Stock Assessment of Aleutian Islands Atka Mackerel

Sandra Lowe, James Ianelli, Harold Zenger, Kerim Aydin, and Robert Lauth

EXECUTIVE SUMMARY

Summary of Major Changes

Relative to the November 2003 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.

2) The 2003 fishery age composition data were included.

3) The 2002 Aleutian Islands survey age composition data were included.

4) Biomass and length data from the 2004 Aleutian Islands bottom trawl survey were included.

Changes in the Assessment Methodology

1) The model allows for within-year mortality to the month that the survey occurs for computing modeled survey abundance

2) A lognormal error assumption for the survey biomass estimates is used instead of assuming a normal distribution

3) Survey catchability (q) is estimated with a moderate prior on q (mean = 1.0, $\sigma^2 = 0.2^2$)

4) The projection model assumes an average selectivity vector for the years 1999-2003.

Changes in Assessment Results

1) The mean recruitment from the stochastic projections is 501 million recruits, which gives an estimated $B_{40\%}$ level of 96,900 mt.

2) The projected female spawning biomass for 2005 under an $F_{40\%}$ harvest strategy is estimated at 151,400 mt; BSAI Atka mackerel are in Tier 3a

3) The projected age 3+ biomass at the beginning of 2005 is estimated at 485,700 mt.

4) The addition of the 2002 survey and 2003 fishery age compositions greatly impacted the estimated magnitude of the 1999 and 2000 year classes. The 1999 year class is now estimated to be the largest year class in the time series, followed by an above average 2000 year class.

5) The projected 2005 yield at $F_{40\%}$= 0.52 is 123,900 mt.

6) The projected 2005 overfishing level at $F_{35\%}$ (F = 0.64) is 146,900 mt.

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

The SSC did not make any comments specific to the BSAI Atka assessment requiring a response.

15.1 Introduction

Distribution: Atka mackerel (*Pleurogrammus monopterygius*) are distributed from the east coast of the Kamchatka peninsula, 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. Their center of abundance according to past resource assessment surveys has been in the Aleutian Islands, particularly from Buldir Island to Seguam Pass.

Early life history: Until recently, very little has been documented of the early life history of Atka mackerel prior to their appearance in trawl surveys and the fishery at about age 2-3 years. Eggs develop at depth and release planktonic larvae which have been reported at great distances in offshore waters (Gorbunova 1962). The Alaska Fisheries Science Center (AFSC) is currently collaborating with the Alaska SeaLife Center (ASLC) on early life history and reproductive ecology research on Atka mackerel. Live adult Atka mackerel were captured and transferred to the ASLC for reproductive ecology studies and for the development of a reference collection to stage eggs. During August and September 2004, numerous clutches of eggs were spawned. Developing eggs are being kept in special temperature-controlled incubators. Egg clutches at several different temperatures are being sampled and preserved for creating egg developmental series which will be used to estimate spawning and hatching dates from egg samples obtained from nesting sites across the Aleutian archipelago.

Reproductive ecology: Russian literature describes demersal spawning with adhesive eggs and male nest guarding (Gorbunova 1962, Zolotov 1993). In Kamchatkan waters, spawning and nest guarding was reported to occur as shallow as 10 m (Gorbunova 1962) and as deep as 32 m (Zolotov 1993). Spawning began in late June and adhesive eggs were laid in rock crevices and among stones. The first *in situ* observation of a nesting site in the U.S. Exclusive Economic Zone (EEZ) was in August 1999 off Seguam Island in the Aleutian Archipelago. Male Atka mackerel have been returning to this nesting site each year since it was first observed. Physical characteristics of the environment were similar to those reported in Gorbunova (1962) and Zolotov (1993). Clutches of eggs were found at depths ranging from 15 to 32 m. The AFSC used an underwater towed camera for subsequent investigations of Atka mackerel spawning and nesting sites during the spawning season. Camera drops were made on offshore reefs and in and around island passes across the Aleutian archipelago from Stalemate Bank to Akutan Pass. Recorded observations documented aggregations of males exhibiting exactly the same dispersal patterns, sexually dichromatic color patterns, and nesting behaviors as those males observed with *in situ* cameras at the nearshore nesting site at Seguam Island. Bottom depths for these later sites extended to approximately 100 m, far greater than those previously documented as the lower depth limit for Atka mackerel spawning and nesting. The lower limit depth limit for spawning and nesting of Atka mackerel in the Aleutian Islands is unknown. An underwater time-lapse camera was used to determine that male Atka mackerel nesters first appear at the nearshore Seguam Island nesting site in mid-June. Males were still present when the time-lapse camera was removed on August 31st. Studies of ovarian condition of Atka mackerel from Alaska indicate that females continue spawning through October (McDermott and Lowe 1997). Ongoing experiments with Atka mackerel egg incubation at the ASLC show that development is temperature dependent. Based on what is known from *in situ* temperatures and egg samples from nesting sites, the nesting period may be more protracted than observed in the western Pacific Ocean (Gorbunova 1962, Zolotov 1993).

Prey and predators: Adult Atka mackerel in the Aleutians consume a variety of prey, but principally calanoid copepods and euphausiids, 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.

Stock structure and management units: A morphological and meristic study suggested that 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. However, results from a 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). Between-sample variation was extremely low among the four samples indicating that a large amount of gene flow is occurring throughout the range. It is presumed that gene flow is occurring during the larval, pelagic stage, and that the localized aggregations reflect the distribution of surviving, settled juveniles. Differences in growth rates consistently observed throughout their Alaskan range are believed to be phenotypic characteristics reflecting differences in the local environment. Further analyses are currently underway using microsatellite DNA to evaluate genetic structuring of Atka mackerel.

While genetic information suggests that the Aleutian Island (AI) and Gulf of Alaska (GOA) populations of Atka mackerel could be managed as a unit stock, there are significant differences in population size, distribution, recruitment patterns, and resilience to fishing that suggest otherwise. Bottom trawl surveys and fishery data suggest that the Atka mackerel population in the GOA is smaller and much more patchily distributed than that in the AI, and composed almost entirely of fish > 30 cm in length. There are also more areas of moderate Atka mackerel density in the AI than in the GOA. The lack of small fish in the GOA suggests that Atka mackerel recruit to that region differently than in the AI. We presume that there is some limited spawning activity in the Gulf of Alaska, perhaps supplemented by juveniles moving east from the larger population in the AI in addition to larval settlement in the area. This might also explain the greater sensitivity to fishing depletion in the GOA as reflected by the history of the GOA fishery since the early 1970s. Catches of Atka mackerel from the GOA peaked in 1975 at about 27,000 mt. Recruitment to the AI population was low from 1980-1985, and catches in the GOA declined to 0 in 1986. Only after a series of large year classes recruited to the AI region in the late 1980s, did the population and fishery reestablish in the GOA beginning in the early 1990s. After passage of these year classes through the population, the GOA population, as sampled in the 1996 and 1999 GOA bottom trawl surveys, has declined and is very patchy in its distribution. These differences in population resilience, size, distribution, and recruitment argue for separate assessments and management of the GOA and AI stocks despite their genetic similarities.

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 mt in 1978 (see BSAI SAFE Table 3). Atka mackerel became a reported species group in the BSAI Fishery Management Plan in 1978. Catches (including discards and community development quota [CDQ] catches) by region and corresponding Total Allowable Catches (TAC) set by the North Pacific Fishery Management Council (Council) from 1978 to the present are given in Table 15.1. Table 15.2 documents annual research catches (1977 - 2004) from NMFS trawl surveys.

From 1970-1979, Atka mackerel were landed off Alaska exclusively by the distant water fleets of the U.S.S.R., Japan and the Republic of Korea. U.S. joint venture fisheries began in 1980 and dominated the landings of Atka mackerel from 1982 through 1988. The last joint venture allocation of Atka mackerel off Alaska was in 1989, and since 1990, all Atka mackerel landings have been made by U.S. fishermen. Total landings declined from 1980-1983 primarily due to changes in target species and allocations to various nations rather than changes in stock abundance. From 1985-1987, Atka mackerel catches were some of the highest on record, averaging 34,000 mt annually. 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 made in the western Aleutian Islands (west of 180°W longitude). In the late 1970s and through the 1980s, fishing effort moved eastward, with the majority of landings occurring near Seguam and Amlia Islands. In 1984 and 1985 the majority of landings came from a single 1/2° latitude by 1° longitude block bounded by 52°30'N, 53°N, 172°W, and 173°W in Seguam Pass (73% in 1984, 52% in 1985). Areas fished by the Atka mackerel fishery from 1977 to 1992 are displayed in Fritz (1993). Areas of 2004 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 mt was caught by 11 March, almost entirely south of Seguam Island. This initial TAC release represented the amount of Atka mackerel that the Council thought could be appropriately harvested in the eastern portion of the Aleutian Islands subarea (based on the assessment for 1993; Lowe 1992). In mid-1993, however, Amendment 28 to the Bering Sea/Aleutian Islands (BSAI) Fishery Management Plan became effective, dividing the Aleutian subarea into three districts at 177°W and 177°E for the purposes of spatially apportioning TACs (Figure 15.1). On 11 August 1993, an additional 32,000 mt of Atka mackerel TAC was released to the Central (27,000 mt) and Western (5,000 mt) districts. Since 1994, the BSAI Atka mackerel TAC has been allocated to the three regions based on the average distribution of biomass estimated from the Aleutian Islands bottom trawl surveys.

In June 1998, the Council passed a fishery regulatory amendment that proposed a four-year timetable to temporally and spatially disperse and reduce the level of Atka mackerel fishing within Steller sea lion critical habitat (CH) in the BSAI Islands. Temporal dispersion was accomplished by dividing the BSAI Atka mackerel TAC into two equal seasonal allowances, an A-season beginning January 1 and ending April 15, and a B-season from September 1 to November 1. Spatial dispersion was accomplished through a planned 4-year reduction in the maximum percentage of each seasonal allowance that could be caught within CH in the Central and Western Aleutian Islands. This was in addition to bans on trawling within 10 nm of all sea lion rookeries in the Aleutian district and within 20 nm of the rookeries on Seguam and Agligadak Islands (in area 541), which were instituted in 1992. The goal of spatial dispersion was to reduce the proportion of each seasonal allowance caught within CH to no more than 40% by the year 2002. No CH allowance was established in the Eastern subarea because of the year-round 20 nm trawl exclusion zone around the sea lion rookeries on Seguam and Agligadak Islands that minimized effort within CH. The regulations implementing this four-year phased-in change to Atka mackerel fishery management became effective on 22 January 1999 and lasted only 3 years (through 2001). In 2002, new regulations affecting management of the Atka mackerel, pollock, and Pacific cod fisheries went into effect. Furthermore, all trawling was prohibited in CH from 8 August 2000 through 30 November 2000 by the Western District of the Federal Court because of violations of the Endangered Species Act (ESA).

As part of the plan to respond to the Court and comply with the ESA, NMFS and the NPFMC formulated new regulations for the management of Steller sea lion and groundfish fishery interactions that went into effect in 2002. The objectives of temporal and spatial fishery dispersion, cornerstones of the 1999 regulations, were retained. Season dates and allocations remained the same (A season: 50% of annual TAC from 20 January to 15 April; B season: 50% from 1 September to 1 November). However, the maximum seasonal catch percentage from CH was raised from the goal of 40% in the 1999 regulations to 60%. To compensate, effort within CH in the Central (542) and Western (543) Aleutian fisheries was limited by allowing access to each subarea to half the fleet at a time. Vessels fishing for Atka mackerel are randomly assigned to one of two teams, which start fishing in either area 542 or 543. Vessels may not switch areas until the other team has caught the CH allocation assigned to that area. In the 2002 regulations, trawling for Atka mackerel was prohibited within 10 nm of all rookeries in areas 542 and 543; this was extended to 15 nm around Buldir Island and 3 nm around all major sea lion haulouts. Steller sea lion CH east of 178°W in the Aleutian district, including all CH in subarea 541 and a 1° longitude-wide portion of subarea 542, is closed to directed Atka mackerel fishing.

15.2.4 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 2002 and 2003 discards of northern rockfish as a total of the Atka mackerel catch has remained at about 7%, the actual amount of northern discards accounts for a large portion of the AI northern TAC. The 2002 fishery discarded 3,341 mt of northern rockfish, about 50% of the AI 2002 northern TAC. The 2003 Atka mackerel fishery discarded 4,123 mt of northern rockfish which accounted for 70% of the northern TAC.

Discard data have been available for the groundfish fishery since 1990. Discards of Atka mackerel for 1990-1998 have been presented in previous assessments (Lowe et al. 2003). Discard data from 1999 to present are given below:

Year	Fishery	Discarded (mt)	Retained (mt)	Total (mt)	Discard Rate (%)
1999	Atka mackerel	4,010	47,351	51,361	7.8
	All others	743	1,751	2,494	
	All	4,753	49,102	53,855	
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	9,199	41,971	51,170	18.0
	All others	700	1,070	1,770	
	All	9,899	43,041	52,940	

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 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

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 western AI (543) nearly doubled and exceeded the central area rate:

		Aleutian Islands Subarea		
Year		**541**	**542**	**543**
1999	Retained (mt)	14,307	18,036	15,008
	Discarded (mt)	258	2,556	1,197
	Rate	2%	12%	7%
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)	5,005	22,478	14,488
	Discarded (mt)	354	4,852	3,993
	Rate	7%	18%	22%

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 domestic 2003 and 2004 fisheries by management area and season are shown in Figures 15.2 and 15.3, respectively. Differences in the distributions between the 2003 A- and B-seasons are most notable for area 519 (north of Akutan and Akun Islands). Also, the 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). The modes at about 31-35 cm in the 2003 fishery length distributions represent the 1999 year class which dominated the 2003 fishery age composition (Figure 15.4). Only the 2004 A season data are presented and should be considered preliminary (Figure 15.3). The 2004 A-season fishery showed a similar distribution to the 2003 B season distribution with modes at 33-35 cm.

15.2.6 Steller Sea Lions and Atka mackerel Fishery Interactions

Since 1979, the Atka mackerel fishery has occurred largely within areas designated as Steller sea lion critical habitat in 1993 (20 nm around rookeries and major haulouts). While total removals from critical habitat may be small in relation to estimates of total Atka mackerel biomass in the Aleutian region, fishery harvest rates in localized areas may have been high enough to affect prey availability of Steller sea lions (Section 12.2.2 of Lowe and Fritz 1997). The localized pattern of fishing for Atka mackerel apparently does not affect fishing success from one year to the next since local populations in the Aleutian Islands appear to be replenished by immigration and recruitment. However, this pattern could create temporary reductions in the size and density of localized Atka mackerel populations which could affect Steller sea lion foraging success during the time the fishery is operating and for a period of unknown duration after the fishery is 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*. in press). Results indicate that the 20 nm trawl exclusion zone around the rookeries on Seguam and Agligadak Islands is effective in minimizing disturbance to prey fields within them. The boundary of the 20 nm trawl exclusion zone at Seguam appears to occur at the approximate boundary of two naturally occurring assemblages. The movement rate between the two assemblages is small. Therefore, the results obtained here regarding the efficacy of the trawl exclusion zone may not generally apply to other, smaller zones to the west. The tagging work has been expanded and tagging was conducted inside and outside the 10 nm trawl exclusion zones in Tanaga Pass (in 2002) and near Amchitka Island (in 2003). Movement rates at Tanaga pass appear similar to those at Seguam with the trawl exclusion zones forming natural boundaries to local aggregations. Movement rates at Amchitka appear to be higher relative to Seguam (pers. comm. Elizabeth Logerwell and Susanne McDermott, AFSC). The boundaries at Amchitka bisect Atka mackerel habitat unlike Seguam and Tanaga.

15.3 Data

15.3.1 Fishery Data

Fishery data consist of total catch biomass from 1977 to 2004 (Table 15.1), and the age composition of the catch from 1977-2003 (Table 15.3). Catch-at-age (in numbers) was estimated using the length frequencies described above and age-length keys. The formulas used are described by Kimura (1989). As with the length frequencies, the age data for 1980-1981, 1989, 1992-1993, and 1997 presented problems. The commercial catches in 1980 and 1981 were not sampled for age structures, and there were too few age structures collected in 1989, 1992, 1993, and 1997 to construct age-length keys. Kimura and Ronholt (1988) used the 1980 survey age-length key to estimate the 1980 commercial catch age distribution, and these data were further used to estimate the 1981 commercial catch age distribution with a mixture model (Kimura and Chikuni 1987). However, this method did not provide satisfactory results for the more recent (1989, 1992, 1993 and 1997) catch data and these years were excluded from the analysis.

The most salient features of the estimated catch-at-age (Table 15.3) are the strong 1975 and 1977 year classes, and the appearance of a large number of 4-year-olds in 1988, 1995, 1996, 1999 and most recently in 2002 and 2003, representing the 1984, 1991, 1992, 1995 and the 1998 and 1999 year classes, respectively. The 1975 year class appeared strong as 3 and 4-year-olds in 1978 and 1979. It is unclear why this year class did not continue to show up strongly after age 4. The 1977 year class appeared strong through 1987, after entering the fishery as 3-year-olds in 1980. The 1988 fishery was basically supported by the 1984 year class which showed up strongly as 4-year-olds. The 1988 year class persisted in large numbers in the 1992-1996 commercial catches, and also dominated the catch in the 1994 survey. The 1996-1998 catch data were dominated by the strong 1992 year class, and the 1999 and 2000 catch data were dominated by the 1995 year class (Table 15.3). The 2002 fishery age data showed the first appearance in the fishery of the 1999 year class. The most recent 2003 fishery age data show the first appearance in the fishery of the 2000 year class, and the 1998 and particularly the 1999 year class continues to show up in large numbers (Table 15.3 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 and 2004 domestic trawl surveys, provide the only direct estimates of population biomass from throughout the Aleutian Islands region. Furthermore, the biomass estimates from the early U.S-Japan cooperative surveys are not directly comparable with the biomass estimates obtained from the U.S. trawl surveys because of differences in the net, fishing power of the vessels, and sampling design (Barbeaux et al. 2003).

Trawl survey biomass estimates of Atka mackerel varied from 197,529 mt in 1980 to 306,780 mt in 1983, and 544,754 mt in 1986 (Table 15.4). However, the high value for 1986 is not directly comparable to previous estimates. During the 1980 survey, no successful sampling occurred in shallow waters (<100 m) around Kiska and Amchitka Islands, and during the 1983 survey very few shallow water stations were successfully trawled. However, during the 1986 survey, several stations were successfully trawled in waters less than 100 m, and some produced extremely large catches of Atka mackerel. In 1986, the biomass estimate from this one depth interval alone totaled 418,000 mt in the Southwest Aleutians (Table 15.4), or 77% of the total biomass of Atka mackerel in the Aleutian Islands. This was a 403,000 mt increase over the 1983 biomass estimate for the same stratum-depth interval. The 1986 biomass estimate is associated with a large coefficient of variation (0.63). Due to differences in area and depth coverage of the surveys, it is not clear how this biomass estimate compares to earlier years.

The most recent biomass estimate from the 2004 Aleutian Islands bottom trawl survey is 886,783 mt, up 15% relative to the 2002 survey estimate (Table 15.5). Previous to this, the 2002 Aleutian Islands bottom trawl survey biomass estimate of 772,798 mt increased 51% relative to the 2000 survey. The breakdown of the Aleutian biomass estimates by area corresponds to the management sub-districts (541-Eastern, 542-Central, and 543-Western). The increase in biomass in the 2004 survey is largely a result of an increase in biomass found in the Western area (372,782). Relative to the 2002 survey, the 2004 biomass estimates are up 46% in the Western area, down 17% in the Central area, and up 28% in the Eastern area (Figure 15.5). The 95% confidence interval about the mean total 2004 Aleutian biomass estimate is **771,645-1,537,033** mt. The coefficient of variation (*CV*) of the 2004 mean Aleutian biomass is 17%, consistent with the *CV* from the 2002 survey, and the lowest since the 1991 survey (Table 15.5).

The distribution of biomass in the Western, Central, and Eastern Aleutians, and the southern Bering Sea shifted between each of the surveys, and most dramatically in area 541 in the 2000 survey (Figure 15.5). The 2000 Eastern area biomass estimate (900 mt) was the lowest of all surveys, contributing only 0.2% of the total 2000 Aleutian biomass and represented a 98% decline relative to the 1997 survey. The extremely low 2000 biomass estimate for the Eastern area has not been reconciled, but there are several factors that may have had a significant impact on the distribution of Atka mackerel that were discussed in Lowe et al. (2001). We note that the distribution of Atka mackerel in the Eastern area is generally patchier, and up until the 2004 survey, the area specific variances for the Eastern area have always been high relative to the Central and Western areas. Lowe et al. (2001) suggest that a combination of these factors coupled with the typically patchier distribution of 541 Atka mackerel 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 2004 survey showed that the Eastern area contributed 28% of the total biomass, which is little change from 25% of the biomass that was detected in the 2002 survey.

In both 1991 and 1994, the Western area contributed approximately half of the total estimated Aleutian biomass, but this proportion dropped each subsequent survey to 33% in 2002. The proportion of biomass in the Western area increased to 42% in the most recent 2004 survey. In 1994, 14% of the Aleutian biomass was found in the Central area compared to 51% in 1997 and up to 65% 2000 survey. The most recent 2004 survey showed the Central area contributing 30% of the Aleutian biomass (Table 15.5).

