Stock Assessment of Aleutian Islands Atka Mackerel

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EXECUTIVE SUMMARY

Summary of Major Changes

Relative to the November 2002 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 2002 fishery age composition data were included.

Changes in the Assessment Methodology

1) The projection model assumes an average selectivity vector from the years 1999-2002.

Changes in Assessment Results

1) The mean recruitment from the stochastic projections is 434 million recruits, which gives an estimated $B_{40\%}$ level of 83,800 mt.

2) The projected female spawning biomass for 2004 under an $F_{40\%}$ harvest strategy is estimated at 86,000 mt; BSAI Atka mackerel are in Tier 3a

3) The projected age 3+ biomass at the beginning of 2004 is estimated at 286,200 mt.

4) The addition of the 2002 fishery age composition showed the presence of the above average 1999 year class.

5) The projected 2004 yield at $F_{40\%}$= 0.67 is 66,700 mt.

6) The projected 2004 overfishing level at $F_{35\%}$ (F = 0.83) is 78,500 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.

The SSC did not make any comments on assessments in general.

15.1 Introduction

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 surveys has been in the Aleutian Islands, particularly from Buldir Island to Seguam Pass.

Very little is known about the biology of Atka mackerel. The earliest accounts of their spawning and nesting behavior by Turner (1886) were probably erroneous. He described spawning Atka mackerel from above water as forming several strata with the least mature fish in the top layer and the spawning "vigorous males and females" in the bottom stratum. He reported that females deposit eggs on kelp and that both sexes remain until the spawning season ends in late July. This conflicts with later accounts by Gorbunova (1962) and Zolotov (1993) who used trawling, seining, and hook-and-line for collecting specimens and scuba diving for making direct observations of nesting behavior in Kamchatkan waters. Based on trawl and seine work, they surmised a shoreward spawning migration during the May-June period. Other American observers have also made note of large aggregations of Atka mackerel in coastal regions in Alaska during the summer months (Turner 1986, Bean 1887, Tanner 1890), but it is unknown whether these surface aggregations related to spawning or feeding behavior.

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). Bottom type, depth, and temperature along with moderate tidal current were important factors for a nesting site. Spawning began in late June and adhesive eggs were laid in rock crevices and among stones. Marking the end of the spawning and nesting season was an absence of guardian males caught via hook and line (Zolotov 1993), and the presence of spent females in trawl catches (Gorbunova 1962). Coinciding with the end of spawning and nesting was an offshore movement of adults into deeper water, again surmised by what was seen in trawl, seine catches, and hook-and-line catches.

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. Nesting males were golden yellow with black vertical bands and they hovered close to a nest that covered an area approximately 4 m^2. Males aggregated within the nesting area and neighboring males and nests were contiguous throughout the site.

An underwater towed camera was used for subsequent investigations of Atka mackerel nesting sites during the spawning season. Camera drops were made in offshore areas and in island passes across the Aleutian Archipelago, from Attu Island to Umnak Pass. Documented were 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. Schools of gravid females were frequently seen either passing through these nesting areas or on the fringes. Bottom depths for these later sites extended to 100 m, far greater than those previously documented as the lower depth limit for Atka mackerel spawning and nesting. Sites below 100 m have not been searched so it is unknown if spawning and nesting extends even deeper. Indirect evidence from cannibalized eggs (Yang 1999) and archival tags (Dan Nichol pers. comm.) suggest there may be nests as deep as 180 m.

If in fact Atka mackerel are spawning over most of their depth range, the paradigm that there is an annual shoreward spawning migration may be incorrect. Recent tag recapture information from Alaska suggests that Atka mackerel populations are localized and do not travel long distances (FIT reference). Furthermore, sexually mature males and females are routinely caught in trawls hauls during the spawning season from depths below 100 m, indicating that spawning and nesting may be occurring offshore in trawlable areas. An alternate description for this annual spawning phenomenon may be that males segregate from females and disperse to areas with suitable nesting habitat, which are not necessarily exclusive to the nearshore regions.

Another difference between studies from Alaska and Kamchatka Peninsula is with the timing and duration of the nesting season. An underwater time-lapse camera was used to determine that male Atka mackerel nesters first appeared at the nearshore Seguam Island nesting site in mid-June. Males were still present when the time-lapse camera was removed on August 31st. Samples of eggs from various clutches and nests were taken and many were in the early stages of development. A freshly laid clutch of eggs collected from a nest in early August was incubated in the laboratory at 6 °C, the same temperature present at the nesting site. Time till hatching was 75-80 days. This is almost twice as long as the 40-45 days that has been reported in the literature. Studies of ovarian condition of Atka mackerel from Alaska, indicate that females continue spawning through October (McDermott and Lowe 1997). If clutches are being deposited in October, and males guard nests until hatching, it is conceivable that some males are staying on nests through December. The 4 month spawning period and 6 month nesting period are more protracted than what was observed in the western Pacific Ocean (Gorbunova 1962; Zolotov 1993).

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 and little to no movement at night.

Little is known of the life history of young Atka mackerel prior to their appearance in trawl surveys and the fishery at about age 2-3 years. 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), and seabirds (e.g., tufted puffins, Byrd et al. 1992).

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 larvae and 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, perhaps as juveniles moving east from the larger population in the AI rather than from 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 - 1998) 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 2003 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 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. The directed Atka mackerel fishery has had low bycatch rates of rockfish (1-5% of the total Atka mackerel catch) and slightly higher bycatch rates of cod (3-15%). There were reports of high discard rates of northern rockfish in the 2001 Atka mackerel fishery. While the 2001 discard of northern rockfish as a total of the Atka mackerel catch was low (1.7%), the actual amount of northern discards (1,037 mt) was about 15% of the 2001 BSAI northern TAC (6,760 mt). The 2002 fishery discarded 3,341 mt of northern rockfish, about 50% of the Aleutian Islands 2002 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. 2000). Discard data from 1995 to present are given below:

Year	Fishery	Discarded (mt)	Retained (mt)	Total (mt)	Discard Rate (%)
1995	Atka mackerel	13,669	66,153	79,823	17.1
	All others	849	499	1,349	
	All	14,519	66,652	81,171	
1996	Atka mackerel	15,354	84,835	100,189	15.3
	All others	1,298	1,638	2,936	
	All	16,652	86,473	103,125	
1997	Atka mackerel	5,829	57,850	63,680	9.1
	All others	552	1,393	1,945	
	All	6,381	59,243	65,625	
1998*	Atka mackerel	4,585	50,184	54,769	8.4
	All others	483	846	1,329	
	All	5,068	51,030	57,098	
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	

*Includes CDQ catch

The discard rate of Atka mackerel by the directed fishery has decreased from 17% in 1995 to the 2000 value of 5%, the lowest reported discard rate since data collection began. Small Atka mackerel were encountered in large numbers in 1995 which may have been the strong 1992 year class, a likely factor contributing to the second highest discard rate since data collection began (Lowe et al., 2000). 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.

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). After 1998, discard rates have been higher in the central AI (542) and have remained lowest in the east (541):

	Aleutian Islands Subarea		
	541	**542**	**543**
1995			
Retained (mt)	11,791	40,832	13,530
Discarded (mt)	1,371	9,005	3,294
Rate	10%	18%	20%
1996			
Retained (mt)	22,685	28,096	34,055
Discarded (mt)	3,919	4,910	6,525
Rate	15%	15%	16%
1997			
Retained (mt)	14,528	18,060	25,262
Discarded (mt)	969	1,562	3,298
Rate	6%	8%	12%
1998			
Retained (mt)	9,385	17,311	23,488
Discarded (mt)	1,287	2,593	705
Rate	12%	13%	3%
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%

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 1995.

Atka mackerel length distributions from the domestic 2002 and 2003 fisheries by location and season are shown in Figures 15.2 and 15.3, respectively. Differences in the distributions between the 2002 A- and B-seasons are most notable for the Near Islands, Petral Bank and Seguam Bank. Fish from Petral Bank were significantly smaller compared to the other areas and also smaller relative to the Petral Bank distributions for 2000 and 2001 (Lowe et al. 2002). The 2002 fishery length distributions are bimodal. The modes at about 30-35 cm are likely the 1999 year class which, along with the 1998 year class dominated the 2002 fishery age composition (Figure 15.4). Only the 2003 A season data are presented and should be considered preliminary (Figure 15.3). As in 2002, fish from Petral Bank in 2003 were notably smaller compared to the other areas. There was a lack of larger fish from the 2003 Seguam Bank A-season fishery; these fish showed a similar distribution to the 2002 B season distribution with a mode of small fish at 32-34 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 CH.

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). Preliminary 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. Consequently, tagging work was conducted inside and outside 10 nm trawl exclusion zones in Tanaga Pass (in 2002) and near Amchitka Island (in 2003).

15.3 Data

15.3.1 Fishery Data

Fishery data consist of total catch biomass from 1977 to 2003 (Table 15.1), and the age composition of the catch from 1977-2002 (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, representing the 1984, 1991, 1992, 1995 and the 1998 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 are 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 most recent 2002 fishery age data show the first appearance in the fishery of the 1999 year class, and the 1998 and 1995 year classes continue to show up in large numbers (Table 15.3 and Figure 15.4). Indications are that the 1998 year class is a very strong year class, and may be followed by a strong 1999 year class.

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, and 2002 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 areal 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 2002 Aleutian Islands bottom trawl survey is 772,798 mt, up 51% relative to the 2000 survey estimate (Table 15.5). Previous to this, the 2000 Aleutian Islands bottom trawl survey biomass estimate of 510,857 mt increased about 40% relative to the 1997 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 2002 survey is mainly attributed to the increase in biomass found in the Eastern area (190,817 mt); in the 2000 survey, biomass in the Eastern area was slightly less than 1000 mt. Relative to the 2000 survey, the 2002 biomass estimates are up 41% in the Western area, down 1% in the Central area, and up 20,597% in the Eastern area (Figure 15.5). The 95% confidence interval about the mean total 2002 Aleutian biomass estimate is 417,072-1,128,523 mt. The coefficient of variation (*CV*) of the 2002 mean Aleutian biomass is 20%, consistent with the *CV*s from the 1997 and 2000 surveys, as are the CVs by area for these surveys (Table 15.5).

The distribution of biomass in the Western, Central, and Eastern Aleutians, and the southern Bering Sea shifted between each of the 1991, 1994, 1997, 2000 and 2002 surveys, and most dramatically in area 541 in the 2000 survey (Figure 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 (66,600 mt). This occurred again in 1997 (95,700 mt) and most recently in 2002 (59,883 mt, Table 15.5). These biomass estimates are a result of large catches from a single haul encountered north of Akun Island in all three surveys. In both 1991 and 1994, the Western area contributed approximately half of the total estimated Aleutian biomass, but dropped to 37% in 1997. The proportion of biomass in the Western area has remained fairly stable since 1997. In 1994, 14% of the Aleutian biomass was found in the Central area compared to 40% in 1991 and up to 65% 2000 survey. The most recent 2002 survey showed the Central area contributing 42% of the Aleutian biomass.

The Eastern area contributed 25% of the total biomass according to the 2002 survey. 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 patchier; 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 survey in the Eastern area.

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, Segaum Pass, Tanaga Pass, south of Amchitka Island, Kiska Island, Buldir Island, and Stalemate Bank (Figure 15.6). In the 2002 survey, Atka mackerel were much less patchily distributed relative to previous surveys and were encountered in 55% of the hauls, which is the highest rate of encounter 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.

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 and 0.20 from the 1997, 2000, and 2002 AI surveys, respectively, compared with 0.99, 0.45, 1.00, and 0.35 from the 1996, 1999, 2001 and 2002 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%, and 55% of the hauls in the 1991, 1994, 1997, 2000 and 2002 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 2002 GOA surveys, respectively. For these reasons we utilize bottom trawl surveys to assess the relative abundance of Atka mackerel in the Aleutian Islands, but do not consider the highly variable estimates of biomass from the GOA surveys useful for tracking abundance trends.

Survey Length Frequencies

The 2000 and 2002 bottom trawl surveys 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). This pattern is also apparent in the fishery data (Figure 15.3). The length distributions of fish in the 2002 survey were somewhat smaller in the Central and Western area compared to the 2002 fishery. Differences in the timing and location of survey and fishery catches may account for the observed differences in Atka mackerel sizes encountered in the east. Smaller sample sizes in these regions may also be a factor. The fishery is currently excluded from Seguam Pass (10 and 20 nm trawl exclusion zones) and fishes almost exclusively southeast of the pass in winter. Recent surveys, conducted in summer, have been unsuccessful in capturing Atka mackerel southeast of the pass in the summer, but have found large fish inside the pass. In general, the observed differences in fish size between the fishery and survey may be due to differences in timing and distribution of the fishery and survey, and related to inshore movements of the reproductive (i.e., larger-sized) fish in summer for spawning. In winter, the population is thought to distribute more offshore in deeper waters and appears to be more mixed by size and sex than in summer (Fritz and Lowe, 1998). The 2000 survey length frequency distributions showed a mode a fish between 20 and 25 cm in all areas, which was found to be the 1998 year class (Figure 15.9a). The 2002 survey length frequency distributions show bimodal distributions with modes at 27-28 cm which may be early indications of the 1999 year class.

Survey Age Frequencies

The age compositions from the 1991, 1994, 1997 and 2000 Aleutian surveys are shown in Figure 15.9. In the 1991 survey, the catch was dominated by 3-year-old fish of the 1988 year class. The 1988 year class showed up strongly as 6-year-olds in the 1994 survey catches, and was still evident as 9-year-olds in the 1997 survey catch. 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 15.9a). 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 (Figure 15.9b). The mean age in the 1991 survey was 3.9 years, the youngest mean age of any survey. The mean ages of the 1994, 1997, and 2000 surveys were 5.4, 4.8, and 5.0 years, respectively.

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 areas 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 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).

15.4.1 Model structure

The Stock Assessment Toolbox model 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-likehood (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

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

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 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).

In the current assessment, a natural mortality value of 0.3 was used for Models 1-6. Those models assume a fixed, constant value of M. Models 7-9 allow M to be estimated within the model while the value of survey catchability is fixed at 1.0. Model 7 assumes an informative prior for M with a mean of 0.3 and a coefficient of variation (CV) of 0.05. Models 8 and 9 assume diffuse priors for M with means of 0.3 and CVs of 0.1 and 0.2 for Models 8 and 9, respectively. A CV of 0.2 was selected based on a subjective evaluation which assumes the probability of M being less than 0.20 and greater than 0.46 is about 1.5%.

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.

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 7 from last year's assessment (Lowe et al. 2002).

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. Models 1-2 and 7-9 assume a fixed value of 1.0 for the catchability coefficient. Models 3-6 explore the use of a prior on catchability, with a mean of 1.0 and *CVs* of 0.1, 0.2, 0.3, and 0.4, respectively.

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 last year's 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

To examine model assumptions, data sensitivities and uncertainty, we evaluated 9 different model configurations (Table 15.8). Model exploration focused on the estimation of natural mortality and survey catchability-at-age. A summarized list of the models follows:

Model 1 *Baseline Model*. This model is essentially equivalent to the Reference Model 7 selected from last year's assessment, with updated catch data and the 2002 fishery age composition.

Model 2 *Reference Model*. As Baseline Model but with a slightly higher fixed default value for recruitment variability.

Model 3 As Reference Model but estimating survey catchability (q) with a prior on q (mean=1.0, σ^2=0.1^2). Natural mortality (M) is fixed at a value of 0.3.

Model 4 As Reference Model but estimating survey catchability with a prior on q (mean=1.0, σ^2=0.2^2). M is fixed at a value of 0.3.

Model 5 As Reference Model but estimating survey catchability with a prior on q (mean=1.0, σ^2=0.3^2). M is fixed at a value of 0.3.

Model 6 As Reference Model but estimating survey catchability with a prior on q (mean=1.0, σ^2=0.4^2). M is fixed at a value of 0.3.

Model 7 As Reference Model but estimating natural mortality with an informative prior on M (mean=0.3, σ^2=0.05^2). Survey catchability is fixed at a value of 0.1.

Model 8 As Reference Model but estimating natural mortality with a moderate prior on M (mean=0.3, σ^2=0.1^2). Survey catchability is fixed at a value of 0.1.

Model 9 As Reference Model but estimating natural mortality with a diffuse prior on M (mean=0.3, σ^2=0.2^2). Survey catchability is fixed at a value of 0.1.

The models can be categorized as follows:

Model 1 Baseline model. Year 2002 model configuration with updated fishery catch and age information.

Model 2 Reference Model. As Baseline Model but with a slightly higher default value for recruitment variability.

Models 3-6 Configured as Reference Model 2 and explore the use of a prior on q with a fixed value of M = 0.3.

