15. Stock Assessment of Aleutian Islands Atka Mackerel

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Executive Summary

Summary of Major Changes
Relative to the November 2006 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 was set equal to ABC.
2. The 2006 fishery age composition data were included.
3. Age data from the 2006 Aleutian Islands bottom trawl survey were included.
4. 2006 fishery and survey weight-at-age values were utilized.
5. Updated population weight-at-age values were incorporated which included age data from the 2006 survey.
6. The years used to compute an average selectivity vector for projections was updated from 2001-2005 to 2002-2006.
7. A report titled *The association between surface temperature and the occurrence of juvenile Atka mackerel (Pleurogrammus monopterygius) in the Eastern Bering Sea*, is appended to the stock assessment.

Changes in the Assessment Methodology

There were no changes in the assessment model methodology.

Changes in Assessment Results

8. The mean recruitment (1978-2006) from the stochastic projections is 493 thousand recruits (up 0.2% from last year's mean estimate for 1978-2005), which gives an estimated $B_{40\%}$ level of 94,100 t and an estimated $B_{35\%}$ level of 82,300 t, down about 1% from last year's estimates of $B_{40\%}$ and $B_{35\%}$.
9. The projected female spawning biomass for 2008 under an $F_{40\%}$ harvest strategy is estimated at 110,200 t which is 47% of unfished spawning biomass and above $B_{40\%}$ (94,100 t), thereby placing BSAI Atka mackerel in Tier 3a. The 2008 estimate of spawning biomass is down about 15% from last year's estimate for 2007. These results are consistent with the survey trend estimate (18% decline in 2006 relative to 2004).
10. The projected age 3+ biomass at the beginning of 2008 is estimated at 323,400 t, down about 11% from last year's estimate for 2007. There is less of a decrease in projected biomass in this year's assessment relative to last year's projections. This is probably due to large increases in the magnitude of recent year classes.
11. The addition of the 2006 fishery and survey age compositions impacted the estimated magnitude of the 1999, 2001-2004 year classes. The current assessment's estimates of the 1999, 2003, and 2004 year classes increased 8, 46, and 68%, respectively. While the magnitude of the 2001 and 2002 year classes decreased 13, and 34%, respectively, relative to last year's assessment.
12. The 2002-2006 average fishery selectivity pattern used in projections is very similar to last year's average selectivity for the years 2001-2005. The slight changes in selectivity for ages 7+ result in a 3% decrease in this year's estimates of $F_{40\%}$ and $F_{35\%}$ relative to last year's estimates.
13. The projected 2008 yield at $F_{40\%}$= 0.331 is 60,700 t, down about 18% from last year's estimate for 2007.

14. The projected 2008 overfishing level at $F_{35\%}$ (F = 0.398) is 71,400 t, down about 18% from last year's estimate for 2007.

Responses to comments by the Scientific and Statistical Committee (SSC)
Comments Specific to the Atka Mackerel Assessment
There were no comments specific to the Atka mackerel assessment from the December 2006 SSC minutes that required a response.

SSC Comments on Assessments in General
There were no comments on assessments in general from the December 2006 minutes that were directed to assessment authors.

15.1 Introduction

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

Distribution
Atka mackerel (*Pleurogrammus monopterygius*) are 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.* 2007). Water temperatures below 3°C and above 15°C can be lethal to developing embryos (Gorbunova 1962). Incubation times for developing eggs range from 44 days at a water temperature of 9.85° to 100 days at 3.89°C (Lauth *et al*. in press). Descriptions from a complete embryonic development series for eggs incubated at 6.2°C is found in Lauth and Blood (in press). Larvae hatch from October to January with maximum hatching in late November (Lauth *et al.* in press). Hatched larvae are neustonic and are about 10 mm in length (Kendall and Dunn 1985). Along the outer shelf and slope of Kodiak Island, the mean length of larvae increased from 10.3 mm in the fall to 17.6 mm the following spring (Kendall and Dunn 1985). Larvae can be carried great distances to offshore waters (Gorbunova 1962).

The Bering-Aleutian Salmon International Survey (BASIS) project studies salmon during their time at the high seas, and has conducted detailed surveys of the upper pelagic layer in the Bering Sea from 2004 to 2006. In addition to collecting data pertaining to salmon species BASIS has also collected and recorded information for many other Alaskan fish species, including juvenile Atka mackerel. Appendix B (Wetzel and McDermott, this document) examines the distribution of juvenile Atka mackerel in the eastern Bering Sea sampled by the BASIS project, exploring possible relationships between temperature and Atka mackerel abundance along with community composition based upon the presence or absence of Atka mackerel.

Reproductive ecology
Atka mackerel 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*). In early June, reproductively mature males begin aggregating and establishing territories in nesting colonies (Lauth *et al.* in press). Atka mackerel nesting colonies are widespread across the continental shelf of the Aleutian Islands and GOA and they are invariably located on rocky shelf substrates in areas with moderate or strong current (Lauth *et al.* 2007). Historical data from the outer shelf and slope of Kodiak in the 1970's and 1980's (Kendall and Dunn 1985, Ronholt 1989) suggest that past nesting grounds may have extended further east into the central Gulf of Alaska than the present known geographical range (Lauth *et al.* 2007). Evidence of Atka mackerel spawning and nesting has been observed as shallow as 10 m (Gorbunova 1962) and as deep as 144 m (Lauth *et al.* 2007). Possible factors limiting the upper and lower depth limit of Atka mackerel spawning and nesting include temperature, light penetration, wave surge, and high densities of kelp and green sea urchins (Gorbunova 1962, Lauth *et al.* 2007, Zolotov 1993). The second phase of the mating period is spawning, which begins in July and lasts through October (Lauth *et al.* in press). Female Atka mackerel spawn an average of 4.6 separate batches of eggs during the 12-week spawning period (McDermott *et al.* 2007). After spawning ends, territorial males with nests continue to brood egg masses until eggs hatch. The male brooding period can increase substantially with longer incubation periods caused by lower water temperatures so that the combined mating and brooding period can last up to 7 months at some nesting sites (Lauth *et al.* in press).

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

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 a consistent pattern of differentiation. Examination of these results over time (2004, 2006) showed temporal stability in Stalemate Bank but not at Seguam Pass. 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 populations of Atka mackerel should be managed as a unit stock or separate populations given that there is a lack of consistent genetic stock structure over the species range. There are significant differences in population size, distribution, recruitment patterns, and resilience to fishing suggesting that management as separate stocks is appropriate. Bottom trawl surveys and fishery data suggest that the Atka mackerel population in the GOA is smaller and much more patchily distributed than that in the AI, and composed almost entirely of fish >30 cm in length. There are also more areas of moderate Atka mackerel density in the AI than in the GOA. The lack of small fish in the GOA suggests that Atka mackerel recruit to that region differently than in the AI. Nesting sites have been located in the Gulf of Alaska in the Shumagin Islands (Lauth *et al.* in press), and historical ichthyoplankton data from the 1970's around Kodiak Island indicate there was a spawning and nesting population even further to the east (Kendall and Dunn 1985), but the source of these spawning populations is unknown. They may be migrant fish from strong year classes in the Aleutian Islands or a self-perpetuating population in the Gulf, or some combination of the two. The idea that the western GOA is the eastern extent of their geographic range might also explain the greater sensitivity to fishing depletion in the GOA as reflected by the history of the GOA fishery since the early 1970s. Catches of Atka mackerel from the GOA peaked in 1975 at about 27,000 t. Recruitment to the AI population was low from 1980-1985, and catches in the GOA declined to 0 in 1986. Only after a series of large year classes recruited to the AI region in the late 1980s, did the population and fishery reestablish in the GOA beginning in the early 1990s. After passage of these year classes through the population, the GOA population, as sampled in the 1996 and 1999 GOA bottom trawl surveys, has declined and is very patchy in its distribution. Most recently, the strong 1998 and 1999 year classes documented in the Aleutian Islands showed up in the Gulf of Alaska. Leslie depletion analyses using historical AI and GOA fishery data suggest that catchability increased from one year to the next in the GOA fished areas, but remained the same in the AI areas (Lowe and Fritz 1996; 1997). These differences in population resilience, size, distribution, and recruitment support separate assessments and management of the GOA and AI stocks and a conservative approach to management of the GOA portion of the population.

Management units
Amendment 28 to the Bering Sea/Aleutian Islands (BSAI) Fishery Management Plan became effective in mid-1993, and divided the Aleutian subarea into three districts at 177°W and 177°E for the purposes of spatially apportioning TACs. Since 1994, the BSAI Atka mackerel TAC has been allocated to the three regions (541 Eastern Aleutians, 542 Central Aleutians, 543 Western Aleutians) based on the average distribution of biomass estimated from the Aleutian Islands bottom trawl surveys.

15.2 Fishery

15.2.1 Catch history

Annual catches of Atka mackerel in the eastern Bering Sea (EBS) and Aleutian Islands (AI) regions increased during the 1970s reaching an initial peak of over 24,000 t in 1978 (see BSAI SAFE Table 3). Atka mackerel became a reported species group in the BSAI Fishery Management Plan in 1978. Catches (including discards and community development quota [CDQ] catches) 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. Total landings declined from 1980-1983 primarily due to changes in target species and allocations to various nations rather than changes in stock abundance. Catches increased quickly thereafter, and from 1985-1987 Atka mackerel catches averaged 34,000 t annually, dropping to a low of 18,000 t in 1989. The last joint venture allocation of Atka mackerel off Alaska was in 1989, and since 1990, all Atka mackerel landings have been made by U.S. fishermen.

Beginning in 1992, TACs increased steadily in response to evidence of a large exploitable biomass, particularly in the central and western Aleutian Islands.

15.2.2 Description of the Directed Fishery

The patterns of the Atka mackerel fishery generally reflect the behavior of the species: (1) the fishery is highly localized and usually occurs in the same few locations each year; (2) the schooling semi-pelagic nature of the species makes it particularly susceptible to trawl gear fished on the bottom; and (3) trawling occurs almost exclusively at depths less than 200 m. In the early 1970s, most Atka mackerel catches were in the western Aleutian Islands (west of 180°W longitude). In the late 1970s and through the 1980s, fishing effort moved eastward, with the majority of landings occurring near Seguam and Amlia Islands. In 1984 and 1985 the majority of landings came from a single 1/2° latitude by 1° longitude block bounded by 52°30'N, 53°N, 172°W, and 173°W in Seguam Pass (73% in 1984, 52% in 1985). Areas fished by the Atka mackerel fishery from 1977 to 1992 are displayed in Fritz (1993). Areas of 2007 fishery operations are shown in Figure 15.1.

15.2.3 Management History

Prior to 1992, ABCs were allocated to the entire Aleutian management district with no additional spatial management. However, because of increases in the ABC beginning in 1992, the Council recognized the need to disperse fishing effort throughout the range of the stock to minimize the likelihood of localized depletions. In 1993, an initial Atka mackerel TAC of 32,000 t was caught by 11 March, almost entirely south of Seguam Island. This initial TAC release represented the amount of Atka mackerel that the Council thought could be appropriately harvested in the eastern portion of the Aleutian Islands subarea (based on the assessment for the 1993 fishery; Lowe 1992). In mid-1993, however, Amendment 28 to the Bering Sea/Aleutian Islands (BSAI) Fishery Management Plan became effective, dividing the Aleutian subarea into three districts at 177°W and 177°E for the purposes of spatially apportioning TACs (Figure 15.1). On 11 August 1993, an additional 32,000 t of Atka mackerel TAC was released to the Central (27,000 t) and Western (5,000 t) districts. Since 1994, the BSAI Atka mackerel TAC has been allocated to the three regions based on the average distribution of biomass estimated from the Aleutian Islands bottom trawl surveys.

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.

15.2.4 Bycatch and Discards

Atka mackerel are not commonly caught as bycatch in other directed Aleutian Islands fisheries. The largest amounts of discards of Atka mackerel, which are likely under-size fish, occur in the directed Atka mackerel trawl fishery. Atka mackerel are also caught as bycatch in the trawl Pacific cod and rockfish fisheries. Northern and light dusky rockfish are caught in the Aleutian Islands Atka mackerel fishery. While the 2005 and 2006 discards of northern rockfish as a total of the Atka mackerel catch were both 4%, the actual amount of northern discards accounts for a large portion of the AI northern TAC. The 2005 fishery discarded 2,717 t of northern rockfish, about 54% of the 2005 AI northern TAC. The 2006 Atka mackerel fishery discarded 2,426 t of northern rockfish which accounted for 48% of the northern TAC.

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

Year	Fishery	Discarded (mt)	Retained (mt)	Total (mt)	Discard Rate (%)
2000	Atka mackerel	2,388	43,977	46,365	5.1
	All others	201	272	473	
	All	2,589	44,249	46,838	
2001	Atka mackerel	3,832	55,744	59,567	6.4
	All others	551	1,217	1,768	
	All	4,384	56,961	61,344	
2002	Atka mackerel	7,125	36,112	43,237	16.5
	All others	239	1,205	1,443	
	All	7,364	37,317	44,680	
2003	Atka mackerel	9,209	41,994	51,203	18.0
	All others	709	1,076	1,785	
	All	9,918	43,070	52,988	
2004	Atka mackerel	6,709	45,841	52,550	12.8
	All others	448	407	855	
	All	7,157	46,248	53,405	
2005	Atka mackerel	2,403	55,359	57,762	4.2%
	All others	264	448	712	
	All	2,667	55,807	58,474	
2006	Atka mackerel	1,558	56,596	58,154	2.7%
	All others	325	232	557	
	All	1,883	56,828	58,711	

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

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.

Year		Aleutian Islands Subarea 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)	709	4,998	4,210
	Rate	11%	18%	22%
2004	Retained (mt)	3,161	26,560	16,527
	Discarded (mt)	520	3,610	3,027
	Rate	14%	12%	15%
2005	Retained (mt)	3,356	33,598	18,852
	Discarded (mt)	305	1,472	891
	Rate	8%	4%	4%
2006	Retained (mt)	4,013	38,440	14,374
	Discarded (mt)	232	1,387	263
	Rate	5%	3%	2%

15.2.5 Fishery Length Frequencies

From 1977 to 1988, commercial catches were sampled for length and age structures by the NMFS foreign fisheries observer program. There was no JV allocation of Atka mackerel in 1989, when the fishery became fully domestic. Since the domestic observer program was not in full operation until 1990, there was little opportunity to collect age and length data in 1989. Also, the 1980 and 1981 foreign observer samples were small, so these data were supplemented with length samples taken by R.O.K. fisheries personnel from their commercial landings. Data from the foreign fisheries are presented in Lowe and Fritz (1996).

Atka mackerel length distributions from the 2006 and preliminary 2007 fisheries by management area and season are shown in Figures 15.2 and 15.3, respectively. In 2006, seasonal differences were apparent in the southern Bering Sea area 519 with the A-season showing more small fish relative to the B-season. Fish sampled from 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). Too few fish were collected in the 2006 Eastern Aleutian (541) A-season). The modes at about 35-47 cm in the 2006 AI fishery length distributions represent the 2001 year class which dominated the 2006 fishery age composition, and the persistent 1999 year class (Figure 15.4). The available 2007 fishery data are presented and should be considered preliminary (Figure 15.3). Preliminary data from the 2007 Central and Western Aleutian A-season fisheries showed similar distributions to the 2006 A- and B-season distributions with modes at about 36-37 cm (Figure 15.3). It is interesting to note that the fish sampled in the 2007 A season from area 519 are significantly smaller (ranging from 37-42 cm, Figure 15.3), compared to the 2006 area 519 fish which ranged from 42-51 cm (Figure 15.2).

15.2.6 Steller Sea Lions and Atka mackerel Fishery Interactions

Since 1979, the Atka mackerel fishery has occurred largely within areas designated in 1993 as Steller sea lion critical habitat (20 nm around rookeries and major haulouts). While total removals from critical habitat may be small in relation to estimates of total Atka mackerel biomass in the Aleutian region, fishery harvest rates in localized areas may have been high enough to affect prey availability of Steller sea lions (Section 12.2.2 of Lowe and Fritz 1997). The localized pattern of fishing for Atka mackerel apparently does not affect fishing success from one year to the next since local populations in the Aleutian Islands appear to be replenished by immigration and recruitment. However, this pattern could have created temporary reductions in the size and density of localized Atka mackerel populations which may have affected Steller sea lion foraging success during the time the fishery was operating and for a period of unknown duration after the fishery closed. As a consequence, the NPFMC passed regulations in 1998 and 2001 (described above in Section 15.2.3) to disperse fishing effort temporally and spatially as well as reduce effort within Steller sea lion critical habitat.

NMFS is investigating the efficacy of trawl exclusion zones as a fishery-Steller sea lion management tool, and trying to determine the local movement rates of Atka mackerel through tagging studies. In August 1999, the AFSC conducted a pilot survey to explore the variance in survey catches of Atka mackerel and the feasibility of tagging as methods to determine small-scale changes in abundance and distribution. The tagging work was very successful and tagging surveys have been conducted near Seguam Pass (in area 541) in August 2000, 2001 and 2002 (McDermott *et al.* 2005). Results indicate that the 20 nm trawl exclusion zone around the rookeries on Seguam and Agligadak Islands is effective in minimizing disturbance to prey fields within them. The boundary of the 20 nm trawl exclusion zone at Seguam appears to occur at the approximate boundary of two naturally occurring assemblages. The movement rate between the two assemblages is small. Therefore, the results obtained here regarding the efficacy of the trawl exclusion zone may not generally apply to other, smaller zones to the west. The tagging work has been expanded and tagging was conducted inside and outside the 10 nm trawl exclusion zones in Tanaga Pass (in 2002), near Amchitka Island (in 2003) and off Kiska Island (in 2006). Movement rates at Tanaga pass and Kiska Island appear similar to those at Seguam with the trawl exclusion zones forming natural boundaries to local aggregations. Movement rates at Amchitka appear to be higher relative to Seguam (pers. comm. Elizabeth Logerwell and Susanne McDermott, AFSC). The boundaries at Amchitka bisect Atka mackerel habitat unlike Seguam and Tanaga.

15.3 Data

15.3.1 Fishery Data

Fishery data consist of total catch biomass from 1977 to 2006 and partial 2007 (Table 15.1), and the age composition of the catch from 1977-2006 (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 notable features of the estimated catch-at-age data (Table 15.2) are the strong 1975, 1977, 1999, 2000, and 2001 year classes, and the very poor showing of the 2002 year class. The 1975 year class appeared strong as 3 and 4-year-olds in 1978 and 1979. It is unclear why this year class did not continue to show up strongly after age 4. The 1977 year class appeared strong through 1987, after entering the fishery as 3-year-olds in 1980. The 2002 fishery age data showed the first appearance in the fishery of the strong 1999 year class, and the 2003 and 2004 fishery data showed the first appearance of large numbers from the 2000 and 2001 year classes, respectively. The 2006 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.

15.3.2 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 t in 1980 to 306,780 t in 1983, and 544,754 t 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 t 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 t increase over the 1983 biomass estimate for the same stratum-depth interval. The 1986 biomass estimate is associated with a large coefficient of variation (0.63). 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 t, 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 t 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 t in 2004 down to 100,693 t in 2006), despite a large increase in the Eastern area. Relative to the 2004 survey, the 2006 biomass estimates are down 73% in the Western area, up 3% in the Central area, and up 44% in the Eastern area (Figure 15.5). The 95% confidence interval about the mean total 2006 Aleutian biomass estimate is **298,858-1,159,013 t**. The coefficient of variation (*CV*) of the 2006 mean Aleutian biomass is 28% (Table 15.4).

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 t) was the lowest of all surveys, contributing only 0.2% of the total 2000 Aleutian biomass and represented a 98% decline relative to the 1997 survey. The extremely low 2000 biomass estimate for the Eastern area has not been reconciled, but there are several factors that may have had a significant impact on the distribution of Atka mackerel that were discussed in Lowe *et al.* (2001). We note that the distribution of Atka mackerel in the Eastern area is generally patchier, and up until the 2004 survey, the area-specific variances for the Eastern area have always been high relative to the Central and Western areas. Lowe *et al.* (2001) suggest that a combination of several factors coupled with the typically patchier distribution of Atka mackerel in area 541 may have impacted the distribution of the fish such that they were not available at the surveyed stations at the time of the 2000 survey.

The 2006 survey showed that the Eastern area contributed 48% of the total biomass, which is a significant increase from 27.5% of the biomass that was detected in the 2004 survey, and the largest proportion in the time series (Table 15.4).

In 1994 for the first time since the initiation of the Aleutian triennial surveys, a significant concentration of biomass was detected in the southern Bering Sea area (66,603 t). This occurred again in 1997 (95,680 t), 2002 (59,883 t), and 2004 survey (267,556 t, Table 15.4). 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 t is the largest biomass encountered in this area in the survey time series. The *CV* of the 2004 southern Bering Sea estimate is 43%, much lower than previous years as several hauls contributed to the 2004 estimate. Most recently, the 2006 survey estimated only 12,284 t of biomass (*CV*=44%) from the southern Bering Sea area.

Areas with large catches of Atka mackerel during the 2002 survey were located north of Akun Island, Seguam Pass, Tanaga Pass, south of Amchitka Island, Kiska Island, Buldir Island, and Stalemate Bank (Figure 15.6). 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 near the middle of the series for all survey years, excluding the year 2000. The average bottom temperatures measured in the 2006 survey were slightly above the 2002 survey and very similar to the 1994 survey temperatures (Figure 15.7).

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: 0.28, 0.20, 0.17, and 0.28 from the 2000, 2002, 2004, and 2006

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

Survey Length Frequencies

The 2000, 2002, and 2004 bottom trawl surveys and the fishery catch data revealed a strong east-west gradient in Atka mackerel size, with the smallest fish in the west and progressively larger fish to the east, (Figure 15.8 in Lowe *et al.* 2003, 2005). The 2006 survey length frequency distributions also 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 45 cm (Figure 15.8).

Survey Age Frequencies

The age compositions from the 2002, 2004, and 2006 Aleutian surveys are shown in Figure 15.9. 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 2006 survey still indicated large numbers from the 1999 year class and a very low number of fish from the 2002 year class. The fishery catch data also confirmed very low numbers of the 2002 year class (Table 15.2). The 2006 survey and fishery saw an unusually high number of 2 year olds from the 2004 year class (Figure 15.9 and Table 15.2). However, it is still too early to predict the strength of the 2004 year class based on numbers of 2 year olds seen in the fishery and the survey. The mean ages of the 2002, 2004, and 2006 surveys are 3.8, 4.2, and 5.3 years, respectively. The mean age in the 2002 survey (3.8 years) is the youngest mean age of any survey.

Survey Abundance Indices

A partial time series of relative indices from the 1980, 1983, 1986, and 1991 Aleutian Islands surveys had been used in the previous stock synthesis assessments (Lowe *et al.* 2001). The relative indices of abundance excluded biomass from the 1-100 m depth strata of the Southwest Aleutian Islands region (west of 180°) due to the lack of sampling in this stratum in some years. Because the excluded area and depth stratum have consistently been found to be locations of high Atka mackerel biomass in later surveys, it was determined that the indices did not provide useful additional information to the model. Analyses to determine the impact of omitting the relative time series 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.

