95	214	151	33	30	15	8	75
2013	674	350	175	186	66	142	96	20	19	9	52
2014	494	500	259	127	130	47	99	66	14	13	43
2015	389	366	369	175	90	90	32	69	46	10	40
2016	433	288	270	260	117	57	55	19	39	29	34
2017	462	321	213	193	169	77	35	32	10	22	43
Average	493	348	266	169	123	97	63	41	27	14	49

Table 17D-3a. Estimates of Model 16.0 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 1977-2018).

	Age 1+ biomass (t)			Female spawning biomass (t)		
Year	Estimate	LCI	UCI	Estimate	LCI	UCI
1977	629,210	373,870	884,550	173,690	97,518	233,122
1978	649,710	378,770	920,650	166,190	88,828	216,337
1979	696,660	399,500	993,820	163,210	82,754	205,736
1980	784,090	449,530	1,118,650	176,580	90,566	224,139
1981	757,060	433,300	1,080,820	213,580	113,932	277,688
1982	733,200	419,260	1,047,140	231,700	124,072	301,958
1983	682,140	391,080	973,200	218,470	118,082	286,358
1984	647,420	377,260	917,580	199,160	106,754	259,711
1985	621,390	361,250	881,530	179,610	93,546	230,124
1986	600,740	350,800	850,680	162,950	83,172	206,233
1987	599,460	358,200	840,720	158,340	82,484	202,896
1988	615,270	379,910	850,630	164,250	88,964	215,571
1989	663,940	432,300	895,580	170,670	97,250	231,210
1990	738,710	509,230	968,190	180,600	109,282	254,223
1991	825,680	590,780	1,060,580	197,580	127,260	289,680
1992	809,030	585,530	1,032,530	222,840	150,812	337,638
1993	790,370	574,850	1,005,890	225,640	153,020	342,350
1994	759,680	550,160	969,200	198,970	131,286	296,414
1995	722,840	516,820	928,860	175,340	110,928	254,062
1996	651,330	451,250	851,410	156,290	91,686	215,674
1997	585,320	387,006	783,634	140,830	78,396	188,009
1998	571,640	375,384	767,896	131,100	71,178	172,317
1999	529,970	339,370	720,570	136,150	75,180	180,845
2000	616,410	404,470	828,350	131,730	71,578	173,232
2001	801,640	546,580	1,056,700	126,270	67,448	164,307
2002	1,020,900	713,980	1,327,820	167,100	98,266	230,949
2003	1,131,800	802,240	1,461,360	245,550	156,424	357,411
2004	1,143,500	811,180	1,475,820	304,500	200,718	453,327
2005	1,021,000	715,800	1,326,200	317,940	211,154	475,701
2006	914,100	630,740	1,197,460	290,130	188,810	428,280
2007	825,120	561,080	1,089,160	246,590	156,040	357,355
2008	791,210	536,830	1,045,590	211,780	130,148	301,112
2009	789,430	534,070	1,044,790	186,980	110,766	259,639
2010	726,350	479,230	973,470	184,020	107,436	253,164
2011	643,590	411,290	875,890	186,650	108,730	256,420
2012	607,250	383,830	830,670	172,280	97,810	232,855
2013	568,350	353,070	783,630	159,800	90,940	216,310
2014	596,530	374,670	818,390	157,110	91,100	215,205
2015	614,790	383,450	846,130	150,030	84,112	201,183
2016	579,000	346,140	811,860	147,190	77,874	190,406
2017	550,420	316,260	784,580	141,715	70,204	176,821
2018	527,650	287,890	767,410	126,689	60,432	156,943

Table 17D-3b. Estimates of Atka mackerel age 3+ biomass and female spawning biomass in metric tons from the current recommended assessment model, Model 16.0b (1977-2018) compared to last year's (2016) assessment results.

