Section 13

ASSESSMENT OF BERING SEA/ALEUTIAN ISLANDS ATKA MACKEREL

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EXECUTIVE SUMMARY

Summary of Major Changes

Relative to the November 2000 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 2000 fishery age composition data were included.

Changes in the Assessment Methodology
1) No substantive changes were made in the assessment model.

Changes in Assessment Results
1) The mean recruitment from the stochastic projections is 502 million recruits, which gives an estimated $B_{40\%}$ level of 124,500 mt.
2) The projected female spawning biomass for 2002 is estimated at 118,000 mt.
3) BSAI Atka mackerel are in Tier 3b for the first time; the 2002 estimated female spawning biomass is below $B_{40\%}$.
4) The projected age 3+ biomass at the beginning of 2002 is estimated at 439,700 mt.
5) The addition of the 2000 fishery age composition resulted in downward revised estimates of recruitment starting in about 1990, which translated to lower estimates of biomass. Last year's assessment projected the 2001 age 3+ biomass to be 553,000 mt which compares to the estimated 2001 age 3+ biomass of 426,000 mt in the current assessment.
6) The projected 2002 yields at $F_{40\% \, adj}$ and F_{ABC} are 71,300 and 49,000 mt, respectively.
7) The **2002 recommended ABC is 49,000 mt** corresponding to $F = 0.21$.
8) The projected 2002 overfishing level at $F_{35\% \, adj}$ ($F = 0.37$) is 82,300 mt.

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

1) "While the SSC recognizes the $F_{40\%}$ value to be clearly too high", they did not accept the procedure used to provide a lower F_{ABC} in last year's assessment. The SSC recommended the $F_{52\%}$ rate that had been adopted for the 1999 and 2000 Atka mackerel ABCs.

   The current assessment recommends the $F_{52\%}$ rate be used to calculate the 2002 ABC.

2) A new TAC apportionment scheme was suggested in last year's assessment. The SSC believed the new time weighting scheme properly accounted for measurement error and recommended using this scheme.

The current assessment has adopted this approach to suggest TAC apportionment for 2002.

13.1 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.

Atka mackerel are pelagic during much of the year, but migrate annually from the lower edge of the shelf to the shallow coastal waters where they become demersal during spawning (Morris et al. 1983). While spawning, they are distributed in dense aggregations near the bottom. Spawning is reported to peak from June through September in eastern Kamchatkan waters (Musienko 1970; Morris 1981), and from July to October in Alaskan waters (McDermott and Lowe 1997). Atka mackerel are reported to deposit their eggs in rock crevices or among stones, guarded by brightly colored males until hatching (Gorbunova 1962; Zolotov 1993). The adhesive eggs hatch in 40-45 days (Musienko 1970), releasing planktonic larvae which have been found up to 800 km from shore. The first in situ observations of spawning habitat in Seguam Pass were recently (August, 1999 and 2000) documented (pers. comm. Harold Zenger and Robert Lauth, AFSC). Nest-guarding males and spawning females were observed. 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 phenotypic characteristics reflecting differences in the local environment.

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.

13.2 FISHERY

13.2.1 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 SAFE Table 3). Atka mackerel became a reported species group in the BSAI Fishery Management Plan in 1978. Catches (including discards) 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 13.1. Table 13.2 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.

13.2.2 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 utilized by the 2001 fisheries are shown in Figure 13.1.

13.2.3 Management History

In 1993, an initial Atka mackerel TAC of 32,000 mt was caught by March 11, almost entirely south of Seguam Island (Seguam Bank). This initial TAC release represented the amount of Atka mackerel which the Council thought could be appropriately harvested in the eastern portion of the Aleutian Islands subarea (based on the assessment for 1993; Lowe 1992) since there was no mechanism in place at the time to spatially allocate TACs in the Aleutians to minimize the likelihood of localized depletions. In mid-1993, however, Amendment 28 to the Bering Sea/Aleutian Islands Fishery Management Plan became effective, dividing the Aleutian subarea into three districts at 177˚W and 177˚E longitudes for the purposes of spatially apportioning TACs (Figure 13.1). On August 11, 1993, an additional 32,000 mt of Atka mackerel TAC was released to the Central (27,000 mt) and Western (5,000 mt) districts. The fishery in the Central area (542) was closed on October 29, 1993 after harvest levels reached 26,560 mt. Only 2,285 mt were landed in the Western area (543) in all of 1993; annual landings for 1993 in the eastern area (541) and the EBS totaled 36,892 mt. 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 which proposed a four-year timetable to temporally and spatially disperse and reduce the level of Atka mackerel fishing within Steller sea lion critical habitat in the Bering Sea/Aleutian Islands. The temporal dispersion is accomplished by dividing the BSAI Atka mackerel TAC into two equal seasonal allowances. The first allowance is made available for directed fishing from January 1 to April 15 (A season), and the second seasonal allowance is made available from September 1 to November 1 (B season). The spatial dispersion is accomplished through maximum catch percentages of each seasonal allowance that can be caught within sea lion critical habitat (CH) as specified for the Central and Western Aleutian Islands. No critical habitat closures are established for the Eastern subarea, but the 20 nm trawl exclusion zones around Seguam and Agligadak rookeries that have been in place only for the pollock A-season, are in effect year-round. These regulations implementing these management changes became effective January 22, 1999. The four-year timetable for spatial dispersion outside of critical habitat is:

Aleutian Island District

	Area 541		**Area 542**		**Area 543**	
Year(s)	*Inside CH*	*Outside CH*	*Inside CH*	*Outside CH*	*Inside CH*	*Outside CH*
1999			80%	20%	65%	35%
2000			67%	33%	57%	43%
2001			54%	46%	49%	51%
2002			40%	60%	40%	60%

Effective August 8, 2000, there was an injunction against all trawl fishing inside critical habitat.

13.2.4 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 fisheries. 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 anecdotal reports of high discard rates of northern rockfish in the 2001 Atka mackerel fishery. While the 2001 discard rate of northern rockfish as a total of the Atka mackerel catch is low (1%), the actual amount of northern discards (716 mt) is about 11% of the 2001 BSAI northern TAC (6,760 mt). The amount of northern rockfish discarded in the Atka mackerel fisheries in 1997, 1998, 1999, and 2000 were 238 mt, 585 mt, 804 mt, and 1,398, respectively.

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	

*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).

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):

	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	14,307	18,036	15,008
Retained (mt)	258	2,556	1,197
Discarded (mt)	2%	12%	7%
Rate			
2000			
Retained (mt)	13,798	20,720	9,458
Discarded (mt)	163	1,484	742
Rate	1%	7%	7%

13.2.5 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 1999-2001 fisheries by location are shown in Figures 13.2-13.5. Length frequency distributions from the 1999 fishery by area and fished are shown in Figure 13.2. The mode centered around 37 cm in the 1999 541 A season distribution represents 4 year-old fish from the 1995 year class. By the B season (September), this mode was centered at 41 cm and the bimodal distribution had disappeared. The recruitment of the 1995 year class was confirmed by the 1999 fishery age composition (Figure 13.3) which was dominated by the 1995 year class in all three management areas.

Length frequency distributions from the 2000 fishery by area and season fished are shown in Figure 13.4. The B season reflects the fishery entirely outside of critical habitat, as there was an injunction on all trawl fishing inside critical habitat effective August 8, 2000. The modes in all areas are comprised mostly of the 1995 year class. The A and B season fisheries at Buldir-Tahoma reef and at Petral Bank were similar. A slightly greater proportion of larger fish were caught during the B season in Seguam. This area was probably the least affected by the injunction as trawl fishing has been prohibited year round in the 20 nm trawl exclusion zones around Seguam and Agligadak rookeries; areas which encompass much of critical habitat in 541. There was only an A season fishery conducted at the Stalemate, Kiska, and Amchitka locations. There was some fishing effort off the Delarof Islands in the B season, but too few specimens were collected for length frequency composition.

Preliminary length frequency distributions from the 2001 fishery by area and season fished are shown in Figure 13.5. The A and B season fisheries at Near Islands, Amchitka, and Petral Bank were similar. There were modes in the length distribution of fish from the B season fishery between 30 and 35 cm at Buldir-Tahoma and Kiska, which may be comprised of 3 year old fish of the 1998 year class. The modes at 35 cm and 37 cm at Delarof Islands and Seguam Bank respectively, may be 4 year old fish from the 1997 year class. The 2001 fishery age data are not yet available.

13.2.6 Steller Sea Lions, Atka mackerel, and the Fishery

The western stock of Steller sea lions (defined as west of 144˚W at Cape Suckling) is currently listed as endangered under the Endangered Species Act, and had been listed as threatened since 1990. In 1991-92, 10 nm year-round trawl exclusion zones were established around all rookeries west of 150˚W; in 1992-93, 20 nm trawl exclusion zones were established around 6 rookeries in the eastern Aleutian Islands that are operational only during the BSAI pollock A-season. Two of the 20 nm zones are located within the Aleutian 541 management district, those around Seguam and Agligadak Islands (Figure 13.1). In 1993, NMFS designated Steller sea lion critical habitat, which includes a 20 nm aquatic zone around all rookeries and major haulouts west of 144˚W, and three foraging areas, one of which is located around Seguam Pass. Sea lion food habits data collected in the Aleutian Islands revealed that Atka mackerel was the most common food item of adults and juveniles in summer (NMFS 1995) and winter (Sinclair and Zeppelin, in press).