15.4 Analytic approach

The 2002 BSAI Atka mackerel stock assessment introduced a new modeling approach implemented through the "Stock Assessment Toolbox" (an initiative by the NOAA Fisheries Office of Science and Technology) that evaluated favorably with previous assessments (Lowe *et al.* 2002). This approach used the Assessment Model for Alaska (AMAK)[1] from the Toolbox, which is similar to the stock synthesis application (Methot 1989, 1990; Fournier and Archibald 1982) used for Aleutian Islands Atka mackerel from 1991 – 2001, but allows for increased flexibility in specifying models with uncertainty in changes in fishery selectivity and other parameters such as natural mortality and survey catchability (Lowe *et al.* 2002). This approach (AMAK) has also been adopted for the Aleutian Islands (Barbeaux *et al.* 2004) and Bogoslof pollock stock assessments (Ianelli *et al.* 2005).

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

15.4.1 Model structure

The AMAK models catch-at-age with the standard Baranov catch equation. The population dynamics follows numbers-at-age over the period of catch history (here 1977-2006) 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:

Data component	Years of data	Likelihood form	*CV* or sample size
Catch biomass	1977-2006	Lognormal	*CV*=5%
Fishery catch age composition	1977-2006	Multinomial	*N*=100
Survey biomass	1986, 1991, 1994, 1997, 2001, 2004, 2006	Lognormal	*CV*=29% (average)
Survey age composition	1986, 1991, 1994, 1997, 2001, 2004, 2006	Multinomial	*N*=50

[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

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

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-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.

Year-specific weight-at-age estimates are used in the model to obtain expected catches in survey and fishery biomass (Table 15.5). 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, unpubl. manuscr.). In addition, the single vector of weight-at-age values used to derive population biomass in the model was updated. The updated population weight at age values used in the current assessment are based on the 2002, 2004, and 2006 surveys in order to allow for better estimation of current biomass (Table 15.5).

Maturity at Age and Length
Female maturity at length and age were determined for Aleutian Islands Atka mackerel (McDermott and Lowe, 1997). The age at 50% maturity is 3.6 years. Length at 50% maturity differs by area as the length at age differs by Aleutian Islands sub-areas:

	Length at 50% maturity (cm)
Eastern Aleutians (541)	35.91
Central Aleutians (542)	33.55
Western Aleutians (543)	33.64

The maturity schedules are given in Table 15.6. Work is currently underway to re-examine and update the maturity information (Cooper and McDermott 2006).

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 described in 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 ABCs and OFLs since 2004. 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. 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.

15.5 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. 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). Model 4 was determined to provide the most biologically reasonable configuration and a reasonable representation of BSAI Atka mackerel dynamics which acknowledges some uncertainty about q (Lowe *et al.* 2004, 2005, 2006) Given that we have submitted a proposal to the Center for Independent Experts (CIE) to review the Aleutian Islands Atka mackerel assessment, we again carry forward Model 4 without any significant changes in the model structure.

15.6 Model Results

The results discussed below are based on Model 4 with the updated fishery, survey, and population weight-at-age values, and the 2006 fishery and survey age compositions.

15.6.1 Selectivity

The estimated selectivity at age schedules for the fishery and survey are shown in Figures 15.10-15.12 and given in Table 15.7.

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 15.10). After 1991, fishery selectivity patterns are fairly similar with gradual transitions, particularly between the ages of 3-9. The 2005 and 2006 estimates of selectivity at age reflects the large numbers of 4, 5, 6, and 7 year old fish from the 1999, 2000, and 2001 year classes (Figure 15.10, 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 2005 and 2006 are fairly similar but do show slight differences after age 3, and are shown for comparison in Figure 15.11. The 2005 pattern reflects the large numbers of 4, 5 and 6-year olds, and the 2006 pattern reflects the large numbers of 5, 6, and 7-year olds (2001, 2000, and 1999 year classes) in the 2005 and 2006 catches. The age at 50% selectivity is estimated at about age 3.5 for both 2005 and 2006 (Figure 15.11). This is the youngest age at 50% selectivity in recent years due to the particularly strong showing of the 1999, 2000, and 2001 year classes (Tables 15.2 and 15.8). Selectivity after age 7 is lower in the 2006 fishery relative to the 2005 fishery. This is a reflection of the 2006 fishery which caught fewer numbers of fish older than age 7 relative to the 2005 fishery (Table 15.2). Fish older than age 9 make up a very small percentage of the population each year, and the differences in the selectivity assumptions for the older ages are not likely to have a large impact. However, differences in selectivity for ages 3-8 can have a significant impact. It is important to note the maturity-at-age vector which is very similar to the estimated 2005 and 2006 selectivity patterns up to age 6 (age at 50% maturity is 3.6 years, Figure 15.11). The estimated 2006 selectivity pattern indicates the current fishery is harvesting fish similarly to the 2005 fishery and in proportion to the maturity schedule. The average selectivity pattern estimated for the years 2002 to 2006 is shown for perspective (Figure 15.11).

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 15.12).

15.6.2 Abundance Trend

The estimated time series of total numbers at age are given in Table 15.9. The estimated time series of total biomass with approximate upper and lower 95% confidence limits are shown in Figure 15.13 and given in Table 15.10. For comparison, the time series of female spawning biomass from the 2006 and 2007 (current) assessments are also plotted (Figure 15.14).

A comparison of the spawning biomass trend from the current and previous assessments (Figure 15.14, Table 15.10) indicates consistent trends throughout the time series, i.e., biomass increased during the early 80s and again in the late 80s to early 90s. After the estimated peak spawning biomass in 1993, spawning biomass declined for nearly 10 years until 2002, thereafter, spawning biomass began a steep increase which continued to 2006. The decline in biomass for 2007 in the current assessment is estimated to be less than previously projected. This is largely due to the continued persistence of the 1999 year class, and increases in the estimated magnitude of recent year classes (see below).

15.6.3 Recruitment Trend

The estimated time series of age 1 recruits from the current assessment and the 2006 assessment is shown in Figure 15.15 and given in Table 15.11. The strong 1999 year class is most notable in the current assessment, followed by the 1988, 1977, and 2001 year classes. The addition of the 2006 fishery and survey age compositions impacted the estimated magnitude of the 1999, 2001-2004 year classes. The current assessment's estimates of the 1999, 2003, and 2004 year classes increased 8, 46, and 68%, respectively, while the magnitude of the 2001 and 2002 year classes decreased 13 and 34%, respectively, relative to last year's assessment (Figure 15.15). The 2006 fishery data are dominated by the 2001 year class, followed by the 1999 and 2000 year classes (Figure 15.4). The 1999 year class is estimated to be the largest year class in the time series (approximately 1.3 million recruits) due to its continued strong showing in the 2006 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 15.15).

The average estimated recruitment from the time series 1978-2006 is 493 thousand fish and the median is 373 thousand fish (Table 15.11). The entire time series of recruitments (1977-2006) includes the 1976-2005 year classes. The Alaska Fisheries Science Center has recognized that an environmental "regime shift" affecting the long-term productive capacity of the groundfish stocks in the BSAI occurred during the period 1976-1977. Thus, the average recruitment value presented in the assessment is based on year classes spawned after 1976 (1977-2005 year classes). Projections of biomass are based on estimated recruitments from 1978-2006 using a stochastic projection model described below.

15.6.4 Trend in Exploitation

The estimated time series of fishing mortalities on fully selected age groups and the catch-to-biomass (age 3+) ratios are given in Table 15.12 and shown in Figure 15.16.

15.6.5 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 2007 biomass estimate is 18% and the *CV*s on the strength of the 1999 and 2001 year classes at age 1 are 24 and 31%, respectively (Table 15.8). Overall estimated recruitment variability for BSAI Atka mackerel is high (0.628). 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 123 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 0.345 (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 15.17 compares the observed and estimated survey biomass abundance values. The model 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 was 6 years old in 2006, and would have reached peak cohort biomass about 2 years ago. 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 15.17).

The fits to the survey and fishery age compositions for Model 4 are depicted in Figures 15.18 and 15.19, 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. These figures also highlight the patterns in changing age compositions over time. Note that the older age groups in the fishery age data are largely absent until around 1985 when the 1977 year class appears. It is also interesting to note that the 2006 survey observed greater numbers than expected of 2-year olds of the 2004 year class, while the fishery age compositions observed greater numbers than expected of 3-year olds of the 2003 year class (Figure 15.18 and 15.19).

15.7 Projections and harvest alternatives

15.7.1 Amendment 56 Reference Points

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC (*max* F_{ABC}). The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. The overfishing and maximum allowable ABC fishing mortality rates are given in terms of percentages of unfished female spawning biomass ($F_{SPR\%}$), on fully selected age groups. The associated long-term average female spawning biomass that would be expected under average estimated recruitment from 1978-2006 (493 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:

$B_{100\%}$ = 235,200 t female spawning biomass
$B_{40\%}$ = 94,100 t female spawning biomass
$B_{35\%}$ = 82,300 t female spawning biomass

15.7.2 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 2007 selectivity vector. Note that the fishery catch-at-age data exists only up through 2006; the 2007 selectivity vector is a smoothed estimate based on the 2006 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 2002-2006 (Table 15.7, Figure 15.11). 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 2007 ABC projection was based on an average of the years 2001-2005. A comparison of key reference fishing mortality values under the different selectivity assumptions are given below:

	Selectivity Assumption	
Full selection *F*s	2007	Average 2002-2006
F_{2007}	0.298	0.278
$F_{40\%}$	0.324	0.331
$F_{35\%}$	0.386	0.398
$F_{2007}/F_{40\%}$	0.920	0.840

The rates based on the year 2007 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 2002-2006.

For Model 4, the projected year 2008 female spawning biomass (SSB_{08}) is estimated to be 110,200 t 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 2008 female spawning biomass estimate (110,200 t) is above the $B_{40\%}$ value of 94,100 t, placing BSAI Atka mackerel in **Tier 3a**. However, the projected 2009 female spawning biomass estimate (89,900 t) is below $B_{40\%}$, placing BSAI Atka mackerel in Tier 3b for 2009. The maximum permissible ABC and OFL values under Tier 3 are:

Year	Tier	Catch	ABC	OFL	SSB
2008	3a	60,700	60,700	71,400	110,200
2009	3b		47,500	50,600	89,200

Note that the 2008 maximum permissible $F_{ABC} = F_{40\%}$ = 0.331 and $F_{OFL}=F_{35\%}$ = 0.398; also, catch in 2008 is assumed equal to the 2008 maximum permissible ABC. The 2009 maximum permissible F_{ABC} = 0.315 and F_{OFL}= 0.355.

15.8 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, 2008 female spawning biomass is projected to be above $B_{40\%}$ but drop below in 2009 to 2012 (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 2008 $F_{40\%}$ catch is moderate with a *CV* of 22%. 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 15.17).
6) The 2006 fishery age composition data continue to show large numbers from the 1999, 2000, and 2001 year classes (Figure 15.4). Currently we estimate the 1999 year class to be the largest in the time series (but with a moderate degree of uncertainty: *CV*=24%).

We believe the current model configuration as implemented through AMAK with the ADMB software provides an improved assessment of BSAI Atka mackerel relative to past model configurations. In particular, we believe 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, appearance of three consecutive strong year classes, and preliminary indications of greater than expected numbers from the 2003 and 2004 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 15.21. For most of the time series (including the 2007 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 15.21).

The associated 2008 yield associated with the maximum permissible $F_{40\%}$ fishing mortality rate of 0.331 is 60,700 t, which is our 2008 ABC recommendation for BSAI Atka mackerel.

The associated 2009 yield associated with the maximum permissible F_{ABC} fishing mortality rate of 0.315 is 47,500 t, which is our 2009 ABC recommendation for BSAI Atka mackerel.

The 2008 ABC recommendation represents an 18% decrease from the Council's 2007 ABC. This is consistent with a projected decrease in the population combined with a slight decrease in the estimated $F_{40\%}$ fishing mortality rate, relative to last year.

Area Allocation of Harvests

Amendment 28 of the Bering Sea/Aleutian Islands Fishery Management Plan divided the Aleutian subarea into 3 districts at 177° E and 177° W longitude, providing the mechanism to apportion the Aleutian Atka mackerel TACs. The Council used a 4-survey (2000, 2002, 2004, and 2006) weighted average to apportion the 2007 ABC. The rationale for the weighting scheme was described in Lowe *et al.* (2001). We again recommend the same 4-survey weighting scheme which includes the most recent 2006 survey, be used to apportion the 2008 and 2009 ABCs.

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

	2000	2002	2004	2006	2007 and recommended 2008, 2009 ABC Apportionment
541	0.20%	24.7%	27.5%	48.04%	**32.2%**
542	64.6%	42.3%	30.4%	38.14%	**40.0%**
543	35.2%	33.0%	42.0%	13.81%	**27.8%**
Weights	8	12	18	27	

The apportionments of the 2008 and 2009 recommended ABCs based on the most recent 4-survey weighted average are:

	2008	2009
Eastern (541)	19,500	15,300
Central (542)	24,300	19,000
Western (543)	16,900	13,200
Total	60,700	47,500

15.9 Standard Harvest Scenarios and Projection Methodology

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3, of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2007 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2008 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 2002-2006 selectivities), and the best available estimate of total (year-end) catch for 2007 (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 a Supplemental Environmental Impact Statement prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2008, 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 2008 recommended in the assessment to the *max* F_{ABC} for 2008. (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 2003-2007 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

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

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in 2008 or 2) above ½ of its MSY level in 2008 and above its MSY level in 2018 under this scenario, then the stock is not overfished.)

Scenario 7: In 2008 and 2009, 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 2020 under this scenario, then the stock is not approaching an overfished condition.)

15.9.1 Status determination

The projections of female spawning biomass, fishing mortality rate, and catch corresponding to the seven standard harvest scenarios are shown in Table 15.13. 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 2008:

a) If spawning biomass for 2008 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b) If spawning biomass for 2008 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c) If spawning biomass for 2008 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 15.13). If the mean spawning biomass for 2018 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 2010 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

b) If the mean spawning biomass for 2010 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c) If the mean spawning biomass for 2010 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2020. If the mean spawning biomass for 2020 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 2008 is estimated to be above $B_{35\%}$. Therefore, the stock is above its MSST and is not overfished. Mean spawning biomass for 2010 in Table 15.13 is above ½ $B_{35\%}$ but below $B_{35\%}$, and mean spawning biomass for 2020 is above $B_{35\%}$. Therefore, the stock is not approaching an overfished condition.

15.10 Ecosystem Considerations

Steller sea lion food habits data (from analysis of scats) from the Aleutian Islands indicate that Atka mackerel is the most common prey item throughout the year (NMFS 1995, Sinclair and Zeppelin 2002). The prevalence of Atka mackerel and walleye pollock in sea lion scats reflected the distributions of each fish species in the Aleutian Islands region. The percentage occurrence of Atka mackerel was progressively greater in samples taken in the central and western Aleutian Islands, where most of the Atka mackerel biomass in the Aleutian Islands is located. Conversely, the percentage occurrence of pollock was greatest in the eastern Aleutian Islands.

Bottom contact fisheries could have direct negative impacts on Atka mackerel by destroying egg nests and/or removing the males that are guarding nests (Lauth *et al.* 2007); however, this has not been examined quantitatively. Analyses of historic fishery CPUE revealed that the fishery may create temporary localized depletions of Atka mackerel, and historic fishery harvest rates in localized areas may have been high enough to affect prey availability of Steller sea lions (Section 12.2.2 of Lowe and Fritz 1997). The localized pattern of fishing for Atka mackerel could have created temporary reductions in the size and density of localized Atka mackerel populations which may have affected Steller sea lion foraging success during the time the fishery was operating and for a period of unknown duration after the fishery closed.

15.10.1 Ecosystem effects on BSAI Atka mackerel

Prey availability/abundance trends

Figure 15.22 shows the food web of the Aleutian Islands summer survey region, based on trawl survey and food habits data, with an emphasis on the predators and prey of Atka mackerel (see the current Ecosystem Assessment's ecosystem modeling results section for a description of the methodology for constructing the food web).

Adult Atka mackerel in the Aleutians consume a variety of prey, but are primarily zooplanktivors, consuming mainly euphausiids and calanoid copepods (Yang 1996, Yang 2003). Food habits data from 1990-1994 indicates that Atka mackerel feed on calanoid copepods (40%) and euphausiids (25%) followed by squids (10%), juvenile pollock (6%), and finally a range of zooplankton including fish larvae, benthic amphipods, and gelatinous filter feeders (Fig. 15.23a). While Figure 15.23a shows an aggregate diet for the Aleutians management regions, Atka mackerel diet data also show a longitudinal gradient, with euphausiids dominating diets in the east and copepods and other zooplankton dominating in the west. Greater piscivory, especially on myctophids, occurs in the island passes (Ortiz, 2007) Monitoring trends in Atka mackerel prey populations may, in the future, help elucidate Atka mackerel population trends. However, there is no long-term time series of zooplankton, squid, or small forage fish abundance information available.

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

Predator population trends

Atka mackerel are consumed by a variety of piscivores, including groundfish (e.g., Pacific cod, Pacific halibut, and arrowtooth flounder, Livingston *et al.* unpubl. manuscr.), marine mammals (e.g., northern fur seals and Steller sea lions, Kajimura 1984, NMFS 1995, Sinclair and Zeppelin 2002), skates, and seabirds (e.g., thick-billed murres, tufted puffins, and short-tailed shearwaters, Springer *et al.* 1999). Apportionment of Atka mackerel mortality between fishing, predation, and unexplained mortality, based on the consumption rates and food habits of predators averaged over 1990-1994 is shown in Figure 15.24. During these years, approximately 20% of the Atka mackerel exploitation rate (as calculated by stock assessment) was due to the fishery, 62% due to predation, and 18% "unexplained", where "unexplained" is the difference between the stock assessment total mortality and the sum of fisheries exploitation and quantified predation. This unexplained mortality may be due to data uncertainty, or Atka mackerel mortality due to disease, migration, senescence, etc.

Of the 62% of mortality due to predation, a little less than half (25% of total) is due to Pacific cod predation, and one quarter (15% of total) due to Steller sea lion predation, with the remainder spread across a range of predators (Figure 15.23b), based on Steller sea lion diets published by Merrick *et al.* (1997) and summer fish food habits data from the REEM food habits database.

If converted to tonnages, this translates to 100,000-120,000 t/year of Atka mackerel consumed by predatory fish (of which approximately 60,000 t is consumed by Pacific cod), and 40,000-80,000 t/year consumed by Steller sea lions during the early 1990s. Estimating the consumption of Atka mackerel by birds is more difficult to quantify due to data limitations: based on colony counts and residency times, predation by birds, primarily kittiwakes, fulmars, and puffins, on all forage and rockfish combined in the Aleutian Islands is at most 70,000 t/year (Hunt *et al.* 2000). However, colony specific diet studies, for example for Buldir Island, indicate that the vast majority of prey found in these birds is sandlance, myctophids, and other smaller forage fish, with Atka mackerel never specifically identified as prey items, and "unidentified greenlings" occurring infrequently (Dragoo *et al.* 2001). The food web model's estimate, based on foraging overlap between species, estimates the total Atka mackerel consumption by birds to be less than 2,000 t/year. While this might be an underestimate, it should be noted that most predation would occur on juveniles (<1year old) which is not counted in the stock assessment's total exploitation rates.

The abundance trends of Aleutian Islands Pacific cod has been quite variable, alternating between increases and decreases in recent surveys, and Aleutian Islands arrowtooth flounder has been increasing. Northern fur seals are showing declines, and Steller sea lions have shown some slight increases. The population trends of seabirds are mixed, some increases, some decreases, and others stable. Seabird population trends could potentially affect juvenile Atka mackerel mortality. Declining trends in predator abundance could lead to possible decreases in Atka mackerel mortality, while increases in predator biomass could potentially increase the mortality.

Changes in habitat quality

Climate

Interestingly, strong year classes of AI Atka mackerel have occurred in years of hypothesized climate regime shifts 1977, 1988, and 1999, as indicated by indices such as the Pacific Decadal Oscillation (Francis and Hare 1994, Hare and Mantua 2000, Boldt 2005). Bailey *et al.* (1995) noted that some fish species show strong recruitment at the beginning of climate regime shifts and suggested that it was due to a disruption of the community structure providing a temporary release from predation and competition. It is unclear if this is the mechanism that influences Atka mackerel year class strength in the Aleutian Islands. El Nino Southern Oscillation (ENSO) events are another source of climate forcing that influences the North Pacific. Hollowed *et al.* (2001) found that gadids in the GOA have a higher proportion of strong year classes in ENSO years. There was, however, no relationship between strong year classes of AI Atka mackerel and ENSO events (Hollowed *et al.* 2001).

Bottom temperature

Atka mackerel demonstrate schooling behavior and prefer hard, rough and rocky bottom substrate. Eggs are deposited in nests on rocky substrates between 15 and 144 m depth (Lauth *et al.* 2007). The spawning period in Alaska occurs in late July to October (McDermott and Lowe 1997, Lauth *et al.* 2007). During the incubation period egg nests are guarded by males, who will be on the nests until mid-January, given that females have been observed to spawn as late as October and given the length of the egg incubation period (McDermott and Lowe 1997, Lauth *et al.* 2007, Lauth *et al.* in press). The distribution of Atka mackerel spawning and nesting sites are thought to be limited by water temperature (Gorbunova 1962). Temperatures below 3°C and above 15°C are lethal to eggs or unfavorable for embryonic development depending on the exposure time (Gorbunova 1962). Temperatures recorded at Alaskan nesting sites, 3.9 - 10.7 ºC, do not appear to be limiting, as they were within this range (Lauth *et al.* 2007).

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.

15.10.2 Atka mackerel fishery effects on the ecosystem

Atka mackerel fishery contribution to bycatch

The levels of bycatch in the Atka mackerel fishery of prohibited species, forage fish, HAPC biota, marine mammals, birds, and other sensitive non-target species is relatively low except for the species which are noted in Table 15.14 and discussed below.

The Atka mackerel fishery has very low bycatch levels of some species of HAPC biota, e.g. seapens and whips. The bycatch of sponges and coral in the Atka mackerel fishery is highly variable. It is notable that in the last 3 years (2004-2006), the Atka mackerel fishery has taken on average about 58 and 40%, 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 15.14. Skate bycatch in the Aleutian Islands Atka mackerel fishery is variable and has averaged 120 t in the last 3 years (2004-2006). Over this same time period, the Atka mackerel fishery has taken an average of 15% of the total Aleutian Islands skate bycatch. It is unknown if the absolute levels of skate bycatch in the Atka mackerel fishery are of concern.

The bycatch of sculpin is notable and has averaged about 445 t from 2004 to 2006. This level of bycatch represents an average of 54% of the total Aleutian Islands sculpin bycatch. It is unknown if the absolute levels of sculpin bycatch in the Atka mackerel fishery are of concern.

Fishing gear effects on spawning and nesting habitat

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

Indirect effects of bottom contact fishing gear, such as effects on fish habitat, may also have implications for Atka mackerel. Living substrate that is susceptible to fishing gear includes sponges, seapens, sea anemones, ascidians, and bryozoans (Malecha *et al.* 2005). Of these, Atka mackerel sampled in the NMFS bottom trawl survey are primarily associated with emergent epifauna such as sponges and corals (Malecha *et al.* 2005, Stone 2006). Effects of fishing gear on these living substrates could, in turn, affect fish species that are associated with them.

Concentration of Atka mackerel catches in time and space

Steller sea lion protection measures have spread out Atka mackerel harvests in time and space through the implementation of seasonal and area-specific TACs and harvest limits within sea lion critical habitat. However, this is still an issue of possible concern and research efforts continue to monitor and assess the availability of Atka mackerel biomass in areas of concern. Also, in some cases the sea lion protection measures have forced the fishery to concentrate in areas outside of critical habitat that had previously experienced lower levels of exploitation. The impact of the fishery in these areas outside of critical habitat is unknown.