Models 7-9 Configured as Reference Model 2 and explore the use of a prior on M with a fixed value of q = 1.0.

Key results from the models are given in Table 15.8. Model 2 had a better fit (i.e., lower –ln(likelihood function) relative to the Baseline Model 1. The fit to the survey index in Model 2 is poorer relative the Baseline Model, as indicated by the higher survey residual mean square error (RSME) and –ln(survey likelihood). However, the small increase in recruitment variability for Model 2 allowed an improved fit to the fishery and survey age compositions, and an increase in the fishery average effective *N*. The survey indices are highly variable and the age composition data are considered to be more reliable. Therefore, it seems reasonable to improve the fit to the age composition data at the cost of small degradations in fits to the survey indices as in Model 2. For these reasons we believe that the Model 2 configuration is improved over the Baseline Model.

Last year we estimated M and q simultaneously with various combinations of priors. Preliminary results were difficult to interpret biologically (Lowe et al. 2002). In an effort to continue this exploration, Models 3-9 implemented a range of priors on M or q, while the other parameter was fixed. Models 3-6 explore the use of priors on q with M fixed at 0.3. Model 6 had the most diffuse prior (μ=1.0, σ^2=0.4^2) and achieved the best fit among Models 3-6. Survey catchability estimates ranged from 1.12 (Model 3) to 1.44 (Model 6). Improved fits could probably be obtained with even higher values of σ^2 on the prior, however, results from Models 3-6 did not seem biologically reasonable and further exploration was not carried forward for the following reasons. The models are trying to reconcile extremely large increases in survey biomass (40% from 1997 to 2000 and 51% from 2000 to 2002) with the fishery and survey age compositions. Between 1997 and 2002, the 1995, 1998 and 1999 year classes recruited to the fishery in large numbers and showed a strong presence in the surveys. The 1995 year class, while still strongly present in the fishery catch data, represents about 18% of the total distribution (Figure 15.4). The 2002 fishery age composition data are dominated by the 1998 and 1999 year classes. However, the 1998 and

1999 year classes are still relatively young and do not represent a significant proportion of biomass. The magnitude of these year classes would have to be extremely high in order to provide for the observed increase in survey biomass estimates. An alternative explanation is that the numbers of older-age fish increased substantively. However, the age composition data also do not show an increased abundance of older-age fish. One solution to improving the fit to the survey in the absence of appropriate increases in the numbers at age is to have survey catchability increase, resulting in a lower overall biomass hence fitting the increasing trend survey estimates. Even with increased survey catchability, there is only a slight improvement to the fits to the survey, and overall the fit is still fairly poor (Figure 15.10). Increasing survey catchability while *M* remains fixed results in a scaling down of the population biomass trend (Figure 15.11).

Models 7-9 explore the use of priors on *M* with *q* fixed at 1.0. Model 9 which had the most diffuse prior (μ=0.3, σ^2=0.2^2), resulted in the best fit among Models 7-9. Estimates of *M* for this group ranged from 0.44 (Model 7) to 0.53 (Model 9). These estimates are higher than the estimates presented in Section 15.4.2 . Also, these estimates are much higher than for other groundfish stocks in this region. For example, the estimate of EBS pollock *M* is 0.45 for age 2 fish and 0.3 for ages 3+. The estimate of *M* for Bering Sea/Aleutian Island Pacific cod is 0.37. Similar to Models 3-6, Models 7-9 attempt to improve the fit to the survey in the absence of appropriate increases in the numbers at age. The models assume a much higher natural maturity value to provide for increased survey biomass predictions. Higher natural mortality allows for improved fits to the survey, however, recent increases still cannot be replicated at the magnitude observed in the survey (Figure 15.10). Model results with high estimates of *M* and with *q* fixed at 1.0 show a drastically inflated biomass level (Figure 15.11). Estimates of the 2003 biomass range from 860,800 mt to 1.3 million mt. Similarly, the high estimates of *M* result in very high estimates of reference fishing mortality rates (e.g., the $F_{40\%}$ fishing mortality rate ranges from 2.0 to 3.8). Results from Models 7-9 illustrate the sensitivity to assumptions about *q* and *M.* Given the outcome, we feel it is prudent to use models that are more conservative.

In summary, the suite of alternatives represented in Models 3-9 provided insight on our assumptions but, failed to represent improvements over the Reference Model (Model 2). The survey indices are highly variable and more confidence is placed in the fishery and survey age compositions. Given the indication that there are some inconsistencies between data sources, we are concerned whether it is appropriate to make strong conclusions about survey catchability and natural mortality. Further explorations are needed to configure appropriate models with priors on *M* and *q*, perhaps using methods such as Hoenig's and others to illicit appropriate prior distributions for *M*. We consider the fixed values of *M* and *q* at 0.3 and 1.0, respectively, to be a reasonable and prudent model configuration for ABC recommendations.

In summary, we chose Model 2 as our Reference Model for the following reasons:

1) using a fixed value of *M* at 0.3 resulted in conservative biomass estimates relative to models where this was estimated;
2) using a fixed value of *q* = 1.0 provides results consistent with fishery and survey age compositions;
3) Model 2 resulted in an improved overall fit relative to the Baseline Model, in particular the fit to the fishery and survey age compositions.

We believe that the Reference Model configuration is a conservative and reasonable representation of BSAI Atka mackerel dynamics given the uncertainty in the estimation of *M* and *q*.

15.6 Model Results

The results discussed below are based on Reference Model 2.

15.6.1 Selectivity

The estimated selectivity at age schedules for the fishery and survey are shown in Figures 15.12 and 15.13 respectively, and given in Table 15.9. The fishery catches consist of fish 3-12 years old, although a 15-year-old fish was found in the 1994 fishery. Previous assessments with the synthesis software estimated selectivity for the fishery, with 2 separate dome-shaped patterns with steep ascending and descending limbs reflecting the early foreign and later domestic fisheries (Figure 13.11 in Lowe et al. 2001). Under the current model specification, a dome-shaped fishery selectivity pattern is still evident through 1991 (Figure 15.12). A detailed discussion of the move to implement annually varying selectivity is given in Lowe et al. (2002). After 1991, fishery selectivity patterns are fairly similar with gradual transitions, particularly between the ages of 3-9.

The inclusion of the 2002 fishery age composition data had a large impact on the most recent selectivity pattern (Figure 15.14). The 2002 age data still includes large numbers from the 1995 year class and the 1992 year class is still evident. The age at 50% selectivity was estimated at about age 5 in 2002; this is shifted over to about age 6 in the 2003 assessment (Figure 15.14).

For Atka mackerel, the estimated selectivity patterns are particularly important in describing their dynamics. The two key features of the selectivity patterns are the transitions between ages and time-varying selectivity. Last year these features were the focus of the model explorations (Lowe et al. 2002). The current model configuration retains the selectivity assumptions as configured in the Baseline Model (last year's model). The moderate constraint on the selectivity-at-age curvature provides biologically reasonable selectivity assumptions that fit the data well. The low constraint on the time component of selectivity allows the model to capture important differences noted through about 1990 (Figure 15.12). We evaluated a run which imposed higher penalties to constrain the degree of change from 1999-2003. Preliminary results showed more homogenous selectivity patterns over this time period, but resulted in poorer fits to all the log likelihood components (except catch biomass).

The impact of the different selectivity assumptions between the current model and last year's assessment are particularly notable when comparing the difference in magnitude in estimates of $F_{40\%}$ from the current assessment (0.85), relative to the previous estimate (0.66). The estimate of $F_{40\%}$ shown in Table 15.8 is computed based on the most recent selectivity, i.e., the 2003 estimated selectivity for the Reference Model, as compared to the 2002 selectivity for last year's model. These selectivity patterns are compared in Figure 15.14. Fish older than age 9 make up a very small percentage of the population each year (Table 15.10), and the differences in the selectivity assumptions for the older ages are not likely to have a large impact. However, differences in selectivity for ages 3-8 can have a significant impact. It is important to note that the maturity-at-age vector is well to the left of the estimated 2002 and 2003 selectivity patterns (age at 50% maturity is 3.6 years, Figure 15.14). Thus, the 2003 selectivity indicates that the current fishery is harvesting the older, mature population, which translates into much higher reference rates (e.g. $F_{40\%}$ and $F_{35\%}$). While we believe the model configuration regarding selectivity assumptions are reasonable, it is important to note that model results are sensitive to these assumptions and the implications are important to understand.

Survey catches were 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 15.13). 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).

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 15.11. For comparison, the time series of 3+ biomass from the 2002 and 2003 assessments are also plotted (Figure 15.16). The corresponding time series of total numbers at age are given in Table 15.10.

A comparison of the age 3+ biomass trend from the current model and the previous assessment (15.16), indicates identical trends, i.e., biomass increased during the late 70s and early 80s and again in the early 90s. However, the biomass trend from the current assessment is scaled downward over the entire time series. The levels differ most, prior to 1985 and after 1995. The differences in biomass levels are attributed to higher fishing mortalities estimated by the current model, stemming from differences in updated selectivity patterns (see selectivity discussion above). Model results are noted to be quite sensitive to selectivity assumptions. The current model estimate of 2003 age 3+ biomass differs by 21% of the projected 2003 age 3+ biomass from last year's model. It should be noted that the current stock assessment includes the 2002 fishery age composition which was not available for the 2002 assessment. The inclusion of the current fishery age composition data in the current model is responsible for the shift in selectivity and the revised estimates of biomass levels

15.6.3 Recruitment Trend

The estimated time series of age 1 recruits are shown in Figure 15.17. and given in Table 15.12. The strong 1977 year class is most notable, similar in magnitude to the 1988 year class. The current assessment estimates above average (greater than 20% of the mean) recruitment from the 1977, 1986, 1988, 1992, 1995, 1998 and 1999 year classes (Figure 15.17). The addition of the 2002 fishery age composition data continues to show large numbers of the 1998 year class and the first indication of a potentially strong 1999 year class. The 1998 year class is estimated to be the fourth largest year class in the time series, after the 1977, 1988, and 1992 year classes. The average estimated recruitment from the time series 1978-2002 is 434 million fish and the median is 304 million fish (Figure 15.17). The entire time series of recruitments (1977-2002) includes the 1976-2001 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 (1977-2002 year classes). Projections of biomass are based on estimated recruitments from 1978-2002 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 15.13 and shown in Figure 15.18

15.6.5 Model Fit

Comparing the Reference Model with the Baseline Model shows an improved overall goodness of fit (i.e., a lower –ln(likelihood) function; Table 15.8). The coefficient of variation or *CV* (reflecting uncertainty) about the 2003 biomass estimate is 27% and the *CV* on the strength of the 1998 year class is 55% (Table 15.8). Overall estimated recruitment variability for BSAI Atka mackerel is high (0.579) for the Reference Model. 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 109 and average survey effective *N* of 49, which compare very well with the fixed values. The overall residual mean square error

(RSME) for the survey is estimated at 0.475 (Table 15.8). The RSME is in line with estimates of sampling-error *CV*s for the survey which range from 15-63% and average 31% 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. The model fit the 1986 and 2002 survey estimates 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 from the 1994 to 1997 surveys appears to be consistent with recruitment patterns, while the large increase in biomass from the 2000 to 2002 surveys appears to be inconsistent with the recent recruitment patterns. Although the 1998 and potentially the 1999 year classes appear to be above average, the 51% increase in biomass observed between the 2000 and 2002 surveys appears to be inconsistent with the other data. In fact, the model prediction is slightly lower than the lower 95% confidence bound (based on sampling error alone) for the 2002 survey (Figure 15.19). Last year we evaluated a model run where we artificially reduced the uncertainty of the 2002 survey estimate by a factor of 3 and tuned the model. This resulted in a near perfect fit to the 2002 survey estimate but substantially degraded the fit to the fishery age composition data (Lowe et al. 2002). It also increased the estimate of current stock size by over 50% and the projected maximum permissible ABC for 2003 by over 65% compared to the 2002 Reference Model. Based on this, we felt that the lack of fit to the recent estimate was reasonable in a statistical sense and also provided an extra measure of precaution.

The fits to the survey and fishery age compositions for Model 2 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 slightly less so. This reflects the fact that the sample sizes for age and length composition data are higher for the fishery than the survey. These figures also highlight the patterns in changing age compositions over time. Note that the older age groups in the fishery age data are largely absent until around 1985 when the 1977 year class appears. It is also interesting to note that in the 2000 survey they found much larger than expected number of 2-year old fish (1998 year class) for which the selectivity is estimated to be relatively low (0.16). The observed number of 3-year olds (1997 year class) in 2000 was much lower than expected even though the estimated selectivity is about 60% (Figure 15.13).

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 1978-2002 (434 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 selected the following values from Reference Model 2 results computed based on recruitment from post-1976 spawning events:

$B_{100\%}$ = 209,500 mt female spawning biomass
$B_{40\%}$ = 83,800 mt female spawning biomass
$B_{35\%}$ = 73,300 mt female spawning biomass

Note: Last year the above reference biomass values were presented in terms of male *and* female spawning biomass. This error has been rectified and the above values are correctly presented in terms of 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 2003 selectivity vector. As noted above (see selectivity discussion under Section 15.6.1), the 2003 selectivity vector is shifted over to the right relative to the 2002 selectivity estimated in last year's assessment, particularly affecting ages 5-8. Model results are sensitive to the selectivity assumptions and this is reflected in the reference fishing mortality values. While we believe the Reference 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 believe it is appropriate to use an average of recent years. To provide for a more robust selectivity pattern for projection purposes, we used an average of the years 1999-2002 (Table 15.9, Figure 15.22). We believe these years reflect a reasonable range of recent selectivity estimates since the implementation of Steller sea lion regulations that affect the Atka mackerel fishery. A comparison of key reference fishing mortality values under the different selectivity assumptions are given below:

Selectivity Assumption

Full selection *F*s	2003	Average 1999-2002
F_{2003}	0.708	0.544
$F_{40\%}$	0.847	0.668
$F_{35\%}$	1.068	0.833
$F_{2003}/F_{40\%}$	0.836	0.791

The rates based on the year 2003 selectivity are those presented in the results Table 15.8. Reference rates based on the average of the 1999-2002 selectivities are nearly identical to the reference rates presented in last year's assessment. Recommendations provided below are based on projections incorporating the average selectivity vector.

For Reference Model 2, the projected year 2004 female spawning biomass (SB_{04}) is estimated to be 86,000 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 2004 female spawning biomass is above the $B_{40\%}$ value of 83,800 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}	$F_{40\%}$	0.67	66,700
F_{OFL}	$F_{35\%}$	0.83	78,500

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. Some of these concerns are repeated below:

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, the 2000 and 2002 survey estimates showed 40 and 50% increases respectively, that could not be fit by the stock assessment model.

2) Under an $F_{40\%}$ harvest strategy, 2004 female spawning biomass is projected to be above $B_{40\%}$, but drop below by 2005.

3) The uncertainty about the estimate of the 2004 $F_{40\%}$ catch is considerable with a *CV* of 32%. 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 model's predicted survey biomass trend is extremely conservative relative to the recent (2000 and 2002) observed survey biomass values. The residuals are highly positive. The model estimated abundance trend is conservative relative to the trend indicated by the bottom trawl survey.

5) The 2002 fishery age composition data continue to show large numbers from the 1998 year class and the first appearance in the fishery of the 1999 year class. The 2002 fishery age data are dominated by these two year classes. Currently we estimate the 1998 year class to be the fourth largest in the time series (but with a high degree of uncertainty: *CV*=55%).

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 selectivity assumptions in describing the population dynamics of Atka mackerel are sensible from a biological and mechanistic standpoint. However, given the factors listed above, we felt that an added conservation measure may be warranted for other considerations. For this reason, we implemented the "constant-buffer" scheme of Dorn et al. (2001). This gave a 2004 yield of 57,600 mt compared to a maximum permissible ABC of 66,700 mt. We noted that the long-term expected catch under the maxF_{ABC} was about 60,600 mt, which was the harvest strategy selected by the SSC for the 2003 ABC recommendation. This scenario (as expected) reduced the probability of the biomass dropping below $B_{40\%}$ (Figure. 15.23). These alternatives are offered as a means for added conservation to encompass other considerations. However, given the current stock size and the appearance two consecutive strong year classes, from a biological perspective (for Atka mackerel) the maximum permissible is acceptable.

The associated 2004 yield associated with the maximum permissible $F_{40\%}$ fishing mortality rate of 0.67 is 66,700 mt, which is our 2004 ABC recommendation for BSAI Atka mackerel.

This ABC recommendation represents a modest 6% increase over the Council's 2003 ABC. Given the positive signs from the last two surveys and the fact that the model prediction is substantially below these survey biomass estimates, and the incoming 1999 year class, this level of increase is likely to be precautionary. That is, as the age-composition information from the 2002 survey becomes available along with other data in the coming years, we expect that our current biomass estimate is more likely to be higher rather than lower. Nonetheless, alternative prudent yield levels warrant consideration and include the "constant buffer" scheme value of 57,600 mt and the long-term average yield of 60,600 mt.