Since 1979, the Atka mackerel fishery has occurred largely within areas designated as Steller sea lion critical habitat. 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.

To address the possibility that the fishery creates localized depletions of Atka mackerel and adversely modifies Steller sea lion critical habitat by disproportionately removing prey, the Council passed the fishery management regulatory amendment described in Section 13.2.3 in June 1998. As a result of this

NMFS/Council action, the U.S. District Court, Western District agreed with NMFS' conclusion that the Atka mackerel fishery, as modified by this regulatory amendment, was not likely to jeopardize the continued existence of the Steller sea lion nor adversely modify its critical habitat.

NMFS is investigating the efficacy of trawl exclusion zones as a fishery-Steller sea lion management tool, and trying to determine the local movement rates of Atka mackerel through tagging studies. In August 1999, the AFSC conducted a pilot survey to explore the variance in survey catches of Atka mackerel and the feasibility of tagging as methods to determine small-scale changes in abundance and distribution. The tagging work was very successful and a dedicated tagging survey was conducted again in August 2000 and 2001 in the closed and open areas of 541. This was followed by a tag recovery survey conducted in the closed area of 541 in September 2000; a recovery effort is also planned for 2001.

13.3 DATA

13.3.1 Fishery Data

Fishery data consist of total catch biomass from 1977 to 2001 (Table 13.1), and the age composition of the catch from 1977-2000 (Table 13.3). 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. Therefore, the 1980 survey age-length key was used to estimate the 1980 commercial catch age distribution, and these data were further used to estimate the 1981 commercial catch age distribution using 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. Thus, the 1989, 1992, 1993 and 1997 fishery length frequency data were used directly in stock synthesis and fitted simultaneously with the time series of catch-age data. Length frequency data were converted to ages within the model using a transition matrix. The transition matrix for length data was defined from a von Bertalanffy growth function of the form:

$$L_t = L_\infty + (L_1 - L_\infty) * \exp(-K(t-1))$$

Where L_∞ is the asymptotic length, L_1 is the mean size at age 1, and K is the growth parameter. Parameters for this equation were estimated from the 1986, 1991 and 1994 age-length data collected from the surveys.

Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Length (cm)	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34

Bin	16	17	18	19	20	21	22	23	24	25
Length (cm)	35	36	37	38	39	40	41-45	46-50	51-55	56-64

The most salient features of the estimated catch-at-age (Table 13.3) are the strong 1975 and 1977 year classes, and the appearance of a large number of 4-year-olds in 1988, 1992, 1995, 1996, and most recently in 1999 representing the 1984, 1988, 1991, 1992 and the 1995 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 length frequency data from the 1988 foreign fishery, correspondingly showed a large drop in the mean length as the 1984 year class appeared in large numbers. This year class did not continue to show up strongly after 1988 in the domestic fisheries. 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 13.3)

It is interesting to note that before 1984, catches consisted of fish less than 7 years old. Since 1984, 7+ year-old fish have made up a significant portion of the catches. It is not known if there has been an increase in the numbers of older fish, or if they were previously unavailable to the fishery.

13.3.2 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, and 2000 domestic surveys, provide the only direct estimates of population biomass from throughout the Aleutian Islands region.

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 13.4). 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 13.4), 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 2000 Aleutian Islands bottom trawl survey is 510,900 mt, up about 40% relative to the 1997 survey estimate (Table 13.5). Previous to this, the 1997 Aleutian Islands bottom trawl survey biomass estimate of 366,300 mt, was down about 50% and 40% relative to the 1991 and 1994 survey estimates, respectively (Table 13.5). The breakdown of the Aleutian biomass estimates by area corresponds to the management districts (541-Eastern, 542-Central, and 543-Western). The increase in biomass in the 2000 survey all occurred in the Western and Central areas; biomass in the Eastern area was slightly less than 1000 mt in the 2000 survey. Relative to the 1997 survey, the 2000 biomass estimates are up 34% in the Western area, up 77% in the Central area, and down 98% in the Eastern area (Figure 13.6). The 98% decline in the Eastern area follows a 78% decline in the 1997 survey relative to the 1994 survey. The 95% confidence intervals about the mean total 1991, 1994, 1997, and 2000 Aleutian biomass estimates are 475,860-971,975 and 201,701-1,002,621 mt, and 146,296-586,331 and 214,779 -806,934 mt, respectively. The coefficient of variation (*CV*) of the 2000 mean Aleutian biomass is 28%, consistent with the *CV*s from the 1994 and 1997 surveys, as are the *CV*s by area for these surveys (Table 13.5).