In 1994 for the first time since the initiation of the Aleutian triennial surveys, a significant concentration of biomass was detected in the southern Bering Sea area (66,603 mt). This occurred again in 1997 (95,680 mt), 2002 (59,883 mt), and most recently in the 2004 survey (267,556 mt, Table 15.5). These biomass estimates are a result of large catches from a single haul encountered north of Akun Island in all four surveys. In addition, large catches of Atka mackerel in the 2004 survey were also encountered north of Unalaska Island, with a particularly large haul in the northwest corner of Unalaska Island (Figure 15.6). The 2004 southern Bering Sea strata biomass estimate of 267,556 mt is the largest biomass encountered in this area in the survey time series. The *CV* of the 2004 southern Bering Sea estimate is 43% much lower than previous years as several hauls contributed to the 2004 estimate.

Areas with large catches of Atka mackerel during the 2000 survey, included Tanaga Pass, south of Amchitka Island, Buldir Island, and Stalemate Bank (Figure 15.6). In the 2002 survey, areas with large catches 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 58% of the hauls respectively, which are the highest rates of encounters in the survey time series.

The average bottom temperatures measured in the 2000 survey were the lowest of any of the Aleutian surveys, particularly in depths less than 200 m where 99% of the Atka mackerel are caught in the surveys (pers. comm., Harold Zenger, AFSC, Figure 15.7). The average bottom temperatures measured in the 2002 survey were the second lowest of the Aleutian surveys, but significantly higher than the 2000 survey and very similar to the 1994 survey. The average bottom temperatures measured in the 2004 survey fell right about in the middle of the series for all survey years, excluding the year 2000.

There is greater confidence in Atka mackerel biomass estimates from bottom trawl surveys of the groundfish community of the Aleutian Islands (AI) than the Gulf of Alaska (GOA). First, the coefficients of variation of the mean Atka mackerel biomass estimates have been considerably smaller from the recent AI surveys than the recent GOA surveys: 0.29, 0.28, 0.20, and 0.17 from the 1997, 2000, 2002, and 2004 AI surveys, respectively, compared with 0.99, 0.45, 1.00, and 0.35 from the 1996, 1999, 2001 and 2003 GOA surveys. Second, while patchy in its distribution compared to other groundfish species, Atka mackerel have been much more consistently encountered in the AI than the GOA surveys, appearing in 41%, 33%, 23%, 33%, 55%, and 58% of the hauls in the 1991, 1994, 1997, 2000, 2002, and 2004 AI surveys, compared to 5%, 28%, 12%, 20%, 10% and 35% of the hauls in the Shumagin area in the 1990, 1993, 1996, 1999, 2001, and 2003 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

In the past, the 2000 and 2002 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). The 2004 survey length frequency distributions also showed a strong east-west gradient in Atka mackerel size, but the Western and Central distributions were very similar with modes at 33-34 cm (Figure 15.8), similar to the 2003 B-season fishery data in these areas (Figure 15.2). The 2004 survey length frequency distributions from the Eastern area showed a mode of fish at 37 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 43 cm (Figure 15.8).

Survey Age Frequencies

The age compositions from the 1997, 2000, and 2002 Aleutian surveys are shown in Figure 15.9. The 1997 age composition was mainly comprised of 3, 4, and 5-year olds of the 1992 to 1994 year classes. The large number of 3-year olds in the 1997 survey was an initial indication of the strong 1992 year class. The 2000 survey age composition shows the strong 1992 and 1995 year classes (8 and 5-year olds, respectively), and a very strong showing of 2 year olds from the 1998 year class (Figure 15.9). The selectivity of 2 year olds in the survey is thought to be fairly low, and this age group has not shown up in significant proportions in previous surveys (Lowe et al. 2003). The 2002 survey age composition is dominated by the 1999 year class and continues to show large numbers of the 1998 year class (Figure 15.9). The mean ages of the 1997, 2000, and 2002 surveys are 4.8, 5.0, and 3.8 years, respectively. The mean age in the 2002 survey of 3.8 years is the youngest mean age of any survey.

Survey Abundance Indices

A partial time series of relative indices from the 1980, 1983, 1986, and 1991 Aleutian Islands surveys had been used in the previous stock synthesis assessments (Lowe et al. 2001). The relative indices of abundance excluded biomass from the 1-100 m depth strata of the Southwest Aleutian Islands region (west of 180°) due to the lack of sampling in this strata in some years. Because the excluded area and depth strata 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 " that evaluated favorably with previous assessments (Lowe et al. 2002). The model 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).

The Stock Assessment Toolbox 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 and Stock Assessment Toolbox is that it includes post-convergence routines to calculate standard errors (or likelihood profiles) for quantities of interest.

15.4.1 Model structure

The Stock Assessment Toolbox models catch-at-age with the standard catch equation. The population dynamics follows numbers-at-age over the period of catch history (here 1977-2003) 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 (or simple mean). Deviations between the observations and the expected values are quantified with a specified error model and cast in terms of a penalized log-likelihood. This 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[1] likelihood components and the distribution assumption of the error structure are given below:

Likelihood Component	Distribution Assumption
Catch biomass	Lognormal
Catch age composition	Multinomial
Survey catch biomass	Lognormal
Survey catch age composition	Multinomial
Recruitment deviations	Lognormal
Stock recruitment curve	Lognormal
Selectivity smoothness (in age-coefficients, survey and fishery)	Lognormal
Selectivity change over time (fishery only)	Lognormal
Priors (where applicable)	Lognormal

15.4.2 Parameters

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

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

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).

Last year's 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 for all models.

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 length at age 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.

Parameters of the von Bertalanffy length-age equation and a weight-length equation have been calculated for (1) the combined 1986, 1991, and 1994 survey data for the entire Aleutians region, and for the Eastern (541) and combined Central and Western (542 and 543) subareas, and (2) the combined 1990-96 fishery data for the same areas:

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

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

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

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

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

The observed differences in the weight-length relationships from the survey and fishery data, particularly in the exponent of length, probably reflect the differences in the timing of sample collection. The survey data were all collected in summer, the spawning period of Atka mackerel when gonad weight would contribute the most to total weight. The fishery data were collected primarily in winter, when gonad weight would be a smaller percentage of total weight than in summer. The average length-at age and weights-at-age used in the model are given in Table 15.6.

Maturity at Age

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

	Length at 50% maturity (cm)
Eastern Aleutians (541)	33.9
Central Aleutians (542)	31.1
Western Aleutians (543)	31.2

The maturity schedules are given in Table 15.7. Work is currently underway to re-examine and update the maturity information (pers. comm. Susanne McDermott AFSC and Dan Cooper Univ. of Wash.).

Parameters estimated conditionally

Deviations between the observations and the expected values are quantified with a specified error structure. Lognormal error is assumed for survey biomass estimates and fishery catch, and a multinomial error structure is assumed for survey and fishery age compositions. These error structures are used to estimate the following parameters conditionally within the model.

Fishing Mortality

Fishing mortality is parameterized to be separable with a year component and an age (selectivity) component in all models. The selectivity relationship is modeled with a smoothed non-parametric relationship that can take on any shape (with penalties controlling the degree of change and curvature specified by the user; Table A-2). Selectivity is conditioned so that the mean value over all ages will be equal to one. To provide regularity in the age component, a moderate penalty was imposed on sharp shifts in selectivity between ages using the sum of squared second differences (log-scale). In addition, the age component parameters are assumed constant for the last 6 age groups (ages 10-15). Asymptotic growth is reached at about age 9 to 10 years. Thus, it seemed reasonable to assume that selectivity of fish older than age 10 would be the same. Selectivity is allowed to vary annually with a low constraint as in the selected Reference model from last year's 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. Last year Models 3-6 explored the use of a prior on catchability (q) with mixed results that were difficult to interpret biologically (Lowe et al. 2003). This year we carry forward a model (Model 4) with a moderate prior on q (mean = 1.0, $\sigma^2 = 0.2^2$) for evaluation.

Recruitment

The Beverton-Holt form of stock recruitment relationship based on Francis (1992) was used (Table A-2). Values for the stock recruitment function parameters α and β are calculated from the values of R_0 (the number of 0-year-olds in the absence of exploitation and recruitment variability) and the "steepness" of the stock-recruit relationship (h,Table A-2). The "steepness" parameter is the fraction of R_0 to be expected (in the absence of recruitment variability) when the mature biomass is reduced to 20% of its pristine level (Francis 1992). We assumed a steepness value of 0.8 for all model runs presented here, with a 30% *CV*. A value of h = 0.8 implies that at 20% of the unfished spawning stock size will result in an expected value of 80% of the unfished recruitment level. Model runs exploring other values of h and the use of a prior on h were explored in a previous assessment, but were found to have little or no bearing on the stock assessment results and were not carried forward for evaluation at that time (Lowe et al. 2002).

15.5 Model Evaluation

During the past year, a number of refinements were made to the model configuration. These changes were restricted to some key assumptions. Since survey catchability in last year's assessment was conservatively set to a value of 1.0, it was important to correct the model to account for the time of year that the survey takes place. Previously, it had simply assumed begin-year biomass was a suitable proxy. Secondly, the convention in most stock assessment models is to specify a lognormal error distribution for survey data. Model exploration focused on these changes and are detailed as follows:

Baseline Model This model was selected as the basis for ABC/OFL recommendations in 2003

Model 1 The model allows for within-year mortality to the month that the survey occurs for computing modeled survey abundance

Model 2 A lognormal error assumption for the survey biomass estimates was used instead of assuming a normal distribution

Model 3 Both Model 1 and Model 2 options were implemented

Initial explorations with these changes indicated that the differences were significant, therefore Models 1-3 were first run using *last year's* data for contrast with the Baseline Model (Table 15.8). A second set of models are then evaluated using the new data presented above with one additional model (easing the constraint that survey catchability is fixed at a value of 1.0):

Model 4 As Model 3, but estimating survey catchability (q) with a moderate prior on q (mean = 1.0, $\sigma^2 = 0.2^2$)

Stepping through the evaluation of model configuration changes using last year's data, we first compare the Baseline configuration to Model 1which accounts for within-year mortality to the month of July (the mid-point for the time that the survey occurs). The Baseline had an overall better fit (i.e., lower $-\ln(\text{likelihood function})$, Table 15.8). The lower value for the total $-\ln(\text{likelihood function})$ is attributed to fitting the fishery age composition better and having a lower penalty on the selectivity constraint. However, Model 1 fit the survey index better relative to the Baseline Model as indicated by the lower survey residual mean square error (RMSE) and –ln(survey likelihood). Model 1 also fit the survey age composition better. This indicates some inconsistency in the data sources (fishery and survey). Lowe et al. (2002) explored different levels of constraints on the fishery selectivity-at-age curvature in conjunction with allowing selectivity-at-age to vary annually. The best-fitting model was achieved with a moderate constraint on the selectivity-at-age which provided biologically reasonable selectivity assumptions that fit the data well, and a low constraint on the time component of selectivity which allowed the model to capture important differences, particularly in the early years (Lowe et al. 2002). These selectivity assumptions are carried forward in the current model configurations. In summary, changing the timing of the survey while fixing q=1.0 essentially scales the biomass trend upwards relative to the Baseline (see initial biomass and 2003 total biomass in Table 15.8), and also reduces the recruitment variability. In order for the model to account for 6 months of within-year mortality with a q=1.0, a higher absolute biomass level is estimated.

Comparing the Baseline to Model 2, which assumes a log normal error distribution for the survey biomass estimates instead of a normal distribution, also shows better fit (i.e., lower –ln(likelihood function),Table 15.8). As in the first comparison, the lower value for the total –ln(likelihood function) is attributed to a better fit to the fishery age composition and a lower selectivity constraint. However, Model 2 also fit the survey index better relative to the Baseline, as indicated by the lower survey residual mean square error (RMSE) and –ln(survey likelihood). Assuming a log normal error distribution for the survey biomass also results in a scaling up of the biomass trend, although more moderately than for Model 1 (Table 15.8). More importantly, Model 2 reduces the variability of current biomass and recruitment as shown by the lower *CV*s for 2003 total biomass and the 1998 year class (at age 1), and the overall lower recruitment variability (Table 15.8).

A comparison of the Baseline to Model 3 which implements both Model 1 and 2 configuration changes shows the same results described above. In summary, a comparison of Models 1-3 with the Baseline Model with *last year's* data shows that the Baseline Model had an overall better fit (Table 15.8). The lowest value for the total –ln(likelihood function) is attributed to a better fit to the fishery age composition and a lower selectivity constraint. Model 3 had the poorest overall fit (i.e., higher –ln(likelihood function), but fit the survey index best as indicated by the lowest survey residual mean square error (RMSE) and –ln(survey likelihood). Model 3 also fit the survey age composition best. Model 3 resulted in large reductions (relative to the Baseline) in the *CV*s for the estimates of 2003 total biomass and the 1998 year class (at age 1). These reductions in variability about biomass and recruitment translate to large reductions (relative to the Baseline Model) in the *CV*s for projected $F_{40\%}$ and $F_{35\%}$ 2004 catches (Table 15.8). Preliminary explorations with model configurations that relaxed the constraint on the fishery selectivity-at-age curvature (transitions between ages) improved the fit to the fishery age composition but did not change results appreciably from those presented in Table 15.8. Therefore, the current selectivity assumptions were retained since these were explored extensively in 2003. The sensitivity of model results to selectivity constraints will be re-examined in future assessments.

Although, technically the Baseline configuration resulted in the best overall fit, Model 3 provides the most biologically reasonable configuration. It is important to include 6 months of within-year mortality for computing modeled survey abundance, especially when the catchability coefficient is assumed to be 1.0. Also, assuming a lognormal error is most appropriate for survey biomass due to the nature of Atka mackerel and their highly variable survey abundance patterns. For these reasons Model 3 was selected as the basis for further considerations and represents an improvement over the Baseline configuration.

As a second step in the evaluation, the new data were added and used to compare the Baseline configuration (for reference only) with Models 3 and 4 specified above (Table 15.9).

In the 2002 assessment, M and q were estimated simultaneously with various combinations of prior assumptions. These results were difficult to interpret biologically (Lowe et al. 2002). Last year, in an effort to continue this exploration, a range of priors on either M or q were used while the other parameter was fixed (Lowe et al. 2003). These results illustrated the sensitivity to assumptions about q and M and highlighted the need for further independent studies on these quantities. Results from such studies are as yet unavailable. However, it seems prudent to include a model with a moderate prior on q (μ=1.0, σ^2=0.2^2; Model 4). Alternative models with even higher values of σ^2 (including one with q freely estimated) were evaluated; results (e.g. estimated survey catchability and abundance trends) were hard to justify biologically. Note that the assumption that q=1.0 with no uncertainty is also unsatisfactory, especially since preliminary explorations indicate that q is likely greater than 1.0. A value of q somewhat greater than 1.0 could be plausible, considering the patchy distribution and schooling nature of Atka mackerel. Past surveys have shown the impacts of a few extremely large hauls which skew the mean, and are then extrapolated over the entire strata. Therefore, Model 4 is included as a conservative alternative and acknowledges some uncertainty about *q*.

Survey catchability for Model 4 was estimated at 1.4 (Table 15.9). Although results listed for Model 4 in Table 15.9 are not directly comparable to the Baseline and Model 3 due to a difference in the number of parameters, Figures 15.10 and 15.11 illustrate some important impacts. Increasing survey catchability does not significantly improve the fits to the survey; overall the fit is relatively consistent between Models 3 and 4 (Figure 15.10). The improvement in the fit to the survey of Model 3 relative to the Baseline Model was discussed above in the initial evaluation. The most significant difference is shown in a comparison of spawning biomass levels (Figure 15.11). The spawning biomass levels estimated from Model 4 are consistent with the levels estimated from the Baseline Model. The spawning biomass levels estimated from Model 3 are significantly scaled higher across the entire time series, relative to the levels estimated from the Baseline and Model 4. The Model 4 configuration was evaluated under slightly less constraint on the fishery selectivity-at-age curvature and found to give results that were essentially the same (including estimated q=1.4).

The suite of alternatives represented in the Baseline and Models 3 and 4 provided insight on model assumptions. As discussed above, Model 3 configuration is believed to represent an improvement over the Baseline (last year's model). Given that there are inconsistencies between the fishery and survey data sources and large uncertainty about *q*, a model that reflects some indication that q>1.0 seems appropriate (consistent with findings from Lowe et al. 2002 and Lowe et al. 2003). Model 4 provides a reasonable and appropriate alternative to an assumption of q=1.0, is a conservative option with results consistent with last year's model results, and is a move in the right direction supported by previous analyses. Model 4 is therefore selected as a reasonable representation of BSAI Atka mackerel dynamics.

15.6 Model Results

The results discussed below are based on Model 4.

15.6.1 Selectivity

The estimated selectivity at age schedules for the fishery and survey are shown in Figures 15.12-15.14 and given in Table 15.10.

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 15.12). After 1991, fishery selectivity patterns are fairly similar with gradual transitions, particularly between the ages of 3-9. The 2003 estimate of selectivity at age reflects the large numbers of 4-year old fish from the 1999 year class (Figure 15.12).

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 2002 and 2003 are shown for comparison (Figure 15.13). The 2002 catch at age data still included large numbers of 7-year olds from the 1995 year class, while the 2003 pattern reflects the large numbers of 3 and 4 year olds (1999 and 2000 year classes) in the 2003 catch. The age at 50% selectivity is estimated at about age 5 for both 2002 and 2003 (Figure 15.13). Fish older than age 9 make up a very small percentage of the population each year (Table 15.11), 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 well to the left of the estimated 2002 and 2003 selectivity patterns (age at 50% maturity is 3.6 years, Figure 15.13). Thus, the estimated 2002 and 2003 selectivity patterns indicate the current fishery is harvesting the older, mature population. The average selectivity pattern estimated for the years 1999 to 2003 is shown for perspective (Figure 15.13)

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 15.14). Model fits to the survey data are still challenging, but we believe the current selectivity assumptions to be more reasonable and the fits to the survey age composition are improved relative to previous assessments (Lowe et al. 2002 and 2003).

15.6.2 Abundance Trend

The estimated time series of total biomass with approximate upper and lower 95% confidence limits are shown in Figure 15.15 and given in Table 15.12. For comparison, the time series of spawning biomass from the 2003 and 2004 (current) assessments are also plotted (Figure 15.16). The corresponding time series of total numbers at age are given in Table 15.11.

A comparison of the spawning biomass trend from the current model and the previous assessment (Figure 15.16, Table 15.12) indicates consistent trends up to 2000, i.e., biomass increased during the early 80s and again in the late 80s to early 90s. After 2000, biomass increases to a much higher level in 2003 and continues a steep increase to 2004 in the current assessment. Last year's assessment showed a downward trend in spawning biomass after 2003. Recent biomass levels are significantly greater in the current assessment due to greatly revised estimates of the magnitude of the 1999 and 2000 year classes with the addition of the 2002 survey and the 2003 fishery age compositions. Overall, the biomass trend from the current assessment is scaled slightly upward over the entire time series. The inclusion of the current fishery and survey age composition data, and accounting for within-year mortality to the time of the survey in the current model are largely responsible for the shift in the revised estimates of biomass.

15.6.3 Recruitment Trend

The estimated time series of age 1 recruits from the current assessment and the 2003 assessment is shown in Figure 15.17 and given in Table 15.13. The strong 1999 year class is most notable in the current assessment, followed by the 1977, 1988, and 1998 year classes. The current estimates of the 1999 and 2000 year classes are more than doubled in magnitude relative to the 2003 assessment, due to the addition of the 2002 survey and 2003 fishery age compositions (Figure 15.17). The 1999 year class is now estimated to be the largest year class in the time series. The current assessment estimates above average (greater than 20% of the mean) recruitment from the 1977, 1986, 1988, 1992, 1995, 1998, 1999 and 2000 year classes (Figure 15.17). The 2002 survey and 2003 fishery age compositions were dominated by large numbers of the 1999 year class, and the 2003 fishery data provided the first indication of a potentially strong 2000 year class.

The average estimated recruitment from the time series 1978-2003 is 501 million fish and the median is 360 million fish (Figure 15.17). The entire time series of recruitments (1977-2003) includes the 1976-2002 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 (1977-2003 year classes). Projections of biomass are based on estimated recruitments from 1978-2003 using a stochastic projection model described below.

15.6.4 Trend in Exploitation

The estimated time series of fishing mortalities on fully selected age groups and the catch-to-biomass (age 3+) ratios are given in Table 15.14 and shown in Figure 15.18

15.6.5 Model Fit

A summary of key results from Model 4 are presented in Table 15.9. The coefficient of variation or *CV* (reflecting uncertainty) about the 2004 biomass estimate is 14% and the *CV*s on the strength of the 1998 and 1999 year classes at age 1 is 33 and 32%, respectively (Table 15.9). Overall estimated recruitment variability for BSAI Atka mackerel is high (0.604). 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 115 and average survey effective *N* of 51, which compare well with the fixed values. The overall residual mean square error (RMSE) for the survey is estimated at 0.281 (Table 15.9). 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 15.19 compares the observed and estimated survey biomass abundance values. Model fits to survey are greatly improved relative to last year (see Figure 15.19 in Lowe et al. 2003). However, the model still fit 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 model predicts a peak in survey biomass in 2003 followed by a small decline in 2004. This is consistent with the estimated age compositions (relatively strong 1998 and 1999 year classes), since cohort biomass peaks at age 4 for Atka mackerel given the natural mortality rate and recent levels of fishing mortality. The 1998 and 1999 year classes represent a significant proportion of the current population and are both older than age 4 by 2004.

