15. Stock Assessment of Bering Sea/Aleutian Islands Atka Mackerel

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Executive Summary

Summary of Major Changes

Relative to the November 2007 SAFE report, the following substantive changes have been made in the assessment of Atka mackerel.

Changes in the Input Data

1. Fishery catch data were updated.
2. The 2007 fishery age composition data were included.
3. Survey biomass estimates from the southern Bering Sea were included.
4. The 1986 U.S.-Japan cooperative survey biomass estimate was excluded.
5. 2007 fishery weight-at-age values were added.
6. Revised estimates of fishery catch- and weight-at-age values were incorporated.
7. Calculated rather than fixed sample sizes for the fishery catch-at-age data were utilized.
8. The 2008 selectivity vector (equivalent to the estimated vector for 1999-2007) was used for projections.

Changes in the Assessment Methodology

9. The age+ bin was lowered from 15+ to 11+.
10. Ageing error was incorporated with an age misclassification matrix.
11. Four time periods during which selectivity is constant were established. Previous assessments allowed for annually varying selectivity with a moderate constraint.

Changes in Assessment Results

12. The addition of the 2007 fishery age composition impacted the estimated magnitude of the 2004 year class which increased 74% relative to last year's assessment.
13. The mean recruitment (1978-2006) from the stochastic projections is 520 million recruits (up 5% from last year's mean estimate for 1978-2005), which gives an estimated $B_{40\%}$ level of 97,800 t and an estimated $B_{35\%}$ level of 85,500 t, up about 4% from last year's estimates of $B_{40\%}$ and $B_{35\%}$.
14. The projected female spawning biomass for 2009 is estimated at 132,300 t which is 54% of unfished spawning biomass and above $B_{40\%}$ (97,800 t), thereby placing BSAI Atka mackerel in Tier 3a. The 2009 estimate of spawning biomass is up about 20% from last year's estimate for 2008.
15. The projected age 3+ biomass at the beginning of 2009 is estimated at 410,600 t, up about 27% from last year's estimate for 2008. There is less of a decrease in projected biomass in this year's assessment relative to last year's projections. This is probably due to the large increase in the estimated magnitude of the 2004 year class.
16. The current selectivity-at-age vector used for projections differs (shifted to the right) from the fishery selectivity pattern used in last year's projections which was nearly equivalent to maturity-at-age. This change in selectivity particularly impacts ages 4-6 resulting in a 20% increase in this year's estimates of $F_{40\%}$ and $F_{35\%}$ relative to last year's estimates.
17. The projected 2009 yield at $F_{40\%}$ = 0.394 is 83,800 t, up about 38% from last year's estimate for 2008.
18. The projected 2009 overfishing level at $F_{35\%}$ (F = 0.482) is 99,400 t, up about 39% from last year's estimate for 2008.

Summary

Natural mortality = 0.3

2009 (Tier 3a)

Maximum permissible ABC:	$F_{40\%}$ = 0.394	yield =	83,800 t
Recommended ABC:	$F_{40\%}$ = 0.394	yield =	83,800 t
Overfishing (OFL):	$F_{35\%}$ = 0.482	yield =	99,400 t

2010 (Tier 3a)

Maximum permissible ABC:	F_{ABC} = 0.394	yield =	71,000 t
Recommended ABC:	F_{ABC} = 0.394	yield =	71,100 t
Overfishing (OFL):	F_{OFL} = 0.482	yield =	84,400 t

Equilibrium female spawning biomass

$B_{100\%}$	=	244,400 t
$B_{40\%}$	=	97,800 t
$B_{35\%}$	=	85,500 t

Projected 2009 biomass

Age 3+ biomass	= 410,600 t
Female spawning biomass	= 132,300 t

Responses to comments by the Scientific and Statistical Committee (SSC)

SSC Comments on Assessments in General

From the December 2007 SSC minutes: "*The SSC requests that if stocks drop below tier 3a and they are subject to the B20% stopping rule (pollock, cod and Atka mackerel), that the analysts evaluate the probability that the stock will drop below the $B_{20\%}$ threshold. This calculation is currently produced in the GOA pollock assessment. In this assessment the author projects the stock forward for five years and removes catches based on the spawning biomass in each year and the author's recommended fishing mortality schedule. This projection incorporates uncertainty in stock status, uncertainty in the estimate of $B_{20\%}$, and variability in future recruitment*." Atka mackerel are not projected to drop below tier 3a in 2009 or 2010.

Comments Specific to the Atka Mackerel Assessment

From the December 2007 SSC minutes: "*The SSC asks that the stock assessment authors refer to the request above for assessment of the stock status relative to the $B_{20\%}$ reference point set as part of Steller sea lion conservation measures*." Atka mackerel are not projected to drop below tier 3a in 2009 or 2010.

15.1 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 nests 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). Within the range of water temperatures observed at nesting colonies, 3.9°C to 10.5°C (Gorbunova 1962, Lauth *et al*. 2007b), the incubation time required for eggs to hatch can result in a protracted male brooding phase (Lauth *et al*. 2007a).

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, the mean length of larvae increased from 10.3 mm in the fall to 17.6 mm the following spring (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 detailed surveys of the upper pelagic layer in the Bering Sea from 2004 to 2006. In addition to collecting data pertaining to salmon species, BASIS has also collected and recorded information for many other Alaskan fish species, including juvenile Atka mackerel. Appendix B (Wetzel and McDermott, Lowe *et al*. 2007) examined the distribution of juvenile Atka mackerel in the eastern Bering Sea sampled by the BASIS project, exploring possible relationships between temperature and Atka mackerel abundance along with community composition based upon the presence or absence of Atka mackerel.

Reproductive ecology

Atka mackerel exhibit a reproductive cycle consisting of three phases 1) establishing territories; 2) spawning, and 3) brooding (Lauth *et al*. 2007a). In early June, a fraction of the adult males cease schooling and diurnal behavior and begin aggregating and establishing territories in nesting colonies (Lauth *et al*. 2007a). Based on the widespread distribution and depth of nesting colonies and the fact that relatively few are found nearshore, it appears that previous conjecture of a concerted nearshore spawning migration by males in the Aleutian Islands is false (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 second phase of the reproductive cycle is spawning. Spawning 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. The incubation time required for eggs to hatch can extend 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 1991, Zolotov and Tokranov 1991). 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. 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.

The question remains as to whether the Aleutian Island (AI) and Gulf of Alaska populations of Atka mackerel should be managed as a unit stock or separate populations given that there is a lack of consistent genetic stock structure over the species range. There are significant differences in population size, distribution, recruitment patterns, and resilience to fishing suggesting that management as separate stocks is appropriate. Bottom trawl surveys and fishery data suggest that the Atka mackerel population in the GOA is smaller and much more patchily distributed than that in the AI, and composed almost entirely of fish >30 cm in length. There are also more areas of moderate Atka mackerel density in the AI than in the GOA. The lack of small fish in the GOA suggests that Atka mackerel recruit to that region differently than in the AI. Nesting sites have been located in the 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. Most recently, the strong 1998 and 1999 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.

15.2 Fishery

15.2.1 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 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) and Total Allowable Catches (TAC) set by the North Pacific Fishery Management Council (Council) from 1978 to the present are given in Table 15.1.

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.

15.2.2 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 2008 fishery operations are shown in Figure 15.1.

15.2.3 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 11 March, 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 (Figure 15.1). On 11 August 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 15.2 gives the time series of BSAI Atka mackerel catches, corresponding ABC 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 22 January 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 8 August 2000 through 30 November 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 are randomly assigned to one of two teams, which start fishing in either area 542 or 543. Vessels may not switch areas until the other team has 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.

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, a Best Practices Cooperative has been formed under Amendment 80 which includes most of the participants in the BSAI Atka mackerel fishery.

15.2.4 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. Northern and light dusky rockfish are caught in the Aleutian Islands Atka mackerel fishery. While the 2006 and 2007 discards of northern rockfish as a total of the Atka mackerel catch were 4 and 5%, respectively, the actual amount of northern discards accounts for a large portion of the AI northern TAC. The 2006 fishery discarded 2,431 t of northern rockfish, about 49% of the 2006 AI northern TAC. The 2007 Atka mackerel fishery discarded 2,886 t of northern rockfish which accounted for 35% of the northern TAC.

Discard data have been available for the groundfish fishery since 1990. Discards of Atka mackerel for 1990-1999 have been presented in previous assessments (Lowe *et al.* 2003). Aleutian Islands Atka mackerel discard data from 2000 to the present are given below:

Year	Fishery	Discarded (mt)	Retained (mt)	Total (mt)	Discard Rate (%)
2000	Atka mackerel	2,388	43,977	46,365	5.1
	All others	201	272	473	
	All	2,589	44,249	46,838	
2001	Atka mackerel	3,832	55,744	59,567	6.4
	All others	551	1,217	1,768	
	All	4,384	56,961	61,344	
2002	Atka mackerel	7,125	36,112	43,237	16.5
	All others	239	1,205	1,443	
	All	7,364	37,317	44,680	
2003	Atka mackerel	9,209	41,994	51,203	18.0
	All others	709	1,076	1,785	
	All	9,918	43,070	52,988	
2004	Atka mackerel	6,709	45,841	52,550	12.8
	All others	448	407	855	
	All	7,157	46,248	53,405	
2005	Atka mackerel	2,403	55,359	57,762	4.3
	All others	264	448	712	
	All	2,668	55,806	58,474	
2006	Atka mackerel	1,558	56,603	58,161	2.8
	All others	326	232	558	
	All	1,884	56,835	58,719	
2007	Atka mackerel	1,595	53,593	55,188	3.0
	All others	73	481	554	
	All	1,668	54,074	55,742	

The discards and discard rate of Atka mackerel in the Atka mackerel fishery increased dramatically in 2002. The 2002 fishery caught large numbers of 3 and 4 year olds from the 1998 and 1999 year classes. Small fish from the very large 1999 year class may have contributed to the increased discarding in the 2002 fishery. The discards and discard rate increased again in 2003; the 2003 fishery caught large numbers of 3 and 4 year olds from the 1999 and 2000 year classes, and small fish from the 2000 year class may have contributed to the increased discarding in the 2003 fishery. The 2004 discard rate decreased despite the appearance of the above average 2001 year class; the 2004 fishery appeared to have retained larger numbers of 3-year old fish than previous years (Lowe *et al.* 2005). The discard rate decreased dramatically in 2005. The 2006 discard rate continued to decline, and is the lowest rate in the time series (1990-present). The 2007 discard rate for Aleutian Islands Atka mackerel remained the same at 3%.

Until 1998, discard rates of Atka mackerel by the target fishery have generally been greatest in the western AI (543) and lowest in the east (541, Lowe *et al.* 2003). After 1998 and up until 2003, discard rates have been higher in the central AI (542) and have remained lowest in the east (541). However, in 2003, the discard rate in the eastern (541) and western AI (543) nearly doubled, and the western rate exceeded the central area rate. In the 2004 fishery, the discard rates decreased in both the central and western Aleutians (542 & 543) while the eastern rate increased again. The 2005 discard rates dropped significantly in all three areas, contributing to the large overall drop in the 2005 discard rate shown above.

		Aleutian Islands Subarea		
Year		**541**	**542**	**543**
2000	Retained (t)	13,798	20,720	9,458
	Discarded (t)	163	1,484	742
	Rate	1%	7%	7%
2001	Retained (t)	7,632	28,678	19,333
	Discarded (t)	54	3,102	676
	Rate	1%	10%	3%
2002	Retained (t)	3,607	17,156	15,348
	Discarded (t)	213	4,827	2,085
	Rate	6%	22%	12%
2003	Retained (t)	5,626	22,566	14,877
	Discarded (t)	709	4,998	4,210
	Rate	11%	18%	22%
2004	Retained (t)	3,161	26,560	16,527
	Discarded (t)	520	3,610	3,027
	Rate	14%	12%	15%
2005	Retained (t)	3,356	33,598	18,852
	Discarded (t)	305	1,472	891
	Rate	9%	4%	5%
2006	Retained (t)	4,013	38,447	14,374
	Discarded (t)	232	1,389	263
	Rate	6%	4%	2%
2007	Retained (t)	19,752	25,475	8,847
	Discarded (t)	169	1,248	251
	Rate	1%	5%	3%

Discards of Atka mackerel in the southern Bering Sea occur mainly in areas 519, 517, and 509 in the Atka mackerel, Pacific cod, and pollock fisheries. The highest level of Atka mackerel discards occurs in area 519 in the Pacific cod fishery.

15.2.5 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 2007 and preliminary 2008 fisheries by management area and season are shown in Figures 15.2 and 15.3, respectively. The modes at about 36-45 cm in the 2007 BSAI fishery length distributions represent the 2001 year class which dominated the 2007 fishery age composition, and the persistent 1999 year class, and (Figure 15.4). The available 2008 fishery data are presented and should be considered preliminary (Figure 15.3). Preliminary data from the 2008 BSAI A-season fisheries showed similar distributions to the 2007 A- and B-season distributions with slightly larger modes at about 36-47 cm (Figure 15.3).

15.2.6 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 in Section 15.2.3) to disperse fishing effort temporally and spatially as well as reduce effort within Steller sea lion critical habitat.

NMFS is investigating the efficacy of trawl exclusion zones as a fishery-Steller sea lion management tool, and trying 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 have been conducted near Seguam Pass (in area 541) in August 2000, 2001 and 2002 (McDermott *et al.* 2005). Results indicate 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 here 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 was 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 forming 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.

15.3 Data

15.3.1 Fishery Data

Fishery data consist of total catch biomass from 1977 to 2007 and partial 2008 catch data (Table 15.1). Also, length measurements collected by observers and otoliths read by the AFSC Age and Growth Lab (Table 15.3) were used to create age-length keys to determine the age composition of the catch from 1977-2007 (Table 15.4). In previous assessments 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 attempted this year in response to issues raised during the 2008 Center for Independent Experts (CIE) review of the Aleutian Islands Atka mackerel and pollock assessments. This entailed stratifying the catch by region (Table 15.2) and compiling (to the extent possible) region-specific age-length keys stratified by sex. This also accounted 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 15.4). 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. The three strata for the Atka mackerel coincided with the three management areas (eastern, central, and western regions of the Aleutian Islands). This method was used to derive the age compositions for 1990-2007 (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. Figure 15.5 shows the revised estimates of proportion of catch-at-age based on the mean from bootstrap sampling of the revised catch-at-age estimates compared to the estimates used in past assessments. The revised estimates compare fairly well with the previous estimates and are considered an improvement as they incorporate stratum differences. The bootstrap method also allows evaluation of sample-size scalings 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 most notable features of the estimated catch-at-age data (Table 15.4) are the strong 1975, 1977, 1999, 2000, and 2001 year classes, and the very poor showing of the 2002 year class. 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 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 2007 fishery data indicated that the 1999, 2000, and 2001 year classes continued to show up in large numbers (Table 15.4 and Figure 15.4). The progression of the 2001 year class is clearly evident in the modes of the 2005, 2006, and 2007 fishery age data (Figure 15.4).

Atka mackerel are a summer-fall spawning fish that do not appear to lay down an otolith annulus in the first year (Anderl *et al.*, 1996). 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.

15.3.2 Survey Data

Due to the cancellation of the 2008 Aleutian Islands trawl survey the most recent fishery-independent data available is from the 2006 Aleutian Islands survey. Hence, this section remains the same as the previous assessment except for some updates to survey estimates as provided by the Resource Assessment and Conservation Ecology (RACE) Division.

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; and (3) their schooling behavior and patchy distribution result in survey estimates with large variances. Despite these shortcomings, the U.S.-Japan cooperative trawl surveys conducted in 1980, 1983, 1986, and the 1991, 1994, 1997, 2000, 2002, 2004, and 2006 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 1,21,148 t in 1986 (Table 15.5). 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 15.5), 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 2006 Aleutian Islands bottom trawl survey is 728,935 t, down 18% relative to the 2004 survey estimate (Table 15.6). Previous to this, the 2004 Aleutian Islands bottom trawl survey biomass estimate of nearly 900,000 t increased 16% relative to the 2002 survey. 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 2006 survey is largely a result of a decrease in biomass found in the Western area (376,414 t in 2004 down to 100,693 t in 2006), despite a large increase in the Eastern area. Relative to the 2004 survey, the 2006 biomass estimates are down 73% in the Western area, up 3% in the Central area, and up 44% in the Eastern area (Figure 15.6). The 95% confidence interval about the mean total 2006 Aleutian biomass estimate is **298,858-1,159,013 t**. The coefficient of variation (*CV*) of the 2006 mean Aleutian biomass is 28% (Table 15.6).

The distribution of biomass in the Western, Central, and Eastern Aleutians, and the southern Bering Sea shifted between each of the surveys, and most dramatically in area 541 in the 2000 survey (Figure 15.6). The 2000 Eastern 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 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). We note that the distribution of Atka mackerel in the Eastern area is generally patchier, and up until the 2004 survey, the area-specific variances for the Eastern area have always been high relative to the Central and Western areas. Lowe *et al.* (2001) suggest that a combination of several factors coupled with the typically patchier distribution of Atka mackerel in area 541 may have impacted the distribution of the fish such that they were not available at the surveyed stations at the time of the 2000 survey.

The 2006 survey showed that the Eastern area contributed 48% of the total biomass, which is a significant increase from 27.5% of the biomass that was detected in the 2004 survey, and the largest proportion in the time series (Table 15.6).

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), and 2004 survey (267,556 t, Table 15.6). These biomass estimates are a result of large catches from a single haul encountered north of Akun Island in all four 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 (Figure 15.7). 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 2006 survey estimated only 12,284 t of biomass (*CV*=44%) from the southern Bering Sea area.

Areas with large catches of Atka mackerel during the 2002 survey were located north of Akun Island, Seguam Pass, Tanaga Pass, south of Amchitka Island, Kiska Island, Buldir Island, and Stalemate Bank (Figure 15.7). Areas with large catches of Atka mackerel during the 2004 survey included north of Akun Island and Unalaska Islands, Seguam Pass, Tanaga Pass, Kiska Island, Buldir Island, and Stalemate Bank (Figure 15.7). In the 2002 and 2004 surveys, Atka mackerel were much less patchily distributed relative to previous surveys and were encountered in 55% and 60% of the hauls respectively, which are the highest rates of encounters in the survey time series. Similar to the 2004 survey, areas with large catches of Atka mackerel in the most recent 2006 survey included Seguam Pass, Tanaga Pass, Kiska Island, and Stalemate Bank (Figure 15.7). Atka mackerel were encountered in 51% of the hauls.

The average bottom temperatures measured in the 2000 survey were the lowest of any of the Aleutian surveys, particularly in depths less than 200 m where 99% of the Atka mackerel are caught in the surveys (Figure 15.8). The average bottom temperatures measured in the 2002 survey were the second lowest of the Aleutian surveys, but significantly higher than the 2000 survey and very similar to the 1994 survey. The average bottom temperatures measured in the 2004 survey fell near the middle of the series for all survey years, excluding the year 2000. The average bottom temperatures measured in the 2006 survey were slightly above the 2002 survey and very similar to the 1994 survey temperatures (Figure 15.8).

There is greater confidence in Atka mackerel biomass estimates from bottom trawl surveys of the groundfish community of the Aleutian Islands (AI) than the Gulf of Alaska (GOA). First, the coefficients of variation of the mean Atka mackerel biomass estimates have been considerably smaller from the recent AI surveys than the recent GOA surveys: 0.28, 0.20, 0.17, and 0.28 from the 2000, 2002, 2004, and 2006 AI surveys, respectively, compared with 0.45, 1.00, 0.35, 0.50, and 0.46 from the 1999, 2001, 2003, 2005, and 2007 GOA surveys. Second, while patchy in its distribution compared to other groundfish species, Atka mackerel have been much more consistently encountered in the AI than the GOA surveys, appearing 33%, 55%, 60, and 51% of the hauls in the 2000, 2002, 2004, and 2006 AI surveys, compared to 20%, 10%, 44%, 29%, and 20% of the hauls in the Shumagin area in the1999, 2001, 2003, 2005, and 2007 GOA surveys, respectively. For these reasons we utilize bottom trawl surveys to assess the relative abundance of Atka mackerel in the Aleutian Islands, but do not consider the highly variable estimates of biomass from the GOA surveys useful for tracking abundance trends.