Atka mackerel fishery effects on amount of large size Atka mackerel

The numbers of large size Atka mackerel are largely impacted by highly variable year class strength rather than by the directed fishery. Year to year differences are attributed to natural fluctuations.

Atka mackerel fishery contribution to discards and offal production

There is no time series of the offal production from the Atka mackerel fishery. The Atka mackerel fishery has contributed on average about 850 t of non-target discards in the Aleutian Islands from 2004 to 2006. 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 3,600 t over 2004-2006.

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, McDermott *et al*. 2007) of Atka mackerel. These are recent studies and there are no earlier studies for comparison on fish from an unexploited population. Further studies would be needed to determine if there have been changes over time and whether changes could be attributed to the fishery.

15.11 Data gaps and research priorities

Regional and seasonal food habits data for Aleutian Islands is very limited. No time series of information is available on copepod and euphausiid abundance in the Aleutian Islands which would provide information on prey availability and abundance trends. Studies to determine the impacts of environmental indicators such as temperature regime on Atka mackerel are needed. Further studies to determine whether there have been any changes in life history parameters over time (e.g. 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.

15.12 Summary

Natural mortality = 0.3

2008 (Tier 3a)			
Maximum permissible ABC:	$F_{40\%}$ = 0.331	yield =	60,700 t
Recommended ABC:	$F_{40\%}$ = 0.331	yield =	60,700 t
Overfishing (OFL):	$F_{35\%}$ = 0.398	yield =	71,400 t

2009 (Tier 3b)			
Maximum permissible ABC:	F_{ABC} = 0.315	yield =	47,500 t
Recommended ABC:	F_{ABC} = 0.315	yield =	47,500 t
Overfishing (OFL):	F_{OFL} = 0.355	yield =	50,600 t

Equilibrium female spawning biomass		
$B_{100\%}$	=	235,200 t
$B_{40\%}$	=	94,100 t
$B_{35\%}$	=	82,300 t

Projected 2008 biomass	
Age 3+ biomass	= 323,400 t
Female spawning biomass	= 110,200 t

15.13 Acknowledgements

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15.15 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 metric tons.

	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
2006	0	a	a	a	a	0	61,882	61,882	61,882	110,200	63,000
2007c	0	a	a	a	a	0	51,697	51,697	51,697	74,000	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) 2007 data as of 10/06/07. 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	--	--	--	--	--
2006	4.72	18.36	6.22	38.77	22.47	22.85	3.60	0.42	0.18	0.16	--	--	--	--

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

Area	Depth (m)	Biomass (t)						
		1991	1994	1997	2000	2002	2004	2006
Aleutian	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. 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. The 2007 fishery weight-at-age values are the average of 2004, 2005, and 2006.

		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
	2006	0.045	0.158	0.332	0.523	0.516	0.675	0.764	0.719	0.855	1.653	0.991	0.872	0.939	1.123	1.104
Ave 2002, 2004, 2006		0.045	0.145	0.336	0.545	0.615	.0750	0.819	0.816	0.893	1.118	0.966	0.981	1.004	1.236	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
	2006	0.0694	0.3109	0.4047	0.4949	0.5358	0.5735	0.5843	0.6461	0.7607	0.7877	0.6638	0.901	1.070	1.440	1.273
Ave. 2004, 2005, 2006	2007	0.069	0.219	0.363	0.464	0.543	0.620	0.673	0.760	0.800	0.818	0.877	0.833	1.070	1.440	1.273

Table 15.6 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 15.7. Estimates of Atka mackerel fishery (over time, 1977-2007) 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	0.37	0.83	1.00	0.76	0.49	0.32	0.22	0.18	0.18	0.18	0.18	0.18	0.18
1978	0.02	0.10	0.44	0.75	1.00	0.91	0.64	0.41	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	0.90	0.65	0.43	0.29	0.22	0.22	0.22	0.22	0.22	0.22
1980	0.01	0.05	0.20	0.59	1.00	0.99	0.86	0.60	0.38	0.27	0.27	0.27	0.27	0.27	0.27
1981	0.01	0.03	0.12	0.24	0.34	0.60	1.00	0.58	0.29	0.18	0.18	0.18	0.18	0.18	0.18
1982	0.01	0.03	0.09	0.31	0.86	1.00	0.70	0.43	0.28	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	0.90	0.53	0.34	0.26	0.26	0.26	0.26	0.26	0.26
1984	0.01	0.03	0.13	0.42	0.76	1.00	0.94	0.67	0.45	0.34	0.34	0.34	0.34	0.34	0.34
1985	0.01	0.06	0.40	0.83	0.99	1.00	0.93	0.82	0.70	0.60	0.60	0.60	0.60	0.60	0.60
1986	0.01	0.04	0.22	0.48	0.67	0.80	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	0.73	0.82	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	0.97	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	0.69	0.66	0.66	0.66	0.66	0.66	0.66
1990	0.00	0.03	0.22	0.79	1.00	0.79	0.65	0.58	0.56	0.56	0.56	0.56	0.56	0.56	0.56
1991	0.00	0.02	0.09	0.42	0.88	1.00	0.85	0.72	0.62	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	0.95	0.89	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	0.97	0.95	0.95	0.95	0.95	0.95	0.95	0.95
1994	0.01	0.02	0.10	0.32	0.65	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	0.53	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	0.98	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	0.79	0.88	0.94	0.98	1.00	1.00	1.00	1.00	1.00	1.00
1999	0.00	0.03	0.14	0.51	0.73	0.83	0.87	0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2000	0.00	0.02	0.16	0.47	0.74	0.88	0.95	1.00	0.95	0.90	0.90	0.90	0.90	0.90	0.90
2001	0.00	0.02	0.14	0.45	0.76	0.92	1.00	0.95	0.82	0.73	0.73	0.73	0.73	0.73	0.73
2002	0.00	0.02	0.12	0.36	0.62	0.86	1.00	0.91	0.76	0.65	0.65	0.65	0.65	0.65	0.65
2003	0.01	0.04	0.21	0.54	0.73	0.90	1.00	0.95	0.81	0.71	0.71	0.71	0.71	0.71	0.71
2004	0.01	0.07	0.31	0.74	0.99	1.00	0.97	0.90	0.79	0.72	0.72	0.72	0.72	0.72	0.72
2005	0.02	0.07	0.30	0.79	1.00	0.94	0.79	0.65	0.56	0.52	0.52	0.52	0.52	0.52	0.52
2006	0.02	0.09	0.33	0.69	1.00	1.00	0.83	0.61	0.51	0.47	0.47	0.47	0.47	0.47	0.47
2007	0.02	0.09	0.33	0.69	1.00	1.00	0.83	0.61	0.51	0.47	0.47	0.47	0.47	0.47	0.47
Avg. 2002-2006	0.01	0.06	0.27	0.67	0.93	1.00	0.97	0.85	0.72	0.65	0.65	0.65	0.65	0.65	0.65
Survey	0.03	0.14	0.56	0.85	0.88	0.91	1.00	0.94	0.77	0.70	0.70	0.70	0.70	0.70	0.70

Table 15.8. Estimates of key results from AMAK for Aleutian Islands Atka mackerel from the current assessment and last year's (2006) assessment. Coefficients of variation (*CV*) for some key reference values appearing directly below, are given in parentheses.

Assessment Model	**2006**	**2007**
Model setup		
Survey catchability	1.476	1.504
Steepness	0.800	0.800
SigmaR	0.6	0.6
Natural mortality	0.300	0.300
Fishery Average Effective *N*	121	123
Survey Average Effective *N*	56	56
RMSE Survey	0.346	0.345
-*log Likelihoods*		
Number of Parameters	388	410
Survey index	4.20	4.28
Catch biomass	0.09	0.09
Fishery age comp	159.39	162.64
Survey age comp	35.54	41.28
Sub total	199.23	208.29
-*log Penalties*		
Recruitment	10.550	11.037
Selectivity constraint	119.467	125.145
Fishing mortality penalty	0.000	0.000
Prior	2.914	3.230
Total	332.196	347.701
Fishing mortalities (full selection)		
F 2007	0.221	0.298
F 2007/*F* 40%	0.635	0.920
F 40%	0.348	0.324
CV	(27%)	(20%)
*F*35%	0.419	0.386
CV	(28%)	(21%)
Stock abundance		
Initial Biomass (t, 1977)	276,750	278,660
CV	(16%)	(16%)
2007 total biomass (t)	569,110	490,860
CV	(16%)	(18%)
2007 Age 3+ biomass (t)	445,002	360,988
1999 year class (1000's at age 1)	1,262	1,364
CV	(27%)	(24%)
2001 year class (1000's at age 1)	967	843.69
CV	(38%)	(33%)
Recruitment Variability	0.622	0.628
Projected catch (unadjusted)		
F 40% 2008 catch (t)	75,969	57,715
CV	(20%)	(22%)
F 35% 2008 catch (t)	89,118	67,361
CV	(21%)	(23%)

Table 15.9. Estimated Atka mackerel numbers at age in thousands, 1977-2007.

Year	1	2	3	4	5	6	7	8	9	10+	Total	% of 10+
1977	202	229	192	53	38	20	17	16	13	58	838	7%
1978	1084	148	164	124	29	19	11	11	10	49	1,650	3%
1979	309	798	106	102	69	14	10	6	7	40	1,461	3%
1980	196	228	584	74	63	40	9	6	4	33	1,237	3%
1981	229	145	167	417	49	39	24	5	4	26	1,106	2%
1982	152	169	107	120	291	33	25	14	3	21	936	2%
1983	225	112	125	78	86	195	22	17	10	18	889	2%
1984	305	166	83	92	57	61	136	15	12	20	947	2%
1985	474	225	123	60	63	36	37	84	10	22	1,134	2%
1986	451	351	165	83	37	38	22	23	52	21	1,243	2%
1987	599	334	257	116	55	23	23	13	13	44	1,476	3%
1988	373	443	245	183	78	36	15	15	8	36	1,433	3%
1989	1083	276	326	175	121	52	24	10	10	30	2,108	1%
1990	511	802	204	238	124	83	35	17	7	28	2,049	1%
1991	267	378	593	149	168	87	59	25	12	25	1,764	1%
1992	539	198	280	435	106	114	58	40	17	26	1,814	1%
1993	813	399	146	204	308	71	73	37	26	28	2,105	1%
1994	293	601	294	106	143	202	43	43	22	32	1,780	2%
1995	318	217	443	212	72	89	120	26	25	31	1,552	2%
1996	727	235	159	313	132	43	52	67	14	30	1,771	2%
1997	143	537	172	112	191	73	21	23	29	20	1,322	1%
1998	247	106	394	123	75	117	41	11	12	25	1,152	2%
1999	725	183	78	281	80	43	63	21	6	18	1,496	1%
2000	1364	536	134	55	179	48	25	36	12	13	2,402	1%
2001	806	1010	395	95	36	109	28	14	20	14	2,528	1%
2002	844	596	742	278	60	20	58	15	8	20	2,641	1%
2003	174	624	439	530	185	37	12	32	8	16	2,057	1%
2004	373	129	458	310	348	116	22	7	19	15	1,799	1%
2005	435	276	94	322	202	218	73	14	4	23	1,662	1%
2006	231	321	202	66	208	126	138	47	9	18	1,367	1%
2007	288	170	233	138	42	122	74	84	30	18	1,201	2%

Table 15.10. Estimates of Atka mackerel biomass in metric tons with approximate lower and upper 95% confidence bounds for age 1+ biomass (labeled as LCI and UCI). Also included are age 3+ and female spawning biomass in metric tons from the current assessment compared to last year's (2006) assessment.

	Current assessment age 1+ biomass (t)			*Age 3+ biomass (t)*		*Female spawning biomass (t)*	
Year	Estimate	LCI	UCI	Current	2006	Current	2006
1977	278,660	191,324	365,996	174,004	171,575	72,293	71,341
1978	310,510	209,900	411,120	159,371	157,280	66,345	65,584
1979	338,200	223,382	453,018	178,567	176,299	64,295	63,787
1980	411,960	273,804	550,116	323,664	321,690	64,376	64,373
1981	446,350	297,220	595,480	339,971	338,406	77,010	77,599
1982	408,910	271,898	545,922	324,538	323,238	117,607	119,427
1983	375,560	250,272	500,848	325,173	323,875	127,295	131,185
1984	355,430	241,070	469,790	334,424	332,661	121,500	123,960
1985	328,190	223,130	433,250	289,091	286,453	106,969	108,185
1986	330,250	227,948	432,552	251,497	248,857	87,045	88,028
1987	369,330	265,174	473,486	363,420	361,267	75,932	76,048
1988	415,100	313,446	516,754	303,182	302,758	79,683	78,534
1989	488,370	388,968	587,772	441,037	440,199	93,176	94,258
1990	562,150	467,848	656,452	642,587	640,155	112,134	114,747
1991	640,280	547,322	733,238	573,293	570,986	134,093	136,810
1992	677,290	586,154	768,426	723,300	720,554	153,382	156,666
1993	653,630	569,010	738,250	620,757	617,881	185,208	188,456
1994	626,880	545,522	708,238	547,426	544,050	183,530	187,668
1995	607,690	524,792	690,588	541,919	537,365	160,225	162,376
1996	558,130	473,852	642,408	469,223	463,982	146,980	148,073
1997	465,990	383,324	548,656	428,784	422,049	134,519	135,697
1998	450,970	364,374	537,566	390,733	383,204	114,999	116,078
1999	421,900	333,854	509,946	374,233	365,561	104,744	104,076
2000	439,570	346,082	533,058	341,806	332,145	107,852	107,249
2001	543,220	428,102	658,338	431,475	416,508	94,645	94,480
2002	685,100	535,580	834,620	514,196	484,748	88,667	86,420
2003	762,760	589,778	935,742	560,278	531,884	119,120	114,692
2004	745,090	562,012	928,168	588,575	586,900	173,477	166,887
2005	667,390	485,346	849,434	524,422	549,834	198,614	195,019
2006	569,600	395,652	743,548	432,256	445,002	199,533	203,752
2007	490,860	317,148	664,572	400,948	364,160	164,942	129,900
2008				323,385		110,170	

Table 15.11 Estimates of age-1 Atka mackerel recruitment (1000's of recruits).

	Age 1 Recruits	
Year	Current	2006
1977	202	200
1978	1084	1084
1979	309	309
1980	196	196
1981	229	227
1982	152	149
1983	225	220
1984	305	302
1985	474	478
1986	451	454
1987	599	595
1988	373	370
1989	1083	1080
1990	511	509
1991	267	265
1992	539	535
1993	813	804
1994	293	287
1995	318	312
1996	727	712
1997	143	139
1998	247	239
1999	725	698
2000	1364	1262
2001	806	798
2002	844	967
2003	174	263
2004	373	255
2005	435	258
2006	231	
Ave 78-06	493	
Med 78-06	373	

Table 15.12. Estimates of full-selection fishing mortality rates and exploitation rates for Atka mackerel.

Year	*F*[a]	Catch/Biomass Rate[b]
1977	0.376	0.125
1978	0.391	0.152
1979	0.246	0.130
1980	0.186	0.063
1981	0.241	0.058
1982	0.115	0.061
1983	0.063	0.036
1984	0.195	0.108
1985	0.210	0.131
1986	0.253	0.127
1987	0.168	0.083
1988	0.118	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	0.261	0.127
1995	0.355	0.150
1996	0.548	0.222
1997	0.371	0.154
1998	0.414	0.149
1999	0.297	0.150
2000	0.260	0.138
2001	0.355	0.143
2002	0.301	0.089
2003	0.221	0.098
2004	0.170	0.103
2005	0.173	0.116
2006	0.231	0.143
2007[c]	0.298	0.157

a Full-selection fishing mortality rates.
b Catch/biomass rate is the ratio of catch to beginning year age 3+ biomass.
c The 2007 catch/biomass rate is based on 2007 TAC.

Table 15.13. Projections of female spawning biomass in metric tons, full-selection fishing mortality rates (*F*) and catch in metric tons for Atka mackerel for the 7 scenarios. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 235,220, 94,088, and 82,327 t, respectively.

	$B_{100\%}$	$B_{40\%}$	$B_{35\%}$	B_{2007}	$B_{2007}/B_{100\%}$		
	235,220	94,088	82,327	110,170	0.468		
Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2007	63,000	63,000	63,000	63,000	63,000	63,000	63,000
2008	60,672	60,672	38,545	16,828	0	71,356	60,672
2009	47,526	47,526	34,203	16,109	0	50,619	47,526
2010	40,486	40,486	33,047	16,314	0	42,666	46,946
2011	44,933	44,933	35,510	17,892	0	48,416	50,238
2012	49,838	49,838	38,716	19,855	0	54,003	54,752
2013	52,681	52,681	40,833	21,309	0	56,803	57,122
2014	53,818	53,818	42,045	22,266	0	57,562	57,701
2015	54,069	54,069	42,617	22,870	0	57,604	57,672
2016	54,403	54,403	43,012	23,262	0	57,736	57,770
2017	54,983	54,983	43,623	23,703	0	58,439	58,459
2018	55,544	55,544	44,086	24,053	0	59,188	59,200
2019	55,588	55,588	44,157	24,197	0	59,206	59,212
2020	55,106	55,106	44,044	24,252	0	58,412	58,414
Fishing M	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2007	0.278	0.278	0.278	0.278	0.278	0.278	0.278
2008	0.331	0.331	0.201	0.084	0.000	0.398	0.331
2009	0.315	0.315	0.201	0.084	0.000	0.355	0.315
2010	0.284	0.284	0.201	0.084	0.000	0.317	0.334
2011	0.289	0.289	0.201	0.084	0.000	0.328	0.335
2012	0.295	0.295	0.201	0.084	0.000	0.339	0.342
2013	0.301	0.301	0.201	0.084	0.000	0.346	0.347
2014	0.303	0.303	0.201	0.084	0.000	0.347	0.348
2015	0.304	0.304	0.201	0.084	0.000	0.348	0.348
2016	0.305	0.305	0.201	0.084	0.000	0.348	0.348
2017	0.304	0.304	0.201	0.084	0.000	0.347	0.347
2018	0.305	0.305	0.201	0.084	0.000	0.349	0.349
2019	0.306	0.306	0.201	0.084	0.000	0.351	0.351
2020	0.305	0.305	0.201	0.084	0.000	0.349	0.349
Spawning biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2007	133,368	133,368	133,368	133,368	133,368	133,368	133,368
2008	110,170	110,170	116,994	123,492	128,403	106,795	110,170
2009	89,923	89,923	103,573	118,526	130,740	84,378	89,923
2010	81,678	81,678	97,293	117,794	135,751	76,025	79,910
2011	87,052	87,052	103,934	129,102	152,335	81,060	82,960
2012	91,891	91,891	110,631	139,947	168,020	85,165	86,009
2013	95,127	95,127	116,475	150,475	184,136	87,486	87,889
2014	96,837	96,837	120,182	157,711	195,959	88,629	88,811
2015	96,702	96,702	121,548	161,920	204,161	88,169	88,263
2016	96,877	96,877	122,696	165,069	210,415	88,250	88,292
2017	98,340	98,340	125,060	169,299	217,540	89,596	89,615
2018	99,401	99,401	126,904	172,720	223,460	90,456	90,466
2019	99,329	99,329	127,454	174,454	227,115	90,207	90,210
2020	98,735	98,735	127,209	175,039	229,200	89,575	89,576

Table 15.14. 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 t 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 t of the total AI trawl non-target and Atka mackerel discards, respectively.	The Atka mackerel fishery is one of the few trawl fisheries operating in the AI. Numbers and rates should be interpreted in this context.	Unknown
Fishery effects on age-at-maturity and fecundity	Unknown	Unknown	Unknown

15.16 Figures

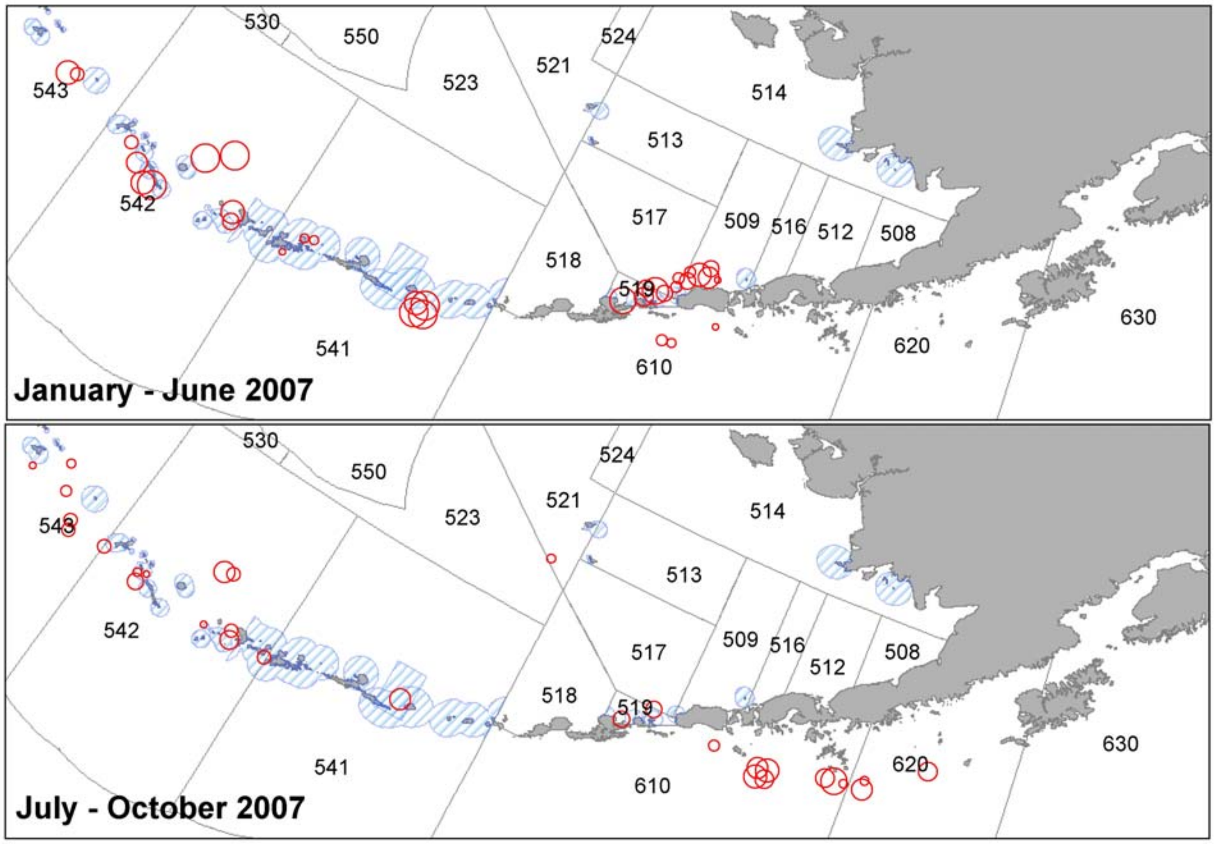


Figure 15.1. Observed catches of Atka mackerel summed for 20 km^2 cells for 2006 (January – June, top panel; and from July-October, bottom panel) where observed catch per haul was greater than 1 t. Shaded areas represent 10 and 20 nm Steller sea lion areas.