The distribution of biomass in the Western, Central, and Eastern Aleutians, and the southern Bering Sea shifted between each of the 1991, 1994, 1997, and 2000 surveys, and most dramatically in area 541 in the 2000 survey (Figure 13.6). In 1994 for the first time since the initiation of the Aleutian triennial surveys, a significant concentration of biomass was detected in the southern Bering Sea area (66,600 mt) and again in 1997 (95,700 mt, Table 13.5). This was attributed to a large catch from a single haul encountered north of Akun Island in 1994 and in 1997. In both 1991 and 1994, the Western area contributed approximately half of the total estimated Aleutian biomass, but dropped to 37% in 1997 and 35% in 2000. In 1994, 14% of the Aleutian biomass was found in the Central area compared to 40% in 1991 and up to 51 and 65% in the 1997 and 2000 surveys, respectively. The contribution of Eastern area biomass from the 1997 survey (12%) was down relative to 1994 (35%), but consistent with the 1991 distribution (11%). The 2000 541 biomass estimate (900 mt) was the lowest of all surveys, contributing only 0.2% of the total 2000 Aleutian biomass.

The area specific variances for area 541 have always been high relative to 542 and 543; the distribution of Atka mackerel in 541 is patchier. The extremely low 2000 biomass estimate for 541 has not been reconciled, but there are at least three factors that may have had a significant impact on the distribution of Atka mackerel in 541: 1) The survey started 3 weeks earlier in May 2000 relative to past surveys which have started in June. Atka mackerel are summer spawners and presumed to distribute themselves differently in the spawning months, becoming more demersal and forming dense aggregations near bottom. A start date in May may have been early enough such that the fish were not distributed in their typical summer spawning mode and habitat; 2) 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 13.7). The low temperatures could have impacted the distribution of Atka mackerel and/or their food source, however, temperatures were significantly lower in the 2000 survey throughout the Aleutians. Atka mackerel in the 2000 survey were found to weigh less for a given age compared to the 1994 and 1997 surveys, suggesting a food related impact in 2000; 3) The sampling in 541 occurred at an extreme high tide; Atka mackerel are thought to be very responsive to tide cycles. During extremes in the tidal cycle, Atka mackerel may not be accessible (pers. comm., Harold Zenger, AFSC). Perhaps the combination of these factors coupled with the typically patchier distribution of 541 Atka mackerel impacted the distribution of the fish such that they were not available at the surveyed stations at the time of the survey in 541.

The survey was able to go back and resample a few stations that historically have had high Atka mackerel catch rates in 541. The lack of biomass as sampled by the survey was corroborated at these resampled stations. The very low survey catch rates in 541 in May, were subsequently not encountered by the 2000 B season fishery or the 2000 August and September Atka mackerel tagging surveys. There is no evidence to suggest that the survey vessels were not sampling properly in 541, rather we presume that the availability of fish in 541 at the time of the survey was different. There is also no evidence to suggest that fish in 541 migrated to adjacent areas in 542. Area specific growth relationships which have been substantiated to be significantly different by area (Kimura and Ronholt 1988, Lowe et al. 1998) were examined and compared with previous years and found to be consistent. Also, short term tagging data from the late 1980s and the 1999 and 2000 studies have not shown any evidence of large scale movements. Appendix 1 examines the distribution of historical Atka mackerel survey data. Simulation results show that it is very possible to underestimate the true biomass when the target organism has a very patchy distribution (E. Conners, Appendix 1).

Virtually all (>99%) of the Atka mackerel biomass in the trawl surveys has been encountered in the 1-200 m depth strata, however, the proportions in the 1-100 m and 100-200 m strata differ among years (Table

13.5). The only thing consistent about Atka mackerel biomass as sampled by the surveys, is that the estimates are highly variable over depth, area, and survey year. Given that the variability associated with the overall 2000 Aleutian biomass estimate is consistent with previous surveys, and the area specific variance associated with area 541 biomass estimate is also consistent with previous surveys, we accepted the overall 2000 Aleutian biomass estimate. Areas with large catches of Atka mackerel during the 1994 survey included south of Buldir Island, north of Akun Island, Seguam Pass, southwest of Atka Island, Stalemate Bank, and south of Amchitka Island. In the 1997 survey, areas with large catches were located north of Akun Island, southwest of Tanaga Island, west of Rat Island, Buldir Island, and Stalemate Bank. In the 2000 survey, areas with large catches were located in Tanaga Pass, south of Amchitka Island, and at Kiska.