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 weighted average to apportion the 2003 ABC. The rationale for the weighting scheme is described in Lowe et al. (2001).

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

	1994	1997	2000	2002	4-survey weighted average
541	34.6%	12.3%	0.20%	24.7%	**16.8%**
542	14.0%	51.0%	64.6%	42.3%	**46.6%**
543	51.4%	36.4%	35.2%	33.0%	**36.5%**
Weights	8	12	18	27	

The apportionment of 66,700 mt based on the most recent 4-survey weighted average is:

Eastern (541)	11,200 mt
Central (542)	31,100 mt
Western (543)	24,400 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 2003 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2003 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 1999-2002 selectivities), and the best available estimate of total (year-end) catch for 2003 (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 2004, are as follow (A "*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 2004 recommended in the assessment to the *max* F_{ABC} for 2004. (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 1997-2001 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 follow (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 2004 or 2) above ½ of its MSY level in 2004 and above its MSY level in 2014 under this scenario, then the stock is not overfished.)

Scenario 7: In 2004 and 2005, 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 2016 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 2004 is 286,200 mt, and the projected 2004 female spawning biomass 86,000 mt. The projected yields, female spawning biomass, and the associated fishing mortality rates for the seven harvest strategies are shown in Table 15.14. Under a harvest strategy of $F_{40\%}$ (Scenario 1), female spawning biomass is projected to be above $B_{40\%}$ in 2004, but drop below in 2005. Female spawning biomass is also projected to drop below $B_{40\%}$ when fishing at F_{OFL} (Scenarios 6 & 7, Table 15.14). 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 1978-2000 (434 million recruits) and $F = F_{35\%}$, denoted $B_{35\%}$ is estimated to be 73,300 mt. This value ($B_{35\%}$), is used in the status determination criteria. Female spawning biomass for 2004 (86,000 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 2016 is 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

Ecosystem considerations for Atka mackerel are summarized in Table 15.15.

15.10.1 Ecosystem effects on BSAI Atka mackerel

Prey availability/abundance trends

Adult Atka mackerel in the Aleutians consume a variety of prey, but principally calanoid copepods and euphausiids. No time series of information is available on Aleutian Islands copepod and euphausiid abundance.

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). 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 15.15 and discussed below.

The Atka mackerel fishery has very low bycatch levels of some species of HAPC biota, e.g. seapens and whips. The bycatch of sponges and coral in the Atka mackerel fishery is variable. It is notable that in the last 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 15.15. 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. 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 and survey catchability, 2) exploration of differential natural mortality at age, and 3) continued evaluation of model sensitivity to a number of input specifications.

15.12 Summary

Natural mortality = 0.3

2004 (Tier 3a)			
Maximum permissible ABC:	$F_{40\%} = 0.67$	yield =	66,700 mt
Recommended ABC:	$F_{40\%} = 0.67$	yield =	66,700 mt
Overfishing (OFL):	$F_{35\%} = 0.83$	yield =	78,500 mt

Equilibrium female spawning biomass		
$B_{100\%}$	=	209,500 mt
$B_{40\%}$	=	83,800 mt
$B_{35\%}$	=	73,300 mt

Projected 2004 biomass	
Age 3+ biomass	= 286,200 mt
Female spawning biomass	= 86,000 mt

15.13 Acknowledgements

We thank the AFSC survey personnel for the collection of data and providing the biomass estimates. 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 (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[C]	0	a	a	a	a	0	50,238	50,238	50,238	60,000

Catch table footnotes:
- a) Eastern Bering Sea catches included with Aleutian Islands.
- b) Atka mackerel was not a reported species group until 1978
- c) 2003 data as of 9/27/03 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	--

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	---	---	---

[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 Aleutian	1-100	95	15,321	418,271			
	101-200	75,857	120,991	51,312			
	201-300	619	2,304	122			
	301-500	105	172	14			
	501-900	9	1	0			
	Total	76,685	138,789	469,719	0.57	0.36	0.73
Southeast Aleutian	1-100	0	65,814	33			
	101-200	21,153	854	89			
	201-300	115	202	3			
	301-500	16	0	0			
	501-900	0	0	0			
	Total	21,284	66,870	125	0.86	0.01	0.64
Northwest Aleutian	1-100	0	41,235	32,564			
	101-200	382	5,571	211			
	201-300	2,524	34	0			
	301-500	0	0	0			
	501-900	4	0	0			
	Total	2,910	46,840	32,775	0.84	0.64	0.65
Northeast Aleutian	1-100	48,211	18,182	1			
	101-200	47,039	34,983	44,889			
	201-300	1,038	1,116	206			
	301-500	362	0	2			
	501-900	0	0	37			
	Total	96,650	54,281	42,135	0.69	0.57	0.46

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

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

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. Coefficients of variation (*CV*) of values appearing directly above are given in parentheses.

Model	Baseline	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
Fishing mortalities (full selection)									
F 2003	0.653	0.708	0.837	0.980	1.063	1.111	0.554	0.555	0.556
F40%	0.809	0.847	0.936	1.023	1.068	1.092	1.996	3.020	3.751
CV	(49%)	(50%)	(48%)	(47%)	(46%)	(46%)	(51%)	(54%)	(56%)
F35%	1.018	1.068	1.184	1.299	1.358	1.390	2.510	3.796	4.716
CV	(51%)	(52%)	(50%)	(48%)	(48%)	(47%)	(52%)	(55%)	(57%)
F 2003/F40%	0.807	0.836	0.894	0.958	0.995	1.017	0.277	0.184	0.148
Stock abundance									
Initial Biomass (1977)	307,330	260,860	250,860	239,320	232,330	228,210	546,700	772,320	934,350
CV	(17%)	(17%)	(17%)	(16%)	(16%)	(16%)	(26%)	(31%)	(35%)
2003 total biomass	447,790	433,550	414,240	395,410	385,250	379,570	860,800	1,139,400	1,329,400
CV	(25%)	(27%)	(26%)	(25%)	(24%)	(24%)	(26%)	(30%)	(33%)
2003 Age 3+ biomass	345,246	336,345	320,344	304,954	296,739	292,179	719,293	975,009	1,149,944
1998 year class (at age 1)	695	698	675	652	640	634	1,944	3,013	3,822
CV	(51%)	(55%)	(53%)	(51%)	(50%)	(50%)	(64%)	(76%)	(85%)
Recruitment Variability	0.550	0.579	0.582	0.587	0.589	0.591	0.552	0.548	0.546
Projected catch (unadjusted)									
F50% 2004 catch	47,649	45,917	42,914	40,015	38,474	37,621	123,620	174,640	208,450
CV	(35%)	(39%)	(38%)	(37%)	(37%)	(36%)	(32%)	(34%)	(36%)
F40% 2004 catch	59,738	57,359	54,707	52,031	50,549	49,711	112,110	139,580	156,620
CV	(28%)	(32%)	(31%)	(31%)	(30%)	(30%)	(25%)	(26%)	(28%)
F35% 2004 catch	55,095	51,769	49,689	47,562	46,371	45,694	90,423	114,990	132,140
CV	(24%)	(27%)	(26%)	(25%)	(25%)	(25%)	(28%)	(31%)	(34%)
Survey catchability	1.000	1.000	1.116	1.269	1.372	1.437	1.000	1.000	1.000
Natural mortality	0.300	0.300	0.300	0.300	0.300	0.300	0.438	0.500	0.533
Fishery Average Effective N	106	109	110	111	112	112	110	110	110
Survey Average Effective N	49	49	49	49	49	49	49	49	49
RMSE Survey	0.426	0.475	0.443	0.412	0.399	0.392	0.256	0.225	0.216
Number of Parameters	361	361	362	362	362	362	362	362	362
-log Likelihoods									
Survey index	4.59	5.12	4.46	3.98	3.86	3.84	2.26	2.20	2.23
Catch biomass	0.06	0.07	0.08	0.11	0.13	0.15	0.03	0.03	0.03
Fishery age comp	153.02	149.49	148.80	148.13	147.78	147.61	143.39	142.22	141.92
Survey age comp	34.29	33.17	32.98	32.70	32.53	32.43	32.32	32.28	32.32
Sub total	191.96	187.84	186.32	184.92	184.30	184.03	178.00	176.73	176.50
-log Penalties									
Recruitment	-2.143	6.002	6.564	7.342	7.883	8.226	-1.006	-2.342	-2.851
Selectivity constraint	107.215	105.004	104.356	103.590	103.107	102.814	105.590	105.946	106.258
Fishing mortality penalty	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.000
Prior	0.073	0.064	0.740	0.976	0.842	0.671	3.844	2.020	0.697
Total	297.101	298.912	297.980	296.825	296.134	295.740	286.427	282.350	280.608

Table 15.9. Estimated Atka mackerel numbers at age in millions, 1977-2003 based on Model 2.

	1	2	3	4	5	6	7	8	9	10+	Total	% of 10+
1977	190	207	165	45	33	18	16	14	12	53	752	7%
1978	1056	140	149	110	26	19	11	10	10	46	1577	3%
1979	302	779	101	99	68	15	11	7	7	39	1428	3%
1980	191	223	571	71	62	40	9	7	5	32	1211	3%
1981	221	141	164	409	48	39	26	6	5	26	1085	2%
1982	145	163	104	118	289	33	26	16	4	22	920	2%
1983	218	107	121	76	85	196	22	18	11	19	873	2%
1984	304	161	79	89	55	60	137	16	13	22	936	2%
1985	482	225	119	57	60	35	36	84	10	24	1131	2%
1986	468	357	164	80	35	35	21	22	52	22	1256	2%
1987	631	346	262	115	53	22	21	12	13	45	1519	3%
1988	389	467	254	185	76	33	13	13	7	34	1471	2%
1989	1111	288	344	182	124	51	22	9	9	28	2168	1%
1990	499	823	212	251	129	84	34	15	6	26	2080	1%
1991	256	370	608	154	174	87	58	24	11	22	1765	1%
1992	512	190	273	446	109	117	58	39	16	23	1785	1%
1993	747	379	140	199	312	71	72	35	24	24	2004	1%
1994	266	552	279	101	138	201	42	41	20	28	1668	2%
1995	291	197	406	201	69	85	118	24	23	26	1440	2%
1996	659	215	144	286	124	40	49	65	13	25	1619	2%
1997	127	487	157	101	172	67	20	21	27	16	1195	1%
1998	247	94	357	112	66	101	35	9	10	19	1049	2%
1999	698	182	69	254	72	38	53	17	4	13	1401	1%
2000	553	516	134	49	158	41	21	28	9	8	1516	1%
2001	230	409	379	94	31	92	23	11	14	8	1291	1%
2002	241	170	299	262	58	17	44	10	4	9	1112	1%
2003	299	178	123	208	173	36	9	21	4	6	1057	1%

Table 14.10. 1977-2002 estimates of Atka mackerel fishery (over time) and survey selectivity for Model 2. 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	0.10	0.39	0.86	1.00	0.74	0.47	0.30	0.21	0.18	0.18	0.18	0.18	0.18	0.18
1978	0.02	0.10	0.47	0.79	1.00	0.87	0.60	0.39	0.27	0.21	0.21	0.21	0.21	0.21	0.21
1979	0.01	0.05	0.25	0.79	1.00	0.87	0.62	0.40	0.27	0.21	0.21	0.21	0.21	0.21	0.21
1980	0.01	0.05	0.21	0.61	1.00	0.97	0.83	0.57	0.36	0.26	0.26	0.26	0.26	0.26	0.26
1981	0.01	0.03	0.13	0.26	0.36	0.62	1.00	0.57	0.28	0.18	0.18	0.18	0.18	0.18	0.18
1982	0.01	0.03	0.10	0.32	0.87	1.00	0.68	0.41	0.27	0.20	0.20	0.20	0.20	0.20	0.20
1983	0.01	0.04	0.15	0.38	0.69	1.00	0.89	0.51	0.32	0.25	0.25	0.25	0.25	0.25	0.25
1984	0.01	0.03	0.14	0.42	0.77	1.00	0.92	0.65	0.43	0.32	0.32	0.32	0.32	0.32	0.32
1985	0.01	0.06	0.40	0.84	1.00	1.00	0.92	0.79	0.66	0.56	0.56	0.56	0.56	0.56	0.56
1986	0.01	0.04	0.21	0.48	0.69	0.84	0.97	1.00	0.83	0.66	0.66	0.66	0.66	0.66	0.66
1987	0.01	0.04	0.21	0.50	0.72	0.83	0.92	1.00	0.98	0.94	0.94	0.94	0.94	0.94	0.94
1988	0.01	0.04	0.30	0.94	1.00	0.90	0.89	0.85	0.82	0.75	0.75	0.75	0.75	0.75	0.75
1989	0.01	0.04	0.18	0.54	0.91	1.00	0.91	0.80	0.73	0.69	0.69	0.69	0.69	0.69	0.69
1990	0.00	0.03	0.22	0.78	1.00	0.81	0.69	0.64	0.62	0.62	0.62	0.62	0.62	0.62	0.62
1991	0.00	0.02	0.09	0.41	0.87	1.00	0.87	0.76	0.67	0.65	0.65	0.65	0.65	0.65	0.65
1992	0.01	0.03	0.10	0.30	0.65	0.94	1.00	0.97	0.94	0.91	0.91	0.91	0.91	0.91	0.91
1993	0.01	0.03	0.09	0.25	0.54	0.86	0.99	0.97	0.97	1.00	1.00	1.00	1.00	1.00	1.00
1994	0.01	0.02	0.10	0.30	0.61	0.78	0.82	0.92	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1995	0.00	0.02	0.13	0.45	0.59	0.63	0.70	0.78	0.88	1.00	1.00	1.00	1.00	1.00	1.00
1996	0.00	0.02	0.10	0.35	0.54	0.70	0.89	1.00	0.98	0.98	0.98	0.98	0.98	0.98	0.98
1997	0.00	0.02	0.08	0.22	0.43	0.65	0.80	0.92	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1998	0.00	0.02	0.08	0.27	0.52	0.68	0.77	0.86	0.94	1.00	1.00	1.00	1.00	1.00	1.00
1999	0.00	0.02	0.10	0.38	0.56	0.66	0.72	0.84	0.94	1.00	1.00	1.00	1.00	1.00	1.00
2000	0.00	0.02	0.11	0.33	0.54	0.68	0.80	0.94	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2001	0.00	0.02	0.11	0.30	0.54	0.73	0.90	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2002	0.01	0.03	0.12	0.22	0.35	0.56	0.79	0.92	0.98	1.00	1.00	1.00	1.00	1.00	1.00
2003	0.01	0.03	0.09	0.20	0.36	0.56	0.75	0.90	0.97	1.00	1.00	1.00	1.00	1.00	1.00
Ave. 1999-2002	0.00	0.02	0.11	0..31	0..50	0.66	0.80	0.92	0..98	1.00	1.00	1.00	1.00	1.00	1.00
Survey	0.03	0.16	0.59	0.93	0.99	0.97	1.00	0.92	0.76	0.68	0.68	0.68	0.68	0.68	0.68

Table 15.11. Model 2 estimates of Atka mackerel biomass 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 from the current assessment compared to last year's (2002) assessment.

	Current assessment age 1+ biomass			Age 3+ biomass		Female spawning biomass	
Year	Estimate	LCI	UCI	Current	2002	Current	2002
1977	260,860	170,650	351,070	206,422	221,470	62,143	64,190
1978	356,130	236,974	475,286	216,903	234,505	59,039	68,391
1979	353,130	231,108	475,152	205,553	224,903	62,415	72,855
1980	456,560	302,286	610,834	382,269	413,785	65,985	90,604
1981	497,430	331,898	662,962	402,869	437,183	82,173	140,305
1982	456,670	305,442	607,898	376,526	411,081	128,560	154,782
1983	413,570	278,968	548,172	347,773	382,425	141,628	143,351
1984	384,470	265,024	503,916	311,470	344,971	130,390	122,764
1985	362,940	252,638	473,242	270,634	303,778	110,165	100,194
1986	363,660	257,942	469,378	255,941	289,101	88,060	88,010
1987	423,980	317,596	530,364	294,142	326,024	76,124	91,182
1988	466,100	361,904	570,296	334,145	362,386	79,442	108,791
1989	602,040	501,748	702,332	412,645	435,913	97,720	131,155
1990	640,030	547,328	732,732	435,872	455,770	121,549	154,109
1991	724,820	635,366	814,274	599,338	615,033	146,274	173,504
1992	771,360	683,406	859,314	623,312	637,109	167,104	205,545
1993	732,550	649,926	815,174	549,802	563,507	200,360	200,025
1994	651,580	573,268	729,892	512,591	527,414	195,300	168,540
1995	632,670	546,938	718,402	534,881	550,782	163,599	152,097
1996	591,260	491,122	691,398	449,632	466,733	146,648	139,013
1997	459,030	359,086	558,974	349,786	369,263	132,938	116,074
1998	449,790	326,978	572,602	380,560	404,857	109,383	105,486
1999	445,320	297,232	593,408	312,895	342,854	97,074	110,974
2000	414,840	250,764	578,916	267,538	312,197	99,868	100,296
2001	438,640	238,766	638,514	336,185	413,724	85,151	98,059
2002	455,030	217,990	692,070	366,554	384,510	75,892	118,455
2003	433,550	195,190	671,910	336,345	358,303	96,062	
2004				286,180		86,000	

Table 15.12 Estimates of age-1 Atka mackerel recruitment (in millions) based on Model 2.