Survey Length Frequencies

The 2000, 2002, and 2004 bottom trawl surveys and the fishery catch data revealed a strong east-west gradient in Atka mackerel size, with the smallest fish in the west and progressively larger fish to the east, (Figure 15.8 in Lowe *et al.* 2003, 2005). The 2006 survey length frequency distributions also show a strong east-west gradient in Atka mackerel size (Figure 15.9). The 2006 survey length frequency distributions from the Eastern area showed a mode of fish at 39 cm, larger than the Central and Western fish, but significantly smaller compared to the size distribution of fish sampled from the southern Bering Sea with a mode of 45 cm (Figure 15.9).

Survey Age Frequencies

The age compositions from the 2002, 2004, and 2006 Aleutian surveys are shown in Figure 15.10. The 2002 survey age composition is dominated by the 1999 year class and continues to show large numbers of the 1998 year class (Figure 15.10). The 2004 survey age data is basically comprised of 3, 4, and 5-year olds of the 1999, 2000, and 2001 year classes, and is dominated by 3-year olds of the 2001 year class (Figure 15.10). The 2006 survey still indicated large numbers from the 1999 year class and a very low number of fish from the 2002 year class. The fishery catch data also confirmed very low numbers of the 2002 year class. The 2006 survey and fishery saw an unusually high number of 2 year olds from the 2004 year class (Figure 15.10 and Table 15.4). The 2007 fishery data confirmed a large number of 3 year olds from the 2004 year class. The mean ages of the 2002, 2004, and 2006 surveys are 3.8, 4.2, and 5.3 years, respectively. The mean age in the 2002 survey (3.8 years) is the youngest mean age of any survey.

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).

15.4 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 (Barbeaux *et al.* 2004) and Bogoslof pollock stock assessments (Ianelli *et al.* 2005).

The Assessment Model for Alaska is developed using ADModel Builder language (ADMB, Fournier 1998; Ianelli and Fournier 1998). The ADMB is a C++ software language extension and automatic differentiation library. It allows for estimation of large numbers of parameters in non-linear models using automatic differentiation software developed into C++ libraries (Fournier 1998). The optimizer in ADMB is a quasi-Newton routine (Press *et al.* 1992). The model is determined to have converged when the maximum parameter gradient is less than a small constant (set to 1×10^{-7}). A feature of ADMB is that it includes post-convergence routines to calculate standard errors (or likelihood profiles) for quantities of interest.

15.4.1 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 1977-2007) with natural and age-specific fishing mortality occurring throughout the 15 or 11-age-groups that are modeled (ages 1-15+ or 1-11+).

[1] AMAK. 2005. A statistical catch at age model for Alaska, version 1.1. NOAA Fisheries Toolbox. NEFSC, Woods Hole, MA. Available at http://nft.nefsc.noaa.gov/

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	1977-2007	Lognormal	*CV*=5%
Fishery catch age composition	1977-2007	Multinomial	Year specific *N*=25-236
Survey biomass	1986*, 1991, 1994, 1997, 2001, 2004, 2006	Lognormal	Average *CV*=29%
Survey age composition	1986, 1991, 1994, 1997, 2001, 2004, 2006	Multinomial	*N*=50
Recruitment deviations		Lognormal	
Stock recruitment curve		Lognormal	
Selectivity smoothness (in age-coefficients, survey and fishery)		Lognormal	
Selectivity change over time (fishery only)		Lognormal	
Priors (where applicable)		Lognormal	

*1986 survey biomass data not used in all model runs as described in Model Evaluation below.

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):

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

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
41	23	10	9	71	60	121	18	90	220	236	109
2002	2003	2004	2005	2006	2007						
144	136	136	136	114	127						

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

From the CIE review, Francis (2008) provided a second approach based on residuals from means (age or length) and using the property of how sample size relates to standard errors of mean values. Essentially, the variance of the mean of a sample from a time frame (typically a year) varies inversely proportional to the sample size. It can be shown that for a given set of input proportions at age (up to the maximum age *A*) $p_{a,i}$ and sample size N_i for year *i*, an adjustment factor for sample size corrections can be computed based on assessment model predicted proportions at age ($\hat{p}_{ij}$) and model predicted mean age ($\hat{\bar{a}}$):

$$f = \mathrm{var}\left(r_i^a \sqrt{\frac{N_i}{s_i}}\right)^{-1}$$

$$r_i^a = \bar{a}_i - \hat{\bar{a}}_i$$

$$s_i = \left[\sum_j^A \bar{a}_i^2 p_{ij} - \hat{\bar{a}}_i^2\right]^{0.5}$$

where r_i^a is the residual of mean age and

$$\hat{\bar{a}}_i = \sum_j^A j\hat{p}_{ij}, \qquad \bar{a}_i = \sum_j^A jp_{ij} .$$

Research on using this type of adjustment to input samples sizes is progressing and future assessments may incorporate some form of adjustment. In this analysis as a preliminary step, we use the above relationship as a diagnostic for evaluating input sample sizes. This approach involves comparing model predicted mean ages with "observed" mean ages for each type of data (here post 1989 fishery data were used). The observed mean ages are accompanied by 95% error bars implied by the input sample size and are used to evaluate model configurations (for both structure and input sample sizes) and is presented below in the section on Model Evaluation.

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 independently

<u>Natural Mortality</u>

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 (Figure 15.11 in Lowe *et al.* 2003). Independent studies are 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) = $L_\infty\{1\text{-exp}[-K(\text{age-}t_0)]\}$

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

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

weight (kg) = 9.08E-06 * length (cm) $^{3.0913}$ (86, 91 & 94 surveys; N = 1,052)
weight (kg) = 3.72E-05 * 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 15.7). 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 2002, 2004, and 2006 surveys is used to derive population biomass from the modeled numbers-at-age in order to allow for better estimation of current biomass (Table 15.7).

The fishery weight-at-age data presented in previous assessments were compiled based on unweighted, unstratified (Aleutian-wide) fishery catch-age samples to construct the year-specific age-length keys (see Table 15.8 in Lowe *et al*. 2007). In the current 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 15.7 for 1990 to 2007, 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 15.7.

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 15.8. 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 conditionally

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

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 and curvature 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 using the sum of squared second differences (log-scale). In addition, the age component parameters are assumed constant for the last 6 age groups (ages 10-15). 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. Selectivity has been allowed to vary annually in previous assessments with a low constraint as described in the 2002 assessment (Lowe *et al*. 2002). As suggested by the 2008 CIE reviewers, we explored model configurations with blocks of years with constant selectivity which correspond approximately to the foreign fishery (1977-1983), the joint venture fishery (1984-1991), the domestic fishery prior to Steller sea lion regulations (1992-1998), and the domestic fishery post Steller sea lion regulations (1999-2007).

Survey Catchability

For the bottom trawl survey, catchability-at-age follows a parameterization similar to the fishery selectivity-at-age presented above (except with no allowance for time-varying selectivity). Here we 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 catchability most reasonably applies. The 2003 assessment explored the use of a prior on survey catchability (q) through AMAK with mixed results that were difficult to interpret biologically (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. Our assumptions on survey catchability have not changed and this year we present models with a moderate prior on q, mean = 1.0, $\sigma^2 = 0.2^2$ for evaluation.

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).

15.5 Model Evaluation

In response to issues raised during the 2008 Center for Independent Experts (CIE) review of the Aleutian Islands Atka mackerel and pollock assessments, we changed a number of aspects of the input data and made refinements to the model configuration for evaluation. In summary, these changes focus on a more consistent approach to include survey data, the incorporation of a lower age+ bin (11+), calculated samples sizes for fishery catch-at-age data, revised compilation of catch- and weight-at-age data using a two-stage catch-estimation scheme based on stratified (by area) catch biomass and catch-at-age fishery samples, inclusion of an age-misclassification matrix, and incorporating blocks of years with constant selectivity. A summary table of the changes follows:

Cumulative changes	Add 2007	Add SBS	Exclude 1986	Bin 11+	Eff N	Rev Age	Age Err	Sel Blocks
Update catch biomass and add 2007 fishery age data	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Include S. Bering Sea survey biomass		Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exclude 1986 survey biomass			Yes	Yes	Yes	Yes	Yes	Yes
Bin ages for 11+ years				Yes	Yes	Yes	Yes	Yes
Use effective N calculations					Yes	Yes	Yes	Yes
Use revised catch- and weight-at-age						Yes	Yes	Yes
Include ageing error							Yes	Yes
4-periods of constant selectivity								Yes

The first model run (Add 2007) was essentially equivalent to Model 4 used in last year's assessment, but with updated catch data and the addition of the 2007 fishery age data. The next two incremental changes were to 1) include southern Bering Sea Biomass estimates (Table 15.6) which had not been included in previous assessments due to extreme variances, and 2) exclude the 1986 survey biomass estimate which has been documented not to be comparable with subsequent surveys (Barbeaux *et al*. 2003). Previous assessments modeled ages 1-15+, however, very few fish reside in age groups 12-15 and the current assessment evaluates a lower age+ bin of 11+. In previous assessments input sample sizes have been fixed at 25 or 50 for foreign and JV fishery data, 100 for the domestic fishery, and 50 for survey data. This year we incorporate sample size calculations for the domestic fishery data. In the past, model-predicted effective sample sizes for the survey have been very close to the fixed value of 50 (Lowe *et al*. 2007). Therefore, in the current assessment we continue to utilize a fixed sample size of 50 for the survey. Two other changes to the input data were using revised estimates of catch- and weight-at age data for 1990-2007 as described above, and the incorporation of an age misclassification matrix (ageing error). A significant change to the model configuration was to establish 4 time periods during which selectivity remains constant within each time period. These time periods 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.

Figure 15.11 compares the female spawning biomass trends for the various model runs incorporating the changes described above. The trends among all runs are consistent. However, the initial 1977 biomass levels differ. These differences remain until about 1992, after which biomass levels are all similar until 2003. It is interesting to note that adding in the southern Bering Sea survey biomass estimates had a negligible impact on abundance levels until 2003. The 2004 survey estimated nearly 270,000 t of biomass (*CV*=43%) from the southern Bering Sea area which we attribute the much higher peak biomass levels in 2005-2006 relative to last year's model configuration (Add 2007). Incorporating 4 time periods of constant selectivity has the effect of moderating the magnitude of recruitment from the strong 1998, 1999, 2000, and 2001 year classes relative to the other model runs, bringing recent abundance levels in line with last year's model configuration (Add 2007).

We believe that changes to the input data as suggested by the CIE reviews are reasonable and result in a more consistent approach. Thus, we focus on evaluation of last year's model configuration with annually varying selectivity and updated catch and 2007 fishery data (Add 2007), hereafter referred to as the Reference Model, with the model run with 4 time periods of constant selectivity (in addition to input data changes described above), hereafter referred to as Model 8.

The CIE reviews also provided an alternative way to evaluate "input" sample size and expected mean age to compare with model predictions (see discussion of sample sizes in section 15.4.1 above. For example, the Reference model shows good consistency between predicted and observed mean ages in the fishery compared to Model 8 results which were acceptable but somewhat less consistent (Figure 15.12). This has to do with the trade-off in the allowance of more process-errors in selectivity for the Reference model (Figure 15.13). Key results from the Reference Model and Model 8 are given in Table 15.9.

Stock abundance results between the two models are consistent and fairly similar as shown in Table 15.9 and Figure 15.11. The time series of selectivity for the two model configurations are compared in Figure 15.13. As expected, Model 8 results in relatively smoothed patterns without abrupt transitions between years. The overriding difference in key results is the reduction in the number of parameters from 412 for the Reference Model to 138 parameters for Model 8. As described above, the Reference Model allows for annually varying fishery selectivity. Model 8 is configured with 4 blocks of years, each with constant selectivity within each block, significantly reducing the number of selectivity parameters. Also, Model 8 has a lower age+ bin contributing to a reduction in the number parameters. We examined the fits to the survey biomass and the fishery and survey age compositions. Fits to the survey biomass are somewhat improved in Model 8, and although there is a large reduction in the residual mean square error (RMSE) relative to the Reference Model (Table 15.9), this is attributed to the exclusion of the extremely high 1986 survey estimate which past assessments have always fit very poorly. The fits to the survey age compositions are similar between the two models, and as expected, the fits to the fishery age compositions degrade somewhat for Model 8 relative to the Reference Model.

We believe that the changes to the input data allow for a more consistent approach and the change in the model configuration of fishery selectivity allows for much greater parsimony with slight improvements to survey biomass fit at the cost of only a slight decrease in fishery age composition fits. We therefore recommend Model 8 as a reasonable and consistent representation of BSAI Atka mackerel dynamics.

15.6 Model Results

The results discussed below are based on Model 8 with updated fishery catch- and weight-at-age values, 2007 fishery data, 4 time periods each with constant selectivity, and other minor changes as described above.

15.6.1 Selectivity

The estimated selectivity at age schedules for the fishery and survey are shown in Figures 15.13-15.15 and given in Table 15.10.

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 1991 during the foreign and joint venture fisheries blocks (Figure 15.13). After 1991, fishery selectivity patterns are divided into 2 blocks of years (1992-1998, 1999-2007) each with constant selectivity. These 2 selectivity patterns are shown in Figure 15.14 with 1998 representing the early pattern and 2007 representing the most recent pattern. The patterns between these two blocks are fairly similar but do show slight differences at ages 3-4 and 7 and more notable differences after age 7. The recent pattern for the years 1999-2007 reflects the large numbers of fish from the 1999, 2000, and 2001 year classes (Figure 15.14, Table 15.4). The age at 50% selectivity is estimated at about age 4 for both time periods (Figure 15.14).

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). The selectivity pattern used for projections in last year's assessment (average of 2002 to 2006) is shown for perspective (Figure 15.14). Selectivity after age 7 differs among all patterns. 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. It is important to note the maturity-at-age vector which is very similar to last year's selectivity pattern up to age 7 (age at 50% maturity is 3.6 years, Figure 15.14). The estimated selectivity patterns since 1991 indicate the fishery is harvesting mature older fish. This is probably a reflection of the large numbers of the 1999 year class still present in fishery catches.

Survey catches are mostly comprised of fish 3-9 years old. A 14-year old fish was found in the 1994 survey and a 15-year old fish was found in the 2000 survey. The current configuration estimates a smoothed slightly dome-shaped selectivity pattern (Figure 15.15), which is very similar to last year's estimate (Figure 15.12 in Lowe *et al*. 2007).

15.6.2 Abundance Trend

The estimated time series of total numbers at age are given in Table 15.11. The estimated time series of total biomass with approximate upper and lower 95% confidence limits are shown in Figure 15.16 and given in Table 15.12. For comparison, the time series of female spawning biomass from the 2007 and 2008 (current) assessment (with confidence bands) are also plotted (Figure 15.17).

A comparison of the spawning biomass trend from the current and previous assessments (Figure 15.17, Table 15.12) 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 2002, thereafter, spawning biomass began a steep increase which continued to 2006. The estimated biomass levels after 2006 in the current assessment are higher than previously projected. This is attributed to the continued persistence of the 1999 year class, and large increase in the estimated magnitude of the 2004 year class (see below).

15.6.3 Recruitment Trend

The estimated time series of age 1 recruits from the current assessment and the 2007 assessment is shown in Figure 15.18 and given in Table 15.13. The strong 1988 year class is most notable in the current assessment, followed by the 1999 and 1977 year classes. The changes implemented in Model 8 impacted the estimated magnitude of the historical 1977 and 1988 year classes which increased 16 and 23% respectively relative to last year's assessment (Figure 15.18). The changes to the model and the addition of the 2007 fishery age composition data impacted the estimated magnitude of the 2004 year class which increased 74% relative to last year's assessment (Figure 15.18). The 2007 fishery data are dominated by the 2001 year class, followed by the 2000 and 2004 year classes (Figure 15.4). The 1999 year class is estimated to be one of the three largest year classes in the time series (approximately 1.3 billion recruits) due to its continued strong showing in the 2007 fishery as 8-year olds (Figure 15.4). The current assessment estimates above average (greater than 20% of the mean) recruitment from the 1977, 1988, 1992, 1995, 1998, 1999, 2000, 2001 and 2004 year classes (Figure 15.18).

The average estimated recruitment from the time series 1978-2006 is 520 million fish and the median is 380 million fish (Table 15.13). The entire time series of recruitments (1977-2007) includes the 1976-2006 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 (1977-2005 year classes). Projections of biomass are based on estimated recruitments from 1978-2006 using a stochastic projection model described below.

15.6.4 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 15.14 and shown in Figure 15.19.

15.6.5 Model Fit

A summary of key results from Model 8 are presented in Table 15.9. The coefficient of variation or *CV* (reflecting uncertainty) about the 2008 biomass estimate is 19% and the *CV*s on the strength of the 1999 and 2001 year classes at age 1 are 21 and 29%, respectively (Table 15.9). Overall estimated recruitment variability for BSAI Atka mackerel is high (0.652). 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 115 and average survey effective *N* of 52, which compares well with the fixed value. The overall residual mean square error (RMSE) for the survey is estimated at 0.190 (Table 15.9). The RMSE is in line with estimates of sampling-error *CV*s for the survey which range from 14-31% and average 24% over the time series. The sampling-error variances should be considered as minimal estimates. Other sources of uncertainty (e.g., due to spatial variability and environmental conditions) can inflate the uncertainty associated with survey biomass estimates.

Figure 15.20 compares the observed and estimated survey biomass abundance values. The model no longer attempts to fit the 1986 survey estimate (1.1 million t) which has always been fit very poorly in previous assessments. The catch-at-age data do not show another strong year class following the 1977 year class that would allow fitting the 1986 survey estimate. This lack of fit was confounded by the large coefficient of variation associated with the 1986 biomass estimate (80%). The large decrease in biomass indicated by the 1994 and 1997 surveys followed by the large increases in biomass from the 2000, 2002, and 2004 surveys appear to be consistent with recruitment patterns. The 2006 survey indicates a downward trend which is consistent with the population age composition at the time. The 2001 year class was 6 years old in 2006, and would have reached peak cohort biomass about 2 years ago. We note that the model's predicted survey biomass trend is very conservative relative to the recent (2000, 2002, 2004, and 2006) observed bottom trawl survey biomass values (Figure 15.20).

The fits to the survey and fishery age compositions for Model 8 are depicted in Figures 15.21 and 15.22, respectively. The model fits the fishery age composition data well particularly after 1995, 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. It is also interesting to note that the 2006 survey observed greater numbers than expected of 2-year olds of the 2004 year class, and the 2006 and 2007 fishery age compositions indicated greater numbers than expected of 3-year olds of the 2003 and 2004 year classes, respectively (Figures 15.21 and 15.22).

15.7 Projections and harvest alternatives

15.7.1 Amendment 56 Reference Points

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC (*max* F_{ABC}). The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. The overfishing and maximum allowable ABC fishing mortality rates are given in terms of percentages of unfished female spawning biomass ($F_{SPR\%}$), on fully selected age groups. The associated long-term average female spawning biomass that would be expected under average estimated recruitment from 1978-2006 (520 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 8 results based on recruitment from post-1976 spawning events:

$B_{100\%}$ = 244,400 t female spawning biomass
$B_{40\%}$ = 97,800 t female spawning biomass
$B_{35\%}$ = 85,500 t female spawning biomass

15.7.2 Specification of OFL and Maximum Permissible ABC

In the past when the model was configured to allow for annually varying selectivity, we used an average selectivity pattern over recent years to provide a more robust selectivity pattern for projection purposes. In the 2007 assessment we used an average selectivity from 2002-2006 which is shown in Figure 15.14. In the current assessment, Model 8 is configured with 4 time periods of constant selectivity. The last time period (1999-2007) reflects the domestic fishery after implementation of Steller sea lion protection measures. This selectivity pattern is shown in Figure 15.14 and used for projection purposes. The following rates are based on the 1999-2007 selectivity pattern estimated by Model 8:

Full selection Fs	
F_{2008}	0.229
$F_{40\%}$	0.394
$F_{35\%}$	0.482
$F_{2008}/F_{40\%}$	0.581

It should be noted 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. Recent TACs have not gone above 63,000 t even when the ABC is greater. Therefore, for specification purposes we fixed the 2009 catch at 63,000 t to project a more realistic 2010 ABC catch. For Model 8, the projected year 2009 female spawning biomass (SSB_{09}) is estimated to be 132,300 t under an assumed 2009 catch of 63,000 t. (SSB_{09} under the maximum allowable ABC harvest strategy ($F_{40\%}$) is 126,200 t). The projected 2009 female spawning biomass estimate is above the $B_{40\%}$ value of 97,800 t, placing BSAI Atka mackerel in **Tier 3a**. The maximum permissible ABC and OFL values under **Tier 3a** are:

Year	Catch	ABC	OFL	SSB
2009	63,000	83,800	99,400	132,300
2010	71,100	71,100	84,400	108,400

Note that the 2009 maximum permissible $F_{ABC} = F_{40\%}$ = 0.394 and F_{OFL}=$F_{35\%}$ = 0.482; also, catch in 2009 is assumed equal to 63,000 t (below the maximum ABC level). As a conservative measure, female spawning biomass for 2010 was calculated assuming the maximum permissible $F_{ABC} = F_{40\%}$.