The fits to the survey and fishery age compositions for Model 4 are depicted in Figures 15.20 and 15.21. The model fits the fishery age composition data quite well and the survey age composition data less so. This reflects the fact that the sample sizes for age and length composition data are higher for the fishery than the survey. The exception is the fit to the 2002 survey age composition which is quite good and the best fit in the survey time series (Figure 15.20). 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 2000 survey observed much greater than expected numbers of 2-year old fish (1998 year class) for which the selectivity is estimated to be relatively low (0.15). The observed number of 3 and 4-year olds (1997 and 1996 year classes) in 2000 was much lower than expected even though the estimated selectivity is about 60% for 3 year olds, and 4 year olds are expected to be nearly fully selected (Figure 15.14). The 2002 survey age composition was dominated by 4 and 5-year olds of the 1999 and 1998 year classes (Figure 15.20). The 2003 fishery age composition is comprised of 3-5-year olds of the 1998, 1999, and 2000 year classes, but largely dominated by the 1999 year class (4-year olds). It is interesting to note that both the 2002 survey and 2003 fishery age compositions observed greater numbers than expected of the 1999 year class (Figure 15.20 and 15.21).

15.7 Projections and harvest alternatives

15.7.1 Reference fishing mortality rates and yields

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 1978-2003 (501 million age 1 recruits) and F equal to $F_{40\%}$ and $F_{35\%}$ are denoted $B_{40\%}$ and $B_{35\%}$, respectively. The Tiers require reference point estimates for biomass level determinations. We present the following reference points for BSAI Atka mackerel for Tier 3 of Amendment 56. For our analyses, we computed the following values from Model 4 results based on recruitment from post-1976 spawning events:

$B_{100\%}$ = 242,285 mt female spawning biomass
$B_{40\%}$ = 96,900 mt female spawning biomass
$B_{35\%}$ = 84,800 mt 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 2004 selectivity vector. Note that the fishery catch-at-age data exists only up through 2003; the 2004 selectivity vector is a smoothed estimate based on the 2003 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 1999-2003 (Table 15.10, Figure 15.13). 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 discussed and implemented last year; the 2004 ABC projection was based on an average of the years 1999-2002 (Lowe et al. 2003). A comparison of key reference fishing mortality values under the different selectivity assumptions are given below:

Selectivity Assumption

Full selection Fs	2004	Average 1999-2003
F_{2004}	0.254	0.226
$F_{40\%}$	0.563	0.520
$F_{35\%}$	0.696	0.642
$F_{2004}/F_{40\%}$	0.451	0.435

The rates based on the year 2004 selectivity are those presented in the results Table 15.9. Recommendations provided below are based on projections incorporating the average selectivity vector for the years 1999-2003.

For Model 4, the projected year 2005 female spawning biomass (SB_{05}) is estimated to be 151,400 mt under the maximum allowable ABC harvest strategy ($F_{40\%}$). (It should be noted that for BSAI Atka mackerel, projected female spawning biomass calculations depend on the harvest strategy because spawning biomass is estimated at peak spawning (August), thus projections incorporate 7 months of the specified fishing mortality rate). The projected 2005 female spawning biomass is above the $B_{40\%}$ value of 96,900 mt, placing BSAI Atka mackerel in **Tier 3a**. The maximum permissible ABC and OFL values under Tier 3a are:

Harvest Strategy	FSPR%	Fishing Mortality Rate	2004 Projected yield (mt)
max F_{ABC}	$F_{40\%}$	0.52	123,900
F_{OFL}	$F_{35\%}$	0.64	146,900

15.8 ABC Considerations and Recommendation

15.8.1 ABC Considerations

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.

2) Under an $F_{40\%}$ harvest strategy, 2005 female spawning biomass is projected to be above $B_{40\%}$, but drop below in 2007 to 2010 (Figure 15.22).

3) The uncertainty about the estimate of the 2005 $F_{40\%}$ catch is moderate with a CV of 20%. The Stock Assessment Toolbox model 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)

5) The model's predicted survey biomass trend is very conservative relative to the recent (2000, 2002, and 2004) observed bottom trawl survey biomass values (Figure 15.19).

6) The 2003 fishery age composition data continues to show large numbers from the 1998 year class, and now shows *extremely* large numbers from the 1999 year class and the first appearance in the fishery of the above average 2000 year class (Figure 15.4). The 2003 fishery age data are dominated by these three year classes. Currently we estimate the 1999 year class to be the largest in the time series (but with a high degree of uncertainty: CV=32%).

15.8.2 ABC Recommendation

We believe the current model configuration as implemented with the ADMB software provides an improved assessment of BSAI Atka mackerel. 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. However, given the first 3 factors listed above, we felt that an added conservation measure may be warranted for other considerations, including fishery stability. For these reasons we point out projections under a 5-year (2000-2004) average F harvest policy (Scenario 4, Table 15.15 and Figure 15.23). The 5-year (2000-2004) average F projection gave a 2005 yield of 74,900 mt compared to a maximum permissible ABC of 123,900 mt. This scenario (as expected) significantly reduced the probability of the biomass dropping below $B_{40\%}$ (Figure. 15.23). We note that the long-term expected catch under the maxF_{ABC} policy is about 70,000 mt (Table 15.15 and Figure 15.22). These alternatives are offered as a means for added conservation to encompass other considerations. However, given the current stock size and the appearance of two and possibly three consecutive strong year classes, from a biological perspective (for Atka mackerel) the maximum permissible is acceptable.

The associated 2005 yield associated with the maximum permissible $F_{40\%}$ fishing mortality rate of 0.52 is 123,900 mt, which is our 2005 ABC recommendation for BSAI Atka mackerel.

This ABC recommendation represents a significant 86% increase over the Council's 2004 ABC. However, this level of increase is supported by the data given the positive signs from the last three surveys and the fact that the model prediction is substantially below these survey biomass estimates, the 1999 year class is extremely strong and estimated to be the largest in the time series, and the incoming 2000 year class. Nonetheless, alternative prudent yield levels warrant consideration.

15.8.3 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 (1994, 1997, 2000, 2002) weighted average to apportion the 2004 ABC. The rationale for the weighting scheme was described in Lowe et al. (2001).

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

	1997	2000	2002	2004	2004 TAC Apportionment .	4-survey weighted average
541	12.3%	0.20%	24.7%	27.5%	16.8%	**19.8%**
542	51.0%	64.6%	42.3%	30.4%	46.6%	**42.6%**
543	36.4%	35.2%	33.0%	42.0%	36.5%	**37.6%**
Weights	8	12	18	27		

The apportionment of 123,900 mt based on the most recent 4-survey weighted average is:

Eastern (541)	24,600 mt
Central (542)	52,700 mt
Western (543)	46,600 mt

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 2004 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2005 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 1999-2003 selectivities), and the best available estimate of total (year-end) catch for 2004 (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 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 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2005, 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 2005 recommended in the assessment to the *max* F_{ABC} for 2005. (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 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 2000-2004 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 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 2005 or 2) above ½ of its MSY level in 2005 and above its MSY level in 2015 under this scenario, then the stock is not overfished.)

Scenario 7: In 2005 and 2006, 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 2017 under this scenario, then the stock is not approaching an overfished condition.)

15.9.1 Projections and status determination

The projected age 3+ biomass at the beginning of 2005 is 485,700 mt, and the projected 2005 female spawning biomass 151,400 mt. The projected yields, female spawning biomass, and the associated fishing mortality rates for the seven harvest strategies are shown in Table 15.15. Under a harvest strategy of $F_{40\%}$ (Scenario 1), female spawning biomass is projected to be above $B_{40\%}$ in 2005, but drop below in 2007 until 2010. It should be noted that in the projections, the fishing mortality rates are prescribed on the basis of the harvest scenario and the spawning biomass in each year. Thus, fishing mortality rates may not be constant within the projection if spawning biomass drops below $B_{40\%}$ in any run.

The associated long-term average female spawning biomass that would be expected under average estimated recruitment from 1978-2003 (501 million recruits) and $F = F_{35\%}$, denoted $B_{35\%}$ is estimated to be 84,800 mt. This value ($B_{35\%}$), is used in the status determination criteria. Female spawning biomass for 2005 (151,400 mt) is projected to be above $B_{35\%}$ thus, the BSAI Atka mackerel stock is determined to be *above* its minimum stock size threshold (MSST) and is *not overfished*. Female spawning biomass for 2017 is also projected to be above $B_{35\%}$ thus the BSAI Atka mackerel stock is *not* expected to fall below its MSST in two years and is *not approaching an overfished condition*.

15.10 Ecosystem Considerations

15.10.1 Ecosystem effects on BSAI Atka mackerel

Prey availability/abundance trends

Figure 15.24 shows the food web of the Aleutian Islands summer survey region, based on trawl survey and food habits data, with an emphasis on the predators and prey of Atka mackerel (see the current Ecosystem Assessment's ecosystem modeling results section for a description of the methodology for constructing the food web).

Adult Atka mackerel in the Aleutians consume a variety of prey, but are primarily planktivorous. Food habits data from 1990-1994 indicates that Atka feed on calanoid copepods (40%) and euphausiids (25%) followed by squids (10%) pollock juveniles (6%) and finally a range of zooplankton including fish larvae (Fig. 15.25a). While Figure 15.25a shows an aggregate diet for the Aleutians management regions, Atka mackerel feeding also shows a longitudinal gradient, with euphausiids dominating diets in the east and copepods and other zooplankton dominating in the west. Greater piscivory, especially on myctophids, occurs in the island passes (I. Ortiz pers. comm.) No time series of information is available on Aleutian Islands zooplankton, squid, or small forage fish abundance.

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 unpublished results). Since these sensitivity analyses treat the Aleutian Islands as a single "box model", it is possible that this is a mitigating or underlying factor for the geographical separation between Atka mackerel and pollock as a partitioning of foraging habitat.

Predator population trends

Atka mackerel are consumed by a variety of piscivores, including groundfish (e.g., Pacific cod and arrowtooth flounder, Livingston et al. unpubl. manuscr.), marine mammals (e.g., northern fur seals and Steller sea lions, Kajimura 1984, NMFS 1995, Sinclair and Zeppelin 2002), and seabirds (e.g., tufted puffins, Byrd et al. 1992). 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 15.26. During these years, approximately 20% of Atka mackerel exploitation rate (as calculated by stock assessment) was due to the fishery, 62% due to predation, and 18% "unexplained", where "unexplained" is the difference between the stock assessment total mortality and the sum of fisheries exploitation and quantified predation. This unexplained mortality may be due to data uncertainty, or Atka mackerel mortality due to disease, migration, senescence, etc.

Of the 62% of mortality due to predation, a little less than half (25% of total) is due to Pacific cod predation, and one quarter (15% of total) due to Steller Sea lion predation, with the remainder spread across a range of predators (Figure 15.25b), based on Steller sea lion diets published by Merrick et al. (1997) and summer fish food habits data from the REFM food habits database.

If converted to tonnages, this translates to 100,000-120,000t/year of Atka mackerel consumed by predatory fish (of which approximately 60,000t is consumed by Pacific cod), and 40,000-80,000t/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 70,000tons/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 (U.S. F&W 2001). The food web model’s estimate, based on foraging overlap between species, puts the total Atka mackerel consumption by birds at less than 2,000t/year. While this might be an underestimate, it should be noted that most predation would occur on juveniles (<1year old) which are not counted in the stock assessment’s total exploitation rates.

The abundance trends of Aleutian Islands Pacific cod and arrowtooth flounder is relatively stable. Northern fur seals are showing declines, and Steller sea lions have shown some slight increases. Declining trends in predator abundance could lead to possible decreases in Atka mackerel mortality. The population trends of seabirds are mixed, some increases, some decreases, and others stable. Seabird population trends could affect young-of-the-year mortality.

Changes in habitat quality

The 2002 Aleutian Islands summer bottom temperatures indicated that 2002 was the second coldest year after the 2000 survey. 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 Atka mackerel.

15.10.2 Atka mackerel fishery effects on the ecosystem

Atka mackerel fishery contribution to bycatch

The levels of bycatch in the Atka mackerel fishery of prohibited species, forage fish, HAPC biota, marine mammals, birds, and other sensitive non-target species is relatively low except for the species which are noted in Table 15.16 and discussed below.

The Atka mackerel fishery has very low bycatch levels of some species of HAPC biota, e.g. seapens and whips. The bycatch of sponges and coral in the Atka mackerel fishery is variable. It is notable that in the last 5 years (1998-2002), the Atka mackerel fishery has taken on average about 50 and 40%, respectively of the total Aleutian Islands trawl sponge and coral catches. It is unknown if the absolute levels of sponge and coral bycatch in the Atka mackerel fishery are of concern.

The bycatch of skates, which are considered a sensitive or vulnerable species based on life history parameters, is noted in Table 15.16. Skate bycatch in the Aleutian Islands Atka mackerel fishery is variable and has averaged a little over 90 mt in the last 5 years (1998-2002). Over this same time period, the Atka mackerel fishery has taken an average of 66% of the total Aleutian Islands trawl 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 400 mt from 1998 to 2002. This level of bycatch represents an average of 66% of the total Aleutian Islands trawl sculpin bycatch. It is unknown if the absolute levels of sculpin bycatch in the Atka mackerel fishery are of concern.

Concentration of Atka mackerel catches in time and space

Steller sea lion protection measures have spread out Atka mackerel harvests in time and space through the implementation of seasonal and area-specific TACs and harvest limits. 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.

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 765 mt and 10,120 mt of non-target and target species discards respectively, from 1998 to 2002. Most of the Atka mackerel fishery discards of target species are comprised of small Atka mackerel. These levels of discard represent an average of about 56 and 76% respectively, of the total Aleutian Islands trawl non-target and target species discards.

Atka mackerel fishery effects on Atka mackerel age-at-maturity and fecundity

The effects of the fishery on the age-at-maturity and fecundity of Atka mackerel are unknown. Studies were conducted to determine age-at-maturity (McDermott and Lowe 1997) and fecundity (McDermott 2003) of Atka mackerel. These are recent studies and there are no earlier studies for comparison on fish from an unexploited population. Further studies would be needed to determine if there have been changes over time and whether changes could be attributed to the fishery.

15.10.3 Data gaps and research priorities

No time series of information is available on copepod and euphausiid abundance in the Aleutian Islands. Regional and seasonal food habits data for Atka mackerel is also lacking. 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.

15.11 Future considerations

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

15.12 Summary

Natural mortality = 0.3

2005 (Tier 3a)			
Maximum permissible ABC:	$F_{40\%}$ = 0.52	yield =	123,900 mt
Recommended ABC:	$F_{40\%}$ = 0.52	yield =	123,900 mt
Overfishing (OFL):	$F_{35\%}$ = 0.64	yield =	146,900 mt

Equilibrium female spawning biomass		
$B_{100\%}$	=	242,285 mt
$B_{40\%}$	=	96,900 mt
$B_{35\%}$	=	84,800 mt

Projected 2005 biomass	
Age 3+ biomass	= 485,700 mt
Female spawning biomass	= 151,400 mt

15.13 Acknowledgements

We thank the AFSC survey personnel for the collection of data and providing the biomass estimates. We are especially grateful to all the fishery observers of the North Pacific Groundfish Observer Program who collect vital data for the stock assessments. We also thank the staff of the AFSC Age and Growth Unit for the ageing of otoliths used to determine the age compositions in the assessment.

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15.15 Tables

Table 15.1. Atka mackerel catches (including discards and CDQ catches) by region and corresponding Total Allowable Catches (mt, TAC) set by the North Pacific Fishery Management Council from 1978 to the present. Catches are in mt.

	Eastern Bering Sea				Aleutian Islands Region				BSAI	
Year	Foreign	Domestic		Total	Foreign	Domestic		Total		
		JVP	DAP			JVP	DAP		Total	TAC
1977	0	0	0	a	21,763	0	0	21,763	21,763	b
1978	831	0	0	831	23,418	0	0	23,418	24,249	24,800
1979	1,985	0	0	1,985	21,279	0	0	21,279	23,264	24,800
1980	4,690	265	0	4,955	15,533	0	0	15,533	20,488	24,800
1981	3,027	0	0	3,027	15,028	1,633	0	16,661	19,688	24,800
1982	282	46	0	328	7,117	12,429	0	19,546	19,874	24,800
1983	140	1	0	141	1,074	10,511	0	11,585	11,726	24,800
1984	41	16	0	57	71	35,927	0	35,998	36,055	23,130
1985	1	3	0	4	0	37,856	0	37,856	37,860	37,700
1986	6	6	0	12	0	31,978	0	31,978	31,990	30,800
1987	0	12	0	12	0	30,049	0	30,049	30,061	30,800
1988	0	43	385	428	0	19,577	2,080	21,656	22,084	21,000
1989	0	56	3,070	3,126	0	0	14,868	14,868	17,994	20,285
1990	0	0	480	480	0	0	21,725	21,725	22,205	21,000
1991	0	0	2,596	2,596	0	0	24,144	24,144	26,740	24,000
1992	0	0	2,610	2,610	0	0	47,425	47,425	50,035	43,000
1993	0	0	213	213	0	0	65,524	65,524	65,737	64,000
1994	0	0	189	189	0	0	69,401	69,401	69,590	68,000
1995	0	0	a	a	0	0	81,554	81,554	81,554	80,000
1996	0	0	a	a	0	0	103,943	103,943	103,943	106,157
1997	0	0	a	a	0	0	65,845	65,845	65,845	66,700
1998	0	0	a	a	0	0	58,310	58,310	58,310	64,300
1999	0	0	a	a	0	0	56,231	56,231	56,231	66,400
2000	0	0	a	a	0	0	47,227	47,227	47,227	70,800
2001	0	0	a	a	a	0	61,612	61,612	61,612	69,300
2002	0	0	a	a	a	0	45,594	45,594	45,594	49,000
2003	0	a	a	a	a	0	54,890	54,890	54,890	60,000
2004[C]	0	a	a	a	a	0	54,890	52,965	52,965	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) 2004 data as of 9/25/04 from NMFS Alaska Regional Office Home Page.

Table 15.2 Research catches (mt) of Atka mackerel from NMFS trawl surveys in the Aleutian Islands.

Year	Catch
1980	47.9
1981	3.9
1982	0.9
1983	151.4
1986	130.2
1991	77.1
1994	146.5
1997	85.2
2002	--
2004	--

Table 15.3 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	---	---	---

[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 15.4 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	1-100	95	15,321	418,271			
Aleutian	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	1-100	0	65,814	33			
Aleutian	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	1-100	0	41,235	32,564			
Aleutian	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	1-100	48,211	18,182	1			
Aleutian	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 15.5 Atka mackerel biomass (mt), and the percentage distribution and coefficients of variation (*CV*) by management area from the bottom trawl surveys in the Aleutian Islands in 1991, 1994, 1997, 2000, 2002, and 2004. Biomass is also reported by survey depth interval.

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

Table 15.6 Mean weight-at-age (kg) and length-at-age values (cm) for Atka mackerel from the Aleutian trawl surveys and the commercial fishery. The survey vectors are derived from data from the years 1986, 1991, and 1994; the fishery vectors are derived from data from the years 1990 to 1996.

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

Table 15.7 Schedules of age and length specific maturity of Atka mackerel from McDermott and Lowe (1997) by Aleutian Islands subareas. Eastern - 541, Central - 542, and Western - 543.

		INPFC Area			Proportion
Length (cm)	541	542	543	Age	mature
25	0	0	0	1	0
26	0	0	0	2	0.04
27	0	0.01	0.01	3	0.22
28	0	0.02	0.02	4	0.69
29	0.01	0.04	0.04	5	0.94
30	0.01	0.07	0.07	6	0.99
31	0.03	0.14	0.13	7	1
32	0.06	0.25	0.24	8	1
33	0.11	0.4	0.39	9	1
34	0.2	0.58	0.56	10	1
35	0.34	0.73	0.72		
36	0.51	0.85	0.84		
37	0.68	0.92	0.92		
38	0.81	0.96	0.96		
39	0.9	0.98	0.98		
40	0.95	0.99	0.99		
41	0.97	0.99	0.99		
42	0.99	1	1		
43	0.99	1	1		
44	1	1	1		
45	1	1	1		
46	1	1	1		
47	1	1	1		
48	1	1	1		
49	1	1	1		
50	1	1	1		

Table 15.8. Estimates of key results for some of the Atka mackerel models evaluated for this assessment **using only last year's data.** Coefficients of variation (*CV*) for some key reference values appearing directly above are given in parentheses.

Model	Base	Model_1	Model_2	Model_3
Model setup				
Survey catchability	1.000	1.000	1.000	1.000
Steepness	0.800	0.800	0.800	0.800
SigmaR	0.6	0.6	0.6	0.6
Natural mortality	0.300	0.300	0.300	0.300
Fishery Average Effective *N*	109	107	108	106
Survey Average Effective *N*	49	49	49	49
RMSE Survey	0.475	0.436	0.327	0.305
-log Likelihoods				
Number of Parameters	361	361	361	361
Survey index	5.12	4.36	3.25	2.67
Catch biomass	0.07	0.05	0.06	0.04
Fishery age comp	149.49	153.58	151.59	155.51
Survey age comp	33.17	32.63	33.47	32.60
Sub total	187.84	190.61	188.37	190.82
-log Penalties				
Recruitment	6.002	4.582	5.075	3.639
Selectivity constraint	105.004	108.573	107.221	110.551
Fishing mortality penalty	0.001	0.000	0.000	0.000
Prior	0.064	0.058	0.061	0.054
Total	298.912	303.821	300.725	305.068
Fishing mortalities (full selection)				
*F*2003	0.708	0.279	0.381	0.208
*F*40%	0.847	0.498	0.670	0.475
*F*35%	1.068	0.612	0.837	0.582
Stock abundance				
Initial Biomass (mt, 1977)	260,860	314,950	293,080	360,380
CV	(17%)	(20%)	(17%)	(18%)
2003 total biomass (mt)	433,550	591,870	579,050	734,770
CV	(27%)	(26%)	(17%)	(16%)
2003 Age 3+ biomass (mt)	336,345	471,560	459,772	592,908
1998 year class (1000's at age 1)	698	883	912	1,078
CV	(55%)	(53%)	(38%)	(38%)
Recruitment Variability	0.579	0.570	0.573	0.565
Projected catch (unadjusted)				
F40% 2004 catch (mt)	71,843	100,140	101,480	126,450
CV	(35%)	(30%)	(22%)	(21%)
F35% 2004 catch (mt)	86,394	118,710	121,270	149,460
CV	(35%)	(31%)	(22%)	(22%)

Table 15.9. Estimates of key results for some of the Atka mackerel models evaluated for this assessment **using the latest survey and fishery data.** Coefficients of variation (*CV*) for some key reference values appearing directly above are given in parentheses.

