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

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Executive Summary

Relative to the November 2012 SAFE report, the following substantive changes have been made in the assessment of Atka mackerel.

Summary of Changes in Assessment Inputs

1. Fishery catch data were updated.
2. The 2012 fishery age composition data were added.
3. The 2012 Aleutian Islands survey age data were included.
4. The estimated average selectivity for 2009-2013 was used for projections.
5. We assume that 64% of the BSAI-wide ABC is likely to be taken under the implemented Steller Sea Lion Reasonable and Prudent Alternatives (SSL RPAs). This percentage was applied to the 2014 maximum permissible ABC, and that amount was assumed to be caught in order to estimate the 2015 ABCs and OFL values.

Summary of Changes in the Assessment Methodology

1. In the current assessment we estimate the degree of inter-annual selectivity variability and provide a method for estimating the degree of penalty. This method follows Annex 2.1.1 of the 2012 BSAI Pacific cod assessment (p. 442-445).

Summary of Results

1. The addition of the 2012 fishery and survey age compositions in conjunction with model configuration changes impacted the estimated magnitude of the 1999-2001 year classes which increased 14-20%, and the magnitude of the 2007 year class which increased 9%, relative to last year's assessment.
2. Average recruitment (1978-2012) from the stochastic projections is 609 million recruits (5% higher than last year's mean estimate (1978-2011).
3. Estimated values of $B_{100\%}$, $B_{40\%}$, $B_{35\%}$ are about 4% higher relative to last year's assessment.
4. Projected 2014 female spawning biomass (117,171 t) is up 12% relative to last year's estimate of 2013 female spawning biomass,.
5. Projected 2014 female spawning biomass is just above $B_{40\%}$, thereby placing BSAI Atka mackerel in Tier 3a. Last year projected 2013 female spawning biomass was below $B_{40\%}$ ($B_{37\%}$) and BSAI Atka mackerel were placed in Tier 3b.
6. The projected age 3+ biomass at the beginning of 2014 is estimated at 387,308 t, up about 25% from last year's estimate for 2013.
7. The average 2009-2013 fishery selectivity-at-age vector used for projection differs (lower selectivity for ages 3-5 and ages 7-9 and higher selectivity after age 9) from the fishery selectivity pattern estimated with last year's model configuration.
8. The addition of the 2012 fishery and survey age composition data, changes in selectivity, and moving from Tier 3b to Tier 3a resulted in a 23-24% increase in $maxF_{ABC}$, F_{ABC}, and F_{OFL} (adjusted $F_{40\%}$ and adjusted F_{OFL} [Tier 3b] to $F_{40\%}$ and F_{OFL} [Tier 3a]).
9. The projected 2014 yield at $F_{ABC} = F_{40\%} = 0.421$ is 64,100 t, which is 22% higher relative to last year's estimate for 2013.

10. The projected 2014 overfishing level at $F_{35\%}$ ($F = 0.514$) is 74,500 t, which is 23% higher than last year's estimate for 2013.

Quantity	As estimated or *specified last* year for: 2013	2014	As estimated or *recommended this* year for: 2014	2015
M (natural mortality rate)	0.30	0.30	0.30	0.30
Tier	3b	3b	3a	3b
Projected total (age 3+) biomass (t)	288,936		384,364	387,308
Female spawning biomass (t)				
Projected				
Upper 95% confidence interval	170,922	167,544	206,545	203,619
Point estimate	103,034	100,998	117,171	115,640
Lower 95% confidence interval	62,111	60,883	66,471	65,674
$B_{100\%}$	278,462	278,462	291,028	291,028
$B_{40\%}$	111,385	111,385	116,411	116,411
$B_{35\%}$	97,462	97,462	101,860	101,860
F_{OFL}	0.388	0.332	0.514	0.514
$maxF_{ABC}$	0.322	0.288	0.421	0.421
F_{ABC}	0.322	0. 288	0.421	0.421
OFL (t)	57,700	56,500[1]	74,492	74,898[1]
maxABC (t)	50,000	48,900[1]	64,131	64,477[1]
ABC (t)	50,000	48,900[1]	64,131	64,477[1]
Status	As determined *last* year for: 2011	2012	As determined *this* year for: 2012	2013
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

[1] These values were calculated assuming reduced catch levels under SSL RPAs.

Area apportionment of ABC

The apportionments of the 2014 and 2015 recommended ABCs based on the most recent 4-survey weighted average are:

	2014 (t)	2015 (t)
Eastern (541+S.BSea)	21,652	21,769
Central (542)	20,574	20,685
Western (543)	21,905	22,023
Total	64,131	64,477

Responses to SSC and Plan Team Comments on Assessments in General

Responses to the SSC comments on assessments in general, will be deferred to 2014.

From the December 2012 SSC minutes: The SSC recommends that the authors consider whether it is possible to estimate M with at least two significant digits in all future stock assessments to increase validity of the estimated OFL. The SSC encourages assessment authors of stocks managed in Tier 5 to consider the recommendations found in the draft survey averaging workgroup report.

From the September 2013 Joint Plan Team minutes:
<u>Accounting for total catch removals</u>: The Teams recommended that SAFE chapter authors continue to include "other" removals as an appendix. Optionally, authors could also calculate the impact of these removals on reference points and specifications, but are not required to include such calculations in final recommendations for OFL and ABC

> For 2013 only, revised guidelines for SAFE reports require each stock assessment to report removals from sources other than those that are included in the Alaska Region's official estimate, in tables that will be posted on the ftp site. A table of "other" removals of Atka mackerel will be reported on the designated site.

<u>Retrospective analyses</u>: In conformity with the main recommendations of the Retrospective Working Group, the Team recommended the following:

1. *Assessment authors should routinely do retrospective analyses extending back 10 years, plot spawning biomass estimates and error bars, plot relative differences, and report Mohn's rho (revised).*
2. *If a model exhibits a retrospective pattern, try to investigate possible causes.*
3. *Communicate the uncertainty implied by retrospective variability in biomass estimates.*
4. *For the time being, do not disqualify a model on the grounds of poor retrospective performance alone.*
5. *Do consider retrospective performance as one factor in model selection.*

> For 2013, within-model retrospective analyses are *not* required. Given the abbreviated stock assessments with limited model configurations presented, it is not useful to conduct an in-depth retrospective analysis. The current assessment presents provisional retrospective plots for Model 1 and Model 2 (recommended model). The 2014 assessment will include a more comprehensive retrospective analysis.

<u>Total Current Year Removals</u>: The Teams recommended that each stock assessment model incorporate the best possible estimate of the current year's removals.

> The Atka mackerel assessment assumes the 2013 TAC of 25,920 t as the best estimate of the expected current year's removal.

<u>Responses to SSC and Plan Team Comments Specific to the Atka Mackerel Assessment</u>
Responses to these comments will be deferred to 2014, and discussed at the upcoming 2014 CIE review for BSAI Atka mackerel.

From the December 2012 SSC minutes: SSC recommends that the authors:
i) estimate M and q directly in the model and report the correlation between these two estimates from the variance-covariance matrix of the final model, or
ii) conduct a sensitivity analysis between various input Ms around 0.20-0.40 and estimated q's.

From the September 2013 BSAI Plan Team minutes: The Team recommended that the authors include the base model approach (with a subjective constraint on the degree of dome shape) and the authors' proposed (more objective) approach to specifying the penalty terms for time- and age-varying selectivity.

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, north along the eastern Bering Sea shelf, and through the Gulf of Alaska 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 Gulf of Alaska. 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).

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° to 169 days at 1.6 °C, however, an incubation water temperature of 15°C was lethal to developing embryos (Guthridge and Hillgruber 2008). In the eastern and central Aleutian Islands, 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 eastern Bering Sea (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 time period 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 Aleutian Islands 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 Aleutian Islands are inside fishery trawl exclusion zones which may serve as *de facto* marine reserves for protecting Atka mackerel (Cooper and McDermott 2008).

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. 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), 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.

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 Gulf of Alaska and the Aleutian Islands (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, Aleutian Islands and Gulf of Alaska. 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 Gulf of Alaska with samples from the eastern, central, and western Aleutian Islands 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 Aleutian Islands, Japan, and the Gulf of Alaska 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 (AI) and Gulf of Alaska (GOA) 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 Gulf of Alaska 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 Aleutian Islands or a self-perpetuating population in the Gulf, 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 and 2006 year classes documented in the Aleutian Islands showed up in the Gulf of Alaska. 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 TACs. Since 1994, the BSAI Atka mackerel TAC has been allocated to the three regions (541 Eastern Aleutians, 542 Central Aleutians, 543 Western Aleutians) based on the average distribution of biomass estimated from the Aleutian Islands bottom trawl surveys.

Fishery

Catch History

Annual catches of Atka mackerel in the eastern Bering Sea (EBS) and Aleutian Islands (AI) regions increased during the 1970s reaching an initial peak of over 24,000 t in 1978 (see BSAI SAFE Introduction Table 3). 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), Total Allowable Catches (TAC), and Overfishing Levels (OFL) set by the North Pacific Fishery Management Council (Council) from 1978 to the present are given in Table 17.1.

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 Aleutian Islands.

Description of the Directed 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 Aleutian Islands (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 1/2° 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 2011 and 2012 fishery operations are shown in Fig. 17.1.

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 Aleutian Islands subarea (based on the assessment for the 1993 fishery; Lowe 1992). In mid-1993, however, Amendment 28 to the Bering Sea/Aleutian Islands (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. Since 1994, the BSAI Atka mackerel TAC has been allocated to the three regions based on the average distribution of biomass estimated from the Aleutian Islands bottom trawl surveys. Table 17.2 gives the time series of BSAI Atka mackerel catches, corresponding ABC, OFL, and TAC by region.

In June 1998, the Council passed a fishery regulatory amendment that proposed a four-year timetable to temporally and spatially disperse and reduce the level of Atka mackerel fishing within Steller sea lion critical habitat (CH) in the BSAI Islands. Temporal dispersion was accomplished by dividing the BSAI Atka mackerel TAC into two equal seasonal allowances, an A-season beginning January 1 and ending April 15, and a B-season from September 1 to November 1. 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 Aleutian Islands. 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, is closed to directed Atka mackerel fishing.

Most recently, the 2010 NMFS Biological Opinion found that the fisheries for Alaska groundfish in the Bering Sea and Aleutian Islands and Gulf of Alaska, 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 Biological Opinion found jeopardy and adverse modification of critical habitat, the agency is required to implement reasonable and prudent alternatives (RPAs) to the proposed actions (the fisheries). The Biological Opinion includes RPAs which require changes in groundfish fishery management in Management Sub-areas 543, 542, and 541 in the Aleutian Islands Management Area. NOAA Fisheries implemented the direct final rule measures before the start of the 2011 fishery in January. The RPAs specific to Atka mackerel are listed below:

<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 acceptable biological catch (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.
- Close the Bering Sea subarea year round to directed fishing for Atka mackerel.

Amendment 80 to the BSAI Groundfish FMP was adopted by the Council in June 2006 and implemented for the 2008 fishing year. This action allocates several BSAI non-pollock trawl groundfish species among trawl fishery sectors, and facilitates the formation of harvesting cooperatives in the non-American Fisheries Act (non-AFA) trawl catcher/processor sector. Bering Sea/Aleutian Islands Atka mackerel is one of the groundfish species directly affected by 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 2000-2005 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 2006 to the present are given below:

Year	**Fishery**	**Discarded (t)**	**Retained (t)**	**Total (t)**	**Discard Rate (%)**
2006	Atka mackerel	1,793	57,815	59,608	3.0
	All others	1,251	1,035	2,286	
	All	3,044	58,850	61,894	
2007	Atka mackerel	1,730	55,563	57,293	3.0
	All others	340	1,130	1,470	
	All	2,070	56,694	58,764	
2008	Atka mackerel	1,091	54,024	55,114	2.0
	All others	163	2,810	2,973	
	All	1,253	56,835	58,087	
2009	Atka mackerel	2,620	67,271	69,891	3.7
	All others	326	2,590	2,916	
	All	2,946	69,861	72,807	
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	421	2,384	2,805	
	All	1,350	46,481	47,831	

Discard rates have been 2-3% until 2009 when the discard rate increased to nearly 4%. The increases in 2009 and 2010 may have been due to large numbers of small fish from the 2006 and 2007 year classes. 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.

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 and 2012 data from the Western AI (543) are minimal Atka mackerel catches from the rockfish fisheries; directed fishing for Atka mackerel in 543 is prohibited under Steller sea lion protection measures.

		Aleutian Islands Subarea		
Year		**541**	**542**	**543**
2006	Retained (t)	6,029	38,447	14,374
	Discarded (t)	1,392	1,389	263
	Rate	***2%***	***4%***	***2%***
2007	Retained (t)	22,372	25,475	8,847
	Discarded (t)	571	1,248	251
	Rate	***3%***	***5%***	***3%***
2008	Retained (t)	19,005	22,180	15,650
	Discarded (t)	112	746	395
	Rate	***1%***	***3%***	***2%***
2009	Retained (t)	25,934	28,415	15,512
	Discarded (t)	484	1,722	740
	Rate	***2%***	***6%***	***5%***
2010	Retained (t)	23,176	24,035	17,460
	Discarded (t)	431	2,354	1,190
	Rate	***2%***	***9%***	***6%***
2011	Retained (t)	40,216	9,828	0.3
	Discarded (t)	675	886	205
	Rate	***2%***	***8%***	***100%***
2012	Retained (t)	36,881	9,599	0.2
	Discarded (t)	432	723	195
	Rate	***1%***	***7%***	***100%***

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 2012 and 2013 fisheries by management area are shown in Figures 17.2 and 17.3, respectively. The modes at about 28-34 cm and 27-36 cm in the 2012 and 2013 542 fishery length distributions represent the 2006 and 2007 year classes. The 2013 542 fisheries also show a mode of small fish at 20 cm which may include 1 and 2 year olds of the 2010 and 2011 year classes. The available 2013 fishery data are presented and should be considered preliminary, but are very similar to the 2012 distributions. A significant difference in 2013 is the bimodal distribution of Southern Bering Sea fish with modes at 40 and 50 cm. The 2013 Southern Bering Sea mode at 40 cm is comprised of fish from area 521. The 50 cm modes from the Southern Bering Sea in 2012 and 2013 are comprised of fish from area 519.

Steller Sea Lions and Atka Mackerel Fishery Interactions

Since 1979, the Atka mackerel fishery has occurred largely within areas designated in 1993 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, 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 apparently does not affect fishing success from one year to the next since local populations in the Aleutian Islands appear to be replenished by immigration and recruitment. However, this pattern 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 consequence, 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 ongoing investigations 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 through tagging studies. In August 1999, the AFSC conducted a pilot survey to explore the variance in survey catches of Atka mackerel and the feasibility of tagging as methods to determine small-scale changes in abundance and distribution. The tagging work was very successful and tagging surveys were conducted near Seguam Pass (in area 541) in August 2000, 2001 and 2002 (McDermott *et al.* 2005). Results indicated that the 20 nm trawl exclusion zone around the rookeries on Seguam and Agligadak Islands is effective in minimizing disturbance to prey fields within them. 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 work has been expanded and tagging studies were conducted 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 appear to be higher relative to Seguam (pers. comm. Elizabeth Logerwell and Susanne McDermott, AFSC). The boundaries at Amchitka bisect Atka mackerel habitat unlike Seguam and Tanaga.

After the release of the 2010 Biological Opinion and implementation of the closure of area 543 to the Atka mackerel and Pacific cod fisheries, another tagging study was 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 under a Memorandum of Agreement. 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). A tag recovery survey was conducted by a chartered fishing vessel and augmented with recoveries from the fishery in the open areas outside the trawl exclusion zones. Even though tags were released both inside and outside the closed areas during the recent release cruises in 2011 and 2012, recoveries were not conducted inside the trawl exclusion zones in order to minimize potential negative impacts of Atka mackerel removals to the Steller sea lion prey fields inside the closed areas. In addition to the data collected from the tag and release experiment, biological data including stomachs, gonad samples, age structures, sexed length frequencies, genetic tissue samples, and catch composition were also collected from each haul during the tag recovery charter. The second objective of this study was to use catch composition data to estimate relative abundance indexes (CPUEs) for all major fish and invertebrate species present in the study areas. The third objective of this study was to characterize Atka mackerel habitat by conducting underwater camera tows at each area where fish were recaptured. In 2011 and 2012 underwater camera tows were conducted in the areas of tag releases and recoveries to define bottom characteristics of areas with high abundance of Atka mackerel, and to develop methods for estimating indices of abundance of Atka mackerel and other Steller sea lion prey species with non-extractive methods such as camera tows.

Additionally, during the 2012 survey there was an opportunity to study the prey distribution of a Steller sea lion adult female that was tagged in November 2011 by the AFSC National Marine Mammal Laboratory. A hydroacoustic transect was conducted, species composition data collected, 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. Tag recoveries from this study are ongoing, and the analyses of the tagging data are currently being conducted. Further details and preliminary results can be found at: http://www.afsc.noaa.gov/REFM/Stocks/fit/FITcruiserpts.htm.

Data

Fishery Data

Fishery data consist of total catch biomass from 1977 to 2012 and projected end of year 2013 catch data (Table 17.1). Also, 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 1977-2011 (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 1990-2012 (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 year class which showed up in the 2009 and 2010 fisheries. 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 (Table 17.4). There are significant numbers of 3 year olds of the 2009 year class that were observed in the 2013 catches.

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). For stock assessment purposes, one year is added to the number of otolith hyaline zones determined by the Alaska Fisheries Science Center Age and Growth Unit. 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, 1994, 1997, 2000, 2002, 2004, 2006, 2010, and 2012 domestic trawl surveys, provide the only direct estimates of population biomass from throughout the Aleutian Islands region. Furthermore, 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.* 2003).

Aleutian Islands trawl survey biomass estimates of Atka mackerel varied from 63,215 t in 1980 to 489,486 t in 1983, and 1,121,148 t in 1986 (Table 17.5). However, the high value for 1986 is not directly comparable to previous estimates. During the 1980 survey, no successful sampling occurred in shallow waters (<100 m) around Kiska and Amchitka Islands, and during the 1983 survey very few shallow water stations were successfully trawled. However, during the 1986 survey, several stations were successfully trawled in waters less than 100 m, and some produced extremely large catches of Atka mackerel. In 1986, the biomass estimate from this one depth interval alone totaled 1,011,991 t in the Central Aleutians (Table 17.5), or 90% of the total biomass of Atka mackerel in the Aleutian Islands. This was a 908,403 t increase over the 1983 biomass estimate for the same stratum-depth interval. The 1986 biomass estimate is associated with a large coefficient of variation (0.80). Due to differences in area and depth coverage of the surveys, it is not clear how this biomass estimate compares to earlier years.

The most recent Aleutian Islands biomass estimate from the 2012 Aleutian Islands bottom trawl survey is 276,877 t, down 70% relative to the 2010 survey estimate (Table 17.6). 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 2012 survey is largely a result of decreases in biomass found in the Eastern and Southern Bering Sea areas (down 91 and 99%, respectively), but all areas showed large declines (Table 17.6). Relative to the 2010 survey, the 2012 biomass estimates are down 48% in the Western area, down 45% in the Central area, and down 99% in the combined Southern Bering Sea/Eastern area (Fig. 17.4). The 95% confidence interval about the mean total 2012 Bering Sea/Aleutian Islands biomass estimate is 106,811-447,595 t. The coefficient of variation (*CV*) of the 2012 mean Bering Sea/Aleutian Islands biomass is 18% (Table 17.6).

The distribution of biomass in the Western, Central, and Eastern Aleutians and the southern Bering Sea 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 and 2010. During these two previous surveys, the biomass from area 541 comprised 40 to 47% of the Aleutian Island biomass, but during 2012, only comprised 12% of the Atka mackerel biomass (Table 17.6).

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). Previous studies suggest that temperature affects the incubation period and potentially the occupation of nesting habitats by males (Lauth *et al.* 2007a). The effect of temperature on survey catchability and fish behavior should be examined more fully in the future to examine whether temperature affects the vertical or broad scale distribution of Atka mackerel to make them less available to the trawl during cold years.

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 not any 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 affect 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 17.6). 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 2012 survey estimated only 1,010 t of biomass in the southern Bering Sea (*CV*=77%). Very little biomass was observed in the southern Bering Sea in 2012 and no large hauls were encountered north of Akun Island similar to the 2006 survey (Fig. 17.4).