15.8 ABC Recommendation

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

1) Trawl survey estimates of biomass are highly variable; the 2000, 2002, and 2004 survey estimates showed 40, 50, and 15% increases respectively. The most recent 2006 survey estimate of biomass decreased 18% relative to the 2004 survey.
2) Under an $F_{40\%}$ harvest strategy, 2009 female spawning biomass is projected to be above $B_{40\%}$ but drop below in 2011 to 2015 (Figure 15.23). However, it should be noted that in recent years the catches have been below TAC=ABC, thus actual *F*s have been below $F_{40\%}$.
3) The model's predicted survey biomass trend is very conservative relative to the recent (2000, 2002, 2004 and 2006) observed bottom trawl survey biomass values (Figure 15.20).
4) The 2007 fishery age composition data continue to show large numbers from the 1999, 2000, and 2001 year classes and large numbers of recruiting 3-year-olds from the 2004 year class (Figure 15.4). Currently we estimate the 1999 year class to be the second largest in the time series (but with a moderate degree of uncertainty: *CV*=24%).

We believe the current model configuration as implemented through AMAK with the ADMB software provides an improved assessment of BSAI Atka mackerel relative to past model configurations. In particular, we believe that the changes to the input data allow for a more consistent approach and the change in the model configuration of fishery selectivity allows for much greater parsimony with slight improvements to survey biomass fit at the cost of only a slight decrease in fishery age composition fits. Given the current stock size, appearance of four consecutive strong year classes, and indications of an above average 2004 year class, from a biological perspective (for Atka mackerel) the maximum permissible is acceptable. For perspective, a plot of relative harvest rate ($F/F_{35\%}$) versus relative female spawning biomass ($B/B_{35\%}$) is shown in Figure 15.24. For most of the time series (including the 2008 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 (Figure 15.24).

The associated 2009 yield associated with the maximum permissible $F_{40\%}$ fishing mortality rate of 0.394 is 83,800 t, which is our 2009 ABC recommendation for BSAI Atka mackerel.

The associated 2010 yield associated with the maximum permissible F_{ABC} fishing mortality rate of 0.394 is 71,100 t, which is our 2010 ABC recommendation for BSAI Atka mackerel.

The 2009 ABC recommendation represents a 38% increase from the Council's 2008 ABC. This is consistent with much less of a predicted decreasing population trend due to the strong showing of the 2004 year class, combined with an increase in the estimated $F_{40\%}$ fishing mortality rate relative to last year.

15.8.1 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 (2000, 2002, 2004, and 2006) weighted average to apportion the 2008 ABC. The rationale for the weighting scheme was described in Lowe *et al.* (2001). As there was no Aleutian Islands survey conducted in 2008, we again recommend the same 4-survey weighting scheme which includes the most recent 2006 survey, be used to apportion the 2009 and 2010 ABCs. The data used to derive the percentages for the weighting scheme are given below:

	2000	2002	2004	2006	2008 and recommended 2009, 2010 ABC Apportionment
541	0.20%	24.7%	27.5%	48.04%	**32.2%**
542	64.6%	42.3%	30.4%	38.14%	**40.0%**
543	35.2%	33.0%	42.0%	13.81%	**27.8%**
Weights	8	12	18	27	

The apportionments of the 2009 and 2010 recommended ABCs based on the most recent 4-survey weighted average are:

	2009	2010
Eastern (541)	27,000	22,900
Central (542)	33,500	28,500
Western (543)	23,300	19,700
Total	83,800	71,100

Given that Atka mackerel exhibit spatial differences in relative abundance, recruitment patterns, and response to fishing impacts, there is a need to appropriately include spatial structure for management purposes. Work is currently in progress to explore the application of spatially explicit survey data to area-specific allocations of ABCs and appropriately account for survey uncertainties among three management areas (Ianelli *et al*. in prep).

15.9 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 2008 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2009 using a fixed value of natural mortality of 0.3, the recent schedule of selectivity estimated in the assessment (in this case the 1999-2007 selectivity), and the best available estimate of total (year-end) catch for 2008 (in this case assumed equal to 93% of the 2008 TAC; the 2007 ratio of catch to TAC = 0.93). 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 2009, 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 2009 recommended in the assessment to the *max* F_{ABC} for 2009. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, *F* is set equal to the 2004-2008 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 2009 or 2) above ½ of its MSY level in 2009 and above its MSY level in 2019 under this scenario, then the stock is not overfished.)

Scenario 7: In 2009 and 2010, *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 2021 under this scenario, then the stock is not approaching an overfished condition.)

15.9.1 Status determination

The projections of female spawning biomass, fishing mortality rate, and catch corresponding to the seven standard harvest scenarios are shown in Table 15.15. 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 2009:

a) If spawning biomass for 2009 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b) If spawning biomass for 2009 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c) If spawning biomass for 2009 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 15.15). If the mean spawning biomass for 2019 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

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

a) If the mean spawning biomass for 2011 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

b) If the mean spawning biomass for 2011 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c) If the mean spawning biomass for 2011 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2021. If the mean spawning biomass for 2021 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

In the case of BSAI Atka mackerel, spawning biomass for 2009 is estimated to be above $B_{35\%}$. Therefore, the stock is above its MSST and is not overfished. Mean spawning biomass for 2011 under scenario 7 in Table 15.15 is above $B_{35\%}$ therefore, the stock is not approaching an overfished condition.

15.10 Ecosystem Considerations

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.

15.10.1 Ecosystem effects on BSAI Atka mackerel

Prey availability/abundance trends

Figure 15.25 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. 15.26a). While Figure 15.26a 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*. in press). 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 15.27. During these years, approximately 20% of the Atka mackerel exploitation rate (as calculated by stock assessment) was due to the fishery, 62% due to predation, and 18% "unexplained", where "unexplained" is the difference between the stock assessment total mortality and the sum of fisheries exploitation and quantified predation. This unexplained mortality may be due to data uncertainty, or Atka mackerel mortality due to disease, migration, senescence, etc.

Of the 62% of mortality due to predation, a little less than half (25% of total) is due to Pacific cod predation, and one quarter (15% of total) due to Steller sea lion predation, with the remainder spread across a range of predators (Figure 15.26b), 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).

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 Aleutian Islands summer bottom temperatures indicated that 2000 was the coldest year followed by summer bottom temperatures from the 2002 survey, which indicated the second coldest year (Figure 15.8). The 2004 AI summer bottom temperatures indicated that 2004 was an average year, while the 2006 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.

15.10.2 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 15.16 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 (2005-2007), the Atka mackerel fishery has taken on average about 47 and 33%, 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.

The bycatch of skates, which are considered a sensitive or vulnerable species based on life history parameters, is noted in Table 15.16. Skate bycatch in the Aleutian Islands Atka mackerel fishery is variable and has averaged 126 t in the last 3 years (2005-2007). Over this same time period, the Atka mackerel fishery has taken an average of 15% of the total Aleutian Islands skate bycatch. It is unknown if the absolute levels of skate bycatch in the Atka mackerel fishery are of concern.

The bycatch of sculpin is notable and has averaged about 466 t from 2004 to 2006. This level of bycatch represents an average of 54% of the total Aleutian Islands sculpin bycatch. It is unknown if the absolute levels of sculpin 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. However, this 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 913 t of non-target discards in the Aleutian Islands from 2005 to 2007. 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 1,850 t over 2005-2007.

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.

15.11 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.

15.12 Acknowledgements

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

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15.14 Tables

Table 15.1. Time series of Bering Sea/Aleutian Islands Atka mackerel catches (including discards and CDQ catches), corresponding Acceptable Biological Catches (ABC), and Total Allowable Catches (TAC) set by the North Pacific Fishery Management Council from 1978 to the present. Catches, ABCs, and TACs are in metric tons.

Year	Catch	ABC	TAC
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
1993	66,006	117,100	64,000
1994	65,360	122,500	68,000
1995	81,554	125,000	80,000
1996	103,942	116,000	106,157
1997	65,842	66,700	66,700
1998	57,097	64,300	64,300
1999	56,237	73,300	66,400
2000	47,230	70,800	70,800
2001	61,563	69,300	69,300
2002	45,288	49,000	49,000
2003	54,045	63,000	60,000
2004	60,562	66,700	63,000
2005	62,012	124,000	63,000
2006	61,894	110,200	63,000
2007	58,763	74,000	63,000
2008b	58,471	60,700	60,700

Catch table footnotes:
a) Atka mackerel was not a reported species group until 1978.
b) 2008 data as of 11/08/08. Available at http://www.fakr.noaa.gov/2008/car110_bsai_with_cdq.pdf
Sources: compiled from NMFS Regional Office web site and various NPFMC reports.

Table 15.2. 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	2000	Catch	14,344	22,383	10,503	47,230
	ABC				24,000		ABC	16,400	24,700	29,700	70,800
	TAC				21,000		TAC	16,400	24,700	29,700	70,800
1991	Catch	6,154	11,761	8,711	26,626	2001	Catch	8,424	32,829	20,309	61,563
	ABC				24,000		ABC	7,800	33,600	27,900	69,300
	TAC				24,000		TAC	7,800	33,600	27,900	69,300
1992	Catch	11,217	21,438	15,878	48,532	2002	Catch	4,920	22,291	18,077	45,288
	ABC				43,000		ABC	5,500	23,800	19,700	49,000
	TAC				43,000		TAC	5,500	23,800	19,700	49,000
1993	Catch	15,256	29,156	21,594	66,006	2003	Catch	10,725	25,435	17,885	54,045
	ABC				117,100		ABC	10,650	29,360	22,990	63,000
	TAC				64,000		TAC	10,650	29,360	19,990	60,000
1994	Catch	15,106	28,871	21,383	65,360	2004	Catch	10,838	30,169	19,554	60,562
	ABC	13,475	55,125	53,900	122,500		ABC	11,240	31,100	24,360	66,700
	TAC	13,475	44,525	10,000	68,000		TAC	11,240	31,100	20,660	63,000
1995	Catch	14,201	50,386	16,967	81,554	2005	Catch	7,200	35,069	19,743	62,012
	ABC	13,500	55,900	55,600	125,000		ABC	24,550	52,830	46,620	124,000
	TAC	13,500	50,000	16,500	80,000		TAC	7,500	35,500	20,000	63,000
1996	Catch	28,173	33,523	42,246	103,942	2006	Catch	7,421	39,836	14,637	61,894
	ABC	26,700	33,600	55,700	116,000		ABC	21,780	46,860	41,360	110,200
	TAC	26,700	33,600	45,857	10,657		TAC	7,500	40,000	15,500	63,000
1997	Catch	16,315	19,990	29,537	65,842	2007	Catch	22,943	26,723	9,097	58,763
	ABC	15,000	19,500	32,200	66,700		ABC	23,800	29,600	20,600	74,000
	TAC	15,000	19,500	32,200	66,700		TAC	23,800	29,600	9,600	63,000
1998	Catch	12,271	20,209	24,617	57,097	2008*	Catch	19,470	22,359	16,642	58,471
	ABC	14,900	22,400	27,000	64,300		ABC	19,500	24,300	16,900	60,700
	TAC	14,900	22,400	27,000	64,300		TAC	19,500	24,300	16,900	60,700
1999	Catch	17,453	22,419	16,366	56,237						
	ABC	17,000	25,600	30,700	73,300						
	TAC	17,000	22,400	27,000	66,400						

* 2008 data as of 11/08/08. Available at http://www.fakr.noaa.gov/2008/car110_bsai_with_cdq.pdf

Table 15.3. Numbers of Atka mackerel length-weight data, length frequency, and aged samples based on NMFS observer data 1990-2007.

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

Table 15.4 Estimated catch-in-numbers at age (in millions) of Atka mackerel from the Aleutian Islands. These data were used to tune the age-structured analysis.

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	1.59	14.00	8.88	4.57	16.47	13.33	10.54	2.09	0.71	0.08

[a] Too few fish were sampled for age structures in 1989 to construct an age-length key (see Section 15.3.1).

Table 15.5 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 15.6 Atka mackerel biomass in metric tons, and the percentage distribution and coefficients of variation (*CV*) by management area from the bottom trawl surveys in the Aleutian Islands in 1991, 1994, 1997, 2000, 2002, 2004, and 2006. Biomass is also reported by survey depth interval.

Area	Depth (m)	Biomass (t)						
		1991	1994	1997	2000	2002	2004	2006
Aleutian Islands	1-100	429,826	145,000	188,504	145,001	330,891	394,594	364,490
	101-200	293,554	455,452	177,663	357,138	393,055	485,428	326,136
	201-300	538	1,688	127	8,635	48,630	7,474	38,249
	301-500	-	22	20	82	221	288	61
	Total	723,918	602,161	366,314	510,857	772,798	886,783	728,935
	Area % of Total	100%	100%	100%	100%	100%	100%	100%
	CV	15%	33%	29%	28%	20%	17%	28%
Western 543	1-100	168,968	93,847	90,824	106,168	51,921	140,669	64,429
	101-200	185,748	214,228	43,478	65,600	154,820	226,043	35,926
	201-300	304	1,656	63	7,912	f48,366	6,033	318
	301-500	-	6	-	-	7.6	36	21
	Total	355,020	309,737	134,364	179,680	255,115	372,782	100,693
	Area % of Total	49.0%	51.4%	36.7%	35.2%	33.0%	42.0%	13.8%
	CV	18%	55%	56%	51%	31%	24%	35%
Central 542	1-100	187,194	50,513	70,458	38,805	126,811	198,501	192,832
	101-200	104,413	33,517	116,295	290,766	199,743	70,793	85,102
	201-300	71	13	53	674	169	470	103
	301-500	-	3	6	9	143	194	-
	Total	291,679	84,046	186,813	330,255	326,866	269,958	278,036
	Area % of Total	40.3%	14.0%	51.0%	64.6%	42.3%	30.4%	38.1%
	CV	18%	48%	36%	34%	24%	34%	24%
Eastern 541	1-100	73,663	641	27,222	29	152,159	54,424	107,230
	101-200	3,392	207,707	17,890	772	38,492	188,592	205,108
	201-300	163	19	11	48	94	971	37,829
	301-500	-	12	14	73	71	57	40
	Total	77,218	208,379	45,137	922	190,817	244,043	350.206
	Area % of Total	10.7%	34.6%	12.3%	0.2%	24.7%	27.5%	48.0%
	CV	83%	44%	68%	74%	58%	33%	55%
Bering Sea	1-100	47	66,562	95,672	1,853	59,682	127,896	12,284
	101-200	3	30	9	187	103	142,616	176
	201-300	11	3	-	4	98	39	1,842
	301-500	-	8	-	-	-	4	6
	Total	61	66,603	95,680	2,044	59,883	267,556	12,308
	CV	37%	99%	99%	87%	99%	43%	44%

Table 15.7. 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 2002, 2004, and 2006. The 2008 fishery weight-at-age values are the average of 2005, 2006, and 2007.

		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
Ave 2002, 2004, 2006		0.045	0.145	0.336	0.545	0.615	.0750	0.819	0.816	0.893	1.118	0.966
Fishery	1977	0.069	0.132	0.225	0.306	0.400	0.470	0.507	0.379	0.780	0.976	1.034
Foreign	1978	0.069	0.072	0.225	0.300	0.348	0.388	0.397	0.371	0.423	0.976	1.034
	1979	0.069	0.496	0.319	0.457	0.476	0.475	0.468	0.546	0.780	0.976	1.034
	1980	0.069	0.365	0.317	0.450	0.520	0.585	0.630	0.546	0.780	0.976	1.034
	1981	0.069	0.365	0.317	0.450	0.520	0.585	0.630	0.546	0.780	0.976	1.034
	1982	0.069	0.365	0.273	0.443	0.564	0.695	0.795	0.546	0.780	0.976	1.034
	1983	0.069	0.365	0.359	0.499	0.601	0.686	0.810	0.546	0.780	0.976	1.034
	1984	0.069	0.297	0.410	0.617	0.707	0.777	0.802	0.890	0.910	0.976	1.034
	1985	0.069	0.302	0.452	0.552	0.682	0.737	0.775	0.807	1.007	1.011	1.034
	1986	0.069	0.146	0.334	0.528	0.546	0.786	0.753	0.829	0.858	0.954	0.979
	1987	0.069	0.265	0.435	0.729	0.908	0.859	0.964	1.023	1.054	1.088	1.105
	1988	0.069	0.196	0.351	0.470	0.564	0.624	0.694	0.783	0.818	0.850	1.017
Domestic	1989	0.069	0.295	0.440	0.577	0.739	0.838	0.664	0.817	0.906	1.010	0.951
	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	0.277	0.408	0.509	0.704	0.696	0.733	0.773	0.811	1.241	0.998
	2008	0.069	0.263	0.403	0.497	0.597	0.622	0.679	0.818	0.948	1.013	0.997

Table 15.8. 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 15.9. Estimates of key results from AMAK for Bering Sea/Aleutian Islands Atka mackerel from the Reference Model (Ref Model) configured as in last year's assessment and Model 8. Both models include current fishery catch and age data. Coefficients of variation (*CV*) for some key reference values appearing directly below, are given in parentheses.

Assessment Model	**Ref Model**	**Model 8**
Model setup		
Survey catchability	1.51	1.56
Steepness	0.800	0.800
SigmaR	0.6	0.6
Natural mortality	0.300	0.300
Fishery Average Effective *N*	123	115
Survey Average Effective *N*	62	52
RMSE Survey	0.351	0.190
-log Likelihoods		
Number of Parameters	412	138
Survey index	4.35	4.95
Catch biomass	0.10	0.09
Fishery age comp	164.72	152.97
Survey age comp	39.00	39.82
Sub total	208.16	197.84
-log Penalties		
Recruitment	11.913	16.383
Selectivity constraint	124.417	46.999
Fishing mortality penalty	0.000	0.000
Prior	3.294	3.945
Total	347.782	265.170
Fishing mortalities (full selection)		
F 2008	0.315	0.229
F 2008/*F* 40%	0.818	0.581
F 40%	0.385	0.394
*F*35%	0.463	0.482
Stock abundance		
Initial Biomass (t, 1977)	274,010	322,450
CV	(16%)	(14%)
2008 total biomass (t)	439,010	545,210
CV	(19%)	(19%)
1999 year class (millions at age 1)	1,375	1,273
CV	(24%)	(21%)
2001 year class (millions at age 1)	879	900
CV	(31%)	(29%)
Recruitment Variability	0.637	0.652

Table 15.10. Estimates of Atka mackerel fishery (over time, 1977-2008) and survey selectivity at age for Model 8. These are full-selection (maximum = 1.0) estimates.