	Age 3+ biomass (t)		Female spawning biomass (t)	
Year	Current	2016	Current	2016
1977	542,270	600,325	173,690	194,135
1978	541,230	604,684	166,190	187,696
1979	484,290	545,585	163,210	184,824
1980	710,780	783,585	176,580	198,180
1981	695,300	794,704	213,580	245,803
1982	666,550	738,223	231,700	257,912
1983	626,370	693,872	218,470	243,375
1984	576,660	653,539	199,160	227,795
1985	538,280	606,376	179,610	204,616
1986	510,550	573,316	162,950	185,122
1987	513,510	575,154	158,340	180,099
1988	517,710	578,463	164,250	186,380
1989	551,260	606,970	170,670	191,005
1990	550,440	609,609	180,600	201,256
1991	733,280	785,368	197,580	216,924
1992	740,980	804,875	222,840	245,262
1993	684,570	733,085	225,640	242,320
1994	631,400	671,131	198,970	213,464
1995	658,920	698,388	175,340	190,682
1996	564,240	607,462	156,290	169,352
1997	462,290	489,281	140,830	149,411
1998	530,450	566,426	131,100	141,020
1999	448,040	497,421	136,150	151,702
2000	414,840	447,096	131,730	143,116
2001	501,220	543,336	126,270	138,829
2002	808,250	882,832	167,100	187,098
2003	946,640	1,050,846	245,550	275,350
2004	1,088,100	1,190,008	304,500	333,747
2005	948,580	1,057,734	317,940	354,805
2006	831,450	928,604	290,130	326,248
2007	736,240	833,231	246,590	282,022
2008	632,540	725,049	211,780	245,929
2009	676,470	745,900	186,980	214,408
2010	674,580	730,883	184,020	208,870
2011	569,320	612,418	186,650	204,269
2012	545,460	574,538	172,280	182,981
2013	478,330	515,011	159,800	172,271
2014	489,190	539,387	157,110	170,225
2015	535,000	553,053	150,030	162,615
2016	510,470	510,847	147,190	154,396
2017	474,990	487,620	141,715	145,258
2018	448,510		126,689	

Table 17D-4. Estimates of Model 16.0 age-1 Atka mackerel recruitment (millions of recruits) and standard deviation (Std. dev.). Estimates of age-1 recruitment from last year's assessment (2016) are shown for comparison.

	Age 1 recruitment		
Year	Current	Std. dev	2016 assessment
1977	320	86	340
1978	1520	341	1,623
1979	460	116	489
1980	340	92	359
1981	421	112	445
1982	301	83	318
1983	396	101	421
1984	463	112	491
1985	550	129	574
1986	462	116	473
1987	617	139	635
1988	439	103	463
1989	1275	209	1,282
1990	606	126	610
1991	353	84	374
1992	524	106	525
1993	883	150	860
1994	375	81	398
1995	370	76	380
1996	901	142	948
1997	210	48	220
1998	328	68	341
1999	903	156	952
2000	1952	281	2,048
2001	1201	177	1,273
2002	1359	190	1,467
2003	301	58	321
2004	386	69	419
2005	527	88	563
2006	360	64	376
2007	969	144	959
2008	809	127	750
2009	242	49	238
2010	474	89	486
2011	321	69	338
2012	473	99	558
2013	674	150	541
2014	494	131	423
2015	389	114	467
2016	433	173	484
2017	462	190	
Average 78-16	617		638
Median 78-16	463		486

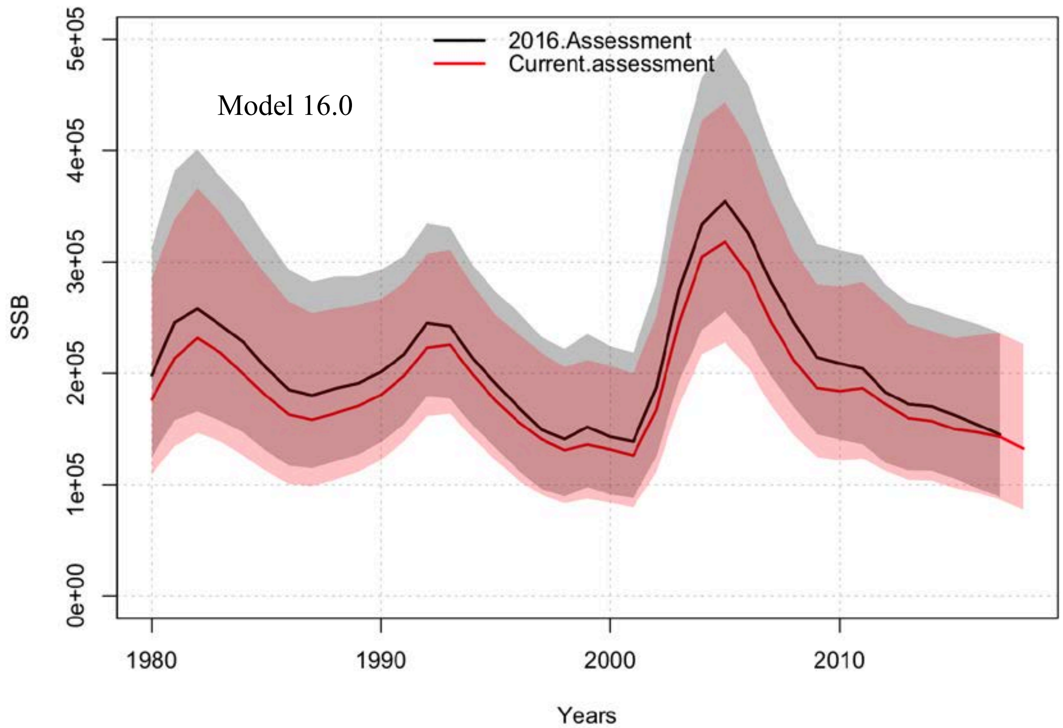
Table 17D-5. Estimates of Model 16.0 full-selection fishing mortality rates and exploitation rates (Catch/Biomass) for BSAI Atka mackerel.