	Age 1 Recruits	
Year	Current	2002
1977	189.7	208.0
1978	1056.0	1124.0
1979	301.6	327.0
1980	190.9	212.6
1981	220.9	245.7
1982	144.6	164.7
1983	217.7	242.2
1984	303.5	329.2
1985	482.3	501.4
1986	468.0	476.1
1987	630.9	632.4
1988	388.6	395.4
1989	1111.3	110.9
1990	499.4	506.9
1991	256.5	268.9
1992	512.4	528.3
1993	746.6	761.7
1994	265.8	282.0
1995	290.5	312.6
1996	659.1	693.6
1997	127.1	156.7
1998	246.7	321.8
1999	697.7	850.4
2000	553.3	288.0
2001	229.7	
2002	240.7	
Ave 78-02	433.7	
Med 78-02	303.5	

Table 15.13. Estimates of full-selection fishing mortality rates and exploitation rates for Atka mackerel based on Model 2 results.

Year	F^a	Catch/Biomass Rate[b]
1977	0.269	0.105
1978	0.235	0.108
1979	0.221	0.104
1980	0.154	0.041
1981	0.189	0.041
1982	0.100	0.052
1983	0.059	0.033
1984	0.209	0.116
1985	0.228	0.140
1986	0.256	0.125
1987	0.226	0.102
1988	0.108	0.065
1989	0.091	0.036
1990	0.086	0.050
1991	0.109	0.040
1992	0.194	0.076
1993	0.263	0.119
1994	0.298	0.135
1995	0.411	0.152
1996	0.585	0.231
1997	0.538	0.188
1998	0.513	0.153
1999	0.465	0.180
2000	0.436	0.177
2001	0.617	0.183
2002	0.523	0.124
2003	0.708	0.149

[a] Full-selection fishing mortality rates.
[b] Catch/biomass rate is the ratio of catch to beginning year age 3+ biomass.
[c] The 2003 catch/biomass rate is based on catch as of 9/27/03

Table 15.14. Projections of Model 2 spawning biomass, *F* and catch for Atka mackerel for the 7 scenarios. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 209,500, 83,800, and 73,300 mt, respectively. Fishing mortality rates given are full-selection values.

Sp.Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2003	105,190	105,190	105,190	105,190	105,190	105,190	101,666
2004	85,950	85,950	95,322	90,262	105,871	82,112	82,475
2005	70,015	70,015	86,323	75,421	110,398	64,591	68,544
2006	68,168	68,168	86,252	72,157	119,933	62,967	65,567
2007	76,028	76,028	95,896	79,946	137,817	70,515	71,432
2008	83,164	83,164	106,034	88,505	156,210	76,633	76,881
2009	86,969	86,969	113,003	94,084	171,165	79,420	79,457
2010	87,994	87,994	116,531	96,515	181,927	79,786	79,780
2011	87,700	87,700	117,777	97,045	189,236	79,230	79,223
2012	87,559	87,559	118,433	97,292	194,702	79,049	79,046
2013	87,778	87,778	119,075	97,701	199,114	79,272	79,271
2014	88,103	88,103	119,656	98,141	202,648	79,579	79,578
2015	88,255	88,255	119,999	98,377	205,310	79,704	79,704
2016	87,596	87,596	119,436	97,754	206,466	79,056	79,056
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2003	0.544	0.544	0.544	0.544	0.544	0.544	0.669
2004	0.669	0.669	0.334	0.510	0.000	0.818	0.657
2005	0.552	0.552	0.310	0.510	0.000	0.632	0.540
2006	0.536	0.536	0.308	0.510	0.000	0.615	0.642
2007	0.571	0.571	0.314	0.510	0.000	0.670	0.678
2008	0.594	0.594	0.319	0.510	0.000	0.705	0.707
2009	0.609	0.609	0.324	0.510	0.000	0.724	0.724
2010	0.613	0.613	0.325	0.510	0.000	0.728	0.728
2011	0.613	0.613	0.326	0.510	0.000	0.726	0.726
2012	0.612	0.612	0.326	0.510	0.000	0.725	0.724
2013	0.613	0.613	0.327	0.510	0.000	0.726	0.726
2014	0.613	0.613	0.327	0.510	0.000	0.726	0.726
2015	0.613	0.613	0.327	0.510	0.000	0.726	0.726
2016	0.614	0.614	0.327	0.510	0.000	0.726	0.726
Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2003	59,994	59,994	59,994	59,994	59,994	59,994	71,638
2004	66,664	66,664	36,349	52,946	0	78,545	62,397
2005	47,345	47,345	33,159	47,549	0	49,714	44,952
2006	43,719	43,719	33,205	44,591	0	45,625	50,299
2007	48,922	48,922	35,742	45,737	0	52,518	54,295
2008	54,273	54,273	39,028	49,007	0	58,827	59,415
2009	58,286	58,286	42,159	52,300	0	62,758	62,916
2010	60,076	60,076	44,371	54,517	0	64,093	64,119
2011	60,466	60,466	45,644	55,602	0	63,939	63,936
2012	60,474	60,474	46,292	56,075	0	63,745	63,740
2013	60,625	60,625	46,728	56,353	0	63,881	63,879
2014	60,801	60,801	47,031	56,584	0	64,116	64,115
2015	60,852	60,852	47,184	56,699	0	64,111	64,111
2016	60,630	60,630	47,070	56,529	0	63,831	63,831

Table 15.15. Ecosystem effects

Ecosystem effects on Atka mackerel			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Zooplankton	Stomach contents, ichthyoplankton surveys	None	Unknown
Predator population trends			
Marine mammals	Fur seals declining, Steller sea lions increasing slightly	Possibly lower mortality on Atka mackerel	No concern
Birds	Stable, some increasing some decreasing	Affects young-of-year mortality	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

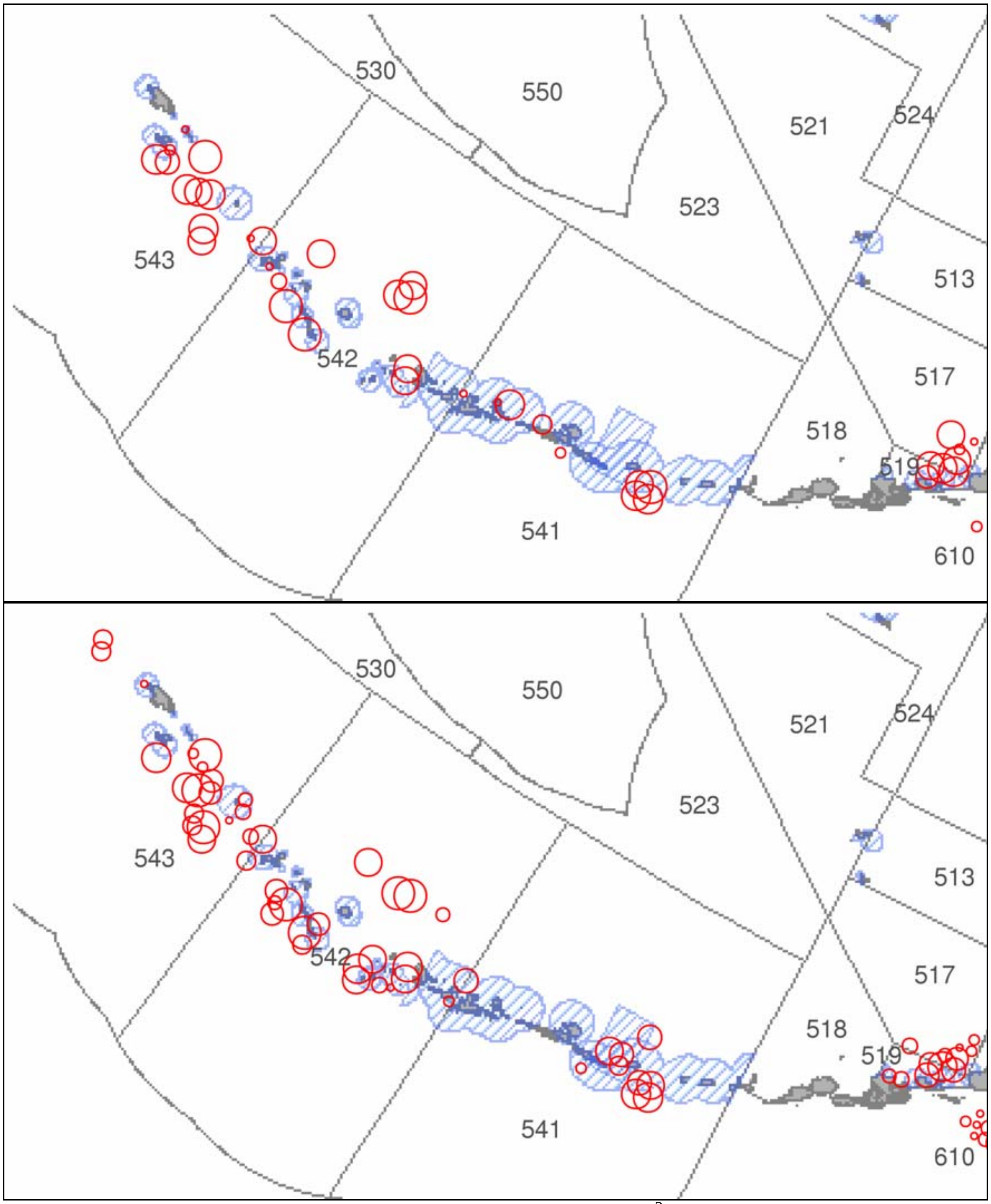


Figure 15.1. Observed catch of Atka mackerel summed for 20km^2 cells for 2003 (January – June, top panel; and from July-November, bottom panel) where observed catch per haul was greater than 1mt. Shaded areas represent 10 and 20 nm Steller sea lion areas.

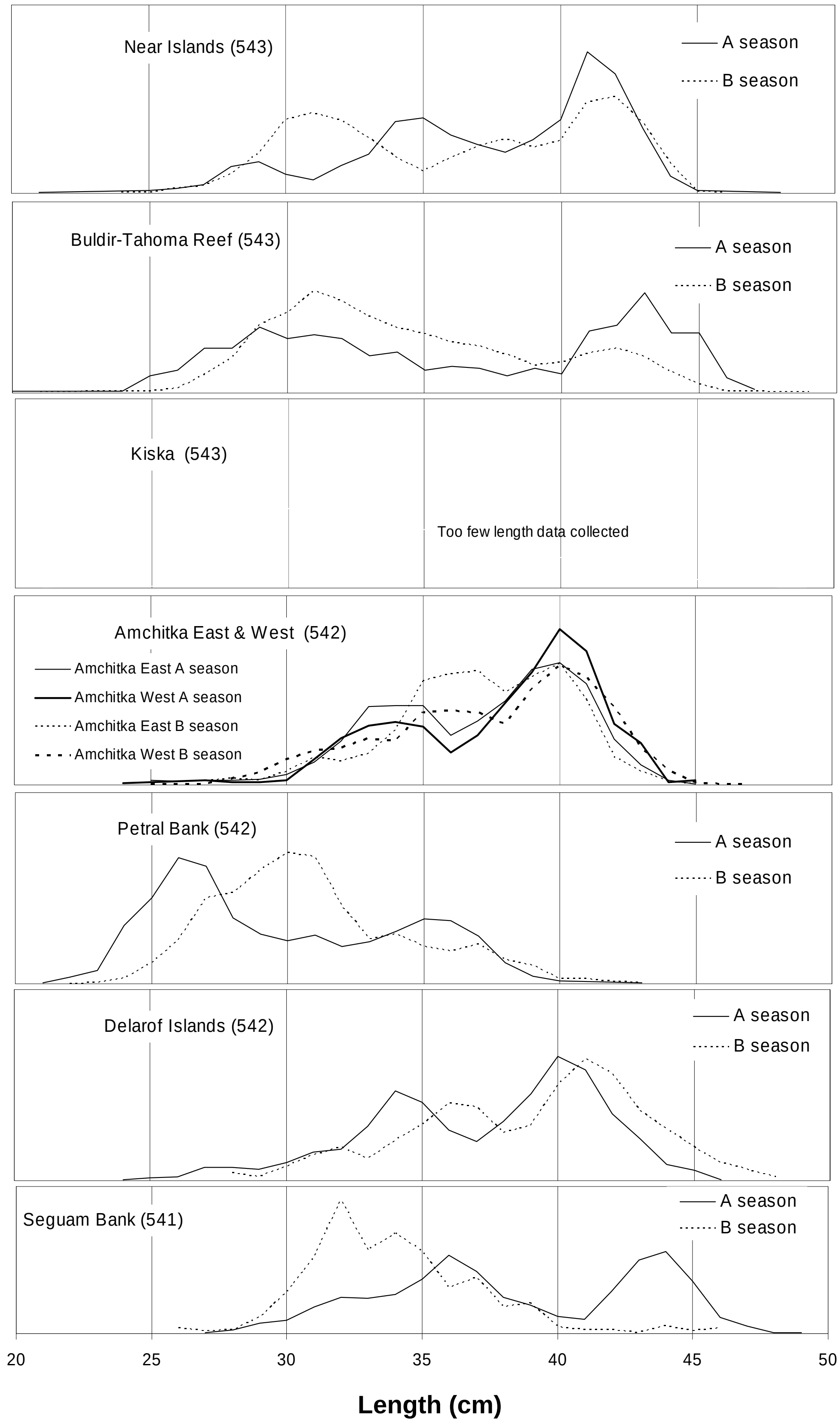


Figure 15.2. 2002 Atka mackerel fishery length-frequency by area fished. (see Figure 15.1). Numbers refer to management areas.

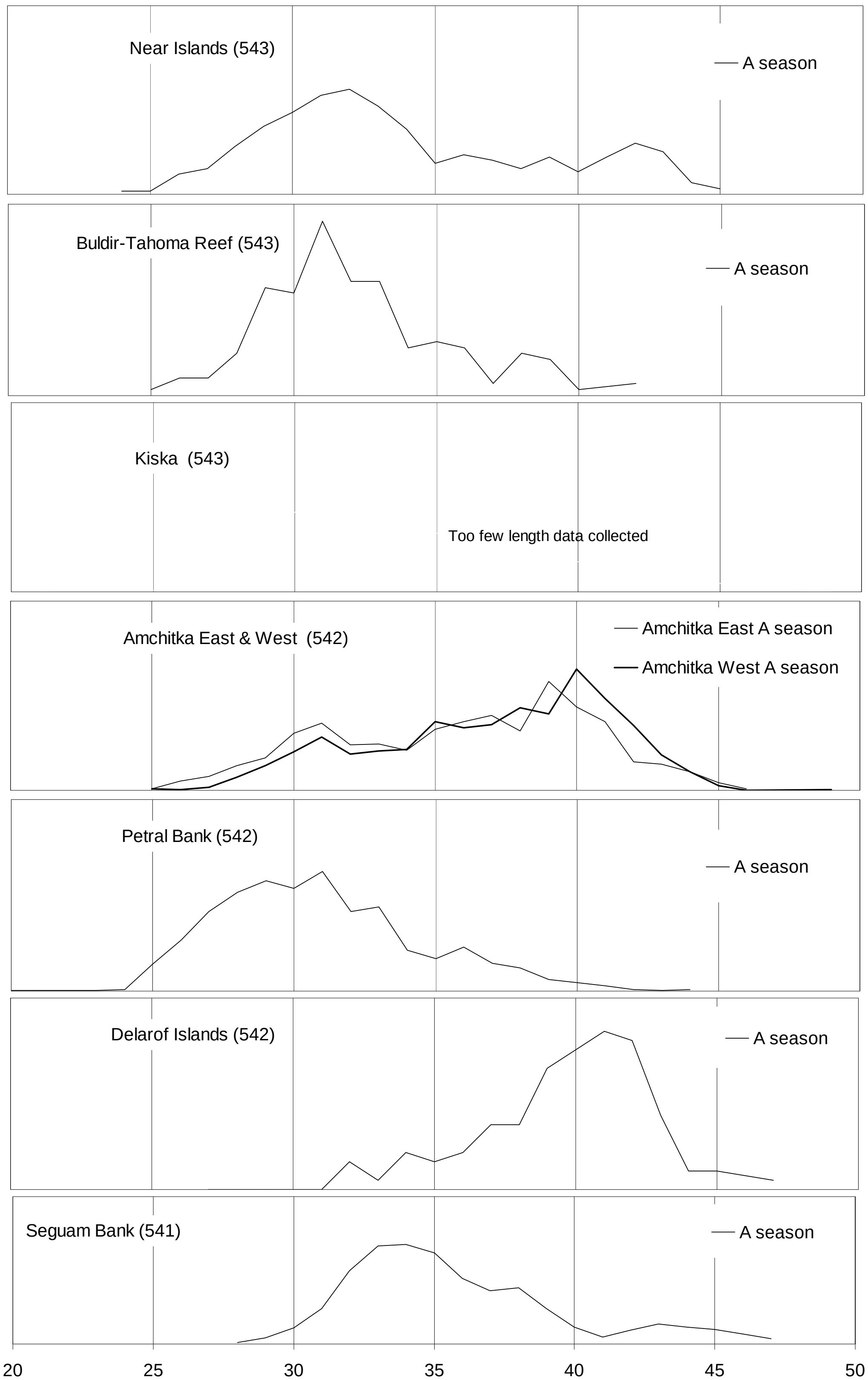


Figure 15.3. Preliminary 2003 A season Atka mackerel fishery length-frequency by area fished. (see Figure 15.1). Numbers refer to management areas.