	Age										
Year	1	2	3	4	5	6	7	8	9	10	11+
1977	0.004	0.042	0.341	0.738	1.000	0.946	0.840	0.708	0.622	0.562	0.562
1978	0.004	0.042	0.341	0.738	1.000	0.946	0.840	0.708	0.622	0.562	0.562
1979	0.004	0.042	0.341	0.738	1.000	0.946	0.840	0.708	0.622	0.562	0.562
1980	0.004	0.042	0.341	0.738	1.000	0.946	0.840	0.708	0.622	0.562	0.562
1981	0.004	0.042	0.341	0.738	1.000	0.946	0.840	0.708	0.622	0.562	0.562
1982	0.004	0.042	0.341	0.738	1.000	0.946	0.840	0.708	0.622	0.562	0.562
1983	0.004	0.042	0.341	0.738	1.000	0.946	0.840	0.708	0.622	0.562	0.562
1984	0.003	0.036	0.350	0.905	1.000	0.989	0.966	0.901	0.846	0.788	0.788
1985	0.003	0.036	0.350	0.905	1.000	0.989	0.966	0.901	0.846	0.788	0.788
1986	0.003	0.036	0.350	0.905	1.000	0.989	0.966	0.901	0.846	0.788	0.788
1987	0.003	0.036	0.350	0.905	1.000	0.989	0.966	0.901	0.846	0.788	0.788
1988	0.003	0.036	0.350	0.905	1.000	0.989	0.966	0.901	0.846	0.788	0.788
1989	0.003	0.036	0.350	0.905	1.000	0.989	0.966	0.901	0.846	0.788	0.788
1990	0.003	0.036	0.350	0.905	1.000	0.989	0.966	0.901	0.846	0.788	0.788
1991	0.003	0.036	0.350	0.905	1.000	0.989	0.966	0.901	0.846	0.788	0.788
1992	0.002	0.017	0.123	0.488	0.759	0.835	0.919	1.000	0.977	0.955	0.955
1993	0.002	0.017	0.123	0.488	0.759	0.835	0.919	1.000	0.977	0.955	0.955
1994	0.002	0.017	0.123	0.488	0.759	0.835	0.919	1.000	0.977	0.955	0.955
1995	0.002	0.017	0.123	0.488	0.759	0.835	0.919	1.000	0.977	0.955	0.955
1996	0.002	0.017	0.123	0.488	0.759	0.835	0.919	1.000	0.977	0.955	0.955
1997	0.002	0.017	0.123	0.488	0.759	0.835	0.919	1.000	0.977	0.955	0.955
1998	0.002	0.017	0.123	0.488	0.759	0.835	0.919	1.000	0.977	0.955	0.955
1999	0.001	0.017	0.201	0.560	0.742	0.863	1.000	0.977	0.870	0.785	0.785
2000	0.001	0.017	0.201	0.560	0.742	0.863	1.000	0.977	0.870	0.785	0.785
2001	0.001	0.017	0.201	0.560	0.742	0.863	1.000	0.977	0.870	0.785	0.785
2002	0.001	0.017	0.201	0.560	0.742	0.863	1.000	0.977	0.870	0.785	0.785
2003	0.001	0.017	0.201	0.560	0.742	0.863	1.000	0.977	0.870	0.785	0.785
2004	0.001	0.017	0.201	0.560	0.742	0.863	1.000	0.977	0.870	0.785	0.785
2005	0.001	0.017	0.201	0.560	0.742	0.863	1.000	0.977	0.870	0.785	0.785
2006	0.001	0.017	0.201	0.560	0.742	0.863	1.000	0.977	0.870	0.785	0.785
2007	0.001	0.017	0.201	0.560	0.742	0.863	1.000	0.977	0.870	0.785	0.785
2008	0.001	0.017	0.201	0.560	0.742	0.863	1.000	0.977	0.870	0.785	0.785
Survey	0.018	0.119	0.524	0.869	0.904	0.939	1.000	0.854	0.615	0.501	0.501

Table 15.11. Estimated Atka mackerel numbers at age in millions, 1977-2008.

	Age										
Year	1	2	3	4	5	6	7	8	9	10	11+
1977	207	346	203	65	43	20	18	15	13	11	62
1978	1256	153	254	139	41	25	12	11	10	8	48
1979	311	929	112	172	85	23	15	7	7	6	36
1980	198	230	684	79	113	54	15	9	5	4	28
1981	221	146	170	488	54	75	36	10	6	3	23
1982	154	164	108	122	341	37	52	25	7	5	18
1983	216	114	121	78	86	235	25	36	17	5	16
1984	290	160	84	88	56	61	167	18	26	13	15
1985	432	215	118	60	58	36	40	109	12	17	19
1986	380	320	158	82	38	36	23	25	69	8	23
1987	565	282	235	110	51	23	22	14	15	43	20
1988	336	419	208	166	72	33	15	14	9	10	42
1989	1332	249	309	148	111	48	22	10	10	6	35
1990	577	987	184	223	103	77	33	15	7	7	29
1991	274	428	729	134	157	72	54	23	11	5	25
1992	473	203	316	524	91	107	49	37	16	7	21
1993	891	350	150	230	362	61	70	32	23	10	18
1994	289	660	258	109	155	233	39	44	19	14	18
1995	301	214	487	186	72	97	142	23	26	12	19
1996	798	223	158	345	116	41	53	76	12	13	16
1997	139	591	164	110	203	60	20	25	35	6	14
1998	272	103	435	117	71	120	35	11	14	19	11
1999	642	201	76	308	72	40	65	18	6	7	16
2000	1273	476	148	53	196	44	23	37	10	3	14
2001	855	943	351	104	34	120	26	13	21	6	10
2002	900	633	694	242	63	19	66	14	7	12	9
2003	182	667	467	488	155	39	12	38	8	4	13
2004	401	135	492	330	316	96	23	7	22	5	10
2005	758	297	100	349	216	199	59	14	4	14	9
2006	378	562	219	71	229	136	123	35	8	2	14
2007	315	280	414	155	46	142	82	72	21	5	10
2008	318	233	207	293	101	29	87	49	43	13	10

Table 15.12. 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). Also included are age 3+ and female spawning biomass in metric tons from the current assessment compared to last year's (2006) assessment.

	Current assessment age 1+ biomass (t)			*Age 3+ biomass (t)*		*Female spawning biomass (t)*	
Year	Estimate	LCI	UCI	Current	2007	Current	2007
1977	322,450	229,632	415,268	194,180	174,004	75,681	66,345
1978	377,270	263,156	491,384	194,628	159,371	77,012	64,295
1979	420,480	286,916	554,044	225,771	178,567	84,920	64,376
1980	500,030	339,490	660,570	395,114	323,664	101,260	77,010
1981	531,840	358,728	704,952	405,797	339,971	147,910	117,610
1982	478,230	320,818	635,642	385,512	324,538	155,720	127,290
1983	430,190	288,038	572,342	371,230	325,173	144,940	121,500
1984	397,240	269,424	525,056	377,658	334,424	125,550	106,970
1985	357,020	241,390	472,650	319,991	289,091	100,750	87,045
1986	344,030	234,522	453,538	272,392	251,497	85,800	75,931
1987	368,740	260,034	477,446	369,594	363,420	86,182	79,683
1988	400,090	296,522	503,658	295,189	303,182	94,556	93,176
1989	473,300	376,222	570,378	418,278	441,037	107,160	112,130
1990	562,610	471,646	653,574	527,198	642,587	126,010	134,090
1991	665,820	577,496	754,144	479,865	573,293	146,580	153,380
1992	714,020	627,294	800,746	721,683	723,300	190,790	185,210
1993	686,190	606,382	765,998	657,479	620,757	194,700	183,530
1994	649,200	573,548	724,852	522,903	547,426	170,050	160,220
1995	629,100	552,880	705,320	480,063	541,919	149,680	146,980
1996	572,320	495,472	649,168	447,624	469,223	136,370	134,520
1997	472,400	397,998	546,802	422,929	428,784	115,890	115,000
1998	463,690	385,896	541,484	371,894	390,733	105,730	104,740
1999	433,990	355,168	512,812	389,934	374,233	112,060	107,850
2000	442,280	359,198	525,362	347,964	341,806	98,804	94,645
2001	533,050	430,702	635,398	392,400	431,475	90,924	88,667
2002	662,330	526,748	797,912	445,874	514,196	114,300	119,120
2003	742,090	580,096	904,084	514,019	560,278	162,120	173,480
2004	737,500	559,868	915,132	593,355	588,575	190,180	198,610
2005	686,040	499,820	872,260	514,571	524,422	196,040	199,530
2006	615,660	425,182	806,138	459,303	432,256	165,530	164,940
2007	583,090	378,110	788,070	528,053	400,948	146,610	134,000
2008	545,210	334,730	755,690	469,013	323,385	146,550	110,200
2009				410,589		132,330	

Table 15.13. Estimates of age-1 Atka mackerel recruitment (millions of recruits).

	Age 1 Recruits	
Year	Current	2007
1977	207	202
1978	1256	1084
1979	311	309
1980	198	196
1981	221	229
1982	154	152
1983	216	225
1984	290	305
1985	432	474
1986	380	451
1987	565	599
1988	336	373
1989	1332	1083
1990	577	511
1991	274	267
1992	473	539
1993	891	813
1994	289	293
1995	301	318
1996	798	727
1997	139	143
1998	272	247
1999	642	725
2000	1273	1364
2001	855	806
2002	900	844
2003	182	174
2004	401	373
2005	758	435
2006	378	231
2007	315	
Ave 78-06	520	
Med 78-06	380	

Table 15.14. Estimates of full-selection fishing mortality rates and exploitation rates for Atka mackerel.

Year	*F*[a]	Catch/Biomass Rate[b]
1977	0.228	0.112
1978	0.263	0.125
1979	0.161	0.103
1980	0.110	0.052
1981	0.080	0.049
1982	0.072	0.052
1983	0.046	0.032
1984	0.132	0.095
1985	0.179	0.118
1986	0.185	0.117
1987	0.132	0.081
1988	0.117	0.075
1989	0.069	0.043
1990	0.059	0.042
1991	0.087	0.055
1992	0.142	0.067
1993	0.187	0.100
1994	0.232	0.125
1995	0.357	0.170
1996	0.478	0.232
1997	0.296	0.156
1998	0.367	0.154
1999	0.268	0.144
2000	0.257	0.136
2001	0.352	0.157
2002	0.257	0.102
2003	0.238	0.105
2004	0.218	0.102
2005	0.216	0.121
2006	0.238	0.135
2007	0.223	0.111
2008[c]	0.229	0.129

a Full-selection fishing mortality rates.
b Catch/biomass rate is the ratio of catch to beginning year age 3+ biomass.
c The 2008 catch/biomass rate is based on 2008 TAC.

Table 15.15. 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 244,400, 97,800, and 85,500 t, respectively.

	$B_{100\%}$	$B_{40\%}$	$B_{35\%}$	B_{2008}	$B_{2008}/B_{100\%}$
	244,400	97,800	85,500	132,300	0.541

Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2008	56,617	56,617	56,617	56,617	56,617	56,617	56,617
2009	63,000	63,000	63,000	63,000	63,000	99,412	83,762
2010	71,091	71,091	27,394	18,675	0	71,780	66,412
2011	58,013	58,013	27,492	19,281	0	54,792	62,349
2012	54,720	54,720	29,084	20,793	0	56,073	58,877
2013	55,959	55,959	30,579	22,152	0	59,105	60,182
2014	56,976	56,976	31,759	23,227	0	60,621	61,014
2015	57,356	57,356	32,904	24,251	0	60,509	60,660
2016	58,327	58,327	33,812	25,081	0	62,084	62,128
2017	59,305	59,305	34,463	25,687	0	62,887	62,899
2018	60,109	60,109	35,076	26,222	0	63,599	63,601
2019	61,120	61,120	35,838	26,831	0	64,935	64,935
2020	63,622	63,622	36,802	27,566	0	67,996	67,995
2021	66,402	66,402	37,949	28,420	0	71,378	71,377
Fishing M	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2008	0.229	0.229	0.229	0.229	0.229	0.229	0.229
2009	0.286	0.286	0.286	0.286	0.286	0.482	0.394
2010	0.394	0.394	0.139	0.093	0.000	0.460	0.394
2011	0.369	0.369	0.139	0.093	0.000	0.396	0.422
2012	0.349	0.349	0.139	0.093	0.000	0.393	0.402
2013	0.352	0.352	0.139	0.093	0.000	0.404	0.407
2014	0.353	0.353	0.139	0.093	0.000	0.407	0.408
2015	0.350	0.350	0.139	0.093	0.000	0.401	0.401
2016	0.354	0.354	0.139	0.093	0.000	0.409	0.410
2017	0.359	0.359	0.139	0.093	0.000	0.415	0.415
2018	0.360	0.360	0.139	0.093	0.000	0.415	0.415
2019	0.359	0.359	0.139	0.093	0.000	0.414	0.414
2020	0.365	0.365	0.139	0.093	0.000	0.424	0.424
2021	0.371	0.371	0.139	0.093	0.000	0.435	0.435
Spawning biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2008	146,555	146,555	146,555	146,555	146,555	146,555	146,555
2009	132,334	132,334	132,334	132,334	132,334	121,466	126,200
2010	108,373	108,373	121,329	123,822	129,072	93,353	101,334
2011	92,667	92,667	119,269	125,199	138,369	81,238	86,434
2012	92,114	92,114	126,006	134,571	154,490	83,257	85,361
2013	94,355	94,355	133,891	144,750	170,968	86,097	86,906
2014	96,534	96,534	141,011	153,931	186,150	88,135	88,451
2015	97,503	97,503	145,478	160,002	197,230	89,044	89,168
2016	97,877	97,877	148,228	163,981	205,344	89,319	89,369
2017	98,237	98,237	150,567	167,301	212,155	89,552	89,570
2018	99,005	99,005	153,177	170,773	218,780	90,270	90,275
2019	101,146	101,146	156,823	175,098	225,655	92,268	92,268
2020	103,602	103,602	160,934	179,817	232,606	94,390	94,390
2021	107,082	107,082	166,566	186,059	240,949	97,306	97,306

Table 15.16. Ecosystem effects

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 increasing	Possible increased predation on Atka mackerel	No concern
Changes in habitat quality			
Temperature regime	2006 AI summer bottom temperature slightly below average (excl. 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
Sensitive non-target species	Skate catches are variable and have averaged 126 t from 2005-2007, which is about 15% of the AI skate catch over this time period	Data limited, need species-specific catch information	Possible concern
Other non-target species	Sculpin catch is variable and has been increasing over 2005-2007	Unknown	Unknown
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	Probably no concern
Fishery contribution to discards and offal production	Offal production—unknown The Atka mackerel fishery contributes an average of 900 and 1,850 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

15.15 Figures

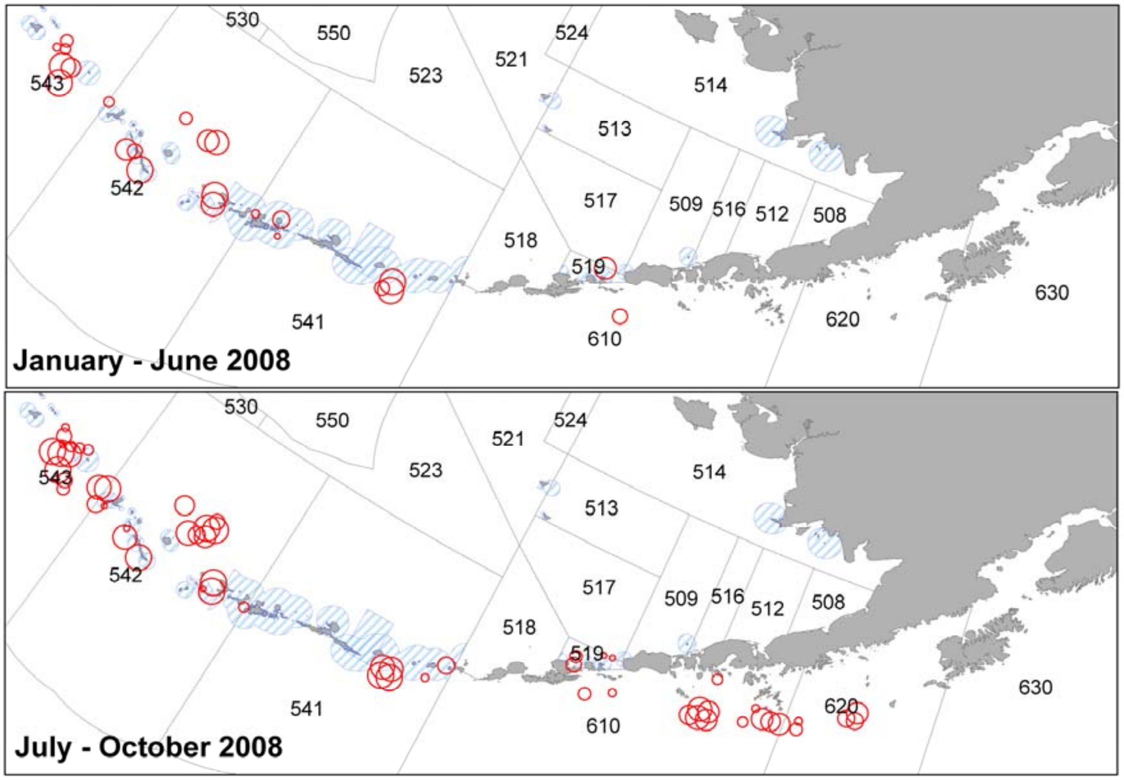


Figure 15.1. Observed catches of Atka mackerel summed for 20 km^2 cells for 2008 (January – June, top panel; and from July-October, bottom panel) where observed catch per haul was greater than 1 t. Shaded areas represent 10 and 20 nm Steller sea lion areas.

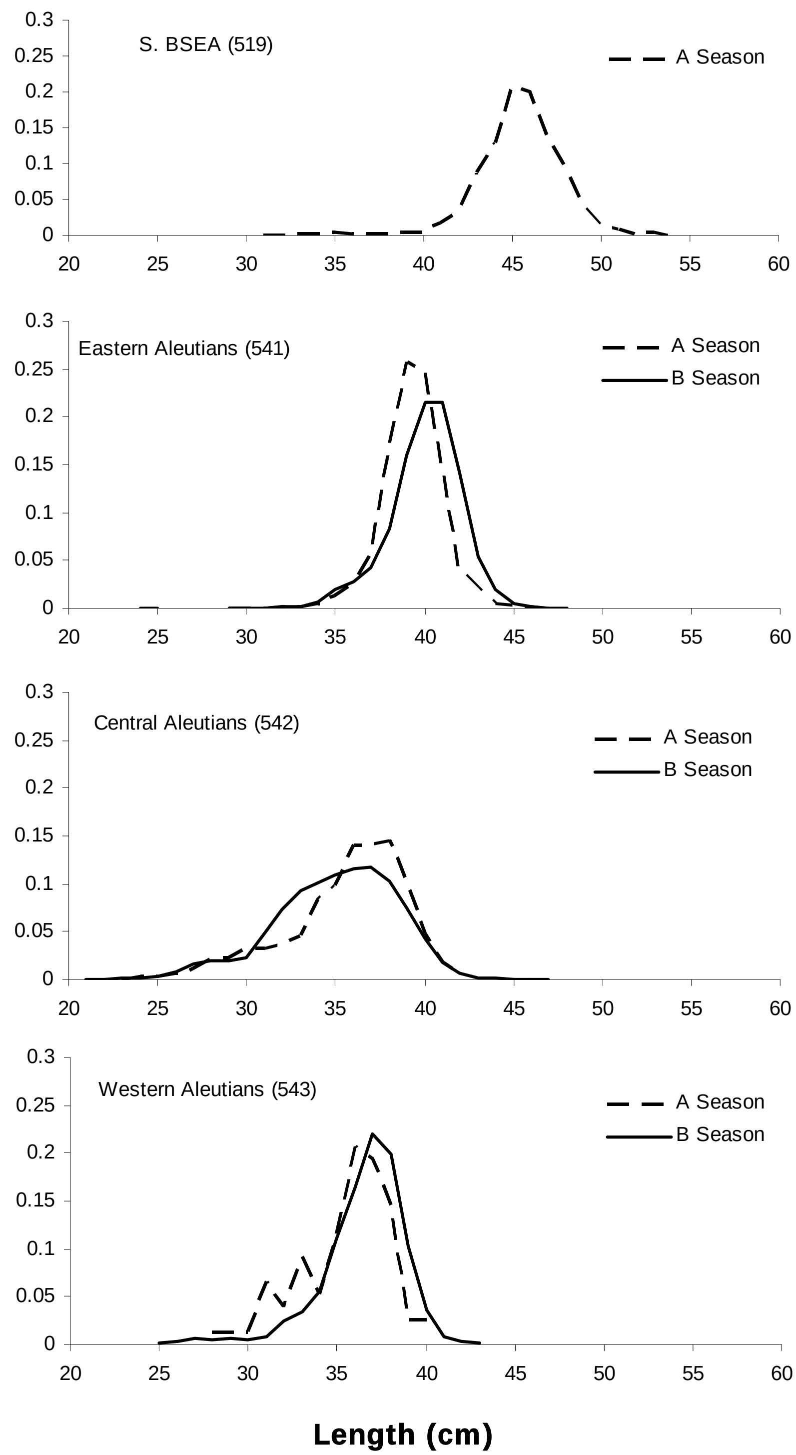


Figure 15.2. 2007 Atka mackerel fishery length-frequency data by area fished (see Figure 15.1). Numbers refer to management areas.