	Model	Baseline	Model_3	Model_4
Model setup				
	Survey catchability	1.000	1.000	1.405
	Steepness	0.800	0.800	0.800
	SigmaR	0.6	0.6	0.6
	Natural mortality	0.300	0.300	0.300
-log Likelihoods				
	Number of Parameters	373	373	374
	Survey index	3.73	2.20	2.34
	Catch biomass	0.06	0.04	0.06
	Fishery age comp	154.80	159.96	155.54
	Survey age comp	35.11	34.70	35.09
	Sub total	193.70	196.91	193.03
-log Penalties				
	Recruitment	7.720	5.758	8.013
	Selectivity constraint	113.031	117.445	113.496
	Fishing mortality penalty	0.000	0.000	0.000
	Prior	0.063	0.054	2.117
	Total	314.513	320.163	316.656
	Fishery Average Effective *N*	115	111	115
	Survey Average Effective *N*	52	52	51
	RMSE Survey	0.349	0.274	0.281
Fishing mortalities				
	Average F over all ages			
	F 2004	0.232	0.099	0.181
	F 2004/*F*40%	0.495	0.348	0.451
	*F*40%	0.467	0.284	0.403
	CV	(47%)	(33%)	(42%)
	*F*35%	0.581	0.345	0.497
	CV	(49%)	(35%)	(43%)
	Fishing mortalities (full selection)			
	F 2004	0.342	0.146	0.254
	*F*40%	0.690	0.418	0.563
	*F*35%	0.858	0.508	0.696
Stock abundance				
	Initial Biomass (mt, 1977)	287,670	373,740	291,350
	CV	(17%)	(18%)	(17%)
	2004 total biomass (mt)	643,260	892,340	696,280
	CV	(19%)	(13%)	(14%)
	2004 Age 3+ biomass (mt)	587,897	821,554	640,046
	1998 year class (at age 1)	763	1,005	820
	CV	(39%)	(32%)	(33%)
	1999 year class (1000's at age 1)			1,298
	CV			(32%)
	Recruitment Variability	0.603	0.593	0.604
Projected catch (unadjusted)				
	*F*50% 2005 catch (mt)	81,834	112,780	88,869
	CV	(24%)	(18%)	(19%)
	*F*40% 2005 catch (mt)	117,360	156,500	122,835
	CV	(24%)	(19%)	(20%)
	*F*35% 2005 catch (mt)	139,740	183,950	149,610
	CV	(25%)	(20%)	(20%)

Table 15.10. 1977-2004 estimates of Atka mackerel fishery (over time) and survey selectivity 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	0.11	0.40	0.88	1.00	0.72	0.45	0.29	0.20	0.16	0.16	0.16	0.16	0.16	0.16
1978	0.02	0.11	0.49	0.82	1.00	0.85	0.57	0.37	0.25	0.20	0.20	0.20	0.20	0.20	0.20
1979	0.01	0.05	0.26	0.80	1.00	0.85	0.59	0.38	0.25	0.20	0.20	0.20	0.20	0.20	0.20
1980	0.01	0.06	0.22	0.62	1.00	0.96	0.79	0.53	0.33	0.24	0.24	0.24	0.24	0.24	0.24
1981	0.01	0.04	0.14	0.28	0.38	0.63	1.00	0.56	0.27	0.17	0.17	0.17	0.17	0.17	0.17
1982	0.01	0.03	0.10	0.34	0.90	1.00	0.66	0.39	0.25	0.19	0.19	0.19	0.19	0.19	0.19
1983	0.01	0.04	0.16	0.39	0.70	1.00	0.86	0.48	0.30	0.23	0.23	0.23	0.23	0.23	0.23
1984	0.01	0.03	0.14	0.43	0.78	1.00	0.91	0.62	0.40	0.29	0.29	0.29	0.29	0.29	0.29
1985	0.01	0.06	0.41	0.84	1.00	0.99	0.90	0.76	0.61	0.50	0.50	0.50	0.50	0.50	0.50
1986	0.01	0.04	0.23	0.50	0.71	0.85	0.97	1.00	0.82	0.63	0.63	0.63	0.63	0.63	0.63
1987	0.01	0.04	0.24	0.55	0.77	0.86	0.94	1.00	0.96	0.90	0.90	0.90	0.90	0.90	0.90
1988	0.01	0.05	0.31	0.97	1.00	0.87	0.83	0.77	0.73	0.66	0.66	0.66	0.66	0.66	0.66
1989	0.01	0.04	0.20	0.57	0.93	1.00	0.88	0.75	0.66	0.62	0.62	0.62	0.62	0.62	0.62
1990	0.00	0.03	0.23	0.79	1.00	0.79	0.65	0.58	0.55	0.53	0.53	0.53	0.53	0.53	0.53
1991	0.00	0.02	0.09	0.42	0.89	1.00	0.84	0.71	0.61	0.58	0.58	0.58	0.58	0.58	0.58
1992	0.01	0.03	0.10	0.31	0.67	0.95	1.00	0.95	0.90	0.86	0.86	0.86	0.86	0.86	0.86
1993	0.01	0.03	0.10	0.27	0.56	0.88	1.00	0.97	0.96	0.98	0.98	0.98	0.98	0.98	0.98
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	0.69	0.77	0.84	0.91	1.00	1.00	1.00	1.00	1.00	1.00
1996	0.00	0.02	0.10	0.35	0.54	0.71	0.90	1.00	0.94	0.91	0.91	0.91	0.91	0.91	0.91
1997	0.01	0.02	0.09	0.25	0.51	0.76	0.89	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1998	0.00	0.02	0.09	0.32	0.60	0.78	0.87	0.93	0.98	1.00	1.00	1.00	1.00	1.00	1.00
1999	0.00	0.02	0.13	0.47	0.69	0.79	0.84	0.94	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2000	0.00	0.02	0.15	0.43	0.70	0.85	0.93	1.00	0.98	0.94	0.94	0.94	0.94	0.94	0.94
2001	0.00	0.02	0.13	0.40	0.70	0.89	1.00	0.99	0.89	0.82	0.82	0.82	0.82	0.82	0.82
2002	0.01	0.03	0.12	0.32	0.54	0.79	1.00	0.99	0.91	0.84	0.84	0.84	0.84	0.84	0.84
2003	0.01	0.06	0.22	0.47	0.54	0.69	0.88	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2004	0.02	0.06	0.16	0.34	0.55	0.74	0.89	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ave. 1999-2003	0.01	0.03	0.15	0.42	0.63	0.80	0.93	0.98	0.95	0.92	0.92	0.92	0.92	0.92	0.92
Survey	0.02	0.13	0.56	0.91	0.99	0.98	1.00	0.92	0.75	0.66	0.66	0.66	0.66	0.66	0.66

Table 15.11. Estimated Atka mackerel numbers at age in thousands, 1977-2004 based on Model 4.

	1	2	3	4	5	6	7	8	9	10+	Total	% of 10+
1977	209	226	180	50	37	20	18	16	14	49	819	6%
1978	1,149	154	163	121	30	22	13	12	11	43	1,718	3%
1979	328	848	112	109	76	18	14	8	8	38	1,558	2%
1980	208	242	622	79	69	46	11	9	6	33	1,324	2%
1981	240	154	178	447	54	45	30	8	6	28	1,189	2%
1982	158	178	113	129	316	37	30	19	5	23	1,008	2%
1983	236	117	131	83	93	217	25	21	14	20	957	2%
1984	325	175	86	97	60	66	152	18	15	17	1,012	2%
1985	508	240	129	62	66	39	41	95	12	19	1,211	2%
1986	484	376	176	88	39	40	23	25	60	20	1,330	1%
1987	638	358	276	124	58	25	24	14	15	18	1,549	1%
1988	393	472	263	195	83	37	15	15	9	34	1,517	2%
1989	1,130	291	348	189	132	55	25	11	10	30	2,221	1%
1990	522	837	215	254	133	90	38	17	7	25	2,139	1%
1991	271	386	618	156	176	91	63	27	12	23	1,823	1%
1992	545	201	286	454	111	119	61	43	18	20	1,855	1%
1993	812	403	148	208	318	73	74	37	26	18	2,117	1%
1994	294	601	296	107	144	205	43	43	22	17	1,772	1%
1995	324	217	442	214	73	90	121	25	25	19	1,549	1%
1996	748	239	159	312	133	43	52	68	14	16	1,785	1%
1997	148	553	175	112	191	74	22	24	30	13	1,342	1%
1998	274	109	406	125	75	114	40	11	12	9	1,175	1%
1999	820	203	80	291	82	44	63	21	6	12	1,621	1%
2000	1,298	607	149	57	185	49	25	35	12	10	2,426	0%
2001	635	961	447	106	37	112	28	14	20	7	2,366	0%
2002	253	469	706	313	67	21	57	14	7	7	1,914	0%
2003	299	187	345	505	212	42	12	32	8	10	1,652	1%
2004	286	221	137	243	338	140	27	8	19	8	1,427	1%

Table 15.12. Model 4 estimates of Atka mackerel biomass in mt with approximate lower and upper 95% confidence bounds for age 1+ biomass (labeled as LCI and UCI). Also included are age 3+ and female spawning biomass in mt from the current assessment compared to last year's (2003) assessment.

	Current assessment age 1+ biomass (mt)			Age 3+ biomass (mt)		Female spawning biomass (mt)	
Year	Estimate	LCI	UCI	Current	2003	Current	2003
1977	291,350	190,592	392,108	231,694	206,422	71,070	62,143
1978	395,610	262,776	528,444	243,781	216,903	67,552	59,039
1979	393,400	257,486	529,314	232,599	205,553	71,459	62,415
1980	506,380	335,104	677,656	425,241	382,269	75,776	65,985
1981	550,710	367,430	733,990	447,516	402,869	93,602	82,173
1982	506,040	339,050	673,030	418,621	376,526	144,131	128,560
1983	458,670	310,736	606,604	387,064	347,773	158,365	141,628
1984	425,380	294,844	555,916	346,635	311,470	145,791	130,390
1985	401,340	281,434	521,246	303,197	270,634	123,986	110,165
1986	400,050	285,484	514,616	287,163	255,941	100,357	88,060
1987	458,960	343,138	574,782	325,513	294,142	87,455	76,124
1988	498,470	384,314	612,626	363,742	334,145	90,448	79,442
1989	631,670	518,478	744,862	438,661	412,645	108,639	97,720
1990	666,810	560,270	773,350	457,895	435,872	131,781	121,549
1991	750,430	644,756	856,104	620,939	599,338	155,162	146,274
1992	799,520	693,828	905,212	645,980	623,312	174,791	167,104
1993	765,800	665,292	866,308	572,049	549,802	207,974	200,360
1994	687,750	592,782	782,718	538,184	512,591	203,415	195,300
1995	677,730	577,244	778,216	571,342	534,881	172,181	163,599
1996	646,120	538,082	754,158	488,291	449,632	157,064	146,648
1997	513,540	410,806	616,274	390,089	349,786	146,594	132,938
1998	512,080	399,114	625,046	434,177	380,560	124,295	109,383
1999	517,630	396,334	638,926	364,898	312,895	113,381	97,074
2000	554,800	421,718	687,882	317,398	267,538	119,300	99,868
2001	621,980	467,740	776,220	404,516	336,185	104,944	85,151
2002	732,980	539,800	926,160	589,473	366,554	97,318	75,892
2003	779,900	568,740	991,060	640,046	336,345	137,041	96,062
2004	696,280	496,060	896,500	568,079	286,180	204,418	
2005				485,719			

Table 15.13 Estimates of age-1 Atka mackerel recruitment (in 1000's) based on Model 4.

	Age 1 Recruits	
Year	Current	2003
1977	209	190
1978	1,149	1,056
1979	328	302
1980	208	191
1981	240	221
1982	158	145
1983	236	218
1984	325	304
1985	508	482
1986	484	468
1987	638	631
1988	393	389
1989	1,130	1,111
1990	522	499
1991	271	257
1992	545	512
1993	812	747
1994	294	266
1995	324	291
1996	748	659
1997	148	127
1998	274	247
1999	820	698
2000	1,298	553
2001	635	230
2002	253	241
2003	299	241
Ave 78-03	501	
Med 78-03	360	

Table 15.14. Estimates of full-selection fishing mortality rates and exploitation rates for Atka mackerel based on Model 4 results.

Year	*F*[a]	Catch/Biomass Rate[b]
1977	0.237	0.094
1978	0.207	0.099
1979	0.196	0.100
1980	0.136	0.048
1981	0.160	0.044
1982	0.088	0.047
1983	0.053	0.030
1984	0.189	0.104
1985	0.205	0.125
1986	0.221	0.111
1987	0.190	0.092
1988	0.099	0.061
1989	0.082	0.041
1990	0.082	0.048
1991	0.104	0.043
1992	0.183	0.077
1993	0.246	0.115
1994	0.269	0.129
1995	0.359	0.143
1996	0.537	0.213
1997	0.423	0.169
1998	0.386	0.134
1999	0.324	0.154
2000	0.290	0.149
2001	0.412	0.152
2002	0.280	0.077
2003	0.216	0.086
2004	0.254	0.111

[a] Full-selection fishing mortality rates.
[b] Catch/biomass rate is the ratio of catch to beginning year age 3+ biomass.
[c] The 2004 catch/biomass rate is based on 2004 TAC

Table 15.15. Projections of Model 4 spawning (sp.) biomass in mt, full-selection fishing mortality rates (F) and catch in mt for Atka mackerel for the 7 scenarios. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 242,285, 96,900, and 84,800 mt, respectively.

Sp.Biomass (mt)	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2004	204,418	204,418	204,418	204,418	204,418	204,418	182,900
2005	151,378	151,378	169,182	166,975	189,252	143,693	128,971
2006	103,052	103,052	134,710	130,442	178,320	92,382	92,687
2007	84,558	84,558	116,617	111,635	173,557	75,976	78,100
2008	88,586	88,586	118,873	113,334	183,487	81,234	82,180
2009	96,058	96,058	127,129	120,963	198,190	88,251	88,599
2010	100,494	100,494	133,656	127,005	210,939	91,793	91,893
2011	101,724	101,724	136,940	129,959	219,998	92,336	92,358
2012	101,303	101,303	137,871	130,694	225,765	91,623	91,626
2013	101,138	101,138	138,414	131,129	230,078	91,420	91,420
2014	101,589	101,589	139,287	131,945	233,906	91,858	91,858
2015	102,181	102,181	140,217	132,843	237,214	92,391	92,391
2016	102,470	102,470	140,819	133,420	239,765	92,616	92,616
2017	101,691	101,691	140,213	132,786	240,622	91,832	91,832
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2004	0.226	0.226	0.226	0.226	0.226	0.226	0.520
2005	0.520	0.520	0.260	0.291	0.000	0.642	0.520
2006	0.520	0.520	0.260	0.291	0.000	0.613	0.496
2007	0.448	0.448	0.260	0.291	0.000	0.495	0.510
2008	0.446	0.446	0.252	0.291	0.000	0.514	0.519
2009	0.460	0.460	0.251	0.291	0.000	0.540	0.541
2010	0.472	0.472	0.253	0.291	0.000	0.556	0.556
2011	0.475	0.475	0.254	0.291	0.000	0.560	0.560
2012	0.475	0.475	0.254	0.291	0.000	0.558	0.558
2013	0.475	0.475	0.254	0.291	0.000	0.557	0.557
2014	0.476	0.476	0.254	0.291	0.000	0.558	0.558
2015	0.476	0.476	0.255	0.291	0.000	0.559	0.559
2016	0.476	0.476	0.255	0.291	0.000	0.559	0.559
2017	0.476	0.476	0.254	0.291	0.000	0.559	0.559
Catch (mt)	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2004	62,996	62,996	62,996	62,996	62,996	62,996	132,573
2005	123,859	123,859	67,721	74,883	0	146,942	104,100
2006	89,167	89,167	58,014	62,817	0	94,262	74,768
2007	60,585	60,585	49,892	53,222	0	59,372	62,823
2008	58,317	58,317	45,802	49,856	0	60,995	62,451
2009	62,805	62,805	46,736	50,636	0	67,416	67,997
2010	67,150	67,150	49,094	52,770	0	72,079	72,278
2011	69,079	69,079	50,929	54,499	0	73,678	73,732
2012	69,390	69,390	51,874	55,367	0	73,398	73,410
2013	69,303	69,303	52,311	55,776	0	73,078	73,080
2014	69,565	69,565	52,682	56,093	0	73,409	73,409
2015	69,949	69,949	53,040	56,421	0	73,892	73,892
2016	70,142	70,142	53,270	56,647	0	74,009	74,009
2017	69,799	69,799	53,127	56,548	0	73,575	73,575

Table 15.16. Ecosystem effects

Ecosystem effects on Atka mackerel			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Zooplankton	Stomach contents, ichthyoplankton surveys	None	Unknown
Predator population trends			
Marine mammals	Fur seals declining, Steller sea lions increasing slightly	Possibly lower mortality on Atka mackerel	No concern
Birds	Stable, some increasing some decreasing	Affects young-of-year mortality	Unknown
Fish (Pacific cod, arrowtooth flounder)	Pacific cod and arrowtooth abundance trends are stable	None	No concern
Changes in habitat quality			
Temperature regime	2002 AI summer bottom temperature 2nd coldest year after 2000 survey	Colder than average year, 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 about 100 mt from 1997-2002	Data limited	Unknown
Other non-target species	Sculpin catch is variable, large increase in bycatch in 2002	Unknown	Unknown
Fishery concentration in space and time	Steller sea lion protection measures spread out Atka mackerel catches in time and space	Mixed potential impact (fur seals vs Steller sea lions)	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 56 and 76% of the total AI trawl non-target and target 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

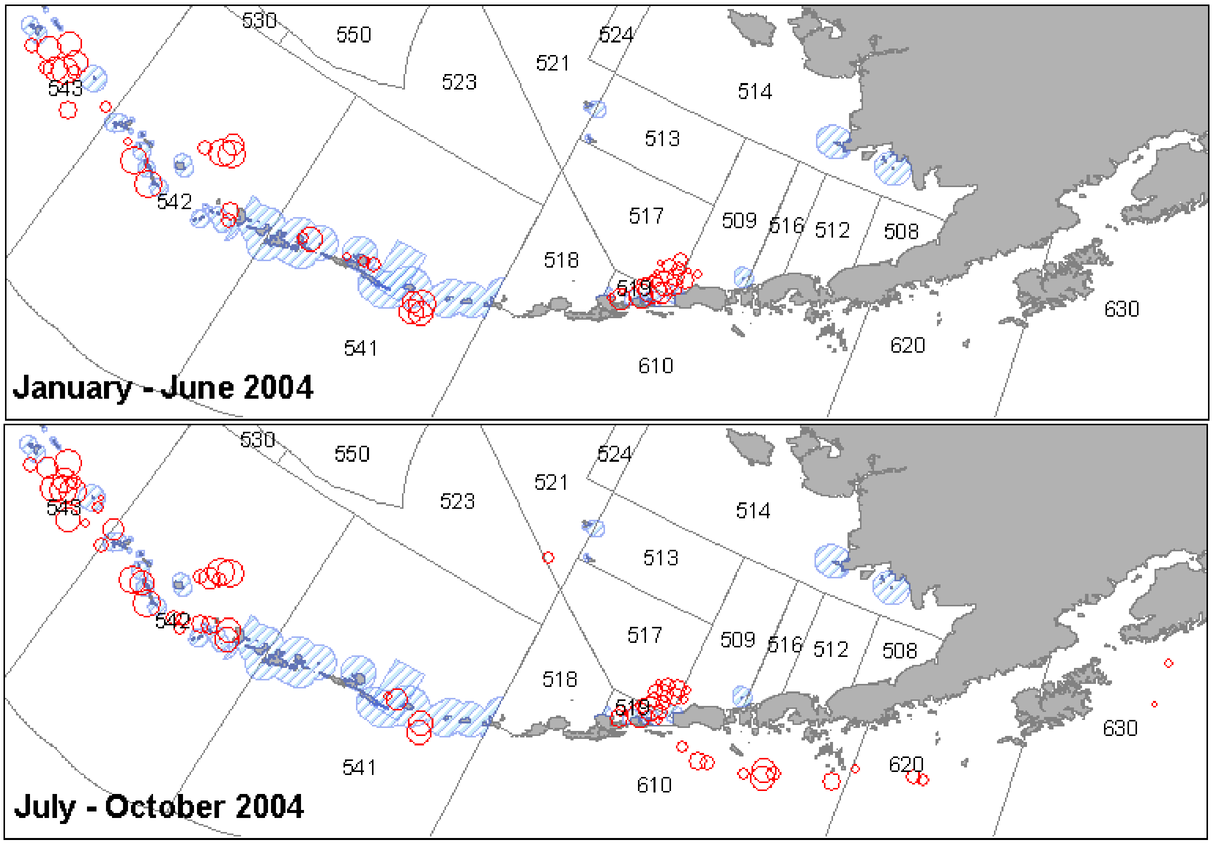


Figure 15.1. Observed catch of Atka mackerel summed for $20km^2$ cells for 2004 (January – June, top panel; and from July-October, bottom panel) where observed catch per haul was greater than 1mt. Shaded areas represent 10 and 20 nm Steller sea lion areas.

