15. Stock Assessment of Aleutian Islands Atka Mackerel

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Executive Summary

Summary of Major Changes

Relative to the November 2005 SAFE report, the following substantive changes have been made in the assessment of Atka mackerel.

Changes in the Input Data

1. Catch data were updated and catch assumed for projections were set equal to ABC, whereas projections in last year's assessment used constrained TAC levels (<ABC).
2. The 2005 fishery age composition data were included.
3. Biomass and length data from the 2006 Aleutian Islands bottom trawl survey were included.
4. Year-specific fishery and survey weight-at-age values were utilized.
5. Updated population weight-at-age values were incorporated.
6. The years used to compute an average selectivity vector for projections was updated from 2000-2004 to 2001-2005.

Changes in the Assessment Methodology

There were no changes in the assessment model methodology.

Changes in Assessment Results

7. The mean recruitment (1978-2005) from the stochastic projections is 492 thousand recruits (down 0.8% from last year's mean estimate for 1978-2004), which gives an estimated $B_{40\%}$ level of 95,000 mt and an estimated $B_{35\%}$ level of 83,100 mt, down about 1% from last year's estimates of $B_{40\%}$ and $B_{35\%}$.
8. The projected female spawning biomass for 2007 under an $F_{40\%}$ harvest strategy is estimated at 129,900 mt which is 55% of unfished spawning biomass and above $B_{40\%}$ (95,000 mt), thereby placing BSAI Atka mackerel in Tier 3a. The 2007 estimate of spawning biomass is down about 17% from last year's estimate for 2006. These results are consistent with the survey trend estimate (18% decline in 2006 relative to 2004). There is a greater decrease in the projected biomass in this year's assessment than in last year's assessment, mainly because catches this year are assumed to equal the full ABC rather than recent TACs (<ABC), and because the three most recent recruitments (2003-2005) are only average. Last year one of the three most recent recruitments was well above average (2002).
9. The projected age 3+ biomass at the beginning of 2007 is estimated at 364,200 mt, down about 18% from last year's estimate for 2006.
10. The addition of the 2005 fishery age composition impacted the estimated magnitude of the 1999, 2000, and 2001 year classes. The current assessment's estimates of the 1999, 2000, and 2001 year classes increased 13, 16, and 35%, respectively, relative to last year's assessment.
11. The 2001-2005 average fishery selectivity pattern has shifted to reflect greater numbers of younger ages in the recent catches. The shift in fishery selectivity towards younger ages is reflected in decreases in the estimated $F_{40\%}$ and $F_{35\%}$ fishing mortality rates relative to last year (down about 22%).
12. The projected 2007 yield at $F_{40\%}$= 0.342 is 74,000 mt, down about 33% from last year's estimate for 2006.
13. The projected 2007 overfishing level at $F_{35\%}$ (F = 0.412) is 86,900 mt, down about 33% from last year's estimate for 2006.

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

Comments Specific to the Atka Mackerel Assessment

From the December 2005 SSC minutes*: "The SSC continues to request a rationale for, and examination of, the assumed steepness parameter (0.8) for the Beverton-Holt stock recruitment relationship implied in the model (see the December 2004 SSC minutes)."* In Section 15.4.1 Model Structure, under the paragraph heading Recruitment, the following text addresses this issue: "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."

SSC Comments on Assessments in General

From the December 2005 SSC minutes: *"The SSC appreciates the inclusion of phase-plane diagrams of relative harvest rate versus biomass, but we recommend standardization of units along the axes in all chapters to facilitate comparisons across species. The SSC suggests considering a quad plot based on* $F/F_{35\%}$ *versus* $B/B_{35\%}$*."* The authors have added a plot of $F/F_{35\%}$ *versus* $B/B_{35\%}$ (see Figure 15.25).

"The SAFEs have been improved overall by expanded sections on ecosystem considerations to include discussion of predator-prey interactions. To this end, tables and figures have been added from ECOPATH models. One problem that has arisen is that there is some confusion about whether the information presented is stomach contents data, output from a single-species model, or output from an ECOPATH model. Figures and tables should more explicitly describe the source of the information presented. To avoid confusion between statistically-driven single species models and manually-adjusted ECOPATH models, the word "estimate" should be reserved for output from single-species models. In the absence of a statistical fitting procedure, outputs from ECOPATH/ECOSIM models should be referred to as adjusted parameters or just outputs. When ECOPATH/ECOSIM parameters are assumed to take on particular values, such assumptions should be stated explicitly. Care should be taken to avoid mixing results from different model structures."

The Ecosystem Considerations figures have been updated with some added shading/striping to indicate which pie slices are direct from data and which are model outputs. The figure captions will reference a detailed description of the methods in an appendix of the Ecosystem Assessment.

Introduction

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

Distribution: Atka mackerel (*Pleurogrammus monopterygius*) are distributed along the continental shelf in areas 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 (Rutenberg 1962). Moving eastward, they are distributed throughout the Komandorskiye and Aleutian Islands, north to the Pribilof Islands in the eastern Bering Sea, and eastward through the Gulf of Alaska to southeast Alaska.

Early life history: Single or multiple clumps of adhesive eggs comprising a nest are laid on rocky substrates at nesting sites characterized by moderate or strong currents, water depths from 10 m to 144 m, and temperatures ranging from and 3.9°C to 10.5°C (Gorbunova 1962, Lauth et al. *in review*). Gorbunova (1962) reported that the incubation time for eggs was from 40-45 days, but was not specific about the temperature at which eggs were incubated. More recent incubation experiments by researchers from the Alaska Sea Life Center (ASLC) and University of Alaska Fairbanks (UAF) determined that the number of days until first hatching ranged from 39 days at 10°C to 96 days at 4°C. Historical icthyoplankton surveys around the outer shelf and slope of Kodiak Island found Atka mackerel larvae in neuston tows from fall through spring, with a maximum abundance of larvae in the late fall (Kendall and

Dunn 1985). The mean length of larvae increased from 10.3 mm in the fall to 17.6 mm in the spring (Kendall and Dunn 1985). Larvae can be carried great distances to offshore waters (Gorbunova 1962).

Reproductive ecology: Atka mackerel are sexually dichromatic (Medveditsyna 1962, Rutenberg 1962) and sexually dimorphic (Zolotov 1981). They have a polygamous mating system and are obligate demersal spawners with male parental care. Molecular genetics is being used to study the mating system of Atka mackerel in more detail, and early indications are that it is complex and most likely involves alternative reproductive strategies resulting in multiple parentage in a single egg mass (Mike Canino AFSC, *pers. comm*). Spawning and nesting has been observed as shallow as 10 m (Gorbunova 1962) and as deep as 144 m (Lauth et al. *in review*). Possible factors limiting the upper and lower depth limit of Atka mackerel spawning and nesting include kelp, green sea urchins, wave surge, water clarity, light penetration, and temperature (Lauth et al. *in review*, Gorbunova 1962, Zolotov 1993). Higher densities of kelp and algae at shallower depths can directly impede egg aeration and aid stagnation, thereby increasing egg mortality (Zolotov 1993, Gorbunova 1962, Lauth et al. *in press*). Green urchins are opportunistic feeders and have been observed grazing on Atka mackerel eggs (R. Lauth, AFSC, unpublished data). Nesting sites were documented in the western Gulf of Alaska and along the Aleutian archipelago, and they were invariably located on rocky shelf substrates in areas with moderate or strong current (Lauth et al. *in press*). Historical ichthyoplankton and commercial fishing data from the outer shelf and slope of Kodiak in the 1970's and 1980's (Kendall and Dunn 1985, Ronholt 1989) suggest that nesting grounds may have at one time extended further east into the central Gulf of Alaska. In Alaska, the reproductive cycle begins in early June when males with spawning colors start to aggregate at nesting sites (Lauth et al. *in review*). After establishing nests, spawning begins in July and lasts through October (McDermott and Lowe 1997, Cooper and McDermott 2006). Female Atka mackerel spawn an average of 4.6 separate batches of eggs during the 12-week spawning period (McDermott et al. *in press*). Males presumably brood eggs within their nesting territory until December or January when hatching is complete (Lauth et al. *in review)*. The entire reproductive cycle from the establishment of nests until the completion of hatching can last up to 7 months, and the entire time period may get progressively earlier moving from east to west along the Aleutian archipelago and into Russia (Lauth et al. *in review*).

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).

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 and management units: 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). An ongoing 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 any other consistent pattern of differentiation. Examination of the temporal stability of microsatellite DNA results within the Aleutian Islands will take place in 2006-2007. Preliminary work to date indicates 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 (GOA) populations of Atka mackerel should be managed as a unit stock or separate populations. There are significant differences in population size, distribution, recruitment patterns, and resilience to fishing that suggest otherwise. 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 as far east as the Shumagin Islands (Lauth et al. *in review*) and historical ichthyoplankton data from the 70'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 mt. 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. These differences in population resilience, size, distribution, and recruitment argue for separate assessments and management of the GOA and AI stocks while we await results from microsatellite DNA studies.

15.1 Fishery

15.1.1 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 mt 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) by region and corresponding 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. 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. 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 mt annually, dropping to a low of 18,000 mt in 1989. Beginning in 1992, TACs increased steadily in response to evidence of a large exploitable biomass, particularly in the central and western Aleutian Islands.

15.1.2 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 made 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 2006 fishery operations are shown in Figure 15.1.

15.1.3 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 mt 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 mt of Atka mackerel TAC was released to the Central (27,000 mt) and Western (5,000 mt) 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.

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.

15.1.4 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 2004 and 2005 discards of northern rockfish as a total of the Atka mackerel catch were 6 and 4%, respectively, the actual amount of northern discards accounts for a large portion of the AI northern TAC. The 2004 fishery discarded 3,700 mt of northern rockfish, about 74% of the 2004 AI northern TAC. The 2005 Atka mackerel fishery discarded 2,700 mt of northern rockfish which accounted for 54% 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	660	1,076	1,736	
	All	9,868	43,070	52,938	
2004	Atka mackerel	6,709	45,841	52,550	12.8
	All others	421	407	828	
	All	7,130	46,248	53,378	
2005	Atka mackerel	2,403	57,359	57,762	4.2%
	All others	260	448	708	
	All	2,663	55,806	58,469	

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 2005 discard rate decreased dramatically and is the lowest rate in the time series (1990-present). The 2001 year class was 4 years old in 2005, and the data do not appear to indicate above average recruitment following the 2001 year class (see Section 15.5.3 Recruitment Trends). Preliminary data from the 2006 fishery continues to indicate a very low discard rate (approximately 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 (mt)	13,798	20,720	9,458
	Discarded (mt)	163	1,484	742
	Rate	1%	7%	7%
2001	Retained (mt)	7,632	28,678	19,333
	Discarded (mt)	54	3,102	676
	Rate	1%	10%	3%
2002	Retained (mt)	3,607	17,156	15,348
	Discarded (mt)	213	4,827	2,085
	Rate	6%	22%	12%
2003	Retained (mt)	5,626	22,566	14,877
	Discarded (mt)	695	4,964	4,210
	Rate	11%	18%	22%
2004	Retained (mt)	3,161	26,560	16,527
	Discarded (mt)	497	3,607	3,027
	Rate	14%	12%	15%
2005	Retained (mt)	3,356	33,598	18,852
	Discarded (mt)	303	1,469	891
	Rate	8%	4%	5%

15.1.5 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 domestic 2005 and preliminary 2006 fisheries by management area and season are shown in Figures 15.2 and 15.3, respectively. Differences in the distributions between the 2005 A- and B-seasons are indicated in all areas except 541 (too few fish were collected in the 2005 Eastern Aleutian (541) A-season). The 2005 A-season length distribution of fish showed greater numbers of smaller fish relative to the B-season. The fish sampled from Bering Sea area

519 are larger than fish sampled from the Aleutian Islands, but very similar to the size distributions of fish from the Western Gulf of Alaska (area 610). The modes at about 35-45 cm in the 2005 AI fishery length distributions represent the 1999, 2000, and 2001 year classes which dominated the 2005 fishery age composition (Figure 15.4). The available 2006 fishery data are presented and should be considered preliminary (Figure 15.3). The 2006 Central and Western Aleutian fisheries showed similar distributions to the 2005 A and B season distributions with modes at about 35-36 cm (Figure 15.3).

15.1.6 Steller Sea Lions and Atka mackerel Fishery Interactions

Since 1979, the Atka mackerel fishery has occurred largely within areas designated as Steller sea lion critical habitat in 1993 (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) and near Amchitka Island (in 2003). Movement rates at Tanaga pass 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.

15.2 Data

15.2.1 Fishery Data

Fishery data consist of total catch biomass from 1977 to 2006 (Table 15.1), and the age composition of the catch from 1977-2005 (Table 15.2). Catch-at-age (in numbers) was estimated using the length frequencies described above and age-length keys. The formulas used are described by Kimura (1989). As with the length frequencies, the age data for 1980-1981, 1989, 1992-1993, and 1997 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, 1992, 1993, and 1997 to construct age-length keys. 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 more recent (1989, 1992, 1993 and 1997) catch data and these years were excluded from the analysis.

The most salient features of the estimated catch-at-age (Table 15.2) are the strong 1975, 1977, 1999, 2000, and 2001 year classes. 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 2005 fishery data indicated that the 1999, 2000, and 2001 year classes continued to show up in large numbers (Table 15.2 and 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.

15.2.2 Survey Data

Atka mackerel are a difficult species to survey because: (1) they do not have a swim bladder, making them poor targets for hydroacoustic surveys; (2) they prefer hard, rough and rocky bottom which makes sampling with survey bottom trawl gear difficult; 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).

Trawl survey biomass estimates of Atka mackerel varied from 197,529 mt in 1980 to 306,780 mt in 1983, and 544,754 mt in 1986 (Table 15.3). 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 418,000 mt in the Southwest Aleutians (Table 15.3), or 77% of the total biomass of Atka mackerel in the Aleutian Islands. This was a 403,000 mt increase over the 1983 biomass estimate for the same stratum-depth interval. The 1986 biomass estimate is associated with a large coefficient of variation (0.63). 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 biomass estimate from the 2006 Aleutian Islands bottom trawl survey is 728,935 mt, down 18% relative to the 2004 survey estimate (Table 15.4). Previous to this, the 2004 Aleutian Islands bottom trawl survey biomass estimate of 886,783 mt increased 13% 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 (372,782 mt in 2004 down to 100,693 mt 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 15.5).

The 95% confidence interval about the mean total 2006 Aleutian biomass estimate is **298,858-1,159,013** mt. The coefficient of variation (*CV*) of the 2006 mean Aleutian biomass is 28% (Table 15.4).

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 15.5). The 2000 Eastern area biomass estimate (900 mt) 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 15.4). The Eastern area now contributes nearly 50% of total Aleutian area biomass according to the 2006 survey.

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 mt). This occurred again in 1997 (95,680 mt), 2002 (59,883 mt), and 2004 survey (267,556 mt, Table 15.4). 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 15.6). The 2004 southern Bering Sea strata biomass estimate of 267,556 mt 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 mt 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 15.6). 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 15.6). 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 15.6). 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 (pers. comm., Harold Zenger, AFSC, Figure 15.7). 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 right about in the middle of the series for all survey years, excluding the year 2000. The average bottom temperatures measured in the 2006 survey were just above the 2002 survey and very similar to the 1994 survey temperatures (Figure 15.7).

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: 0.29, 0.28, 0.20, 0.17, and 28% from the 1997, 2000, 2002, 2004, and 2006 AI surveys, respectively, compared with 0.99, 0.45, 1.00, 0.35, and 0.50 from the 1996, 1999, 2001, 2003, and 2005 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 in 42%, 33%, 23%, 33%, 55%, 60, and 51% of the hauls in the 1991, 1994, 1997, 2000, 2002, 2004, and 2006 AI surveys, compared to 5%, 28%, 13%, 20%, 10%, 44%, and 29% of the hauls in the Shumagin area in the 1990, 1993, 1996, 1999, 2001, 2003, and 2005 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 showed a strong east-west gradient in Atka mackerel size (Figure 15.8). 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 49 cm (Figure 15.8).

Survey Age Frequencies

The age compositions from the 2000, 2002, and 2004 Aleutian surveys are shown in Figure 15.9. (Age data from the 2006 survey are not yet available). The 2000 survey age composition shows the strong 1992 and 1995 year classes (8 and 5-year olds, respectively), and a very strong showing of 2-year-olds from the 1998 year class (Figure 15.9). The selectivity of 2 year olds in the survey is thought to be fairly low, and this age group has not shown up in significant proportions in previous surveys (Lowe et al. 2003).   The 2002 survey age composition is dominated by the 1999 year class and continues to show large numbers of the 1998 year class (Figure 15.9). 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 15.9). The mean ages of the 2000, 2002, and 2004 surveys are 5.0, 3.8, and 4.2 years, respectively. The mean age in the 2002 survey of 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 in the Stock Assessment Toolbox model showed that results without the relative index are more conservative. The Stock Assessment Toolbox model results corroborated previous assessments which explored the impact of incorporating the early survey index (Lowe 1991). That is, synthesis results showed that including the survey index resulted in higher historical biomass estimates.

15.3 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.

[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/beta

15.3.1 Model structure

The AMAK models catch-at-age with the standard Baravov catch equation. The population dynamics follows numbers-at-age over the period of catch history (here 1977-2005) with natural and age-specific fishing mortality occurring throughout the 15-age-groups that are modeled (ages 1-15+). 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:

Likelihood Component	Distribution Assumption
Catch biomass (1977-2005)	Lognormal
Catch age composition (1977-2005)	Multinomial
Survey catch biomass (1986, 1991, 1994, 1997, 2001, 2004, 2006)	Lognormal
Survey catch age composition (1986, 1991, 1994, 1997, 2001, 2004)	Multinomial
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

Parameters estimated independently

Natural Mortality

Natural mortality (*M*) is a difficult parameter to estimate reliably. One approach we took was to use the regression model of Hoenig (1983) which relates total mortality as a function of maximum age. His equation is:

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

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

An analysis was undertaken to explore alternative methods to estimate natural mortality for Atka mackerel (Lowe and Fritz, 1997). Several methods were employed based on correlations of *M* with life history parameters including growth parameters (Alverson and Carney 1975, Pauly 1980, Charnov 1993), longevity (Hoenig 1983), and reproductive potential (Roff 1986, Rikhter and Efanov 1976). Atka mackerel appear to be segregated by size along the Aleutian chain. Thus, natural mortality estimates based on growth parameters would be sensitive to any sampling biases that could result in under- or over-

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

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

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.

The average length-at age and weights-at-age for combined sexes based on the above described data set and used in *last* year's assessment are given in Table 15.5. This year, where possible, year-specific weight-at-age estimates are used in the model to obtain expected catches in survey and fishery biomass (Table 15.6). For each data source (survey or fishery), unbiased 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 (A. DeRobertis and K. Williams, *manuscript*). In addition, the single vector of weight-at-age values used to derive population biomass in the model was updated. The population weight-at-age values in last year's assessment were based on the 1986, 1991, and 1994 Aleutian trawl surveys (Table 15.5), the updated population weight at age values used in the current assessment are based on the 2000, 2002, and 2004 surveys in order to allow for better estimation of current biomass (Table 15.6).

Maturity at Age

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 15.7. Work is currently underway to re-examine and update the maturity information (pers. comm. Susanne McDermott and Dan Cooper, AFSC).

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 is allowed to vary annually with a low constraint as in the selected Reference model from the 2003 assessment (Lowe et al. 2003).

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 2005 and 2006 ABCs and OFLs. This year we carry forward the accepted model from last year's assessment (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). We assumed a steepness value of 0.8 for all model runs presented here, with a 30% *CV*. 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.

15.4 Model Evaluation

In the 2004 assessment a number of refinements were made to the model configuration (Lowe et al. 2004). These changes were restricted to three key assumptions. The first change was to correct the model to account for the time of year that the survey takes place. Previously, it had simply assumed begin-year biomass was a suitable proxy. Second, we specified a lognormal error distribution for survey data (the convention in most stock assessment models) instead of a normal distribution which had previously been assumed. The third model configuration change was to assume a moderate prior on survey catchability q (μ=1.0, σ^2=0.2^2). Prior to the 2004 assessment, survey catchability had been fixed at 1.0. Model 4 in the 2004 and 2005 assessments incorporated the above changes in model structure (Lowe et al. 2004, 2005). Model 4 was accepted by the BSAI Plan Team and SSC, and was the basis for 2005 and 2006 ABC and OFL recommendations. We again carry forward Model 4 in the current assessment.