Areas with large catches of Atka mackerel in the 2006 survey included Seguam Pass, Tanaga Pass, Kiska Island, and Stalemate Bank (Fig. 17.6). Similarly, areas of large catches 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. 17.6). In the most recent 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 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 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%.

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). The average bottom temperatures measured in the 2002 survey were the third lowest of the Aleutian surveys, but significantly higher than the 2000 and 2012 surveys and very similar to the 1994 survey. The average bottom temperatures measured in the 2006 and 2010 surveys were slightly above the 2002 survey and very similar to the 1994 survey temperatures.

Survey length frequencies

The bottom trawl surveys have consistently revealed a strong east-west gradient in Atka mackerel size, with the smallest fish in the west and progressively larger fish to the east. This was evident in the 2010 and 2012 surveys (Figure 17.7 in Lowe *et al.* 2011 and Lowe *et al.* 2012). The 2012 survey length frequency distributions from the Eastern Aleutians and Southern Bering Sea areas showed modes at 43 and 49-52 cm, respectively, larger than the Central and Western fish with modes at 36-38 cm. The 2012 length frequency distribution in the Central area showed a bimodal distribution with the largest mode at 29 cm. This mode likely reflects 2 and 3-year olds of the 2009 and 2010 year classes (Lowe *et al.* 2012).

Survey age frequencies

The 2010 survey age composition was dominated by 3 and 4-year olds of the 2006 and 2007 year classes (Fig. 17.8 in Lowe *et al.* 2011). The 2009-2012 fishery data confirm the strong presence of the 2006 and 2007 year classes in fishery catches. The most recent 2012 survey age composition is dominated by 3 and 5-year olds of the 2009 and 2007 year classes, respectively (Fig. 17.7). Six year olds of the 2006 year class are still numerous. The mean age in the 2012 survey age composition is 5.6 years. 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.

Survey abundance indices

A partial time series of relative indices from the 1980, 1983, 1986, and 1991 Aleutian Islands surveys had been used in the previous stock synthesis 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. 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)[1] from the Toolbox, which is similar to the stock synthesis application (Methot 1989, 1990; Fournier and Archibald 1982) 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 1977-2013) 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 weighted sum of the calculated log-likelihoods for each data component and model penalties. The component weights are inversely proportional to the specified (or in some cases, estimated) variances. Appendix Tables A-1 – A-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[2] likelihood components and the distribution assumption of the error structure are given below:

Data component	**Years of data**	**Likelihood form**	***CV* or sample size (*N*)**
Catch biomass	1977-2013	Lognormal	*CV*=5%
Fishery catch age composition	1977-2012	Multinomial	Year specific *N*=25-234
Survey biomass	1991, 1994, 1997, 2000 2002, 2004, 2006, 2010, 2012	Lognormal	Average *CV*=24%
Survey age composition	1986, 1991, 1994, 1997, 2000 2002, 2004, 2006, 2010, 2012	Multinomial	*N*=50
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	

The age-composition components are heavily influenced by the sample size assumptions specified for the multinomial likelihood. Since sample variances of our catch-at-age estimates are available (Dorn 1992), "effective sample sizes" ($\dot{N}_{i,j}$) can be derived as follows (where i indexes year, and j indexes age):

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[1] AMAK. 2011. A statistical catch at age model for Alaska, version 2.0. NOAA version available on request to authors.

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

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

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. Thompson and Dorn (2003, p. 137) and Thompson (AFSC pers. comm.) note 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 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):

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	35	10	10	65	59	116	16	82	218	233	103
2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	
135	132	132	88	116	88	143	149	128	83	100	

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. His 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). Since 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 inflated biomass levels (Fig. 17.11 in Lowe *et al.* 2003). Independent studies being conducted outside the assessment which may provide further information to configure appropriate prior distributions for M. 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. More recent analyses by Lowe *et al.* (1998) corroborated differential growth in three sub-areas of the Aleutian Islands and the Western Gulf of Alaska. 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 1986, 1991, and 1994 survey data for the entire Aleutians region, and for the Eastern (541) and combined Central and Western (542 and 543) subareas, and (2) the combined 1990-96 fishery data for the same areas:

Data source	L_∞(cm)	K	t_0
86, 91& 94 surveys			
Areas combined	41.4	0.439	-0.13
541	42.1	0.652	0.70
542 & 543	40.3	0.425	-0.38
1990-96 fishery			
Areas combined	41.3	0.670	0.79
541	44.1	0.518	0.35
542 & 543	40.7	0.562	0.37

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

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) = $9.08\text{E-}06 \times \text{length (cm)}^{3.0913}$ (86, 91 & 94 surveys; N = 1,052)
weight (kg) = $3.72\text{E-}05 \times \text{length (cm)}^{2.6949}$ (1990-1996 fisheries; N = 4,041).

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 complied 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 2004, 2006, and 2010 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 2011, were compiled using the two-stage catch-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 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 and McDermott (2008) 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 within 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 in all models. 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 and assumed a value of 0.3 for σ_d for the recommended Model 2 which was accepted (Lowe *et al*. 2012). This assumption is carried forward in the current 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 correspond 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 current assessment, based on analysis developed and presented at the CAPAM workshop on selectivity, a method to allow fishery selectivity to vary without having to subjectively specify an arbitrary degree of penalty was developed. This followed the procedure outlined in Annex 2.1.1 of the 2012 BSAI Pacific cod assessment (p. 442-445) and implements the following procedure:

1) Estimate time-varying selectivity with negligible constraint, and compute the resulting standard deviation of the coefficient residuals (relative to their mean)
2) Iterate models with alternative trial values for time-varying selectivity penalties until the input value equals the output value (of residuals)
3) Compute a final value which weights the two variances, i.e., $\sigma_{sel} = \sqrt{\sigma_1^2 - \sigma_2\left(\sigma_1 - \sigma_2\right)}$ where σ_1, σ_2 are the standard deviations from steps 1 and 2 above.

Survey selectivity and catchability

For the bottom trawl survey, selectivity-at-age follows a parameterization similar to the fishery selectivity-at-age presented above (except with only a single change point in 2000). 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 time periods for survey selectivity, as one approach to help resolve the poor residual pattern identified (Lowe *et al*. 2011). Results were unsatisfactory and little improvement of model fit to survey biomass was noted. The random walk for catchability was not carried forward, but two survey selectivity time blocks were retained which coincided with the break point in the lack of fit. The 2012 assessment inadvertently only reported the post 1999 selectivity-at-age vector. In this assessment we report the pre- and post 1999 survey selectivity estimates. As in the past, we also specified that the average selectivity-at-age for the survey is equal to 1 over ages 4-10. This was done 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.

The 2014 assessment will include a more comprehensive analysis of fishery and survey time-varying selectivity, and also explore the estimation of M and q directly in the model as requested in the 2012 December SSC minutes.

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). In past assessments the recruitment variance (σ_R^2) was fixed at a value of 0.6. In the 2012 and current assessment we estimate σ_R^2.

Results

Model Evaluation

The current assessment begins with the model configuration from 2012 but continues on the theme of evaluating fits to the survey biomass estimates and the implementation of time-varying fishery selectivity consistent with previous explorations and SSC and Plan Team recommendations, and results from the recent Selectivity: theory, estimation, and application in fishery stock assessment models workshop (CAPAM Workshop Series Report, June 2013).

The explorations of natural mortality and survey catchability (M , q) in the 2003 and 2004 assessments indicated inconsistencies between the fishery and survey age compositions and the survey biomass estimates (Lowe *et al*. 2003, 2004). The models evaluated could not reconcile large changes in survey biomass estimates over short time frames without associated extreme changes in the perceived magnitude of incoming year classes, or alternatively, substantial changes in the numbers of older-age fish (Lowe *et al*. 2004). The models' solution to improving the fit to the survey in the absence of appropriate changes in the numbers-at-age (and assuming fixed M) was to have survey catchability increase, resulting in lower overall biomass and fitting the trend in survey estimates (Lowe *et al*. 2004). The 2012 assessment Model 2 assumed a fixed value of 0.3 for the prior of the parameter determining the degree of dome-shape (σ_d) for fishery selectivity, resulting in more plausible values of q and better reflected the fishery age composition data; 2012 Model 2 was the accepted model. The current assessment carries forward this assumption and incorporates a time-varying approach for fishery selectivity which estimates the degree of selectivity smoothness over ages and time.

In summary, we recommend Model 2 for the 2013 assessment and harvest recommendations for the following reasons:

1) Allows the model the flexibility to better reflect the fishery age composition data
2) Provides results consistent with fishery age distributions
3) Results in a plausible value of q = 1.2 which can be reasonably interpreted biologically considering patchy distribution and schooling behavior.
4) The 2012 configuration (Model 1 in the current assessment) resulted in retrospective patterns that fell outside of the confidence bands for spawning stock biomass as compared to Model 2 (Figure 17.8).
5) Model 2 fits the data better and accounts for process errors (mainly in acknowledging selectivity changes over time).
6) This builds from the work done in previous assessments and discussions from the recent Selectivity: theory, estimation, and application in fishery stock assessment models workshop (CAPAM Workshop Series Report, June 2013).

Model Fit

A summary of key results from Model 2 are presented in Table 17.10. Results from last year's model configuration with updated fishery and survey data (Model 1) are presented for comparison. The coefficient of variation or *CV* (reflecting uncertainty) about the 2013 biomass estimate is 25% and the *CV*s on the strength of the 2001 and 2006 year classes at age 1 are 15 and 17%, respectively (Table 17.10). Recruitment variability was moderate and estimated to be 0.58. Sample size values were calculated for the fishery data and fixed at 50 for the bottom trawl survey data. The model estimated an average fishery effective sample size (*N*) of 242 and average survey effective *N* of 129, which are higher than the input values but reasonable given the level of sampling that occurs in the fishery and survey. The overall residual mean square error (RMSE) for the survey is estimated at 0.253, which is in line with estimates of sampling-error *CV*s for the survey which range from 14-35% and average 25% over the time series (Table 17.10).

Figure 17.9 compares the observed and estimated survey biomass abundance values for the Bering Sea/Aleutian Islands. The decreases in biomass indicated by the 1994 and 1997 surveys followed by the large increases in biomass from the 2000 and 2002 surveys appear to be consistent with recruitment patterns. However, the large increase observed in the 2004 survey is fit poorly by the model. 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 most recent 2012 survey is associated with the lowest variance in the time series but is not fit by the model (Figure 17.9). The declining trend in biomass indicated by the 2012 survey is consistent with the population age composition. Population biomass would be expected to decline as the most recent strong year class (2006 year class) is aging and past peak cohort biomass. We note that the model's predicted survey biomass trend is very conservative relative to the recent (2000, 2002, 2004, 2006, and 2010) observed bottom trawl survey biomass values (survey catchability is greater than 1).

The fits to the survey and fishery age compositions for Model 2 are depicted in Figures 17.10 and 17.11, 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. These figures also 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 the recent fishery age composition data in Lowe *et al*. (2012) indicated a need for greater flexibility in selectivity. In the present assessment including more time-varying fishery selectivity flexibility improved fits to the fishery age compositions, as expected. Most importantly, allowing for a structured way to allow the selectivity coefficients to change over time may provide a more realistic way to account for process errors such as distributional changes in fishing patterns. While such models are inherently un-parsimonious, they can provide a more realistic depiction of uncertainty and result in appropriately higher estimates of uncertainty.

The results discussed below are based on the recommended Model 2 with updated fishery catch- and weight-at-age values, 2012 fishery data, 2012 Aleutian Islands survey data, and includes time-varying fishery selectivity. Selected results from Model 1 with the updated data and 4 time periods each with constant selectivity are presented for comparison.

Time Series Results

Selectivity

For Atka mackerel, the estimated selectivity patterns are particularly important in describing their dynamics. Previous assessments have focused on the transitions between ages and time-varying selectivity (Lowe *et al.* 2002, 2008). The current assessment allowed for flexibility (over time and age) and pre and post 1999 selectivity patterns for the survey (Figures 17.12, 17.13, and 17.14 and Table 17.11). The current assessment's terminal year selectivity estimate and the average selectivity for 2009-2013 (used for projections) are more dome-shaped relative to the 2012 configuration, showing lower selectivity for ages 3-5 and ages 7-9, and higher selectivity after age 9 (Figures 17.12 and 17.13).

The fishery catches essentially consist of fish 3-11 years old, although a 15-year-old fish was found in the 1994 fishery. 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.17.12). 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, and 2006 year classes (Table 17.4). The age at 50% selectivity is estimated at about age 3 for 2008, and has been steadily increasing to age 4.5 in 2012 as the large year classes move through the population. It is important to note the maturity-at-age vector relative to the current selectivity patterns (age at 50% maturity is 3.6 years, Fig. 17.13). The estimated selectivity patterns since about 1991 indicate the fishery is harvesting mature older fish relative to the foreign and joint venture fisheries.

Survey catches are mostly comprised of fish 3-9 years old. However, the 2012 survey still shows significant numbers of 11-13 year olds of the 1999, 2000, and 2001 year classes. A 15-year old fish was found in the 2000 survey, and most recently a 17-year old fish was found in the 2012 survey. The current model configuration estimates a slightly dome-shape selectivity pattern (Fig. 17.14).

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+) with approximate upper and lower 95% confidence limits are shown in Figure 17.15 and given in Table 17.13. Total biomass estimates from the recommended Model 2 show similar trends to Model 1 (Figure 17.15, dashed line). This reflects changes in the current recommended model configuration described above. A comparison of the spawning biomass trend from the current and previous assessments (Table 17.13) 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 1993, spawning biomass declined for nearly 10 years until 2001 (Fig. 17.6). 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.

Recruitment trend

The estimated time series of age 1 recruits indicates the strong 1977 and 1999 year class are the most notable in the current assessment, followed by the 1988 and 2001 year classes (Figure 17.17 and 17.18). 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 1.3 billion recruits, respectively) due to the persistent observations of these year classes in the fishery and survey catches. The current assessment estimates above average (greater than 20% of the mean) recruitment from the 1977, 1988, 1992, 1995, 1998, 1999, 2000, 2001, 2006 year classes (Fig 17.17).

The average estimated recruitment from the time series 1978-2012 is 609 million fish and the median is 446 million fish (Table 17.14). The entire time series of recruitments (1977-2013) includes the 1976-2012 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. Thus, the average recruitment value presented in the assessment is based on year classes spawned after 1976 through 2012 (1977-2011 year classes). Projections of biomass are based on estimated recruitments from 1978-2012 using a stochastic projection model described below.

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 provisional retrospective analysis was conducted by regressively eliminating the most current year of information extending back to 2003 (10 years). This allows judgment of the model performance as specified. For a stock with highly variable and uncertain survey information, the change and relative difference in spawning biomass is difficult to predict in subsequent years (Figure 17.8). The current model applied to a shortened time series often gives estimates that vary broadly from the full-data set model used for this assessment. Although the scale and uncertainty exhibited by the retrospective runs generally fall within the confidence bands of the present model, retrospective patterns are still evident and require further investigation.

Projections and Harvest Recommendations

Results and recommendations in this section pertain to the authors’ recommended model (Model 2). A parallel set of results from last year’s model configuration with updated survey and fishery information (Model 1) is provided as an attachment (Appendix 17C).

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 1978-2012 (609 million age-1 recruits) and F equal to $F_{40\%}$ and $F_{35\%}$ are denoted $B_{40\%}$ and $B_{35\%}$, respectively. The Tiers require reference point estimates for biomass level determinations. We present the following reference points for BSAI Atka mackerel for Tier 3 of Amendment 56. For our analyses, we computed the following values from **Model 2** results based on recruitment from post-1976 spawning events:

$B_{100\%}$ = 291,029 t female spawning biomass
$B_{40\%}$ = 116,411 t female spawning biomass
$B_{35\%}$ = 101,860 t female spawning biomass

Specification of OFL and Maximum Permissible ABC

In the current assessment, Model 2 is configured with time-varying selectivity. The average selectivity of the most recent 5-year period (2009-2013) is used for projection purposes. The following rates are based on the average of the 2009-2013 selectivity estimates:

Full selection *F*s	2014
F_{2013}	0.145
$F_{40\%}$	0.421
$F_{35\%}$	0.514
$F_{2013}/F_{40\%}$	0.344

For specification purposes to project the 2014 ABC, we assumed that the full TAC would be taken in 2013 (25,920 t). For projecting to 2015, an expected catch in 2014 is required. Typically this value is set to a recommended ABC, in this case the 2014 recommended ABC. However, recognizing that the Steller Sea Lion RPA's require TAC reductions, we assume the stock-wide catch based on a reduced overall BSAI-wide Atka mackerel catch for 2014. To arrive at such a reduction we assumed that only trace amounts of Atka mackerel (as bycatch in other fisheries) would be taken from Area 543 (Western Aleutian Islands) and about half of the allocation to Area 542 (Central Aleutian Islands) would be taken. We estimated that about 64% of the BSAI-wide ABC is likely to be taken. This percentage was applied to the maximum permissible 2014 ABC and that amount was assumed to be caught in order to estimate the 2015 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. For Model 2, the projected year 2014 female spawning biomass (SSB_{2014}) is estimated to be 117,171 t under an assumed 2013 catch of 25,920 t and reduced 2014 catch reflecting the RPA adjustment to the 2014 ABC.

The projected 2014 female spawning biomass estimate is above the $B_{40\%}$ value of 116,411 t, placing BSAI Atka mackerel in **Tier 3a**. The 2015 female spawning biomass estimate is below $B_{40\%}$, placing BSAI Atka mackerel in **Tier 3b** The maximum permissible ABC and OFL values under **Tier 3** are:

Year	Catch*	ABC	F_{ABC}	OFL	F_{OFL}	SSB	Tier
2014	35,500	64,131	0.421	74,492	0.514	117,171	3a
2015	33,600	64,477	0.421	74,898	0.514	115,640	3b

* Catches in 2014 and 2015 are less than the recommended ABCs to reflect expected catch reductions under Steller sea lion RPAs.

Standard Harvest Scenarios and Projection Methodology

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3, of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of

Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2013 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2026 using a fixed value of natural mortality of 0.3, the recent schedule of selectivity estimated in the assessment (in this case the 2000-2011 selectivity), and the best available estimate of total (year-end) catch for 2013 (in this case assumed equal to the 2013 TAC of 25,920 t). 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. 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 will be used in a Supplemental Environmental Impact Statement prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2014 and 2015, 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 2013 recommended in the assessment to the *max* F_{ABC} for 2014. (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). *Note: We used this scenario to project the BSAI stock assuming catch reductions that may occur under SSL RPAs.*

Scenario 3: In all future years, F is set equal to the 2008-2012 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 4: In all future years, F is set equal to $F_{75\%}$. (Rationale: This scenario represents a very conservative harvest rate and was requested by the Alaska Regional Office based on public comment.)

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 2013 or 2) above ½ of its MSY level in 2013 and above its MSY level in 2023 under this scenario, then the stock is not overfished.)

Scenario 7: In 2014 and 2015, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2026 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 2013:

a) If spawning biomass for 2013 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b) If spawning biomass for 2013 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c) If spawning biomass for 2013 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 2023 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 #7a) If the mean spawning biomass for 2016 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

b) If the mean spawning biomass for 2016 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c) If the mean spawning biomass for 2016 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2026. If the mean spawning biomass for 2026 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 overfishing.

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 2002 and 2004 survey estimates showed increases of 63 and 38% respectively. The 2006 survey estimate of Aleutian Islands biomass decreased 36% relative to the 2004 survey. The planned 2008 survey was not conducted. The 2010 survey increased 25% relative to the 2006 survey, and the most recent 2012 survey decreased 71% relative to the 2010 survey.
2) Under an $F_{40\%}$ harvest strategy and assuming SSL RPA catch reductions in 2014 and 2015, female spawning biomass is projected to be above $B_{40\%}$ in 2014 but drop below $B_{40\%}$ in 2015-2017 (Fig. 17.20 and Table 17.16 Scenario 2). If SSL RPA catch reductions are in place beyond 2015, expected female spawning biomass levels would be higher than projected after 2015.
3) The model's predicted survey biomass trend is very conservative relative to 2000, 2002, 2004, 2006 and 2010 observed bottom trawl survey biomass values.
4) The 2011 and 2012 fishery data are dominated by the 2006 and 2007 year classes (Table 17.4).
5) The 2012 survey age composition is dominated by 3 and 5-year olds of the 2009 and 2007 year classes, respectively. The bottom trawl surveys have been a consistently good indicator of incoming year class strengths.