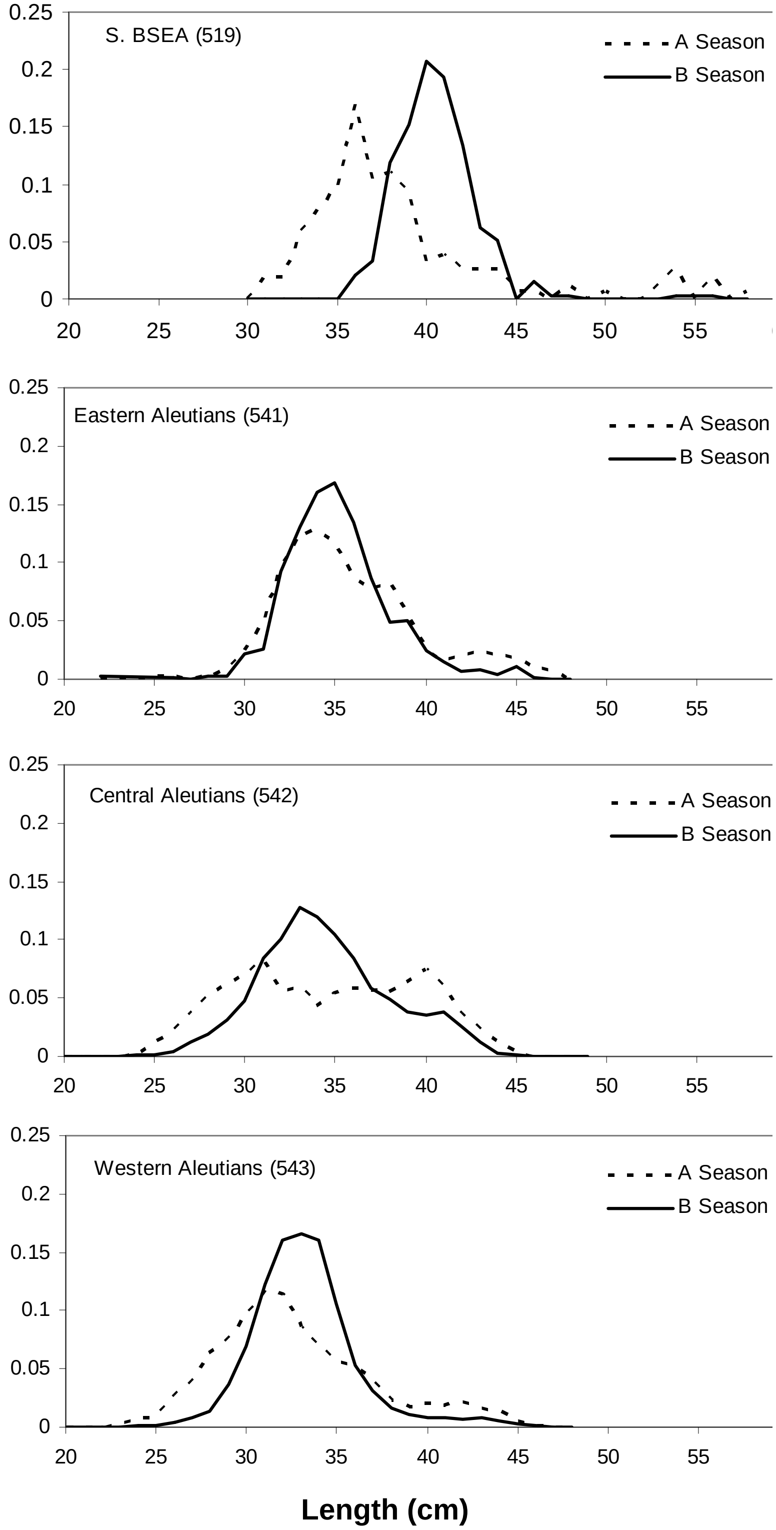


Figure 15.2. 2003 Atka mackerel fishery length-frequency data by area fished. (see Figure 15.1). Numbers refer to management areas.

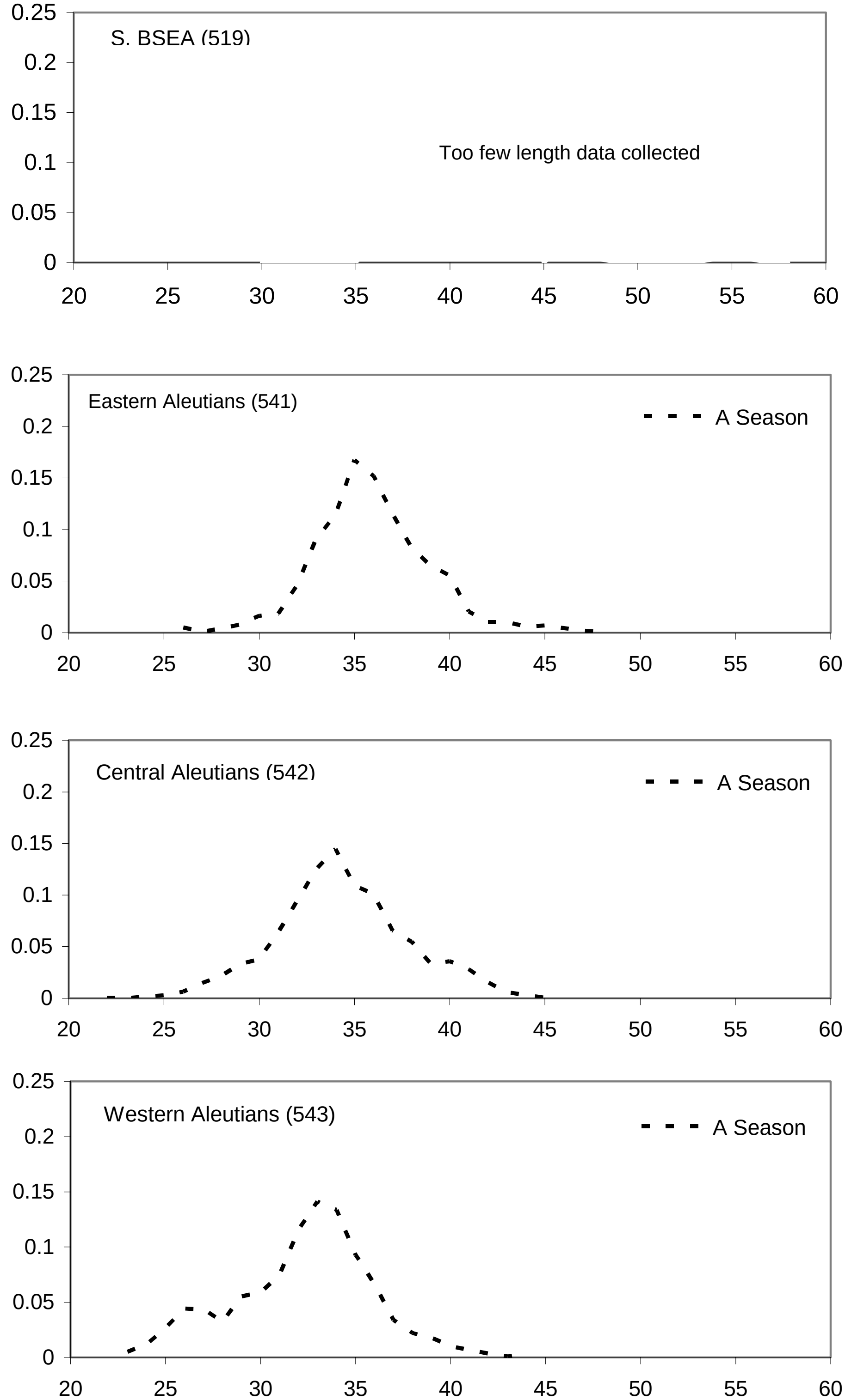


Figure 15.3. Preliminary 2004 A-season Atka mackerel fishery length-frequency data by area fished. (see Figure 15.1). Numbers refer to management areas.

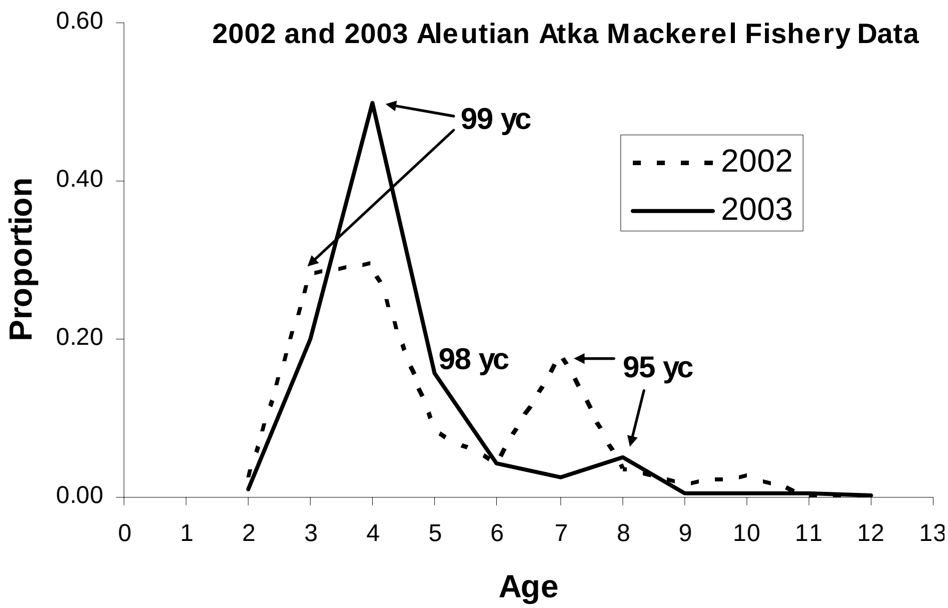


Figure 15.4. 2002 and 2003 Aleutian Atka mackerel fishery age composition data.

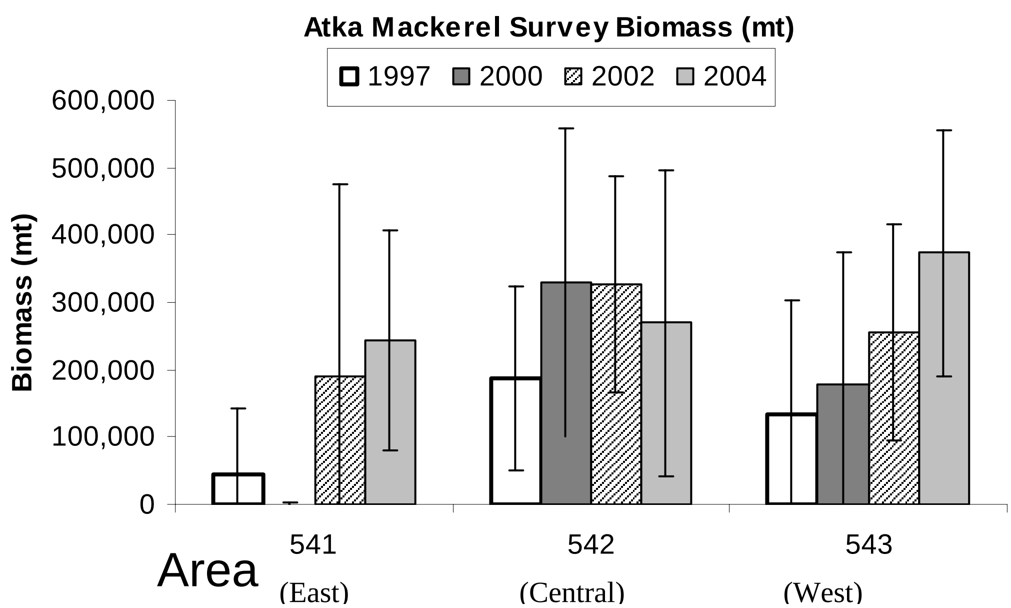


Figure 15.5. Atka mackerel Aleutian survey biomass estimates by area and survey year. Bars represent 95% confidence intervals based on sampling error.

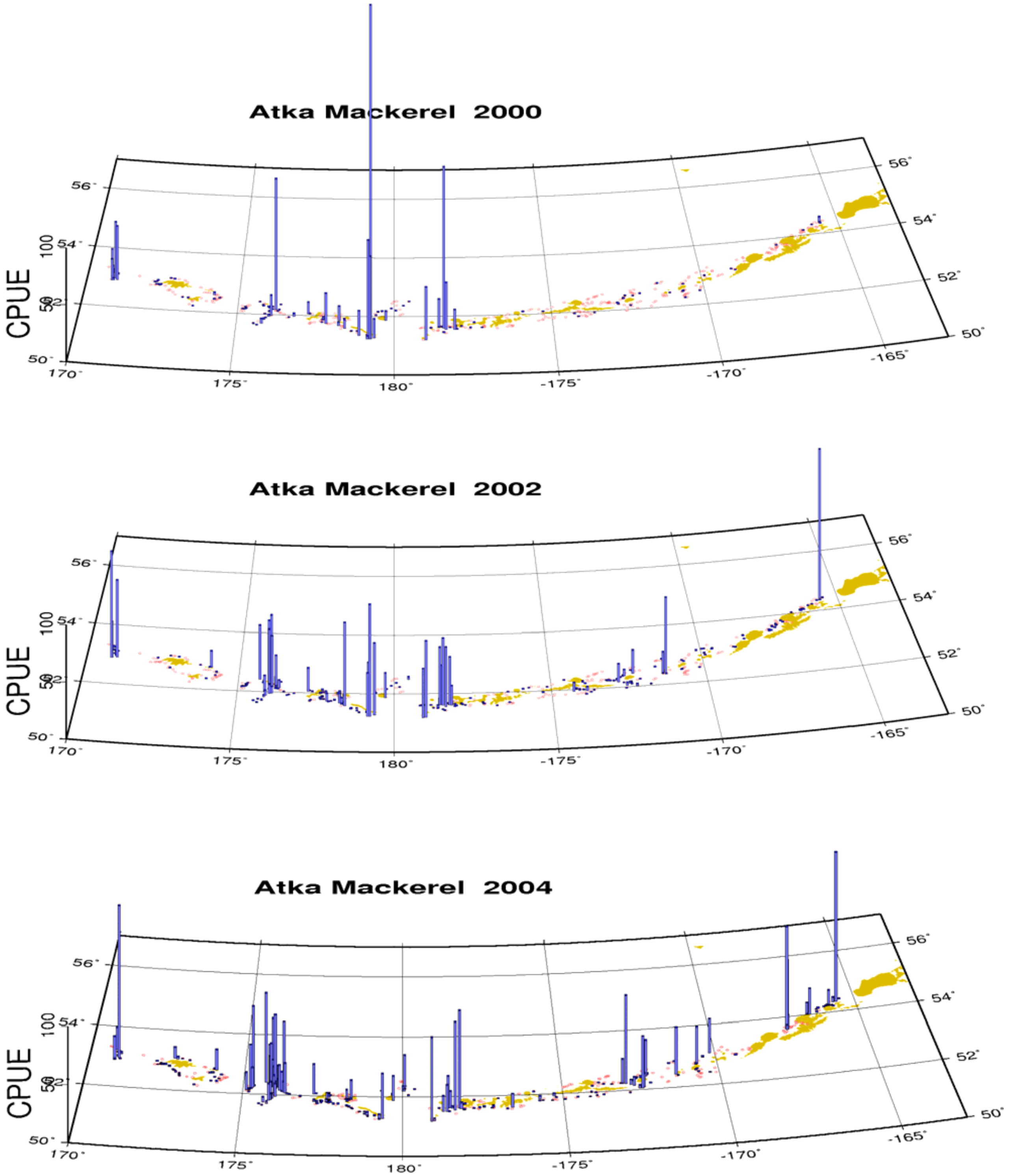


Figure 15.6. Bottom-trawl survey CPUE distributions during the summers of 2000, 2002, and 2004.

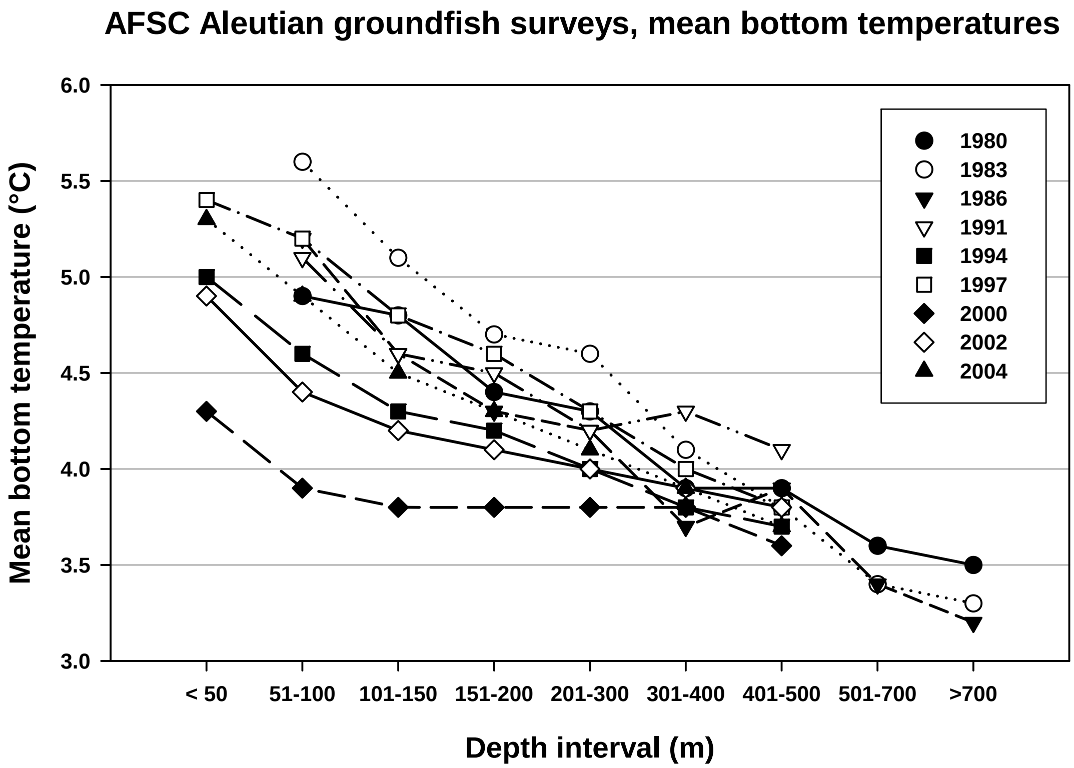


Figure 15.7. Average bottom temperatures by depth interval based on Aleutian Islands summer bottom-trawl surveys since 1980.

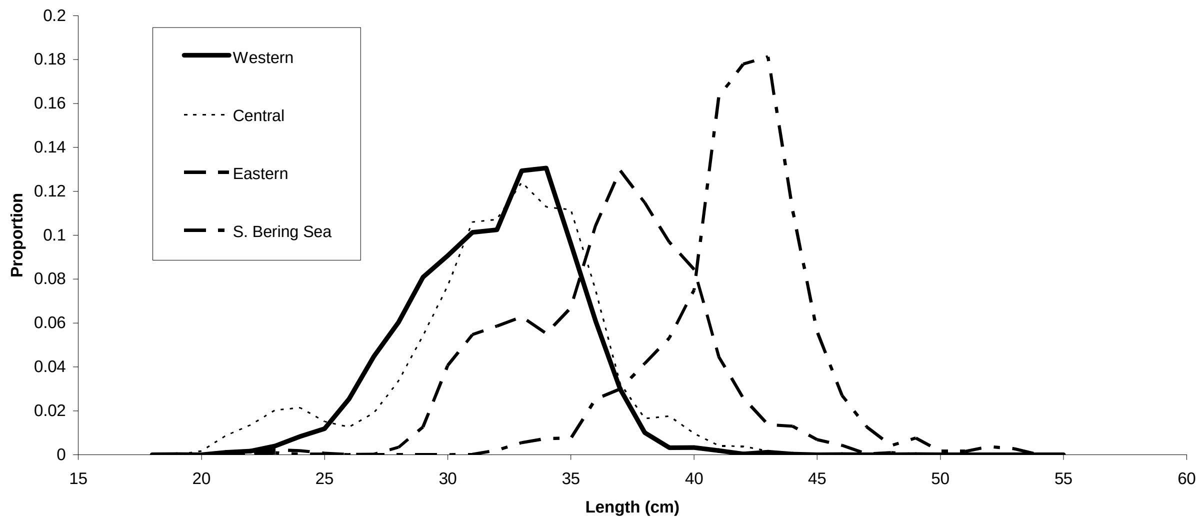


Figure 15.8. Atka mackerel bottom trawl survey length frequency data by subarea from the 2004 Aleutian Island survey.