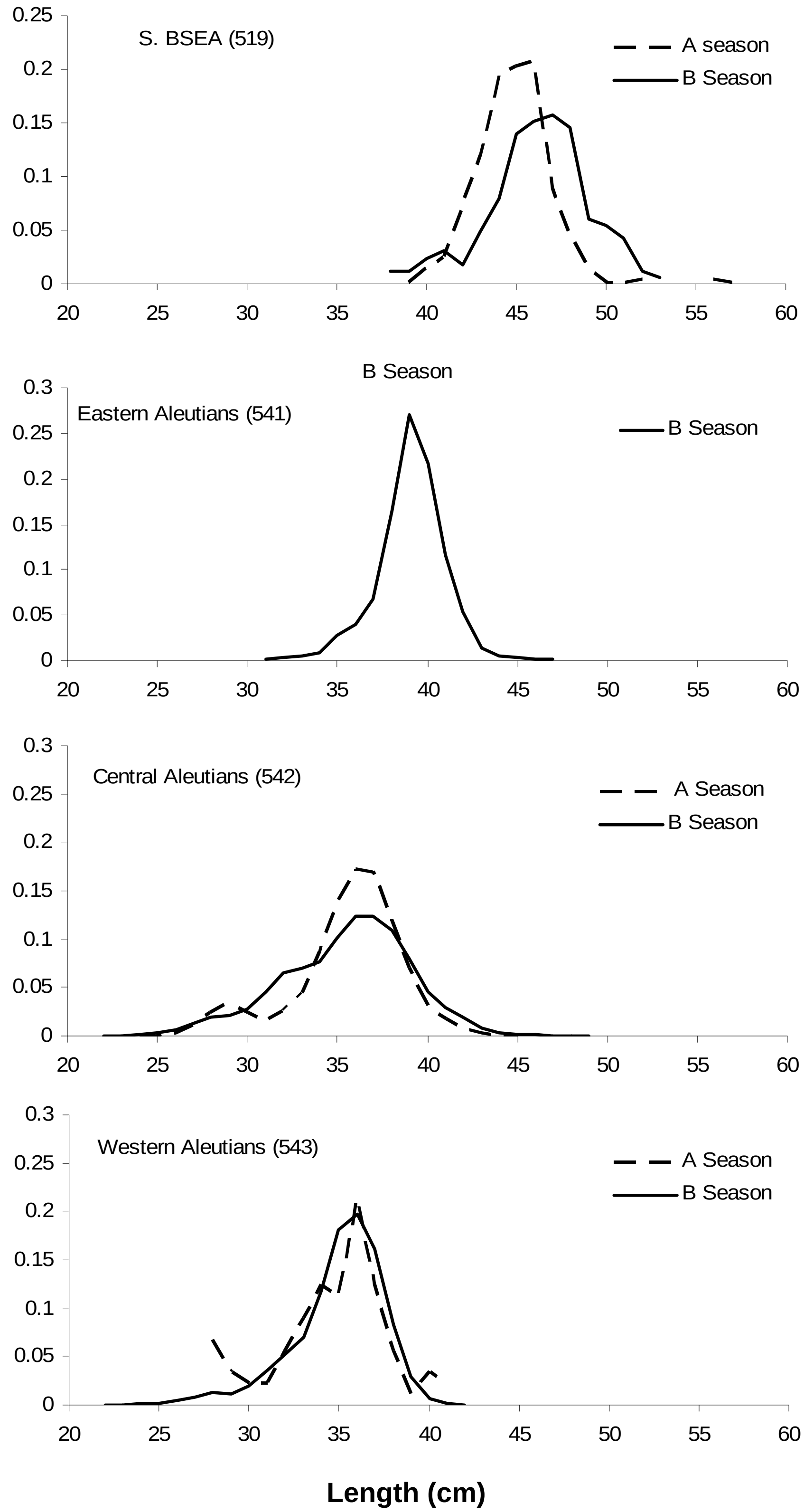


Figure 15.2. 2006 Atka mackerel fishery length-frequency data by area fished (see Figure 15.1). Numbers refer to management areas.

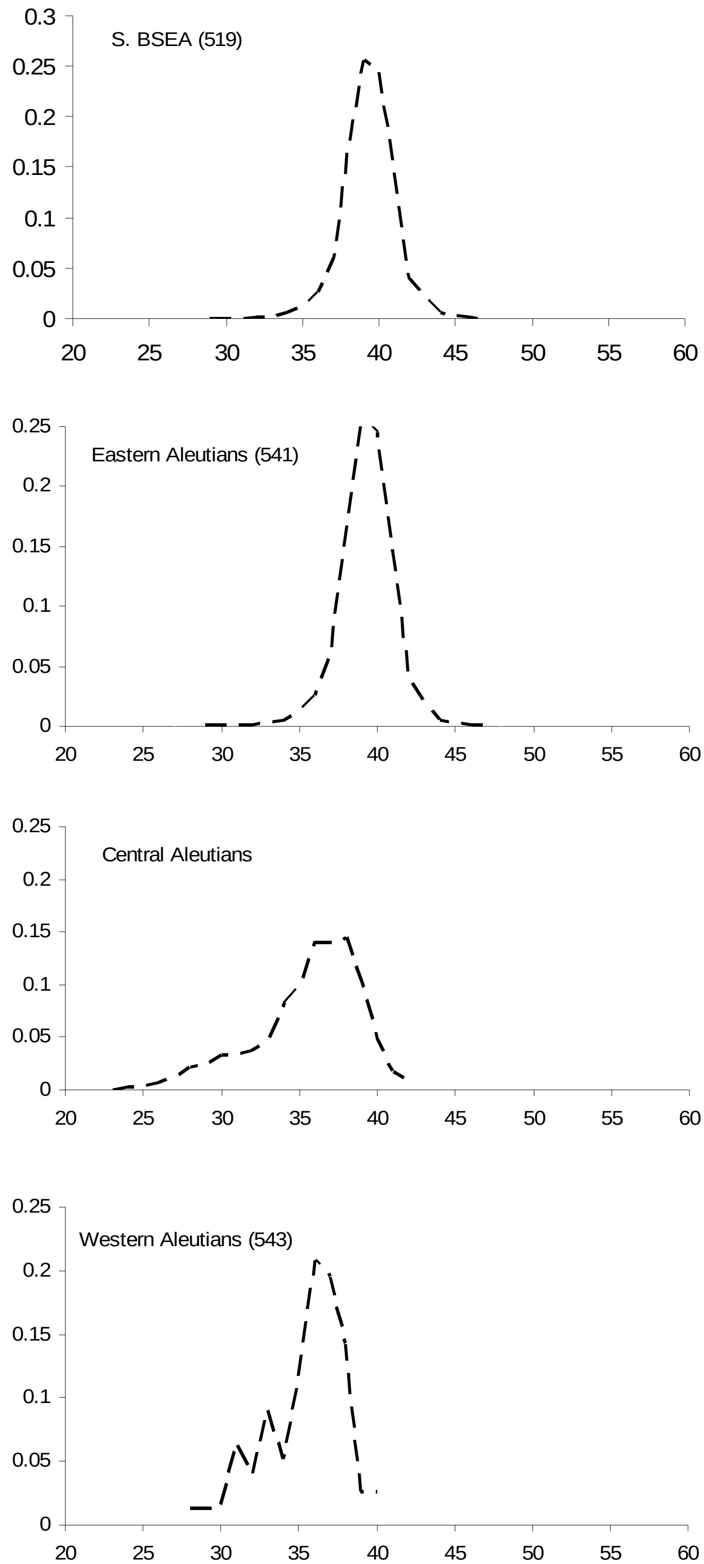


Figure 15.3. Preliminary 2007 A-season Atka mackerel fishery length-frequency data by area fished (see Figure 15.1). Numbers refer to management areas.

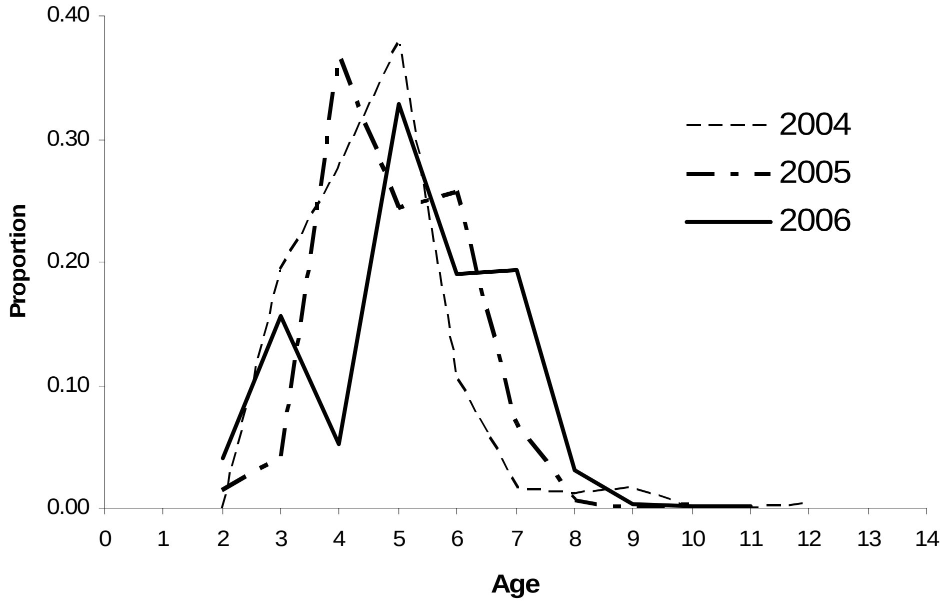


Figure 15.4. Aleutian Islands Atka mackerel fishery age composition data for 2004, 2005, and 2006.

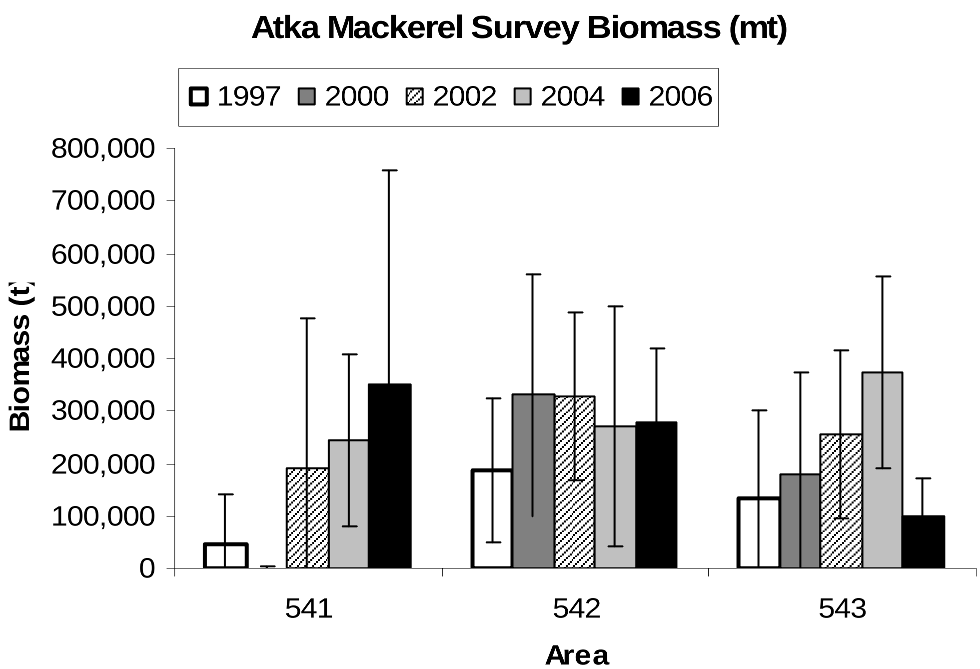


Figure 15.5. Atka mackerel Aleutian Islands survey biomass estimates by area and survey year. Bars represent 95% confidence intervals based on sampling error.

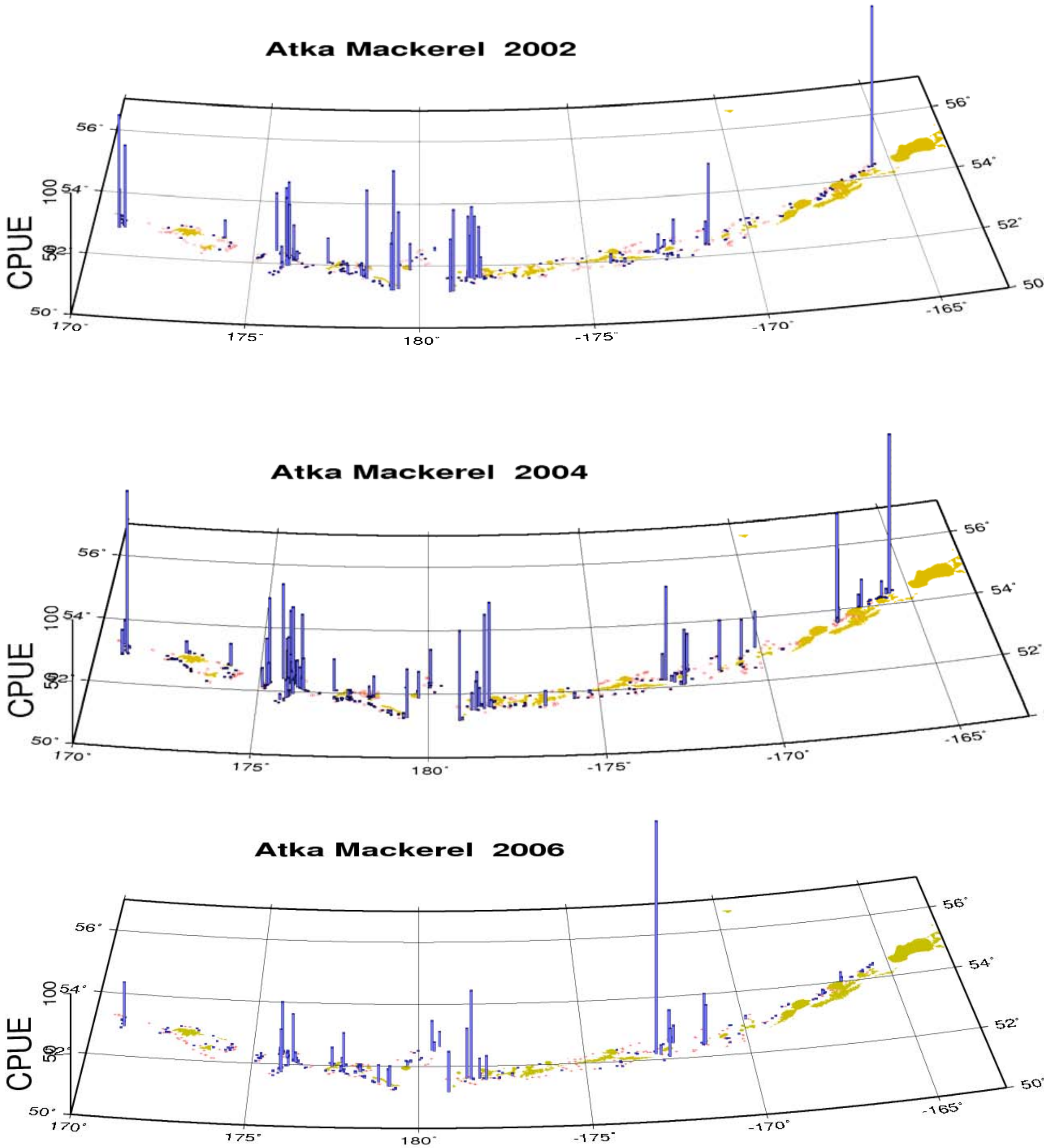


Figure 15.6. Bottom-trawl survey CPUE distributions of Atka mackerel catches during the summers of 2002, 2004, and 2006.

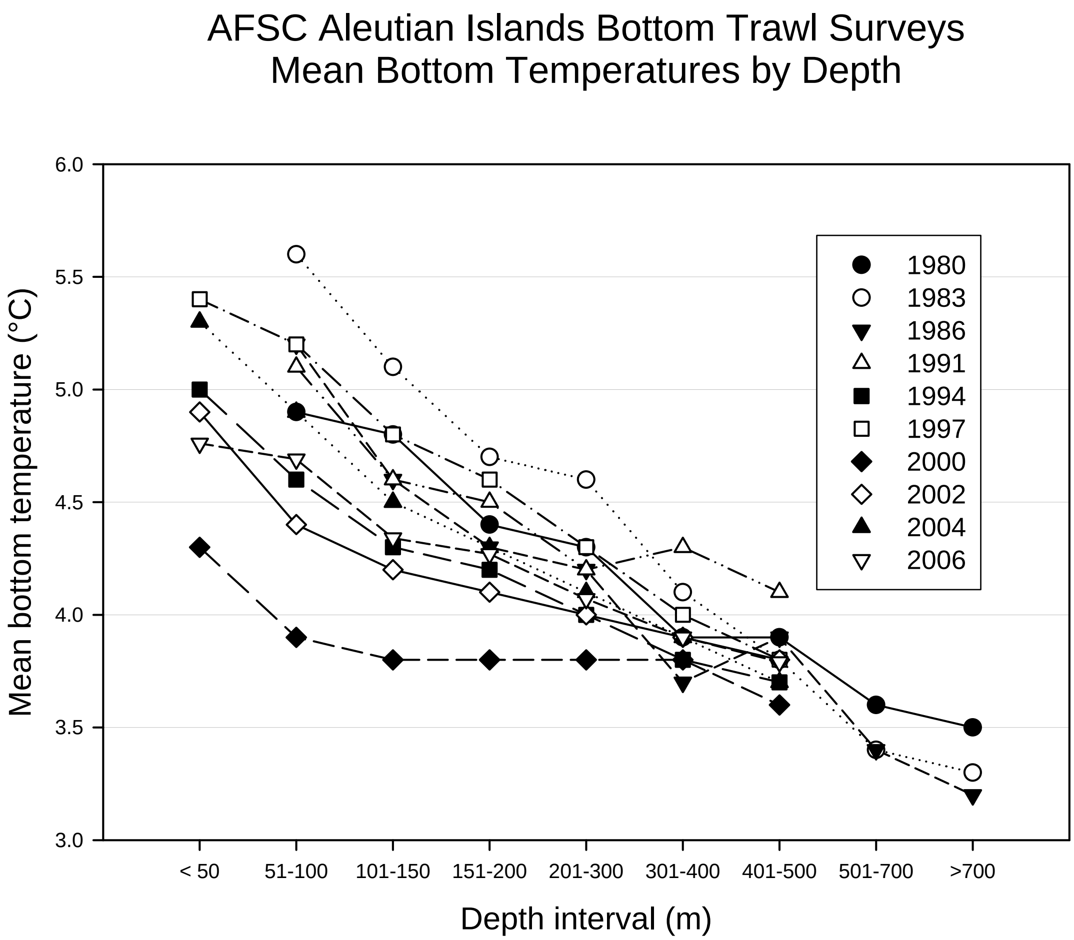


Figure 15.7. Average bottom temperatures by depth interval based on Aleutian Islands summer bottom-trawl surveys since 1980.

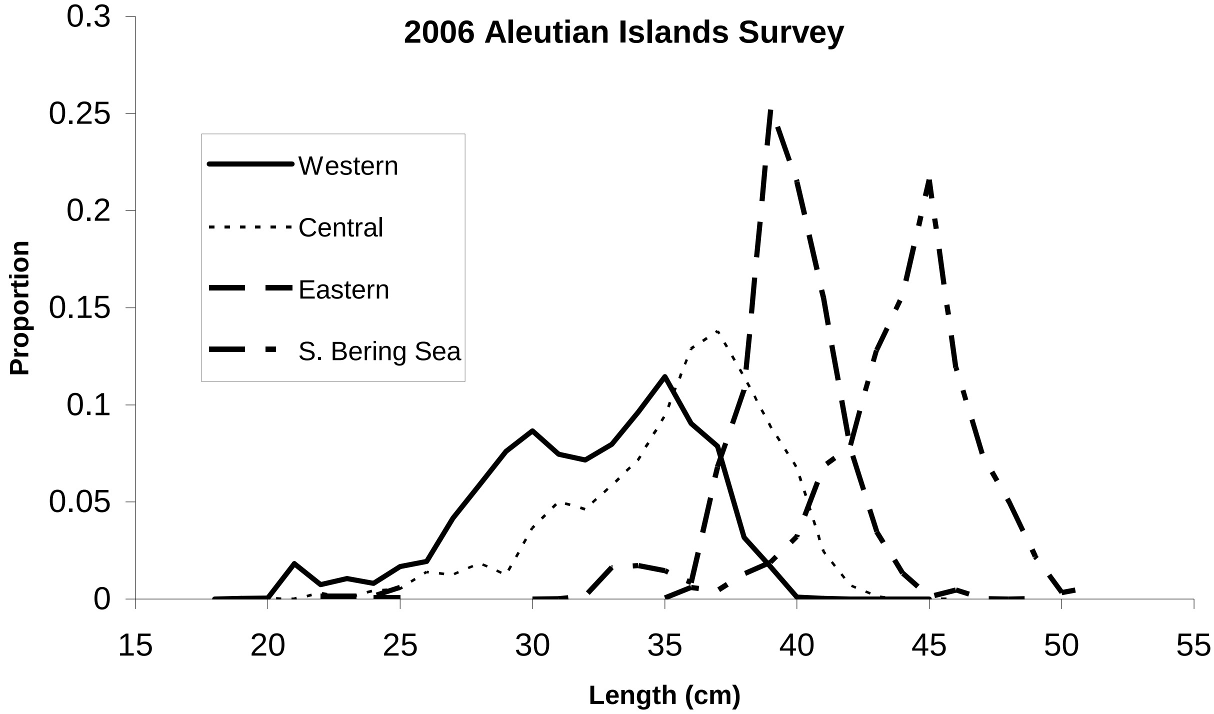


Figure 15.8. Atka mackerel bottom trawl survey length frequency data by subarea from the 2006 Aleutian Island survey.

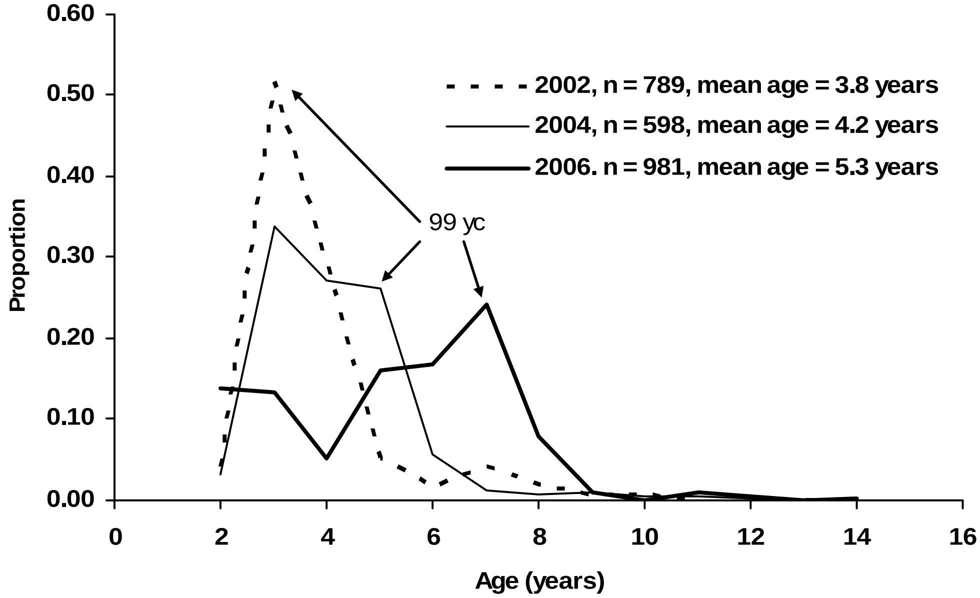


Figure 15.9. Atka mackerel age distributions from the Aleutian Islands region from the 2002, 2004, and 2006 bottom trawl surveys.