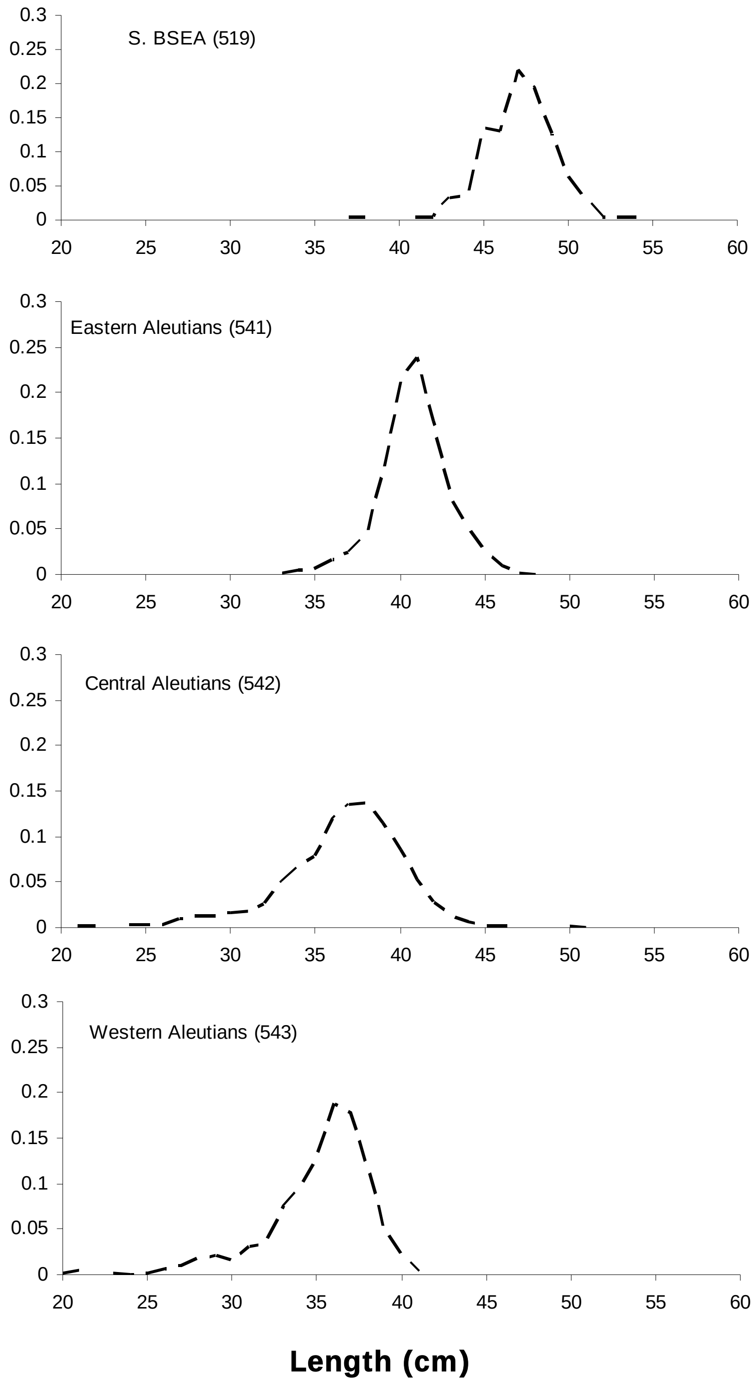


Figure 15.3. Preliminary 2008 A-season Atka mackerel fishery length-frequency data by area fished (see Figure 15.1). Numbers refer to management areas.

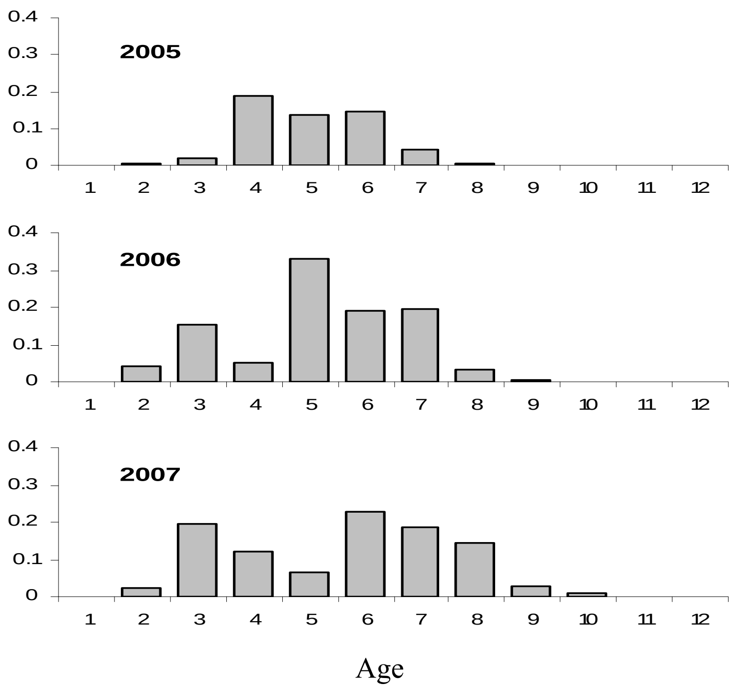


Figure 15.4. Aleutian Islands Atka mackerel fishery age composition data for 2005, 2006, and 2007.

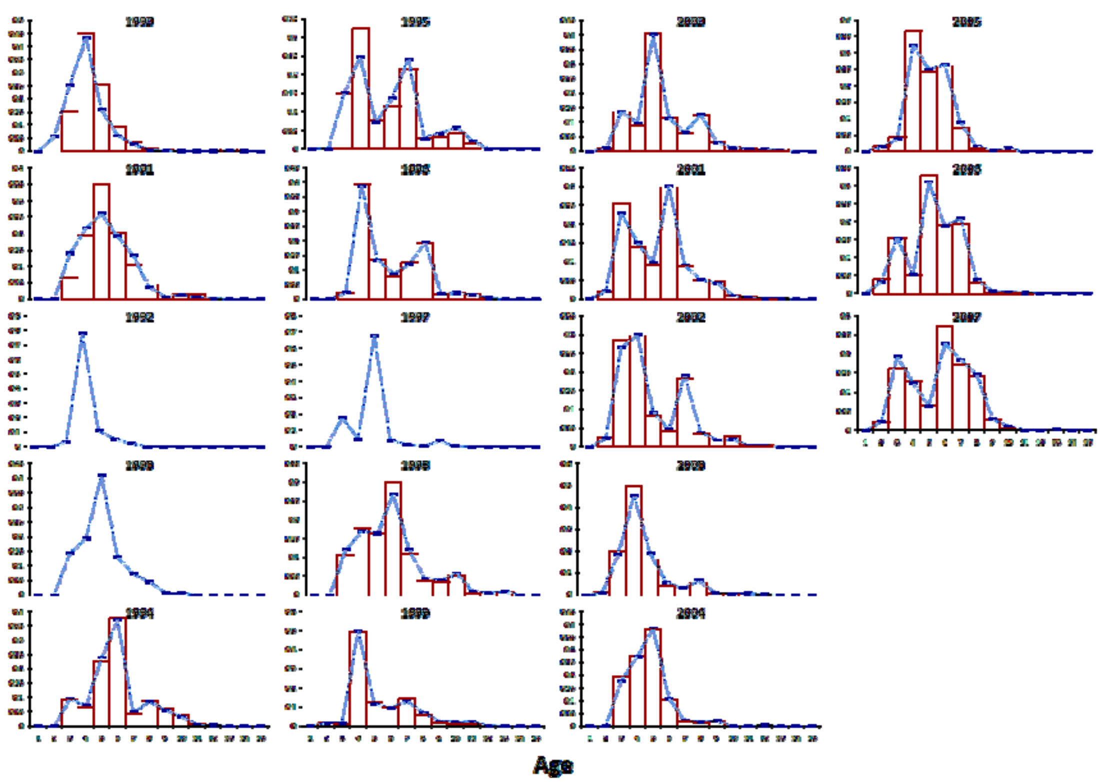


Figure 15.5. Revised estimates of proportion of catch-at-age based on the mean from the bootstrap sampling (lines and dashes) compared to the original data used in past assessments (columns).

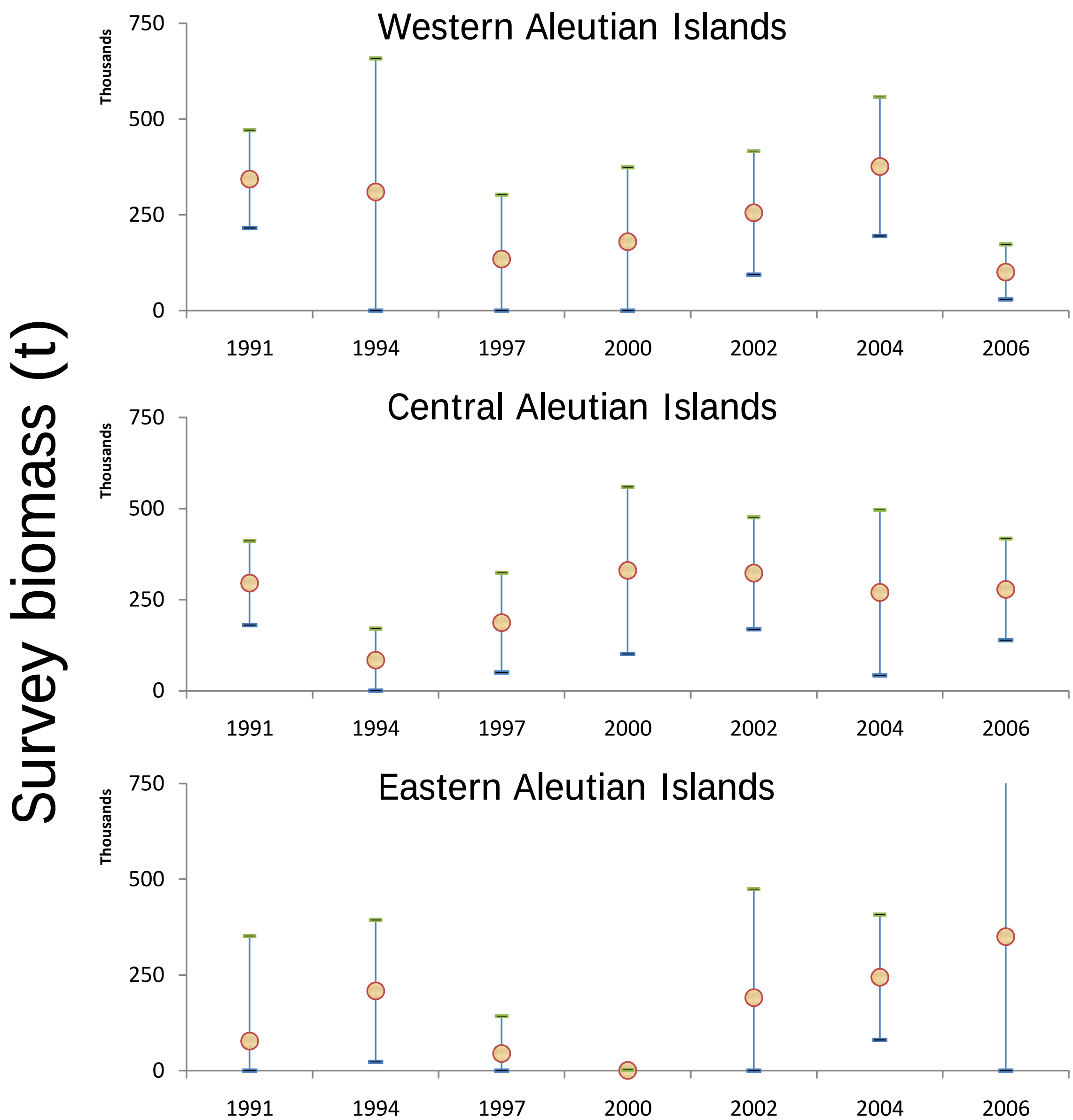


Figure 15.6. Atka mackerel Aleutian Islands survey biomass estimates by area and survey year. Bars represent 95% confidence intervals based on sampling error.

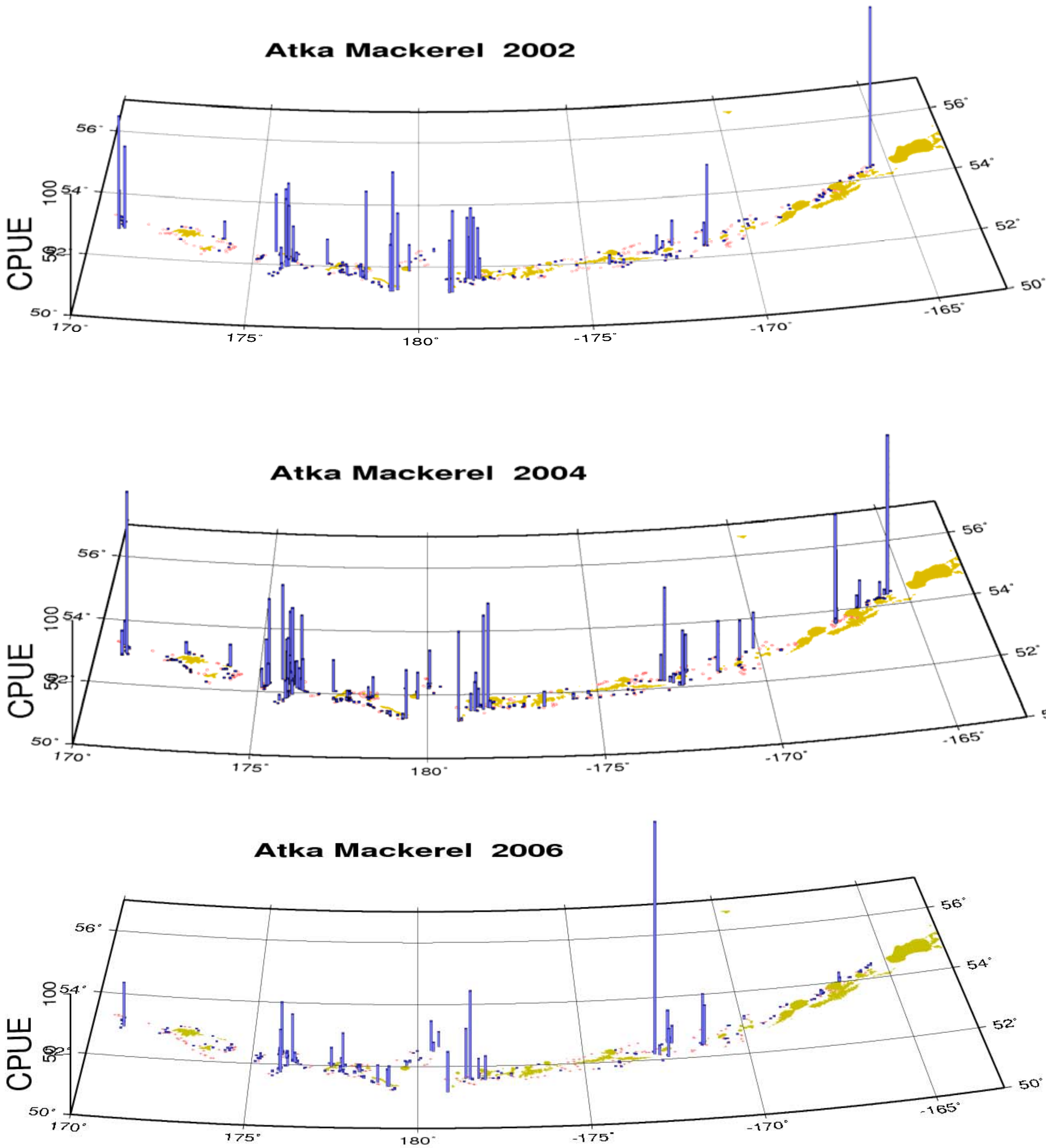


Figure 15.7. Bottom-trawl survey CPUE distributions of Atka mackerel catches during the summers of 2002, 2004, and 2006.

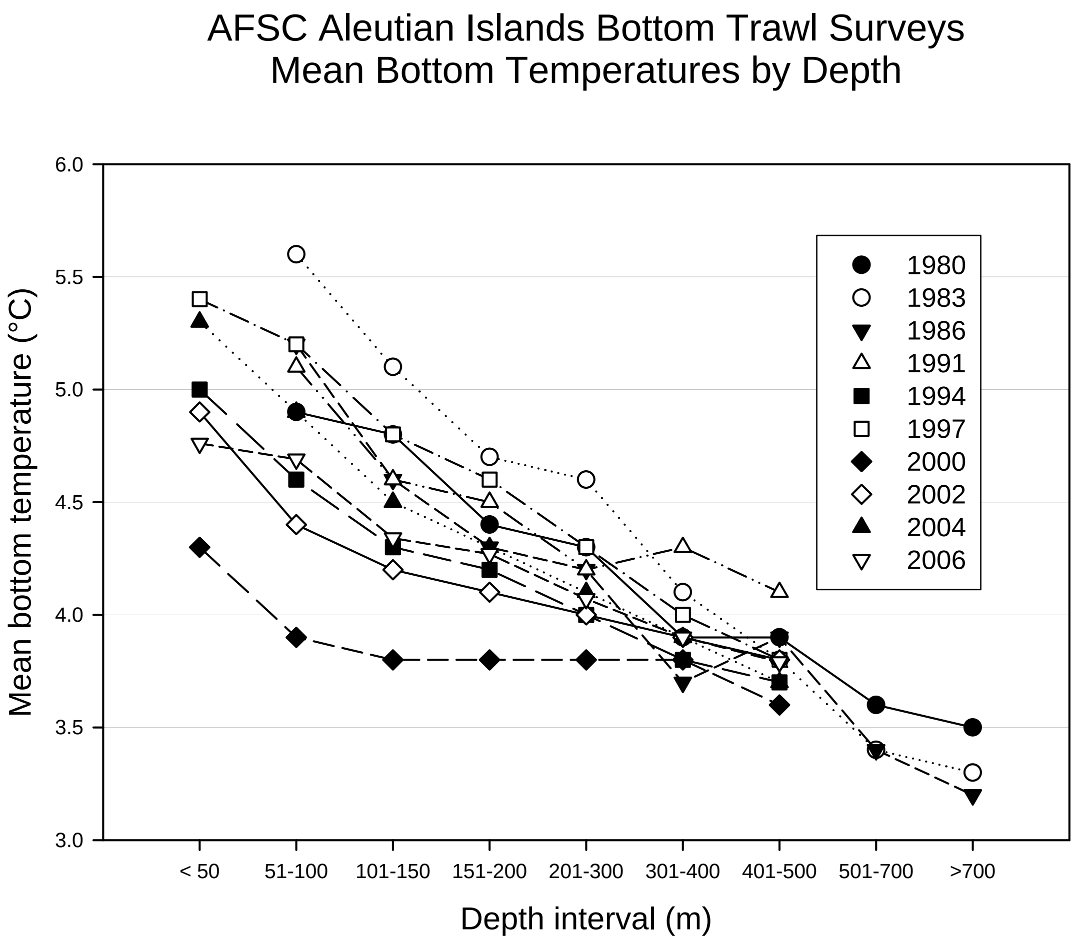


Figure 15.8. Average bottom temperatures by depth interval based on Aleutian Islands summer bottom-trawl surveys since 1980.