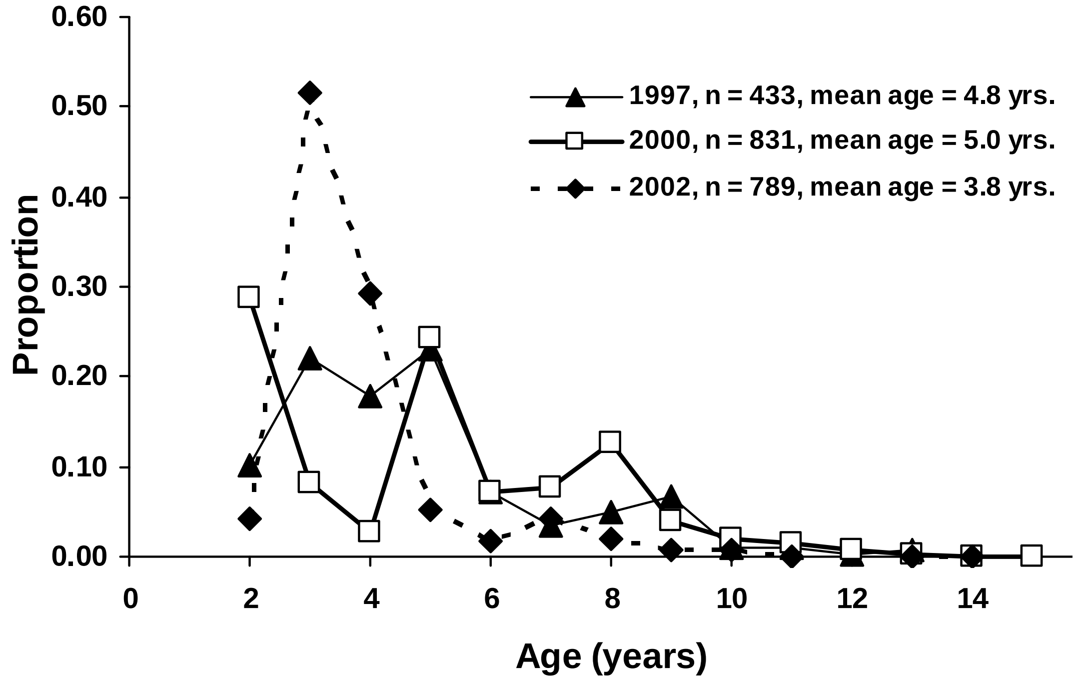


Figure 15.9. Age distributions from the Aleutian Islands region from the 1997, 2000, and 2002 bottom trawl surveys.

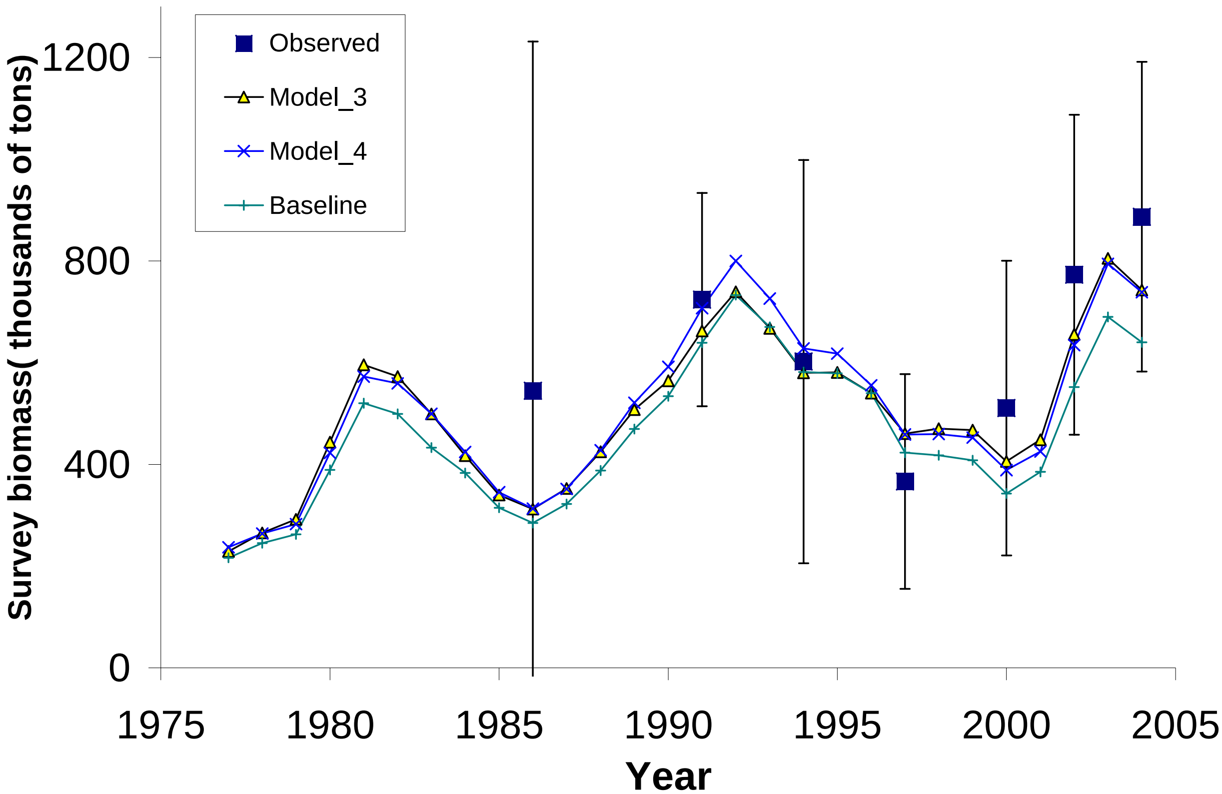


Figure 15.10. Survey biomass predictions for Models 3, 4, and the Baseline (last year's configuration) for BSAI Atka mackerel, 1977-2004.

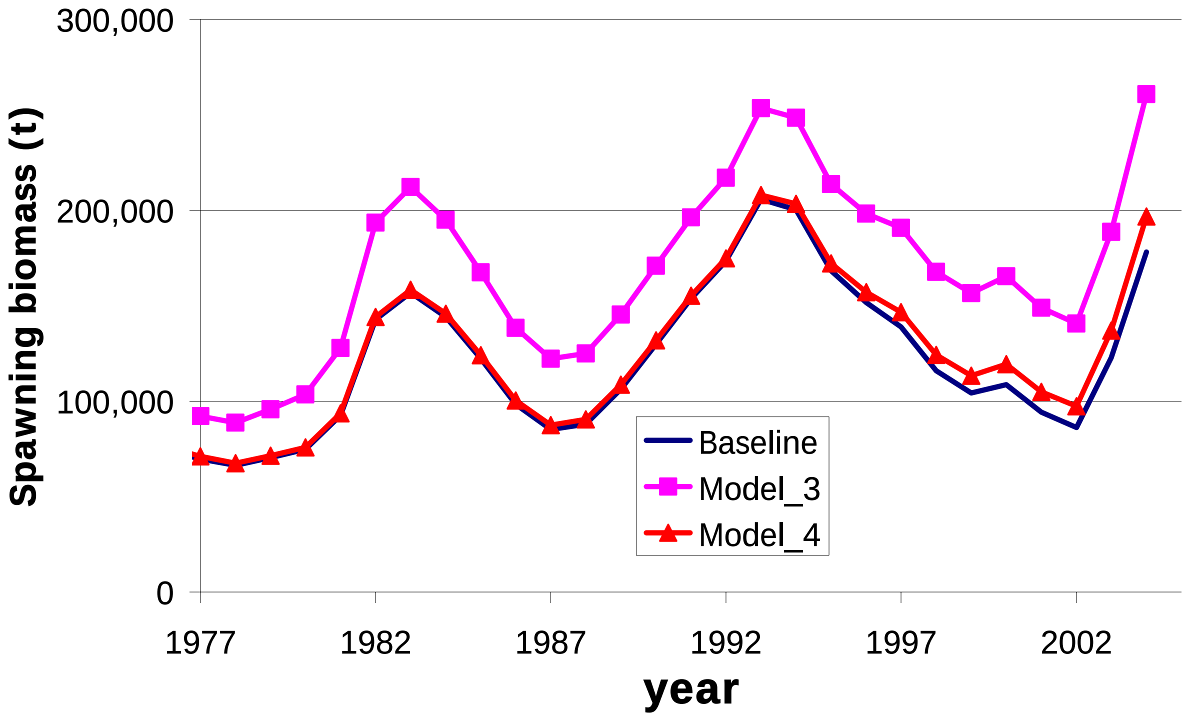


Figure 15.11. Spawning biomass estimates for Models 3, and 4 relative to last year's model configuration (Baseline) for Atka mackerel, 1977-2004.

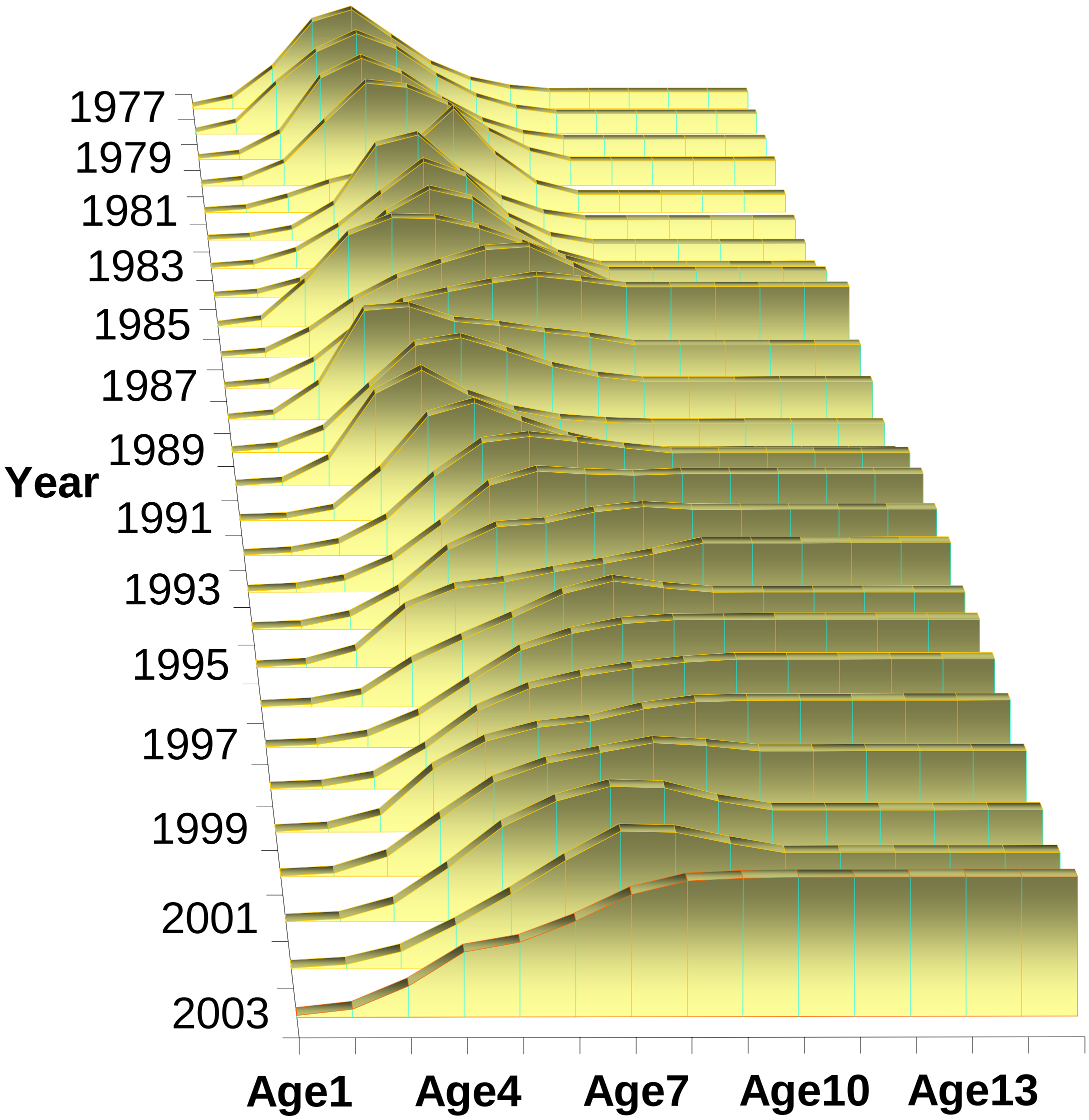


Figure 15.12. Atka mackerel fishery selectivity-at-age estimated for Model 4.

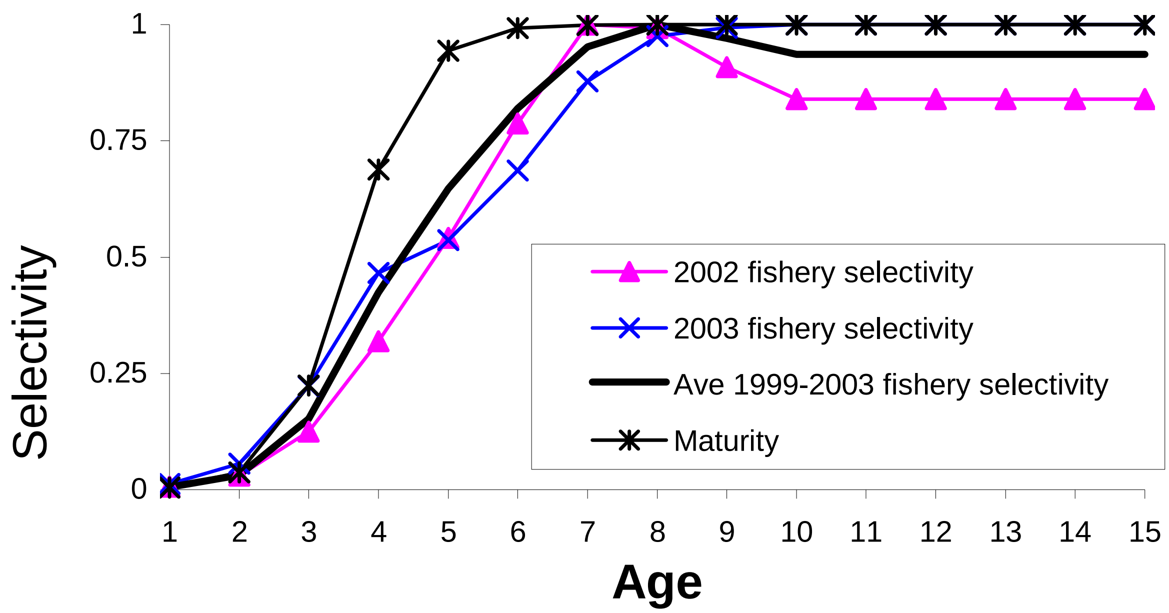


Figure 15.13. Atka mackerel 2002, 2003, and average 1999-2003 selectivity-at-age estimates compared with the maturity at age estimates.

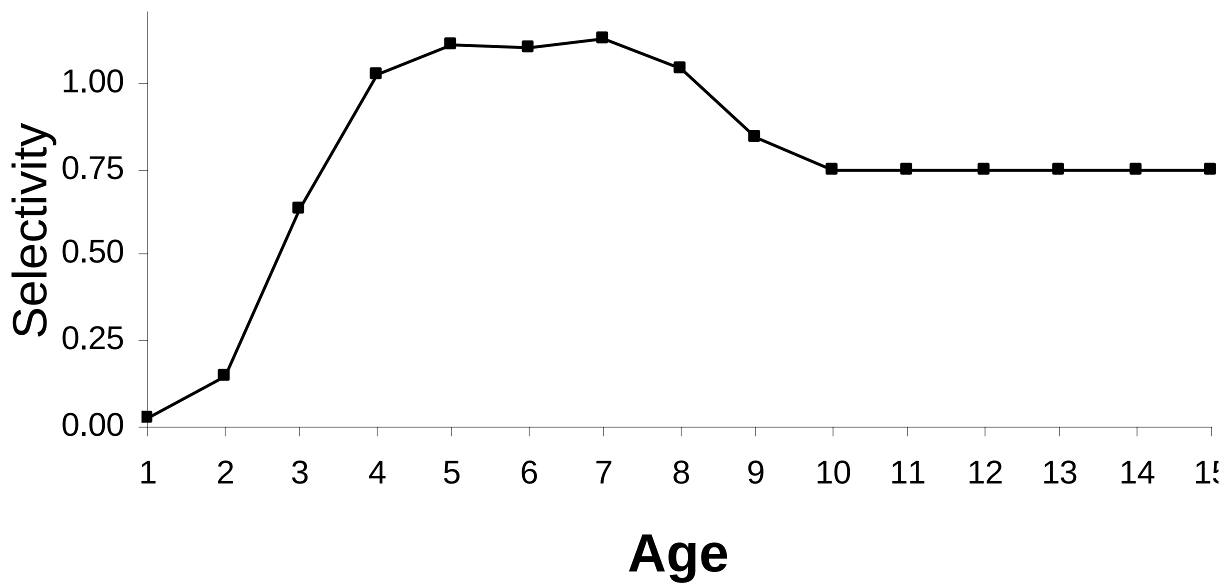


Figure 15.14. Atka mackerel survey selectivity-at-age estimates based on Model 4.

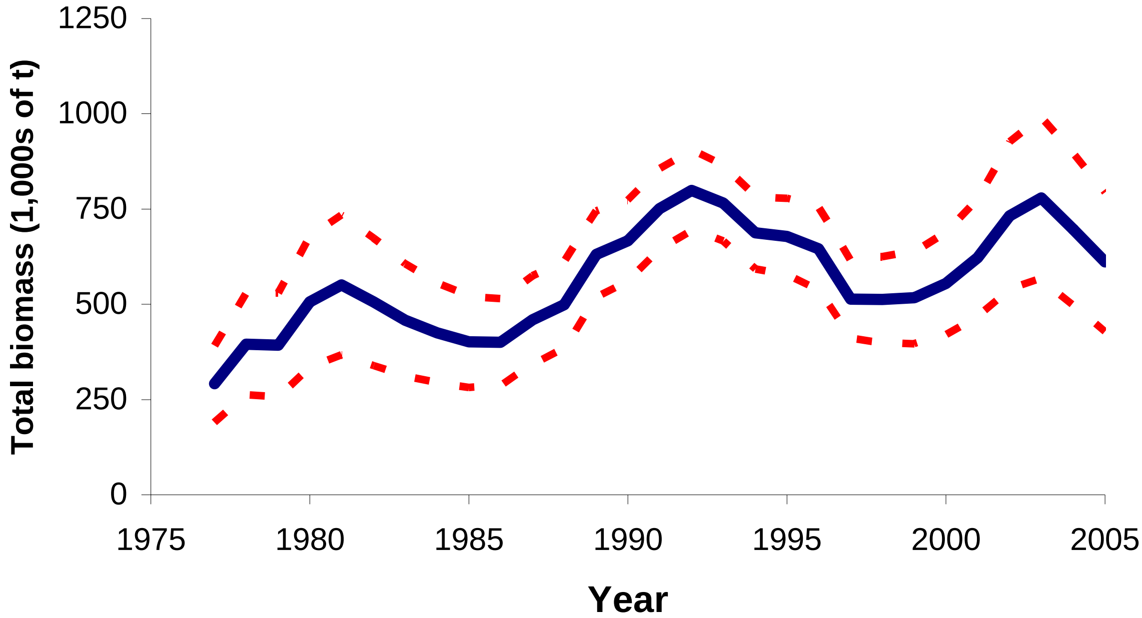


Figure 15.15. Time series of Atka mackerel total biomass estimates and approximate 95% confidence bounds based on Model 4.

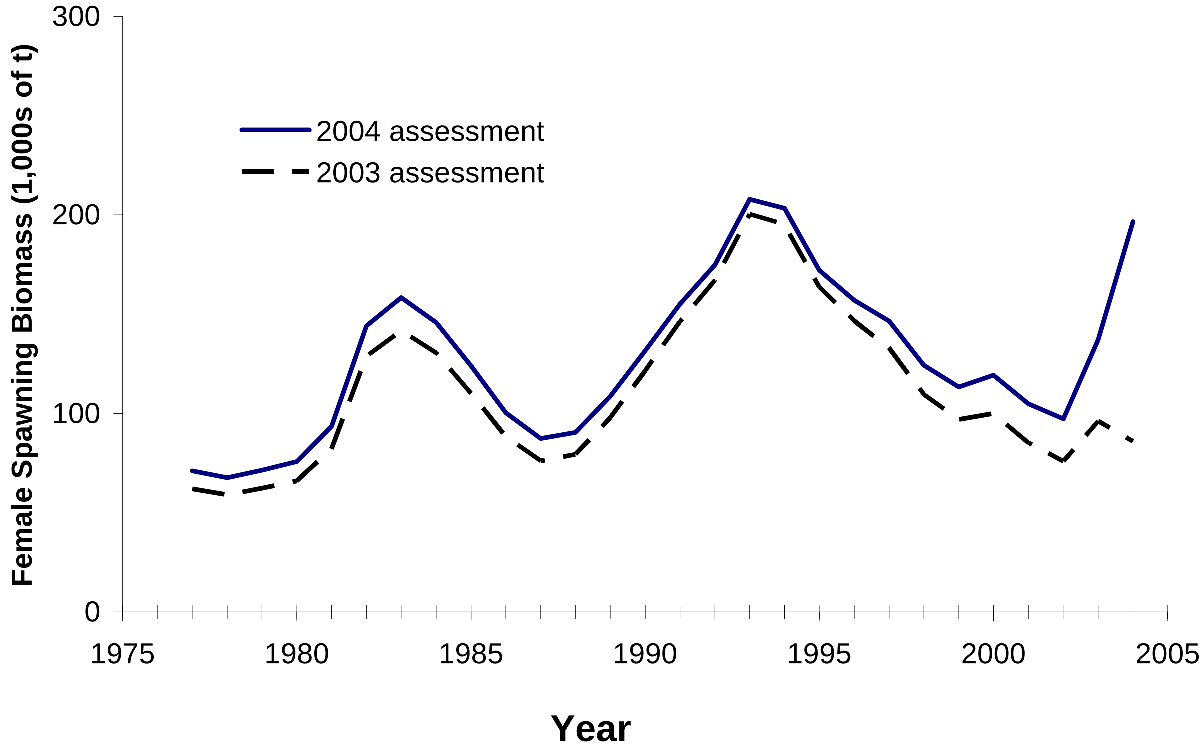


Figure 15.16. Comparison of Lowe et al.'s (2003) assessment of BSAI Atka mackerel to the current Model 4 estimate of female spawning biomass.