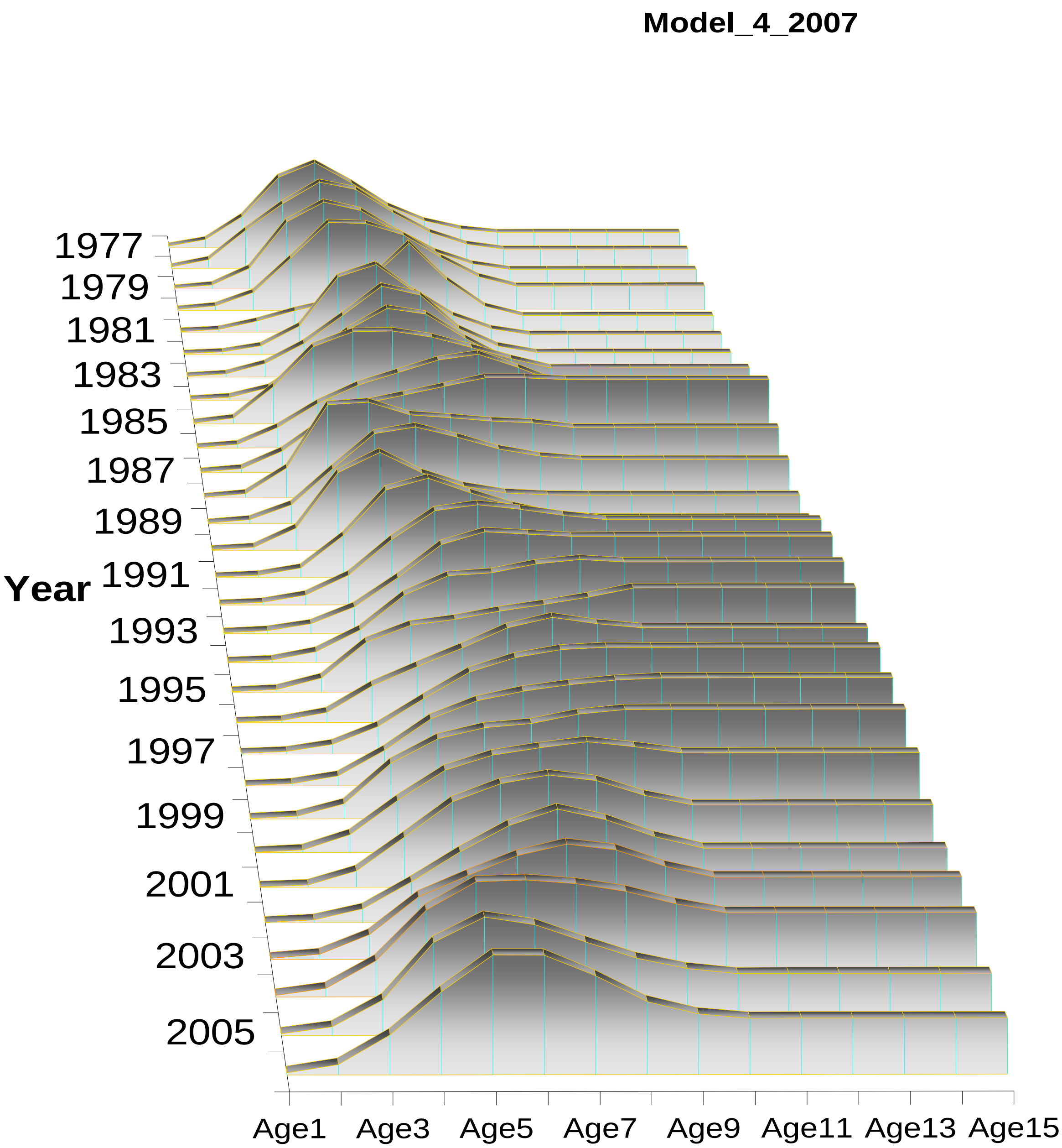


Figure 15.10. Estimated annual Atka mackerel fishery selectivity-at-age patterns.

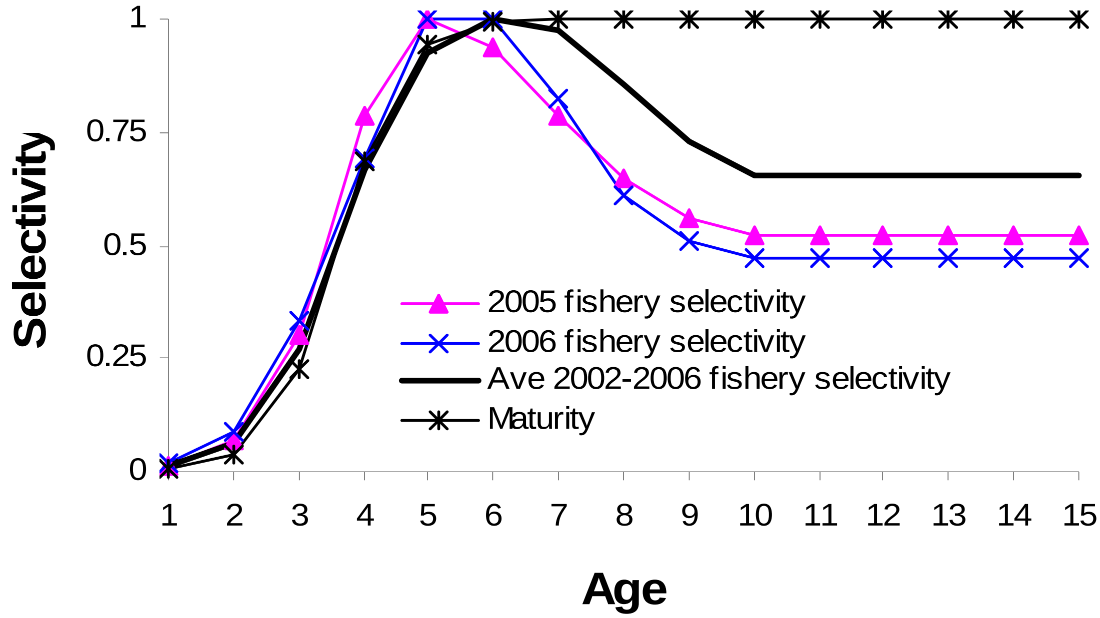


Figure 15.11. Estimated 2005 2006 and the average of the 2002-2006 selectivity-at-age patterns compared with the maturity-at-age estimates for Atka mackerel.

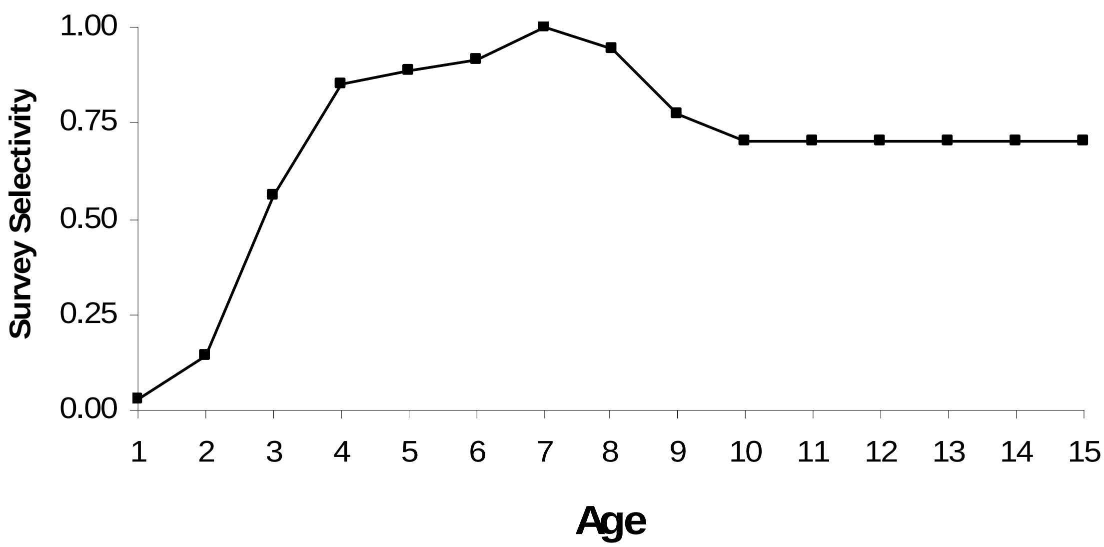


Figure 15.12. Estimated Atka mackerel survey selectivity-at-age.

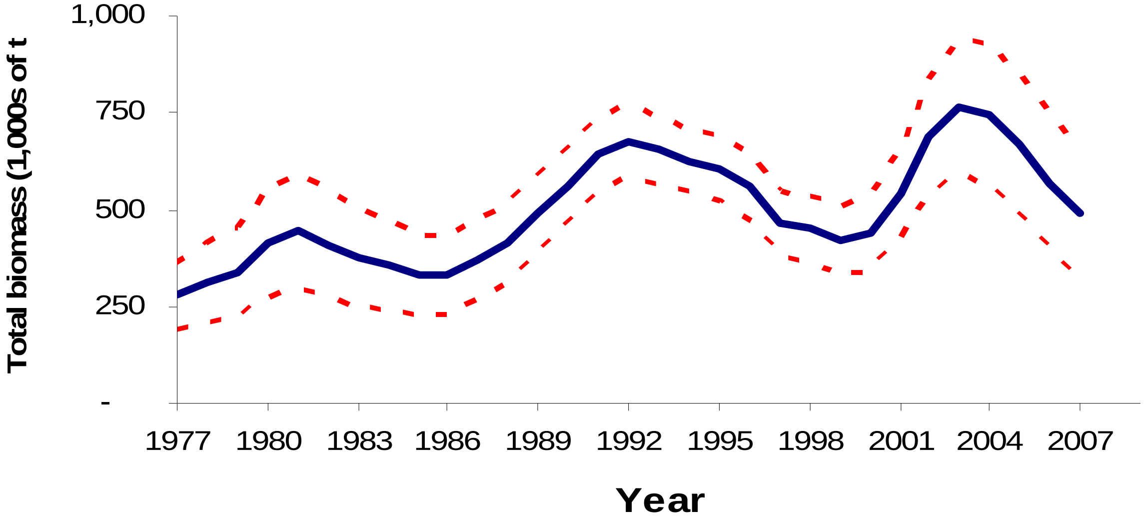


Figure 15.13. Time series of Atka mackerel total (age 1+) biomass estimates in thousands of metric tons, and approximate 95% confidence bounds.

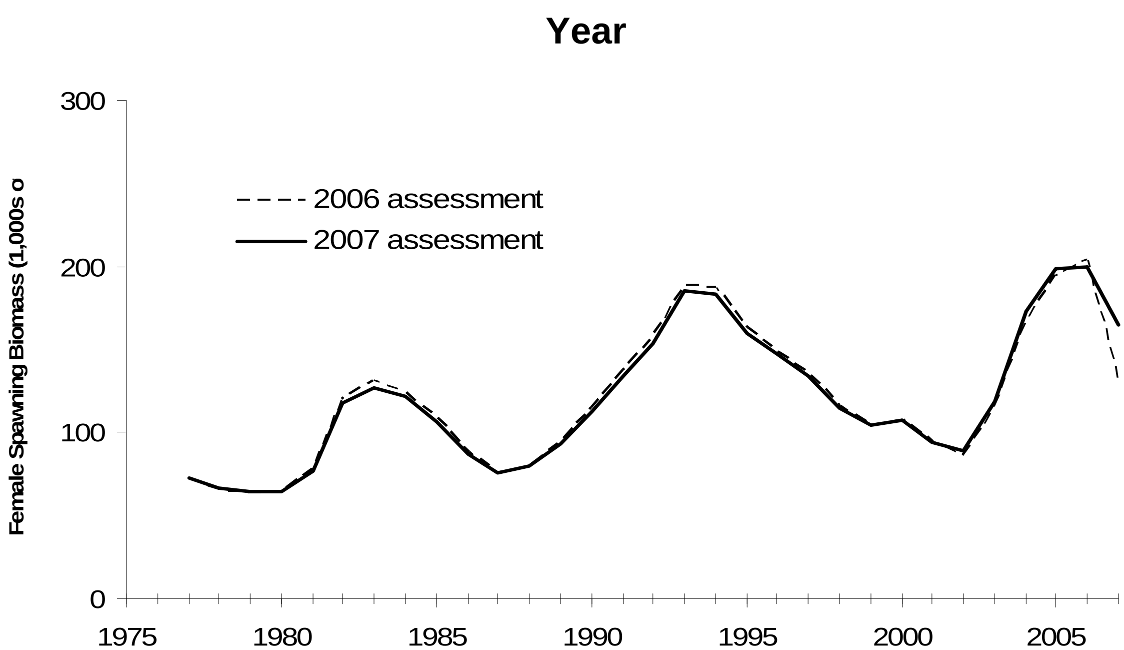


Figure 15.14. Comparison of the 2006 assessment (Lowe *et al.* 2006) of BSAI Atka mackerel female spawning biomass in thousands of metric tons to the current estimate.

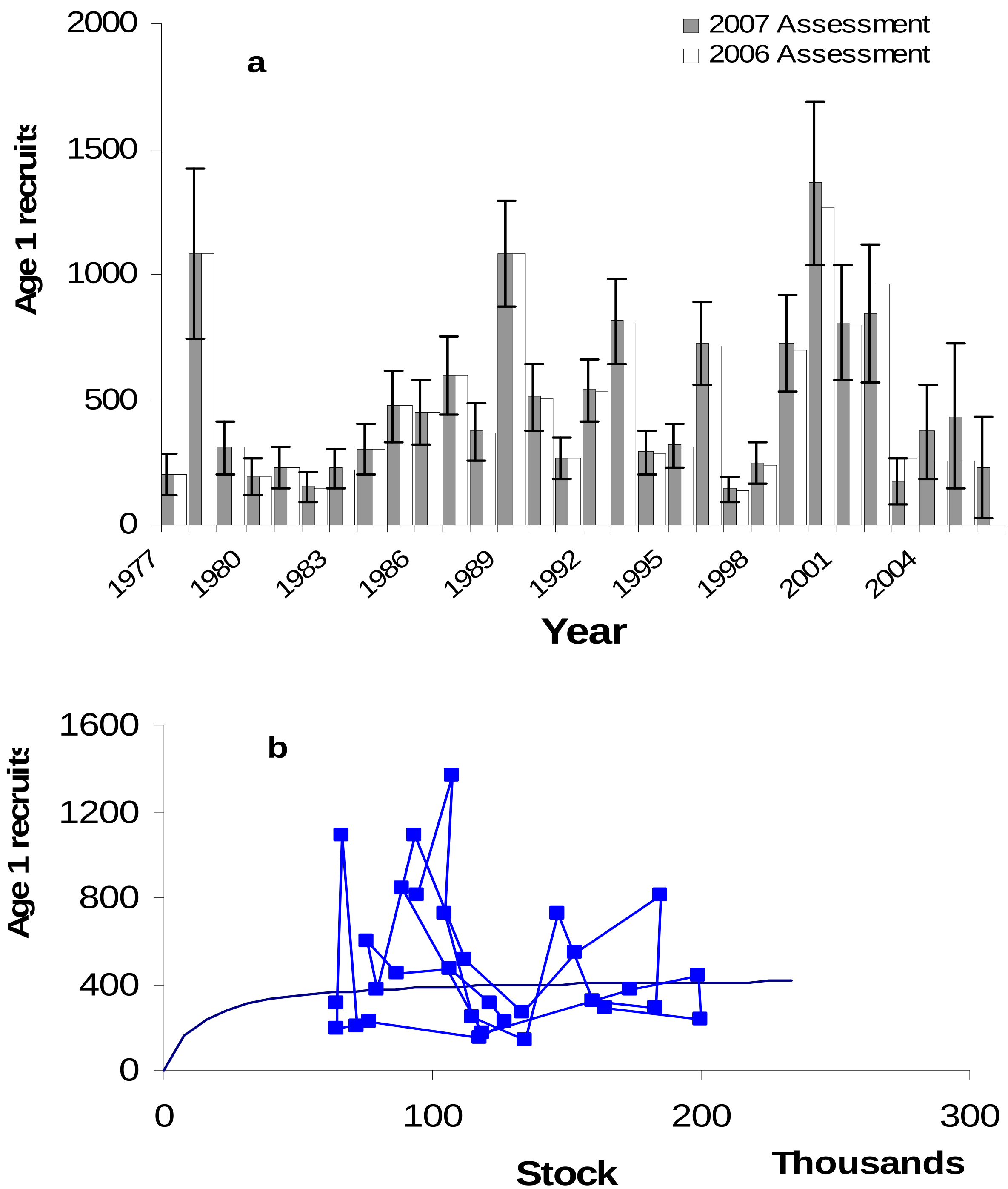


Figure 15.15 a) Age 1 recruitment of Atka mackerel as estimated from the current assessment, with error bars representing two standard errors (top panel), and b) estimated female spawning biomass levels in thousands of metric tons (lower panel). Solid line represents the underlying Beverton-Holt stock recruitment curve assumed in the model.

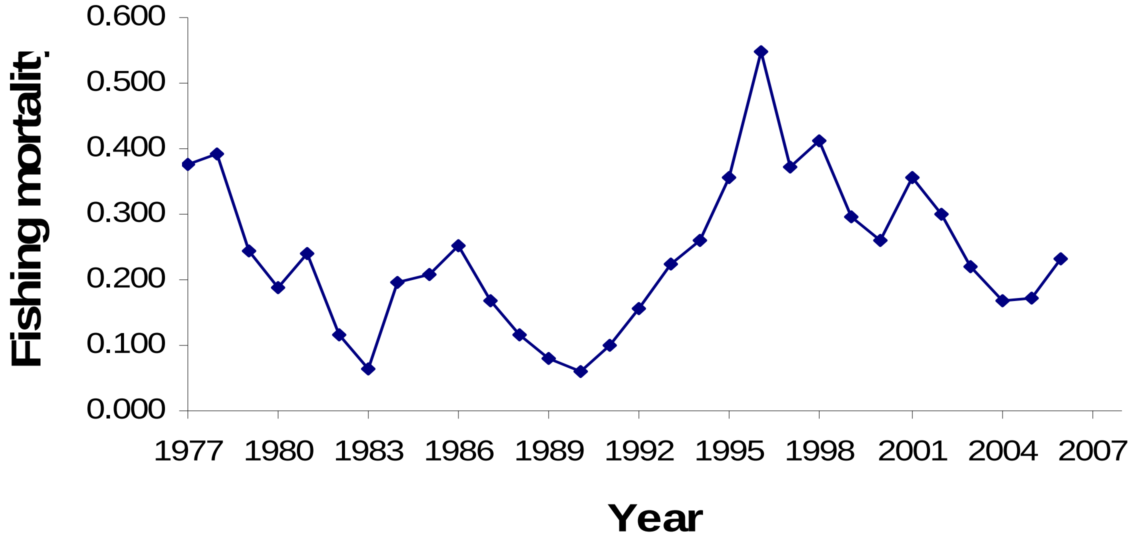


Figure 15.16. Estimated time series of full-selection fishing mortality rates of Atka mackerel, 1977-2006.

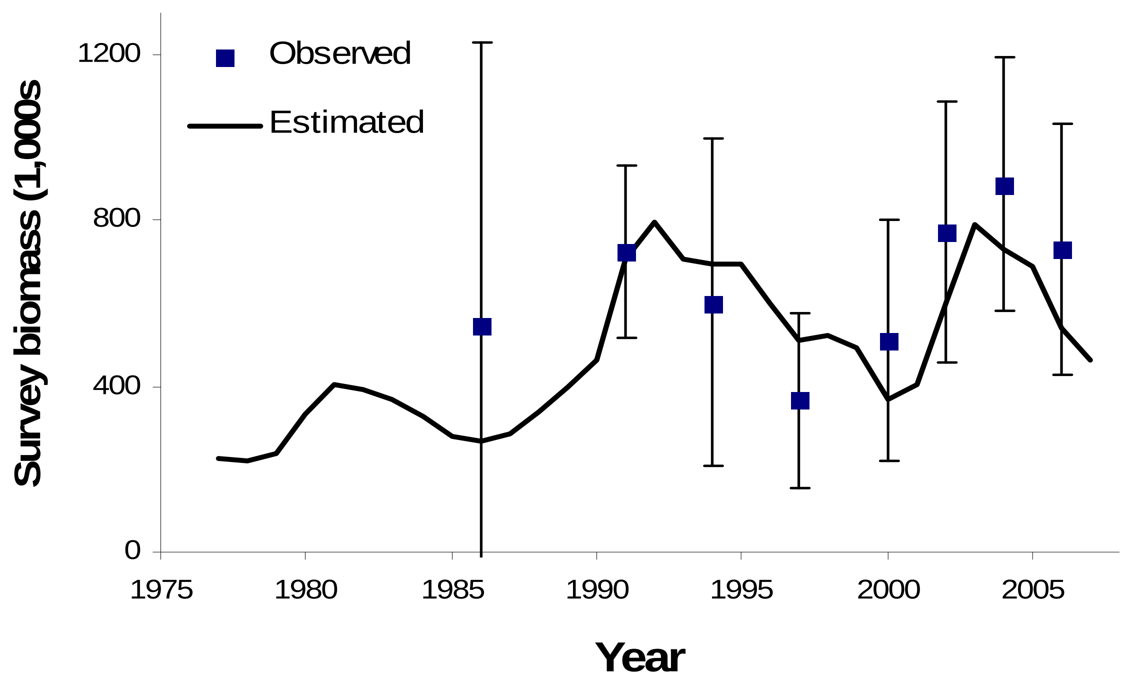


Figure 15.17. Observed and predicted survey biomass estimates in thousands of metric tons for Aleutian Islands Atka mackerel. Error bars represent two standard errors (based on sampling) from the survey estimates.