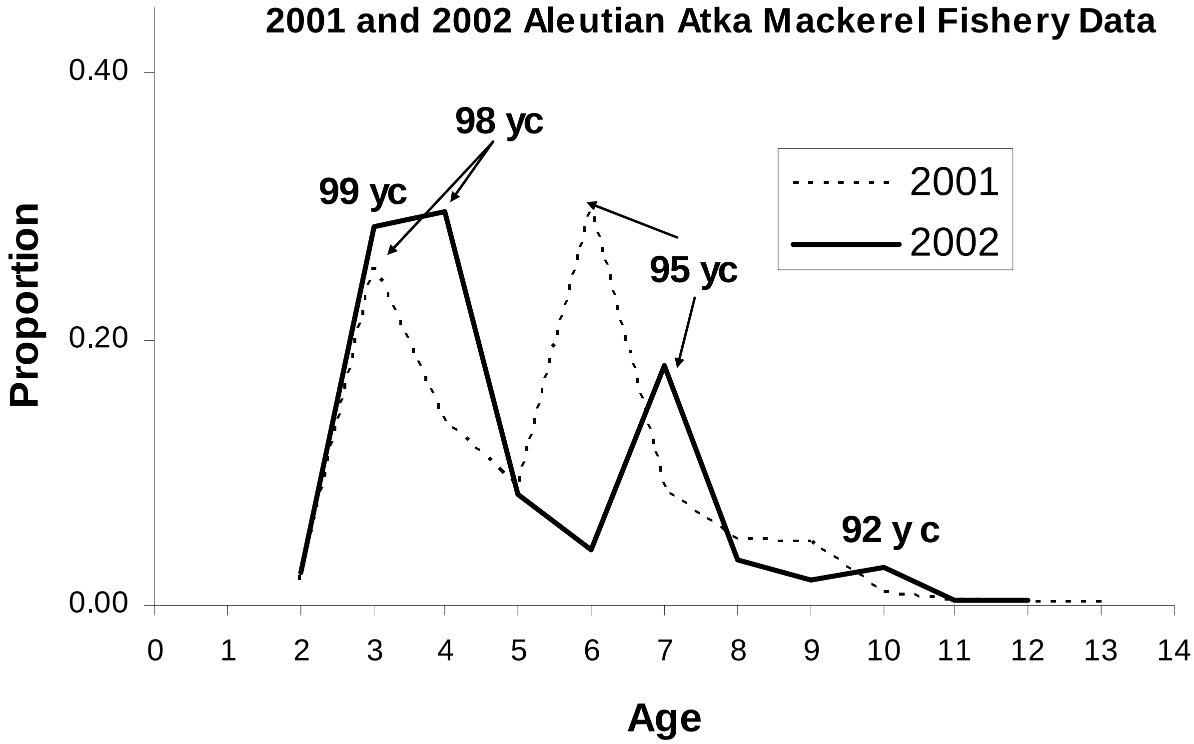


Figure 15.4. 2001 and 2002 Aleutian Atka mackerel fishery age compositon data.

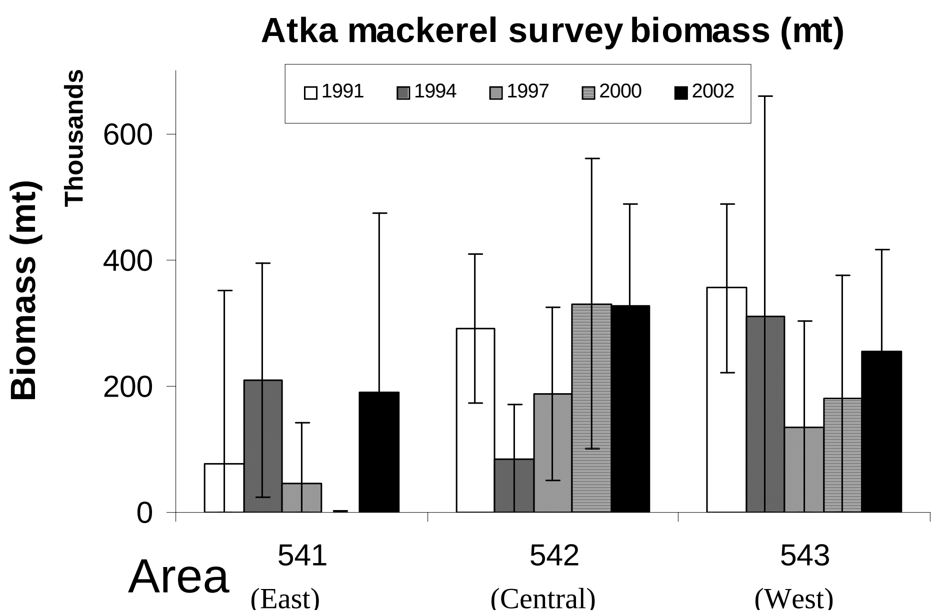


Figure 15.5. Atka mackerel Aleutian survey biomass estimates by area and survey year. Bars represent 95% confidence intervals based on sampling error.

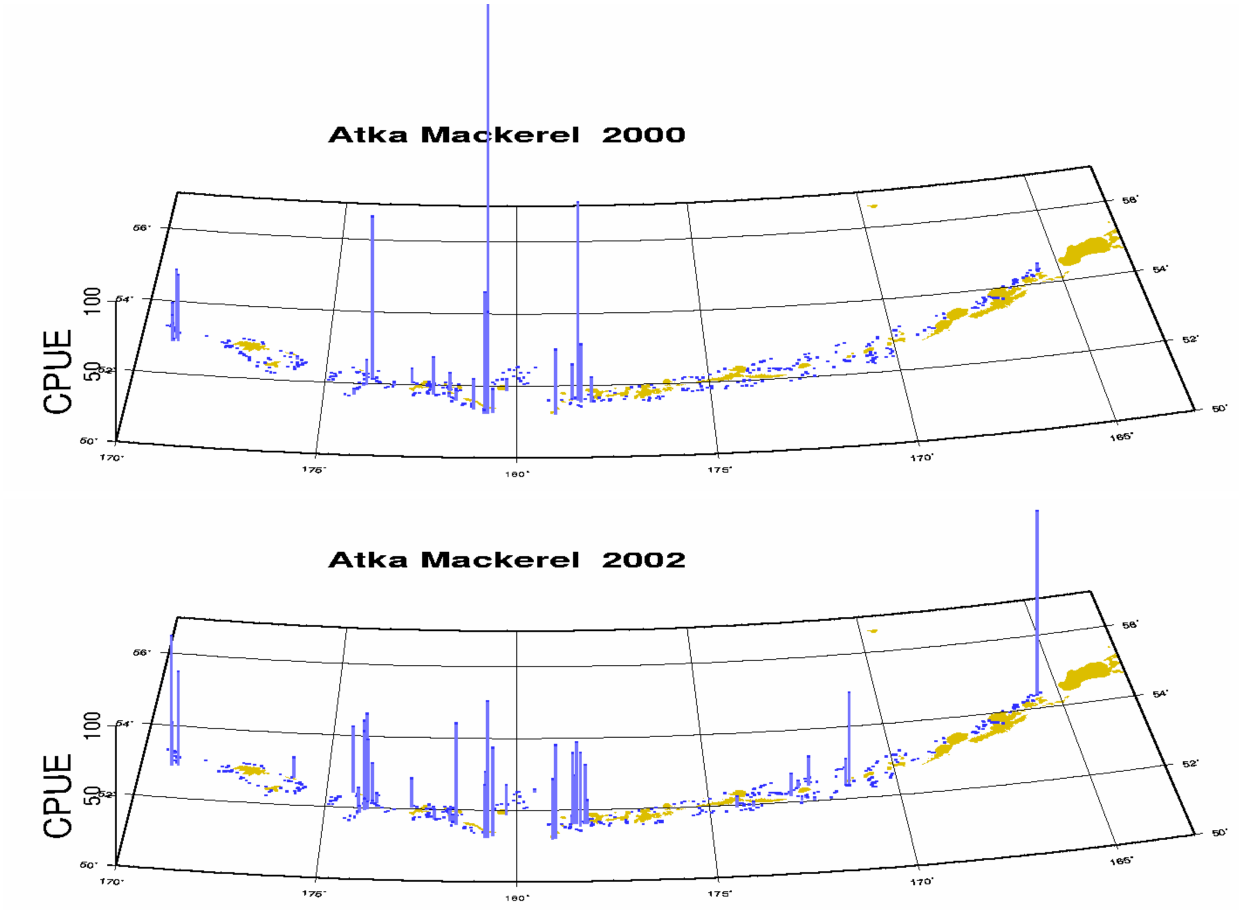


Figure 15.6. Bottom-trawl survey CPUE distributions during the summers of 2000 and 2002.

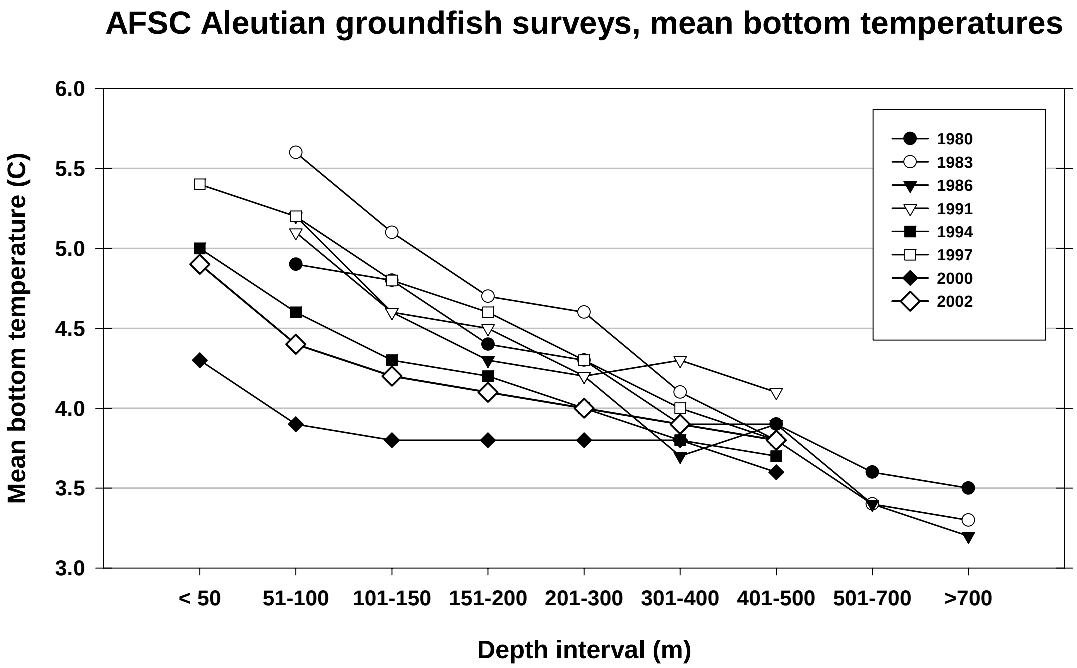


Figure 15.7. Average bottom temperatures by depth interval based on Aleutian Islands summer bottom-trawl surveys since 1980.

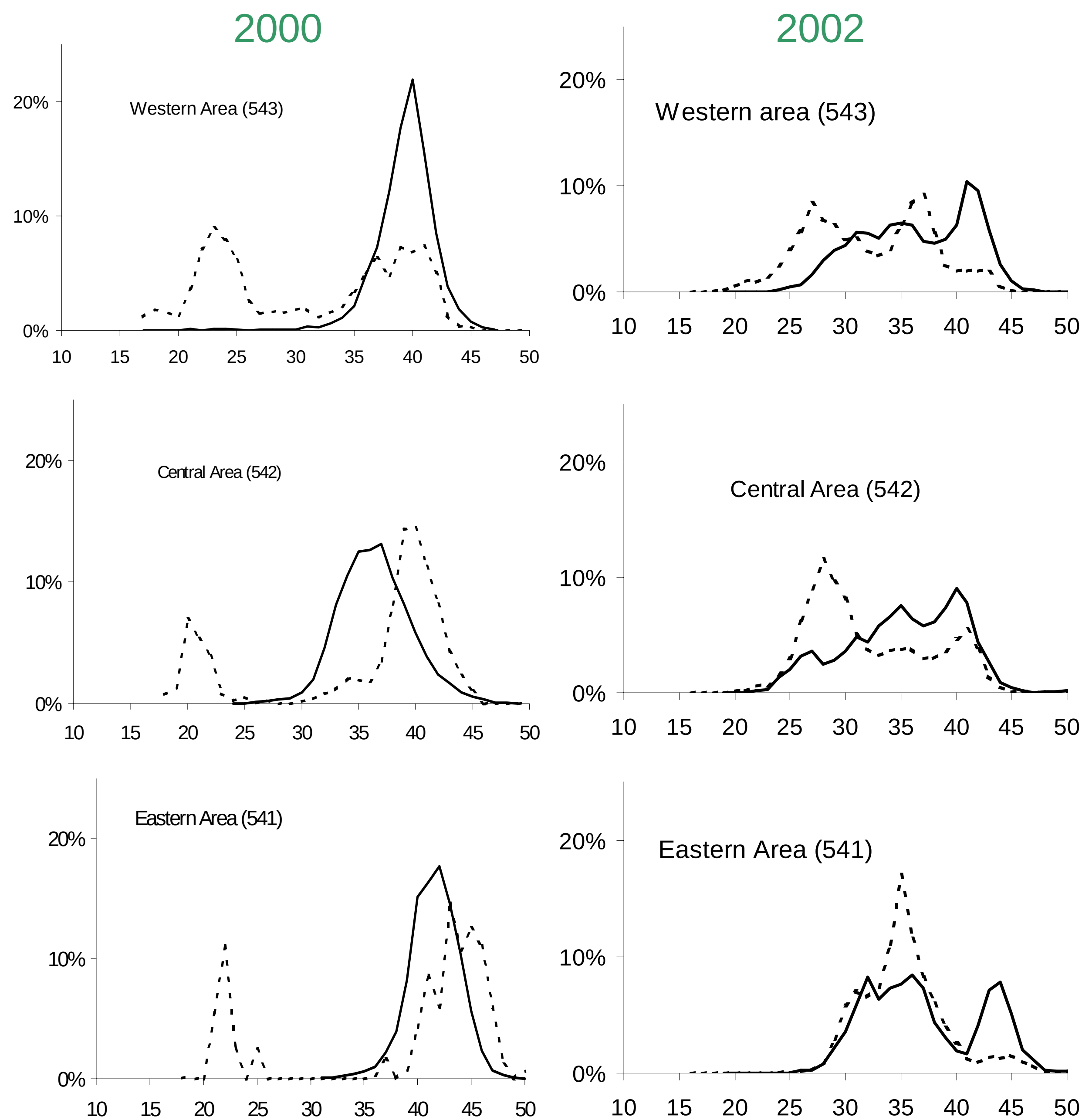


Figure 15.8. Atka mackerel fishery (solid lines) and survey (dashed lines) length frequencies by areas for 2000 and 2002.