Although the current model configuration has not changed relative to last year, we compare key results of two Model 4 runs in order to evaluate the impact of the updated weight at age values (Table 15.8). Overall, Model 4 with updated weight-at-age values (Model 4-New) and Model 4 with the old weight-at age values (Model 4-Old) fit the data equally well as indicated by the total –ln(likelihood) values (Table 15.8). Specifically, Model 4-New fit the survey and fishery age compositions better, but Model 4-Old had a lower survey residual mean square error (RMSE) and also had a lower –ln(survey likelihood). The old survey weight-at–age values were a single vector based on data from the 1986, 1994, and 1997 surveys, whereas the new survey values are year-specific to each of the survey years (Figure 15.10). A comparison of the observed and estimated survey biomass abundance values are shown in Figure 15.11. Estimated biomass values show some differences, with the greatest differences in the historical data prior to 1991 where Model 4-New estimates lower survey biomass. Figure 15.10 shows the 1986 weight-at-age values which are significantly lower over ages 4-8 relative to the old weight-at-age vector. Survey catches are mostly comprised of fish 3-9 years old, and large differences in weight-at-age values over these ages would have a significant impact.

A comparison of the estimated time series of total biomass from Model 4-New and Model 4-Old are shown in Figure 15.12. Prior to 2001, Model 4-New estimates lower abundance levels. A single population weight-at-age vector derived from survey data is used to estimate population abundance in AMAK. Model 4-Old uses weight-at-age values based on the 1986, 1994, and 1997 surveys, and Model 4-New uses more recent values based on the 2000, 2002, and 2004 surveys (Figure 15.13). Combined survey weight-at-age values have remained relatively constant over time with exceptions for 1-year olds and fish greater than 10 years old. Historically, very few numbers of 10+ year olds are in the population (Table 15.10, Lowe et al. 2005) therefore, the differences in total biomass trends are likely attributed to the survey biomass estimates (used to tune the model) and the year-specific weight-at-age values, rather than population weight-at-age values.

15.5 Model Results

The results discussed below are based on Model 4 with the updated fishery, survey, and population weight-at-age values, the 2005 fishery age composition, and the 2006 Aleutian Islands survey biomass estimate.

15.5.1 Selectivity

The estimated selectivity at age schedules for the fishery and survey are shown in Figures 15.14-15.16 and given in Table 15.9.

The fishery catches essentially consist of fish 3-12 years old, although a 15-year-old fish was found in the 1994 fishery. The fishery exhibits a dome-shaped selectivity pattern which is particularly strong prior to 1991 during the foreign and joint venture fisheries (Figure 15.14). After 1991, fishery selectivity patterns are fairly similar with gradual transitions, particularly between the ages of 3-9. The 2005 estimate of selectivity at age reflects the large numbers of 4, 5, and 6-year old fish from the 1999, 2000, and 2001 year classes (Figure 15.14, Table 15.2).

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). As noted above, after 1991 the selectivity patterns are fairly consistent but do reflect annual variability. The estimated selectivity patterns for 2004 and 2005 are shown for comparison (Figure 15.15). The 2004 selectivity pattern reflects the large numbers of 4, 5 and 6 year olds (2000, 1999, and 1998 year classes) in the 2004 fishery catch, while the 2005 pattern reflects the large numbers of 4, 5 and 6-year olds (2001, 2000, and 1999 year classes) in the 2005 catch. The age at 50% selectivity is estimated at about age 3.5 for both 2004 and 2005 (Figure 15.15). This is the youngest age at 50% selectivity in recent years due to the particularly strong showing of the 1999 and 2001 year classes (Tables 15.2 and 15.9). Selectivity after age 6 is lower in the 2005 fishery relative to the 2004 fishery. This is a reflection of the 2005 fishery which caught fewer numbers of fish older than age 7 relative to the 2004 fishery (Table 15.2). Fish older than age 9 make up a very small percentage of the population each year (Table 15.10), 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 the estimated 2004 and 2005 selectivity patterns up to age 6 (age at 50% maturity is 3.6 years, Figure 15.15). The estimated 2005 selectivity pattern indicates the current fishery is harvesting fish similarly to the 2004 fishery and in proportion to the maturity schedule. The average selectivity pattern estimated for the years 2001 to 2005 is shown for perspective (Figure 15.15).

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 15.16).

15.5.2 Abundance Trend

The estimated time series of total biomass with approximate upper and lower 95% confidence limits are shown in Figure 15.17 and given in Table 15.11. For comparison, the time series of spawning biomass from the 2005 and 2006 (current) assessments are also plotted (Figure 15.18). The corresponding time series of total numbers at age are given in Table 15.10.

A comparison of the spawning biomass trend from the current and previous assessments (Figure 15.18, Table 15.11) 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 continues to 2006 as estimated in the current assessment. Prior to 2002, the estimated spawning biomass levels are lower in the current assessment which we attribute to the updated weight-at-age values (see Section 15.5 Model Evaluation). Recent (after 2002), estimated spawning biomass levels are nearly identical in the current assessment.

15.5.3 Recruitment Trend

The estimated time series of age 1 recruits from the current assessment and the 2005 assessment is shown in Figure 15.19 and given in Table 15.12. The strong 1999 year class is most notable in the current assessment, followed by the 1988, and 1977 year classes. The current estimates of the 1999, 2000, and 2001 year classes have increased in magnitude (13, 16, and 35%, respectively), relative to the 2005 assessment due to the addition of the 2005 fishery age composition (Figure 15.19). The 2005 fishery data are dominated by the 2001 year class, followed by the 1999 and 2000 year classes (Figure 15.4). The 1999 year class, which was estimated as the third largest year class in last year's assessment, is now estimated to be the largest year class in the time series (approximately 1.3 million recruits) due to its continued strong showing in the 2005 fishery as 6-year olds (Figure 15.4). The current assessment estimates above average (greater than 20% of the mean) recruitment from the 1977, 1986, 1988, 1992, 1995, 1998, 1999, 2000, and 2001 year classes (Figure 15.19).

The average estimated recruitment from the time series 1978-2005 is 492 thousand fish and the median is 341 thousand fish (Table 15.12). The entire time series of recruitments (1977-2005) includes the 1976-2004 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 (1977-2004 year classes). Projections of biomass are based on estimated recruitments from 1978-2005 using a stochastic projection model described below.

15.5.4 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 15.13 and shown in Figure 15.20

15.5.5 Model Fit

A summary of key results from Model 4 are presented in Table 15.8. The coefficient of variation or *CV* (reflecting uncertainty) about the 2006 biomass estimate is 16% and the *CV*s on the strength of the 1999 and 2001 year classes at age 1 are 27 and 38%, respectively (Table 15.8). Overall estimated recruitment variability for BSAI Atka mackerel is high (0.622). Sample size values were fixed at 100 for the fishery data, and 50 for the bottom trawl survey data. The model estimated an average fishery effective sample size (*N*) of 121 and average survey effective *N* of 56, which compare well with the fixed values. The overall residual mean square error (RMSE) for the survey is estimated at 0.346 (Table 15.8). The RMSE is in line with estimates of sampling-error *CV*s for the survey which range from 15-63% and average 29% 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 15.21 compares the observed and estimated survey biomass abundance values. Model fits to the survey are greatly improved relative to the 2003 assessment under the old model configuration (see Figure 15.19 in Lowe et al. 2003). However, the model still fits the 1986 survey estimate very poorly. The catch-at-age data do not show another strong year class following the 1977 year class that would allow the model to achieve a better fit to the 1986 survey estimate. This lack of fit is confounded by the large coefficient of variation associated with the 1986 biomass estimate (63%). 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. The 2001 year class is 6 years old and would have reached peak biomass, and following the 2001 year class, the data indicate below average recruitment. However, 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 15.21).

The fits to the survey and fishery age compositions for Model 4 are depicted in Figures 15.22 and 15.23, respectively. The model fits the fishery age composition data quite well 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 than the survey. The exception are the fits to the 2002 and 2004 survey age compositions which are quite good and the best fits in the survey time series (Figure 15.22). 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 both the 2004 survey and fishery age compositions observed greater numbers than expected of 3-year olds of the 2001 year class (Figure 15.22 and 15.23).

15.6 Projections and harvest alternatives

15.6.1 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 1978-2005 (492 thousand 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 4 results based on recruitment from post-1976 spawning events:

$B_{100\%}$ = 237,500 mt female spawning biomass

$B_{40\%}$ = 95,000 mt female spawning biomass

$B_{35\%}$ = 83,100 mt female spawning biomass

15.6.2 Specification of OFL and Maximum Permissible ABC

The default projection model uses the ending year selectivity vector from the main model, in this case, the year 2006 selectivity vector. Note that the fishery catch-at-age data exists only up through 2005; the 2006 selectivity vector is a smoothed estimate based on the 2005 selectivity pattern. Model results are sensitive to the selectivity assumptions and this is reflected in the reference fishing mortality values. While we believe the current model configuration regarding selectivity assumptions is reasonable, and that it is important to allow some degree of time-varying selectivity to capture the nature of the fishery, for ABC projection purposes we use an average of recent years. To provide for a more robust selectivity pattern for projection purposes, we use an average of the years 2001-2005 (Table 15.9, Figure 15.15). These years reflect a reasonable range of recent selectivity estimates since the implementation of Steller sea lion regulations that affect the Atka mackerel fishery. This change was first discussed and implemented in the 2003 assessment (Lowe et al. 2003). The 2006 ABC projection was based on an average of the years 2000-2004. A comparison of key reference fishing mortality values under the different selectivity assumptions are given below:

Selectivity Assumption

Full selection *F*s	2006	Average 2001-2005
F_{2006}	0.221	0.217
$F_{40\%}$	0.348	0.342
$F_{35\%}$	0.419	0.412
$F_{2006}/F_{40\%}$	0.635	0.634

The rates based on the year 2006 selectivity are those presented in the results Table 15.8. Recommendations provided below are based on projections incorporating the average selectivity vector for the years 2001-2005.

For Model 4, the projected year 2007 female spawning biomass (SB_{07}) is estimated to be 129,900 mt under the maximum allowable ABC harvest strategy ($F_{40\%}$). 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. The projected 2007 and 2008 female spawning biomass estimates are above the $B_{40\%}$ value of 95,000 mt, placing BSAI Atka mackerel in **Tier 3a**. The maximum permissible ABC and OFL values under Tier 3a are:

Year	Catch	Maximum Permissible ABC	OFL	SSB
2007	74,000	74,000	86,900	129,900
2008		54,900	64,200	97,200

Note that the maximum permissible $F_{ABC} = F_{40\%}$ = 0.342 and F_{OFL}=$F_{35\%}$ = 0.412; also, catch in 2007 is assumed equal to the 2007 Maximum permissible ABC.

15.7 ABC Recommendation

Several observations and characterizations of uncertainty in the Atka mackerel assessment have been noted for ABC considerations since 1997.

1) Trawl survey estimates of biomass are highly variable; the 1997 Aleutian trawl survey biomass estimate was about 40% lower than the 1994 survey estimate, while 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, 2007 female spawning biomass is projected to be above $B_{40\%}$ but drop below in 2009 to 2011 (Figure 15.20). However, it should be noted that in recent years the TAC has been set below ABC, thus actual *F*s have been below $F_{40\%}$.

3) The uncertainty about the estimate of the 2007 $F_{40\%}$ catch is moderate with a *CV* of 20%. The AMAK provides estimates of the standard errors for key output parameters, which we consider a good first approximation of assessment uncertainty and useful for evaluation of abundance patterns.

4) The recommended model configuration with a moderate prior on survey catchability (*q*) gives very conservative results relative to a model configuration with a fixed *q*=1.0 (Figure 15.11 in Lowe et al. 2004)

5) 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 15.21).

6) The 2005 fishery age composition data continue to show large numbers from the 1999, 2000, and 2001 year classes (Figure 5.4). Currently we estimate the 1999 year class to be the largest in the time series (but with a high degree of uncertainty: *CV*=27%).

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 the important survey catchability and selectivity assumptions for describing the population dynamics of Atka mackerel are sensible from biological and mechanistic standpoints. Given the current stock size and the appearance of three consecutive strong year classes, 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 15.25. For most of the time series (including the 2006 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 15.25).

The associated 2007 yield associated with the maximum permissible $F_{40\%}$ fishing mortality rate of 0.342 is 74,000 mt, which is our 2007 ABC recommendation for BSAI Atka mackerel.

The associated 2008 yield associated with the maximum permissible $F_{40\%}$ fishing mortality rate of 0.342 is 54,900 mt, which is our 2008 ABC recommendation for BSAI Atka mackerel.

The 2007 ABC recommendation represents a 33% decrease from the Council's 2006 ABC. The population is projected to decrease and the estimated $F_{40\%}$ fishing mortality rate has decreased relative to last year. The recent fishery selectivity patterns indicate the fishery is harvesting greater numbers of younger fish. The age at 50% selectivity for the estimated selectivity pattern used to determine $F_{40\%}$ in the 2005 assessment was about 4 years, which decreased to about 3.5 years in the current assessment. This compares with the age at 50% maturity of 3.6 years (Figure 15.15). Therefore, the current estimate of the $F_{40\%}$ fishing mortality rate is lower due to the shift in the average selectivity pattern used for projection purposes.

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 (1997, 2000, 2002, and 2004) weighted average to apportion the 2006 ABC. The rationale for the weighting scheme was described in Lowe et al. (2001). We recommend that the 4-survey weighting scheme be updated to include the most recent 2006 survey (2000, 2002, 2004,and 2006) to apportion the 2007 and 2008 ABCs.

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

	1997	2000	2002	2004	2006	2006 TAC Apportionment	Updated survey weighted average
541	12.3%	0.20%	24.7%	27.5%	48.04%	**19.8%**	**32.2%**
542	51.0%	64.6%	42.3%	30.4%	38.14%	**42.6%**	**40.0%**
543	36.4%	35.2%	33.0%	42.0%	13.81%	**37.6%**	**27.8%**
Weights		8	12	18	27		

The apportionments of the 2007 and 2008 recommended ABCs based on the most recent 4-survey weighted average are:

	2007	2008
Eastern (541)	23,800 mt	17,600 mt
Central (542)	29,600 mt	22,000 mt
Western (543)	20,600 mt	15,300 mt
Total	74,000 mt	54,900 mt

15.8 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 2006 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2007 using a fixed value of natural mortality of 0.3, the schedules of selectivity estimated in the assessment (in this case the average of the 2001-2005 selectivities), and the best available estimate of total (year-end) catch for 2006 (in this case assumed equal to TAC). 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 an Environmental Assessment 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 2007, 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 2007 recommended in the assessment to the *max* F_{ABC} for 2007. (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 2002-2006 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 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 2006 or 2) above ½ of its MSY level in 2007 and above its MSY level in 2017 under this scenario, then the stock is not overfished.)

Scenario 7: In 2007 and 2008, 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 2019 under this scenario, then the stock is not approaching an overfished condition.)

15.8.1 Status determination

The projections of female spawning biomass, fishing mortality rate, and catch corresponding to the seven standard harvest scenarios are shown in Table 15.14. 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 2007:

a) If spawning biomass for 2007 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b) If spawning biomass for 2007 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c) If spawning biomass for 2007 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 15.14). If the mean spawning biomass for 2017 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 2009 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

b) If the mean spawning biomass for 2009 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c) If the mean spawning biomass for 2009 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2019. If the mean spawning biomass for 2019 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 2007 is estimated to be above $B_{35\%}$. Therefore, the stock is above its MSST and is not overfished. Mean spawning biomass for 2009 in Table 15.14 is above $B_{35\%}$. Therefore, the stock is not approaching an overfished condition.

15.9 Ecosystem Considerations

Atka mackerel spawning is demersal in moderately shallow waters; observations extend to approximately 100 m, but the lower depth limit for spawning and nesting of Atka mackerel in the Aleutian Islands is unknown. Female Atka mackerel deposit eggs in nests built and guarded by males on rocky substrates or on kelp in shallow water. Specific spawning and nesting sites have been observed off Seguam Island, and on offshore reefs and in and around island passes from Stalemate Bank to Akutan Pass (Lauth et al. *in reveiw*). Just based on depth considerations, there is likely some overlap of the fishery with the distribution of nesting sites, but the extent of the overlap with the spatial distribution of fishing impacted areas is unknown. However, overlap with spawning areas is likely to be low due to the following factors: 1) Atka mackerel are summer spawners and the directed fishery is conducted during 2 seasons which run January 20-April 15 (A season) and September 1-November (B season); 2) observations to date indicate that at least some spawning and nesting grounds occur in areas too shallow and rough for the fishery to operate; 3) there are trawl exclusion zones within 10 nm of all sea lion rookeries in the Aleutians and within 20 nm of the rookeries on Seguam and Agligadak Islands (in area 541); and 4) there are maximum seasonal catch percentage limits in place for sea lion critical habitat areas in the Central (542) and Western (543) Aleutians. These sea lion protection measures likely afford protection to several spawning grounds, and other spawning grounds which are not in closed areas but occur in untrawlable habitat are also afforded protection.

15.9.1 Ecosystem effects on BSAI Atka mackerel

Prey availability/abundance trends

Figure 15.26 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 planktivorous. Food habits data from 1990-1994 indicates that Atka feed on calanoid copepods (40%) and euphausiids (25%) followed by squids (10%), juvenile pollock (6%), and finally a range of zooplankton including fish larvae (Fig. 15.27a). While Figure 15.27a 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 (I. Ortiz, Univ. Wash., pers. comm.) No time series of abundance information is available for Aleutian Islands zooplankton, squid, or small forage fish.

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 (K. Aydin, unpublished results). 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 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). 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 15.28. During these years, approximately 20% of 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 15.27b), 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 mt/year of Atka mackerel consumed by predatory fish (of which approximately 60,000 mt is consumed by Pacific cod), and 40,000-80,000 mt/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 mt/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, puts the total Atka mackerel consumption by birds at less than 2,000 mt/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 and arrowtooth flounder is relatively stable. Northern fur seals are showing declines, and Steller sea lions have shown some slight increases. Declining trends in predator abundance could lead to possible decreases in Atka mackerel mortality. The population trends of seabirds are mixed, some increases, some decreases, and others stable. Seabird population trends could affect young-of-the-year mortality.

Changes in habitat quality

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 15.7). 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.

15.9.2 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 15.15 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 variable. It is notable that in the last 3 years (2003-2005), the Atka mackerel fishery has taken on average about 50 and 30%, 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 15.15. Skate bycatch in the Aleutian Islands Atka mackerel fishery is variable and has averaged 87 mt in the last 3 years (2003-2005). Over this same time period, the Atka mackerel fishery has taken an average of 14% 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 378 mt from 2003 to 2005. This level of bycatch represents an average of 52% 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.

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 690 mt or 58% of non-target discards in the Aleutian Islands from 2003 to 2004. 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 6,100 mt over 2003-2005.

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) and fecundity (McDermott 2003) 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.

15.10 Data gaps and research priorities

Data gaps

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. maturity-at-age, fecundity, 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.

Research priorities

Areas of ongoing assessment research include: 1) a risk-averse evaluation of key model uncertainties related to natural mortality, fishery selectivity, and survey catchability, 2) exploration of differential natural mortality at age and over time, 3) collaboration with Fishery Interaction Team (FIT) personnel to utilize Atka mackerel tagging data to estimate length-specific commercial selectivity and examine independent estimates of natural mortality, and 4) continued evaluation of model sensitivity to a number of input specifications.

15.11 Summary

Natural mortality = 0.3

2007 (Tier 3a)			
Maximum permissible ABC:	$F_{40\%}$ = 0.342	yield =	74,000 mt
Recommended ABC:	$F_{40\%}$ = 0.342	yield =	74,000 mt
Overfishing (OFL):	$F_{35\%}$ = 0.412	yield =	86,900 mt

2008 (Tier 3a)			
Maximum permissible ABC:	$F_{40\%}$ = 0.342	yield =	54,900 mt
Recommended ABC:	$F_{40\%}$ = 0.342	yield =	54,900 mt
Overfishing (OFL):	$F_{35\%}$ = 0.412	yield =	64,200 mt

Equilibrium female spawning biomass		
$B_{100\%}$	=	237,500 mt
$B_{40\%}$	=	95,000 mt
$B_{35\%}$	=	83,100 mt

Projected 2007 biomass	
Age 3+ biomass	= 364,200 mt
Female spawning biomass	= 129,900 mt

15.12 Acknowledgements

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15.14 Tables

Table 15.1. Atka mackerel catches (including discards and CDQ catches) by region and 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 mt.