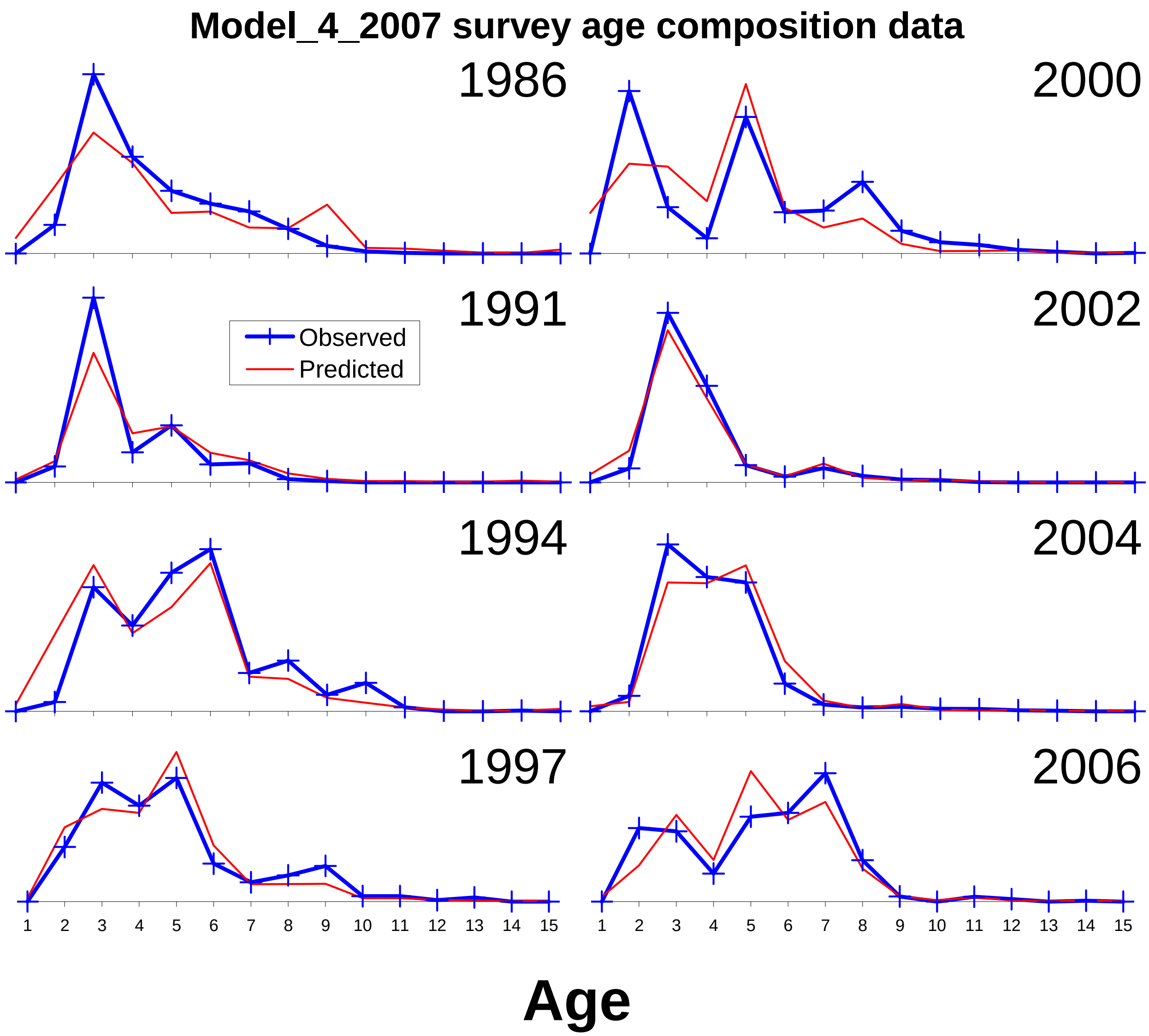


Figure 15.18. Observed and predicted proportions-at-age for Atka mackerel. Continuous lines are the model predictions and lines with "+" symbols are the observed proportions at age.

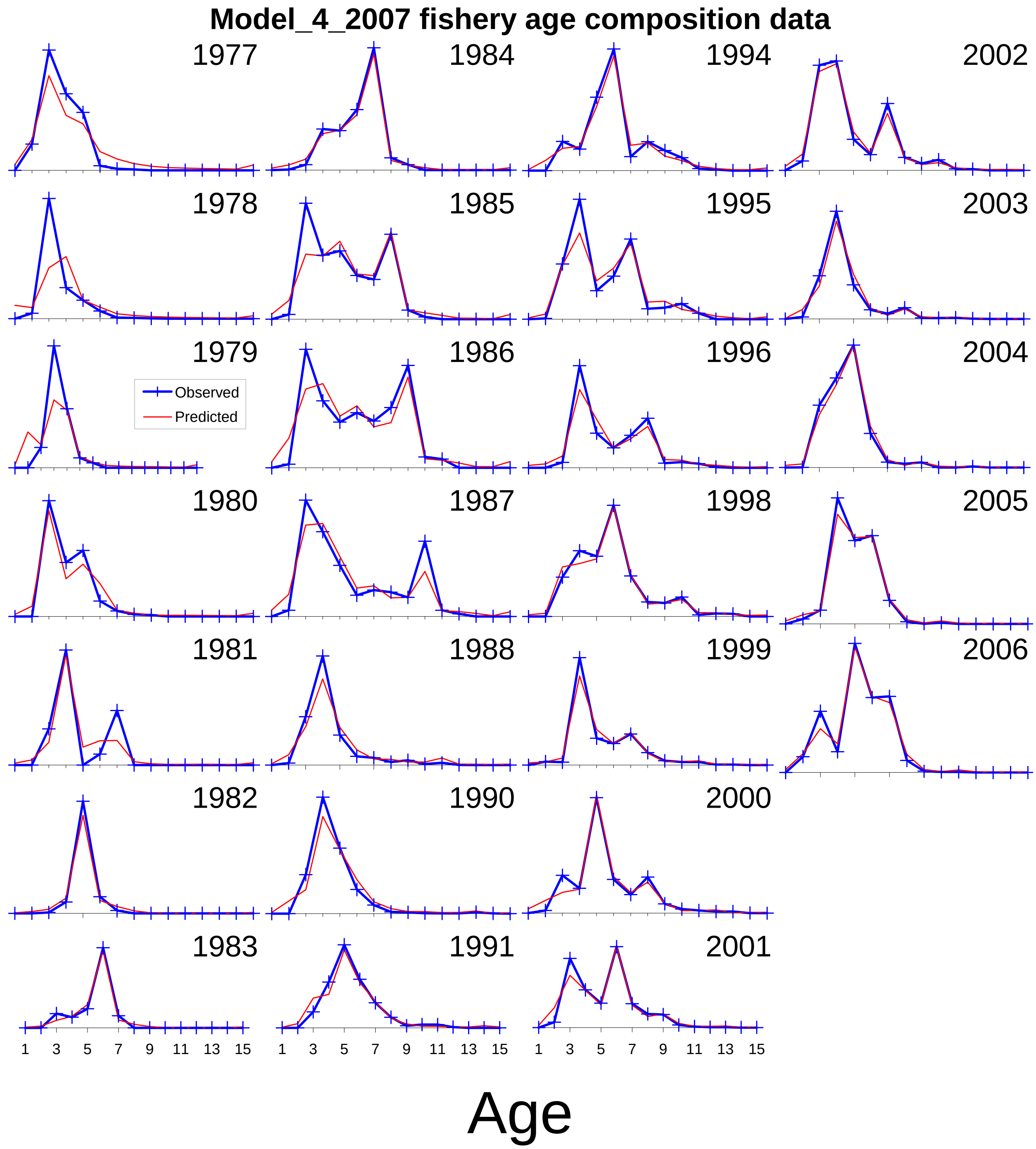
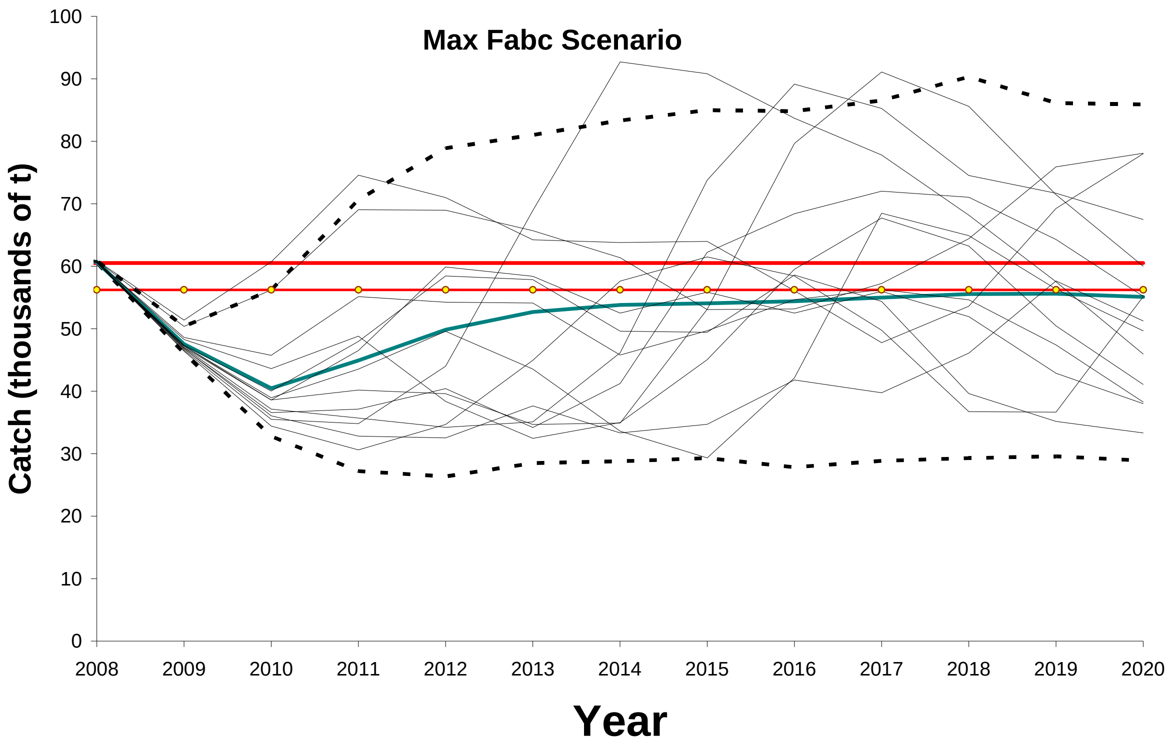


Figure 15.19. Observed and predicted Atka mackerel proportions-at-age for fishery data. Continuous lines are the model predictions and lines with "+" symbol are the observed proportions at age.



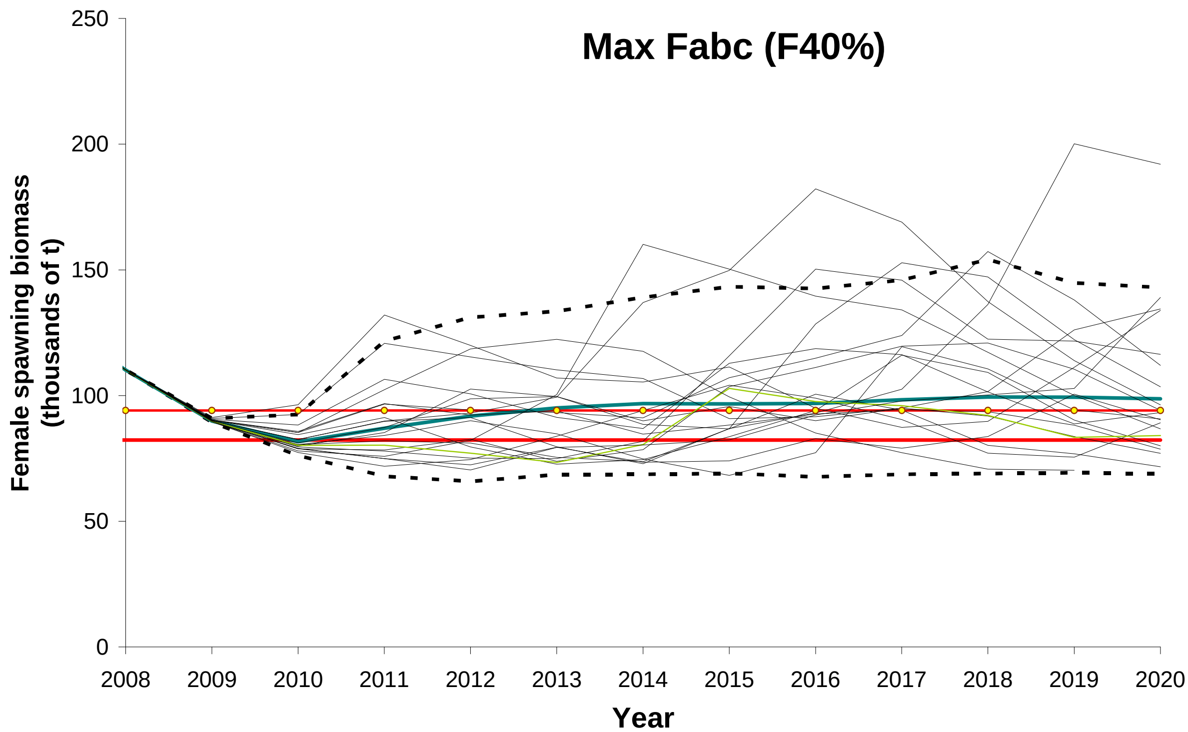


Figure 15.20. Projected catch in (top) and spawning biomass (bottom) in thousands of metric tons under maximum permissible Tier 3a harvest levels. The individual thin lines represent samples of simulated trajectories.

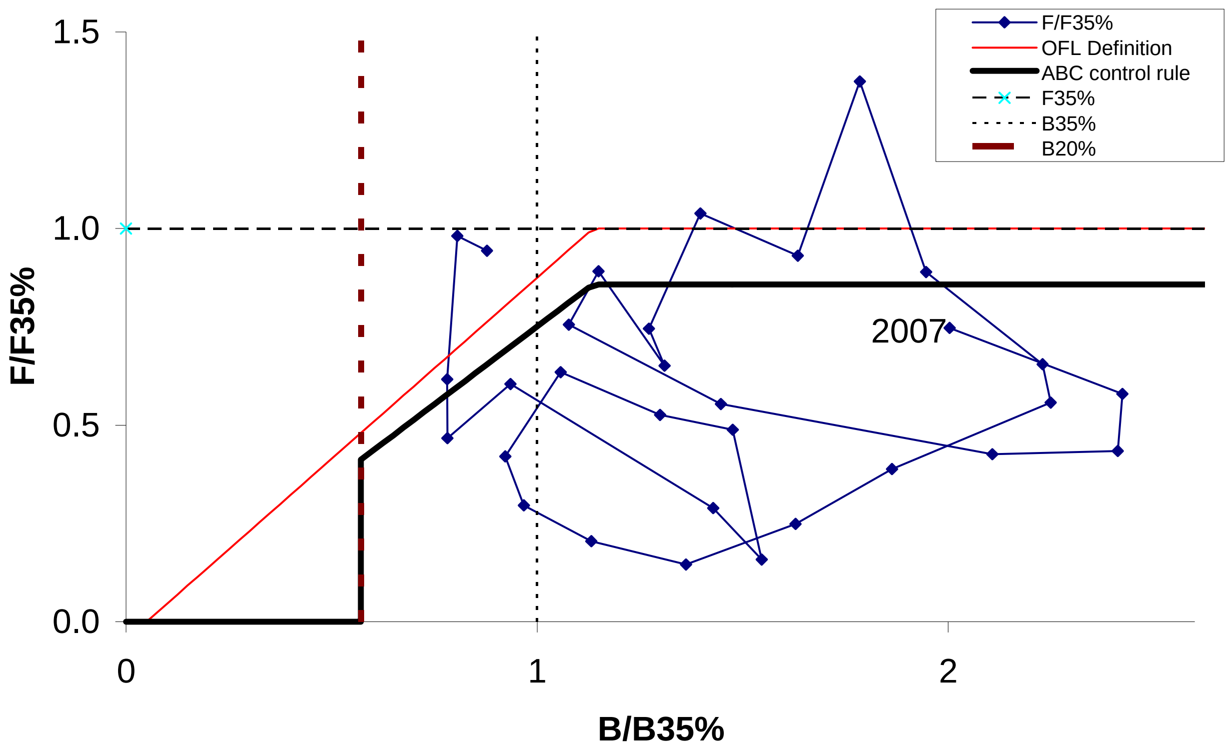


Figure 15.21. Aleutian Islands Atka mackerel spawning biomass relative to $B_{35\%}$ and fishing mortality relative to F_{OFL} (1977-2007). The ratio of fishing mortality to F_{OFL} is calculated using the estimated selectivity pattern in that year. Estimates of spawning biomass and $B_{35\%}$ are based 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.

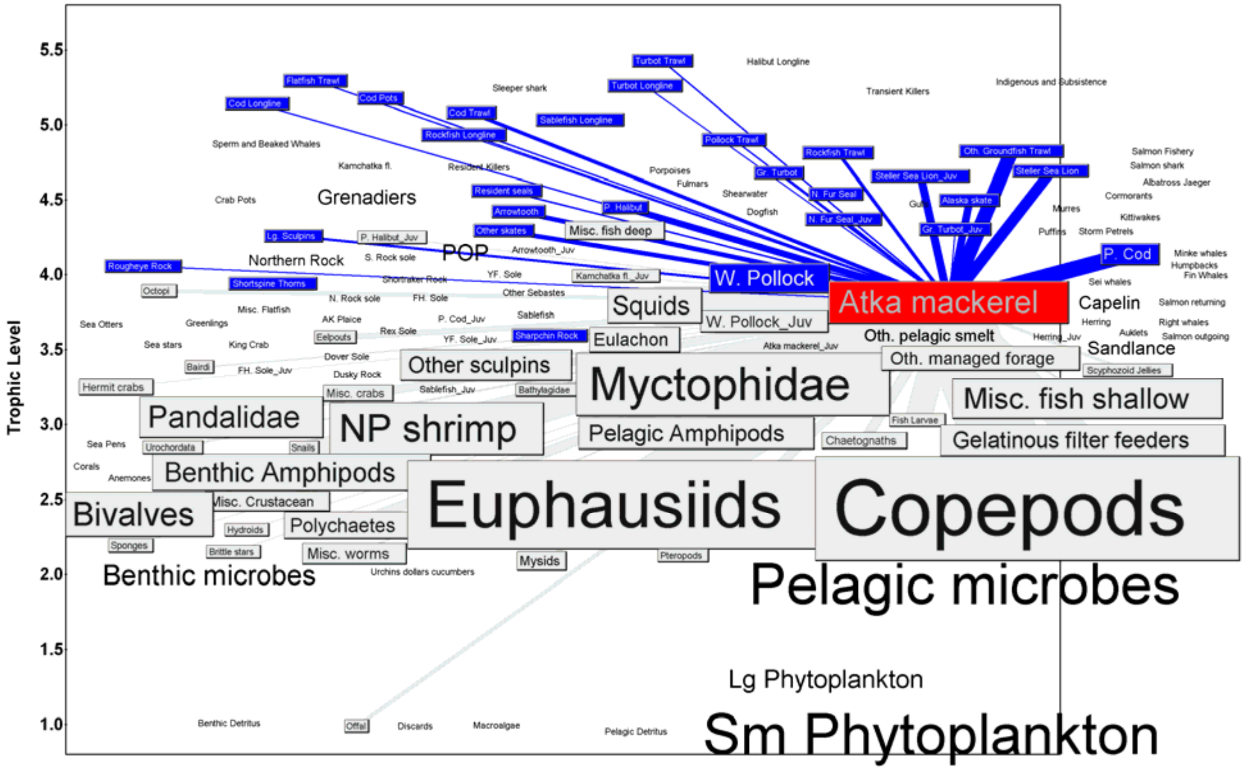


Figure 15.22. The food web of the Aleutian Islands survey region, 1990-1994, emphasizing the position of age 1+ Atka mackerel. Outlined species represent predators of Atka mackerel (dark boxed with light text) and prey of Atka mackerel (light boxes with dark text). Box and text size are proportional to each species' standing stock biomass, while line widths are proportional to the consumption between boxes (t/year). Trophic levels of individual species may be staggered up to +/-0.5 of a trophic level for visibility.

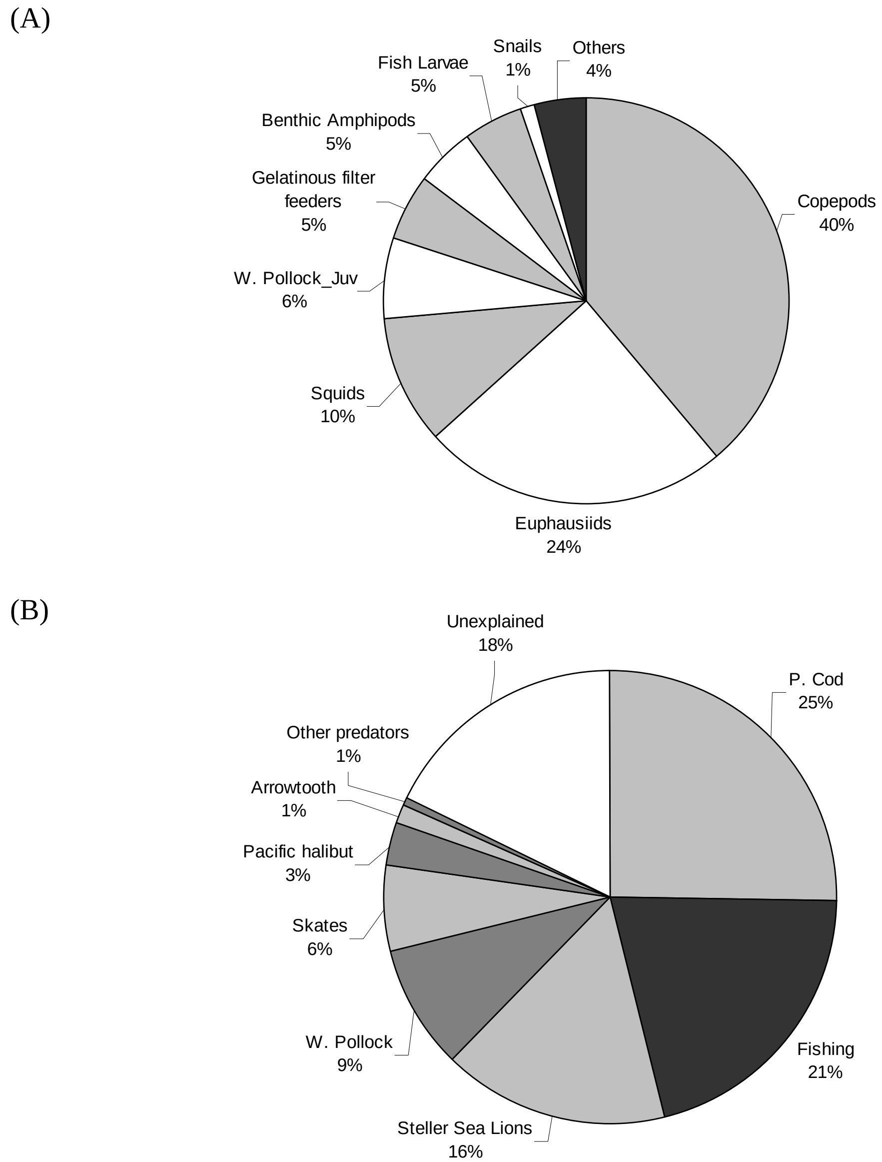


Figure 15.23. (A) Diet of age 1+ Atka mackerel, 1990-1994, by percentage wet weight in diet weighted by age-specific consumption rates. (B) Percentage mortality of Atka mackerel by mortality source, 1990-1994. "Unexplained" mortality is the difference between the stock assessment total exploitation rate averaged for 1990-1994, and the predation and fishing mortality, which are calculated independently of the assessment using predator diets, consumption rates, and fisheries catch.