6) Currently we estimate the 1999 year class to be one of the largest in the time series (but with a moderate degree of uncertainty: *CV*=16%). Most recently the 2006 year class is estimated to be relatively strong, also with a moderate degree of uncertainty: *CV*=17%).

We believe the current model configuration (Model 2) provides an improved assessment of BSAI Atka mackerel relative to past model configurations. Given the current moderate stock size, an above average 2006 year class, and preliminary indications of an above average 2009 year class, the maximum permissible is acceptable for Atka mackerel. We note that the maximum permissible reference fishing mortality rate (F_{ABC}) is higher than the natural mortality rate. This is due to the fact that estimated fishery selectivity-at-age is significantly older than the maturity-at-age. That is, the fishery targets the older mature portion of the population that had opportunities to spawn. 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 17.21. For most of the time series (including the 2013 data point), 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 probability of female spawning biomass dropping below $B_{20\%}$ in the next five years was estimated to be less than 0.125 in the 2012 assessment (Figure 17.26 in Lowe *et al*. 2012), and is expected to be even less in the current assessment due to improved stock status.

The 2014 yield associated with the Tier 3a maximum permissible F_{ABC} fishing mortality rate of 0.421 is 64,131 t, which is our 2014 ABC recommendation for BSAI Atka mackerel.

The 2015 yield associated with the Tier 3b maximum permissible F_{ABC} fishing mortality rate and assuming 2014 catch reductions, is 64,477 t, which is our 2015 ABC recommendation for BSAI Atka mackerel.

The 2014 ABC recommendation is 22% higher relative to the Council's 2013 ABC, and is 24% higher relative to the projections from last year's assessment for 2014.

Area Allocation of Harvests

Amendment 28 of the Bering Sea/Aleutian Islands 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 TACs. The Council used a 4-survey (2004, 2006, 2010, and 2012) weighted average to apportion the 2013 ABC. The rationale for the weighting scheme was described in Lowe *et al.* (2001). The Plan Teams convened a working group to evaluate methods for averaging surveys for apportionment and Tier 5 biomass. Evaluations are ongoing. This year we retain the status quo methodology until further guidance.

The data used to derive the percentages for the weighting scheme are given below:

	2004	2006	2010	2012	2013 and Recommended 2014 & 2015 Apportionment
541[1]	44.21%	48.90%	51.16%	12.34%	**33.76%**
542	23.25%	37.52%	21.38%	39.41%	**32.08%**
543	32.53%	13.58%	27.46%	48.25%	**34.16%**
Weights	8	12	18	27	

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

The apportionments of the 2014 and 2015 recommended ABCs based on the most recent 4-survey weighted average are:

	2014 (t)	2015 (t)
Eastern (541+S.BSea)	21,652	21,769
Central (542)	20,574	20,685
Western (543)	21,905	22,023
Total	64,131	64,477

Ecosystem Considerations

Note: This section and the referenced tables and figures have not been updated for the 2013 assessment.

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). 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.

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. 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.

Ecosystem Effects on BSAI Atka Mackerel

Prey availability/abundance trends

Figure 17.22 shows the food web of the Aleutian Islands summer survey region, based on trawl survey and food habits data, with an emphasis on the predators and prey of Atka mackerel (see the current Ecosystem Assessment’s ecosystem modeling results section for a description of the methodology for constructing the food web).

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). Food habits data from 1990-1994 indicates 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. 17.23a). While Figure 17.23a shows an aggregate diet for the Aleutians management regions, Atka mackerel diet data also show 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) Monitoring trends in Atka mackerel prey populations may, in the future, help elucidate Atka mackerel population trends. However, there is no long-term time series of zooplankton, squid, or small forage fish abundance information available.

Some preliminary results of sensitivity analysis suggest that Atka mackerel foraging in the Aleutian Islands may have a relatively strong competitive effect on walleye pollock distribution and abundance, as opposed to the Bering Sea where pollock may be more bottom-up (prey) controlled, or the Gulf of Alaska where pollock may be top-down (predator) controlled (Aydin *et al.* 2007). Since these sensitivity analyses treat the Aleutian Islands as a single “box model”, it is possible that this is a mitigating or underlying factor for the geographical separation between Atka mackerel and pollock as a partitioning of foraging habitat.

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), skates, and seabirds (e.g., thick-billed murres, tufted puffins, and short-tailed shearwaters, Springer *et al.* 1999). Apportionment of Atka mackerel mortality between fishing, predation, and unexplained mortality, based on the consumption rates and food habits of predators averaged over 1990-1994 is shown in Figure 17.24. During these years, approximately 20% of the Atka mackerel exploitation rate (as calculated by stock assessment) was due to the fishery, 62% due to predation, and 18% “unexplained”, where “unexplained” is the difference between the stock assessment total mortality and the sum of fisheries exploitation and quantified predation. This unexplained mortality may be due to data uncertainty, or Atka mackerel mortality due to disease, migration, senescence, etc.

Of the 62% of mortality due to predation, a little less than half (25% of total) is due to Pacific cod predation, and one quarter (15% of total) due to Steller sea lion predation, with the remainder spread across a range of predators (Fig. 17.23b), based on Steller sea lion diets published by Merrick *et al.* (1997) and summer fish food habits data from the REEM food habits database.

If converted to tonnages, this 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.

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. 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

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 Nino 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). 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 in the fall of 1997/1998, 1999, 2004, and 2006/2007 suggesting increased volume, heat, salt, and nutrient fluxes. 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 on growth, and the temporal and spatial scales over which these effects occur.

Bottom temperature

Atka mackerel demonstrate schooling behavior and prefer hard, rough and rocky bottom substrate. Eggs are deposited in nests on rocky substrates between 15 and 144 m depth (Lauth *et al.* 2007b). The spawning period in Alaska occurs in late July to October (McDermott and Lowe 1997, Lauth *et al.* 2007b). During the incubation period egg nests are guarded by males, who will be on the nests until mid-January, given that females have been observed to spawn as late as October and given the length of the egg incubation period (McDermott and Lowe 1997, Lauth *et al.* 2007b, Lauth *et al.* 2007a). 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 2000 and 2012 was 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. Bottom temperatures could possibly affect fish distribution, but there have been no directed studies, and there is no time series of data which demonstrates the effects on AI Atka mackerel.

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, 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 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 3 years (2009-2011), the Atka mackerel fishery has taken on average about 51 and 23%, respectively of the total Aleutian Islands sponge and coral catches. It is unknown if the absolute levels of sponge and coral bycatch in the Atka mackerel fishery are of concern.

Fishing gear effects on spawning and nesting habitat

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

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

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, Reasonable and Prudent Alternatives (RPAs) from the 2010 Biological Opinion 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 is reduced to no more than 47 percent of the Area 543 ABC. However, 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 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 contributed on average about 363 t of non-target discards in the Aleutian Islands from 2009 to 2011. 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 233 t over 2009-2011.

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 and McDermott 2008) 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.

Data Gaps and Research Priorities

Regional and seasonal food habits data for Aleutian Islands is very limited. No time series of information is available on copepod and euphausiid abundance in the Aleutian Islands which would provide information on prey availability and abundance trends. 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. 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.

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Tables

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

Year	Catch	ABC	TAC	OFL
1977	21,763	a	a	
1978	24,249	24,800	24,800	
1979	23,264	24,800	24,800	
1980	20,488	24,800	24,800	
1981	19,688	24,800	24,800	
1982	19,874	24,800	24,800	
1983	11,726	25,500	24,800	
1984	36,055	25,500	35,000	
1985	37,860	37,700	37,700	
1986	31,990	30,800	30,800	
1987	30,061	30,800	30,800	
1988	22,084	21,000	21,000	
1989	17,994	24,000	20,285	
1990	22,206	24,000	21,000	
1991	26,626	24,000	24,000	
1992	48,532	43,000	43,000	435,000
1993	66,006	117,100	64,000	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	99,700
2005	62,012	124,000	63,000	178,500
2006	61,894	110,200	63,000	147,000
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	47,832	81,400	50,763	96,500
2013	25,920[t]	50,000	25,920	57,700

a) Atka mackerel was not a reported species group until 1978.
b) 2013 data as projected (We assume the full TAC will be taken in 2013)
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 1994 to the present. Apportioned catches prior to 1994 were assumed as the average apportionment for the years 1994-1998. Catches, ABCs, and TACs are in metric tons.

Year	Eastern (541)	Central (542)	Western (543)	Total	Year	Eastern (541)	Central (542)	Western (543)	Total
1990 Catch	5,116	11,058	6,032	22,206	2002 Catch	4,920	22,291	18,077	45,288
ABC				24,000	ABC	5,500	23,800	19,700	49,000
TAC				21,000	TAC	5,500	23,800	19,700	49,000
1991 Catch	6,154	11,761	8,711	26,626	2003 Catch	10,725	25,435	17,885	54,045
ABC				24,000	ABC	10,650	29,360	22,990	63,000
TAC				24,000	TAC	10,650	29,360	19,990	60,000
1992 Catch	11,217	21,438	15,878	48,532	2004 Catch	10,838	30,169	19,554	60,562
ABC				43,000	ABC	11,240	31,100	24,360	66,700
TAC				43,000	TAC	11,240	31,100	20,660	63,000
1993 Catch	15,256	29,156	21,594	66,006	2005 Catch	7,200	35,069	19,743	62,012
ABC				117,100	ABC	24,550	52,830	46,620	124,000
TAC				64,000	TAC	7,500	35,500	20,000	63,000
1994 Catch	15,106	28,871	21,383	65,360	2006 Catch	7,421	39,836	14,637	61,894
ABC	13,475	55,125	53,900	122,500	ABC	21,780	46,860	41,360	110,200
TAC	13,475	44,525	10,000	68,000	TAC	7,500	40,000	15,500	63,000
1995 Catch	14,201	50,386	16,967	81,554	2007 Catch	22,943	26,723	9,097	58,763
ABC	13,500	55,900	55,600	125,000	ABC	23,800	29,600	20,600	74,000
TAC	13,500	50,000	16,500	80,000	TAC	23,800	29,600	9,600	63,000
1996 Catch	28,173	33,523	42,246	103,942	2008 Catch	19,118	22,329	16,643	58,090
ABC	26,700	33,600	55,700	116,000	ABC	19,500	24,300	16,900	60,700
TAC	26,700	33,600	45,857	10,657	TAC	19,500	24,300	16,900	60,700
1997 Catch	16,315	19,990	29,537	65,842	2009 Catch	26.417	30,070	16,319	72,806
ABC	15,000	19,500	32,200	66,700	ABC	27,000	33,500	23,300	83,800
TAC	15,000	19,500	32,200	66,700	TAC	27,000	32,500	16,900	76,400
1998 Catch	12,271	20,209	24,617	57,097	2010 Catch	23,608	26,389	18,650	68,647
ABC	14,900	22,400	27,000	64,300	ABC	23,800	29,600	20,600	74,000
TAC	14,900	22,400	27,000	64,300	TAC	23,800	29,600	20,600	74,000
1999 Catch	17,453	22,419	16,366	56,237	2011 Catch	40,900	10,713	205	51,818
ABC	17,000	25,600	30,700	73,300	ABC	40,300	24,000	21,000	85,300
TAC	17,000	22,400	27,000	66,400	TAC	40,300	11,280	1,500	53,080
2000 Catch	14,344	22,383	10,503	47,230	2012 Catch	37,314	10,323	195	47.832
ABC	16,400	24,700	29,700	70,800	ABC	38,500	22,900	20,000	81,400
TAC	16,400	24,700	29,700	70,800	TAC	38,500	10,763	1,500	50,763
2001 Catch	8,424	32,829	20,309	61,563	2013* Catch	*16,900*	*16,000*	*17,100*	*50,000*
ABC	7,800	33,600	27,900	69,300	ABC	16,900	16,000	17,100	50,000
TAC	7,800	33,600	27,900	69,300	TAC	16,900	7,520	1,500	25,920

* 2013 catch based on NMFS Regional Office Catch Accounting System apportionments (as of Oct 12 2013) and projected to total.

Table 17.3. Numbers of Atka mackerel length-weight data, length frequency, and aged samples based on NMFS observer data 1990-2012.

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

Table 17.4. Estimated catch-in-numbers at age (in millions) of Atka mackerel from the BSAI region, 1978-2012. 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

[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*).

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

Table 17.6. Aleutian Islands Atka mackerel survey biomass by bottom-depth category by region and subareas including area percentages (for each year) and coefficients of variation (*CV*) for 1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010 and 2012.

Area	Depth (m)	Biomass (t)								
		1991	1994	1997	2000	2002	2004	2006	2010	2012
Aleutian Islands + S. BS	1-100	429,873	211,562	284,176	160,940	394,092	518,232	374,774	304,909	130,616
	101-200	277,907	472,725	177,672	344,674	393,159	631,150	326,426	624,294	145,351
	201-300	520	1,691	130	8,636	48,723	7,410	40,091	1,008	886
	301-500	0	30	20	82	221	292	67	41	23
	Total	708,299	686,007	461,997	514,332	836,195	1,157,084	741,358	930,252	276,877
Area % of Total		100%	100%	100%	100%	100%	100%	100%	100%	100%
	CV	*14%*	*32%*	*31%*	*29%*	*20%*	*17%*	*28%*	*35%*	*18%*
Western 543	1-100	168,968	93,847	90,824	120,257	50,481	140,669	64,429	59,449	62,247
	101-200	174,182	231,733	43,478	52,948	154,820	229,675	35,926	195,819	70,983
	201-300	276	1,656	66	7,910	48,362	6,033	318	134	350
	301-500	-	6	-	-	8	36	21	17	8
	Total	343,426	327,242	134,367	181,115	253,671	376,414	100,693	255,419	133,588
Area % of Total		48.5%	47.7%	29.1%	35.2%	30.3%	32.5%	13.6%	27.5%	48.2%
	CV	*18%*	*57%*	*56%*	*56%*	*32%*	*24%*	*35%*	*58%*	*28%*
Central 542	1-100	187,194	50,513	70,458	38,805	131,770	198,243	192,832	102,211	62,238
	101-200	100,329	33,255	116,295	290,766	199,743	70,267	85,215	96,457	46,861
	201-300	70	13	53	674	169	367	103	207	16
	301-500	-	3	6	9	143	194	-	-	15
	Total	287,594	83,784	186,813	330,255	331,824	269,071	278,150	198,874	109,130
Area % of Total		40.6%	12.2%	40.4%	64.2%	39.7%	23.3%	37.5%	21.4%	39.4%
CV		*17%*	*48%*	*36%*	*34%*	*24%*	*35%*	*24%*	*28%*	*27%*
Eastern 541	1-100	73,663	641	27,222	25	152,159	54,424	107,230	44,981	6,029
	101-200	3,392	207,707	17,890	772	38,492	188,592	205,108	327,105	26,685
	201-300	163	19	11	48	94	971	37,829	339	435
	301-500	-	12	14	73	71	57	40	5	-
	Total	77,218	208,379	45,137	919	190,817	244,043	350,206	372,429	33,149
Area % of Total		10.9%	30.4%	9.8%	0.2%	22.8%	21.1%	47.2%	40.0%	12.0%
	CV	*83%*	*44%*	*68%*	*74%*	*58%*	*33%*	*55%*	*74%*	*46%*
Southern Bering Sea	1-100	47	66,562	95,672	1,853	59,682	124,896	10,284	98,268	103
	101-200	3	30	9	187	103	142,616	176	4,914	822
	201-300	11	3	-	4	98	39	1,842	327	85
	301-500	-	8	-	-	-	4	6	19	-
	Total	61	66,603	95,680	2,044	59,883	267,556	12,308	103,529	1,010
Area % of Total		0.0%	9.7%	20.7%	0.4%	7.2%	23.1%	1.7%	11.1%	0.4%
	CV	*37%*	*99%*	*99%*	*88%*	*99%*	*43%*	*44%*	*86%*	*77%*

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+
1991	478	0.00	4.15	6.49	7.78	5.71	3.94	1.04	0.18	0.35	0.22
1994	745	0.05	9.16	6.83	23.13	36.00	4.64	8.21	5.27	3.04	0.61
1997	433	0.00	17.11	4.66	66.28	3.72	1.56	0.67	3.56	0.36	0.00
2000	831	0.54	8.91	6.40	26.59	7.53	4.33	8.33	1.93	0.78	1.01
2002	789	1.94	22.68	25.37	7.88	3.89	16.20	3.23	1.56	1.67	0.53
2004	598	0.09	20.44	31.49	44.20	12.32	2.40	1.56	2.21	0.00	0.39
2006	525	3.56	16.74	5.66	33.56	20.27	22.62	4.12	0.56	0.36	0.26
2010	560	1.67	19.00	47.22	13.06	13.59	6.46	3.82	7.90	4.66	1.75
2012	417	63.17	100.11	40.52	97.73	66.74	20.26	20.26	17.88	8.34	61.98

Table 17.8. Year-specific fishery and survey and the population weight-at-age (kg) values used to obtain expected survey and fishery catch biomass and population biomass. The population weight-at-age values are derived from the Aleutian trawl survey from the years 2004, 2006, and 2010. The 2013 fishery weight-at-age values are the average of the last three years (2010-2012).

		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	0.369	0.633	0.667	0.744	0.974	1.075	0.981	1.041	1.244
Avg 2004, 2006, 2010		0.045	0.153	0.345	0.551	0.597	0.719	0.851	0.917	0.922	1.146	1.019
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	0.218	0.393	0.571	0.667	0.695	0.722	0.776	0.825	0.857	0.884

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 last year's assessment model with updated data (Model 1) and the current recommended assessment model with updated data (Model 2). Both Model 1 and Model 2 results include 2011 fishery catch and age data and 2012 survey data. Coefficients of variation (*CV*) for some key reference values appearing directly below, are given in parentheses.

Assessment Model	**Model 1**	**Model 2**
Model setup		
Survey catchability	1.21	1.20
Steepness	0.8	0.8
SigmaR	0.6	0.48
Natural mortality	0.3	0.3
Fishery Average Effective *N*	100	242
Survey Average Effective *N*	76	129
RMSE Survey	0.263	0.253
-log Likelihoods		
Number of Parameters	169	489
Survey index	6.4	5.5
Catch biomass	0.0	0.0
Fishery age comp	188.1	87.5
Survey age comp	49.3	32.9
Sub total	243.8	126.0
-log Penalties		
Recruitment	11.1	-1.6
Selectivity constraint	59.1	85.6
Prior	0.4	0.4
Sub total	70.7	84.5
Total	314.5	210.4
Fishing mortalities (full selection)		
F 2013	0.131	0.145
F 2013/*F* 40%	0.387	0.344
F 40%	0.339	0.421
*F*35%	0.407	0.514
Stock abundance and recruitment		
Initial Biomass (t, 1977)	493,960	584,500
CV	21%	22%
Assessment year total biomass (t)	416,750	447,190
CV	22%	25%
2001 year class (millions at age 1)	1,230	1,309
CV	13%	15%
2006 year class (millions at age 1)	855	741
CV	15%	17%
Recruitment Variability	0.637	0.577

Table 17.11. Estimates of Atka mackerel fishery (over time, 1977-2013) and survey selectivity at age from Model 2. These are full-selection (maximum = 1.0) estimates.