	Eastern Bering Sea				Aleutian Islands Region				BSAI		
Year	Foreign	Domestic		Total	Foreign	Domestic		Total			
		JVP	DAP			JVP	DAP		Total	ABC	TAC
1977	0	0	0	a	21,763	0	0	21,763	21,763	b	b
1978	831	0	0	831	23,418	0	0	23,418	24,249	24,800	24,800
1979	1,985	0	0	1,985	21,279	0	0	21,279	23,264	24,800	24,800
1980	4,690	265	0	4,955	15,533	0	0	15,533	20,488	24,800	24,800
1981	3,027	0	0	3,027	15,028	1,633	0	16,661	19,688	24,800	24,800
1982	282	46	0	328	7,117	12,429	0	19,546	19,874	24,800	24,800
1983	140	1	0	141	1,074	10,511	0	11,585	11,726	25,500	24,800
1984	41	16	0	57	71	35,927	0	35,998	36,055	25,500	23,130
1985	1	3	0	4	0	37,856	0	37,856	37,860	37,700	37,700
1986	6	6	0	12	0	31,978	0	31,978	31,990	30,800	30,800
1987	0	12	0	12	0	30,049	0	30,049	30,061	30,800	30,800
1988	0	43	385	428	0	19,577	2,080	21,656	22,084	21,000	21,000
1989	0	56	3,070	3,126	0	0	14,868	14,868	17,994	24,000	20,285
1990	0	0	480	480	0	0	21,725	21,725	22,205	24,000	21,000
1991	0	0	2,596	2,596	0	0	24,144	24,144	26,740	24,000	24,000
1992	0	0	2,610	2,610	0	0	47,425	47,425	50,035	43,000	43,000
1993	0	0	213	213	0	0	65,524	65,524	65,737	117,100	64,000
1994	0	0	189	189	0	0	69,401	69,401	69,590	122,500	68,000
1995	0	0	a	a	0	0	81,554	81,554	81,554	125,000	80,000
1996	0	0	a	a	0	0	103,943	103,943	103,943	116,000	106,157
1997	0	0	a	a	0	0	65,845	65,845	65,845	66,700	66,700
1998	0	0	a	a	0	0	58,310	58,310	58,310	64,300	64,300
1999	0	0	a	a	0	0	56,231	56,231	56,231	73,300	66,400
2000	0	0	a	a	0	0	47,227	47,227	47,227	70,800	70,800
2001	0	0	a	a	a	0	61,612	61,612	61,612	69,300	69,300
2002	0	0	a	a	a	0	45,594	45,594	45,594	49,000	49,000
2003	0	a	a	a	a	0	54,890	54,890	54,890	63,000	60,000
2004	0	a	a	a	a	0	60,457	60,457	60,457	66,700	63,000
2005	0	a	a	a	a	0	60,592	60,592	60,592	124,000	63,000
2006c	0	a	a	a	a	0	61,157	61,157	61,157	110,200	63,000

Catch table footnotes:
a) Eastern Bering Sea catches included with Aleutian Islands.
b) Atka mackerel was not a reported species group until 1978
c) 2006 data as of 11/04/06 from NMFS Alaska Regional Office Home Page. Available at http://www.fakr.noaa.gov/2006/car110_bsai_with_cdq.pdf

Table 15.2 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	12	13	14	15
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	0.53	0.22	---	---	---
1988	0.40	9.97	22.49	6.15	1.80	1.54	0.63	0.96	0.20	0.44	0.04	---	---	---
1989[a]														
1990	---	4.05	12.06	6.79	2.49	0.89	0.19	0.13	0.05	0.02	0.04	0.16	0.03	---
1991	---	1.96	5.58	10.11	5.90	3.06	1.29	0.27	0.41	0.40	0.09	---	---	---
1992[a]														
1993[a]														
1994	0.03	9.57	6.95	24.00	39.77	4.57	9.42	6.59	4.26	0.61	0.27	0.00	0.00	0.03
1995	0.24	19.04	41.27	9.78	14.85	27.63	3.57	4.01	5.36	2.04	---	---	---	---
1996	0.03	3.45	65.69	22.31	12.77	20.87	31.93	3.02	3.60	2.64	0.51	0.05	---	---
1997[a]														
1998	---	11.34	18.95	17.30	31.93	11.65	4.15	3.83	5.58	0.47	0.85	0.76	---	---
1999	1.22	1.02	38.78	9.74	7.77	11.17	4.49	1.57	1.06	1.13	0.16	0.13	---	---
2000	0.56	7.74	5.11	23.73	6.94	3.80	7.41	1.89	0.81	0.53	0.32	0.32	---	---
2001	1.55	20.31	11.06	7.17	23.74	6.70	3.98	3.80	0.72	0.33	0.078	0.10	---	---
2002	2.16	24.00	24.93	7.05	3.56	15.23	2.94	1.55	2.42	0.31	0.28	---	---	---
2003	1.08	23.15	57.74	18.29	4.89	2.81	5.99	0.57	0.45	0.68	0.19	---	---	---
2004	0.08	24.26	34.79	47.59	13.25	2.07	1.44	2.01	---	---	0.38	---	---	---
2005	1.61	4.48	41.07	27.19	28.71	7.67	0.67	0.05	0.40	--	--	--	--	--

[a] Too few fish were sampled for age structures in 1989, 1992, 1993, and 1997 to construct age-length keys (see Section 15.3.1).

Table 15.3 Atka mackerel estimated biomass in metric tons from the bottom trawl survey, by subregion, depth interval, and survey year, with the corresponding coefficients of variation.

		Biomass			Coefficient of variation		
Area	Depth (m)	1980	1983	1986	1980	1983	1986
Aleutian	1-100	48,306	140,552	450,869			
	101-200	144,431	162,399	93,501			
	201-300	4,296	3,656	331			
	301-500	483	172	16			
	501-900	13	1	37			
	Total	197,529	306,780	544,754	0.42	0.22	0.63
Southwest Aleutian	1-100	95	15,321	418,271			
	101-200	75,857	120,991	51,312			
	201-300	619	2,304	122			
	301-500	105	172	14			
	501-900	9	1	0			
	Total	76,685	138,789	469,719	0.57	0.36	0.73
Southeast Aleutian	1-100	0	65,814	33			
	101-200	21,153	854	89			
	201-300	115	202	3			
	301-500	16	0	0			
	501-900	0	0	0			
	Total	21,284	66,870	125	0.86	0.01	0.64
Northwest Aleutian	1-100	0	41,235	32,564			
	101-200	382	5,571	211			
	201-300	2,524	34	0			
	301-500	0	0	0			
	501-900	4	0	0			
	Total	2,910	46,840	32,775	0.84	0.64	0.65
Northeast Aleutian	1-100	48,211	18,182	1			
	101-200	47,039	34,983	44,889			
	201-300	1,038	1,116	206			
	301-500	362	0	2			
	501-900	0	0	37			
	Total	96,650	54,281	42,135	0.69	0.57	0.46

Table 15.4 Atka mackerel biomass (mt), 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 (mt)						
		1991	1994	1997	2000	2002	2004	2006
Aleutian	1-100	429,826	145,000	188,504	145,001	330,891	394,594	364,490
Islands	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	1-100	168,968	93,847	90,824	106,168	51,921	140,669	64,429
543	101-200	185,748	214,228	43,478	65,600	154,820	226,043	35,926
	201-300	304	1,656	63	7,912	48,366	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	1-100	187,194	50,513	70,458	38,805	126,811	198,501	192,832
542	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	1-100	73,663	641	27,222	29	152,159	54,424	107,230
541	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 15.5 Mean weight-at-age (kg) and length-at-age values (cm) used in *last* year's assessment for Atka mackerel. The survey values are derived from the Aleutian trawl surveys from years 1986, 1991, and 1994; the fishery values are derived from the commercial fishery from years 1990 to 1996. The survey values were also used for the population weight-at-age values.

Age	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Survey														
(kg)	0.184	0.398	0.549	0.656	0.732	0.785	0.823	0.85	0.869	0.882	0.892	0.899	0.903	0.907
(cm)	25.15	30.92	34.65	37.05	38.59	39.59	40.23	40.65	40.92	41.09	41.20	41.27	41.32	41.35
Fishery														
(kg)	0.128	0.421	0.66	0.756	0.794	0.81	0.816	0.818	0.819	0.82	0.82	0.82	0.82	0.82
(cm)	22.94	31.91	36.49	38.84	40.04	40.66	40.97	41.13	41.21	41.26	41.28	41.29	41.29	41.30

Table 15.6. Year-specific fishery and survey and the population weight-at-age (kg) values used in the current assessment model 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 2000, 2002, and 2004.

		AGE														
	Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Survey	1986	0.045	0.244	0.343	0.447	0.547	0.609	0.632	0.724	0.883	0.881	1.040	1.067	0.939	1.293	1.104
	1991	0.045	0.185	0.449	0.637	0.652	0.751	0.811	0.693	1.053	1.764	0.878	1.067	0.939	1.293	1.104
	1994	0.045	0.177	0.450	0.653	0.738	0.846	0.941	0.988	0.906	0.907	0.516	1.067	0.939	1.293	1.104
	1997	0.045	0.191	0.486	0.686	0.753	0.805	0.887	0.970	0.919	1.375	0.935	0.935	0.886	1.293	1.104
	2000	0.045	0.130	0.387	0.623	0.699	0.730	0.789	0.810	0.792	0.864	0.871	1.261	0.797	1.293	1.104
	2002	0.045	0.139	0.342	0.615	0.720	0.837	0.877	0.773	0.897	0.955	1.084	1.067	1.182	1.293	1.104
	2004	0.045	0.138	0.333	0.497	0.609	0.739	0.816	0.956	0.928	0.745	0.824	1.004	0.892	1.293	1.104
Ave 2000, 2002, 2004		0.045	0.136	0.354	0.579	0.676	0.769	0.827	0.846	0.872	0.855	0.926	1.111	0.957	1.293	1.104
Fishery	1977	0.069	0.132	0.225	0.306	0.400	0.470	0.507	0.379	0.780	0.976	1.034	1.113	0.953	1.113	1.273
Foreign	1978	0.069	0.072	0.225	0.300	0.348	0.388	0.397	0.371	0.423	0.976	1.034	1.113	0.953	1.113	1.273
	1979	0.069	0.496	0.319	0.457	0.476	0.475	0.468	0.546	0.780	0.976	1.034	1.113	0.953	1.113	1.273
	1980	0.069	0.365	0.317	0.450	0.520	0.585	0.630	0.546	0.780	0.976	1.034	1.113	0.953	1.113	1.273
	1981	0.069	0.365	0.317	0.450	0.520	0.585	0.630	0.546	0.780	0.976	1.034	1.113	0.953	1.113	1.273
	1982	0.069	0.365	0.273	0.443	0.564	0.695	0.795	0.546	0.780	0.976	1.034	1.113	0.953	1.113	1.273
	1983	0.069	0.365	0.359	0.499	0.601	0.686	0.810	0.546	0.780	0.976	1.034	1.113	0.953	1.113	1.273
	1984	0.069	0.297	0.410	0.617	0.707	0.777	0.802	0.890	0.910	0.976	1.034	1.113	0.953	1.113	1.273
	1985	0.069	0.302	0.452	0.552	0.682	0.737	0.775	0.807	1.007	1.011	1.034	1.113	0.953	1.113	1.273
	1986	0.069	0.146	0.334	0.528	0.546	0.786	0.753	0.829	0.858	0.954	0.979	1.113	0.953	1.113	1.273
	1987	0.069	0.265	0.435	0.729	0.908	0.859	0.964	1.023	1.054	1.088	1.105	1.121	0.953	1.113	1.273
	1988	0.069	0.196	0.351	0.470	0.564	0.624	0.694	0.783	0.818	0.850	1.017	1.106	0.953	1.113	1.273
Domestic	1989	0.069	0.295	0.440	0.577	0.739	0.838	0.664	0.817	0.906	1.010	0.951	0.950	1.070	1.440	1.273
	1990	0.069	0.395	0.603	0.865	0.978	0.998	1.099	1.384	1.118	1.434	1.600	1.504	1.408	1.440	1.273
	1991	0.069	0.238	0.285	0.583	0.823	0.764	0.757	0.981	1.241	0.867	1.061	0.981	1.070	1.440	1.273
	1992	0.069	0.238	0.373	0.625	0.806	1.009	1.092	0.898	1.023	1.037	1.058	0.954	1.070	1.440	1.273
	1993	0.069	0.238	0.352	0.607	0.749	0.839	0.888	0.898	1.023	1.037	1.058	0.954	1.070	1.440	1.273
	1994	0.069	0.238	0.397	0.590	0.692	0.744	0.815	0.816	0.826	0.838	0.872	0.954	1.070	1.440	1.273
	1995	0.069	0.089	0.296	0.604	0.735	0.768	0.773	0.795	0.821	0.772	0.806	1.022	1.070	1.440	1.273
	1996	0.069	0.175	0.324	0.509	0.693	0.725	0.771	0.781	0.874	0.951	1.180	1.002	1.115	1.440	1.273
	1997	0.069	0.232	0.405	0.670	0.701	0.853	0.900	0.971	0.903	0.904	0.930	0.976	1.070	1.440	1.273
	1998	0.069	0.232	0.350	0.518	0.600	0.647	0.687	0.788	0.761	0.850	0.838	0.705	0.818	1.440	1.273
	1999	0.069	0.243	0.403	0.577	0.694	0.770	0.827	0.850	0.890	0.943	0.894	0.777	1.017	1.440	1.273
	2000	0.069	0.232	0.506	0.600	0.710	0.765	0.823	0.903	0.909	0.949	0.991	1.003	0.998	1.440	1.273
	2001	0.069	0.177	0.454	0.632	0.753	0.835	0.897	0.883	0.980	0.986	1.047	1.073	1.067	1.440	1.273
	2002	0.069	0.255	0.328	0.498	0.641	0.664	0.764	0.750	0.814	0.911	0.797	0.830	1.070	1.440	1.273
	2003	0.069	0.217	0.333	0.444	0.549	0.677	0.722	0.735	0.681	0.839	0.842	0.833	1.070	1.440	1.273
	2004	0.069	0.190	0.331	0.447	0.517	0.606	0.639	0.757	0.744	0.818	0.895	0.765	1.070	1.440	1.273
	2005	0.069	0.251	0.426	0.500	0.563	0.575	0.657	0.787	0.973	0.796	0.895	0.901	1.070	1.440	1.273

Table 15.7 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				Proportion
Length (cm)	541	542	543	Age	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 15.8. Estimates of key results from AMAK for Aleutian Islands Atka mackerel from the current assessment (with and without the updated weight at age values) and last year's (2005) assessment. Coefficients of variation (*CV*) for some key reference values appearing directly above, are given in parentheses.

Assessment Model	**Current** (with old weight–at-age)	**Current** (with updated weight–at-age)	**2005**
Model setup			
Survey catchability	1.418	1.476	1.429
Steepness	0.800	0.800	0.800
SigmaR	0.6	0.6	0.6
Natural mortality	0.300	0.300	0.300
Fishery Average Effective *N*	119	121	115
Survey Average Effective *N*	56	56	48
RMSE Survey	0.267	0.346	0.278
-log Likelihoods			
Number of Parameters	388	388	378
Survey index	3.09	4.20	3.16
Catch biomass	0.07	0.09	0.06
Fishery age comp	161.12	159.39	160.08
Survey age comp	36.67	35.54	40.35
Sub total	200.95	199.23	203.65
-log Penalties			
Recruitment	8.159	10.550	7.036
Selectivity constraint	120.858	119.467	120.721
Fishing mortality penalty	0.000	0.000	0.000
Prior	2.260	2.914	2.464
Total	332.224	332.196	333.870
Fishing mortalities (full selection)			
F 2006	0.200	0.221	
F 2006/*F* 40%	0.518	0.635	
F 40%	0.386	0.348	0.351
CV	(28%)	(27%)	(31%)
*F*35%	0.465	0.419	0.423
CV	(29%)	(28%)	(32%)
Stock abundance			
Initial Biomass (mt 1977)	294,260	276,750	299,360
CV	(17%)	(16%)	(17%)
2006 total biomass (mt)	586,720	569,110	
CV	(15%)	(16%)	
2006 Age 3+ biomass (mt)	421,383	445,002	
1999 year class (1000's at age 1)	1,142	1,262	1,121
CV	(28%)	(27%)	(30%)
2001 year class (1000's at age 1)	882	967	716
CV	(38%)	(38%)	(47%)
Recruitment Variability	0.603	0.622	0.594
Projected catch (unadjusted)			
F 40% 2007 catch (mt)	91,168	75,969	
CV	(20%)	(20%)	
F 35% 2007 catch (mt)	106,700	89,118	
CV	(21%)	(21%)	

Table 15.9. Estimates of Atka mackerel fishery (over time, 1977-2006) and survey selectivity at age for Model 4. These are full-selection (maximum = 1.0) estimates.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1977	0.02	0.09	0.36	0.82	1.00	0.77	0.50	0.32	0.22	0.18	0.18	0.18	0.18	0.18	0.18
1978	0.02	0.10	0.44	0.74	1.00	0.92	0.65	0.42	0.28	0.22	0.22	0.22	0.22	0.22	0.22
1979	0.01	0.05	0.24	0.77	1.00	0.91	0.66	0.43	0.29	0.23	0.23	0.23	0.23	0.23	0.23
1980	0.01	0.05	0.20	0.59	1.00	0.99	0.87	0.61	0.39	0.28	0.28	0.28	0.28	0.28	0.28
1981	0.01	0.03	0.12	0.24	0.33	0.60	1.00	0.59	0.29	0.18	0.18	0.18	0.18	0.18	0.18
1982	0.01	0.03	0.09	0.31	0.85	1.00	0.70	0.43	0.29	0.22	0.22	0.22	0.22	0.22	0.22
1983	0.01	0.03	0.15	0.37	0.68	1.00	0.91	0.54	0.34	0.27	0.27	0.27	0.27	0.27	0.27
1984	0.01	0.03	0.14	0.42	0.76	1.00	0.94	0.68	0.45	0.34	0.34	0.34	0.34	0.34	0.34
1985	0.01	0.06	0.41	0.84	1.00	1.00	0.93	0.82	0.70	0.61	0.61	0.61	0.61	0.61	0.61
1986	0.01	0.04	0.22	0.48	0.68	0.81	0.94	1.00	0.86	0.69	0.69	0.69	0.69	0.69	0.69
1987	0.01	0.04	0.23	0.53	0.74	0.83	0.91	1.00	1.00	0.98	0.98	0.98	0.98	0.98	0.98
1988	0.01	0.05	0.31	0.96	1.00	0.87	0.84	0.80	0.78	0.73	0.73	0.73	0.73	0.73	0.73
1989	0.01	0.04	0.20	0.57	0.93	1.00	0.89	0.77	0.70	0.66	0.66	0.66	0.66	0.66	0.66
1990	0.00	0.03	0.23	0.79	1.00	0.79	0.66	0.59	0.57	0.56	0.56	0.56	0.56	0.56	0.56
1991	0.00	0.02	0.09	0.42	0.89	1.00	0.85	0.72	0.63	0.60	0.60	0.60	0.60	0.60	0.60
1992	0.01	0.03	0.10	0.30	0.65	0.94	1.00	0.96	0.90	0.85	0.85	0.85	0.85	0.85	0.85
1993	0.01	0.03	0.09	0.26	0.55	0.87	1.00	0.98	0.96	0.96	0.96	0.96	0.96	0.96	0.96
1994	0.01	0.02	0.10	0.32	0.66	0.84	0.87	0.96	1.00	0.98	0.98	0.98	0.98	0.98	0.98
1995	0.00	0.03	0.14	0.48	0.64	0.70	0.78	0.84	0.91	1.00	1.00	1.00	1.00	1.00	1.00
1996	0.00	0.02	0.10	0.35	0.54	0.71	0.90	1.00	0.94	0.90	0.90	0.90	0.90	0.90	0.90
1997	0.01	0.02	0.09	0.26	0.52	0.77	0.90	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1998	0.00	0.02	0.09	0.33	0.62	0.78	0.87	0.93	0.98	1.00	1.00	1.00	1.00	1.00	1.00
1999	0.00	0.03	0.14	0.50	0.72	0.82	0.86	0.95	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2000	0.00	0.02	0.16	0.47	0.74	0.87	0.94	1.00	0.96	0.91	0.91	0.91	0.91	0.91	0.91
2001	0.00	0.02	0.14	0.45	0.76	0.92	1.00	0.96	0.83	0.75	0.75	0.75	0.75	0.75	0.75
2002	0.00	0.02	0.12	0.36	0.62	0.85	1.00	0.92	0.78	0.68	0.68	0.68	0.68	0.68	0.68
2003	0.01	0.04	0.20	0.55	0.73	0.90	1.00	0.96	0.84	0.76	0.76	0.76	0.76	0.76	0.76
2004	0.01	0.06	0.25	0.68	0.98	1.00	0.97	0.93	0.84	0.78	0.78	0.78	0.78	0.78	0.78
2005	0.01	0.06	0.23	0.66	0.97	1.00	0.86	0.74	0.67	0.64	0.64	0.64	0.64	0.64	0.64
2006	0.01	0.06	0.23	0.66	0.97	1.00	0.86	0.74	0.67	0.64	0.64	0.64	0.64	0.64	0.64
Avg. 2001-2005	0.01	0.04	0.19	0.54	0.81	0.93	0.97	0.90	0.79	0.72	0.72	0.72	0.72	0.72	0.72
Survey	0.02	0.14	0.60	0.97	1.00	0.96	0.99	0.93	0.77	0.69	0.69	0.69	0.69	0.69	0.69

Table 15.10. Estimated Atka mackerel numbers at age in thousands, 1977-2006.