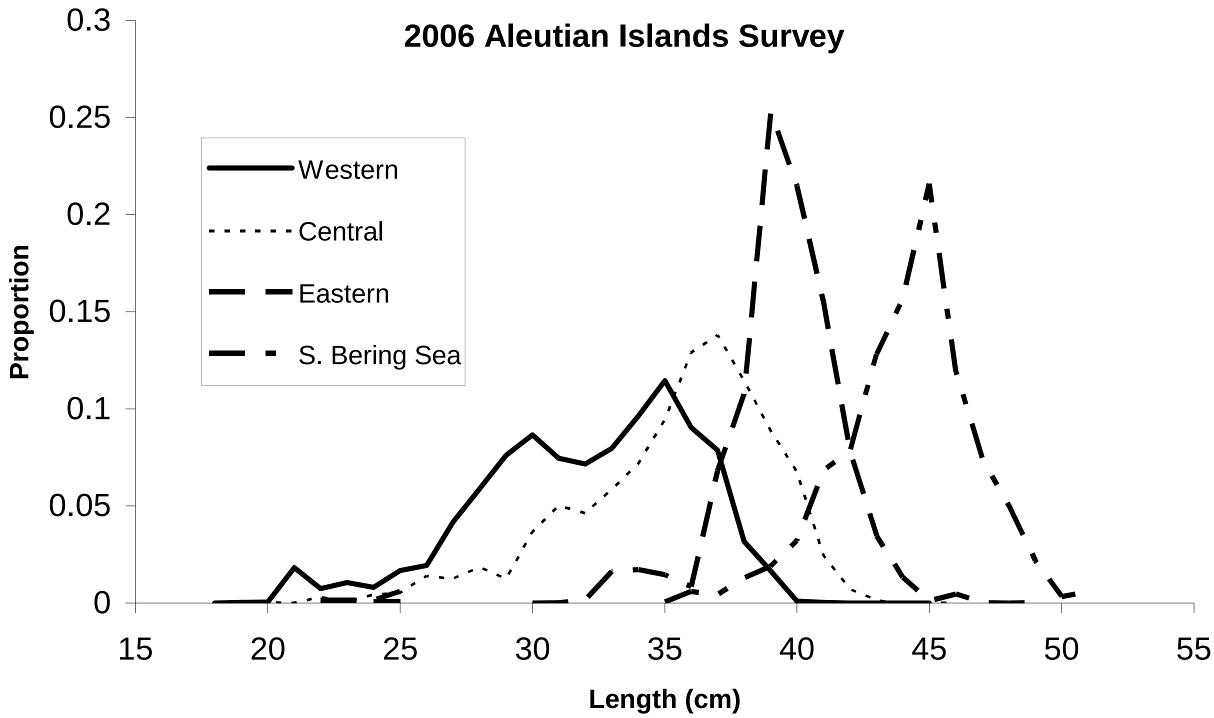


Figure 15.9. Atka mackerel bottom trawl survey length frequency data by subarea from the 2006 Aleutian Island survey.

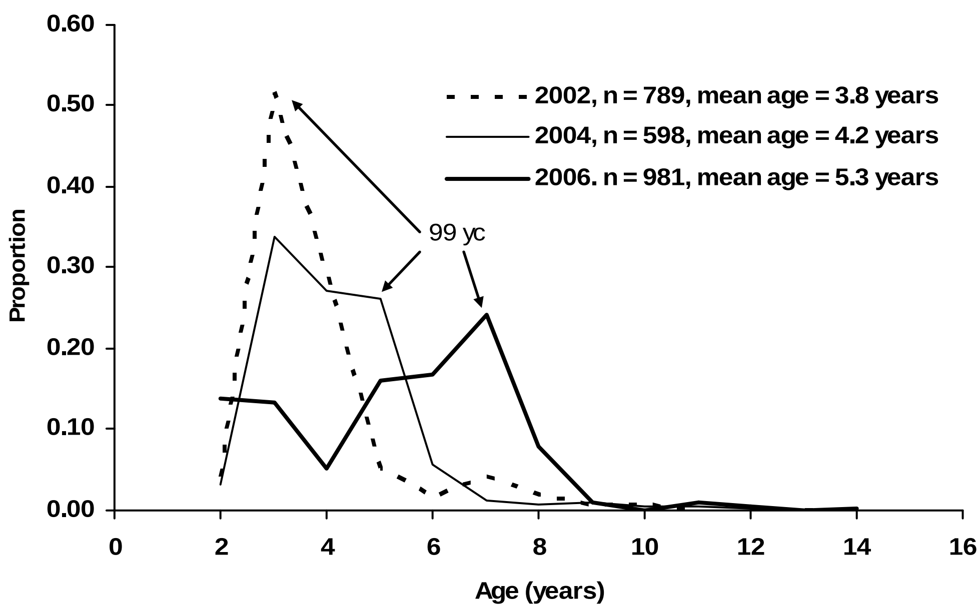


Figure 15.10. Atka mackerel age distributions from the Aleutian Islands region from the 2002, 2004, and 2006 bottom trawl surveys.

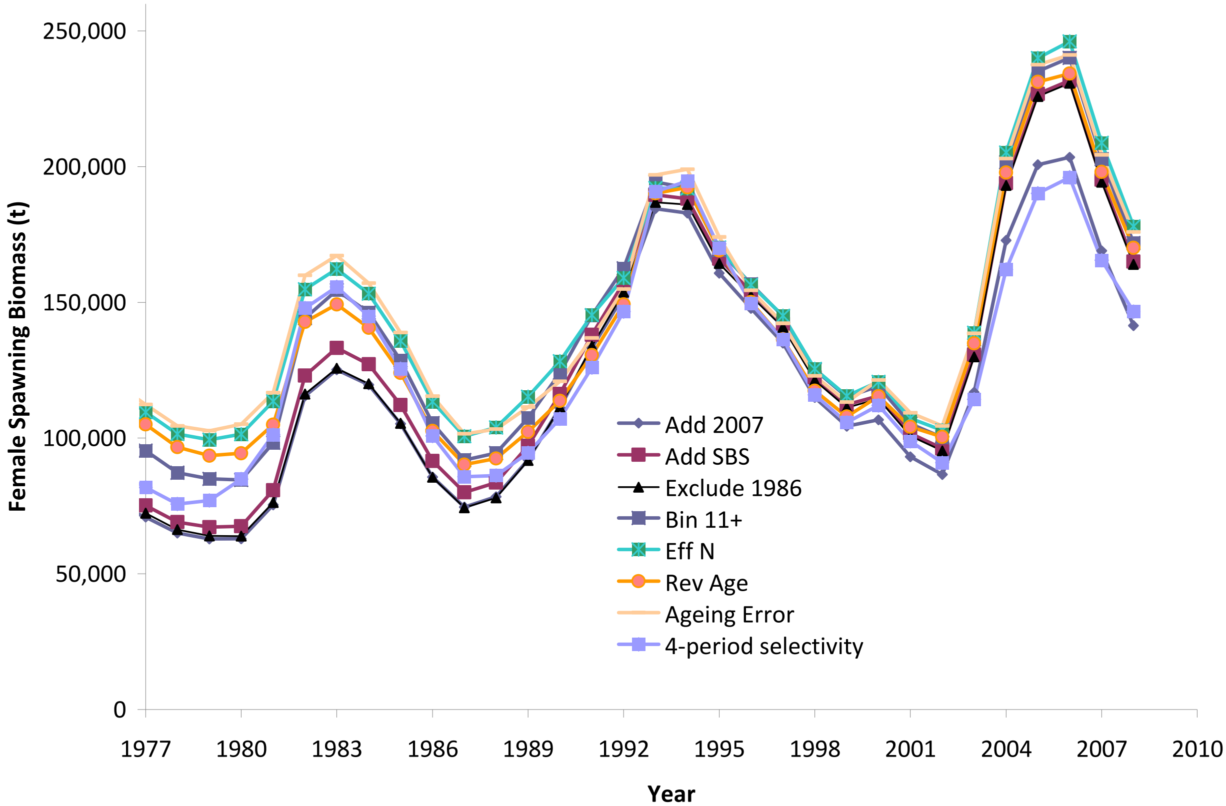
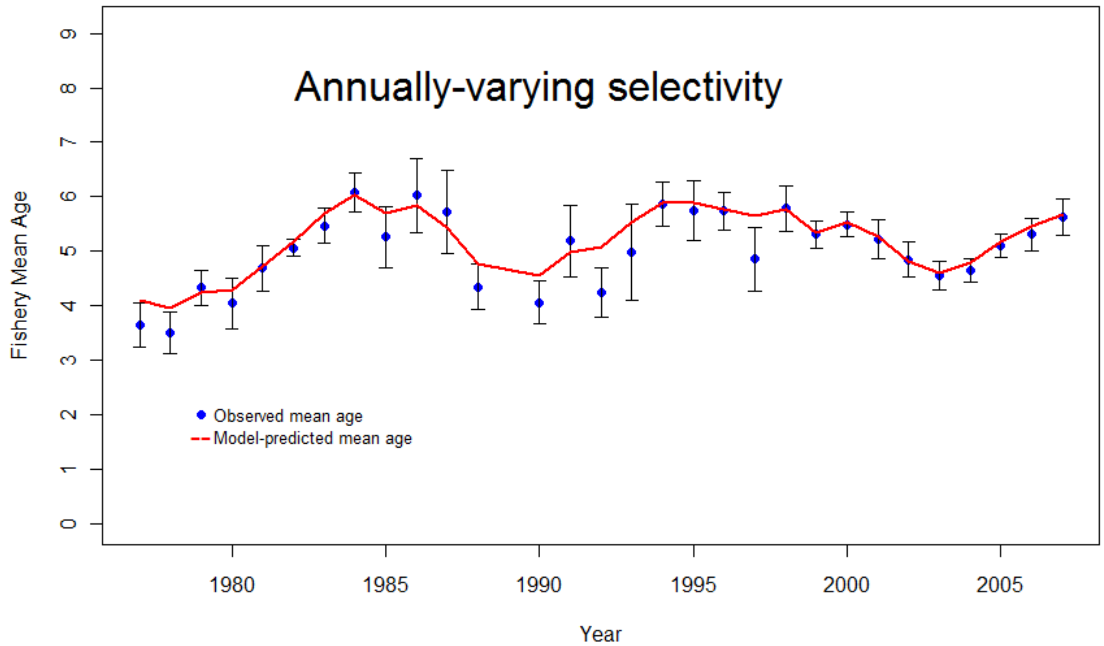


Figure 15.11. Atka mackerel female spawning biomass trends from model runs evaluating changes to the input data and four time periods of constant selectivity. The models runs are differentiated as follows: *Add 2007*- includes updated fishery catch biomass and 2007 fishery age data, *Add SBS* – includes southern Bering Sea survey biomass estimates, Exclude 1986 – excludes the 1986 survey biomass estimate, *Bin 11+* - lowers the age+ bin from 15+ to 11+ years, *Eff N* – uses calculated sample sizes for fishery catch-at-age data, *Rev Age* – uses revised estimates of catch- and weight-at-age data, *Ageing Error* – includes an age misclassification matrix, 4-period selectivity – incorporates 4 time periods during which selectivity is constant. The changes were incorporated in a cumulative fashion in the order listed in the legend, e.g., the Ageing Error model run incorporates all the changes described and listed preceding it in the legend (i.e, it does not include 4 periods of constant selectivity). The 4-period selectivity model run incorporates all the changes described and listed.



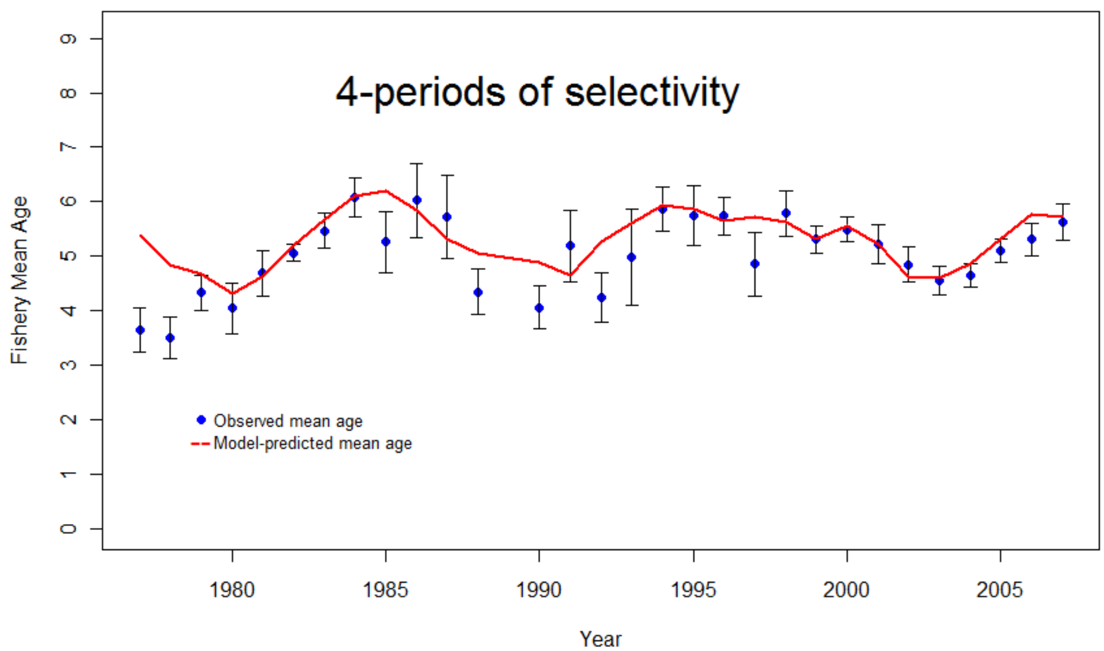


Figure 15.12. Comparisons between two model configurations and consistency with "input" sample size and observed mean ages (dots and error bars) compared to model estimates of fishery mean age in the catch. Description provided in section 15.4.1 .

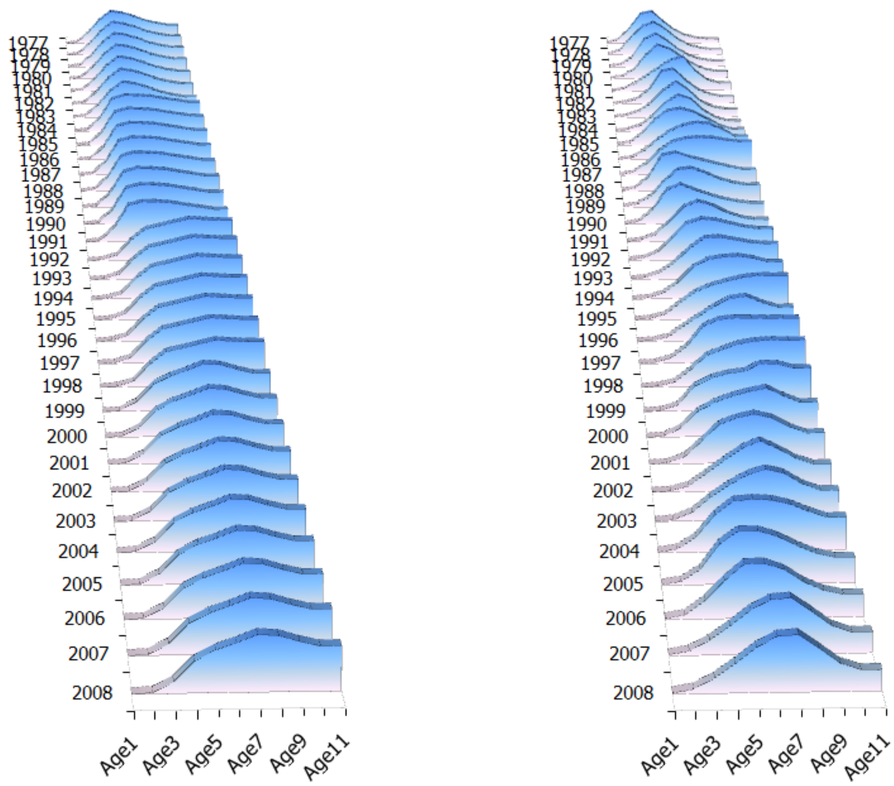


Figure 15.13. BSAI Atka mackerel assessment model configured to have 4 periods of distinct fishery selectivity patterns (left panel) compared to the model where selectivity was allowed to vary from year to year (right panel). The model with the 4 periods (1977-1982, 1983-1991, 1992-1998, and 1999-2007) was selected for analysis.

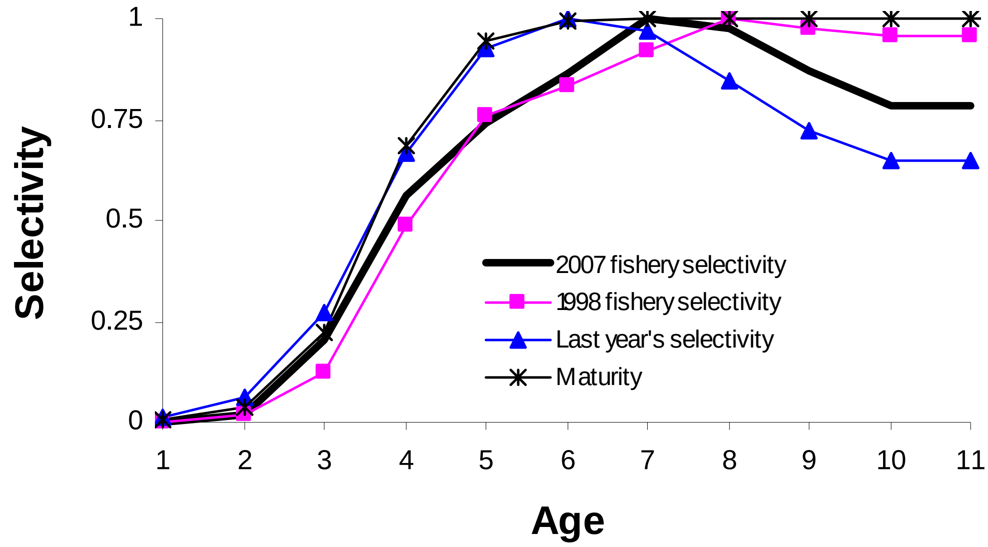


Figure 15.14. Estimated 1998 and 2007 fishery selectivity patterns from Model 8, and last year’s selectivity pattern (average of the 2002-2006 selectivity estimated in last year’s assessment) compared with the maturity-at-age estimates for Atka mackerel.

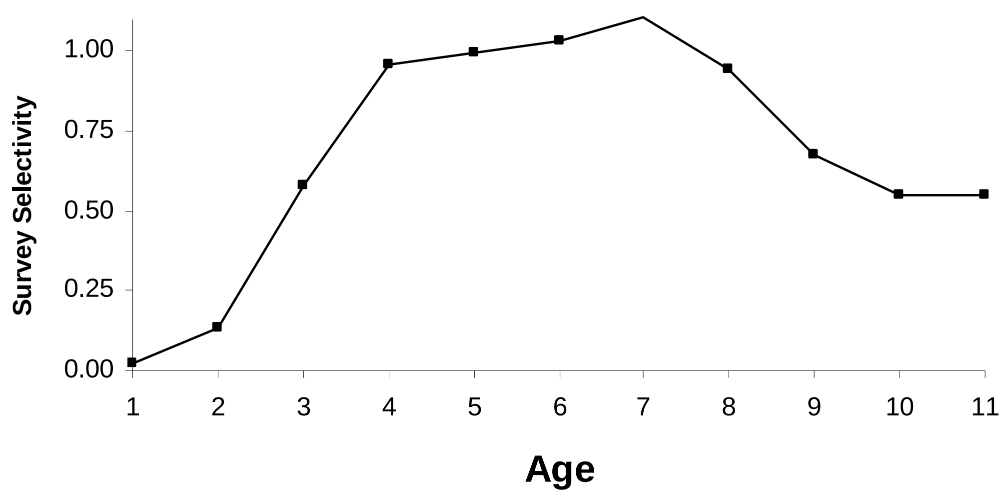


Figure 15.15. Estimated BSAI Atka mackerel survey selectivity-at-age.