	Age										
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11+**
1977	0.010	0.093	0.553	1.000	0.765	0.325	0.145	0.075	0.045	0.033	0.033
1978	0.009	0.115	0.957	1.000	0.931	0.517	0.238	0.116	0.065	0.047	0.047
1979	0.005	0.032	0.270	1.000	0.857	0.456	0.223	0.107	0.057	0.038	0.038
1980	0.005	0.037	0.251	0.822	1.000	0.629	0.406	0.191	0.084	0.049	0.049
1981	0.004	0.029	0.191	0.368	0.386	0.595	1.000	0.286	0.087	0.045	0.045
1982	0.004	0.022	0.096	0.337	1.000	0.930	0.476	0.205	0.093	0.055	0.055
1983	0.004	0.025	0.143	0.345	0.643	1.000	0.634	0.242	0.108	0.066	0.066
1984	0.004	0.027	0.136	0.421	0.713	1.000	0.921	0.432	0.193	0.107	0.107
1985	0.006	0.057	0.538	0.900	0.959	0.997	1.000	0.825	0.444	0.242	0.242
1986	0.005	0.042	0.315	0.538	0.639	0.724	0.880	1.000	0.766	0.373	0.373
1987	0.007	0.061	0.439	0.784	0.864	0.825	0.903	1.000	0.940	0.839	0.839
1988	0.004	0.039	0.359	1.000	0.667	0.465	0.428	0.382	0.331	0.259	0.259
1989	0.006	0.053	0.350	0.936	1.000	0.729	0.524	0.399	0.321	0.275	0.275
1990	0.004	0.041	0.437	1.000	0.779	0.495	0.369	0.281	0.223	0.187	0.187
1991	0.004	0.025	0.145	0.673	0.978	1.000	0.730	0.426	0.285	0.232	0.232
1992	0.004	0.025	0.159	0.706	1.000	0.829	0.627	0.456	0.347	0.293	0.293
1993	0.003	0.025	0.163	0.495	0.812	1.000	0.801	0.628	0.487	0.402	0.402
1994	0.003	0.019	0.149	0.449	0.873	0.967	0.924	1.000	0.799	0.526	0.526
1995	0.002	0.018	0.137	0.576	0.695	0.824	0.944	1.000	0.916	0.713	0.713
1996	0.001	0.011	0.075	0.382	0.524	0.717	0.919	1.000	0.603	0.416	0.416
1997	0.002	0.016	0.127	0.441	1.000	0.864	0.857	0.832	0.722	0.615	0.615
1998	0.002	0.015	0.102	0.466	0.771	0.838	0.997	1.000	0.872	0.697	0.697
1999	0.001	0.014	0.107	0.563	0.569	0.682	0.728	1.000	0.767	0.486	0.486
2000	0.001	0.012	0.242	0.575	0.698	0.723	0.792	1.000	0.617	0.364	0.364
2001	0.001	0.012	0.178	0.555	0.865	0.930	1.000	0.894	0.566	0.332	0.332
2002	0.001	0.013	0.111	0.386	0.568	0.770	1.000	0.712	0.444	0.285	0.285
2003	0.002	0.018	0.183	0.448	0.637	0.825	1.000	0.862	0.470	0.299	0.299
2004	0.004	0.040	0.304	0.792	0.998	0.981	1.000	0.912	0.609	0.372	0.372
2005	0.007	0.056	0.306	0.773	1.000	0.979	0.950	0.682	0.445	0.316	0.316
2006	0.009	0.096	0.629	0.735	0.953	1.000	0.963	0.619	0.411	0.302	0.302
2007	0.008	0.090	0.575	0.808	0.740	0.824	1.000	0.755	0.464	0.304	0.304
2008	0.007	0.074	0.480	0.689	0.680	0.835	1.000	0.902	0.708	0.336	0.336
2009	0.007	0.057	0.350	0.664	0.796	0.804	1.000	0.895	0.641	0.410	0.410
2010	0.006	0.050	0.308	0.881	0.986	1.000	0.946	0.862	0.682	0.371	0.371
2011	0.004	0.031	0.181	0.565	0.939	1.000	0.815	0.676	0.686	0.582	0.582
2012	0.003	0.020	0.133	0.318	0.729	1.000	0.850	0.666	0.672	0.695	0.695
2013	0.003	0.020	0.133	0.318	0.729	1.000	0.850	0.666	0.672	0.695	0.695
Ave 2009-2013	0.005	0.036	0.221	0.549	0.836	0.961	0.892	0.753	0.671	0.551	0.551
Survey before 1999	0.024	0.137	0.562	0.946	0.939	0.950	1.000	0.983	0.884	0.763	0.763
Survey after 1999	0.018	0.185	0.632	0.855	0.777	0.795	0.955	1.000	0.885	0.773	0.773

Table 17.12. Estimated Atka mackerel numbers at age in millions, 1977-2013 from Model 2.

	Age										
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11+**
1977	299	409	283	115	100	62	55	45	35	27	93
1978	1,486	221	297	187	69	63	43	39	32	25	88
1979	446	1,099	160	186	116	43	42	30	28	24	83
1980	321	330	810	114	118	75	30	30	22	21	79
1981	370	238	244	583	77	78	52	21	22	16	73
1982	254	274	176	177	414	54	54	34	15	16	66
1983	341	188	203	129	128	285	38	39	25	11	61
1984	449	253	139	149	94	92	202	27	28	18	53
1985	552	333	186	101	105	64	60	133	19	20	52
1986	456	409	245	129	67	69	42	39	89	13	52
1987	576	338	301	173	89	46	46	27	25	59	46
1988	388	426	249	215	121	61	32	32	19	17	73
1989	1,418	288	314	178	143	83	43	22	23	13	65
1990	614	1,050	212	228	124	100	59	31	16	16	57
1991	327	454	776	153	159	88	72	43	23	12	54
1992	536	242	336	567	106	107	59	50	30	16	48
1993	1,042	397	179	244	387	70	72	41	35	22	46
1994	363	772	293	129	166	249	44	46	27	24	47
1995	394	269	570	211	88	104	154	27	28	17	47
1996	952	291	198	405	132	53	61	86	15	16	39
1997	186	705	215	142	250	76	28	29	39	8	33
1998	342	138	521	155	95	149	47	17	18	25	27
1999	911	253	102	375	101	57	87	26	10	10	32
2000	1,941	675	187	74	244	65	36	55	15	6	28
2001	1,174	1,438	499	132	49	157	42	23	33	10	23
2002	1,309	870	1,062	353	85	29	92	24	13	21	23
2003	289	969	642	766	239	55	18	54	15	9	30
2004	382	214	716	460	523	158	35	11	34	10	28
2005	511	283	158	513	313	348	105	23	7	24	27
2006	330	379	208	113	349	208	231	70	16	5	36
2007	741	244	277	143	77	230	136	152	48	11	30
2008	546	548	179	190	95	51	152	88	102	33	29
2009	197	404	401	122	126	63	33	96	56	67	44
2010	356	145	295	271	76	75	38	19	56	35	74
2011	415	263	106	203	162	44	44	22	11	35	74
2012	382	307	194	76	135	101	27	28	14	7	72
2013	439	283	226	139	52	82	57	16	17	9	49
Average	596	443	329	232	156	103	67	43	29	20	51

Table 17.13. Estimates of Atka mackerel biomass in metric tons with approximate lower and upper 95% confidence bounds for age 1+ biomass (labeled as LCI and UCI; computed for period 1977-2013). Also included are female spawning biomass in metric tons from the current recommended assessment model Model 2 (1977-2014) compared to last year's (2012) assessment results.

	Current assessment age 1+ biomass (t)			Age 3+ biomass (t)		Female spawning biomass (t)	
Year	Estimate	LCI	UCI	Current	2012	Current	2012
1977	584,496	376,251	908,000	508,709	284,202	166,432	117,160
1978	612,097	388,307	964,861	511,845	293,986	160,350	121,490
1979	647,187	404,327	1,035,920	459,482	350,526	156,533	134,230
1980	708,880	442,507	1,135,600	644,062	586,055	165,412	155,900
1981	737,482	459,051	1,184,790	684,587	598,774	211,768	219,100
1982	674,216	417,930	1,087,660	620,979	569,903	217,269	227,240
1983	631,732	391,095	1,020,430	587,724	541,257	209,278	215,080
1984	609,653	380,037	978,000	550,998	542,299	194,367	193,290
1985	571,236	354,271	921,076	495,748	459,498	169,724	161,300
1986	550,841	342,037	887,114	468,031	393,806	151,095	135,480
1987	564,946	354,011	901,565	487,597	511,830	151,932	133,150
1988	570,955	366,460	889,563	488,529	402,766	155,397	134,390
1989	619,100	413,345	927,276	511,701	535,768	161,613	143,170
1990	703,791	490,613	1,009,600	516,109	669,840	173,361	160,840
1991	783,411	563,672	1,088,810	699,411	581,944	187,422	181,000
1992	819,909	598,423	1,123,370	758,922	842,580	228,802	226,570
1993	786,707	575,867	1,074,740	679,479	769,345	227,094	227,500
1994	764,107	557,788	1,046,740	630,072	619,553	202,711	204,650
1995	748,250	542,886	1,031,300	689,584	574,960	184,700	187,870
1996	698,195	496,139	982,539	611,048	551,043	173,044	176,530
1997	601,178	411,418	878,460	485,237	548,152	151,749	153,530
1998	592,652	402,542	872,545	556,278	488,682	145,203	147,280
1999	573,271	385,913	851,590	493,857	525,869	154,603	157,410
2000	617,880	421,903	904,890	427,967	472,965	139,958	141,130
2001	780,906	548,491	1,111,800	508,944	524,728	136,105	133,730
2002	983,469	703,880	1,374,120	792,124	584,564	176,725	161,130
2003	1,106,420	802,683	1,525,090	945,576	662,257	253,824	214,570
2004	1,087,140	789,254	1,497,470	1,037,326	765,487	298,583	245,370
2005	1,013,570	730,085	1,407,130	947,472	679,676	319,943	258,690
2006	883,428	628,402	1,241,950	810,869	581,996	285,825	225,250
2007	798,124	562,065	1,133,320	727,639	593,775	247,858	193,020
2008	740,755	518,674	1,057,920	632,615	483,864	215,237	168,940
2009	685,535	474,208	991,039	615,066	507,992	183,574	147,040
2010	605,232	406,848	900,350	567,089	473,973	166,742	141,320
2011	519,711	335,863	804,196	460,954	461,903	152,826	132,870
2012	470,637	297,682	744,080	406,694	347,965	127,118	113,350
2013	447,189	274,663	728,086	384,364	288,936	118,446	103,034
2014	456,620	280,456	743,441	387,308		117,171	

Table 17.14. Estimates of age-1 Atka mackerel recruitment (millions of recruits) and standard deviation (Std. dev.) from Model 2.

	Age 1 Recruits		
Year	Current	Std. dev	2012 assessment
1977	299	87	289
1978	1,486	361	1,732
1979	446	121	419
1980	321	92	258
1981	370	103	273
1982	254	74	185
1983	341	93	260
1984	449	115	359
1985	552	135	517
1986	457	113	444
1987	576	126	641
1988	388	87	405
1989	1,418	212	1,469
1990	614	112	630
1991	327	69	319
1992	536	94	555
1993	1,042	155	1028
1994	363	73	359
1995	394	80	385
1996	952	158	995
1997	186	43	172
1998	342	72	330
1999	911	168	766
2000	1,941	303	1,550
2001	1,174	188	1006
2002	1,309	199	1,114
2003	289	61	242
2004	382	74	341
2005	511	94	486
2006	330	65	335
2007	741	129	793
2008	546	113	499
2009	197	55	206
2010	356	101	314
2011	415	125	360
2012	382	159	385
2013	439	192	
Average 78-12	609		575
Median 78-12	446		405

Table 17.15. Estimates of full-selection fishing mortality rates and exploitation rates for Atka mackerel from Model 2.

Year	*F*	Catch/Biomass Rate[b]
1977	0.214	0.043
1978	0.178	0.047
1979	0.154	0.051
1980	0.113	0.032
1981	0.118	0.029
1982	0.071	0.032
1983	0.044	0.020
1984	0.129	0.065
1985	0.121	0.076
1986	0.143	0.068
1987	0.079	0.062
1988	0.107	0.045
1989	0.060	0.035
1990	0.063	0.043
1991	0.098	0.038
1992	0.116	0.064
1993	0.171	0.097
1994	0.191	0.104
1995	0.293	0.118
1996	0.485	0.170
1997	0.218	0.136
1998	0.279	0.103
1999	0.230	0.114
2000	0.201	0.110
2001	0.255	0.121
2002	0.236	0.057
2003	0.183	0.057
2004	0.107	0.058
2005	0.111	0.065
2006	0.124	0.076
2007	0.133	0.081
2008	0.167	0.092
2009	0.263	0.118
2010	0.242	0.121
2011	0.187	0.112
2012	0.268	0.125
2013	0.151	0.067

[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 291,028 t, 116,411 t, and 101,860 t, respectively.

Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2013	25,920	25,920	25,920	25,920	25,920	25,920	25,920
2014	35,500	35,500	35,500	35,500	35,500	74,492	64,131
2015	33,600	33,600	33,600	33,600	33,600	59,345	54,318
2016	70,841	70,841	23,434	19,707	0	59,204	64,457
2017	68,770	68,770	26,592	22,586	0	67,867	69,982
2018	72,880	72,880	30,464	26,051	0	76,457	77,218
2019	76,245	76,245	33,478	28,779	0	81,233	81,498
2020	77,739	77,739	35,307	30,466	0	83,168	83,257
2021	78,443	78,443	36,522	31,602	0	83,841	83,871
2022	78,356	78,356	37,308	32,357	0	83,455	83,464
2023	77,794	77,794	37,586	32,661	0	82,696	82,698
2024	77,252	77,252	37,732	32,831	0	82,135	82,136
2025	77,062	77,062	37,905	33,012	0	81,984	81,984
2026	77,369	77,369	38,113	33,212	0	82,410	82,410

Fishing M	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2013	0.145	0.145	0.145	0.145	0.145	0.145	0.145
2014	0.205	0.205	0.205	0.205	0.205	0.467	0.393
2015	0.189	0.189	0.189	0.189	0.189	0.407	0.354
2016	0.401	0.401	0.122	0.102	0.000	0.404	0.422
2017	0.387	0.387	0.122	0.102	0.000	0.427	0.434
2018	0.385	0.385	0.122	0.102	0.000	0.439	0.441
2019	0.388	0.388	0.122	0.102	0.000	0.448	0.449
2020	0.390	0.390	0.122	0.102	0.000	0.453	0.453
2021	0.391	0.391	0.122	0.102	0.000	0.454	0.454
2022	0.390	0.390	0.122	0.102	0.000	0.452	0.452
2023	0.391	0.391	0.122	0.102	0.000	0.453	0.453
2024	0.390	0.390	0.122	0.102	0.000	0.452	0.452
2025	0.389	0.389	0.122	0.102	0.000	0.451	0.451
2026	0.389	0.389	0.122	0.102	0.000	0.451	0.451

Spawning biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2013	118,587	118,587	118,587	118,587	118,587	118,587	118,587
2014	117,171	117,171	117,171	117,171	117,171	106,196	109,169
2015	115,640	115,640	115,640	115,640	115,640	93,498	98,869
2016	112,418	112,418	124,917	125,873	130,865	92,896	96,785
2017	114,075	114,075	143,420	145,922	159,532	100,234	102,026
2018	116,530	116,530	159,308	163,272	185,607	105,031	105,789
2019	118,784	118,784	173,147	178,508	209,658	107,788	108,110
2020	120,662	120,662	184,455	191,059	230,479	109,628	109,757
2021	121,825	121,825	192,675	200,287	246,767	110,626	110,673
2022	120,987	120,987	196,936	205,349	257,706	109,683	109,698
2023	120,781	120,781	200,573	209,641	267,027	109,448	109,452
2024	120,311	120,311	202,316	211,822	272,801	109,024	109,025
2025	120,109	120,109	203,413	213,227	276,905	108,877	108,877
2026	121,109	121,109	205,347	215,391	281,171	109,873	109,873

Table 17.17. Ecosystem effects. *This table was not updated; it will be updated for 2014*.

Ecosystem effects on Atka mackerel			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Zooplankton	Stomach contents, ichthyoplankton surveys	None	Unknown
Predator population trends			
Marine mammals	Fur seals declining, Steller sea lions increasing slightly	Possibly lower mortality on Atka mackerel	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	2012 AI summer bottom temperature was well below average (similar to 2000)	Could possibly affect fish distribution	Unknown

***The Atka mackerel* effects on ecosystem**			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	Stable, heavily monitored	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. Fishery has expanded and concentrates in other 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 The Atka mackerel fishery contributes an average of 363 and 233 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

Figures

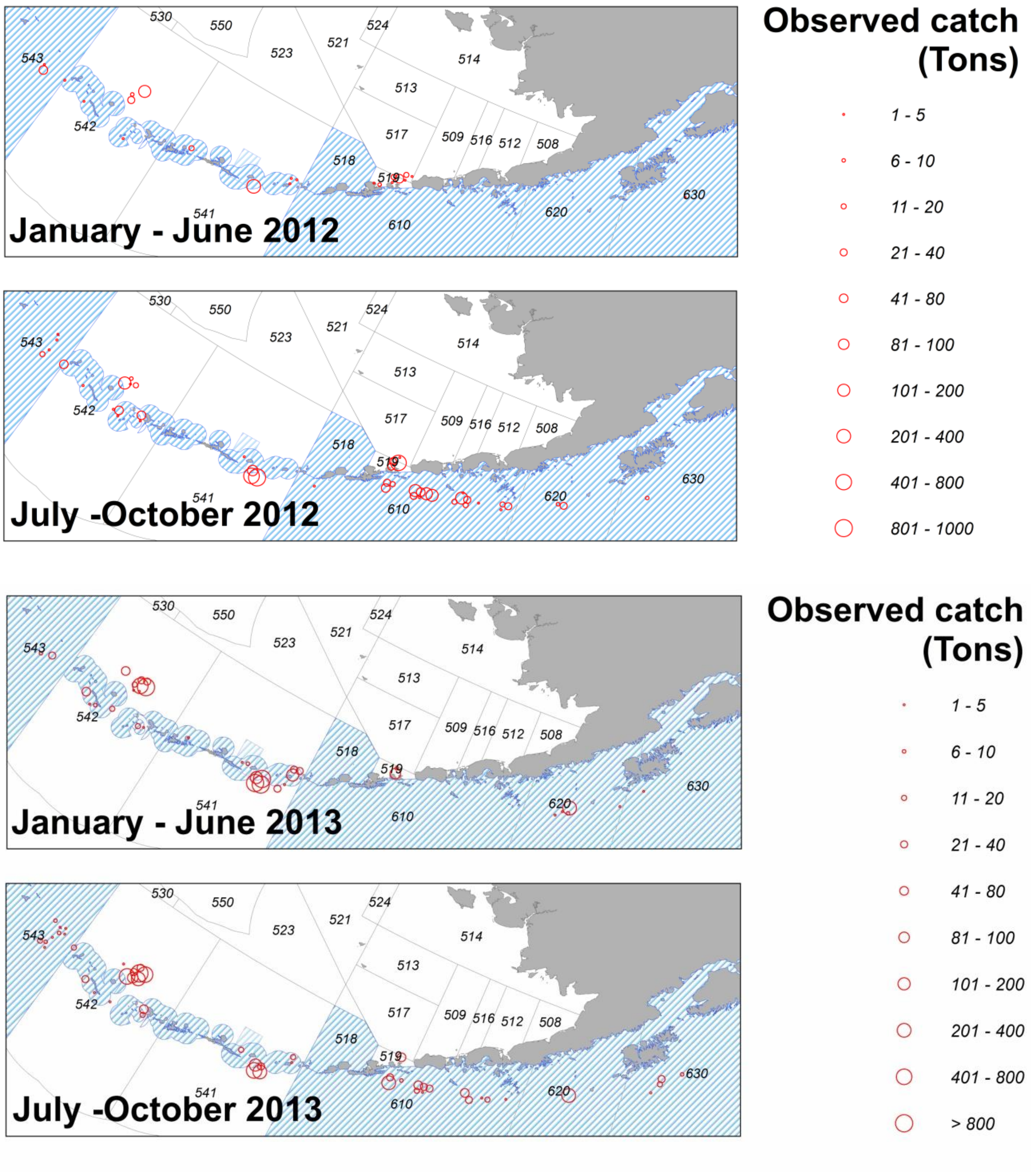


Figure 17.1. Observed catches of Atka mackerel summed for 20 km^2 cells for 2012 and 2013 where observed catch per haul was greater than 1 t. Shaded areas represent areas closed to directed Atka mackerel fishing.