Year	1	2	3	4	5	6	7	8	9	10+	Total	% of 10+
1977	200	228	191	53	38	19	17	15	13	57	832	7%
1978	1,084	147	163	123	29	19	11	10	10	48	1,645	3%
1979	309	798	105	102	68	14	10	6	7	39	1,458	3%
1980	196	228	584	73	62	39	8	6	4	32	1,234	3%
1981	227	145	167	417	49	38	24	5	4	25	1,102	2%
1982	149	168	107	120	291	33	24	14	3	21	931	2%
1983	220	110	124	78	86	195	22	17	10	17	880	2%
1984	302	163	82	91	57	61	136	15	12	20	938	2%
1985	478	223	120	59	62	36	37	84	10	22	1,132	2%
1986	454	354	163	82	37	37	22	23	52	21	1,244	2%
1987	595	336	260	114	54	23	23	13	13	44	1,473	3%
1988	370	440	247	185	77	35	15	14	8	36	1,427	3%
1989	1,080	274	324	176	122	51	23	10	10	30	2,101	1%
1990	509	800	202	237	125	84	35	16	7	28	2,041	1%
1991	265	377	592	148	167	87	59	25	12	25	1,756	1%
1992	535	196	279	434	105	114	59	40	17	25	1,803	1%
1993	804	396	145	203	307	70	73	37	26	27	2,088	1%
1994	287	595	291	105	142	201	43	43	22	32	1,762	2%
1995	312	213	438	210	71	89	120	25	25	31	1,533	2%
1996	712	231	156	309	131	42	51	67	14	29	1,743	2%
1997	139	527	169	109	188	72	21	23	29	19	1,297	1%
1998	239	103	387	121	74	115	40	11	12	24	1,126	2%
1999	698	177	75	275	78	42	61	21	6	18	1,451	1%
2000	1,262	517	130	54	175	46	24	35	11	13	2,266	1%
2001	798	934	380	92	35	106	27	14	20	14	2,420	1%
2002	967	591	686	267	58	20	56	14	7	18	2,684	1%
2003	263	715	434	489	176	35	11	30	8	15	2,178	1%
2004	255	194	525	307	319	110	21	7	18	14	1,771	1%
2005	258	189	142	371	201	197	68	13	4	20	1,464	1%
2006	278	191	138	101	245	125	122	43	9	16	1,268	1%

Table 15.11. Estimates of Atka mackerel biomass in mt 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 mt from the current assessment compared to last year's (2005) assessment.

	Current assessment age 1+ biomass (mt)			Age 3+ biomass (mt)		Female spawning biomass (mt)	
Year	Estimate	LCI	UCI	Current	2005	Current	2005
1977	276,750	189,148	364,352	171,575	239,168	71,341	74,143
1978	309,910	208,144	411,676	157,280	250,738	65,584	70,176
1979	335,660	219,508	451,812	176,299	238,842	63,787	73,903
1980	415,740	273,634	557,846	321,690	433,800	64,373	78,115
1981	452,860	298,634	607,086	338,406	456,323	77,599	96,018
1982	419,290	276,094	562,486	323,238	427,080	119,427	147,158
1983	381,550	251,858	511,242	323,875	395,240	131,185	161,611
1984	357,830	240,808	474,852	332,661	354,018	123,960	148,877
1985	329,960	222,522	437,398	286,453	309,828	108,185	126,862
1986	330,100	226,108	434,092	248,857	293,333	88,028	102,936
1987	367,190	263,186	471,194	361,267	330,901	76,048	89,752
1988	418,210	314,460	521,960	302,758	368,183	78,534	92,526
1989	495,340	392,898	597,782	440,199	442,353	94,258	110,432
1990	566,180	469,698	662,662	640,155	460,612	114,747	133,245
1991	649,450	554,058	744,842	570,986	623,322	136,810	156,321
1992	686,880	593,492	780,268	720,554	647,953	156,666	175,669
1993	663,120	575,978	750,262	617,881	573,659	188,456	208,718
1994	630,040	546,446	713,634	544,050	539,757	187,668	204,069
1995	610,460	524,594	696,326	537,365	572,339	162,376	172,750
1996	560,550	472,192	648,908	463,982	488,616	148,073	157,558
1997	465,640	378,136	553,144	422,049	389,284	135,697	146,891
1998	448,480	356,522	540,438	383,204	427,746	116,078	124,265
1999	418,330	324,084	512,576	365,561	356,850	104,076	112,493
2000	430,090	329,904	530,276	332,145	302,504	107,249	116,695
2001	521,340	399,676	643,004	416,508	355,178	94,480	100,714
2002	664,070	505,908	822,232	484,748	502,929	86,420	87,937
2003	756,570	571,696	941,444	531,884	570,292	114,692	115,451
2004	761,880	563,686	960,074	586,900	611,219	166,887	166,179
2005	682,830	489,298	876,362	549,834	534,805	195,019	186,536
2006	569,110	392,240	745,980	445,002	446,225	203,752	155,800
2007				364,160		129,900	

Table 15.12 Estimates of age-1 Atka mackerel recruitment (1000's of recruits).

	Age 1 Recruits	
Year	Current	2005
1977	200	212
1978	1084	1165
1979	309	333
1980	196	212
1981	227	246
1982	149	160
1983	220	239
1984	302	329
1985	478	510
1986	454	484
1987	595	639
1988	370	392
1989	1080	1132
1990	509	522
1991	265	271
1992	535	546
1993	804	811
1994	287	292
1995	312	319
1996	712	723
1997	139	141
1998	239	239
1999	698	657
2000	1262	1121
2001	798	686
2002	967	716
2003	263	256
2004	255	250
2005	258	
Ave 78-05	492	
Med 78-05	341	

Table 15.13. Estimates of full-selection fishing mortality rates and exploitation rates for Atka mackerel.

Year	*F*[a]	Catch/Biomass Rate[b]
1977	0.381	0.127
1978	0.396	0.154
1979	0.248	0.132
1980	0.188	0.064
1981	0.244	0.058
1982	0.116	0.061
1983	0.063	0.036
1984	0.195	0.108
1985	0.210	0.132
1986	0.254	0.129
1987	0.169	0.083
1988	0.119	0.073
1989	0.082	0.041
1990	0.058	0.035
1991	0.099	0.047
1992	0.155	0.069
1993	0.222	0.106
1994	0.262	0.128
1995	0.357	0.152
1996	0.551	0.224
1997	0.377	0.156
1998	0.425	0.152
1999	0.309	0.154
2000	0.269	0.142
2001	0.369	0.148
2002	0.315	0.094
2003	0.234	0.103
2004	0.184	0.103
2005	0.177	0.110
2006	0.221	0.142

[a] Full-selection fishing mortality rates.
[b] Catch/biomass rate is the ratio of catch to beginning year age 3+ biomass.
[c] The 2006 catch/biomass rate is based on 2006 TAC.

Table 15.14. Projections of female spawning biomass in mt, full-selection fishing mortality rates (*F*) and catch in mt for Atka mackerel for the 7 scenarios. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 237,510, 95,004, and 83,129 t, respectively.

	$B_{100\%}$	$B_{40\%}$	$B_{35\%}$	B_{2007}	$B_{2007}/B_{100\%}$		
	237,510	95,004	83,129	129,892	0.547		
Catch	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2006	63,000	63,000	63,000	63,000	63,000	63,000	63,000
2007	74,035	74,035	32,967	20,587	0	86,939	74,035
2008	54,910	54,910	28,026	18,182	0	58,882	54,910
2009	42,976	42,976	26,425	17,559	0	44,470	49,814
2010	45,608	45,608	27,811	18,664	0	48,710	50,873
2011	50,428	50,428	30,220	20,434	0	54,408	55,287
2012	53,098	53,098	32,214	21,984	0	56,975	57,351
2013	54,383	54,383	33,400	22,969	0	57,924	58,108
2014	54,480	54,480	34,030	23,564	0	57,814	57,902
2015	54,736	54,736	34,402	23,933	0	57,866	57,921
2016	55,141	55,141	34,771	24,228	0	58,413	58,438
2017	55,804	55,804	35,218	24,586	0	59,299	59,311
2018	55,898	55,898	35,360	24,740	0	59,360	59,366
2019	55,350	55,350	35,312	24,769	0	58,480	58,482
F	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2006	0.217	0.217	0.217	0.217	0.217	0.217	0.217
2007	0.342	0.342	0.141	0.086	0.000	0.412	0.342
2008	0.342	0.342	0.141	0.086	0.000	0.392	0.342
2009	0.301	0.301	0.141	0.086	0.000	0.334	0.355
2010	0.300	0.300	0.141	0.086	0.000	0.340	0.348
2011	0.308	0.308	0.141	0.086	0.000	0.353	0.356
2012	0.311	0.311	0.141	0.086	0.000	0.358	0.359
2013	0.314	0.314	0.141	0.086	0.000	0.360	0.361
2014	0.314	0.314	0.141	0.086	0.000	0.360	0.360
2015	0.315	0.315	0.141	0.086	0.000	0.360	0.360
2016	0.314	0.314	0.141	0.086	0.000	0.359	0.359
2017	0.315	0.315	0.141	0.086	0.000	0.361	0.361
2018	0.316	0.316	0.141	0.086	0.000	0.363	0.363
2019	0.315	0.315	0.141	0.086	0.000	0.360	0.360
Spawning Biomass	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2006	174,237	174,237	174,237	174,237	174,237	174,237	174,237
2007	129,892	129,892	143,466	147,418	153,858	125,464	129,892
2008	97,247	97,247	123,697	132,211	146,907	90,374	97,247
2009	84,604	84,604	115,271	126,498	146,851	78,042	82,670
2010	88,739	88,739	121,896	135,328	160,581	82,235	84,417
2011	94,176	94,176	131,293	147,106	177,637	86,945	87,947
2012	96,473	96,473	137,497	155,513	191,131	88,495	88,947
2013	98,465	98,465	143,263	163,413	204,172	89,899	90,129
2014	97,912	97,912	144,626	165,986	209,964	89,136	89,236
2015	98,134	98,134	146,658	169,255	216,652	89,267	89,323
2016	99,375	99,375	148,831	172,102	221,523	90,482	90,504
2017	100,431	100,431	151,046	175,059	226,607	91,352	91,362
2018	100,367	100,367	152,140	176,888	230,551	91,095	91,098
2019	99,665	99,665	151,948	177,102	232,078	90,376	90,377

Table 15.15. 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)	Pacific cod and arrowtooth abundance trends are stable	None	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 87 mt from 2003-2005, which is about 14% 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, large increase in bycatch in 2004	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 690 (58%), and 6,100 mt 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

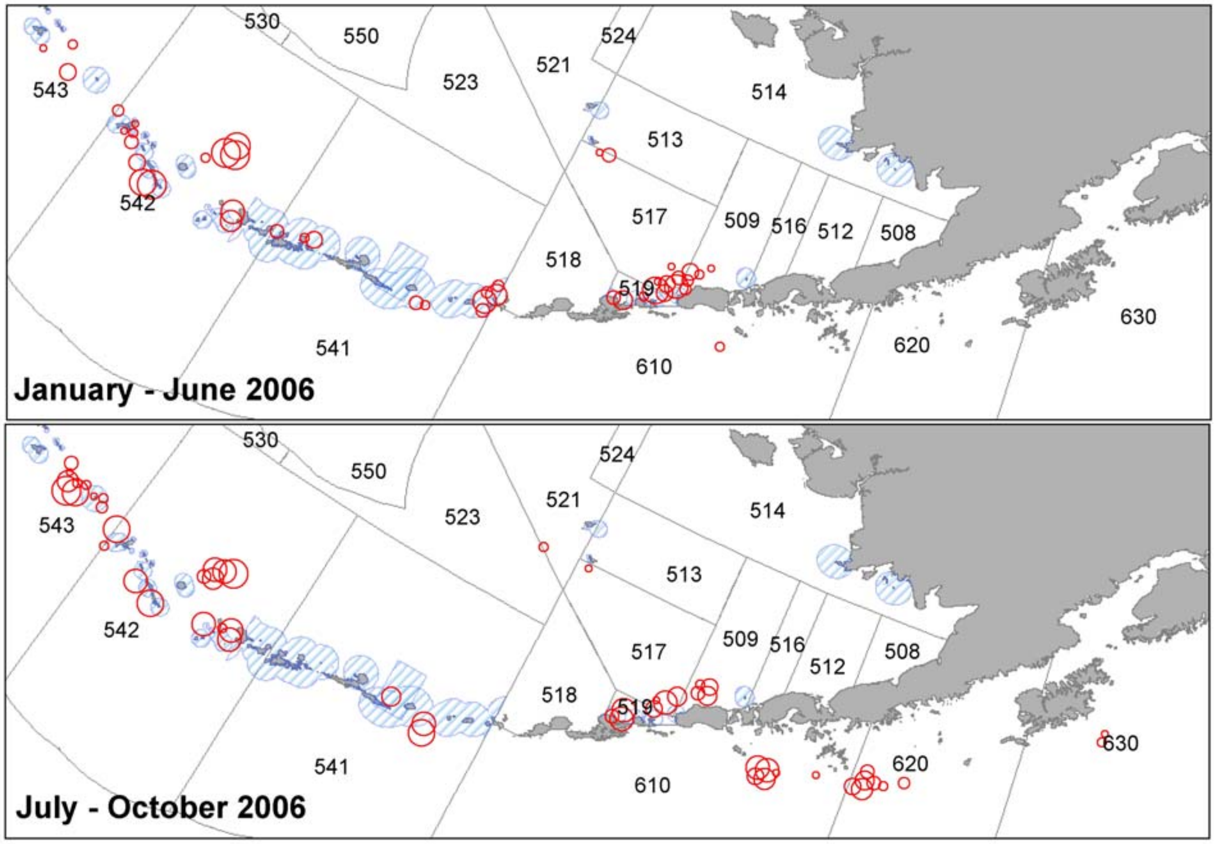


Figure 15.1. Observed catches of Atka mackerel summed for 20 km^2 cells for 2006 (January – June, top panel; and from July-October, bottom panel) where observed catch per haul was greater than 1mt. Shaded areas represent 10 and 20 nm Steller sea lion areas.

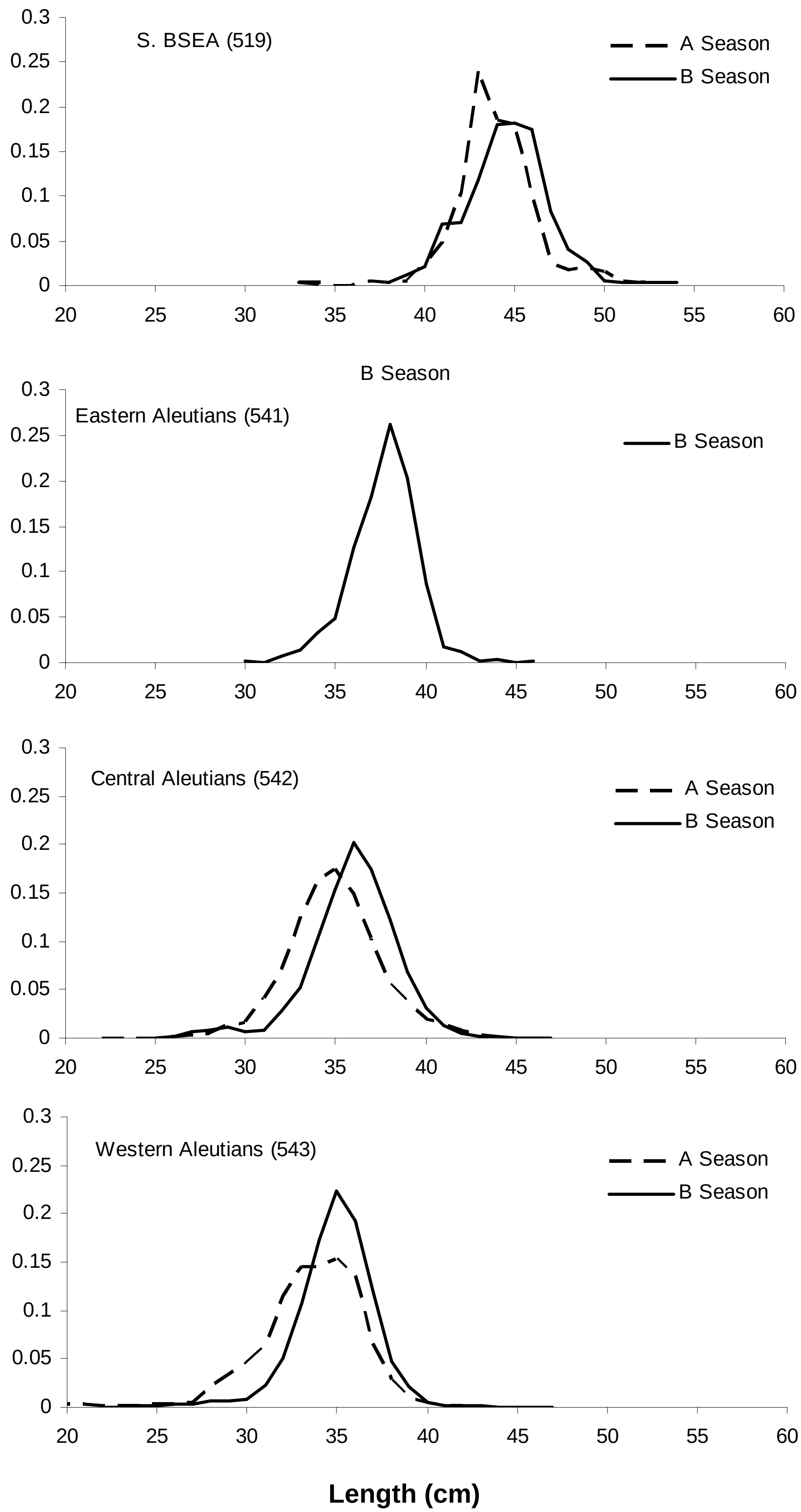


Figure 15.2. 2005 Atka mackerel fishery length-frequency data by area fished (see Figure 15.1). Numbers refer to management areas.