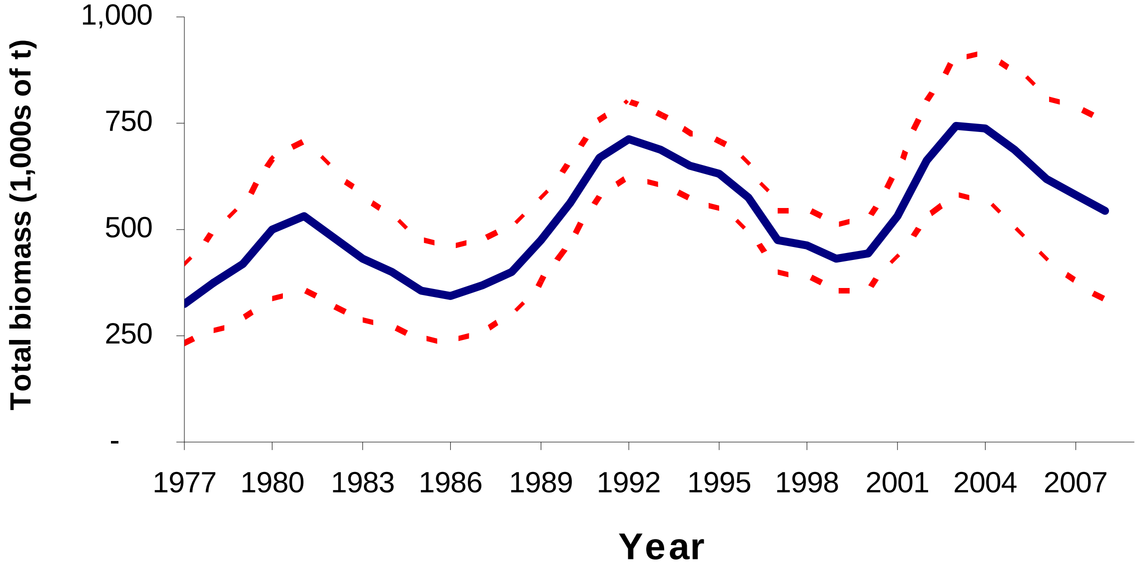


Figure 15.16. Time series of Atka mackerel total (age 1+) biomass estimates in thousands of metric tons, and approximate 95% confidence bounds.

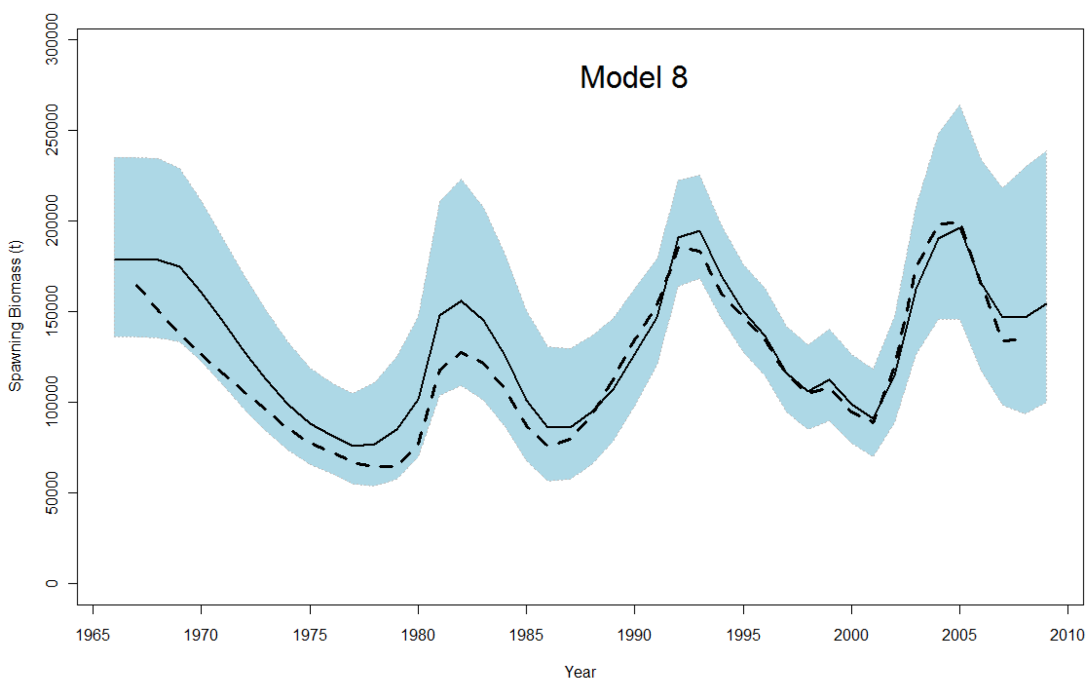


Figure 15.17. Estimated female spawning biomass from the current assessment (solid line) and approximate 95% confidence bounds compared to the female spawning biomass estimates from the 2007 assessment (dashed line, Lowe *et al.* 2007) for BSAI Atka mackerel.

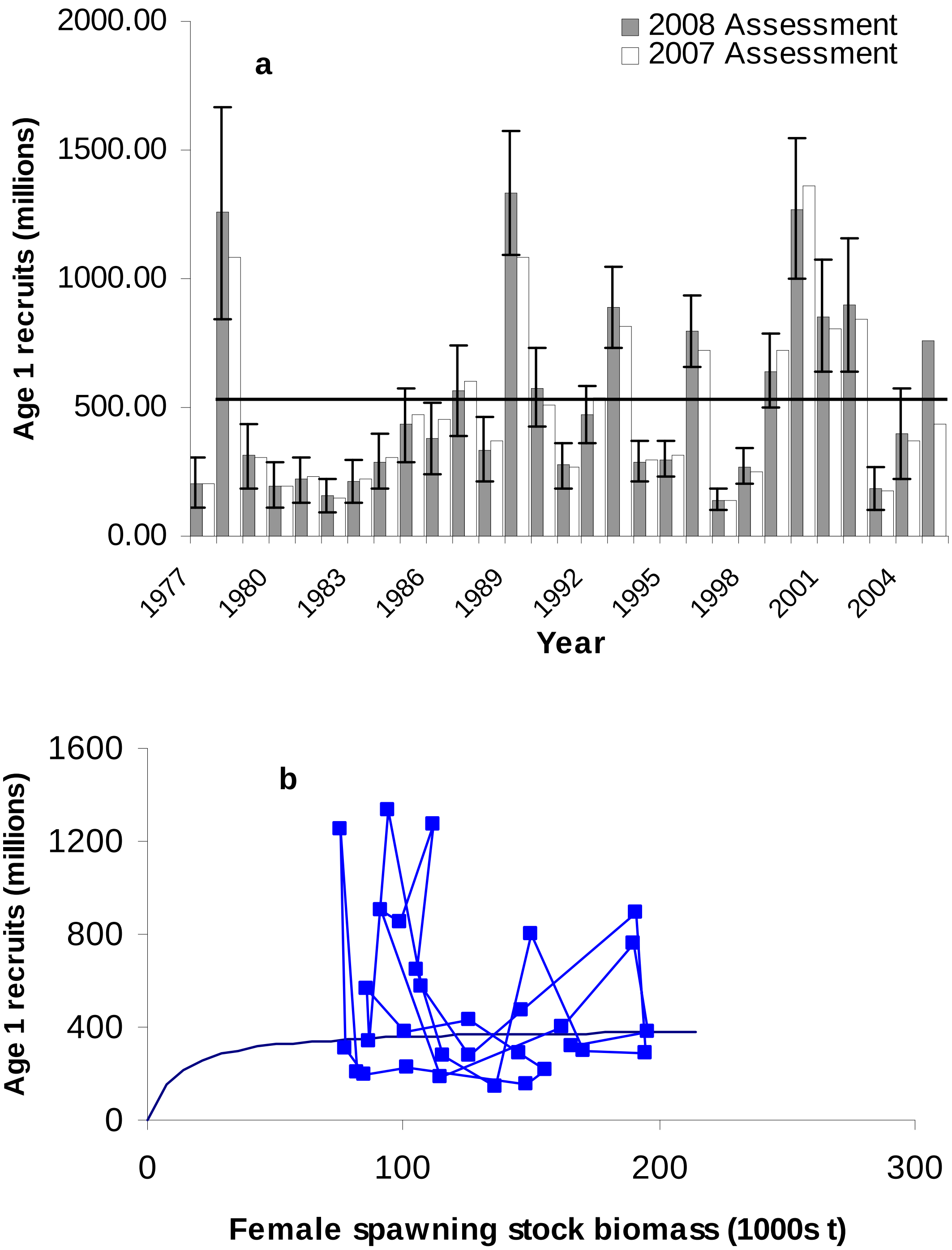


Figure 15.18 a) Age 1 recruitment of Atka mackerel as estimated from the current assessment, with error bars representing two standard errors (top panel) and the solid line indicating average recruitment (520 million) over 1978-2006, and b) estimated female spawning biomass levels in thousands of metric tons (lower panel). Solid line represents the underlying Beverton-Holt stock recruitment curve assumed in the model.

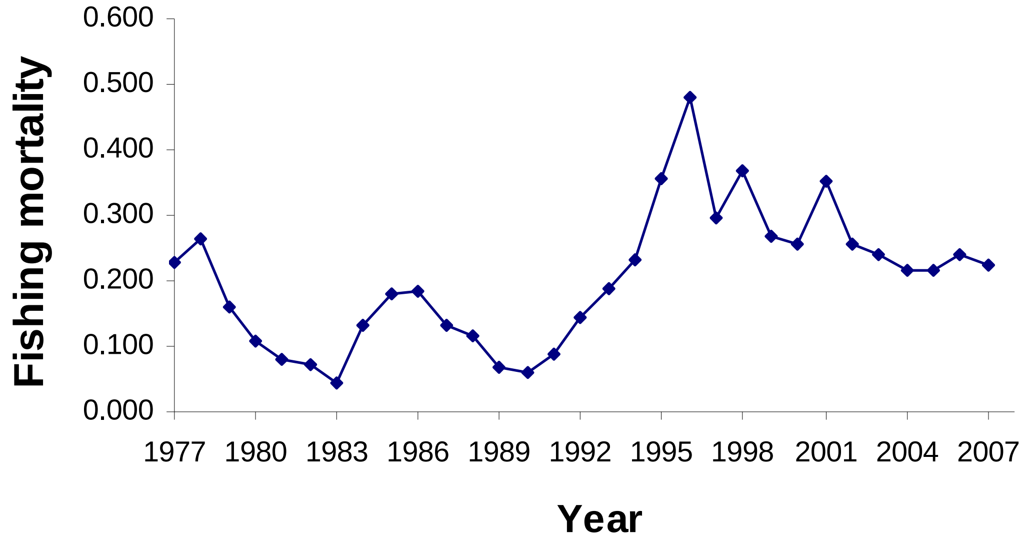


Figure 15.19. Estimated time series of full-selection fishing mortality rates of Atka mackerel, 1977-2008.

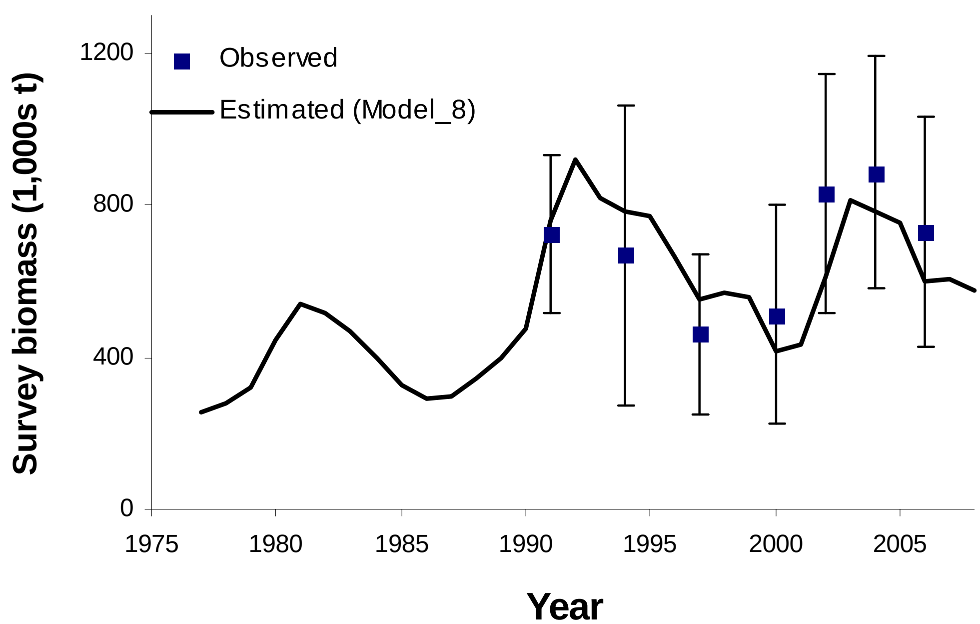


Figure 15.20. Observed and predicted survey biomass estimates in thousands of metric tons for Aleutian Islands Atka mackerel. Error bars represent two standard errors (based on sampling) from the survey estimates.

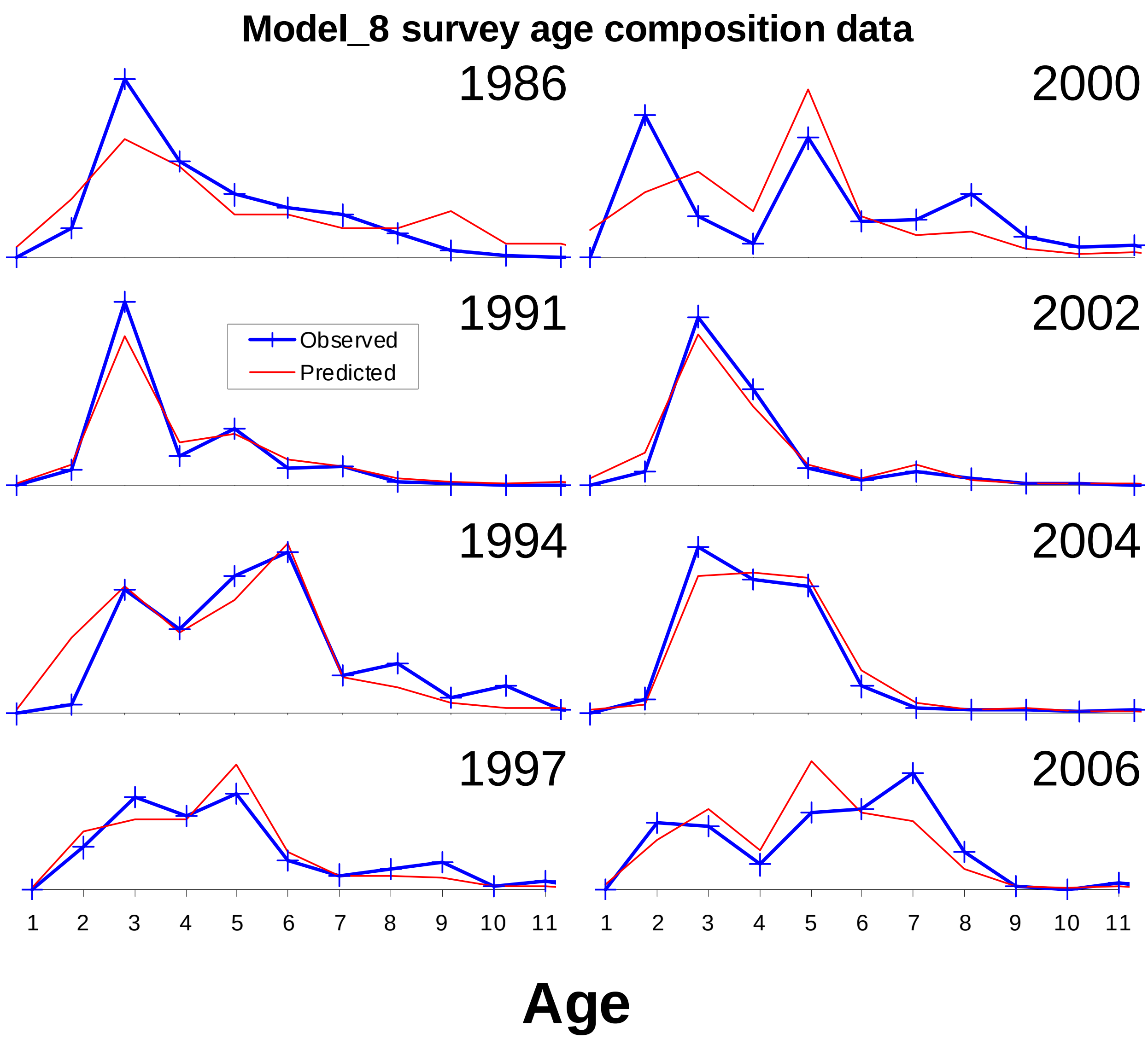


Figure 15.21. Observed and predicted proportions-at-age for Atka mackerel. Continuous lines are the model predictions and lines with "+" symbols are the observed proportions at age.

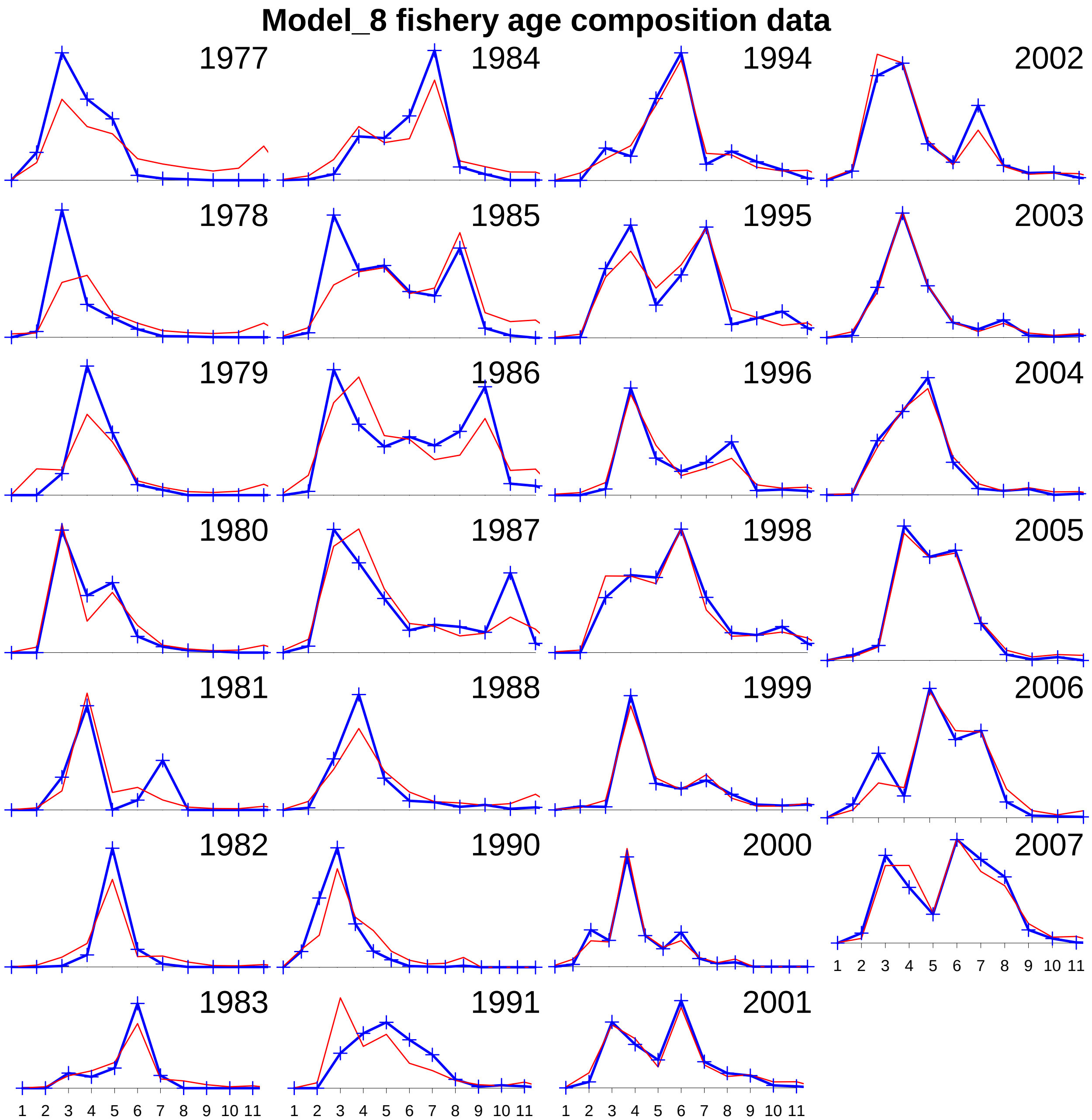
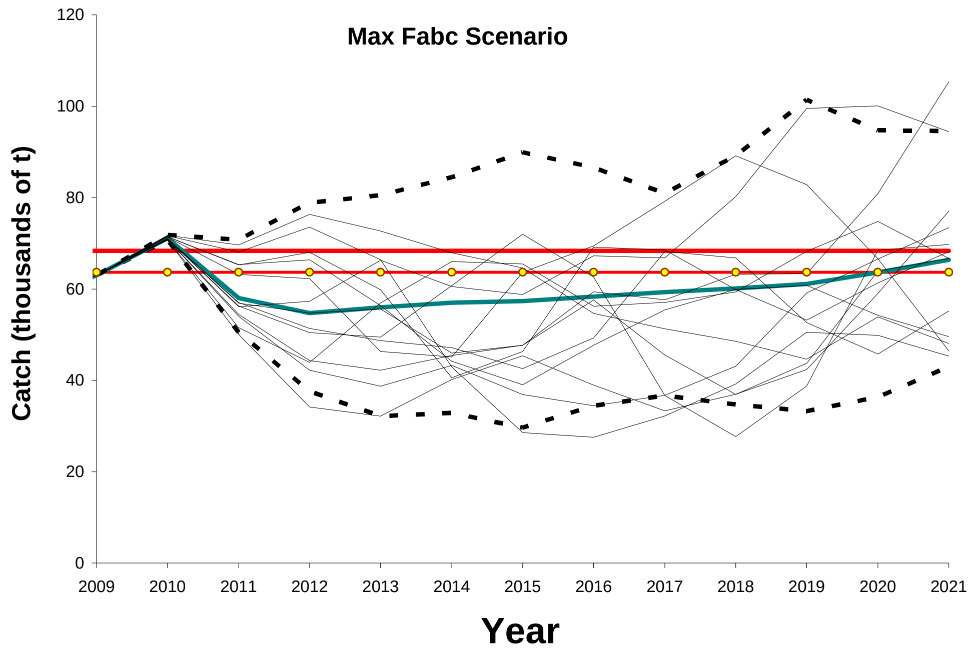


Figure 15.22. Observed and predicted Atka mackerel proportions-at-age for fishery data. Continuous lines are the model predictions and lines with "+" symbol are the observed proportions at age.