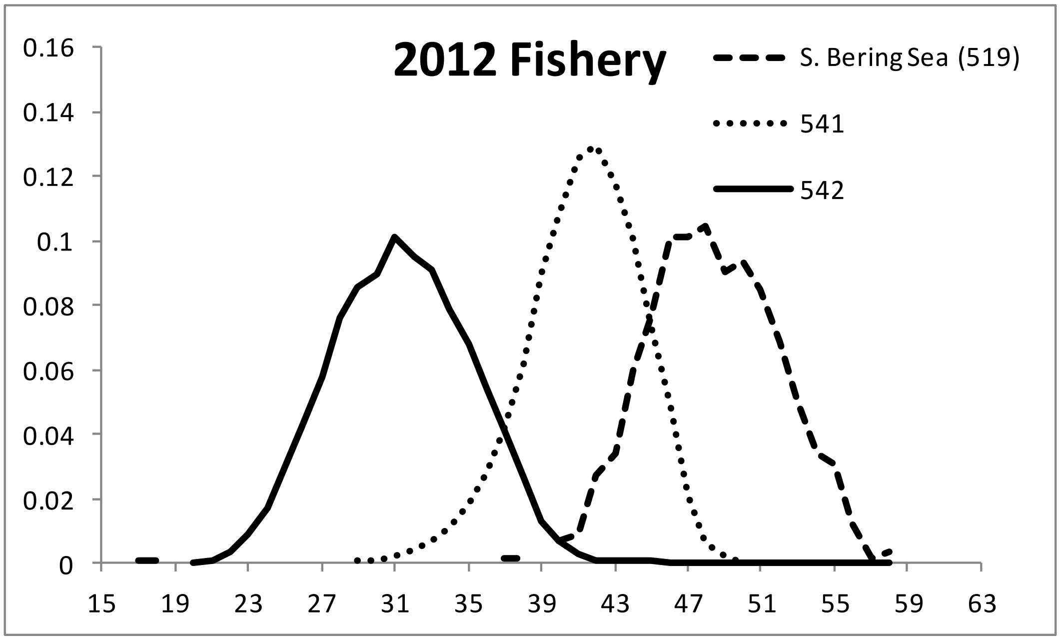


Figure 17.2. 2012 Atka mackerel fishery length-frequency data by area fished (see Figure 17.1). Numbers refer to management areas. Too few fish were measured in area 543 for presentation.

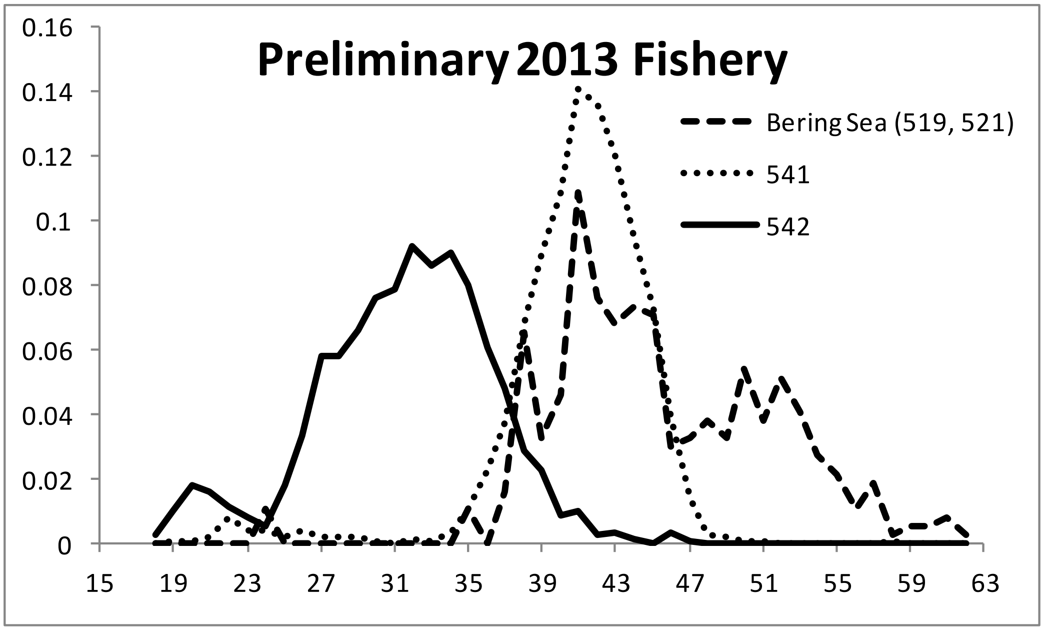


Figure 17.3. Preliminary 2013 Atka mackerel fishery length-frequency data by area fished (see Figure 17.1). Too few fish were measured in area 543 for presentation. Numbers refer to management areas.

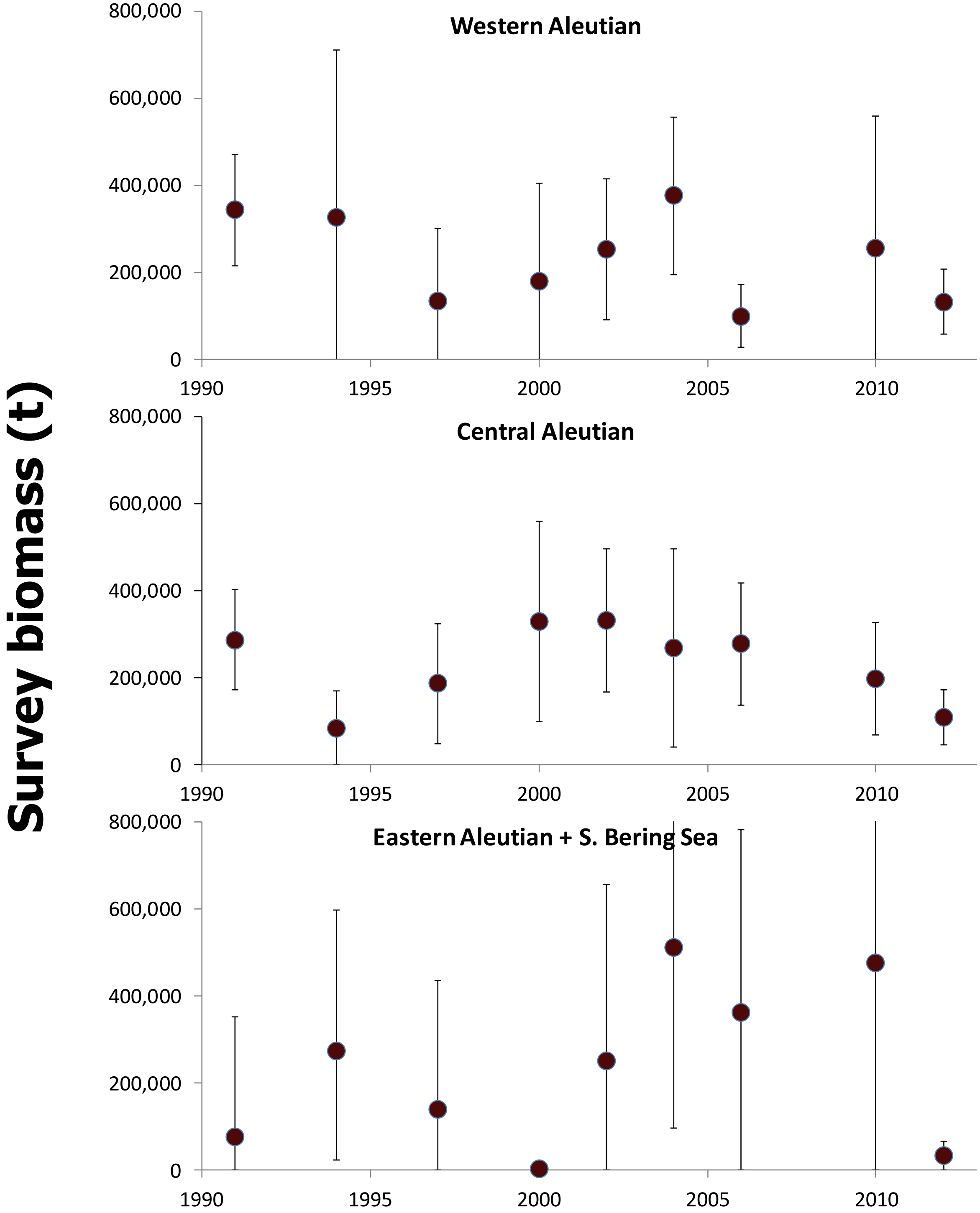


Figure 17.4. Atka mackerel Aleutian Islands survey biomass estimates by area and survey year. Bars represent 95% confidence intervals based on sampling error.

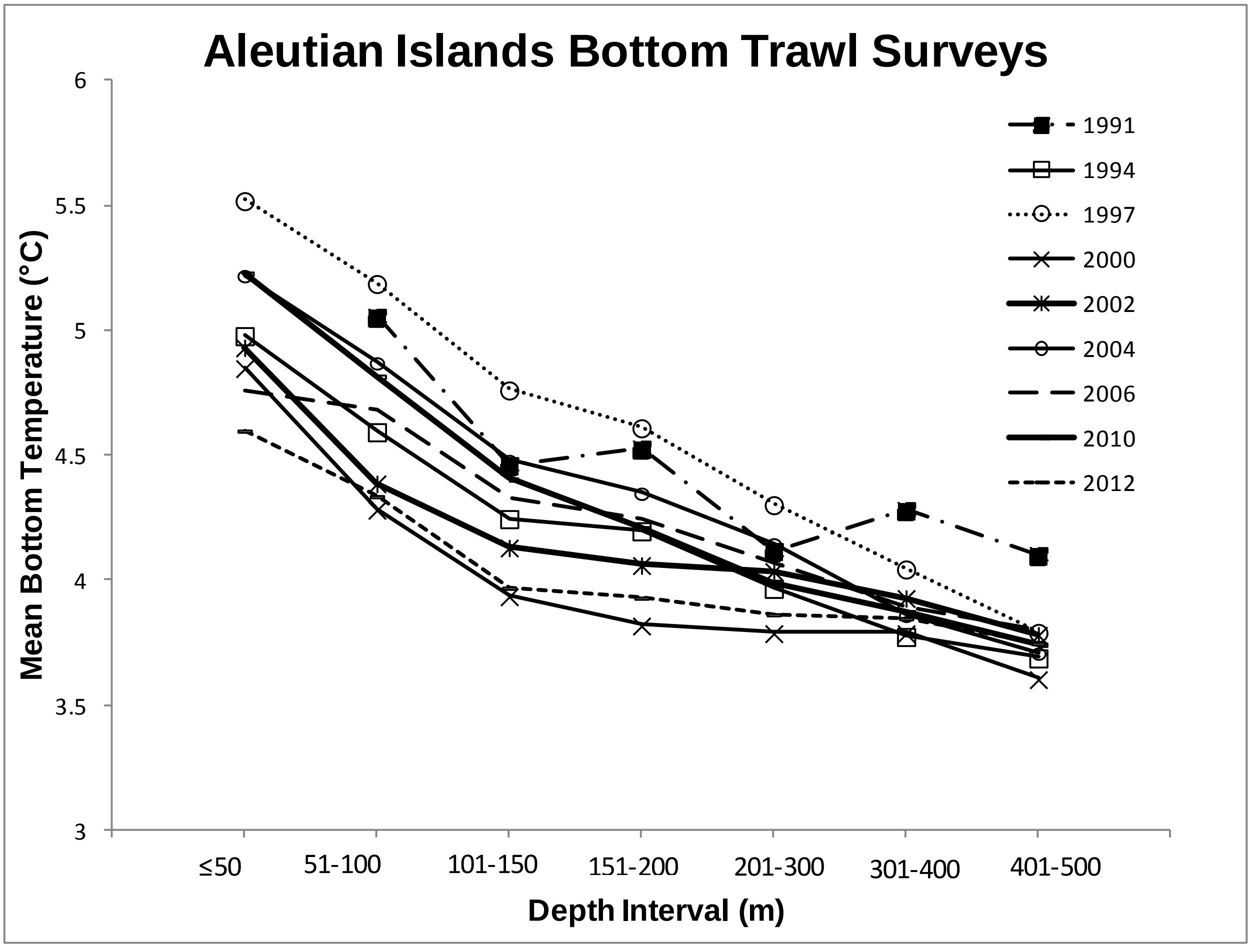


Figure 17.5. Average bottom temperatures by depth interval from Aleutian Islands summer bottom-trawl surveys, 1991 to 2012.

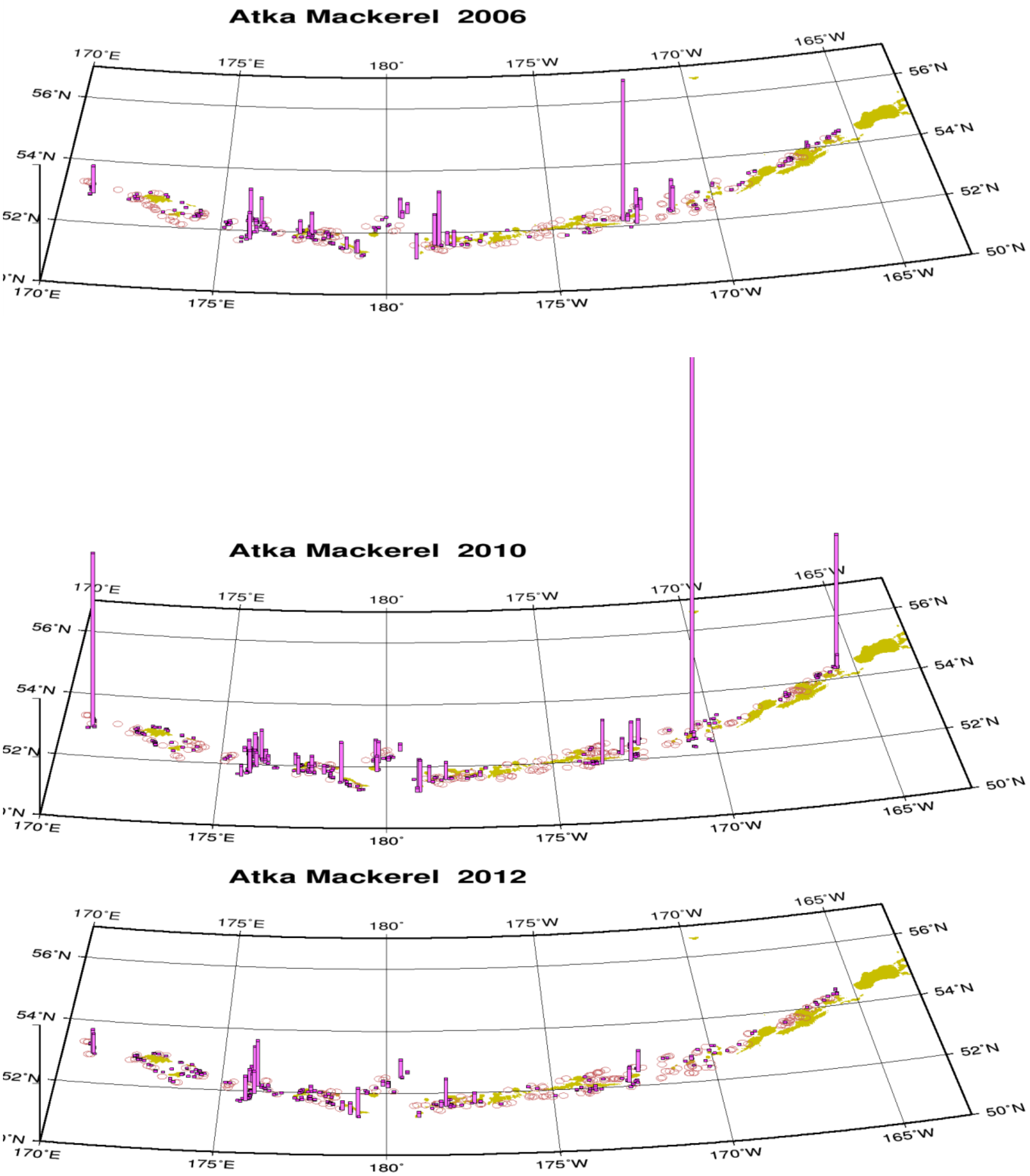


Figure 17.6. Bottom-trawl survey CPUE distributions of Atka mackerel catches during the summers of 2004, 2006, and 2010.

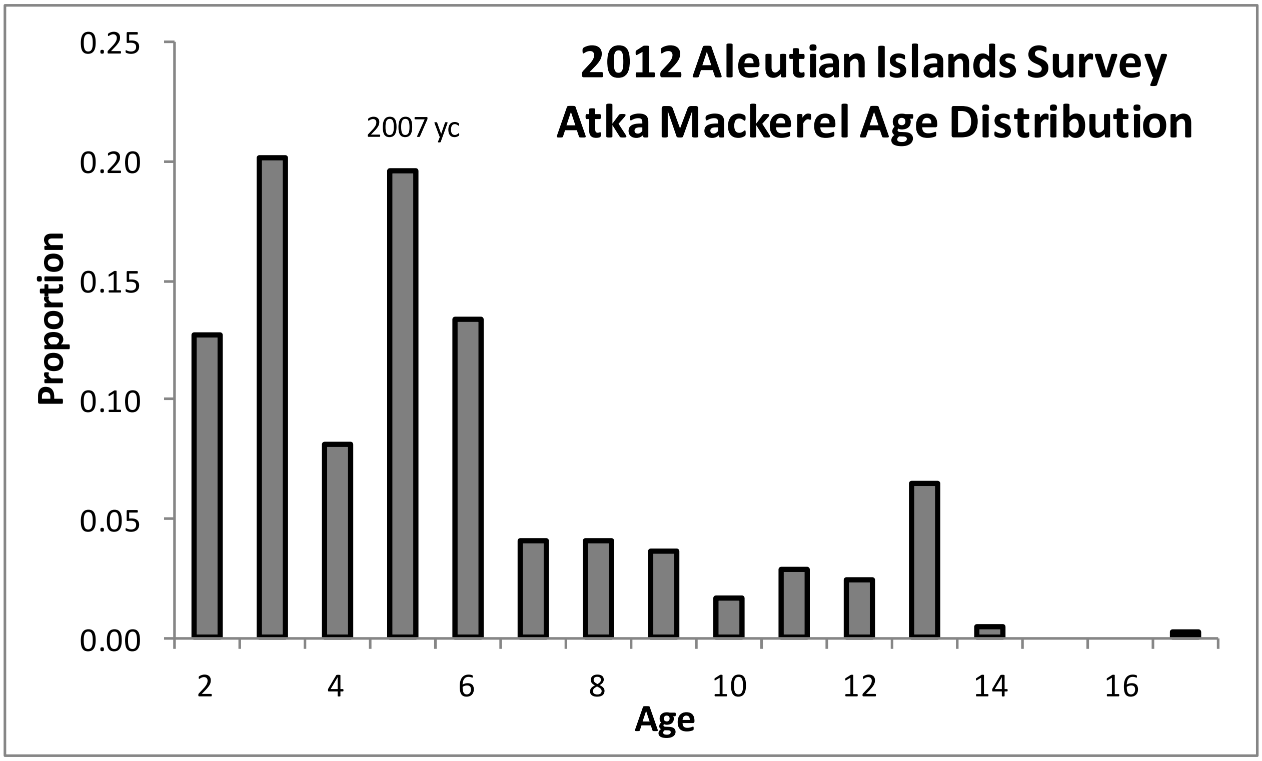


Figure 17.7 Atka mackerel age distribution from the Aleutian Islands 2012 bottom trawl survey. A total of 417 otoliths were aged; mean age from the 2012 survey is 5.6 years.