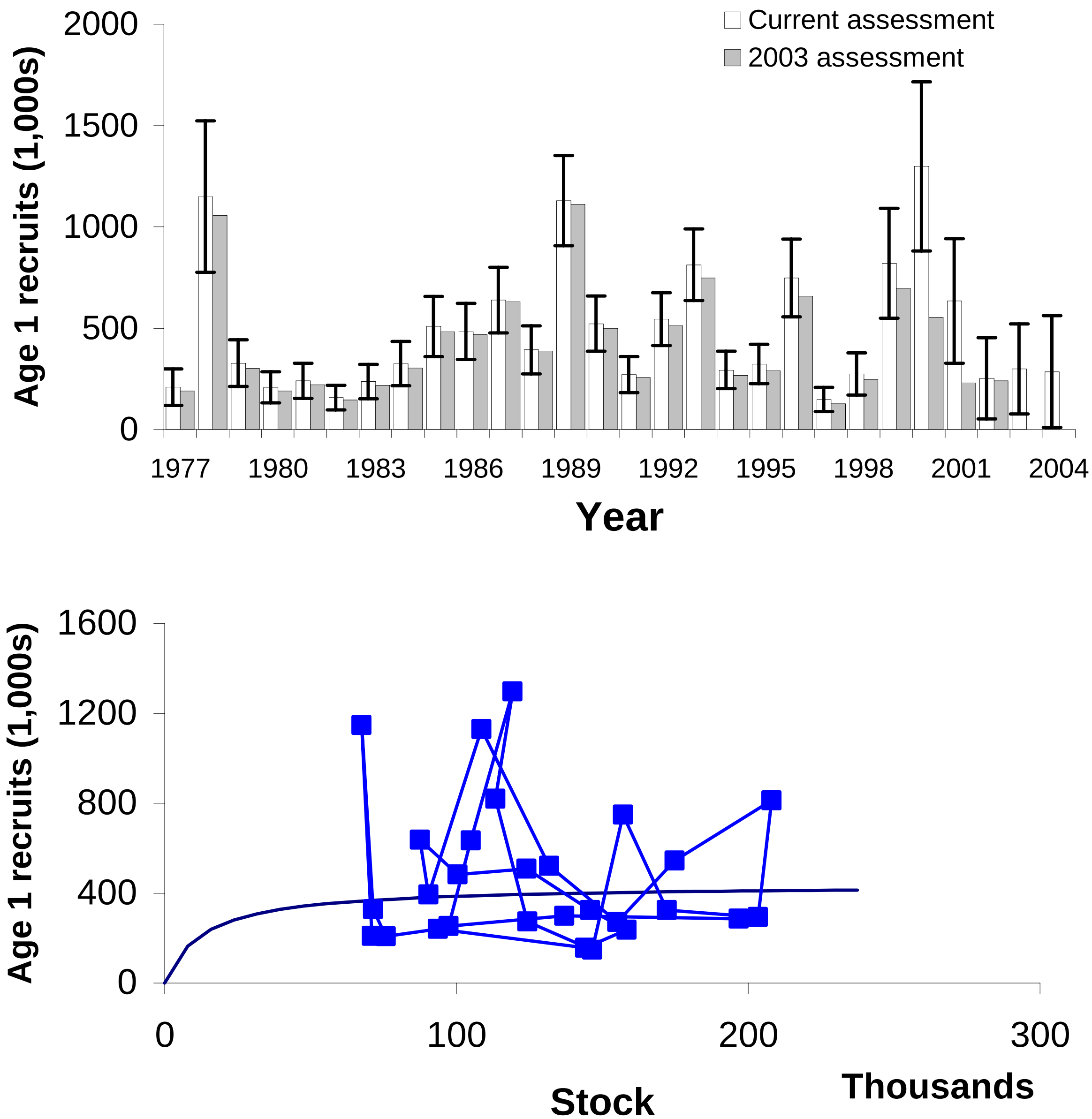


Figure 15.17. Age 1 recruitment of Atka mackerel as estimated from the current assessment for Model 4 with error bars (top panel) and estimated female spawning biomass levels (lower panel).

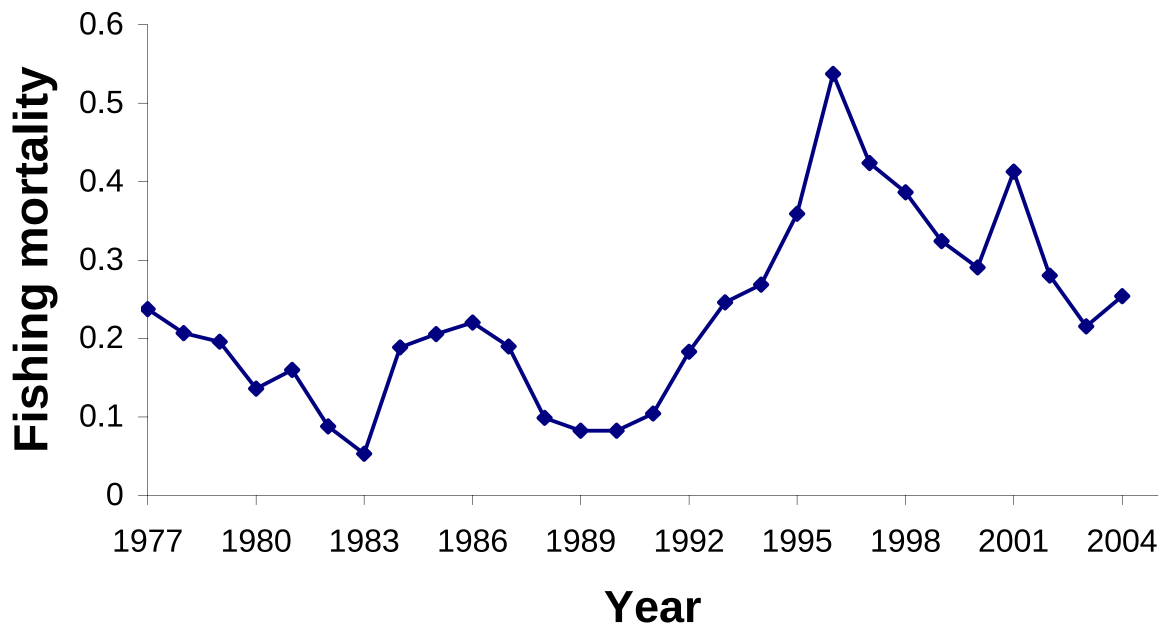


Figure 15.18. Estimated time series of full-selection fishing mortality rates of Atka mackerel based on Model 4, 1977-2004.

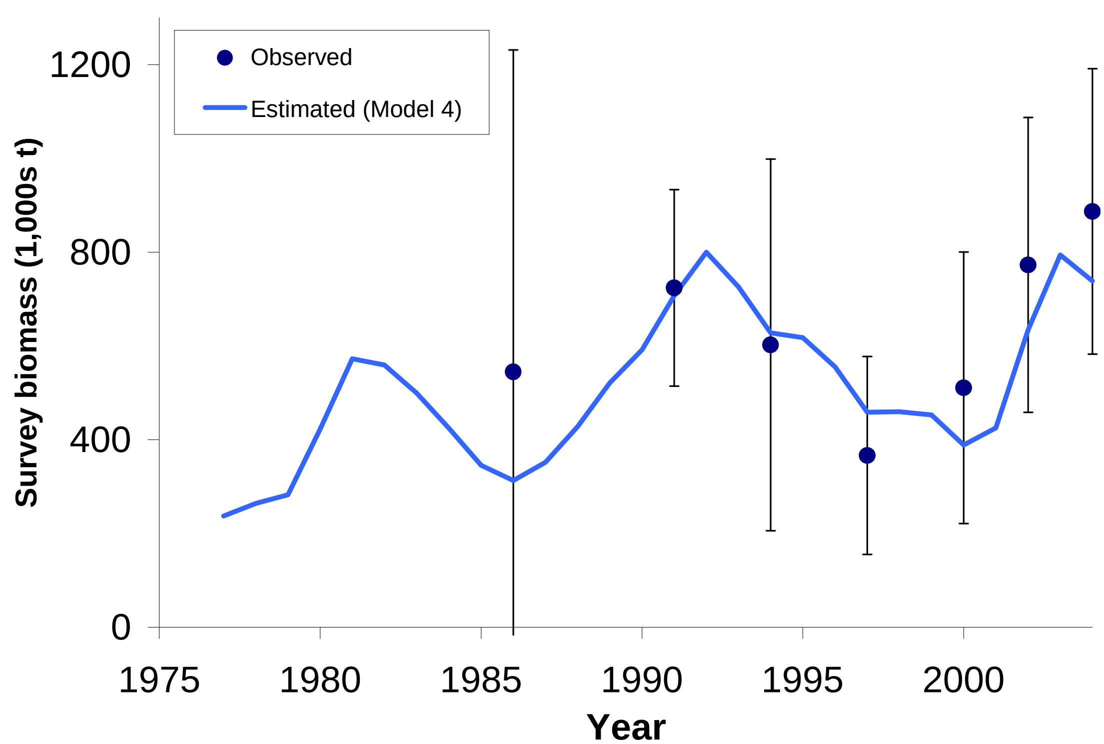


Figure 15.19. Observed and predicted survey biomass for Aleutian Islands Atka mackerel. Error bars represent two standard errors (based on sampling) from the survey estimates.

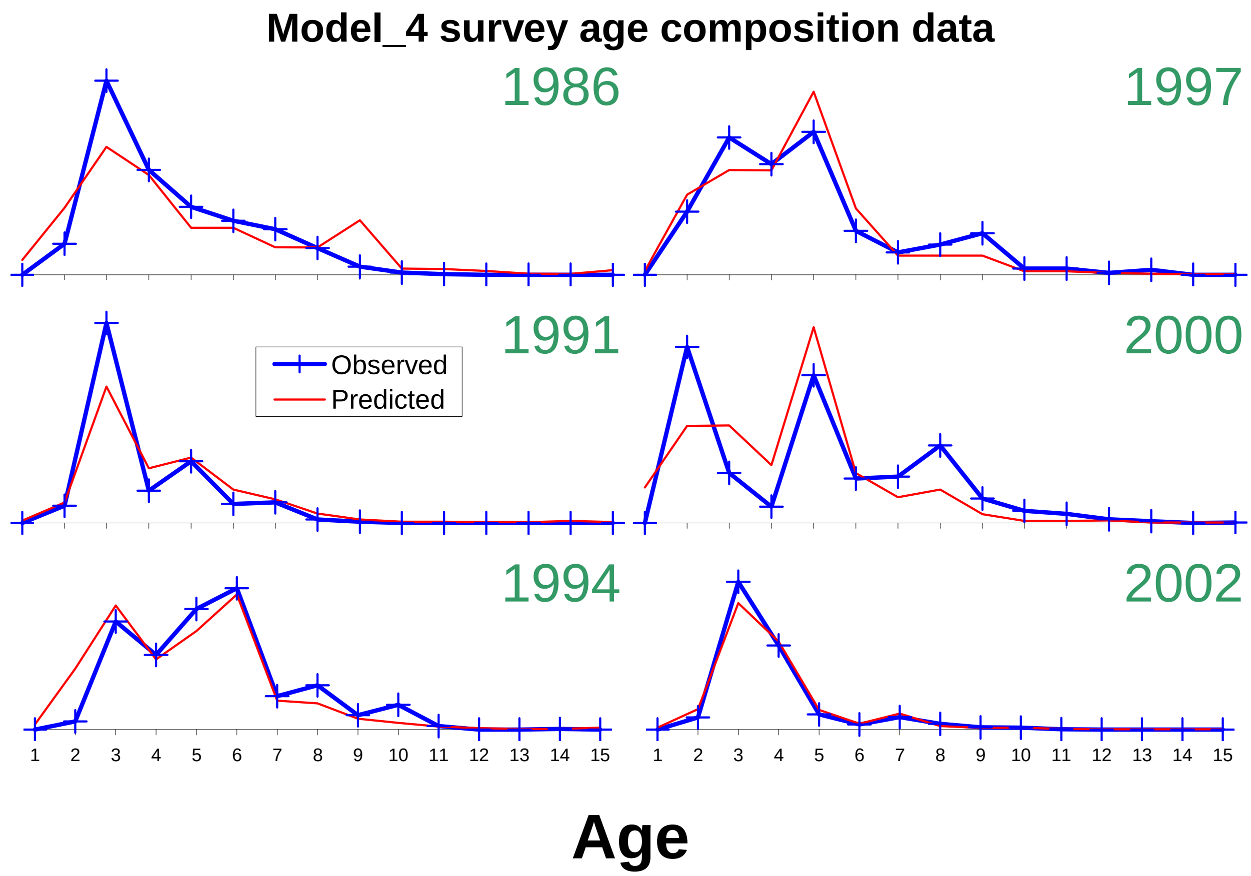


Figure 15.20. Observed and predicted proportions-at-age for Atka mackerel based on Model 4. Continuous lines are the model predictions and lines with + symbol are the observed proportions at age.

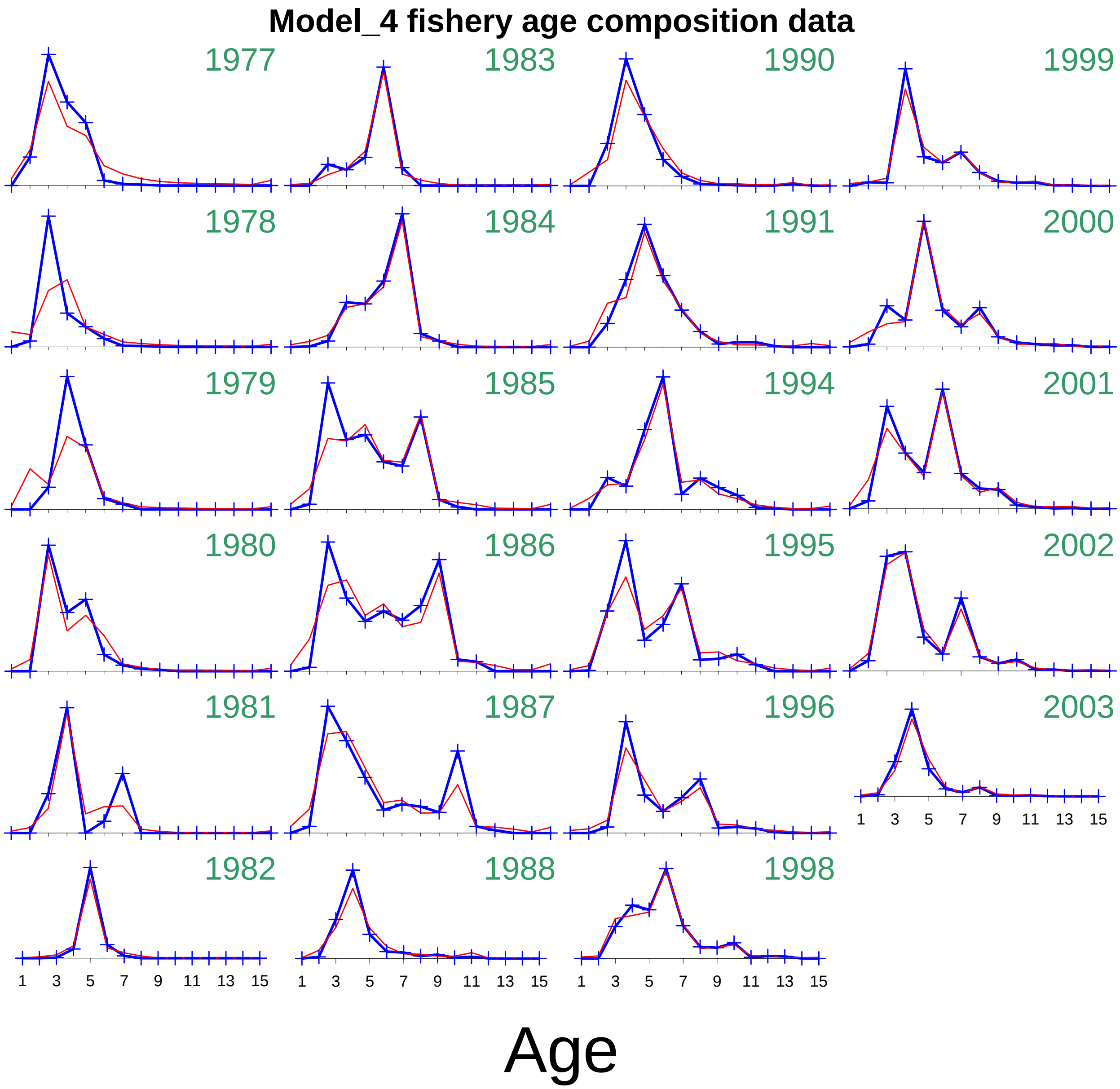
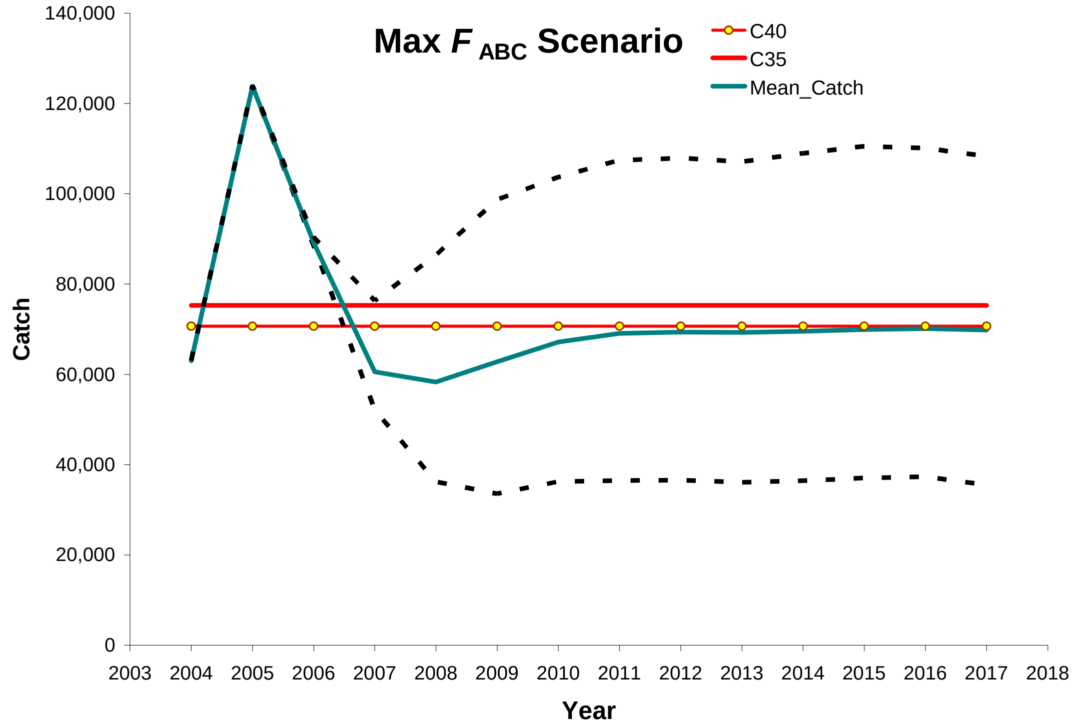


Figure 15.21. Observed and predicted Atka mackerel proportions-at-age for fishery data based on Model 4. Continuous lines are the model predictions and lines with + symbol are the observed proportions at age.