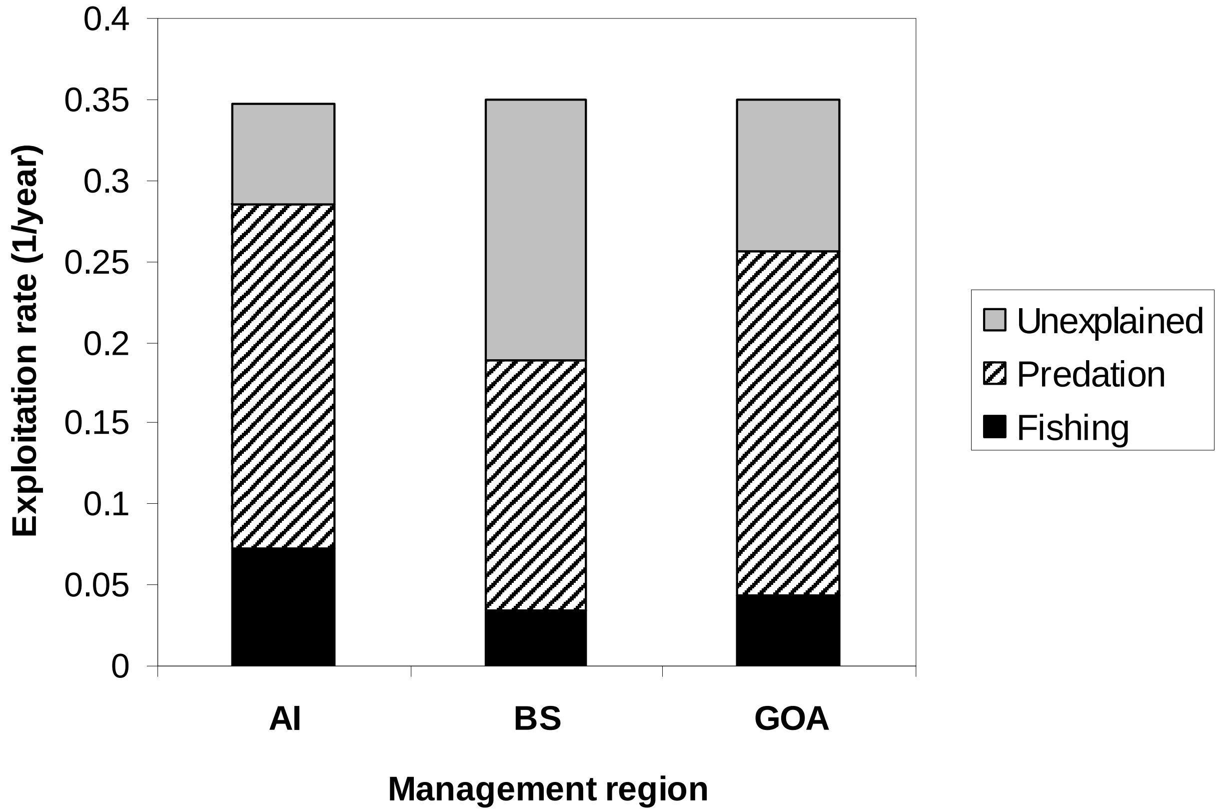


Figure 15.24. Total exploitation rate of age 1+ Atka mackerel, 1990-1994, proportioned into exploitation by fishing (black), predation (striped) and “unexplained” mortality (grey). “Unexplained” mortality is the difference between the stock assessment total exploitation rate averaged for 1990-1994, and the predation and fishing mortality, which are calculated independently of the assessment using predator diets, consumption rates, and fisheries catch.

Appendix 15.A

Table A-1. Variable descriptions and model specification.

General Definitions	Symbol/Value	Use in Catch at Age Model
Year index: i = {1977, …., 2007}		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	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, …, 2007	$\varepsilon_i, \; \sum_{i=1963}^{2007} \varepsilon_i = 0$	$N_{i,1} = e^{\mu_R + \varepsilon_i}$
Index catchability Mean effect	μ^s, μ^f	$q_i^s = e^{\mu^s}$
Age effect	$\eta_j^s, \; \sum_{j=1}^{15^+} \eta_j^s = 0$	$s_j^s = e^{\eta_j^s}$ $\quad j \le \text{maxage}$ $s_j^s = e^{\eta_{\text{maxage}}^s}$ $\quad j > \text{maxage}$
Instantaneous fishing mortality		$F_{ij} = e^{\mu_f + \eta_j^f + \phi_i}$
mean fishing effect	μ_f	
annual effect of fishing in year *i*	$\phi_i, \; \sum_{i=1977}^{2007} \phi_i = 0$	
age effect of fishing (regularized) In year time variation allowed	$\eta_{ij}^f, \; \sum_{j=1}^{15^+} \eta_{ij} = 0$	$s_{ij}^f = e^{\eta_j^f}$, $\quad j \le \text{maxage}$ $s_{ij}^f = e^{\eta_{\text{maxage}}^f}$ $\quad j > \text{maxage}$
In years where selectivity is constant over time	$\eta_{i,j}^f = \eta_{i-1,j}^f$	$i \ne \text{change year}$
Natural Mortality	*M*	
Total mortality		$Z_{ij} = F_{ij} + M$
Recruitment Beverton-Holt form	$\tilde{R}_i$	$\tilde{R}_i = \frac{\alpha B_i}{\beta + B_i}$, $\alpha = \frac{4hR_0}{5h-1}$ and $\beta = \frac{B_0(1-h)}{5h-1}$ where $B_0 = \tilde{R}_0 \varphi$ $\varphi = \frac{e^{-15M} W_{15} p_{15}}{1-e^{-M}} + \sum_{j=1}^{15} e^{-M(j-1)} W_j p_j$

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	$L_3 = \lambda_3 \sum_{i=1963}^{2007} \varepsilon_i^2$	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	$L_4 = \lambda_4 \sum_{i=1977}^{2007} \ln\left(C_i / \hat{C}_i\right)^2$	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	$L_6 = \lambda_6 \sum_{i=1977}^{2007} \phi_i^2$	(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	$\dot{L} = \sum_{i=1}^{7} L_i$	

Appendix B

The association between surface temperature and the occurrence of juvenile Atka mackerel (*Pleurogrammus monopterygius*) in the Eastern Bering Sea

by

Chantel Wetzel and Susanne McDermott

Introduction

Atka mackerel (*Pleurogrammus monopterygius*), a member of the greenling family (Hexamgrammidae), is distributed along the Alaska coastline ranging from the Gulf of Alaska, stretching through the Aleutian Islands and extending into Russian waters. The largest biomass of Atka mackerel occurs along the Aleutian Island chain. Adults form dense aggregations creating patchy distributions of Atka mackerel in areas of high currents such as island passes in the island chain (Lowe et al. 2006).

Atka mackerel is the target of an important commercial fishery with over 60,000 t in reported landings per year from 2004 to 2006 (Lowe et al. 2006). Beyond its commercial importance Atka mackerel plays an important role in the diet of several marine fishes such as Pacific cod, Pacific halibut and arrowtooth flounder (Yang 1999), as well as an important part in the diet of endangered Aleutian Island chain Steller sea lion population (Sinclair and Zeppelin 2002).

Atka mackerel show a distinct growth cline from east to west with fish reaching 50% maturity at 380 mm in the Gulf and 330 mm in the Western Aleutians. However, all areas show fish reaching 50% age at maturity at 3.6 years (McDermott and Lowe 1997). Adult Atka mackerel are batch spawners. Spawning typically occurs between June and October (McDermott and Lowe 1997). Eggs are spawned and fertilized in rock crevices at which point male Atka mackerel practice nest guarding for the duration of egg development (Zolotov 1993). The duration of time prior to hatching varies with water temperature. Hatching on average occurs after 75-80 days at a temperature of 6 °C. This results in a protracted period of male nest guarding that can last from July until January with hatching occurring between October and January (Lauth and Blood, *in press*). The extended period of spawning and hatching times result in an extended range of juvenile Atka mackerel sizes based upon early or late hatching dates.

Following their larval stage juvenile Atka mackerel undergo a steep growth rate for their first two years. During this period of growth juvenile Atka mackerel spend their time off shore in pelagic waters. Despite its importance as a commercial fish stock and a prey item for Steller sea lions, little is known about the distribution of Atka mackerel during their juvenile life stages prior to adult settlement.

The Bering-Aleutian Salmon International Survey (BASIS) project, a study aimed at studying salmon during their time at the high seas, has conducted detailed surveys of the upper pelagic layer in the Bering Sea from 2004 to 2006. The United States branch of the international collaboration has collected biological information during their surveys of the eastern Bering Sea. Additional to collecting data pertaining to salmon species they have also collected and recorded information for many other Alaskan fish species, including juvenile Atka mackerel. This paper examines the distribution of juvenile Atka mackerel in the eastern Bering Sea sampled by the BASIS project, exploring possible relationships between temperature and Atka mackerel abundance along with community composition based upon the presence or absence of Atka mackerel.

Methods

The data analyzed in this study were collected as part of the BASIS project. The area surveyed covered the eastern Bering Sea, extending from the Alaska coastline out to the continental slope. The BASIS project has been geared toward understanding the pelagic distribution of salmon and has conducted standardized surface tows from 2000 until the present. Atka mackerel juveniles have been caught in surface trawls during this survey. The data used for this study were the survey tows from 2004 -2006, since they presented the most comparable data collection and station selection (Figure B-1). Surveys were conducted from mid August to the end of September for the years of 2004 and 2006, with surveying in 2005 starting in mid August and extending into the first part of October (Table B-1). Samples were collected with surface tows by research vessels using the same fishing gear, a midwater rope trawl, model 400/580, made by Cantrawl Pacific Ltd. of Richmond, B.C. with a net length of 198 m long with a hexagonal mesh in the wings and body and a 1.2 cm mesh liner in the codend. Floats were used on the headrope to assist in keeping the headrope at the surface. At each station a tow lasting duration of 30 minutes was conducted at speeds ranging from 3.5 to 5 knots. All species collected were identified, weighed, range of lengths, and numerical abundance recorded, with greenling species being identified down to species level.

At each survey location where Atka mackerel were identified, numbers were recorded along with the largest and smallest individual providing a range of sampled lengths at each sample site. The midpoint of the length range was assumed to be representative of average length at each station with juvenile Atka mackerel defined as individuals that were less than 250 mm fork length.

The distribution and numerical abundance of juvenile Atka mackerel by sample site was plotted for all three years. All hauls were 30 minutes in length, hence effort was assumed to be standardized by haul and numerical abundance could be used as a proxy for CPUE. In 2006 additional stations were covered along the Bering Sea continental slope, expanding the sampling area compared to the two previous years of sampling.

Temperature data were obtained using a CTD at the same time and location the haul was conducted. Surface and bottom temperature readings were recorded at each station over the three survey years. Surface temperature was defined at 5 m in depth with the bottom temperature being the deepest temperature recorded. Surface temperature was compared by surveyed location and the numerical abundance of juvenile Atka mackerel present. Frequency distribution of hauls with Atka mackerel present vs. surface temperature was created to examine sampling effort by degree surface temperature.

To examine haul composition percentage weight, all hauls were broken down into four different categories: hauls with no juvenile Atka mackerel present, hauls with 1 juvenile Atka mackerel, hauls with 2 to 9 juvenile Atka mackerel, and hauls with 10 or more juvenile Atka mackerel. Hauls from 2006 were excluded from this analysis due to incomplete weight data for that year. Species composition was determined for each category using combined data from 2004 and 2005. The main species were recorded with incidental species summarized in the category ‘other species’ (Table B-2).

Results

The distribution of juvenile Atka mackerel over the three survey years is shown in Figure B-2. The distribution of Atka mackerel was similar for the 2004 and 2005 survey years (Figure B-2A,B). In 2006 the distribution of juvenile Atka mackerel was the furthest westward along the Bering Sea continental slope of all sampling years (Figure B-2B,C). Few juvenile Atka mackerel were recorded in the region of the Bering Sea east of the continental slope for the 2006 survey, where in previous years they had been located.

The highest number of juvenile Atka mackerel (352) was surveyed during 2004 with eight stations having at least ten juveniles present (Figure B-2A). The number of juvenile Atka mackerel sampled dropped to 46 in 2005 and to 68 in 2006. The average of the ranges of lengths for 2004, 2005, and 2006 were 181 mm, 178 mm, and 163 mm respectively.

Of the total number of juvenile Atka mackerel surveyed (*N*=338) at stations where a surface temperature was recorded, the highest number were found in surface waters measuring 11 °C, with a total of 208 individuals found over the three survey years (Figure B-3A). The next highest number of individuals occurred at 10 °C with 61 juvenile fish. When haul frequency distribution based upon surface temperature was examined, it showed a range of 7 through 11 hauls across 8 °C to 11 °C surface water temperature (Figure B-3B). This assured similar sampling effort across this temperature range. When bottom temperature was plotted against juvenile Atka mackerel abundance, there seemed to be no relationship between number of juvenile Atka mackerel and bottom temperature ranges (Figure B-4).

Hauls in the category of juvenile Atka mackerel ≥ 10 (N=9) were comprised of a majority of salmon by % weight, followed by walleye pollock, Pacific herring, and Atka mackerel with 59.6%, 23.5%, 9.0%, and 6.4% of the total weight respectively (Figure B-5A). Hauls in the category of $2 \leq \text{Atka mackerel} \leq 9$ (N=13) the majority of the % weight was made up of walleye pollock, followed by Pacific herring, and salmon with 46.4%, 32.9%, and 18.3% total weight respectively (Figure B-5B). Hauls in the category of one juvenile Atka mackerel (N=20) contained a majority of walleye pollock and salmon with 60.9% and 33.5% total weight respectively (Figure B-5C). Hauls in the category were Atka mackerel was absent (N=227) walleye pollock, Pacific herring, and salmon made up the largest percent weight with 55%, 22%, and 17% respectively (Figure B-5D).

Discussion

The numerical abundance and distribution of juvenile Atka mackerel in the eastern Bering Sea varied over the three years of survey work. In 2004 the numerical abundance was larger compared to the other two proceeding years. Following the von Bertalanffy parameters determined by Lowe et al. (2006), the juvenile Atka mackerel surveyed during this year would be approximately 1.5-1.75 years in age, representing part of the 2003 year class. This study suggests that based upon Bering Sea numbers, the 2003 year class was much stronger than the following two year classes of 2004 and 2005. Atka mackerel do not enter the NMFS groundfish survey catches until they are 2 years old and do not show up in the fishery typically until 3 years of age. The BASIS Bering Sea pelagic survey has provided and opportunity for the possible early detection of strong year classes of Atka mackerel.

The geographic distribution of juvenile Atka mackerel varied from 2004 to 2006. The survey extended the farthest west of all three years in 2006 with additional stations along the continental slope. With this extension of sampling effort, the distribution of Atka mackerel detected in 2006 was the farthest west of all years, with the highest occurrence along the Bering Sea continental slope. The sampling in the two previous years unfortunately did not include this region hence the appearance of juvenile Atka mackerel would not have been detected in this area in 2004 and 2005. However, despite this sampling variation, juvenile Atka mackerel were found in different areas in 2006 than in the previous years.

In 2004 and 2005 Atka mackerel were distributed parallel and east to the slope on the shelf, whereas in 2006 they were found along the slope to the west. This might be explained by fact that the waters of the Bering Sea during the sampling period in 2006 were much cooler on average compared to the years of 2004 and 2005. Temperature may be playing an important role in the distribution of juvenile Atka mackerel.

This point was further supported by examining the distribution of juvenile Atka mackerel by surface water temperature. Juvenile Atka mackerel were sampled most frequently in water temperatures of 11 °C. This data points to a possible linkage between surface water temperature and the occurrence of juveniles in the Bering Sea. Adult Atka mackerel situate themselves in very specific locations based upon substrate and water properties (McDermott 2003). The results of this work indicate that juveniles may have their own set of specific preferences of water conditions.

When more than 10 juvenile Atka mackerel were present in a haul the largest contribution by percentage weight was made up of salmon (59.6%), whereas walleye pollock was nearly a third less (23.5%). In haul category of 2-9, walleye pollock had a much larger contribution by weight with 46.4% with salmon dropping to only 18.3%. In hauls with traces of Atka mackerel (1) or no Atka mackerel present, walleye pollock made up and even larger percentage of the haul composition (60.9% and 55.2%, respectively). While the sizes of walleye pollock and salmon included adults, the majority of sizes indicated a juvenile population. This shift of haul composition based upon the level of Atka mackerel presence suggests that Atka mackerel may associate with salmon in their habitat, while juvenile walleye pollock do not appear to be tightly linked to the presence of juvenile Atka mackerel. Juvenile salmon commonly feed upon euphausiids, amphipods, and small nektonic prey such as squid in the eastern Bering Sea (Davis et al. 2003), while juvenile walleye pollock have a diet consisting mainly of euphausiids and copepods (Brodeur et al. 2002). While no data was located for juveniles, adult Atka mackerel diets are composed mostly with euphausiids and calanoid copepods (Yang 1999). One possible explanation is that juvenile Atka mackerel and juvenile walleye pollock are competing for similar resources with Atka mackerel being the superior competitor when present. Either the presence of juvenile Atka mackerel or the absence of walleye pollock can be creating an environment that juvenile salmon are able to exploit. To further test the hypothesis of a linkage between the presence of large quantities of juvenile Atka mackerel and salmon a larger data set along with diet data would be needed. The limited data set used in this study is only an indicator of a possible relationship between the two species.

Additional research can expand upon our knowledge of important connections in the Bering Sea food web, and the role that juvenile Atka mackerel play in this complex system. An increased understanding of Atka mackerel early life history could greatly contribute towards predicting year class success and understanding recruitment mechanisms. Understanding Atka mackerel's complex life history can assist in acknowledging its role in the marine ecosystem and its importance for marine predators, one being the endangered Steller sea lion.

Acknowledgements

Thank you to the BASIS research group for collecting, compiling and sharing their data on Atka mackerel that was so essential to this work. Thank you to Sandra Lowe whose thoughtful comments assisted in the formation of this paper. We also extend my appreciation to Libby Logerwell and the entire Fisheries Interaction Team (FIT) at the Alaska Fishery Science Center (AFSC) that supported our work every step of the way.

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Tables

Table B-1. The number of hauls conducted each survey year by the BASIS project and the number that contained one or more Atka mackerel in the surface tow.

Sampling Dates	Number of Hauls	Number of Hauls with Atka mackerel
8/14/2004 - 9/30/2004	143	24
8/14/2005 - 10/6/2005	127	19
8/16/2006 - 9/20/2006	156	12

Table B-2. List of fish species that comprise the other species category used in the haul composition by weight in each defined Atka mackerel category.

Species	Atka mackerel ≥10	1 < Atka mackerel < 10	Atka mackerel=1	Atka mackerel= 0
Alaska plaice	----	----	----	0.01%
Antlered sculpin	----	----	----	<0.01%
Artic lamprey	0.03%	0.06%	0.02%	0.05%
Bering poacher	----	----	----	<0.01%
Bering wolffish	----	----	0.02%	0.01%
Capelin	----	0.04%	0.73%	----
Crested sculpin	0.02%	0.00%	0.04%	0.03%
Dark rockfish	----	0.38%	----	0.01%
Fish unident.	----	----	----	<0.01%
Gonatus kamtschaticus	<0.01%	0.01%	----	<0.01%
Gonatus sp.	----	----	0.08%	<0.01%
Great sculpin	----	----	----	0.01%
Greenland halibut	<0.01%	----	<0.01%	<0.01%
Kelp greenling	----	----	<0.01%	<0.01%
Ninespine stickleback	----	----	----	0.02%
Northern rock sole	----	----	----	0.04%
Pacific cod	0.33%	0.19%	0.23%	0.45%
Pacific sand lance	<0.01%	----	----	0.16%
Pacific sandfish	0.11%	0.01%	0.41%	0.76%
Plain sculpin	----	----	0.01%	0.05%
Pond smelt	----	0.08%	----	<0.01%
Prowfish	0.15%	0.08%	0.09%	0.02%
Rainbow smelt	----	----	----	0.72%
Ribbed sculpin	----	----	----	<0.01%
Rock greenling	0.77%	<0.01%	0.05%	0.02%
Rockfish unident.	<0.01%	<0.01%		<0.01%
Sablefish	0.03%	0.97%	0.16%	0.12%
Saffron cod	----	----	----	0.01%
Salmon shark	----	----	----	1.20%
Snake prickleback	----	----	----	<0.01%
Sturgeon poacher	----	----	0.03%	0.02%
Threespine stickleback	----	0.08%	----	0.01%
Whitespotted greenling	----	----	<0.01%	0.01%
Yellowfin sole	----	----	0.10%	1.42%
Total Other Species	1.44%	1.89%	1.97%	5.16%

Figures

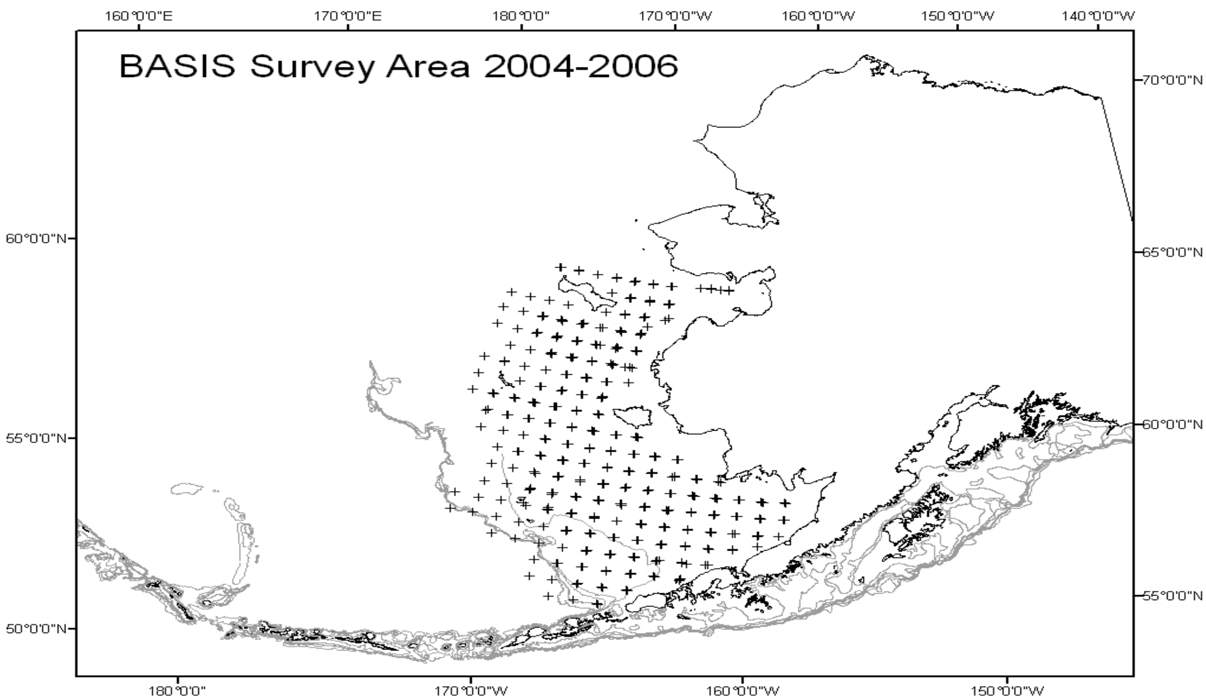


Figure B-1. BASIS project survey sites in the Bering Sea for the years of 2004 to 2006.

A.