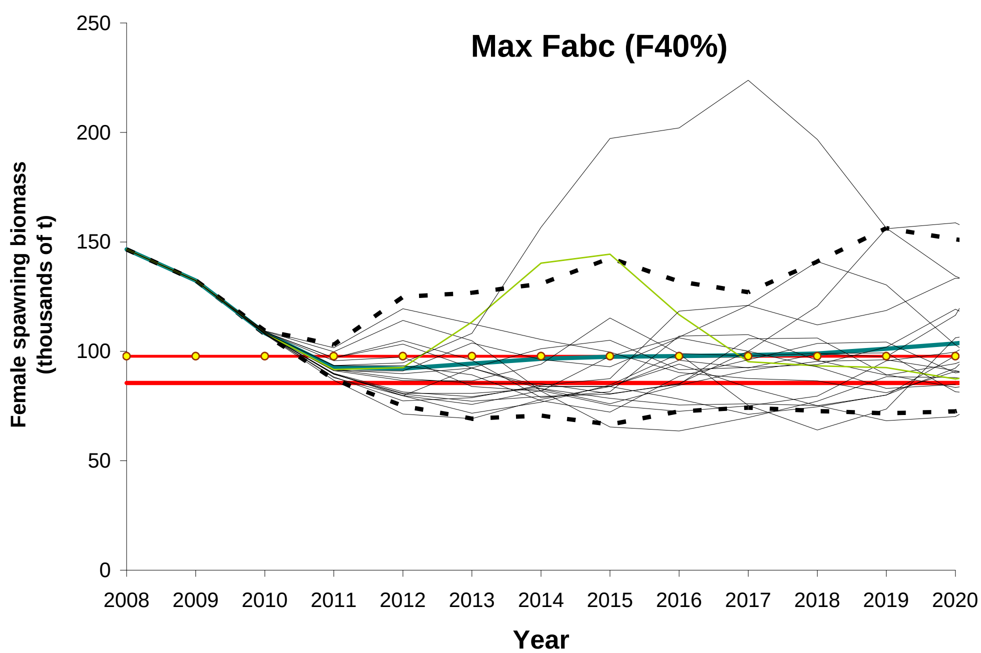


Figure 15.23. Projected catch in (top) and spawning biomass (bottom) in thousands of metric tons under maximum permissible Tier 3a harvest levels. The individual thin lines represent samples of simulated trajectories.

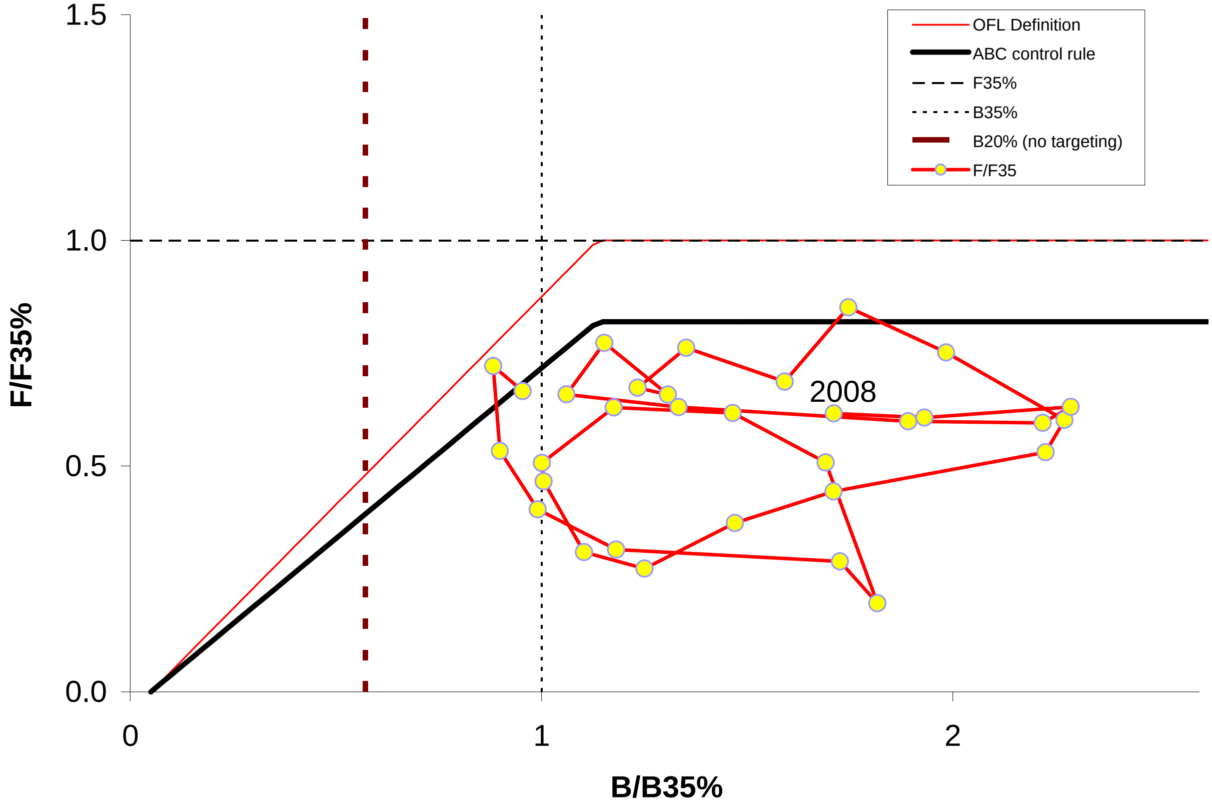


Figure 15.24. Aleutian Islands Atka mackerel spawning biomass relative to $B_{35\%}$ and fishing mortality relative to F_{OFL} (1977-2008). The ratio of fishing mortality to F_{OFL} is calculated using the estimated selectivity pattern in that year. Estimates of spawning biomass and $B_{35\%}$ are based 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.

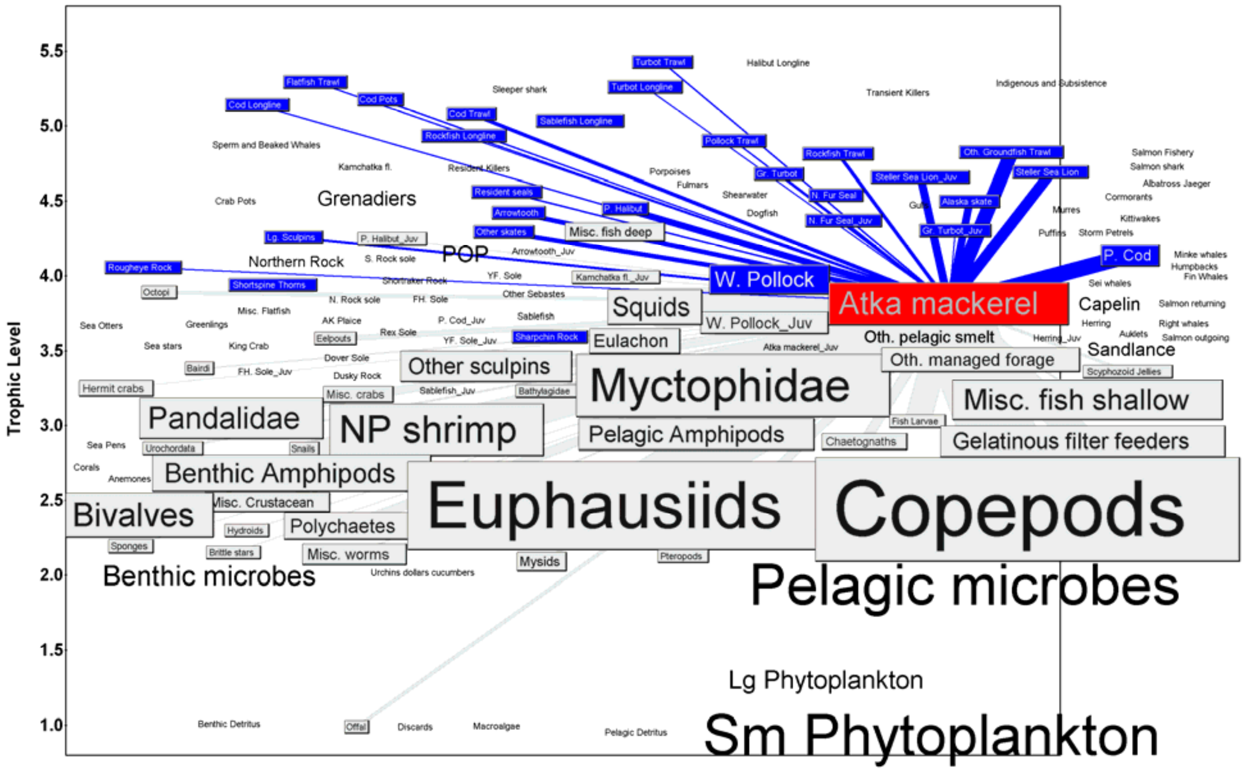
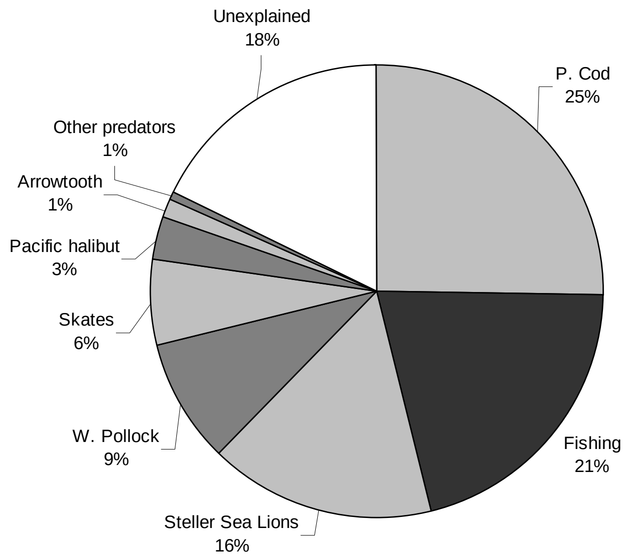
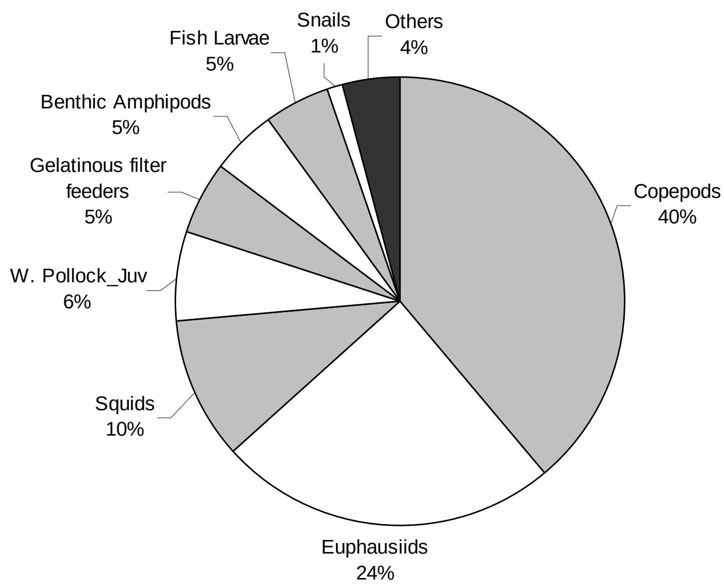


Figure 15.25. The food web of the Aleutian Islands survey region, 1990-1994, emphasizing the position of age 1+ Atka mackerel. Outlined species represent predators of Atka mackerel (dark boxed with light text) and prey of Atka mackerel (light boxes with dark text). Box and text size are proportional 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 15.26. (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.

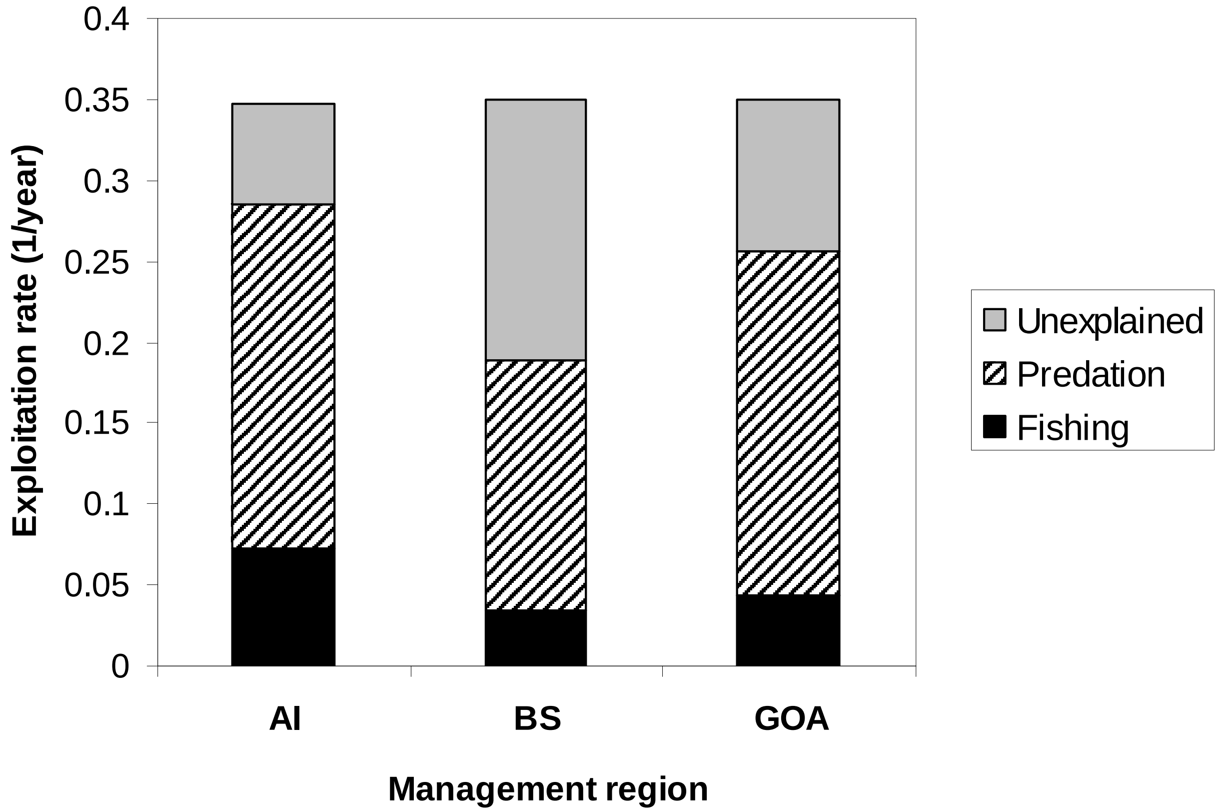


Figure 15.27. Total exploitation rate of age 1+ Atka mackerel, 1990-1994, proportioned into exploitation by fishing (black), predation (striped) and "unexplained" mortality (grey). "Unexplained" mortality is the difference between the stock assessment total exploitation rate averaged for 1990-1994, and the predation and fishing mortality, which are calculated independently of the assessment using predator diets, consumption rates, and fisheries catch.

Appendix 15.A

Table A-1. Variable descriptions and model specification.

General Definitions	Symbol/Value	Use in Catch at Age Model
Year index: i = {1977, …., 2008}		i
Age index: j = {1, 2, 3, …, A}	j	
Mean weight by age j	W_j	
Maximum age beyond which selectivity is constant	*Maxage*	Selectivity parameterization
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		
$\phi_i(27),\ R_0,\ h,\ \varepsilon_i(42), \sigma_R^2,\ \mu^f, \mu^s,\ M,\ \eta_j^s(10),\ \eta_j^f c(10), F_{50\%}, F_{40\%}, F_{30\%}, q^s$		

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, …, 2008	$\varepsilon_i, \sum_{i=1967}^{2008} \varepsilon_i = 0$	$N_{i,1} = e^{\mu_R + \varepsilon_i}$
Index catchability Mean effect	μ^s, μ^f	$q_i^s = e^{\mu^s}$
Age effect	$\eta_j^s, \sum_{j=1}^{A} \eta_j^s = 0$	$s_j^s = e^{\eta_j^s}$ $j \le$ maxage $s_j^s = e^{\eta_{\text{maxage}}^s}$ $j >$ maxage
Instantaneous fishing mortality		$F_{ij} = e^{\mu_f + \eta_j^f + \phi_i}$
mean fishing effect	μ_f	
Annual effect of fishing in year i	$\phi_i, \sum_{i=1977}^{2008} \phi_i = 0$	
Age effect of fishing (regularized) in year time variation allowed	$\eta_{ij}^f, \sum_{j=1}^{A} \eta_{ij} = 0$	$s_{ij}^f = e^{\eta_j^f}$, $j \le$ maxage $s_{ij}^f = e^{\eta_{\text{maxage}}^f}$ $j >$ maxage
In years where selectivity is constant over time	$\eta_{i,j}^f = \eta_{i-1,j}^f$	$i \neq$ change year
Natural Mortality	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 recruitment regularity	$L_3 = \lambda_3 \sum_{i=1967}^{2008} \varepsilon_i^2$	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	$L_4 = \lambda_4 \sum_{i=1977}^{2008} \ln\left(C_i^B / \hat{C}_i^B \right)^2$	Fit to survey
Proportion at age likelihood	$L_5 = -\sum_{l,i,j} T_{ij}^l P_{ij}^l \ln\left(\hat{P}_{ij}^l \cdot P_{ij}^l \right)$	l={s, f} for survey and fishery age composition observations
Fishing mortality regularity	$L_6 = \lambda_6 \sum_{i=1978}^{2008} \phi_i^2$	(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 these are precisely known at 0.3 and 1.0, respectively).
Overall objective function to be minimized	$\dot{L} = \sum_{i=1}^{7} L_i$	

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