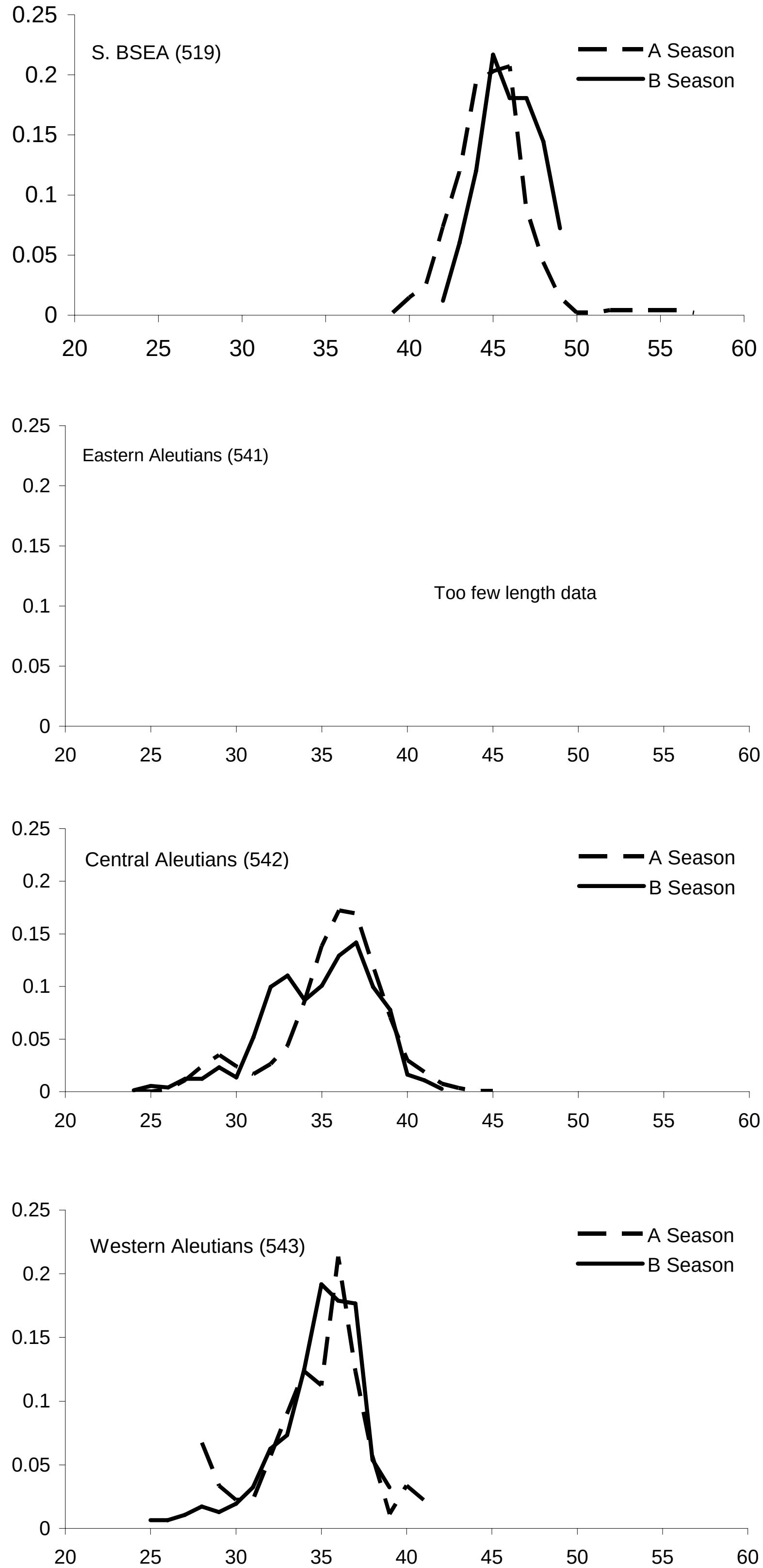


Figure 15.3. Preliminary 2006 A-season Atka mackerel fishery length-frequency data by area fished (see Figure 15.1). Numbers refer to management areas.

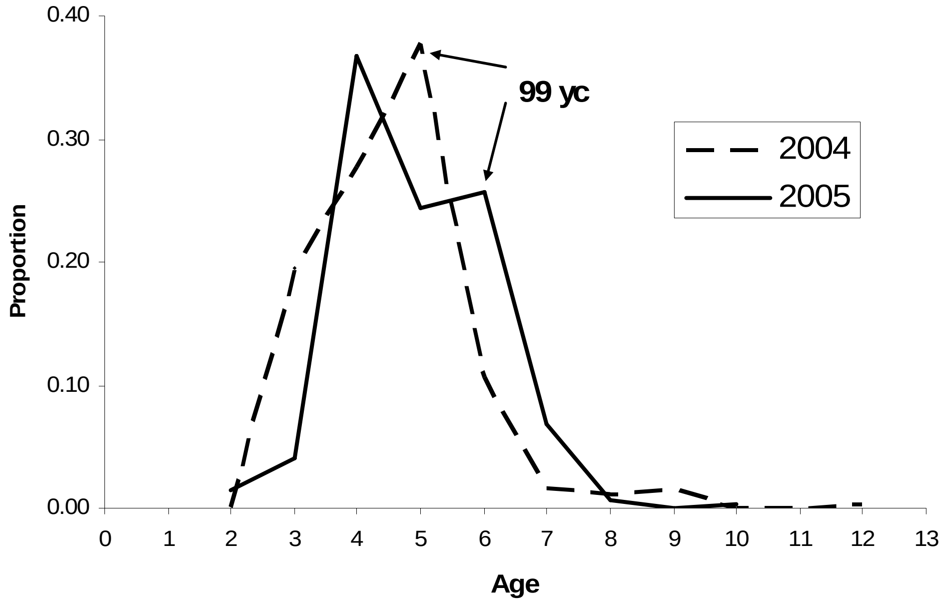


Figure 15.4. Aleutian Islands Atka mackerel fishery age composition data for 2004 and 2005.

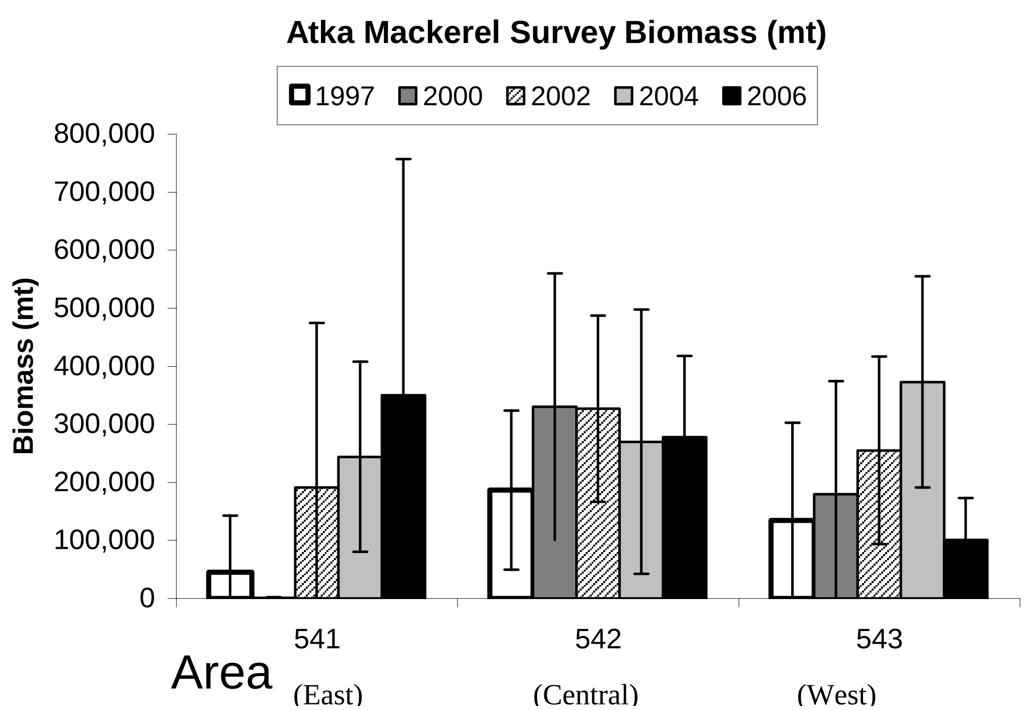


Figure 15.5. Atka mackerel Aleutian Islands survey biomass estimates by area and survey year. Bars represent 95% confidence intervals based on sampling error.

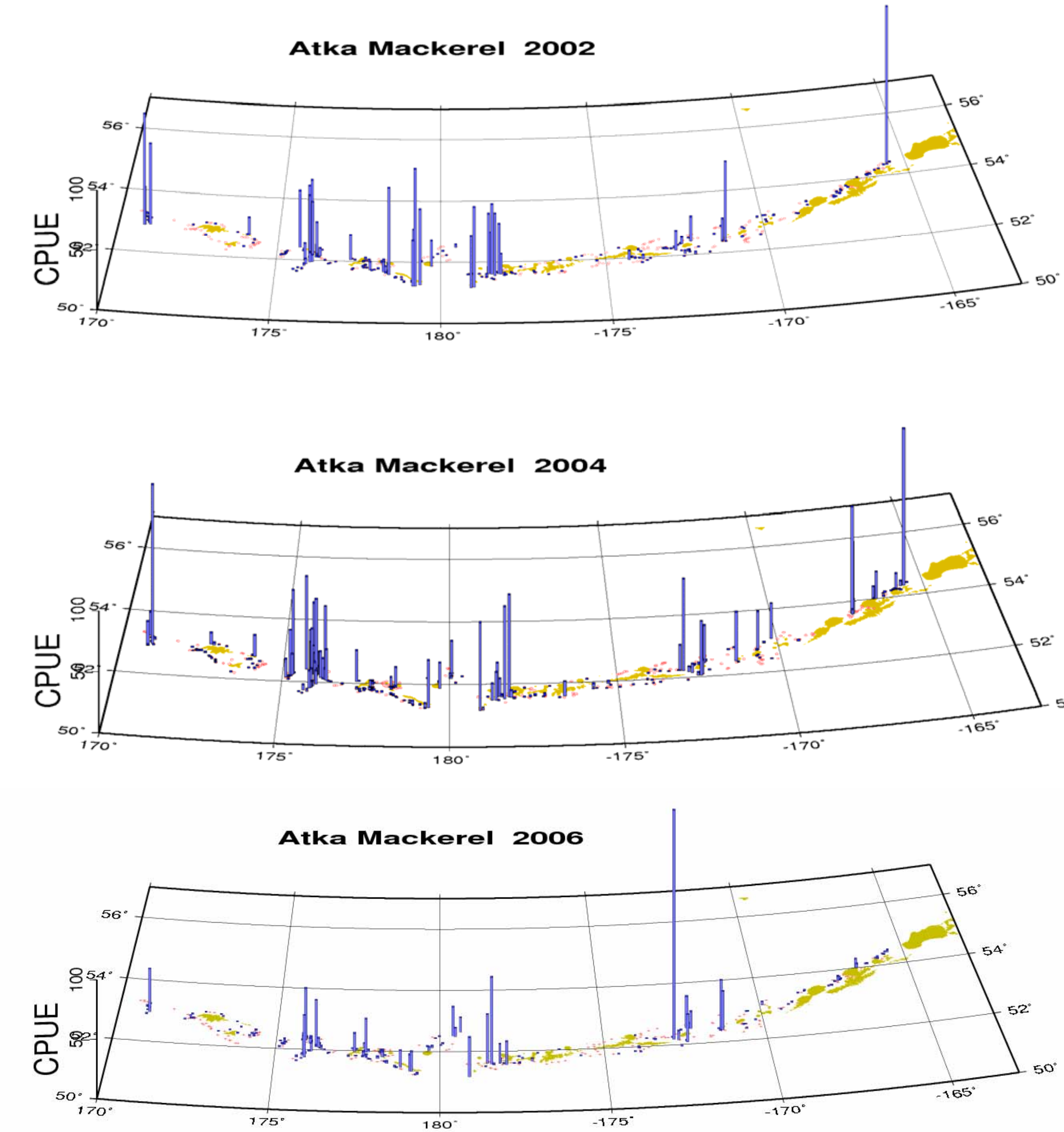


Figure 15.6. Bottom-trawl survey CPUE distributions of Atka mackerel catches during the summers of 2002, 2004, and 2006.

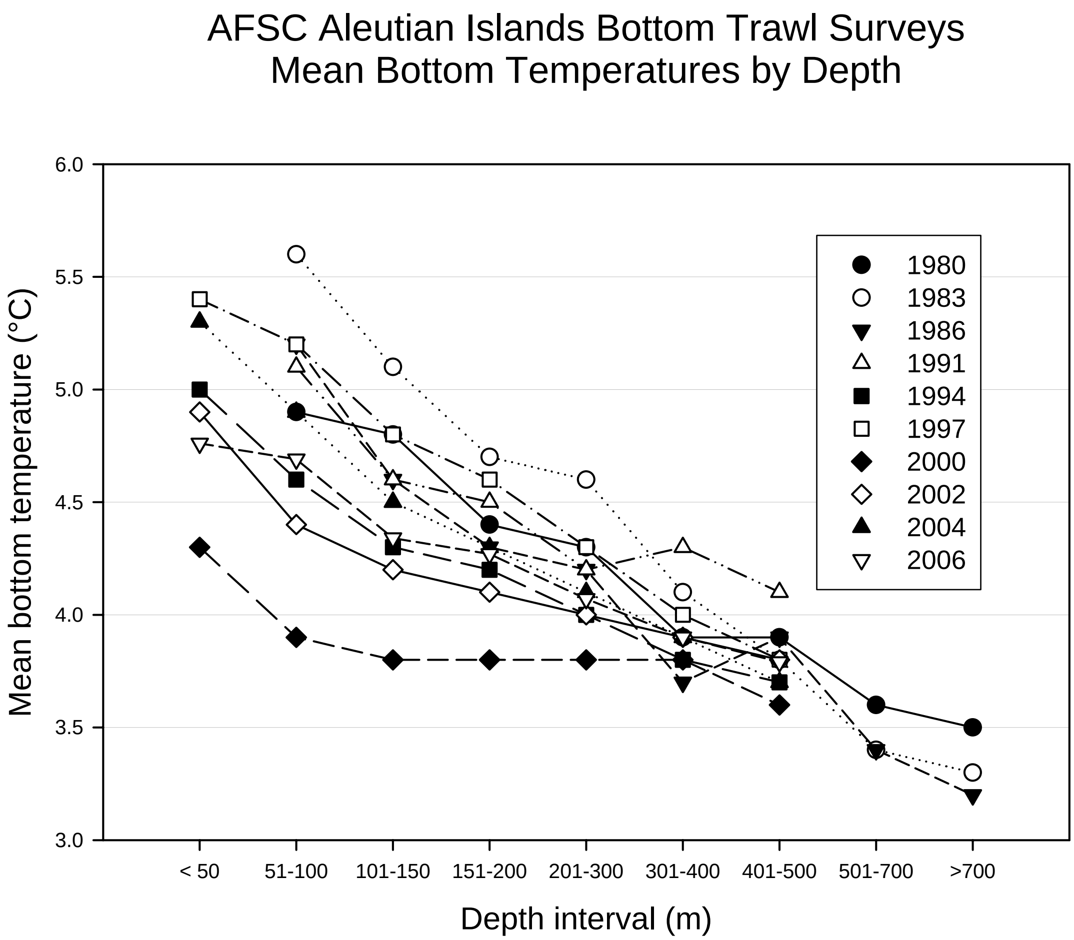


Figure 15.7. Average bottom temperatures by depth interval based on Aleutian Islands summer bottom-trawl surveys since 1980.

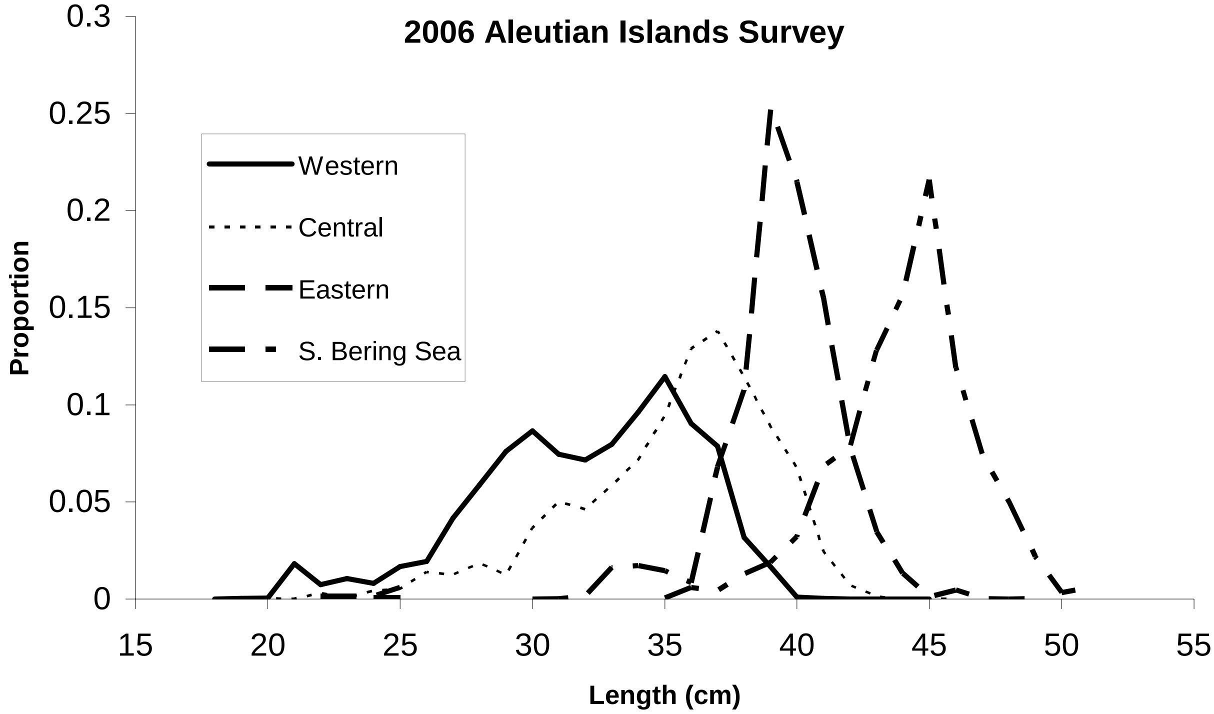


Figure 15.8. Atka mackerel bottom trawl survey length frequency data by subarea from the 2006 Aleutian Island survey.

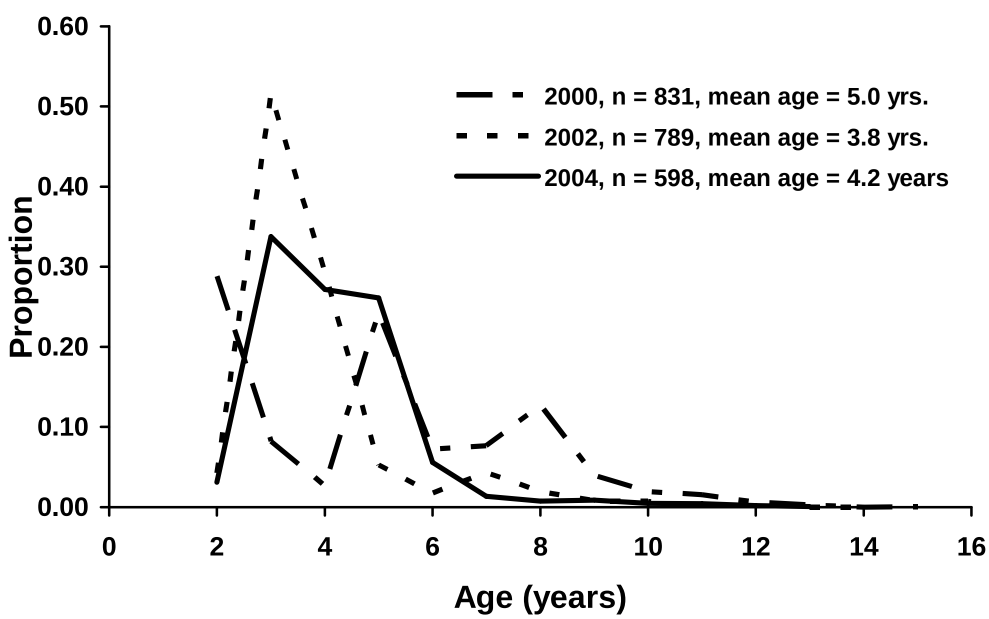


Figure 15.9. Atka mackerel age distributions from the Aleutian Islands region from the 2000, 2002, and 2004 bottom trawl surveys.

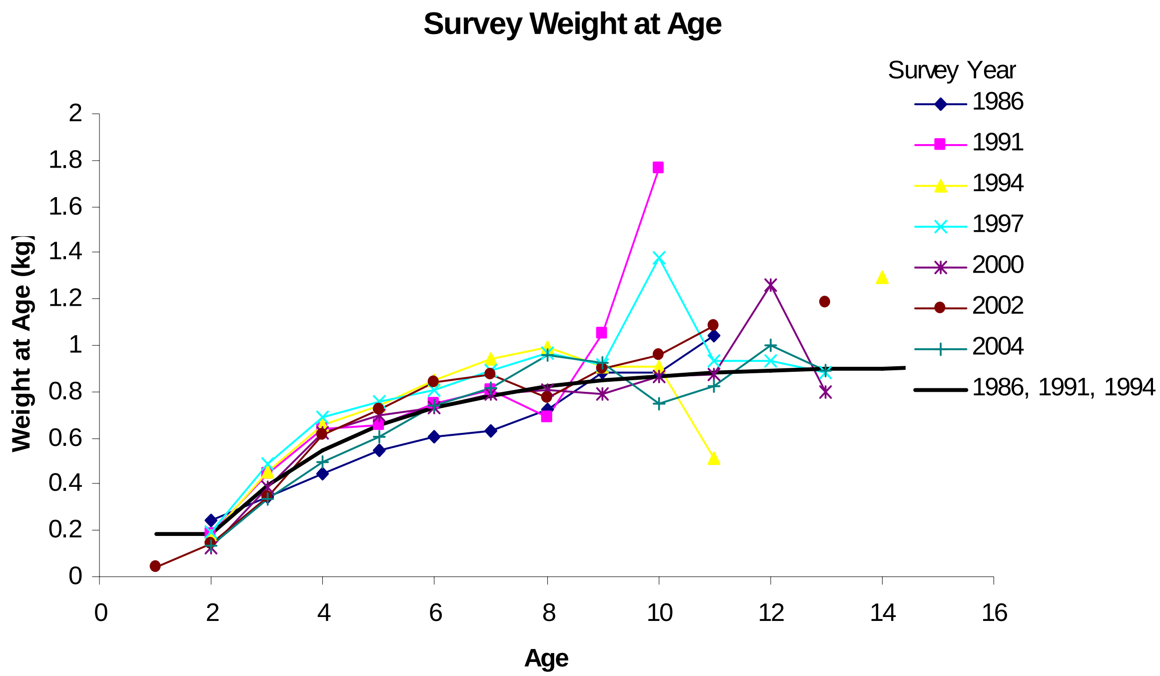


Figure 15.10. Year-specific survey weight-at-age values used in the current assessment, compared to the single set of values used in last year's assessment based on the 1986, 1991, and 1994 surveys combined.