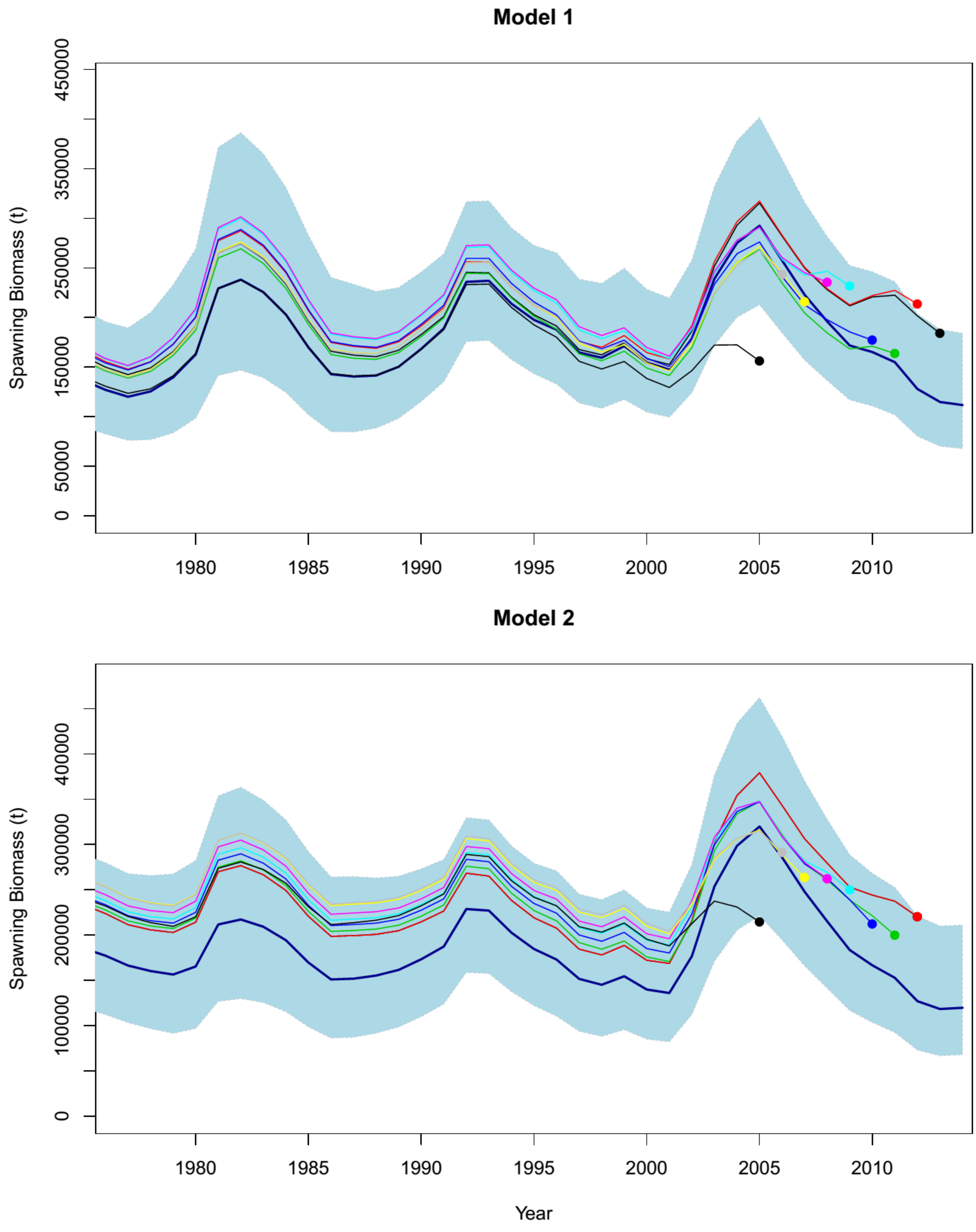


Figure 17.8. Retrospective patterns for BSAI Atka mackerel spawning biomass for Model 1 (top) and Model 2 (bottom).

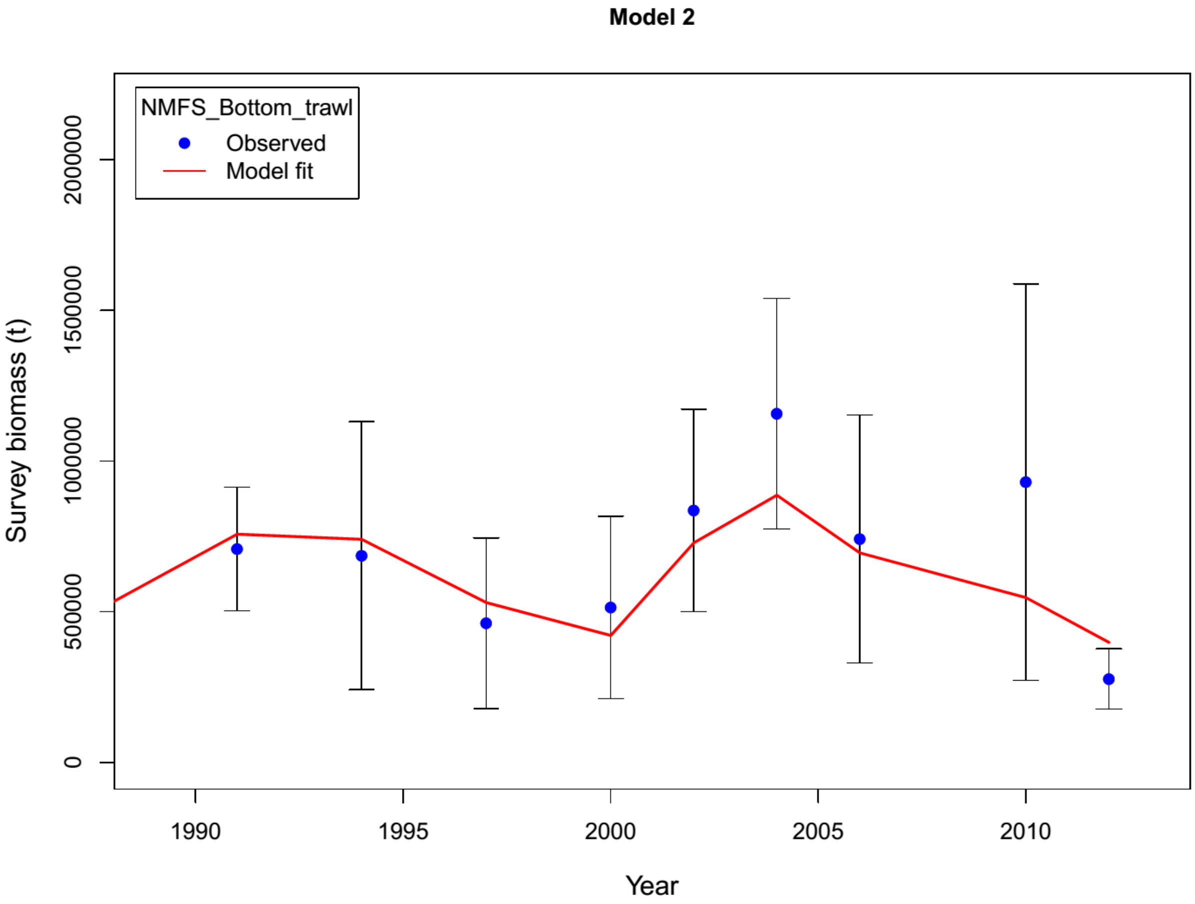


Figure 17.9 Observed (dots) and predicted (trend line) survey biomass estimates (t) for Bering Sea/Aleutian Islands Atka mackerel. Error bars represent two standard errors (based on sampling) from the survey estimates.

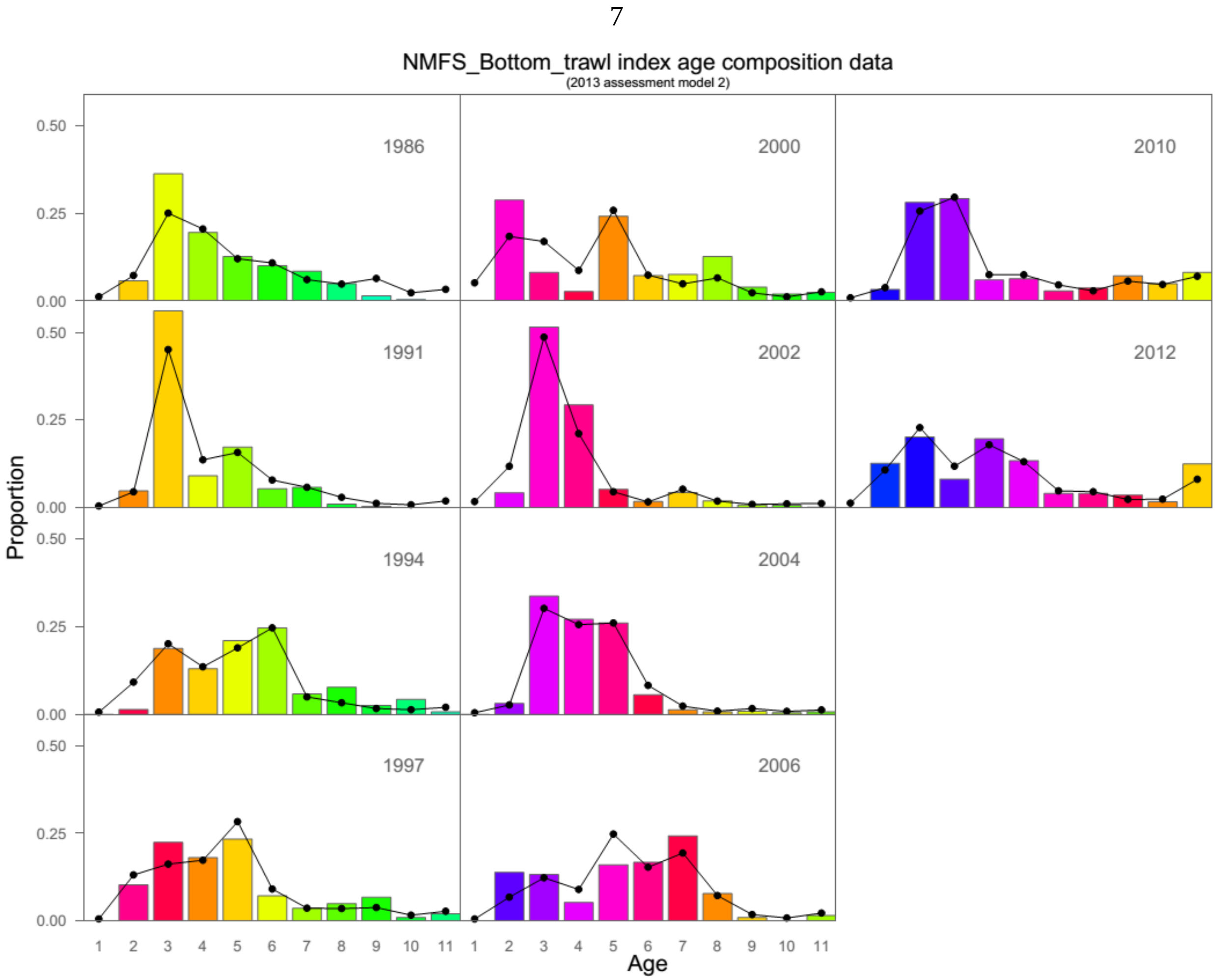


Figure 17.10. Observed and predicted **survey** proportions-at-age for BSAI Atka mackerel. Lines with "•" symbol are the model predictions and columns are the observed proportions at age for Model 2.

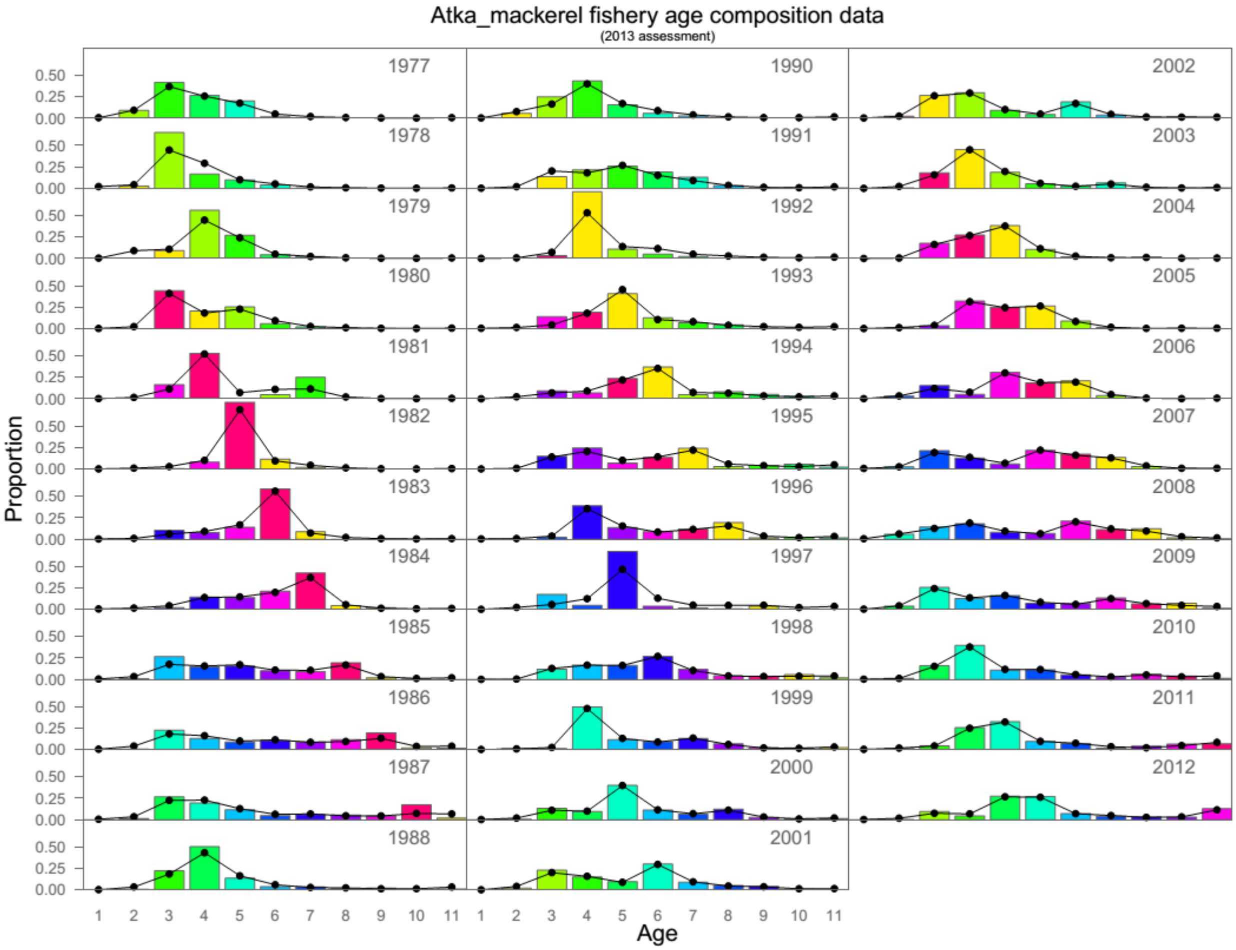


Figure 17.11 Observed and predicted Atka mackerel **fishery** proportions-at-age for BSAI Atka mackerel. Lines with "•" symbol are the model predictions and columns are the observed proportions at age (with colors corresponding to cohorts) for Model 2.

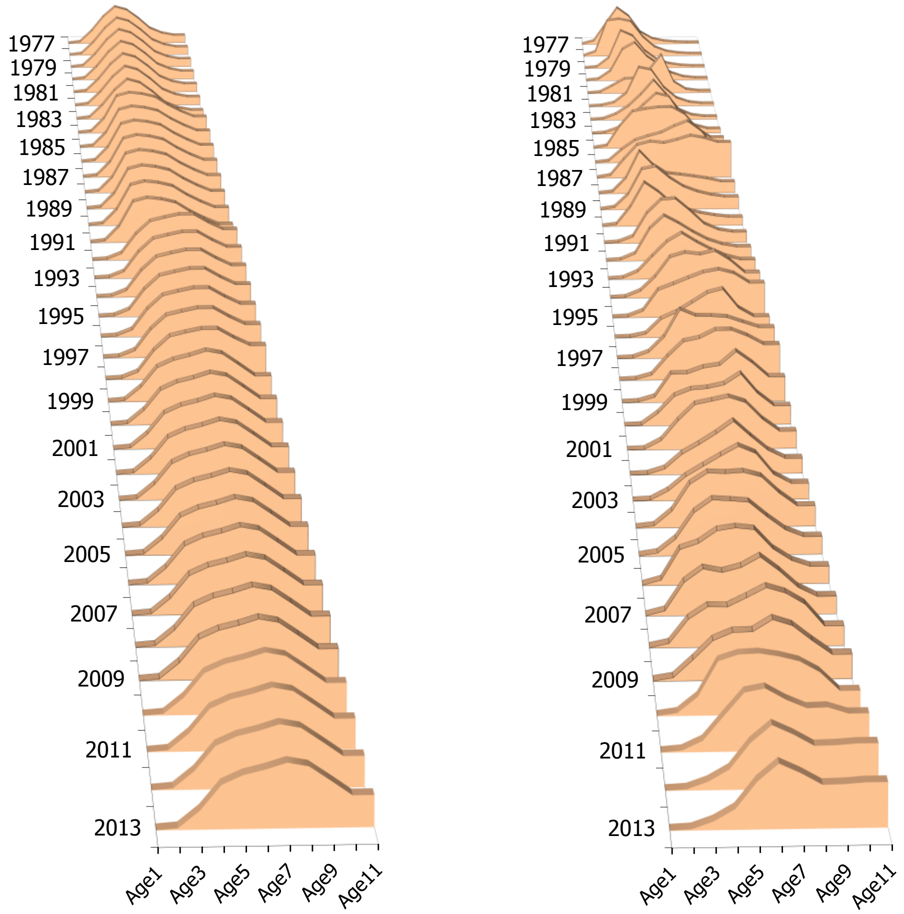


Figure 17.12. Fishery selectivity pattern from the BSAI Atka mackerel assessment models. Left panel (Model 1) is the selectivity pattern from last year's model configuration with updated fishery and survey information. Right panel (Model 2) is the selectivity pattern from the current recommended model configuration with updated fishery and survey information.

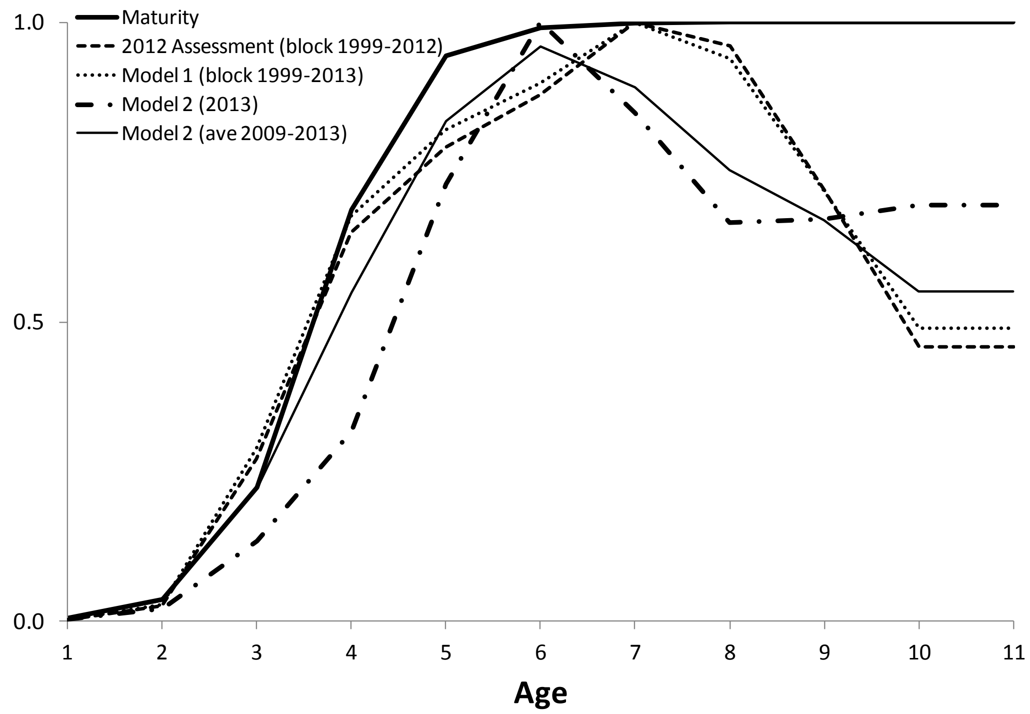


Figure 17.13. Estimated fishery selectivity patterns in the current assessment with a) last year's model configuration with updated data (terminal year, Model 1), b) the recommended model configuration with updated data (terminal year, Model 2), c) the average selectivity for 2009-2013 (used for projections), and last year's assessment (2012 assessment) compared with the maturity-at-age estimates for BSAI Atka mackerel. Selectivity estimates have been normalized to a maximum of 1.0 for presentation.

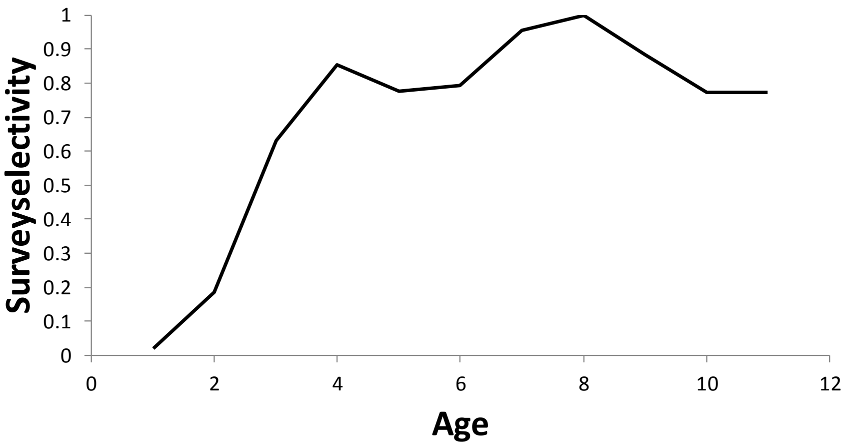


Figure 17.14. Estimated BSAI Atka mackerel survey selectivity-at-age (post 1999) from the current recommended model configuration (Model 2). Selectivity estimates have been normalized to a maximum value of 1.0 for presentation.