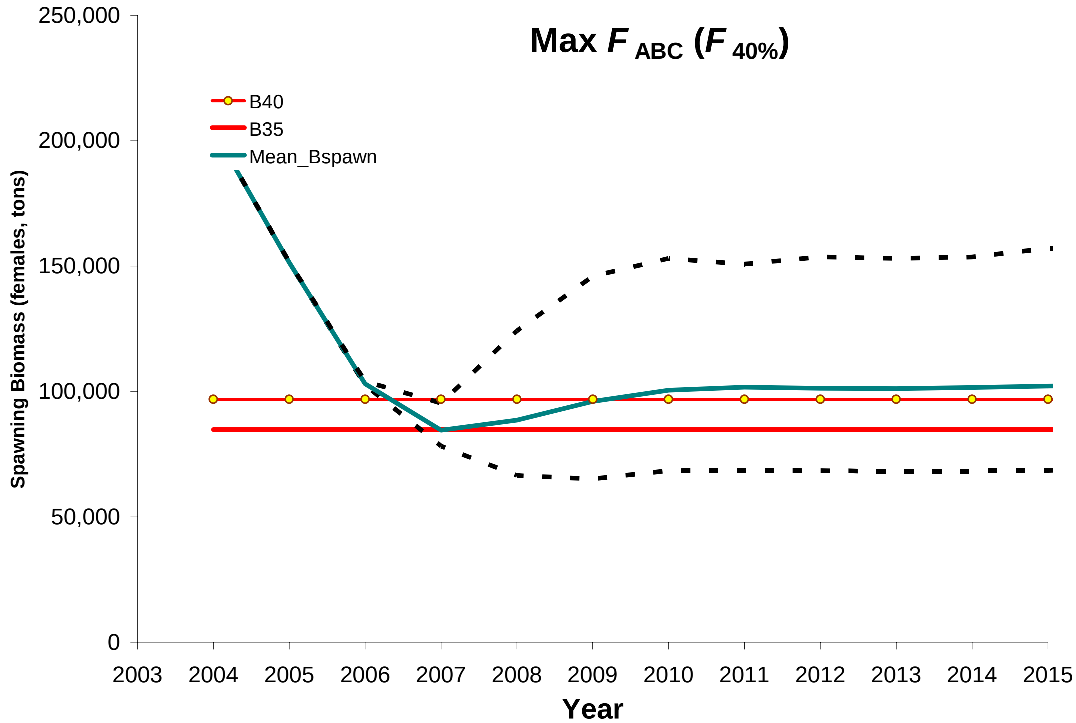
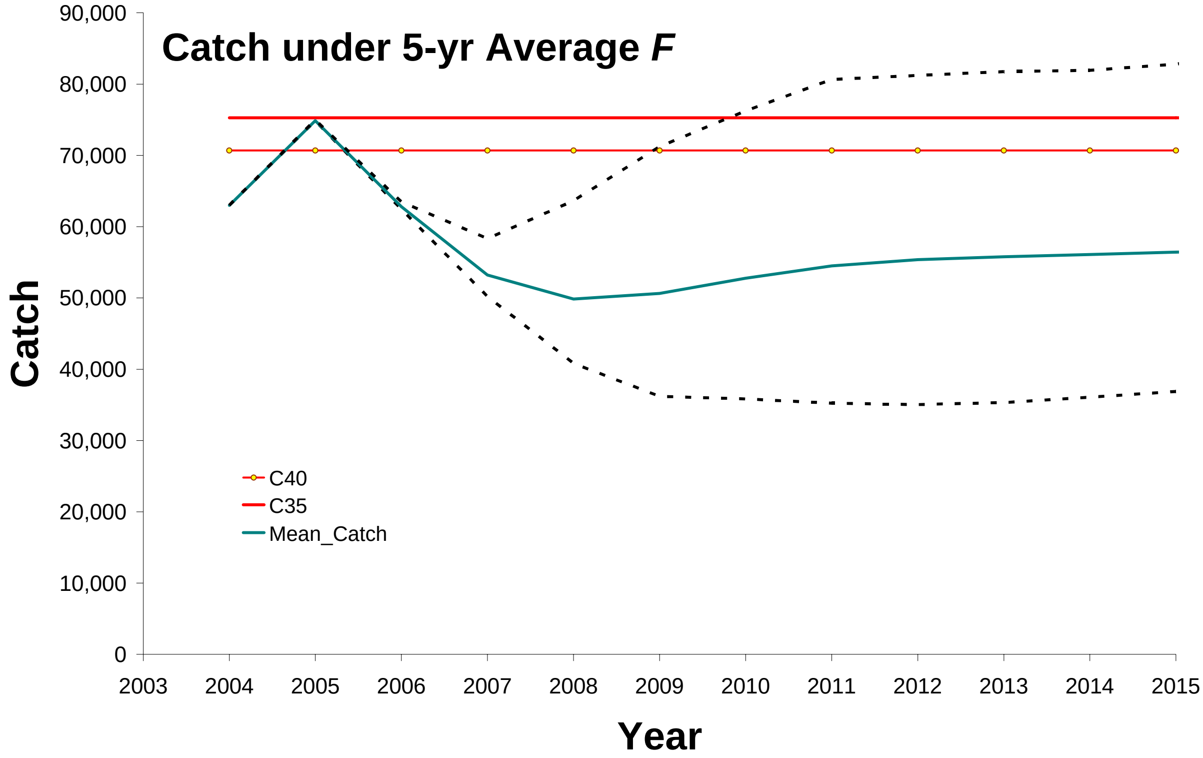


Figure 15.22. Projected catch in mt (top) and spawning biomass in mt (bottom) under maximum permissible Tier 3a harvest levels.



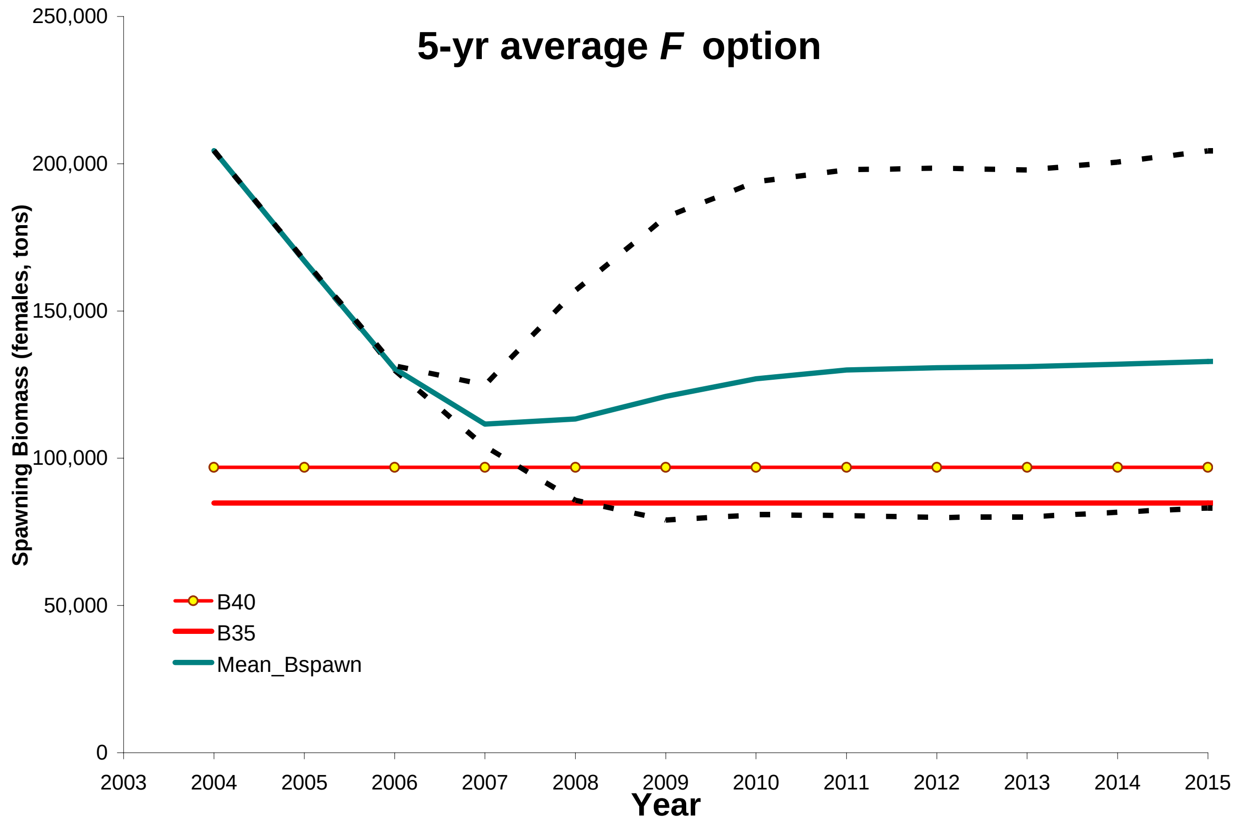
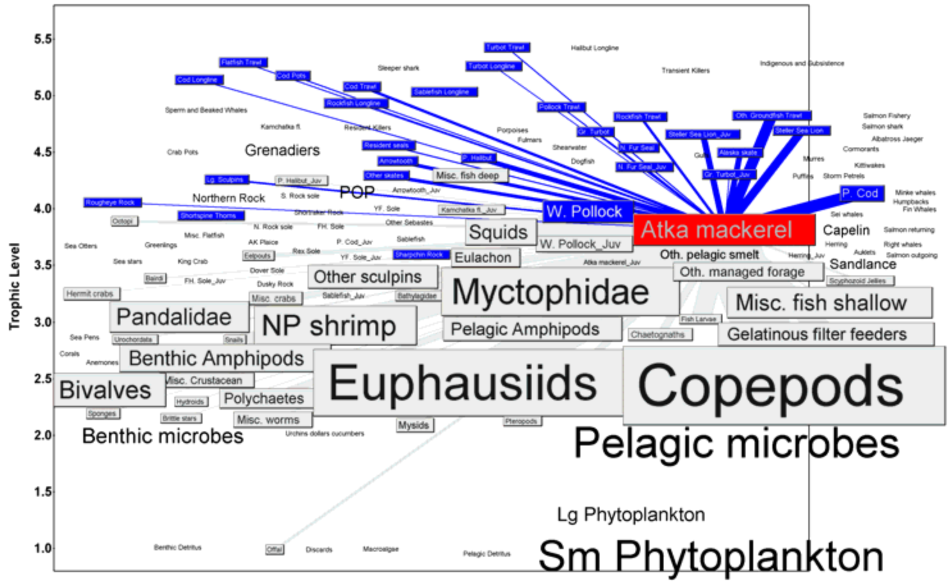


Figure 15.23. Projected catch in mt (top) and spawning biomass in mt (bottom) based on the recent 5-year average fishing mortality estimates.

(A)



(B)

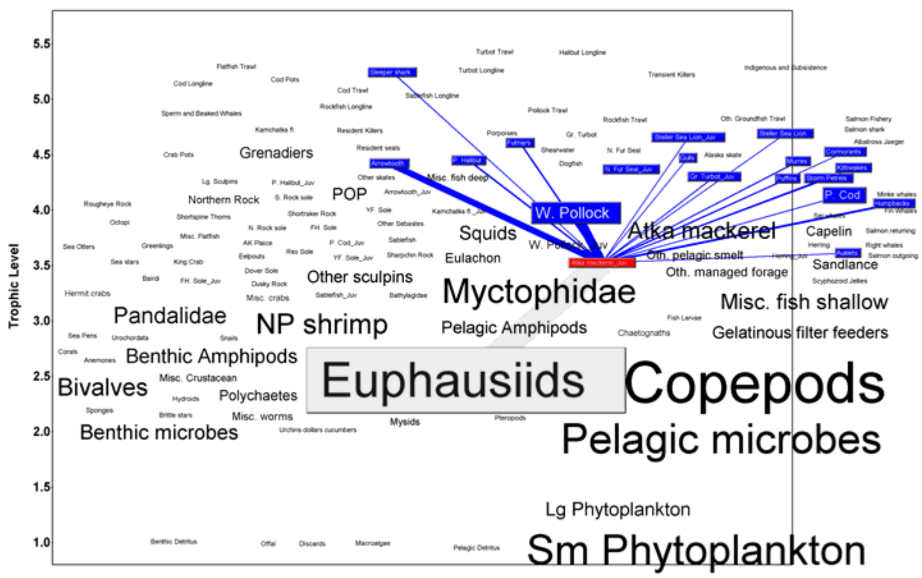
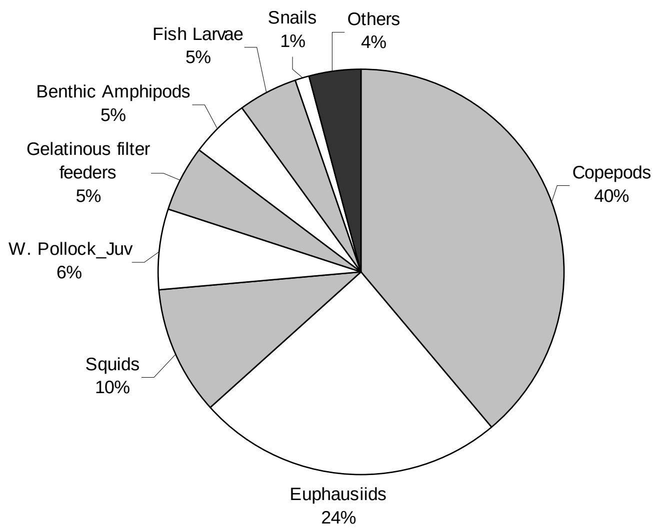


Figure 15.24. The food web of the Aleutian island survey region, 1990-1994, emphasizing the position of Atka mackerel age 1+ fish (A) and juvenile Atka mackerel (B). Outlined species represent predators of Atka mackerel (dark boxed with light text) and prey of Atka mackerel (light boxes with dark text). Box and text size is proportional to each species' standing stock biomass, while line widths are proportional to the consumption between boxes (tons/year). Trophic levels of individual species may be staggered up to +/-0.5 of a trophic level for visibility.

(A)



(B)

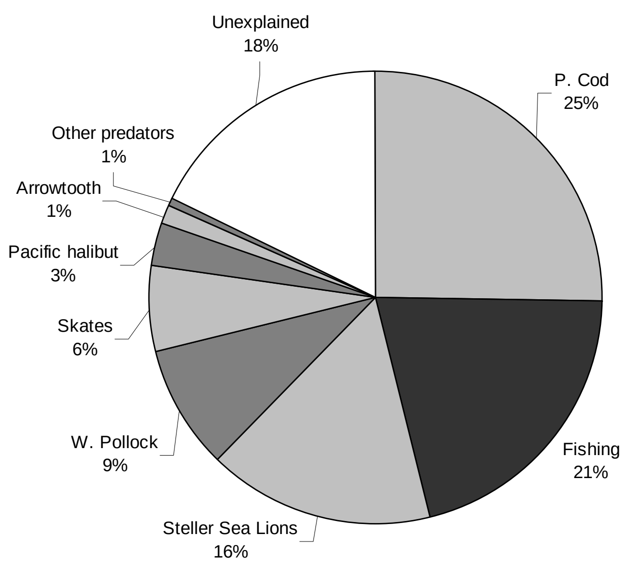


Fig. 15.25. (A) Diet of Atka mackerel age 1+, 1990-1994, by percentage wet weight in diet, weighted by age-specific consumption rates. (B) Percentage mortality of Atka mackerel by mortality source, 1990-1994. "Unexplained" mortality is the difference between the stock assessment total exploitation rate 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.

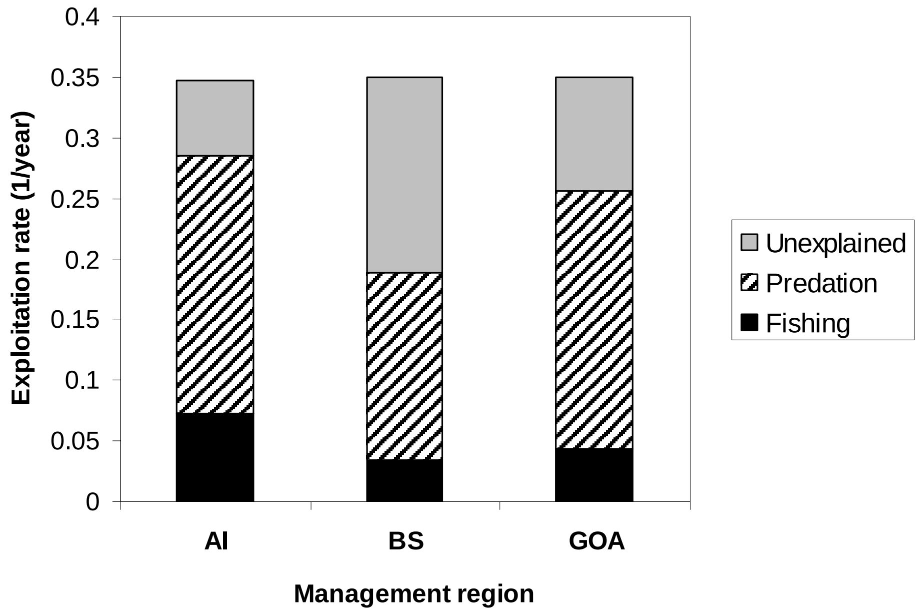


Figure 15.26. Total exploitation rate of Atka mackerel age 1+, 1990-1994, proportioned into fishing exploitation (black), predation (striped) and "unexplained" mortality (grey). "Unexplained" mortality is the difference between the stock assessment total exploitation rate averaged for 1990-1994, and the predation and fishing mortality, which are calculated independently of the assessment, using predator diets, consumption rates, and fisheries catch.

Appendix 15.A

Table A-1. Variable descriptions and model specification.

General Definitions	Symbol/Value	Use in Catch at Age Model
Year index: i = {1977, …., 2004}		i
Age index: $j = \{1, 2, 3, \ldots, 14, 15^+\}$	j	
Mean weight by age j	W_j	
Maximum age beyond which selectivity is constant	*Maxage*	Selectivity parameterization
Instantaneous Natural Mortality	M	Fixed M=0.30, constant over all ages
Proportion females mature at age j	p_j	Definition of spawning biomass
Sample size for proportion at age j in year i	T_i	Scales multinomial assumption about estimates of proportion at age
Survey catchability coefficient	q^s	Prior distribution = lognormal(1.0 , σ_q^2)
Stock-recruitment parameters	R_0	Unfished equilibrium recruitment
	h	Stock-recruitment steepness
	σ_R^2	Stock-recruitment variance
Estimated parameters		
		$\phi_i(26),\ R_0,\ h,\ \varepsilon_i(41), \sigma_R^2,\ \mu^f,\ \mu^s,\ M,\ \eta_j^s(14),\ \eta_j^f c(14), F_{50\%}, F_{40\%}, F_{30\%}, q^s$

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

Table A-2. Variables and equations describing implementation of the stock assessment toolbox model.

Description	Symbol/Constraints	Key Equation(s)
Survey abundance index (s) by year	Y_i^s	$\hat{Y}_i^s = q_i^s \sum_{j=1}^{15^+} s_j^s W_{ij} e^{Z_{i,j}\frac{7}{12}} N_{ij}$
Catch biomass by year	C_i	$\hat{C}_i = \sum_j W_{ij} N_{ij} \frac{F_{ij}}{Z_{ij}}\left(1-e^{-Z_{ij}}\right)$
Proportion at age j, in year i	P_{ij}, $\sum_{j=1}^{15} P_{ij} = 1.0$	$P_{ij} = \frac{N_{ij} s_{ij}^f}{\sum_{k=1}^{15} N_{ik} s_{ik}^f}$
Initial numbers at age	$j = 1$	$N_{1977,1} = e^{\mu_R + \varepsilon_{1977}}$
	$1 < j < 15$	$N_{1977,j} = e^{\mu_R + \varepsilon_{1978-j}} \prod_{j=1}^{j} e^{-M}$
	$j = 15^+$	$N_{1977,15} = N_{1977,14}\left(1-e^{-M}\right)^{-1}$
Subsequent years ($i > 1977$)	$j = 1$	$N_{i,1} = e^{\mu_R + \varepsilon_i}$
	$1 < j < 15$	$N_{i,j} = N_{i-1,j-1} e^{-Z_{i-1,j-1}}$
	$j = 15^+$	$N_{i,15^+} = N_{i-1,14}\, e^{-Z_{i-1,14}} + N_{i-1,15}\, e^{-Z_{i-1,15}}$
Year effect, i = 1963, …, 2004	ε_i, $\sum_{i=1963}^{2004} \varepsilon_i = 0$	$N_{i,1} = e^{\mu_R + \varepsilon_i}$
Index catchability Mean effect	μ^s, μ^f	$q_i^s = e^{\mu^s}$
Age effect	η_j^s, $\sum_{j=1}^{15^+} \eta_j^s = 0$	$s_j^s = e^{\eta_j^s}$ $j \le \text{maxage}$ $s_j^s = e^{\eta_{\text{maxage}}^s}$ $j > \text{maxage}$
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	ϕ_i, $\sum_{i=1977}^{2001} \phi_i = 0$	
age effect of fishing (regularized) In year time variation allowed	η_{ij}^f, $\sum_{j=1}^{15^+} \eta_{ij} = 0$	$s_{ij}^f = e^{\eta_j^f}$, $j \le \text{maxage}$ $s_{ij}^f = e^{\eta_{\text{maxage}}^f}$ $j > \text{maxage}$
In years where selectivity is constant over time	$\eta_{i,j}^f = \eta_{i-1,j}^f$	$i \ne$ change year
Natural Mortality	M	
Total mortality		$Z_{ij} = F_{ij} + M$
Recruitment Beverton-Holt form	$\tilde{R}_i$	$\tilde{R}_i = \frac{\alpha B_i}{\beta + B_i}$, $\alpha = \frac{4hR_0}{5h-1}$ and $\beta = \frac{B_0(1-h)}{5h-1}$ where $B_0 = \tilde{R}_0 \varphi$ $\varphi = \frac{e^{-15M} W_{15} p_{15}}{1-e^{-M}} + \sum_{j=1}^{15} e^{-M(j-1)} W_j p_j$

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

Likelihood /penalty component		Description / notes
Abundance indices	$L_1 = \lambda_1 \sum_i \ln\left(Y_i^s \middle/ \hat{Y}_i^s\right)^2 \frac{1}{2\sigma_i^2}$	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	$L_3 = \lambda_3 \sum_{i=1963}^{2004} \varepsilon_i^2$	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	$L_4 = \lambda_4 \sum_{i=1977}^{2001} \ln\left(C_i / \hat{C}_i\right)^2$	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	$L_6 = \lambda_6 \sum_{i=1977}^{2004} \phi_i^2$	(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	$\dot{L} = \sum_{i=1}^{7} L_i$	