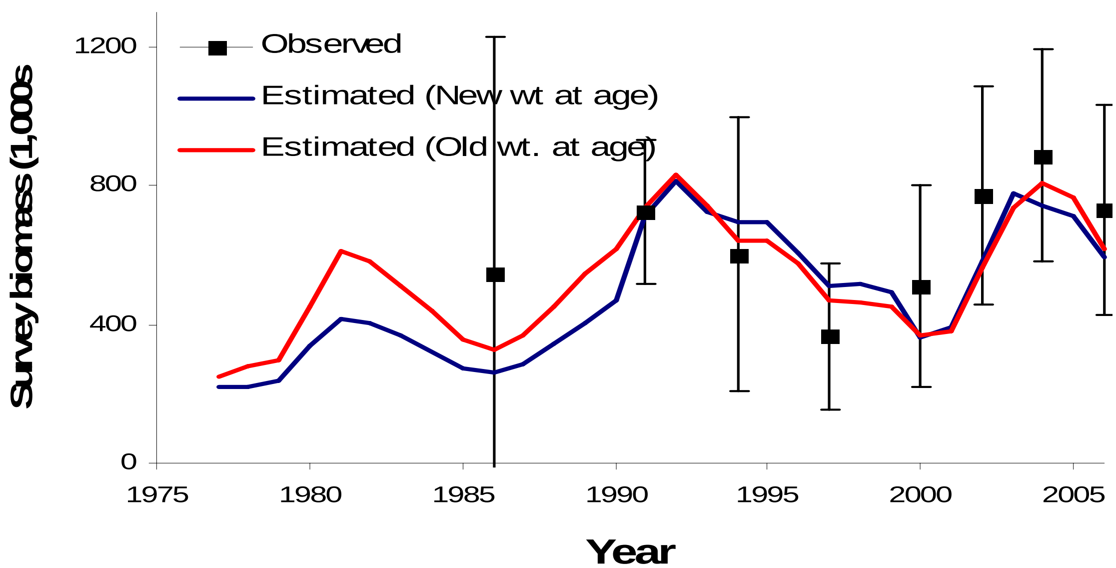


Figure 15.11. Observed and predicted survey biomass estimates for Aleutian Islands Atka mackerel. The estimated trends are results of two Model 4 runs, with (New wt at age) and without (Old wt at age) the updated year-specific weight-at-age values. Error bars represent two standard errors (based on sampling) from the survey estimates.

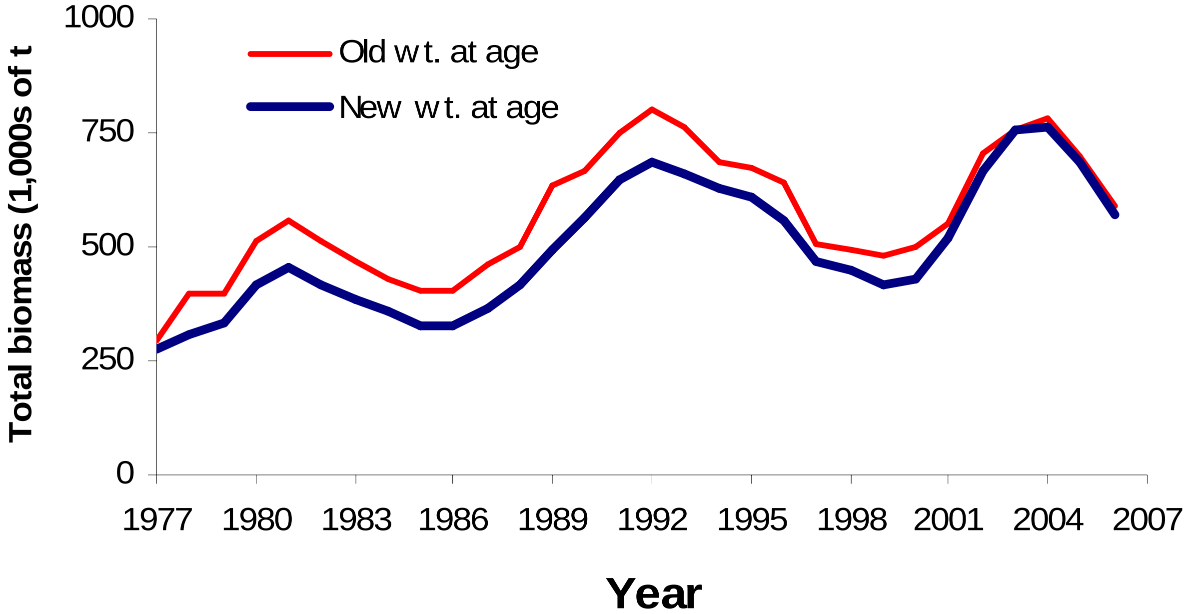


Figure 15.12. Time series of Aleutian Islands Atka mackerel total (age 1+) biomass estimates based on two Model 4 runs with (New wt. at age) and without (Old wt. at age) the updated year-specific weight-at-age values.

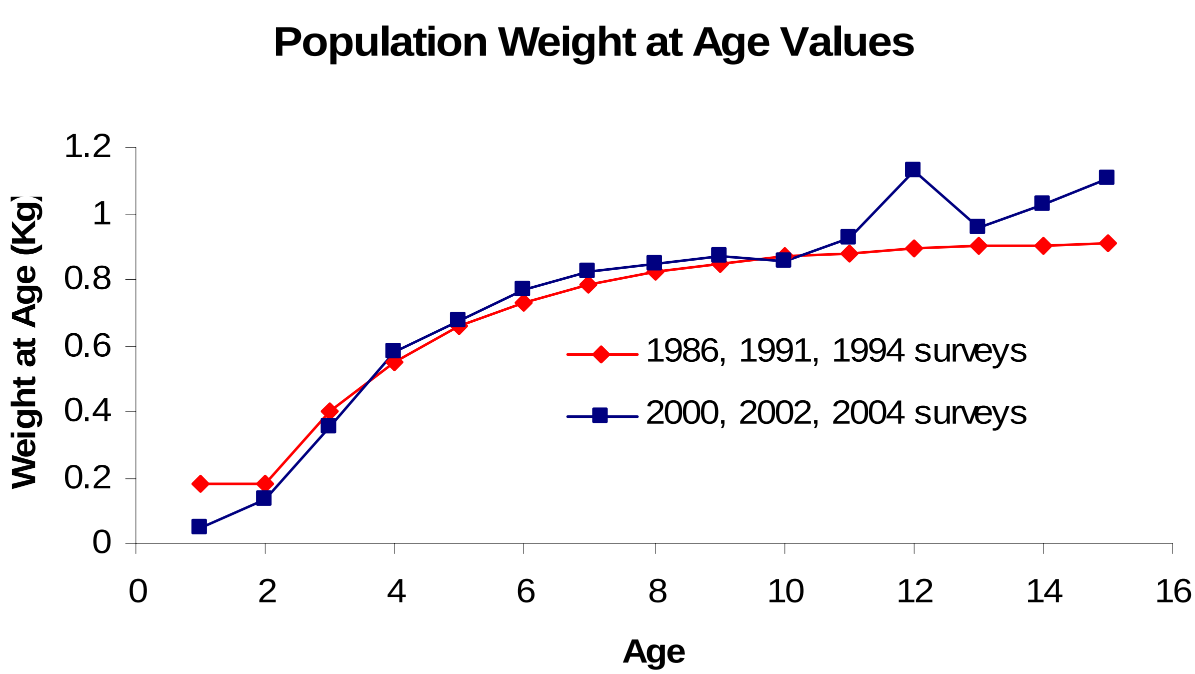


Figure 15.13. Population weight-at-age values used in last year’s assessment (based on the 1986, 1991, and 1994 surveys), and the updated population weight-at-age values used in the current assessment (based on the 2000, 2002, and 2004 surveys).

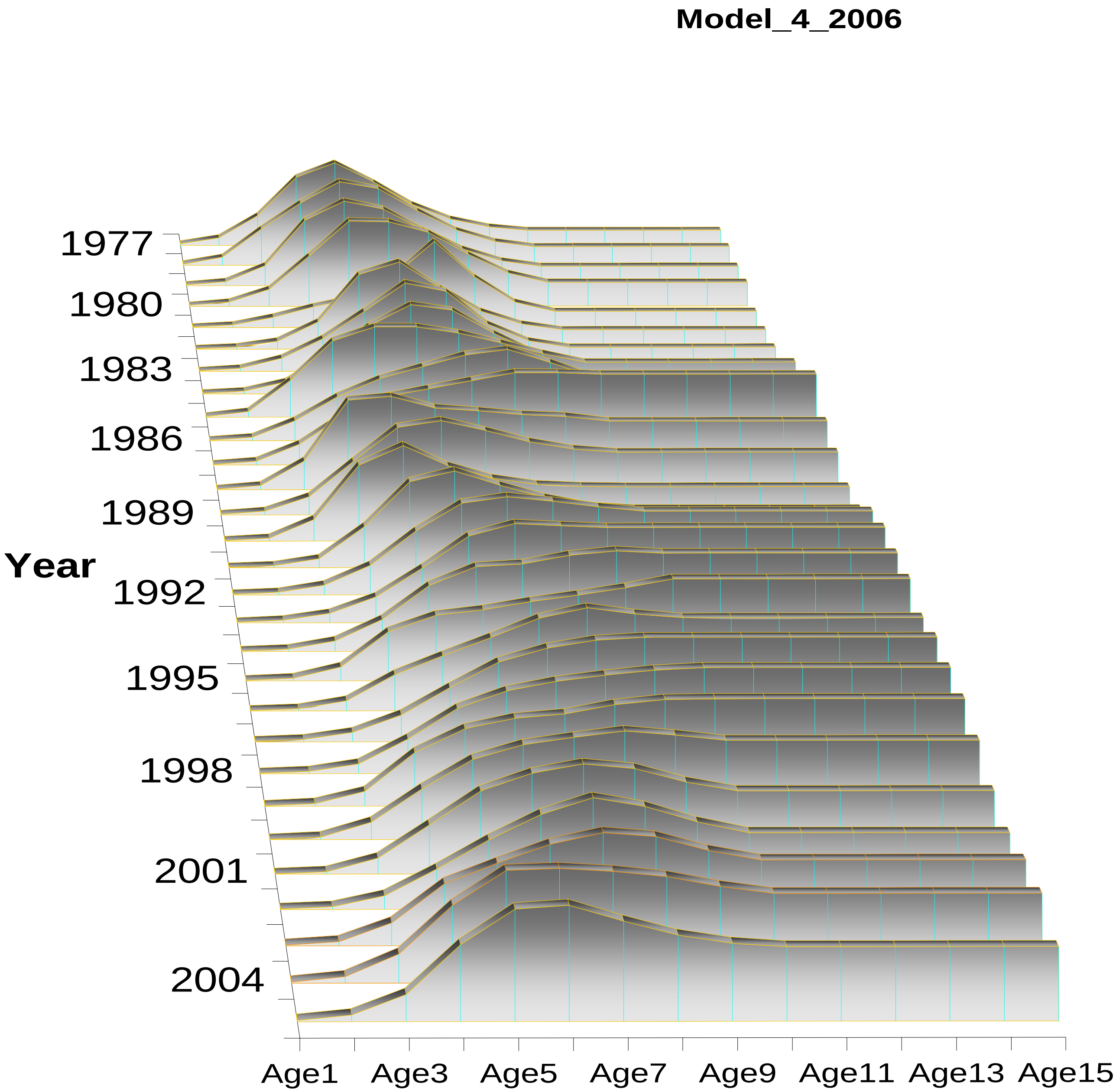


Figure 15.14. Estimated annual Atka mackerel fishery selectivity-at-age patterns.

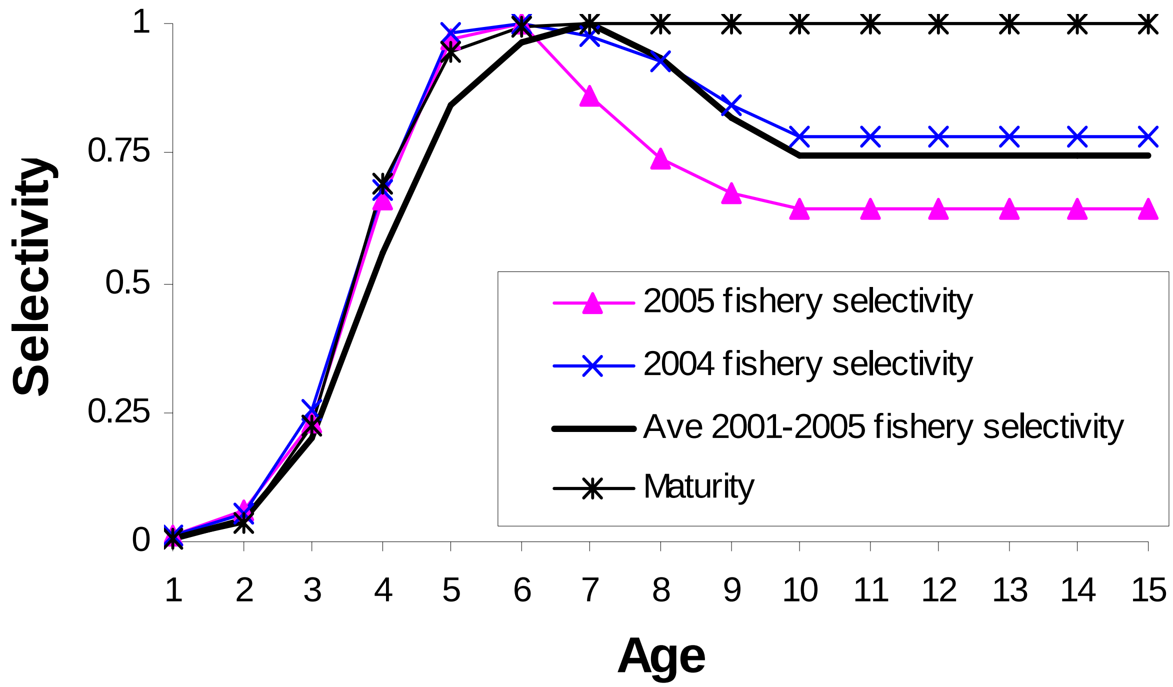


Figure 15.15. Estimated 2004, 2005, and the average of the 2001-2005 selectivity-at-age patterns compared with the maturity-at-age estimates for Atka mackerel.

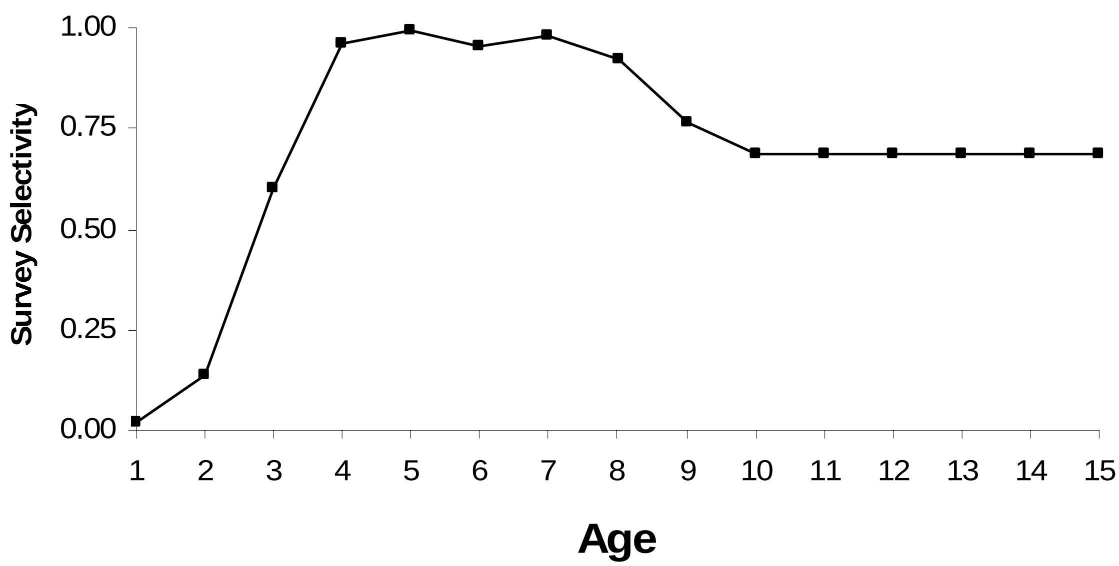


Figure 15.16. Estimated Atka mackerel survey selectivity-at-age.

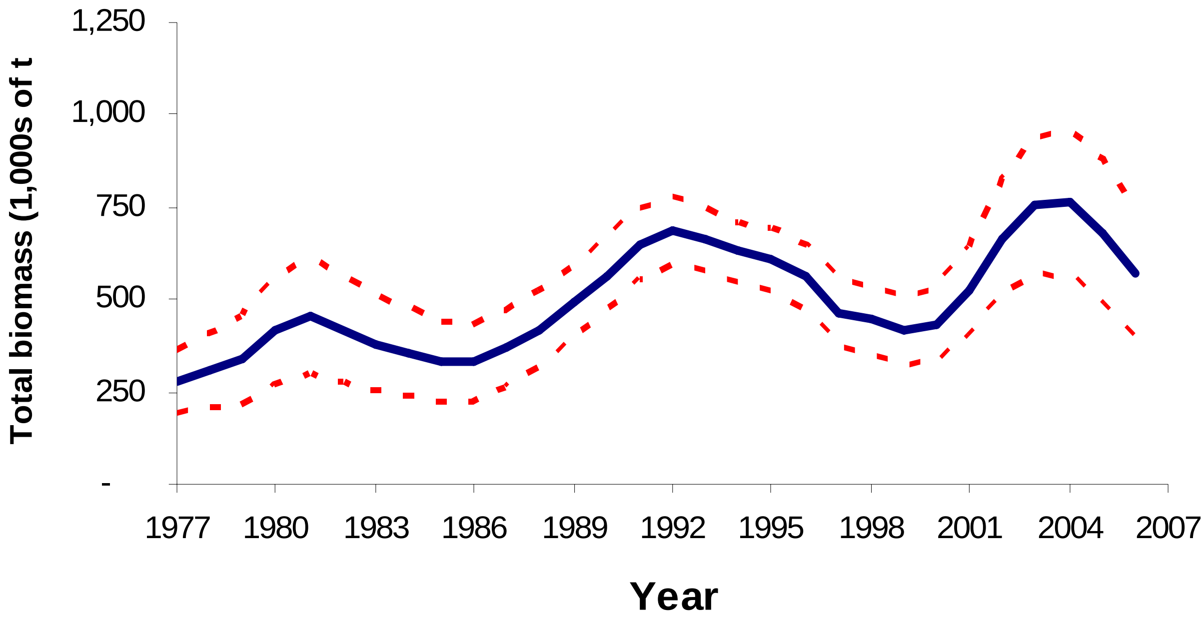


Figure 15.17. Time series of Atka mackerel total (age 1+) biomass estimates and approximate 95% confidence bounds.