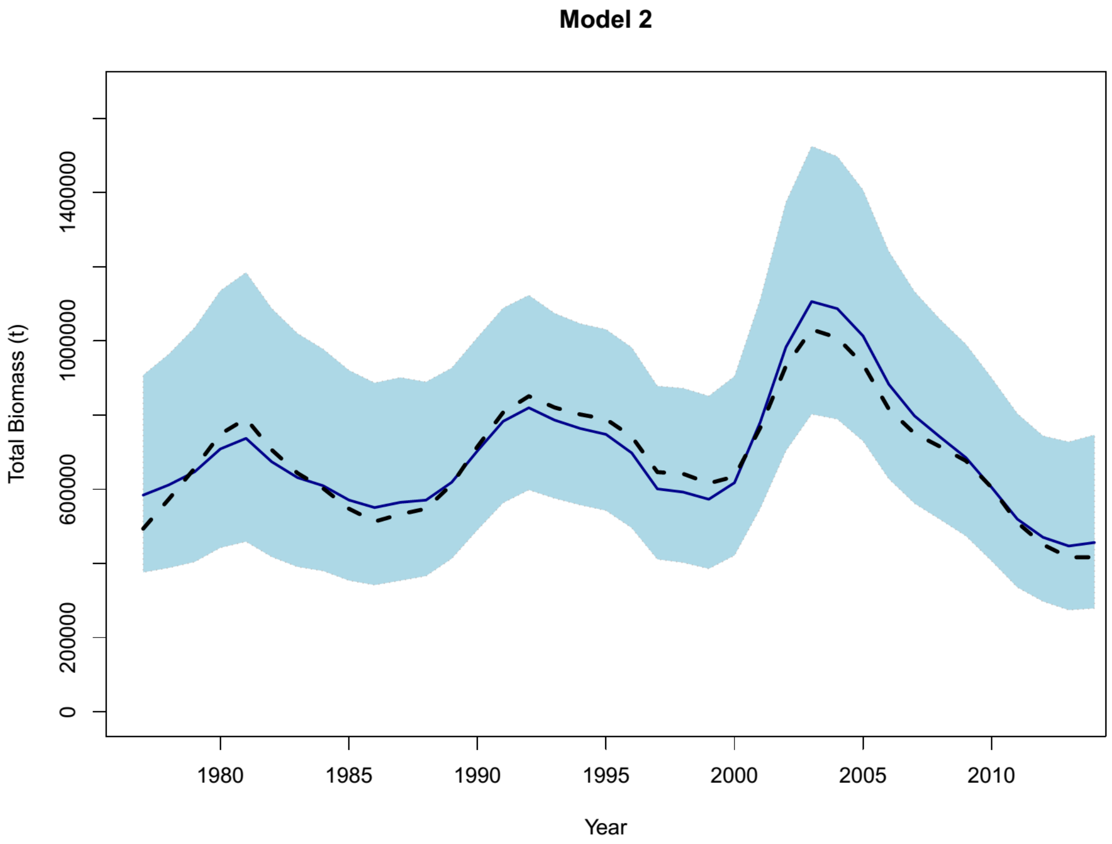


Figure 17.15. Time series of estimated Aleutian Islands Atka mackerel total (age 1+) biomass and approximate 95% confidence bounds from the recommended Model 2 (solid line), and comparison of age 1+ biomass estimated under Model 1 (dashed line).

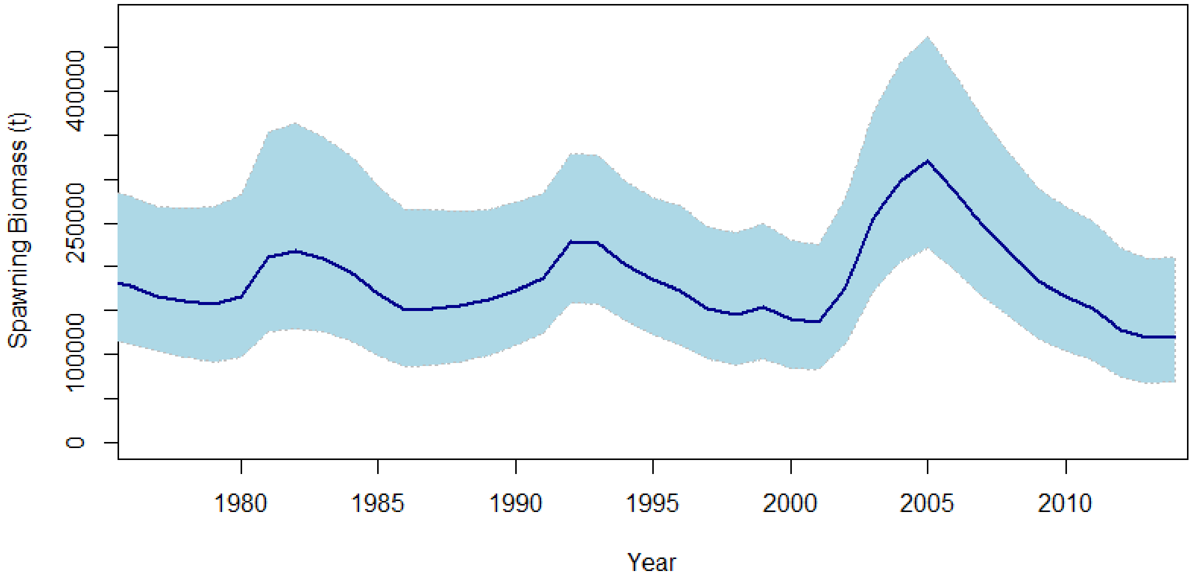


Figure 17.16. Estimated female spawning biomass from the current assessment recommended model (Model 2) with approximate 90% confidence intervals_for BSAI Atka mackerel.

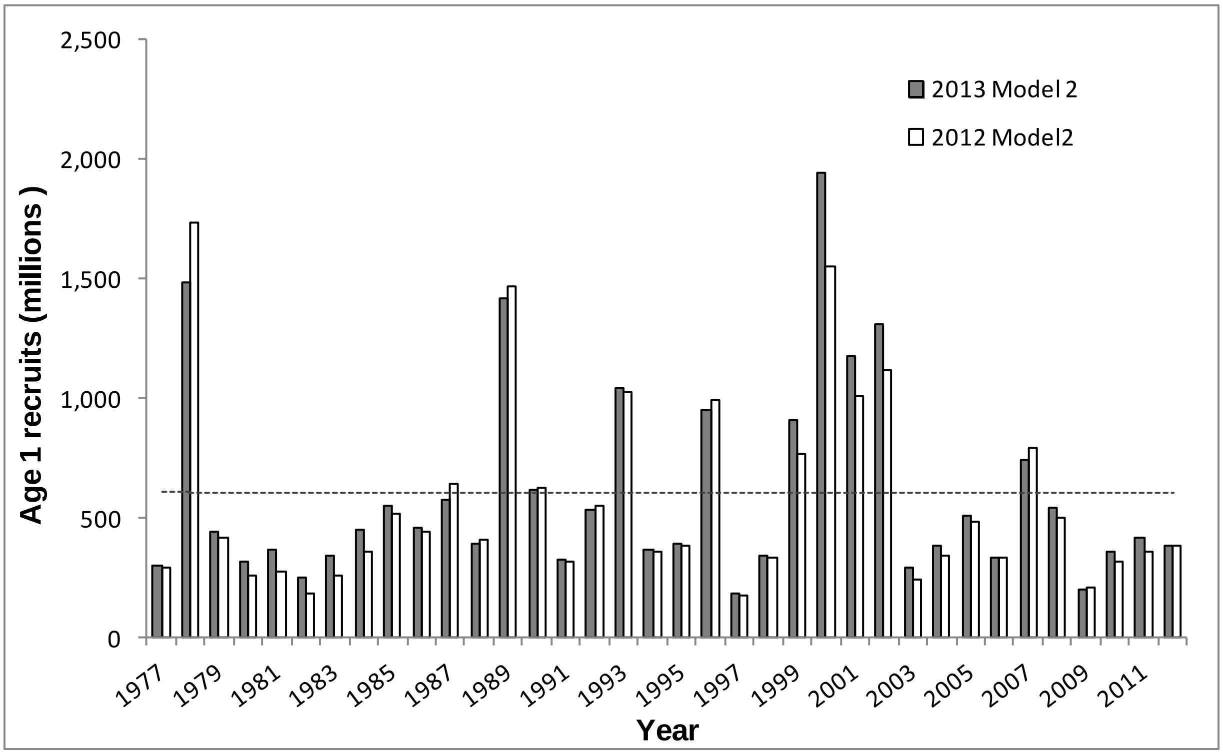


Figure 17.17. Age 1 recruitment from the current assessment recommended model (2013 Model 2) with the dashed line indicating average recruitment (609 million) over 1978-2012, and age 1 recruitment as estimated from the 2012 model configuration (2012 Model 2).

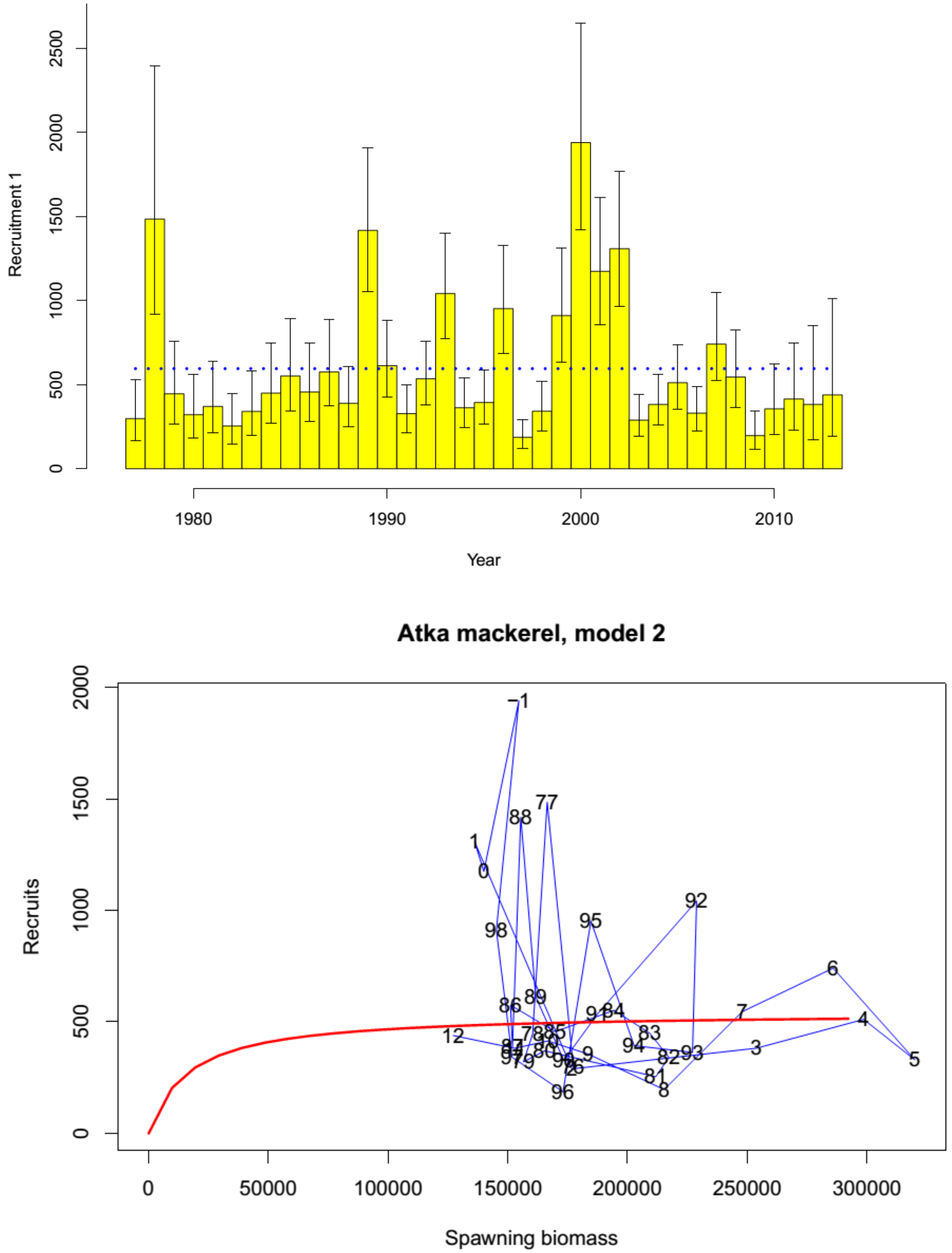


Figure 17.18. Age 1 recruitment of Atka mackerel as estimated from the current assessment recommended model (Model 2), with error bars representing two standard errors (top panel) and the solid line indicating average recruitment (582 million) over 1978-2013, and estimated female spawning biomass levels in thousands of metric tons (lower panel). Solid line represents the underlying Beverton-Holt stock recruitment curve assumed in the model.

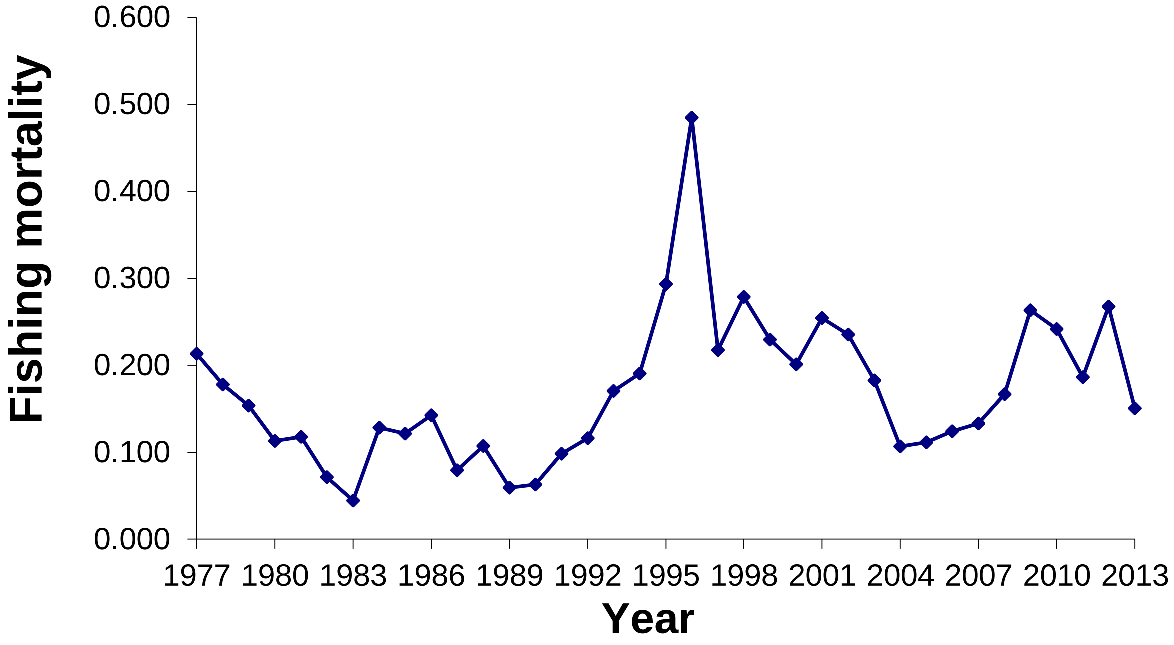


Figure 17.19. Estimated time series of Model 2 full-selection fishing mortality rates of Atka mackerel, 1977-2013.

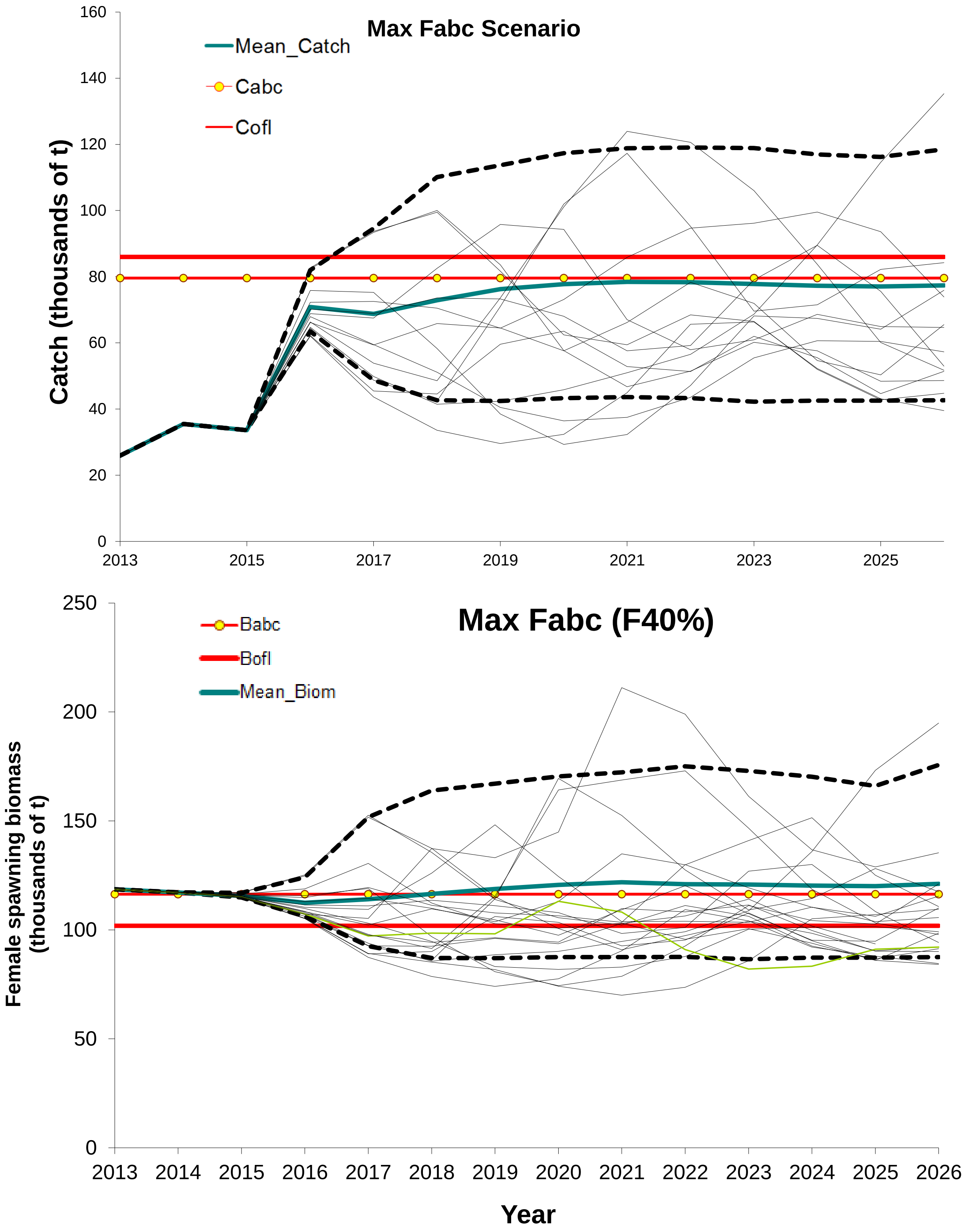


Figure 17.20. Projected Atka mackerel catch (assuming 64% of ABC taken in 2014 and 2015; top) and spawning biomass (bottom) in thousands of metric tons under maximum permissible Tier 3a harvest levels for Model 2. The individual thin lines represent samples of simulated trajectories.