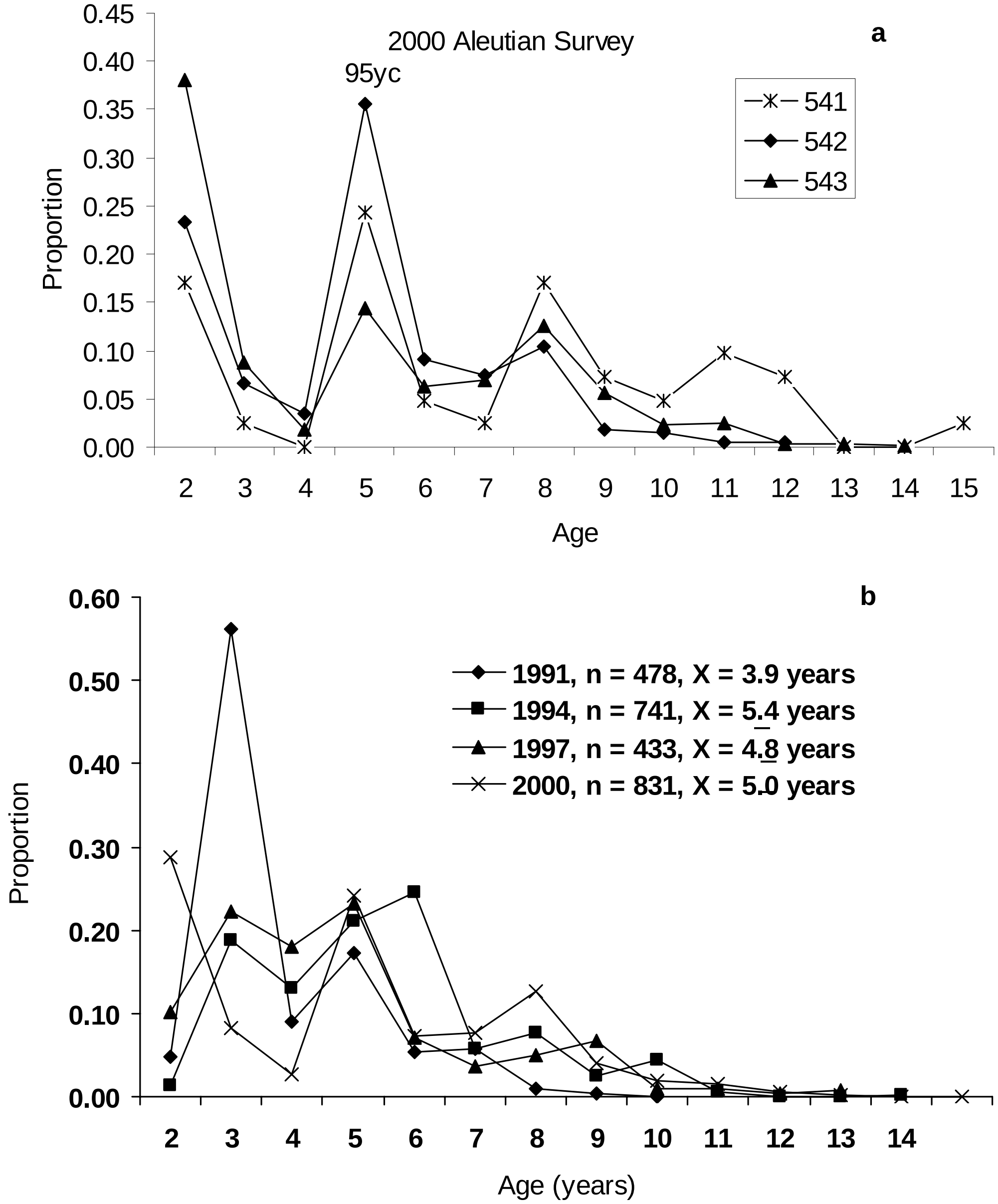


Figure 15.9. Age distributions from the Aleutian Islands region from the 1991, 1994, 1997, and 2000: surveys.

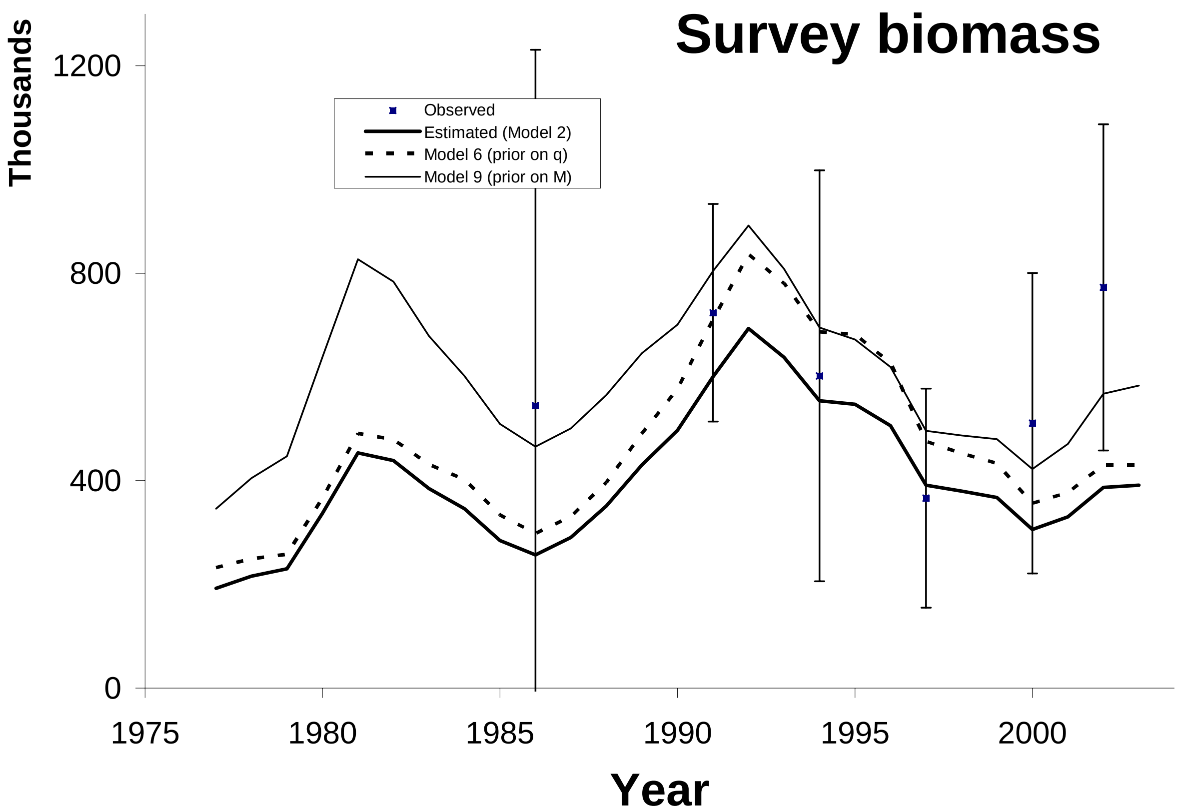


Figure 15.10. Survey biomass compared to Models 2, 6, & 9 predictions for BSAI Atka mackerel, 1977-2003.

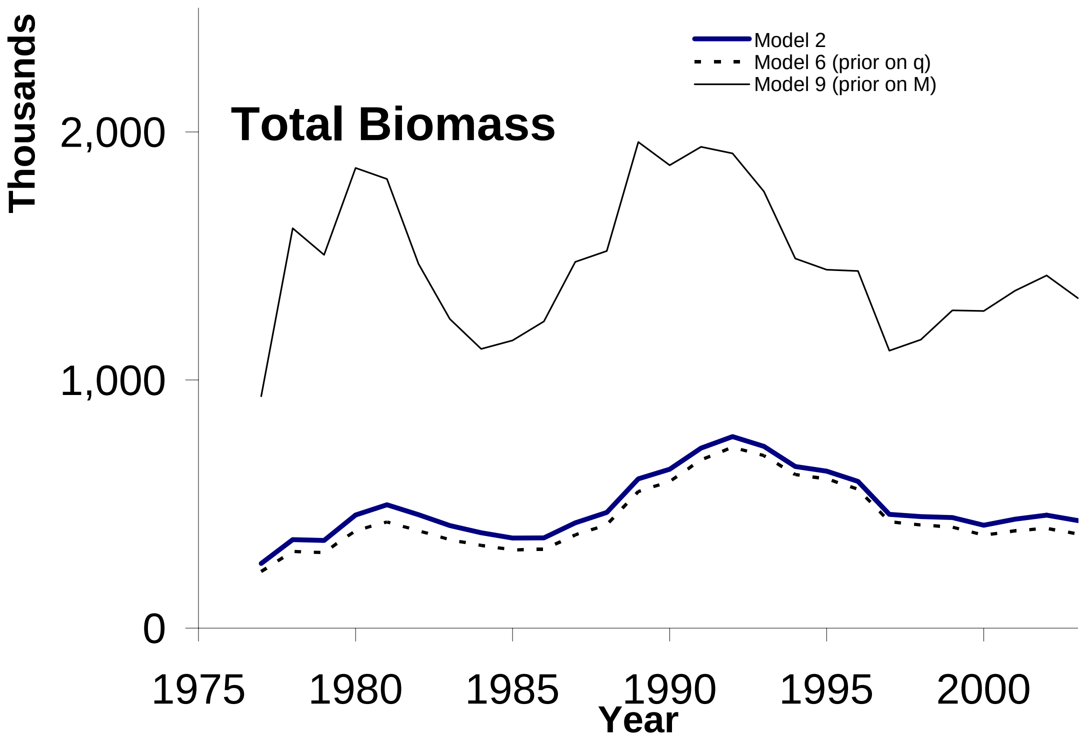


Figure 15.11. Total biomass estimates for Models 2, 6, & 9 for Atka mackerel, 1977-2003.

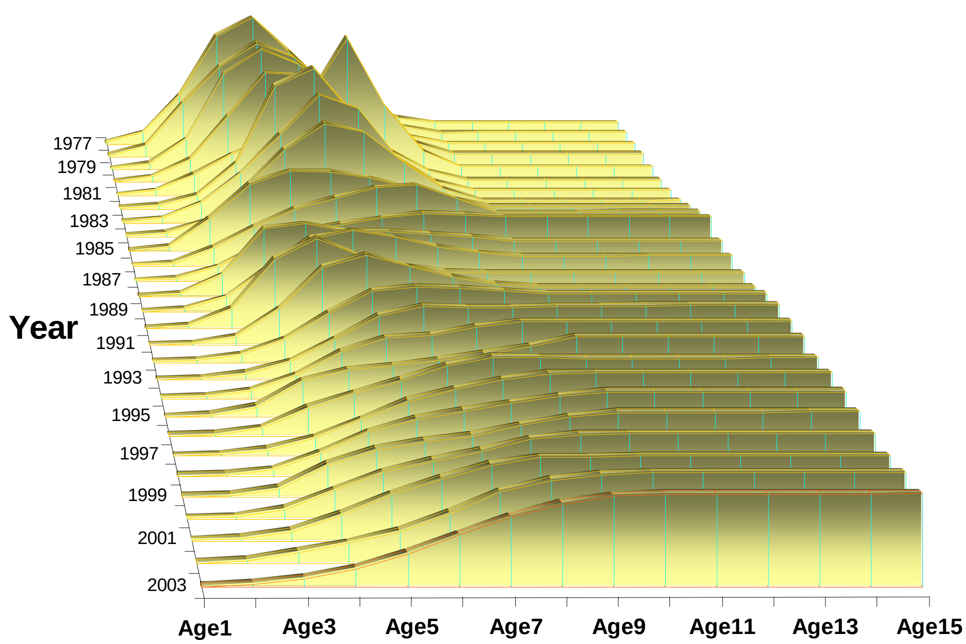


Figure 15.12. Atka mackerel fishery selectivity-at-age estimated for Model 2.

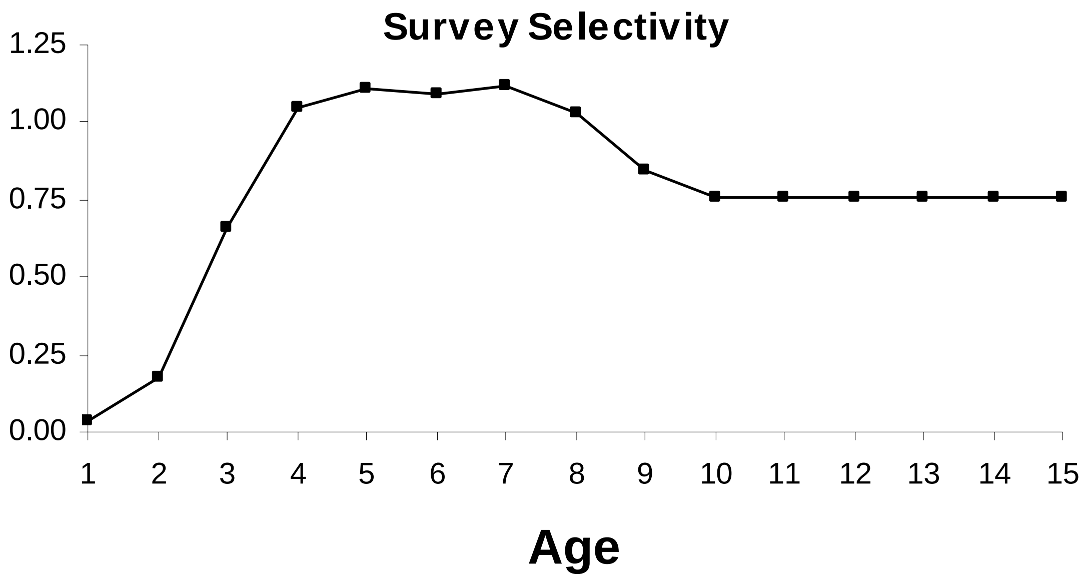


Figure 15.13. Atka mackerel survey selectivity-at-age estimates based on Model 2.

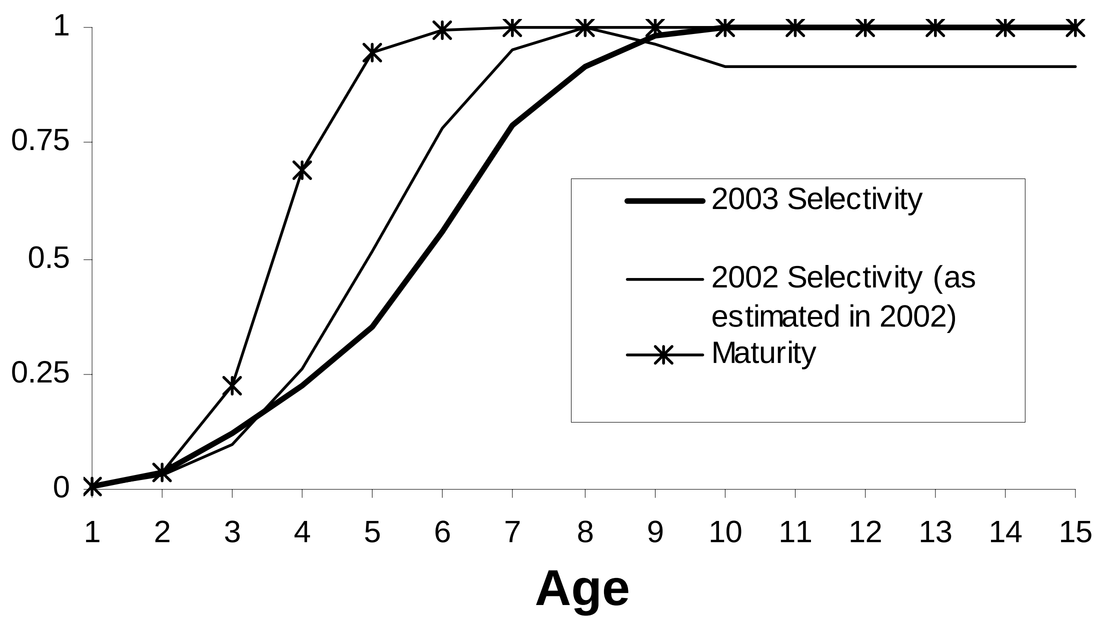


Figure 15.14. Atka mackerel fishery 2003 selectivity-at-age estimate compared with the 2002 estimate (as estimated in 2002, Lowe et al. (2002) and the maturity at age estimates.