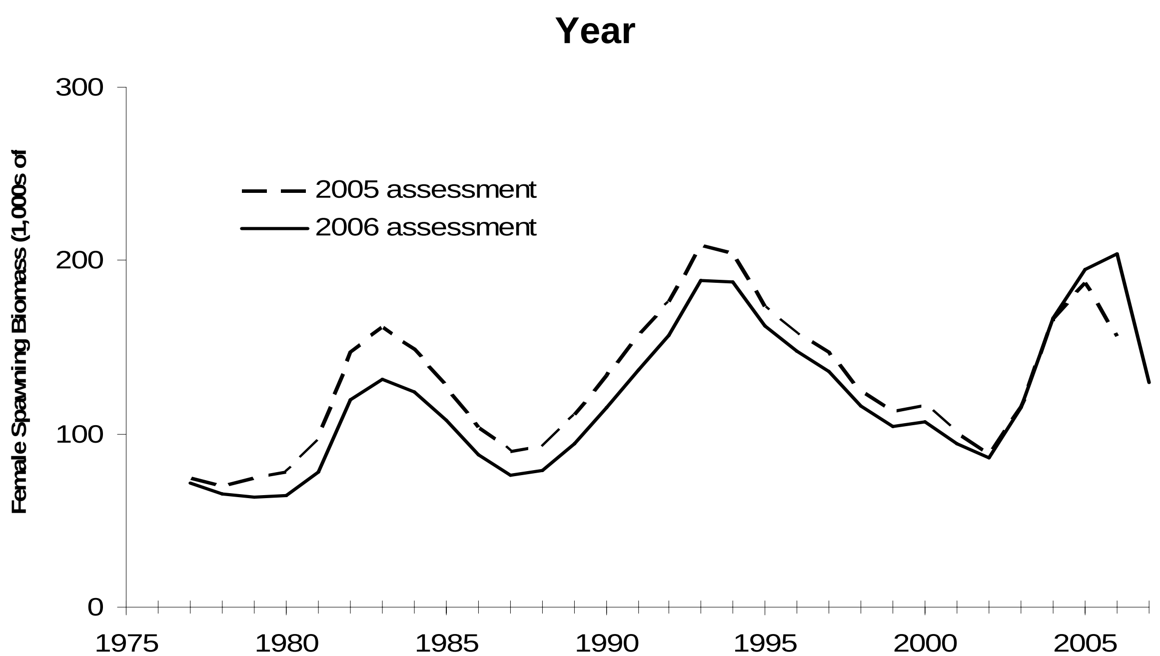


Figure 15.18. Comparison of the 2005 assessment (Lowe et al. 2005) of BSAI Atka mackerel female spawning biomass to the current estimate.

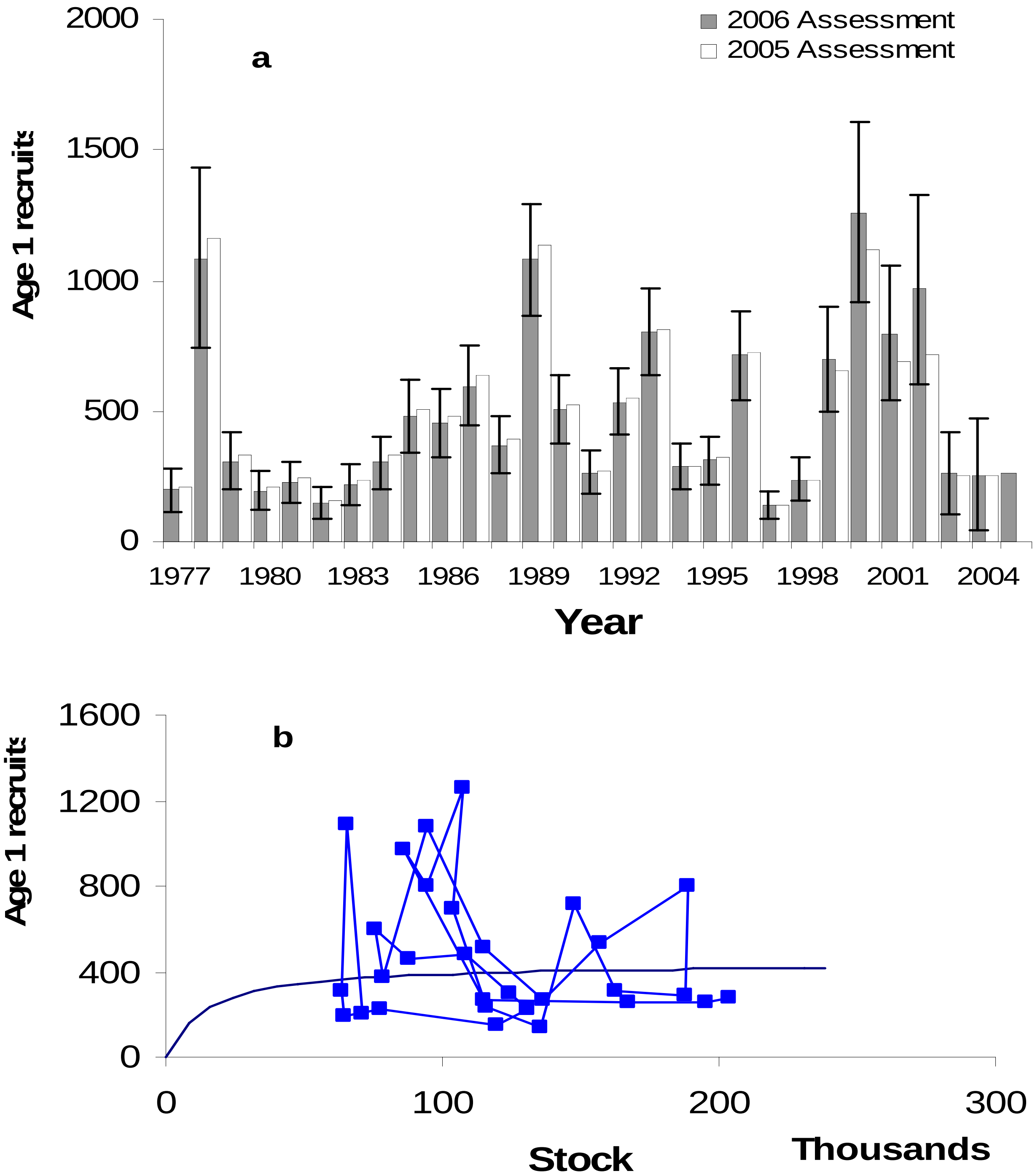


Figure 15.19 a) Age 1 recruitment of Atka mackerel as estimated from the current assessment, with error bars representing two standard errors (top panel), and b) estimated female spawning biomass levels (lower panel). Solid line represents the underlying Beverton-Holt stock recruitment curve assumed in the model.

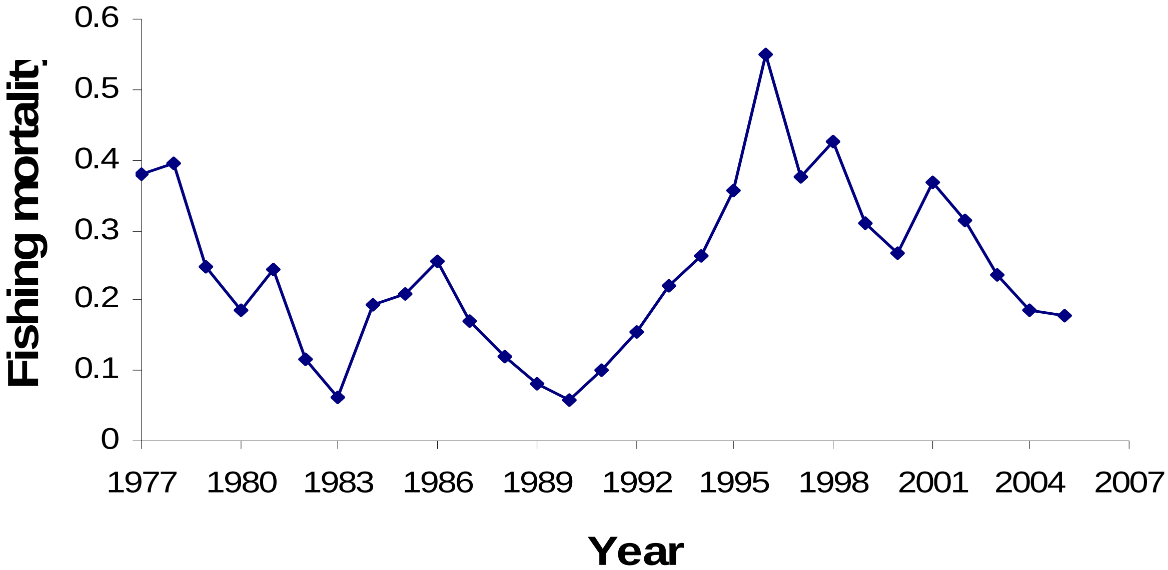


Figure 15.20. Estimated time series of full-selection fishing mortality rates of Atka mackerel, 1977-2005.

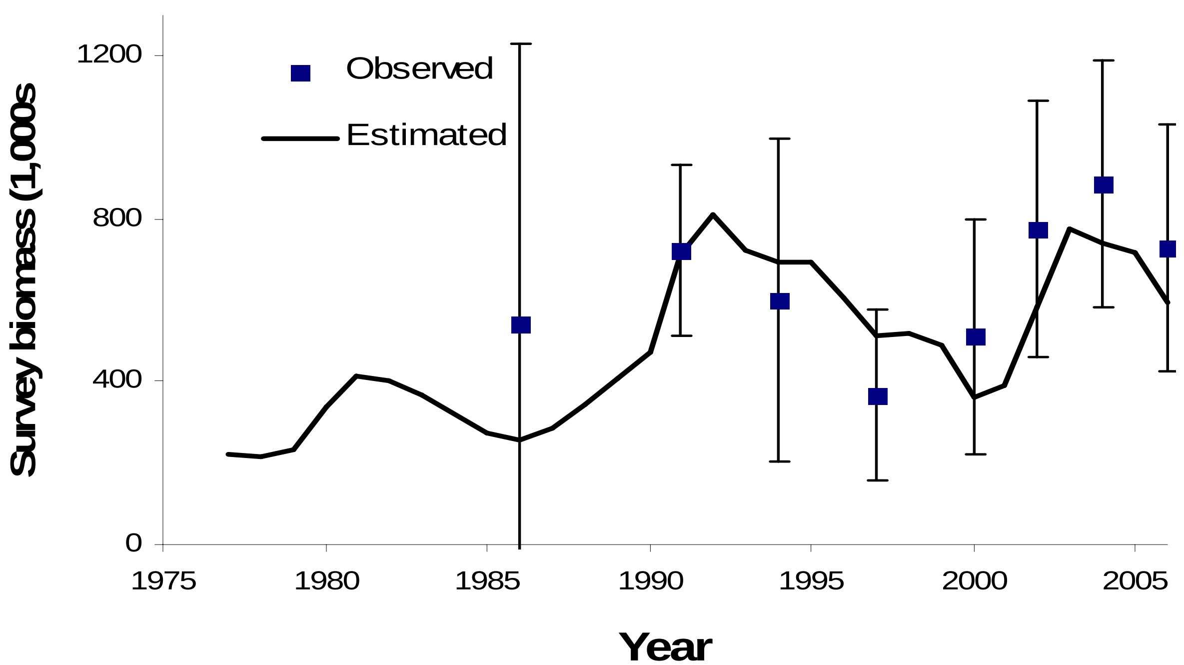


Figure 15.21. Observed and predicted survey biomass estimates for Aleutian Islands Atka mackerel. Error bars represent two standard errors (based on sampling) from the survey estimates.

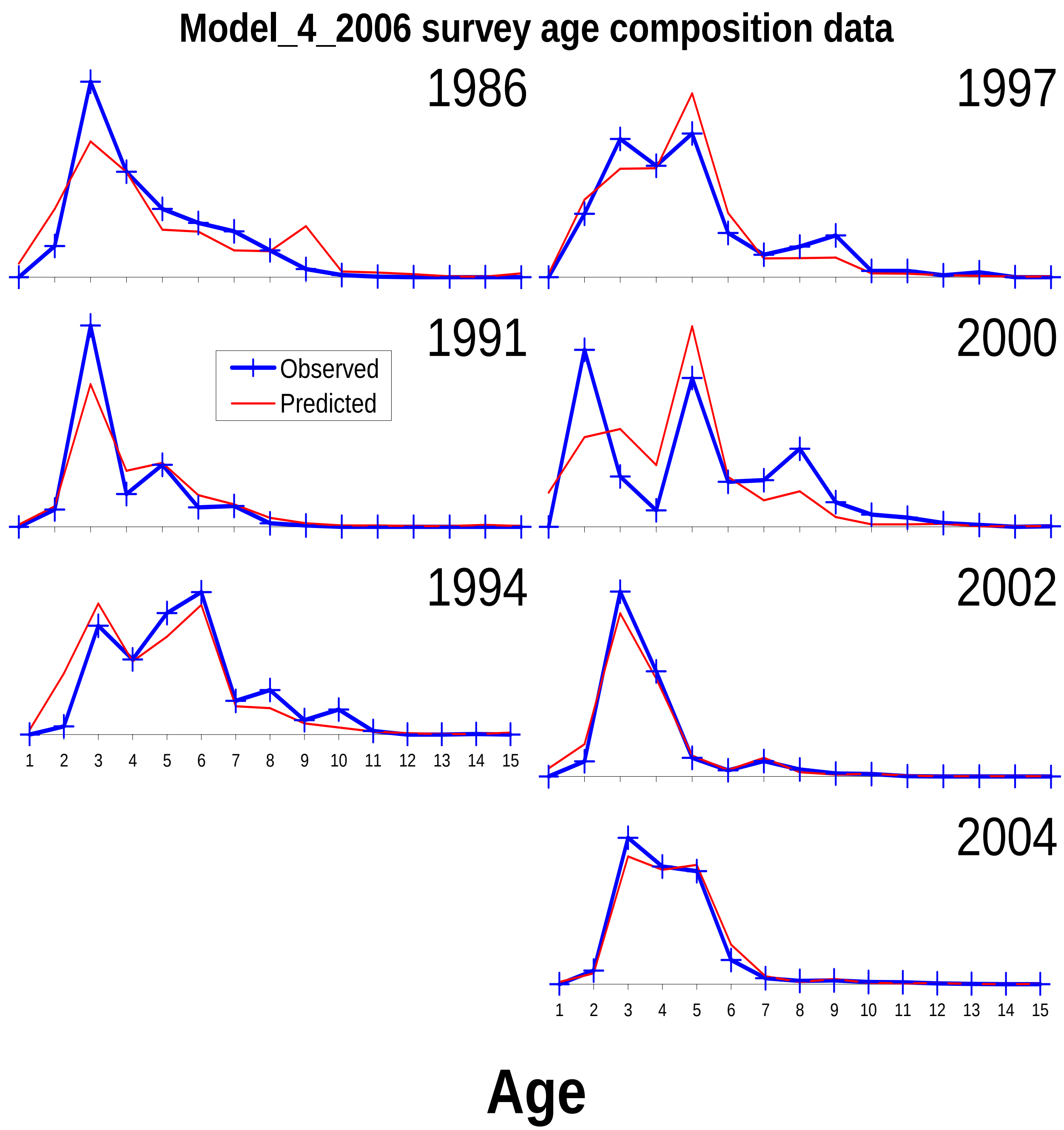


Figure 15.22. Observed and predicted proportions-at-age for Atka mackerel. Continuous lines are the model predictions and lines with "+" symbols are the observed proportions at age.

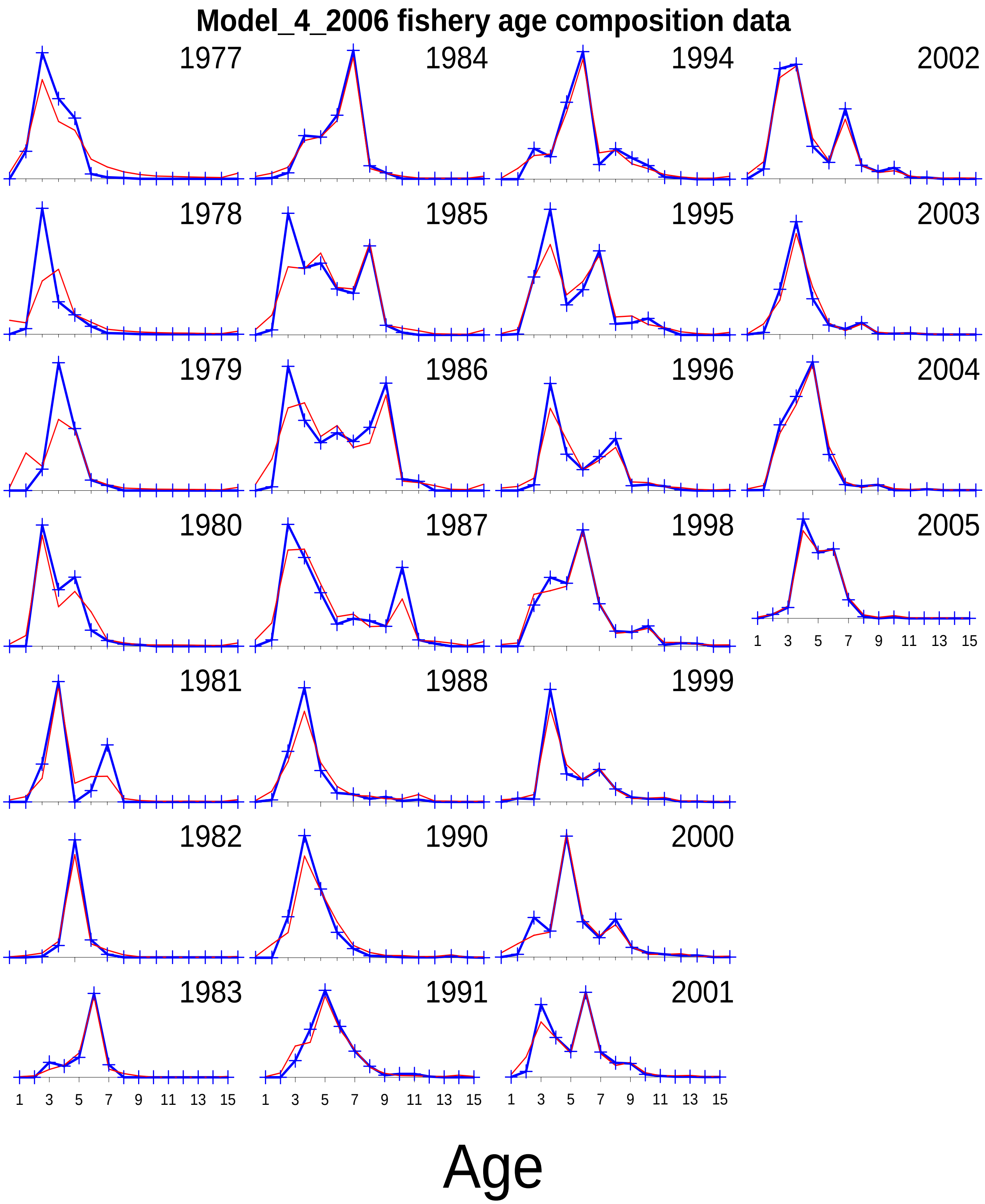
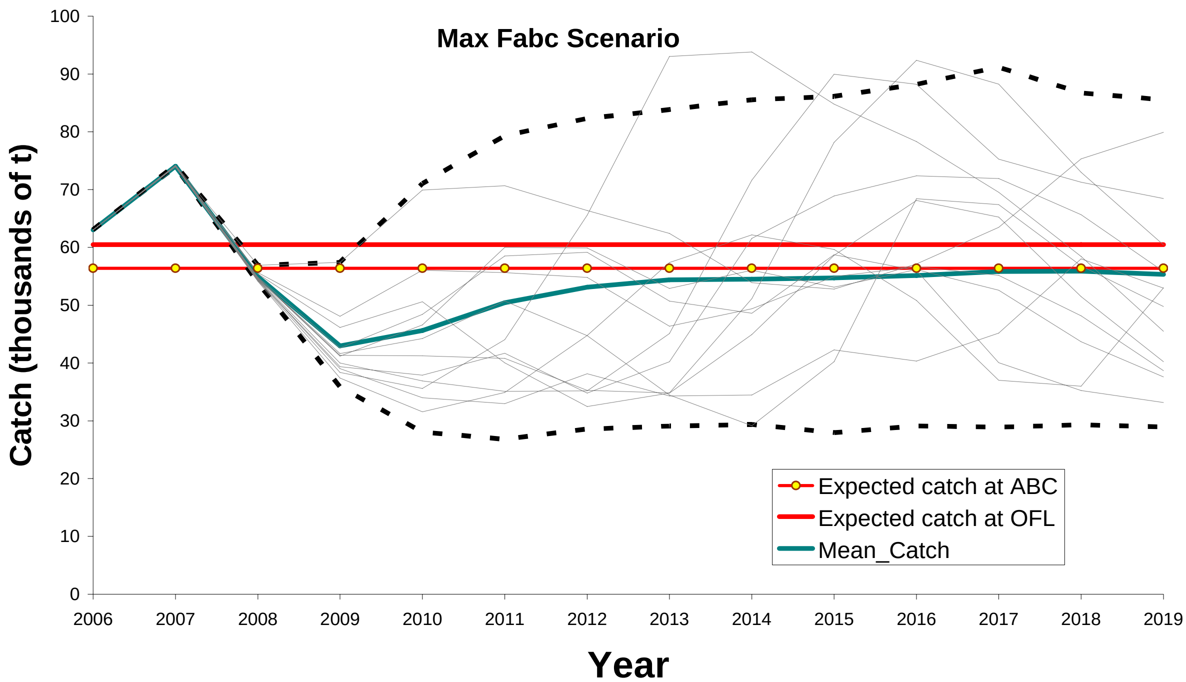


Figure 15.23. Observed and predicted Atka mackerel proportions-at-age for fishery data. Continuous lines are the model predictions and lines with "+" symbol are the observed proportions at age.