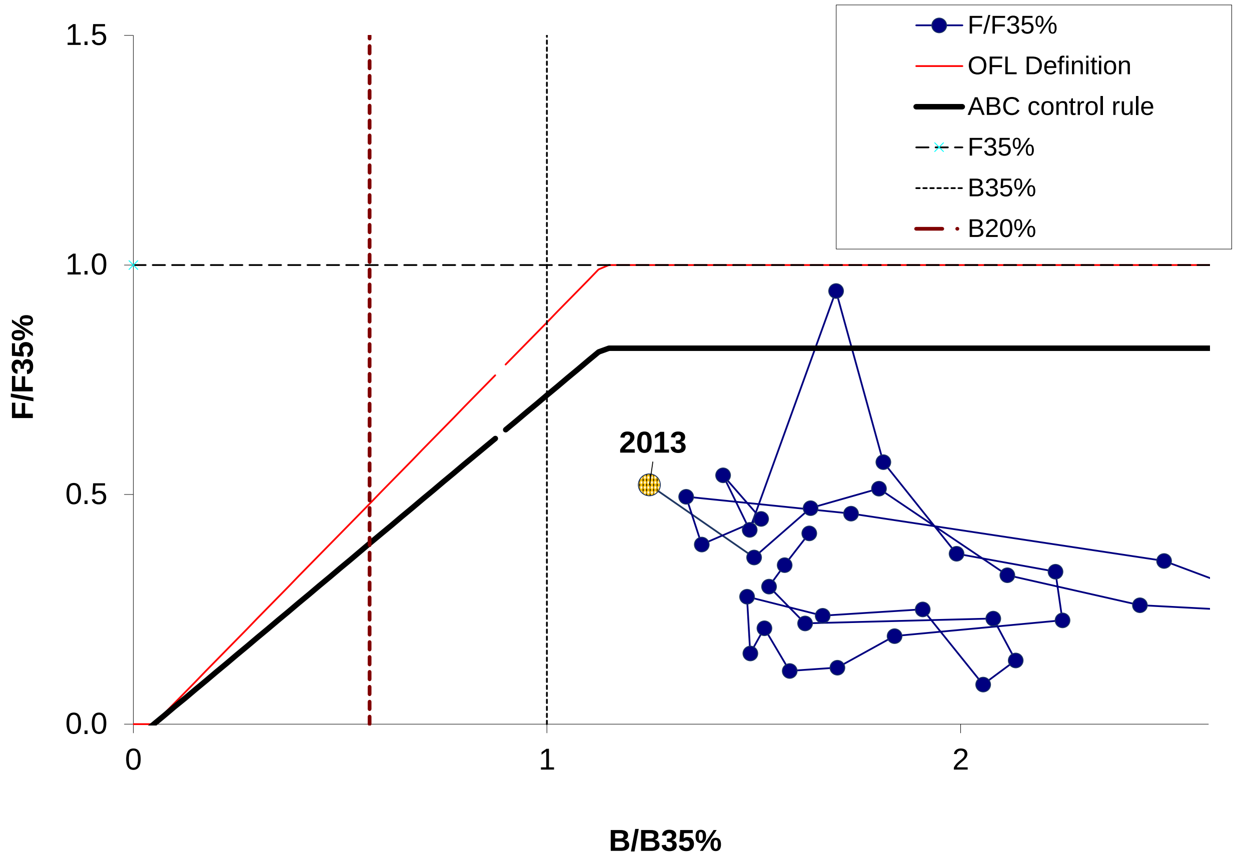


Figure 17.21. Aleutian Islands Atka mackerel spawning biomass relative to $B_{35\%}$ and fishing mortality relative to F_{OFL} (1977-2013). The ratio of fishing mortality to F_{OFL} is calculated using the estimated selectivity pattern in that year. Estimates of spawning biomass and $B_{35\%}$ are based 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.

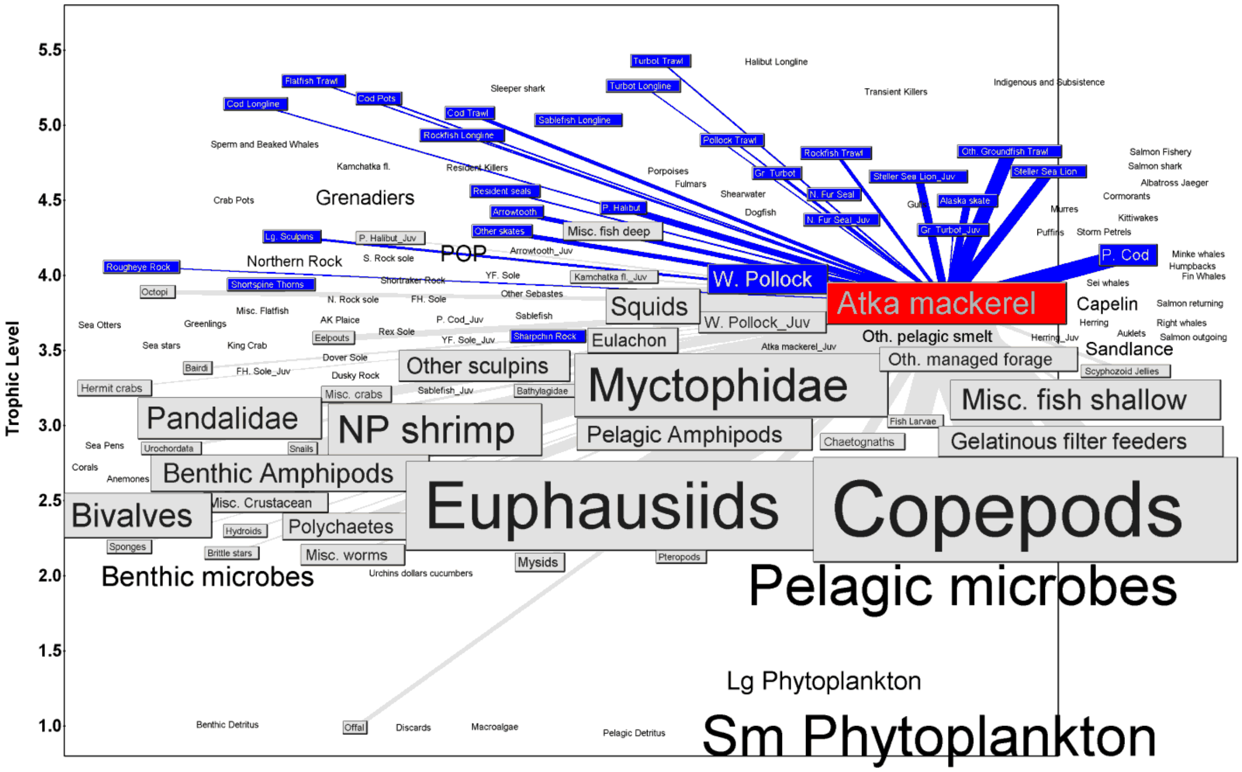
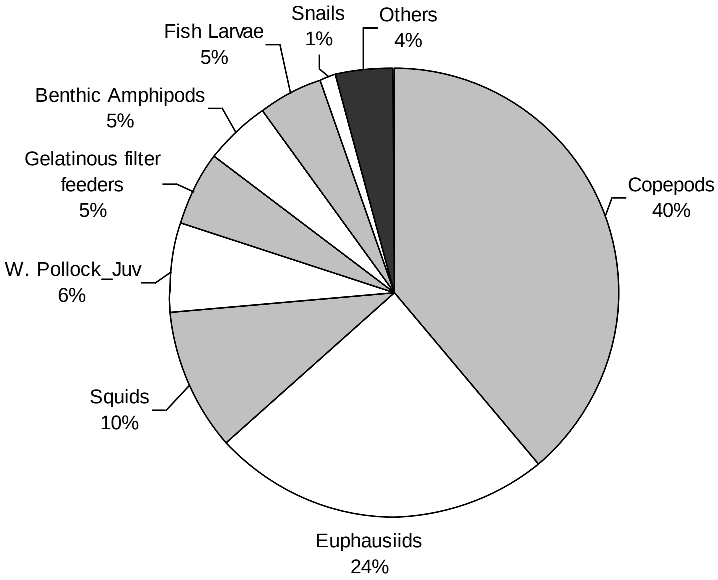
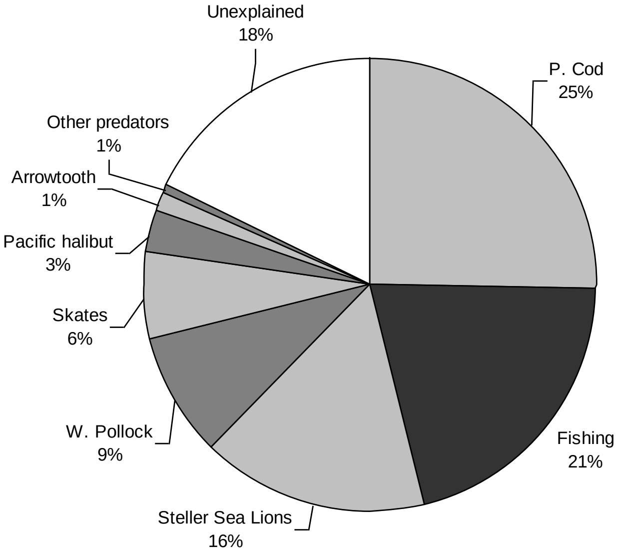


Figure 17.22. The food web of the Aleutian Islands survey region, 1990-1994, emphasizing the position of age 1+ Atka mackerel. Outlined species represent predators of Atka mackerel (dark boxed with light text) and prey of Atka mackerel (light boxes with dark text). Box and text size are proportional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



(A)



(B)

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

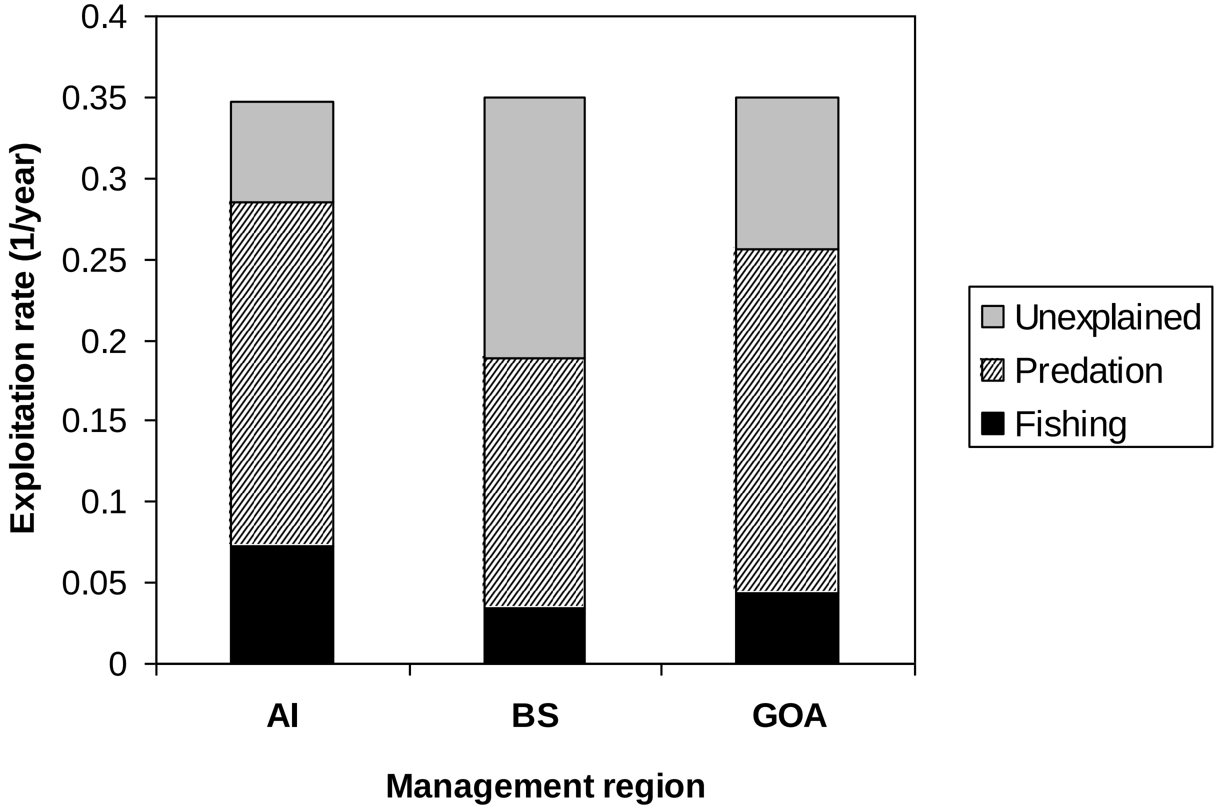


Figure 17.24. Total exploitation rate of age 1+ Atka mackerel, 1990-1994, proportioned into exploitation by fishing (black), predation (striped) and "unexplained" mortality (grey). "Unexplained" mortality is the difference between the stock assessment total exploitation rate averaged for 1990-1994, and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

Appendix 17A

Table A-1. Variable descriptions and model specification.

General Definitions	Symbol/Value	Use in Catch at Age Model
Year index: $i = \{1977, \ldots., 2013\}$	i	
Age index: $j = \{1, 2, 3, \ldots, A\}$	j	
Mean weight by age j	W_i	
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		
		$\phi_i(36),\ R_0,\ \varepsilon_i(46), \sigma_R^2,\ \mu^f, \mu^s,\ M,\ \eta_j^s(10),\ \eta_j^f(10), F_{50\%}, F_{40\%}, F_{30\%}, q^s$

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

Table A-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, …, 2013	$\varepsilon_i, \sum_{i=1967}^{2013} \varepsilon_i = 0$	$N_{i,1} = e^{\mu_R + \varepsilon_i}$
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*	$\phi_i, \sum_{i=1977}^{2012} \phi_i = 0$	
Age effect of fishing (regularized) in year time variation allowed	$\eta_{ij}^f, \sum_{j=1}^{A} \eta_{ij} = 0$	$s_{ij}^f = e^{\eta_j^f}, \quad j \le \text{maxage}$ $s_{ij}^f = e^{\eta_{\text{maxage}}^f} \quad j > \text{maxage}$
In years where selectivity is constant over time	$\eta_{i,j}^f = \eta_{i-1,j}^f$	$i \ne \text{change year}$
Natural Mortality	M	
Total mortality		$Z_{ij} = F_{ij} + M$
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 A-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	$L_4 = \lambda_4 \sum_{i=1967}^{2013} \varepsilon_i^{\,2} +$ $0.5 \sum_{t=1977}^{2011} \left(\ln R_t - \ln \hat{R}_t \right) / \sigma_R^2$	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	$L_5 = \lambda_5 \sum_{i=1977}^{2013} \ln\left(C_i^B / \hat{C}_i^B \right)^2$	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	$L_. = \lambda_6 \sum_{i=1978}^{2013} \phi_i^2$	(relaxed in final phases of estimation)
Priors	$L_7 = \left[\lambda_7 \frac{\ln\left(M / \hat{M} \right)^2}{2\sigma_M^2} + \lambda_8 \frac{\ln\left(q / \hat{q} \right)^2}{2\sigma_q^2} \right]$	Prior on natural mortality, and survey catchability (reference case assumption that *M is* precisely known at 0.3).
Overall objective function to be minimized	$\dot{L} = \sum_{i=1}^{7} L_i$	

Appendix 17B. 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 1977-2011 in Table 17B-1. Removals from activities other than directed fishing totaled 140 t in 2010 and 1,529 t in 2011. This is approximately 0.2 and 2.0% of the 2010 and 2011 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 2013 and 2014 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 17B-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
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				

Appendix 17C.

Table 17C-1. Summary table of Model 1 results:

Quantity	As estimated or *specified last* year for: 2013	2014	As estimated or *recommended this* year for: 2014	2015
M (natural mortality rate)	0.30	0.30	0.30	0.30
Tier	3b	3b	3b	3b
Projected total (age 3+) biomass (t)	288,936			
Female spawning biomass (t)				
Projected				
Upper 95% confidence interval			184,226	181,281
Point estimate	103,034[1]	100,998[1]	109,141	103,535
Lower 95% confidence interval			67,795	65,697
$B_{100\%}$	278,462	278,462	288,683	288,683
$B_{40\%}$	111,385	111,385	115,473	115,473
$B_{35\%}$	97,462	97,462	101,039	101,039
F_{OFL}	0.388	0.332	0.407	0.407
$maxF_{ABC}$	0.322	0.288	0.339	0.339
F_{ABC}	0.322	0. 288	0.339	0.339
OFL (t)	57,700	56,500[1]	63,974	59,111[1]
maxABC (t)	50,000	48,900[1]	55,525	51,150[1]
ABC (t)	50,000	48,900[1]	55,525	51,150[1]
Status	As determined *last* year for: 2011	2012	As determined *this* year for: 2012	2013
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

[1] These values were calculated assuming reduced catch levels under SSL RPAs.

Area apportionment of ABC

The apportionments of the 2014 and 2015 recommended ABCs based on the most recent 4-survey weighted average are:

	2014 (t)	2015 (t)
Eastern (541+S.BSea)	21,598	19,957
Central (542)	20,522	18,964
Western (543)	21,851	20,190
Total	63,971	59,111

Table 17C-2. Projections of Model 1 female spawning biomass (t), full-selection fishing mortality rates (*F*) and catch (t) for Atka mackerel for the 7 scenarios. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 288,683t, 115,473 t, and 101,039 t, respectively.

Catch	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2013	25,920	25,920	25,920	25,920	25,920	25,920	25,920
2014	35,500	35,500	35,500	35,500	35,500	63,974	55,525
2015	33,600	33,600	33,600	33,600	33,600	49,218	44,980
2016	58,225	58,225	24,987	18,034	0	53,407	57,311
2017	65,134	65,134	30,120	22,141	0	66,809	68,570
2018	69,319	69,319	34,183	25,480	0	73,589	74,264
2019	73,261	73,261	37,343	28,117	0	78,581	78,805
2020	74,929	74,929	39,474	29,970	0	80,325	80,388
2021	73,718	73,718	40,211	30,733	0	78,339	78,362
2022	73,667	73,667	40,670	31,193	0	78,230	78,240
2023	72,789	72,789	40,621	31,238	0	77,284	77,289
2024	70,017	70,017	39,844	30,727	0	73,780	73,784
2025	70,571	70,571	39,944	30,811	0	75,028	75,029
2026	72,249	72,249	40,515	31,244	0	76,982	76,983
Fishing M.	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2013	0.131	0.131	0.131	0.131	0.131	0.131	0.131
2014	0.186	0.186	0.186	0.186	0.186	0.355	0.303
2015	0.183	0.183	0.183	0.183	0.183	0.307	0.269
2016	0.301	0.301	0.123	0.088	0.000	0.311	0.324
2017	0.302	0.302	0.123	0.088	0.000	0.333	0.338
2018	0.302	0.302	0.123	0.088	0.000	0.341	0.343
2019	0.306	0.306	0.123	0.088	0.000	0.350	0.350
2020	0.309	0.309	0.123	0.088	0.000	0.353	0.353
2021	0.308	0.308	0.123	0.088	0.000	0.350	0.351
2022	0.308	0.308	0.123	0.088	0.000	0.350	0.350
2023	0.308	0.308	0.123	0.088	0.000	0.350	0.350
2024	0.305	0.305	0.123	0.088	0.000	0.345	0.345
2025	0.305	0.305	0.123	0.088	0.000	0.347	0.347
2026	0.307	0.307	0.123	0.088	0.000	0.349	0.349
Spawning biomass	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2013	114,868	114,868	114,868	114,868	114,868	114,868	114,868
2014	109,141	109,141	109,141	109,141	109,141	101,395	103,726
2015	103,535	103,535	103,535	103,535	103,535	88,522	92,860
2016	104,037	104,037	111,791	113,393	117,496	89,836	93,305
2017	110,286	110,286	131,100	135,641	147,776	98,987	100,756
2018	113,400	113,400	145,883	153,350	174,088	103,267	104,079
2019	117,309	117,309	160,160	170,443	200,009	107,143	107,519
2020	119,208	119,208	170,852	183,694	221,767	108,653	108,837
2021	117,694	117,694	175,385	190,218	235,376	107,022	107,116
2022	117,394	117,394	179,148	195,514	246,462	106,793	106,841
2023	117,465	117,465	182,600	200,273	256,285	106,822	106,844
2024	113,720	113,720	179,978	198,330	257,316	103,357	103,368
2025	114,531	114,531	181,396	200,238	261,485	104,359	104,365
2026	116,045	116,045	183,570	202,785	265,758	105,857	105,860

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