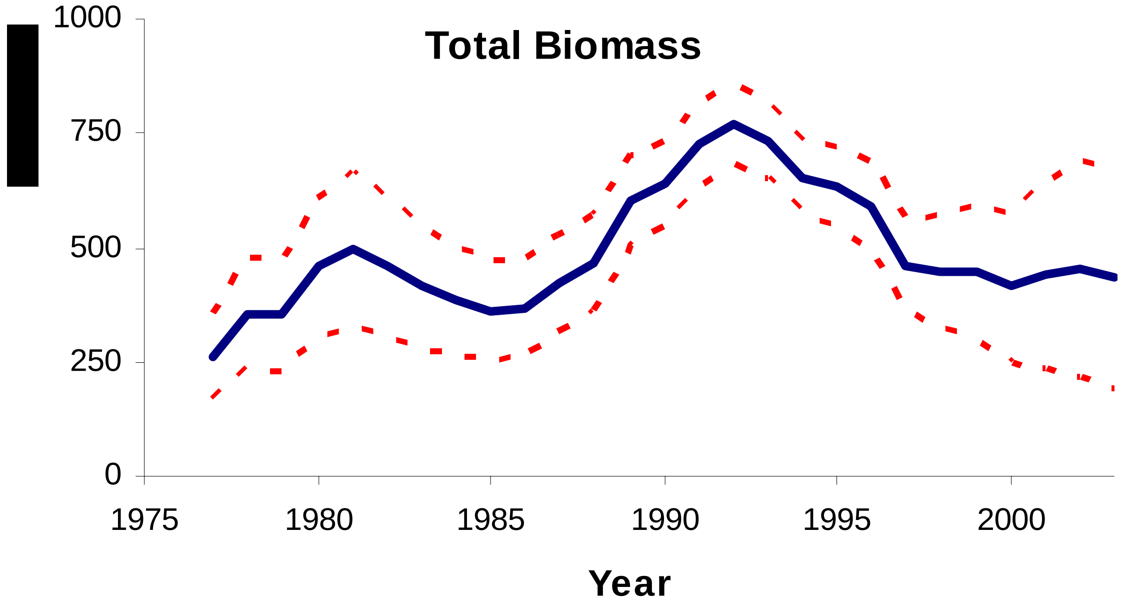


Figure 15.15. Time series of Atka mackerel biomass estimates and approximate 95% confidence bounds based on Model 2.

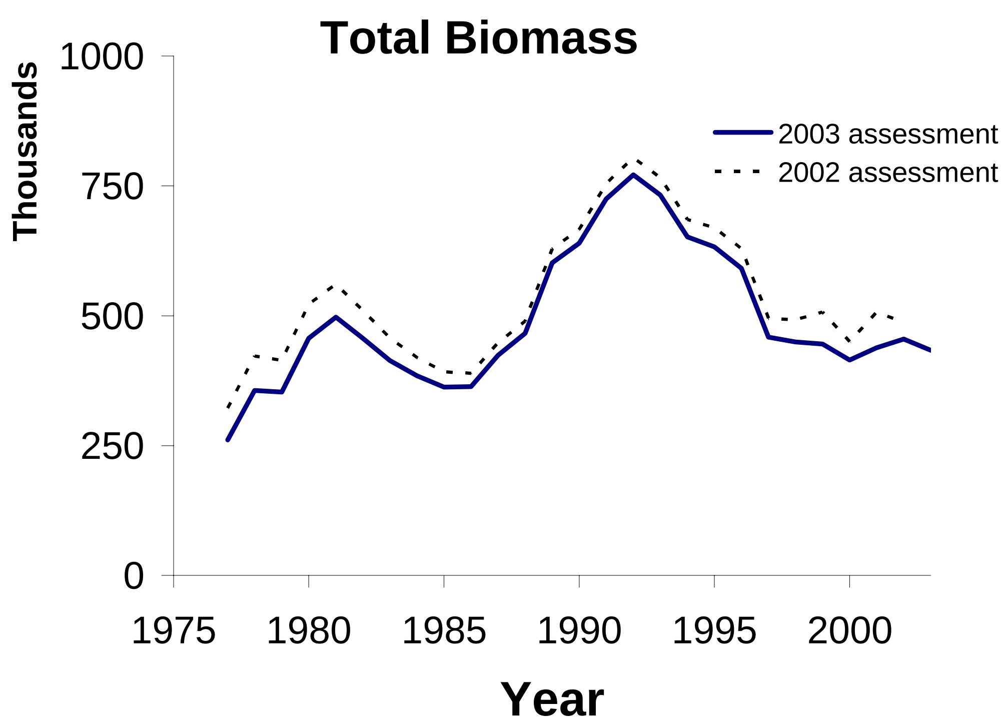
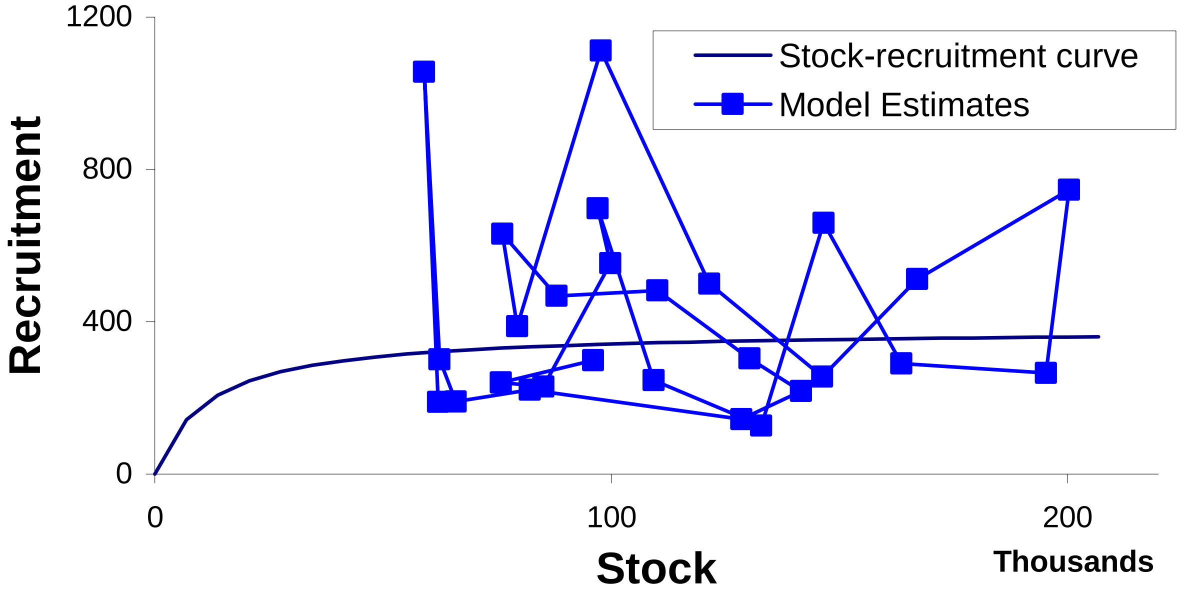


Figure 15.16. Comparison of Lowe et al.'s (2002) assessment of Atka mackerel to the current Model 2 estimate of age 3+ biomass.



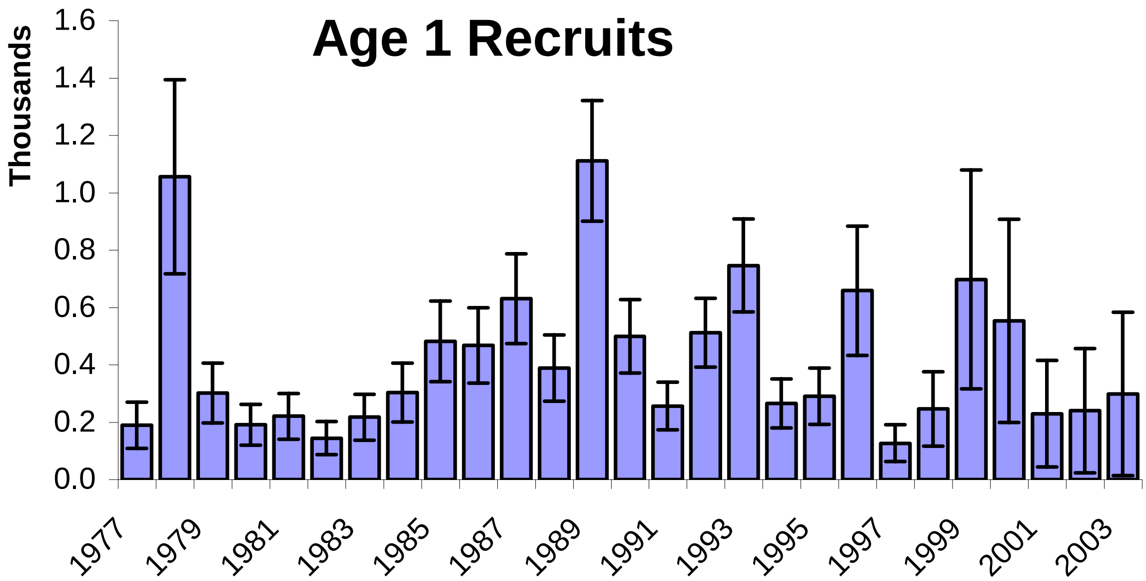


Figure 15.17. Age 1 recruitment (millions) of Atka mackerel as estimated from the current assessment for Model 2 and with error bars (lower panel) and with estimated female spawning biomass levels (top panel).

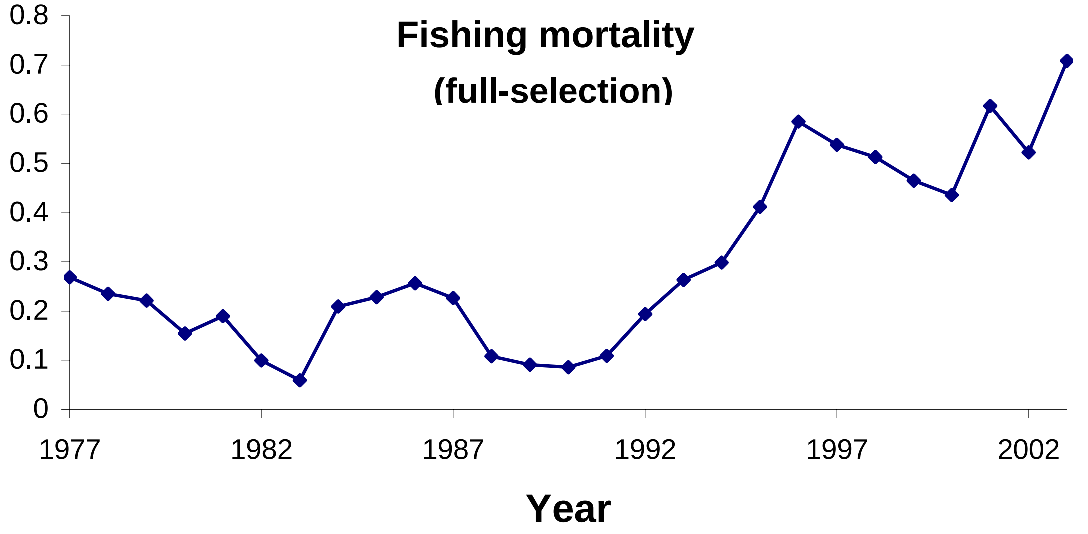


Figure 15.18. Estimated time series of full-selection fishing mortality of Atka mackerel based on Model 2, 1977-2003.

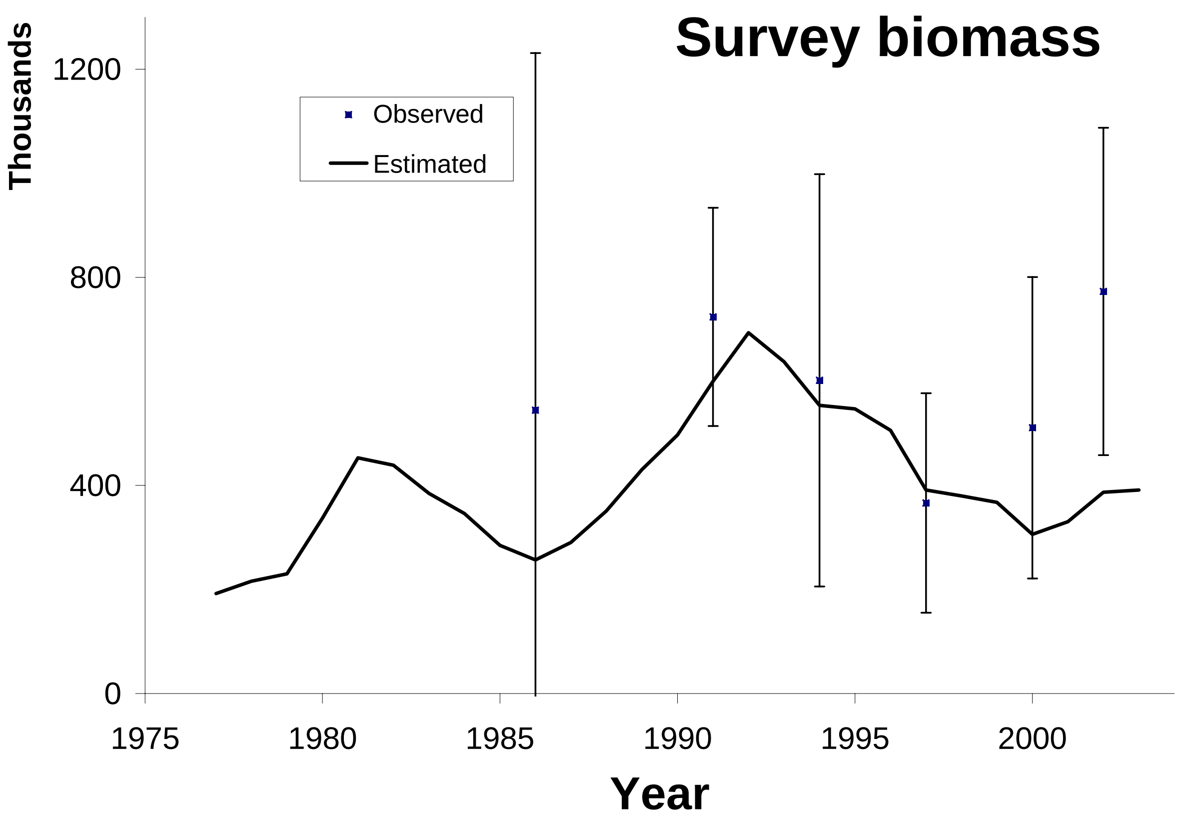


Figure 15.19. Observed and predicted survey biomass for Aleutian Islands Atka mackerel. Error bars represent two standard errors (based on sampling) from the survey estimates.

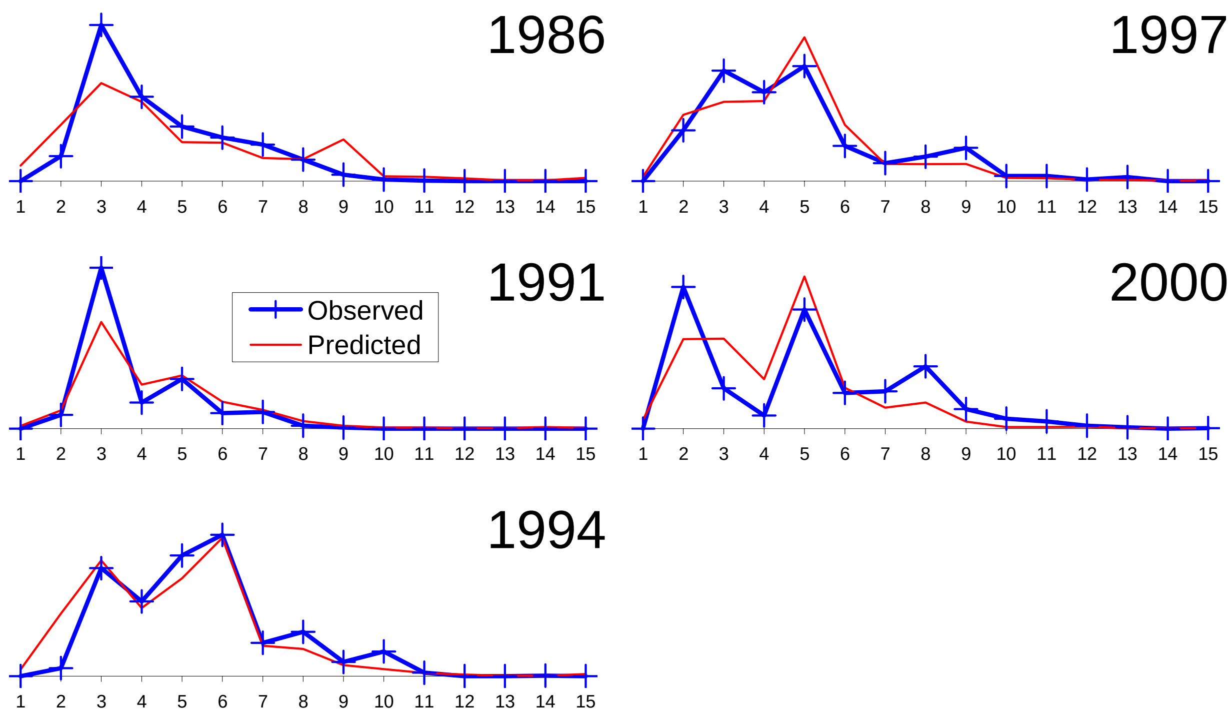


Figure 15.20. Observed and predicted fits to the available survey age composition data for Atka mackerel based on Model 2.