Year	*F*	Catch/Biomass Rate[a]
1977	0.198	0.040
1978	0.168	0.045
1979	0.146	0.048
1980	0.106	0.029
1981	0.109	0.028
1982	0.069	0.030
1983	0.043	0.019
1984	0.124	0.063
1985	0.117	0.070
1986	0.135	0.063
1987	0.071	0.059
1988	0.106	0.043
1989	0.056	0.033
1990	0.059	0.040
1991	0.086	0.036
1992	0.108	0.065
1993	0.169	0.096
1994	0.193	0.104
1995	0.297	0.124
1996	0.473	0.184
1997	0.248	0.142
1998	0.304	0.108
1999	0.230	0.126
2000	0.216	0.114
2001	0.280	0.123
2002	0.244	0.056
2003	0.186	0.057
2004	0.111	0.056
2005	0.109	0.065
2006	0.121	0.074
2007	0.133	0.080
2008	0.159	0.092
2009	0.252	0.108
2010	0.231	0.102
2011	0.155	0.091
2012	0.172	0.088
2013	0.070	0.048
2014	0.092	0.063
2015	0.273	0.100
2016	0.303	0.107
2017	0.334	0.136

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

Table 17D-6. Projections of Model 16.0 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 287,950, 115,180, and 100,780 t, respectively.

Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2017	64,500	64,500	64,500	64,500	64,500	64,500	64,500
2018	69,000	69,000	69,000	69,000	69,000	96,471	82,139
2019	65,000	65,000	65,000	65,000	65,000	75,157	70,208
2020	74,448	74,448	36,099	21,976	0	73,008	79,578
2021	75,576	75,576	40,291	25,300	0	78,740	81,359
2022	78,064	78,064	43,713	28,057	0	83,419	84,317
2023	81,190	81,190	47,000	30,686	0	87,254	87,512
2024	83,838	83,838	49,846	32,985	0	90,026	90,063
2025	84,353	84,353	51,350	34,347	0	90,168	90,157
2026	84,091	84,091	51,993	35,015	0	89,559	89,559
2027	83,873	83,873	52,197	35,278	0	89,132	89,140
2028	83,382	83,382	52,209	35,386	0	88,622	88,627
2029	83,841	83,841	52,516	35,635	0	89,262	89,265
2030	84,050	84,050	52,691	35,784	0	89,546	89,547
Fishing M.	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2017	0.279	0.279	0.279	0.279	0.279	0.279	0.279
2018	0.323	0.323	0.323	0.323	0.323	0.472	0.392
2019	0.324	0.324	0.324	0.324	0.324	0.413	0.366
2020	0.366	0.366	0.168	0.101	0.000	0.393	0.412
2021	0.360	0.360	0.168	0.101	0.000	0.401	0.409
2022	0.363	0.363	0.168	0.101	0.000	0.412	0.414
2023	0.366	0.366	0.168	0.101	0.000	0.419	0.420
2024	0.368	0.368	0.168	0.101	0.000	0.422	0.422
2025	0.369	0.369	0.168	0.101	0.000	0.422	0.422
2026	0.368	0.368	0.168	0.101	0.000	0.421	0.421
2027	0.368	0.368	0.168	0.101	0.000	0.420	0.421
2028	0.368	0.368	0.168	0.101	0.000	0.420	0.420
2029	0.368	0.368	0.168	0.101	0.000	0.420	0.420
2030	0.367	0.367	0.168	0.101	0.000	0.420	0.420
Spawning biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2017	141,715	141,715	141,715	141,715	141,715	141,715	141,715
2018	126,689	126,689	126,689	126,689	126,689	119,780	123,409
2019	113,841	113,841	113,841	113,841	113,841	101,537	107,853
2020	108,515	108,515	116,896	119,934	124,594	96,969	101,572
2021	110,246	110,246	131,192	139,456	152,815	100,484	102,574
2022	114,582	114,582	146,367	159,707	182,259	105,135	105,964
2023	117,523	117,523	157,943	175,748	207,056	107,671	108,002
2024	119,416	119,416	166,572	188,199	227,612	109,057	109,202
2025	120,343	120,343	172,630	197,437	244,089	109,573	109,650
2026	120,033	120,033	175,801	203,029	255,594	109,062	109,113
2027	119,401	119,401	177,324	206,263	263,297	108,432	108,464
2028	119,068	119,068	178,545	208,824	269,511	108,134	108,151
2029	119,117	119,117	179,564	210,791	274,214	108,211	108,220
2030	119,716	119,716	180,889	212,816	278,307	108,776	108,781