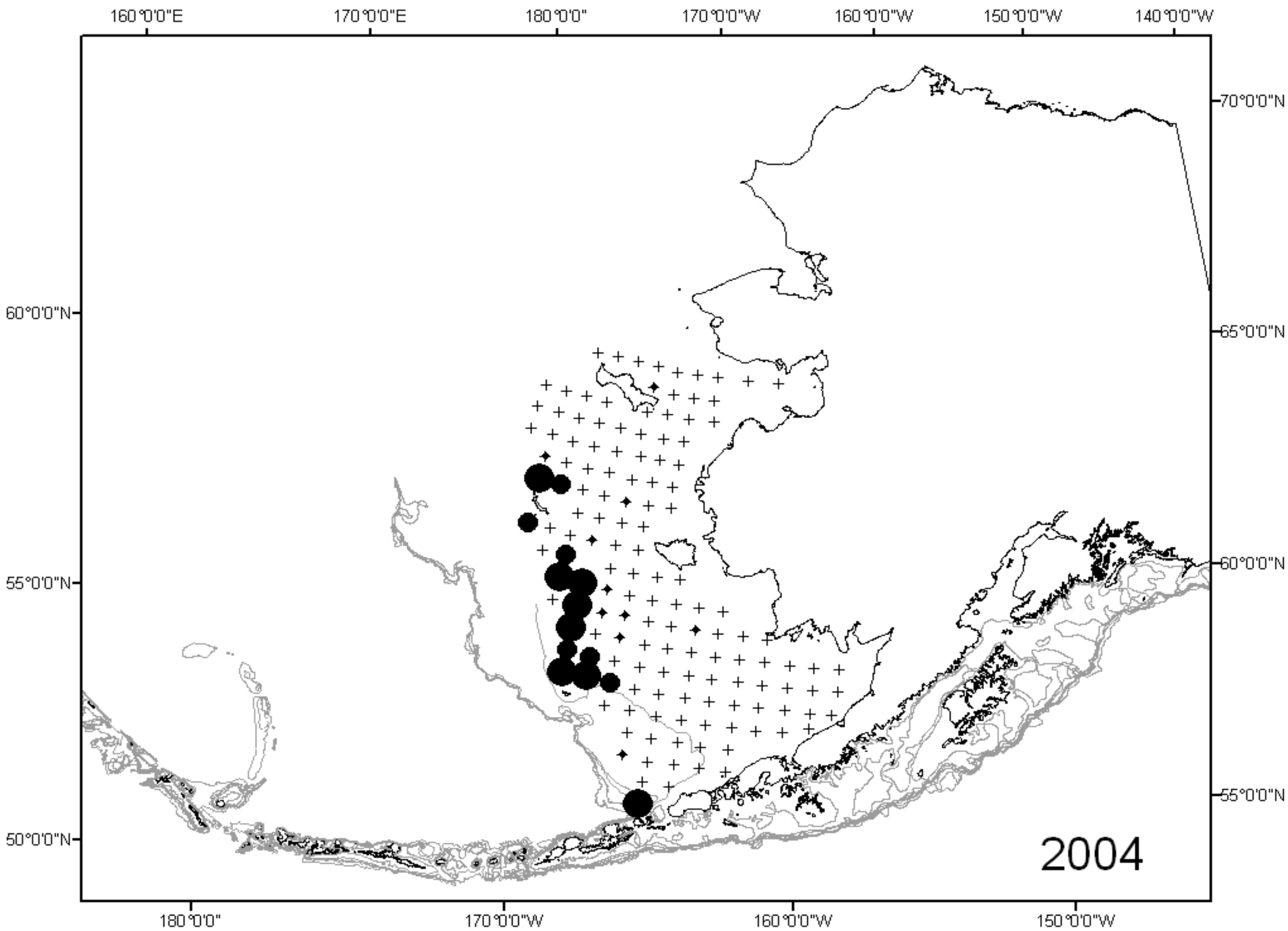


Figure B-2. The surveyed distribution and numerical occurrence by site of juvenile Atka mackerel in the Bering Sea ranging over 2004 (A), 2005 (B), and 2006 (C).

B.

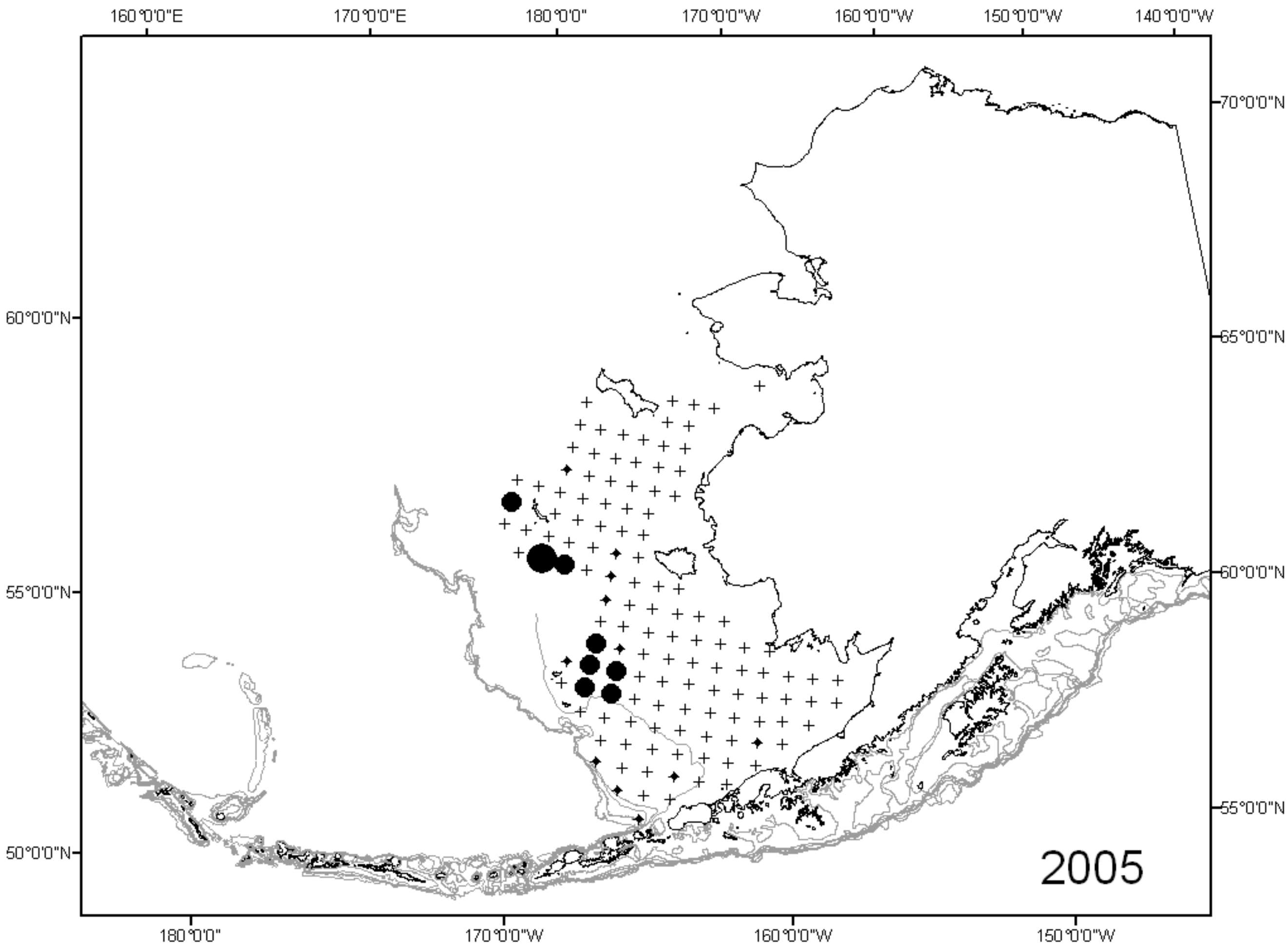


Figure B-2 cont. The surveyed distribution and numerical occurrence by site of juvenile Atka mackerel in the Bering Sea ranging over 2004 (A), 2005 (B), and 2006 (C).

C.

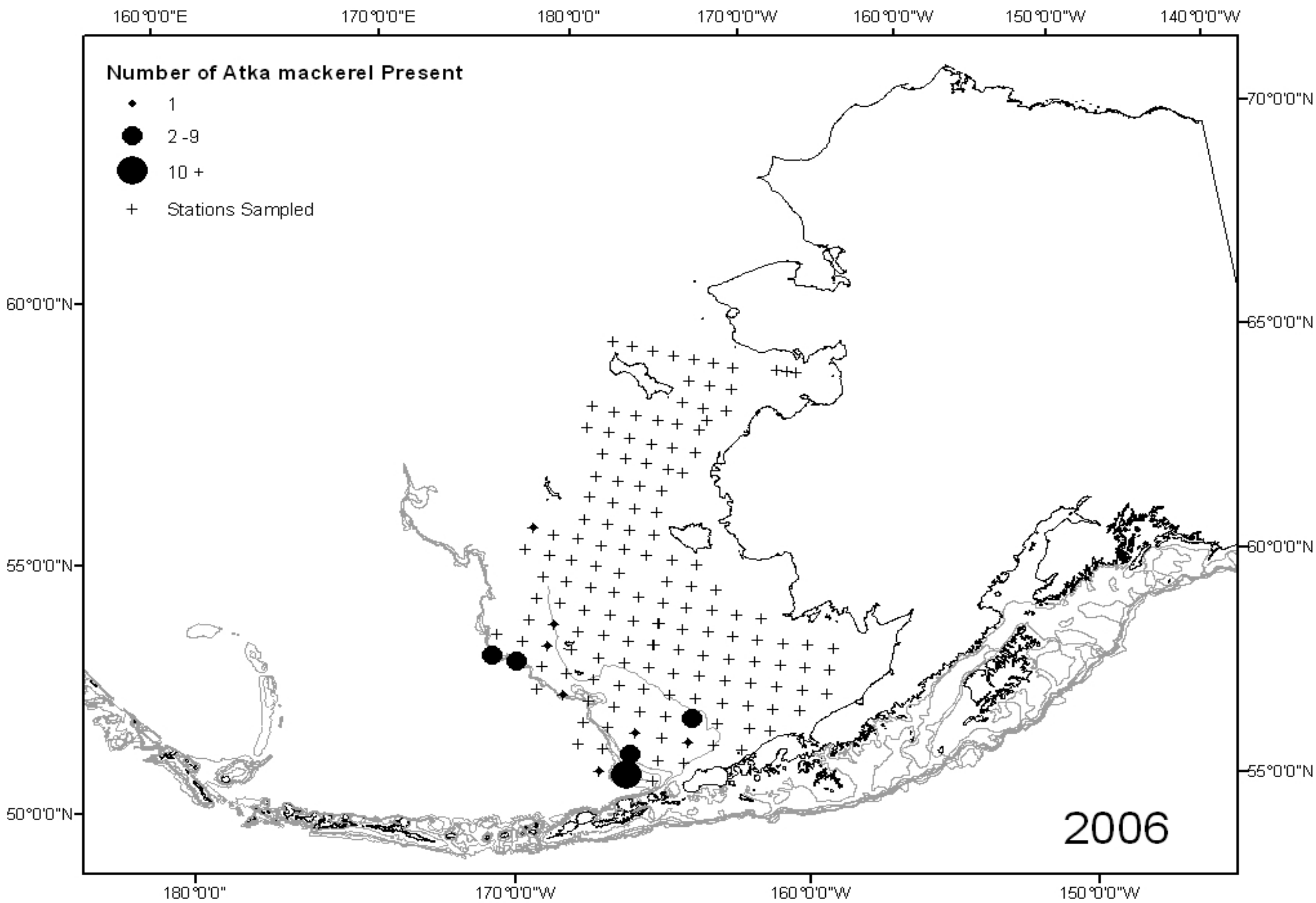
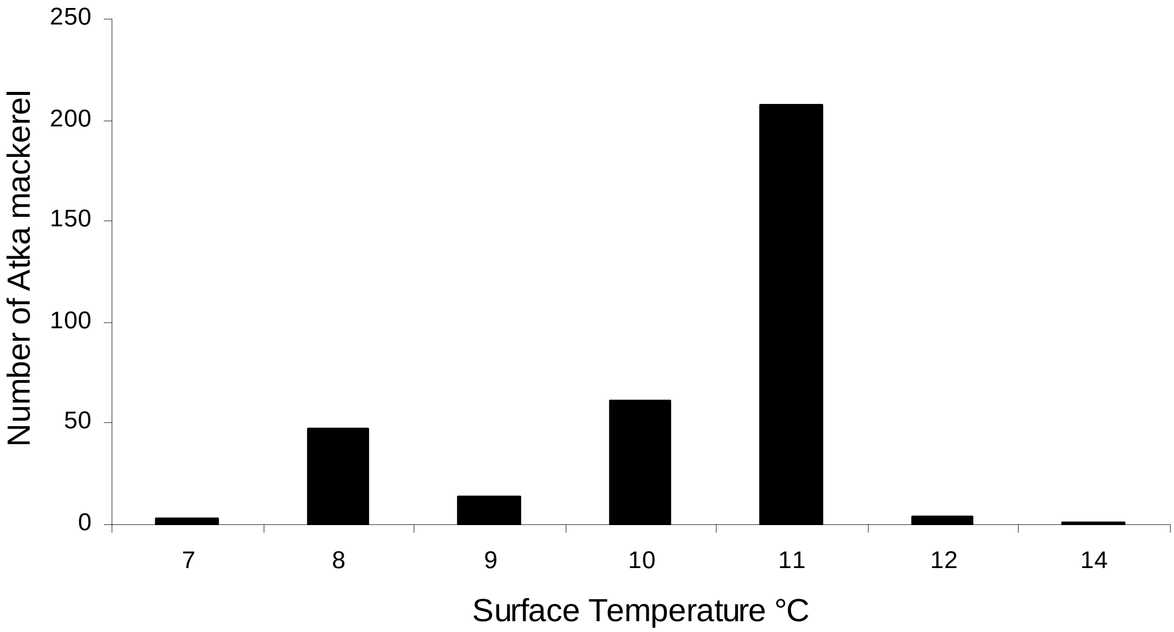


Figure B-2 cont. The surveyed distribution and numerical occurrence by site of juvenile Atka mackerel in the Bering Sea ranging over 2004 (A), 2005 (B), and 2006 (C).

A.



B.

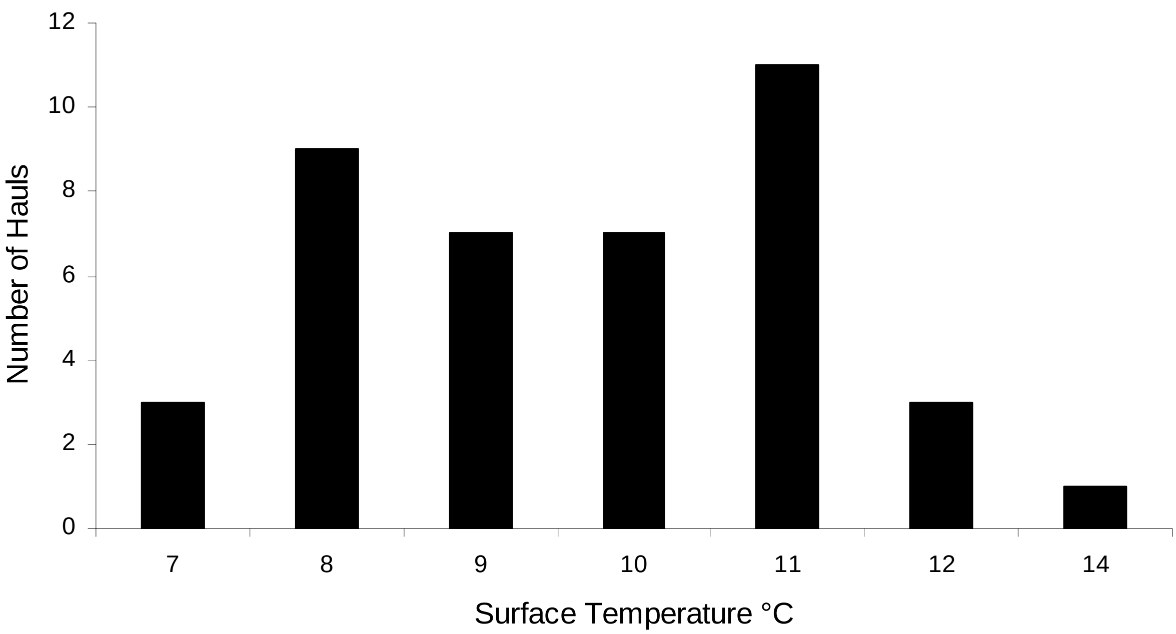


Figure B-3. Surface temperature distribution of the total number of juvenile Atka mackerel (*N*=338) for all hauls combined that contained Atka mackerel (A), and the frequency distribution of hauls with Atka mackerel (*N*=41) by surface temperature (B).

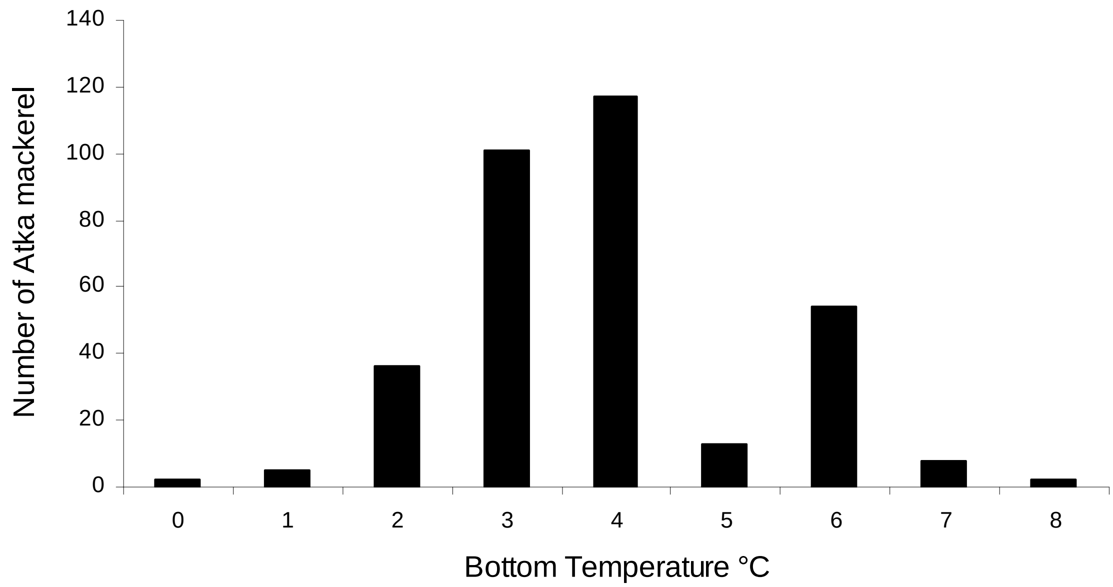
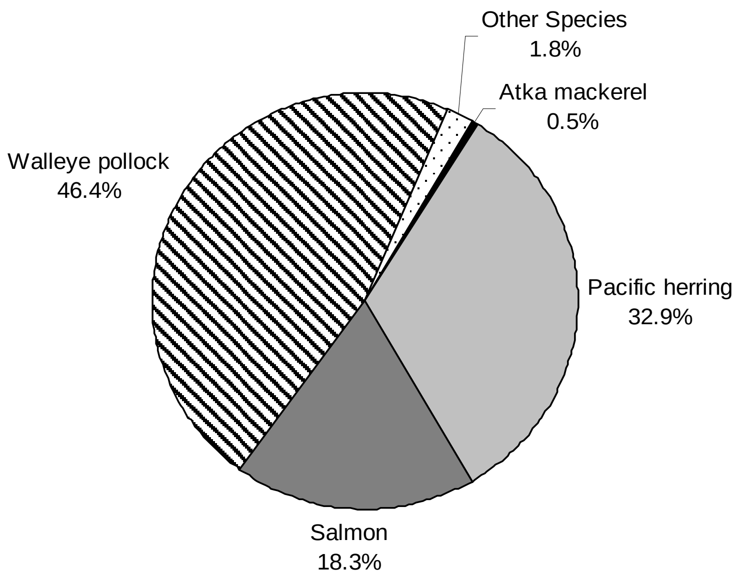


Figure B-4. Bottom temperature distribution of the total number of juvenile Atka mackerel (*N*=338) for all hauls combined that contained Atka mackerel.

A.



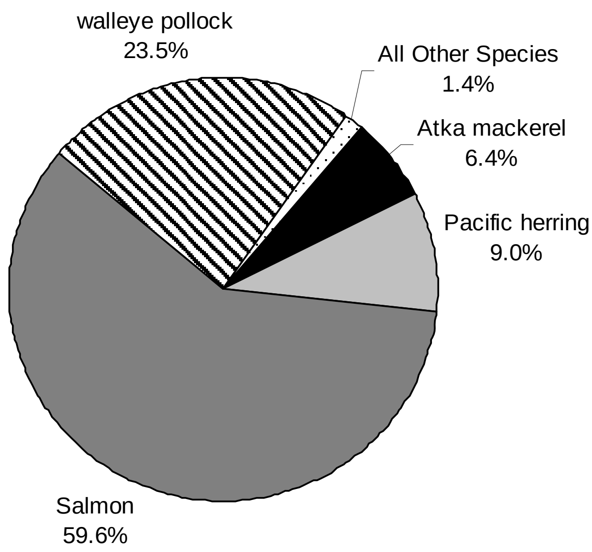
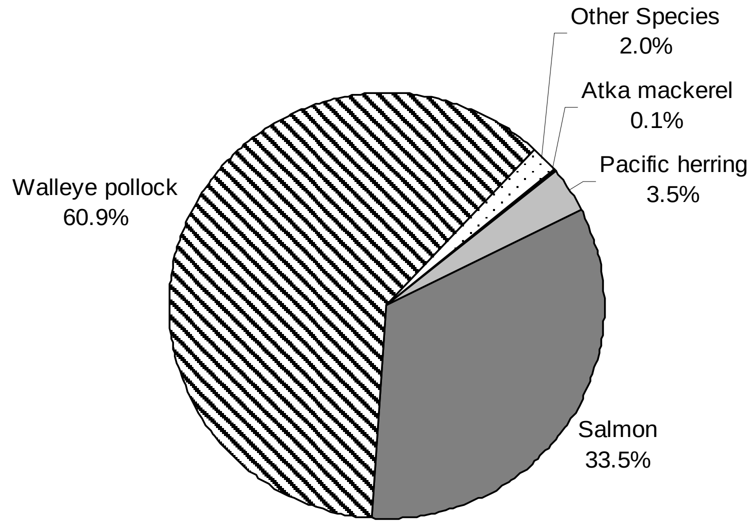


Figure B-5. The haul composition by percent weight when juvenile Atka mackerel numbers at the station equaled ten or greater (*N*=8) (A), when the numbers of juvenile Atka mackerel ranged between 2 and 9 individuals (*N*=13) (B), when only a single juvenile Atka mackerel was present (*N*=24) (C), and when juvenile Atka mackerel were absent from hauls (*N*=227) (D).

C.



D.

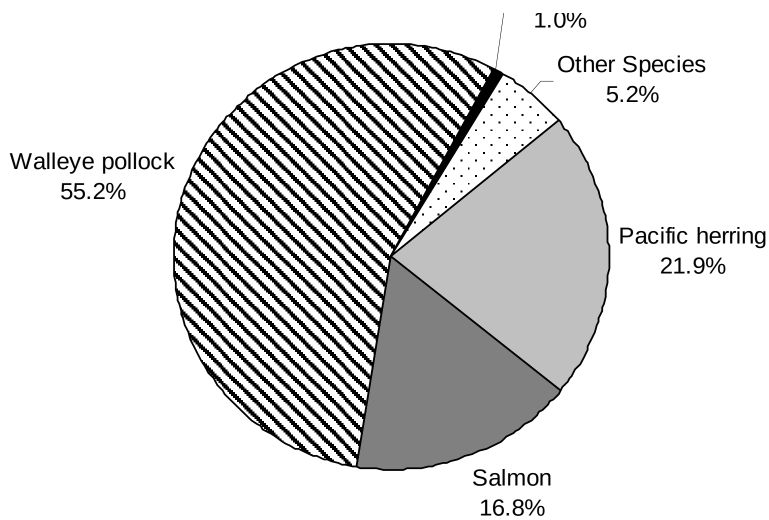


Figure B-5 cont. The haul composition by percent weight when juvenile Atka mackerel numbers at the station equaled ten or greater (*N*=8) (A), when the numbers of juvenile Atka mackerel ranged between 2 and 9 individuals (*N*=13) (B), when only a single juvenile Atka mackerel was present (*N*=24) (C), and when juvenile Atka mackerel were absent from hauls (*N*=227) (D).