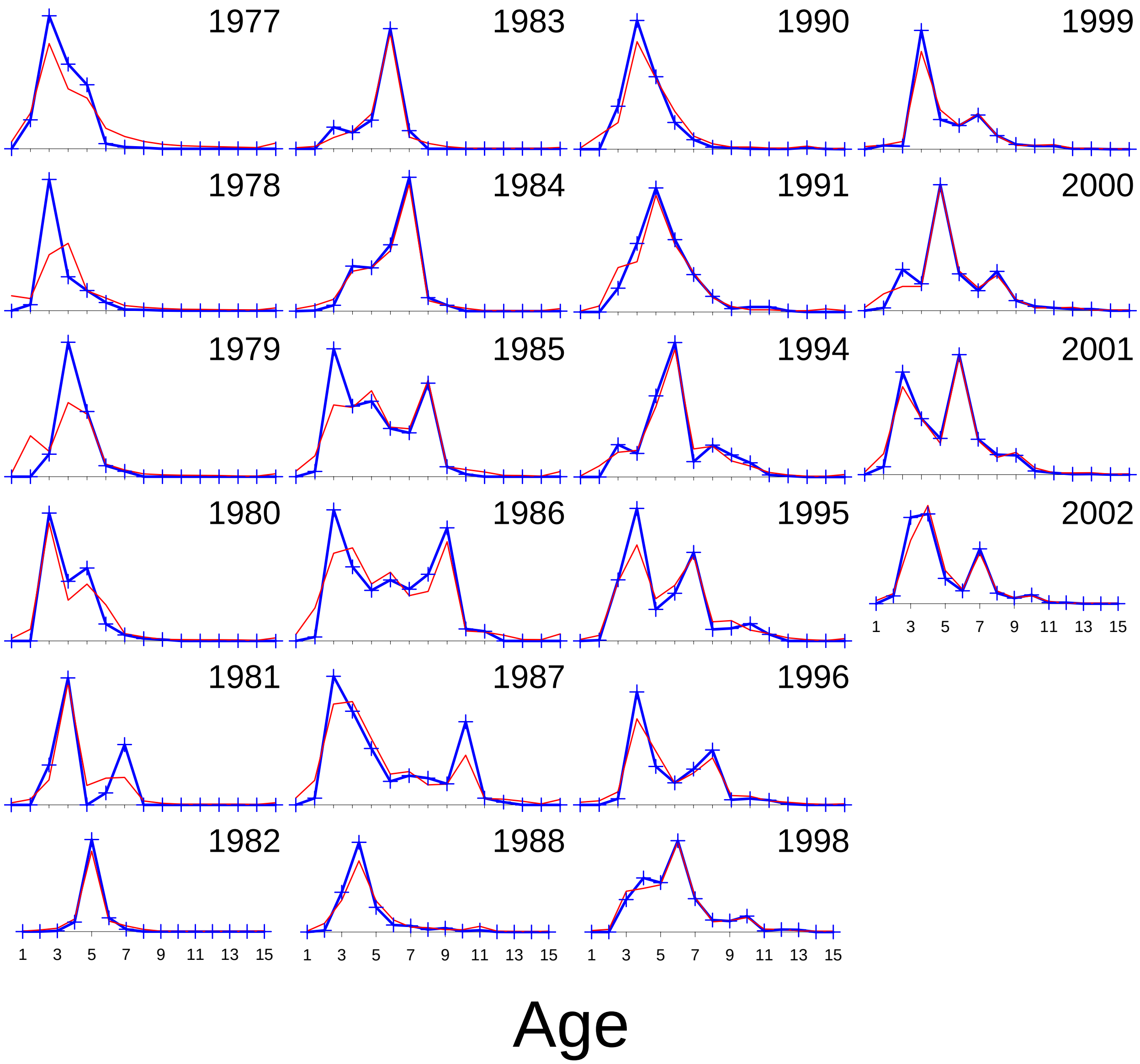


Figure 15.21. Observed and predicted fits to the available fishery age composition data for Atka mackerel based on Model 2. Continuous lines are the model predictions and lines with + symbol are the observed proportions at age.

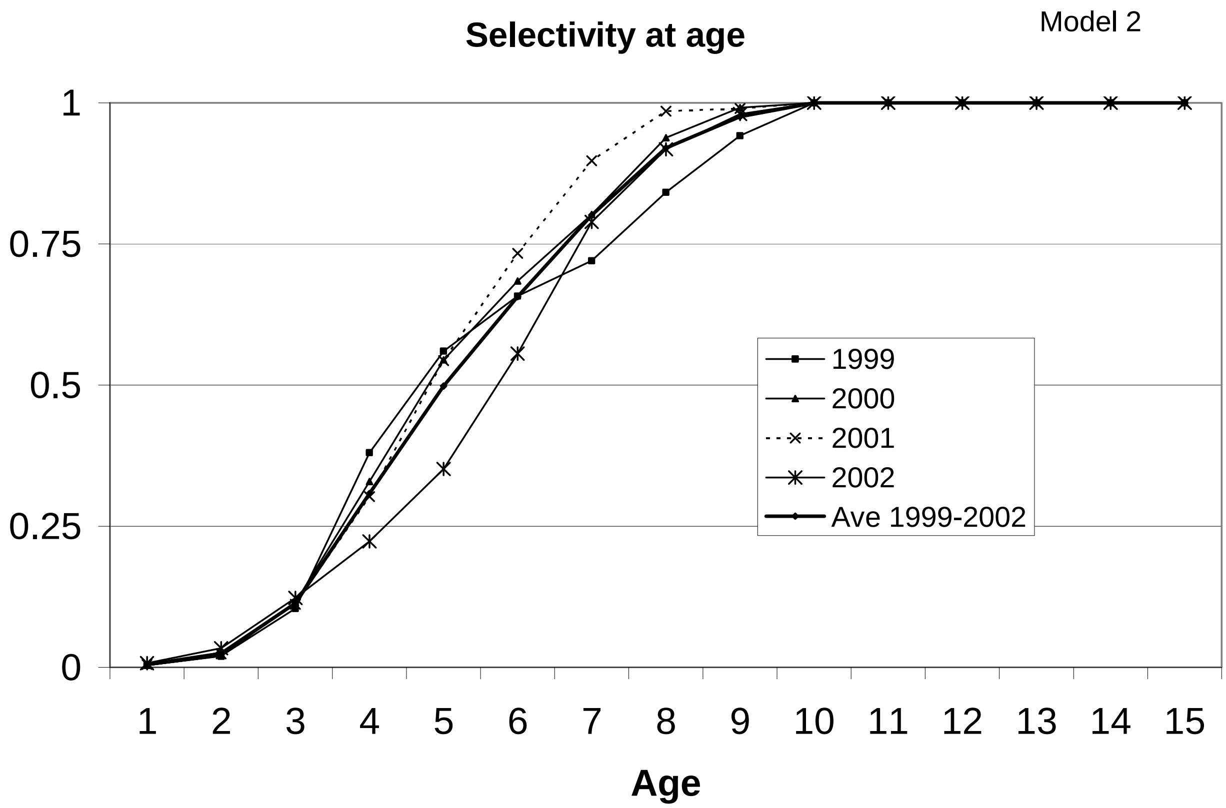


Figure 15.22. Model 2 selectivity estimates in recent years for Atka mackerel compared with the average value used for the $F_{40\%}$ calculations.

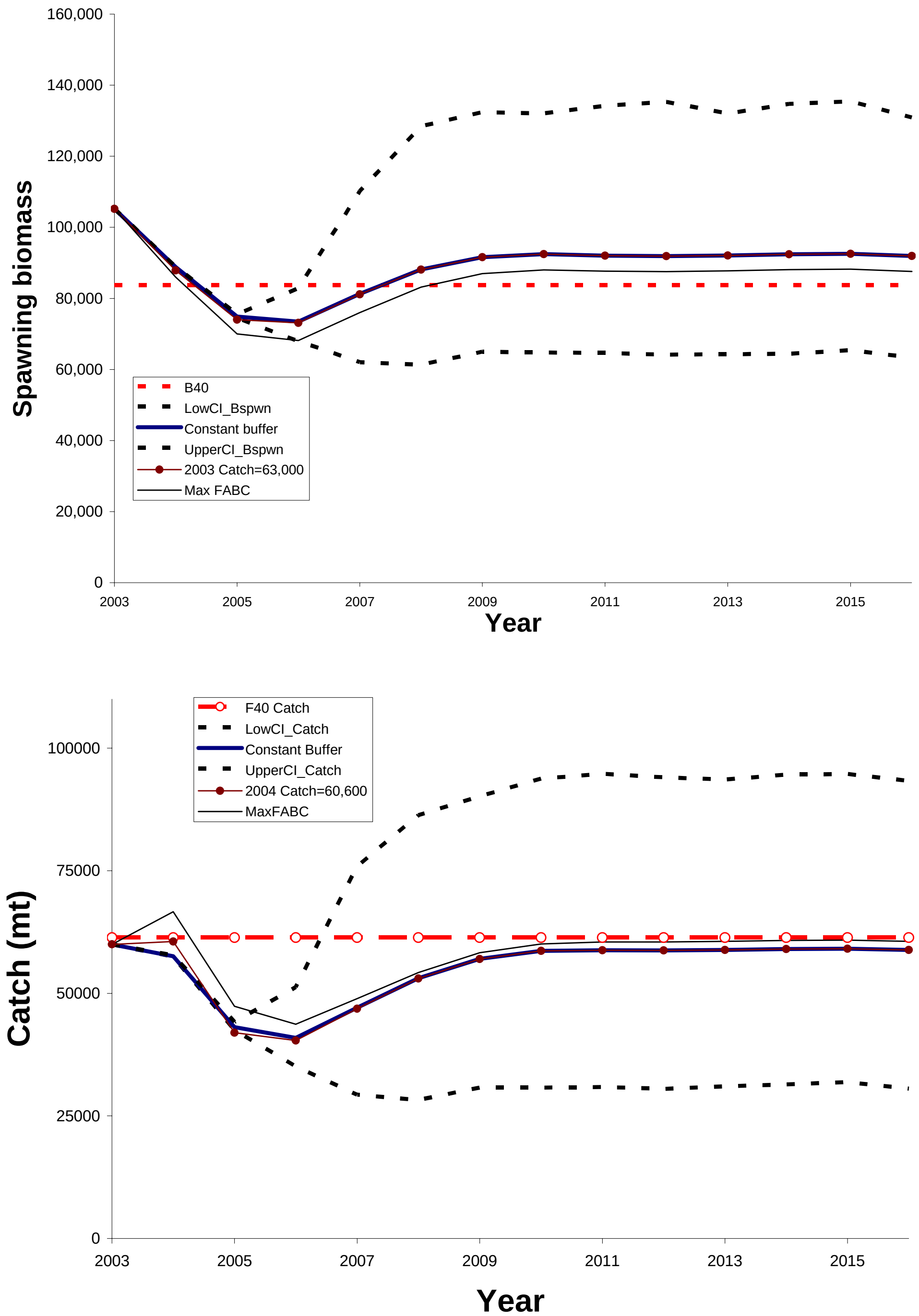


Figure 15.23. Projected spawning biomass (top) and catch (bottom) with the constant-buffer option.

Appendix 14.A

Table A-1. Variable descriptions and model specification.

General Definitions	Symbol/Value	Use in Catch at Age Model
Year index: i = {1977, …., 2002}		i
Age index: j = {1, 2, 3, …, 14, 15^+}	j	
Mean weight by age j	W_j	
Maximum age beyond which selectivity is constant	*Maxage*	Selectivity parameterization
Instantaneous Natural Mortality	M	Prior distribution = lognormal(0.3, 0.6^2)
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 , 0.2^2)
Stock-recruitment parameters	R_0	Unfished equilibrium recruitment
	h	Stock-recruitment steepness
	σ_R^2	Stock-recruitment variance
Estimated parameters		
$\phi_i(26),\ R_0,\ h,\ \varepsilon_i(40), \sigma_R^2,\ \mu^f,\ \mu^s,\ M,\ \eta_j^s(14),\ \eta_j^f(14), F_{50\%}, F_{40\%}, F_{30\%}, q^s$		

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	$\hat{Y}_i^s = q_i^s \sum_{j=1}^{15^+} s_j^s W_{ij} N_{ij}$
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	$j = 1$	$N_{1977,1} = e^{\mu_{R1977} + \varepsilon_{1977}}$
	$1 < j < 15$	$N_{1977,j} = e^{\mu_{R1978-j} + \varepsilon_{1978-j}} \prod_{j=1}^{j} e^{-M}$
	$j = 15^+$	$N_{1977,15} = N_{1977,14} \left(1 - e^{-M}\right)^{-1}$
Subsequent years ($i > 1977$)	$j = 1$	$N_{i,1} = \frac{S_{i-1} e^{\varepsilon_i}}{\alpha + \beta S_{i-1,1}}$
	$1 < j < 15$	$N_{i,j} = N_{i-1,j-1} e^{-Z_{i-1,j-1}}$
	$j = 15^+$	$N_{i,15^+} = N_{i-1,14} e^{-Z_{i-1,14}} + N_{i-1,15} e^{-Z_{i-1,15}}$
Index catchability Mean effect	μ^s, μ^f	$q_i^s = e^{\mu^s}$
Age effect	$\eta_j^s, \ \sum_{j=1}^{15^+} \eta_j^s = 0$	$s_j^s = e^{\eta_j^s}$ $j \le$ maxage $s_j^s = e^{\eta_{\text{maxage}}^s}$ $j >$ maxage
Instantaneous fishing mortality		$F_{ij} = e^{\mu_f + \eta_j^f + \phi_i}$
mean fishing effect	μ_f	
annual effect of fishing in year i	$\phi_i, \ \sum_{i=1977}^{2001} \phi_i = 0$	
age effect of fishing (regularized) In year time variation allowed	$\eta_{ij}^f, \ \sum_{j=1}^{15^+} \eta_{ij} = 0$	$s_{ij}^f = e^{\eta_j^f}$, $j \le$ maxage $s_{ij}^f = e^{\eta_{\text{maxage}}^f}$ $j >$ maxage
In years where selectivity is constant over time	$\eta_{i,j}^f = \eta_{i-1,j}^f$	$i \ne$ change year
Natural Mortality	M	
Total mortality		$Z_{ij} = F_{ij} + M$
Recruitment Beverton-Holt form	μ_{R_i}	$\mu_{R_i} = \frac{\alpha B_i}{\beta + B_i}$, $\alpha = \frac{4hR_0}{5h-1}$ and $\beta = \frac{B_0(1-h)}{5h-1}$ where $B_0 = R_0 \varphi$ $\varphi = \frac{e^{-15M} W_{15} p_{15}}{1 - e^{-M}} + \sum_{j=1}^{15} e^{-M(j-1)} W_j p_j$
Year effect, i = 1977, …, 2002	$\varepsilon_i, \ \sum_{i=1977}^{2002} \varepsilon_i = 0$	$R_i = e^{\mu_{R_i} + \varepsilon_i}$

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	$L_1 = \lambda_1 \sum_i \left(Y_i^s - \hat{Y}_i^s\right)^2 \frac{1}{2\sigma_i^2}$	Survey abundance
Smoother 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
Recruitment regularity	$L_3 = \lambda_3 \sum_{i=1977}^{2001} \varepsilon_i^{\,2} \frac{1}{2\sigma_R^2}$	Influences estimates where data are lacking (e.g., if no signal of recruitment strength is available, then the recruitment estimate will converge to median value).
Catch biomass likelihood	$L_4 = \lambda_4 \sum_{i=1977}^{2001} \ln\left(C_i / \hat{C}_i\right)^2$	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	$L_6 = \lambda_6 \sum_{i=1977}^{2001} \phi_i^2$	(relaxed in final phases of estimation)
Priors	$L_7 = \left[\lambda_7 \frac{\ln\left(M/\hat{M}\right)^2}{2 \cdot 0.05^2} + \lambda_8 \frac{\ln\left(q/\hat{q}\right)^2}{2 \cdot 0.05^2}\right]$	Prior on natural mortality, and survey catchability (reference case assumption that these are precisely known at 0.3 and 1.0, respectively).
Overall objective function to be minimized	$\dot{L} = \sum_{i=1}^{7} L_i$	

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