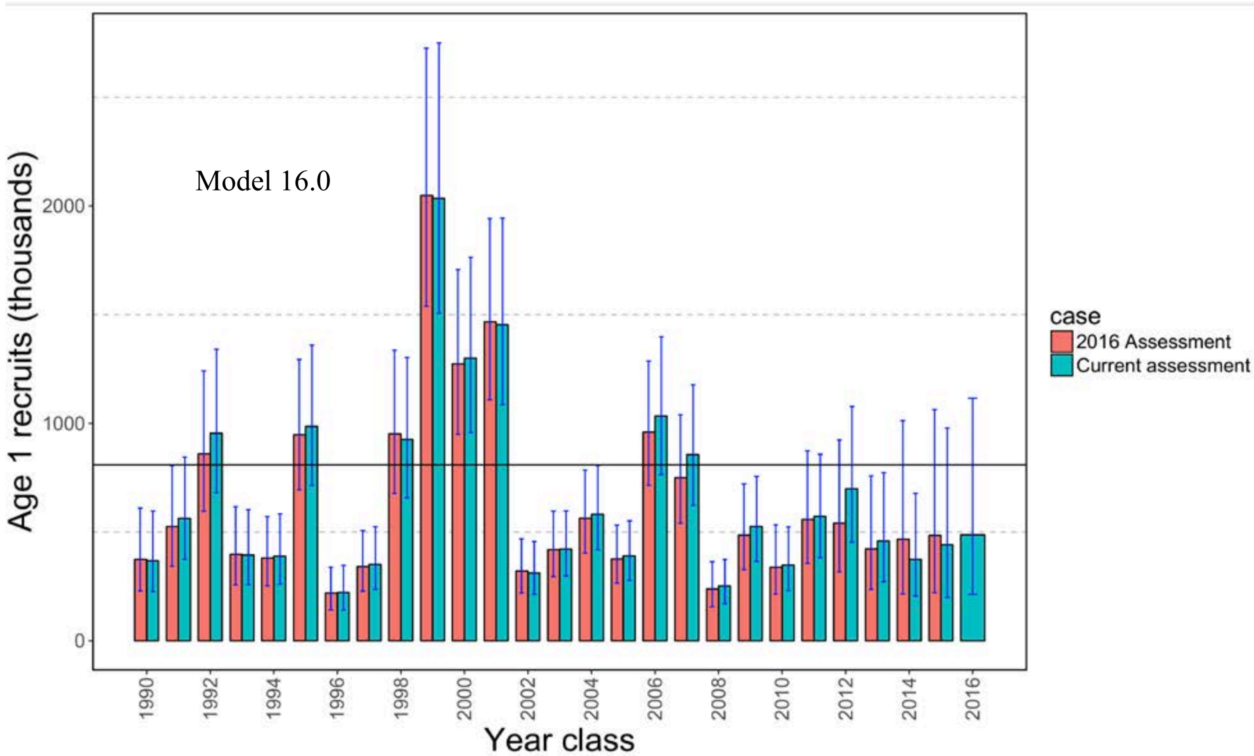


Figure 17D-1 Time series of the this year's Model 16.0 estimated Aleutian Islands Atka mackerel spawning biomass (in t, top) and recruitment at age 1 (bottom) with approximate 95% confidence bounds, compared to last year's Model 16.0 estimates (2016 assessment). The only change in these figures are the new data available in 2017.