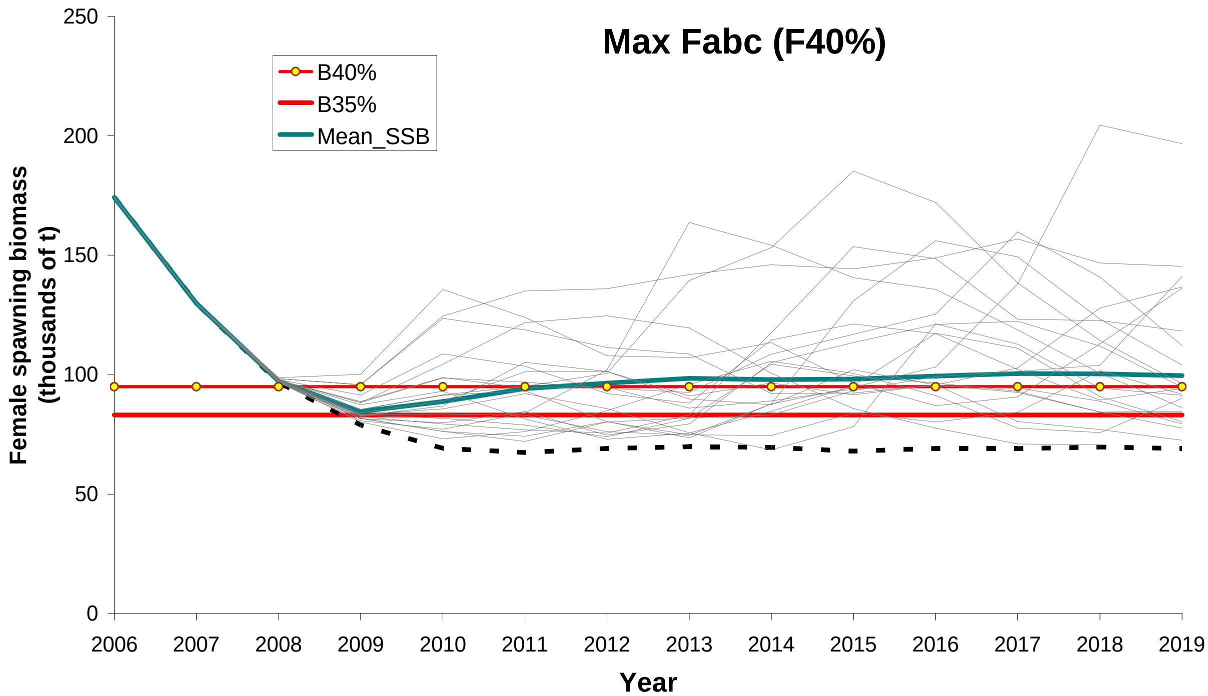


Figure 15.24. Projected catch in (top) and spawning biomass (bottom) under maximum permissible Tier 3a harvest levels. The individual thin lines represent samples of simulated trajectories.

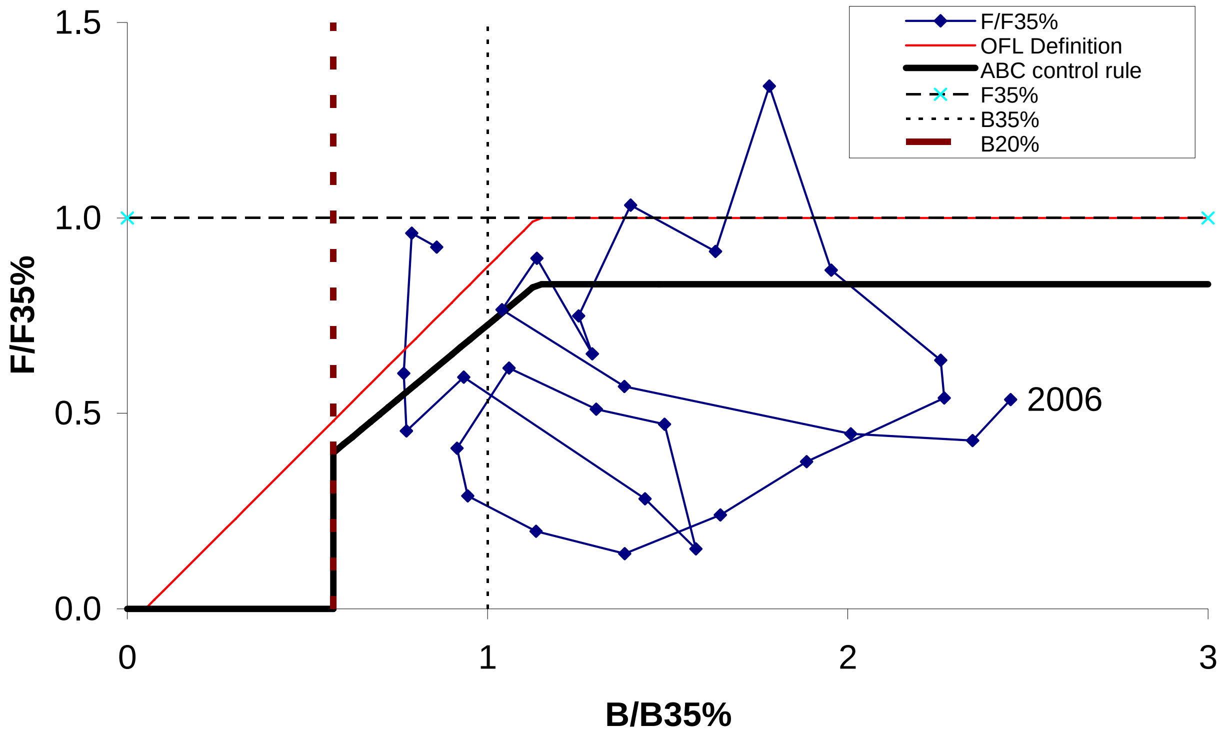


Figure 15.25. Aleutian Islands Atka mackerel spawning biomass relative to $B_{35\%}$ and fishing mortality relative to F_{OFL} (1977-2006). The ratio of fishing mortality to F_{OFL} is calculated using the estimated selectivity pattern in that year. Estimates of spawning biomass and $B_{35\%}$ are based 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.

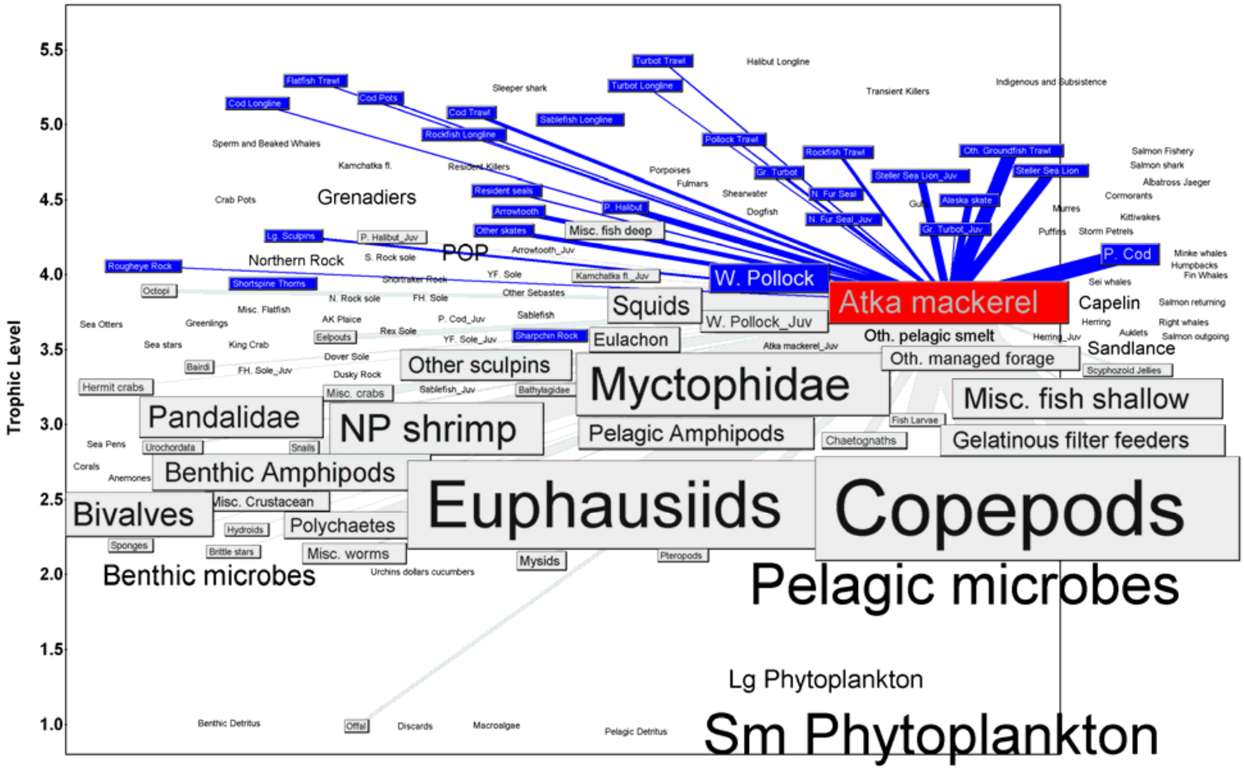
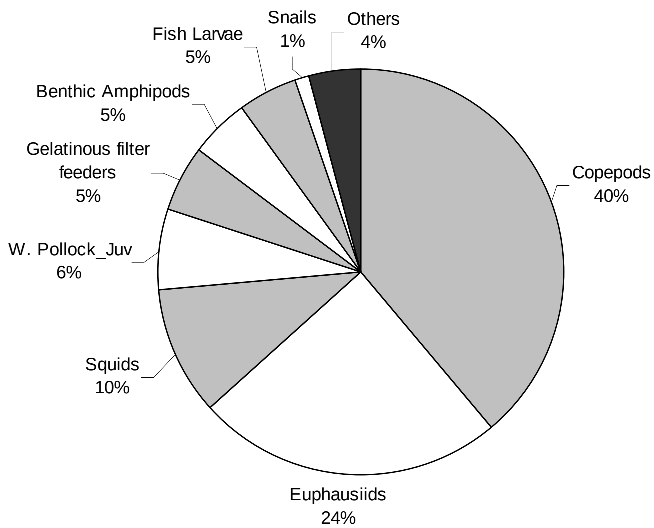


Figure 15.26. The food web of the Aleutian Islands survey region, 1990-1994, emphasizing the position of age 1+ Atka mackerel. Outlined species represent predators of Atka mackerel (dark boxed with light text) and prey of Atka mackerel (light boxes with dark text). Box and text size are proportional to each species' standing stock biomass, while line widths are proportional to the consumption between boxes (mt/year). Trophic levels of individual species may be staggered up to +/-0.5 of a trophic level for visibility.

(A)



(B)

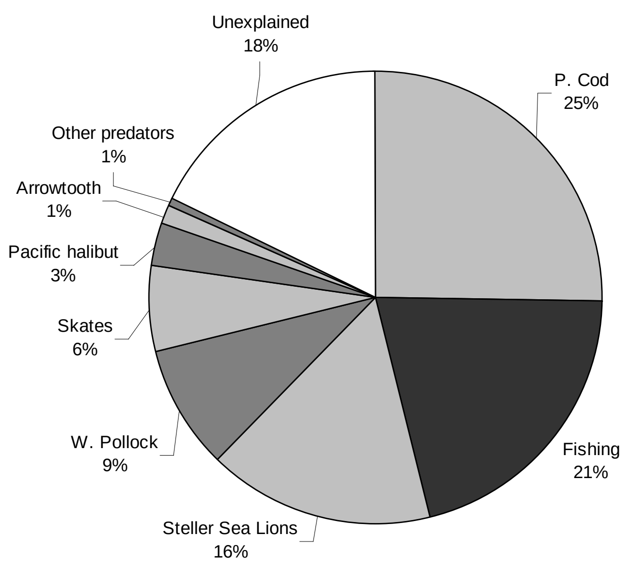


Figure 15.27. (A) Diet of age 1+ Atka mackerel, 1990-1994, by percentage wet weight in diet weighted by age-specific consumption rates. (B) Percentage mortality of Atka mackerel by mortality source, 1990-1994. “Unexplained” mortality is the difference between the stock assessment total exploitation rate 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.

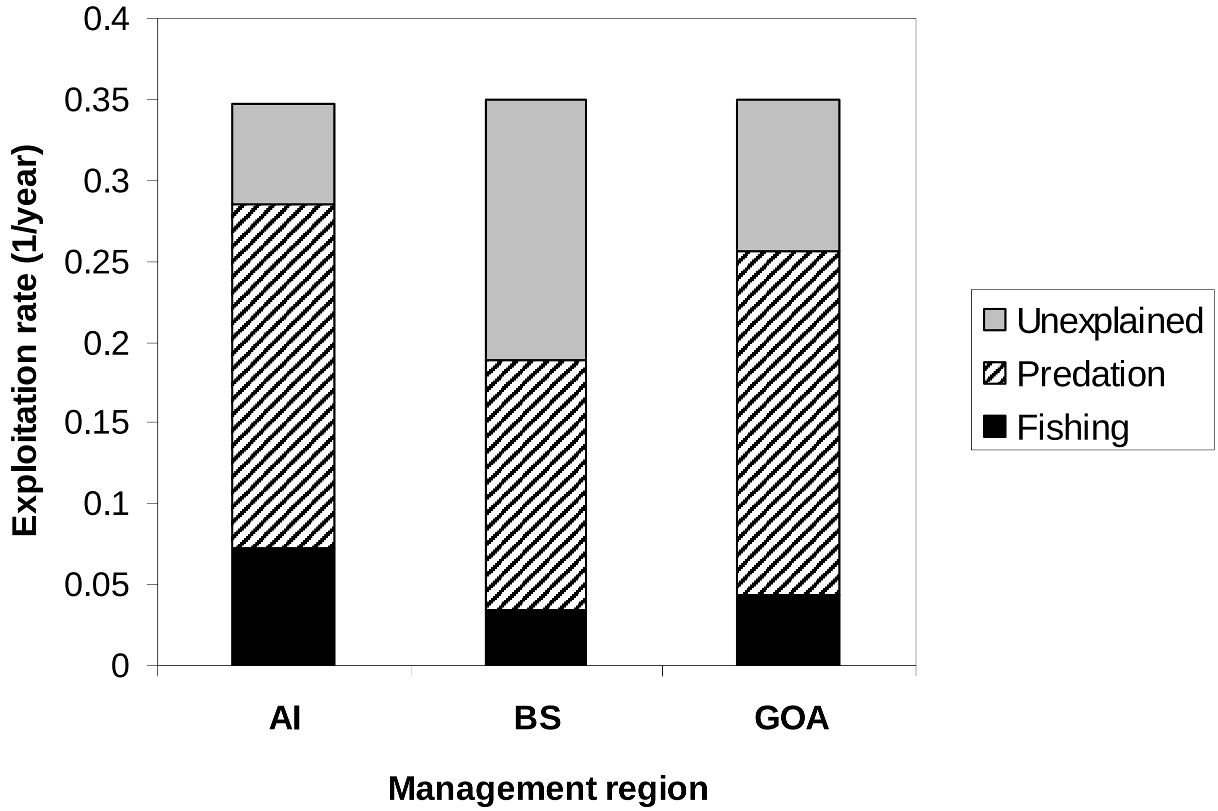


Figure 15.28. Total exploitation rate of age 1+ Atka mackerel, 1990-1994, proportioned into exploitation by fishing (black), predation (striped) and "unexplained" mortality (grey). "Unexplained" mortality is the difference between the stock assessment total exploitation rate averaged for 1990-1994, and 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, …., 2004}		i
Age index: j = {1, 2, 3, …, 14, 15^+}	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	Stock-recruitment variance
Estimated parameters		
$\phi_i(26),\ R_0,\ h,\ \varepsilon_i(41), \sigma_R^2,\ \mu^f,\ \mu^s,\ M,\ \eta_j^s(14),\ \eta_j^f c(14), F_{50\%}, F_{40\%}, F_{30\%}, q^s$		

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	$\hat{Y}_i^s = q_i^s \sum_{j=1}^{15^+} s_j^s W_{ij} e^{Z_{i,j}\frac{7}{12}} N_{ij}$
Catch biomass by year	C_i	$\hat{C}_i = \sum_j W_{ij} N_{ij} \frac{F_{ij}}{Z_{ij}} \left(1 - e^{-Z_{ij}}\right)$
Proportion at age j, in year i	$P_{ij}, \; \sum_{j=1}^{15} P_{ij} = 1.0$	$P_{ij} = \frac{N_{ij} s_{ij}^f}{\sum_{k=1}^{15} N_{ik} s_{ik}^f}$
Initial numbers at age	$j = 1$	$N_{1977,1} = e^{\mu_R + \varepsilon_{1977}}$
	$1 < j < 15$	$N_{1977,j} = e^{\mu_R + \varepsilon_{1978-j}} \prod_{j=1}^{j} e^{-M}$
	$j = 15^+$	$N_{1977,15} = N_{1977,14} \left(1 - e^{-M}\right)^{-1}$
Subsequent years ($i > 1977$)	$j = 1$	$N_{i,1} = e^{\mu_R + \varepsilon_i}$
	$1 < j < 15$	$N_{i,j} = N_{i-1,j-1} e^{-Z_{i-1,j-1}}$
	$j = 15^+$	$N_{i,15^+} = N_{i-1,14}\, e^{-Z_{i-1,14}} + N_{i-1,15}\, e^{-Z_{i-1,15}}$
Year effect, i = 1963, …, 2004	$\varepsilon_i, \; \sum_{i=1963}^{2006} \varepsilon_i = 0$	$N_{i,1} = e^{\mu_R + \varepsilon_i}$
Index catchability Mean effect	μ^s, μ^f	$q_i^s = e^{\mu^s}$
Age effect	$\eta_j^s, \; \sum_{j=1}^{15^+} \eta_j^s = 0$	$s_j^s = e^{\eta_j^s}$ $\quad j \le$ maxage $s_j^s = e^{\eta_{\text{maxage}}^s}$ $\quad j >$ 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	$\phi_i, \; \sum_{i=1977}^{2006} \phi_i = 0$	
age effect of fishing (regularized) In year time variation allowed	$\eta_{ij}^f, \; \sum_{j=1}^{15^+} \eta_{ij} = 0$	$s_{ij}^f = e^{\eta_j^f}$, $\quad j \le$ maxage $s_{ij}^f = e^{\eta_{\text{maxage}}^f}$ $\quad j >$ maxage
In years where selectivity is constant over time	$\eta_{i,j}^f = \eta_{i-1,j}^f$	$i \ne$ 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 $B_0 = \tilde{R}_0 \varphi$ $\varphi = \frac{e^{-15M} W_{15} p_{15}}{1 - e^{-M}} + \sum_{j=1}^{15} e^{-M(j-1)} W_j p_j$

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	$L_2 = \sum_l \lambda_2^l \sum_{j=1}^{15^+} \left(\eta_{j+2}^l + \eta_j^l - 2\eta_{j+1}^l \right)^2$	Smoothness (second differencing), Note: *l={s,* or *f}* for survey and fishery selectivity
Prior on recruitment regularity	$L_3 = \lambda_3 \sum_{i=1963}^{2006} \varepsilon_i^2$	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	$L_4 = \lambda_4 \sum_{i=1977}^{2006} \ln\left(C_i \big/ \hat{C}_i \right)^2$	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	$L_6 = \lambda_6 \sum_{i=1977}^{2006} \phi_i^2$	(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	$\dot{L} = \sum_{i=1}^{7} L_i$	