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: 0.33, 0.29, and 0.28 from the 1994, 1997 and 2000 AI surveys, respectively, compared with 0.61, 0.99, 0.40, and 1.00 from the 1993, 1996, 1999 and 2001 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% and 33% of the hauls in the 1991, 1994, 1997, and 2000 AI surveys, compared to 5%, 28%, 12%, 20% and 10% of the hauls in the Shumagin area in the 1990, 1993, 1996, 1999, and 2001 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 1994, 1997, and 2000 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 13.8). This pattern is also apparent in the fishery data (Figures 13.2-13.5). In 1994 and 1997, the survey found smaller fish in the Western area than did the fishery, while the size distribution of their catches were more similar in the Central area (Figure 13.8). This compares with the 2000 survey where the survey caught larger fish in the Central area. The 1997 survey also found larger Atka mackerel than the fishery in the Eastern area. 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. 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 moves offshore to 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 13.9a).

Survey Age Frequencies

The age compositions from the 1991, 1994, 1997 and 2000 Aleutian surveys are shown in Figure 13.9. 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 a strong 1992 and 1995 year class, and a very strong showing of 2 year olds from the 1998 year class. 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 13.9b). 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.

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.

Survey Abundance Indices

Two time series of survey data are used in the age-structured model: 1) relative indices of abundance with the associated standard errors, and corresponding age compositions from the 1980, 1983, 1986, and 1991 Aleutian Islands surveys; and 2) absolute estimates of abundance with the associated standard errors, and corresponding age compositions from the 1986, 1991, 1994, 1997, and 2000 surveys. These data sets were incorporated into the model to calibrate the estimated abundance to the appropriate level. The relative indices of abundance exclude biomass from the 1-100 m depth strata of the Southwest region due to the lack of sampling in this strata in some years.

13.3.3 Weight at Age Data

Separate weight-at-age vectors were estimated for the fishery and survey data sets (Table 13.6). The survey vector was estimated with 1986, 1991, and 1994 survey data, and the fishery vector was estimated with 1990-1996 fishery data.

13.4 ANALYTIC APPROACH

13.4.1 Age-Structured Modeling Approach

The stock synthesis model described by Methot (1989, 1990) was used to assess the status of Aleutian Islands Atka mackerel as in previous assessments, given a delay in conversion to AD Model Builder software. This approach to catch-at-age analysis was designed to incorporate diverse auxiliary information, and follows the maximum likelihood approach described by Fournier and Archibald (1982). The model is structured to simultaneously analyze catch biomass, age composition and effort from multiple fisheries, and abundance and age composition from multiple surveys (Methot 1990).

In the stock synthesis model deviations between the observations and the expected values are quantified with a specified error model and cast in terms of log-likelihood. The overall log-likelihood (L) is the weighted sum of the calculated log-likelihoods for each type of data or component. The emphasis factors (the component weights) should all be equal to 1 in a perfectly specified model. These emphasis factors are subjectively adjusted to distinguish those components which may be subject to greater error (i.e. those components in which less confidence is placed). Numerical estimation of the derivative of L with respect to small changes in each parameter is used in an iterative approach to maximization of L (Methot 1990).

The basic equations describing the population dynamics are given below:

a	age
y	year
j	fishery or survey
M	instantaneous natural mortality rate
m_a	proportion of mature females at age a
W_{aj}	body weight-at-age for fishery or survey j
s_{aj}	selectivity at age for fishery or survey j
f_y	annual fishing mortality factor
$F_{ya} = f_y s_a$	fishing mortality at age
$Z_{ya}=M + \sum_j(F_{ya})$	total fishing mortality rate
$N_{y+1,a+1}=N_{ya}e^{-Z_{ya}}$	population numbers at age at the beginning of year y
$c_{ya}=[N_{ya}(1-e^{-Z_{ya}})/Z_{ya}]F_{ya}$	catch in numbers at age for year y
$C_{yj} = \sum_a(c_{yaj}W_{aj})$	catch biomass in year y for fishery or survey j
$B_y=N_{ya}\ W_{aj}$	population biomass in year y
$S_y= 0.5\sum_a(N_{ya}\ W_{aj}\ m_a)$	female spawner biomass in year y

13.4.2 Model Assumptions

Some of the basic assumptions of the stock synthesis model are: 1) Catch-at-age (c_{ya}) is modeled by the Baranov catch equation; 2) Catch biomass is measured with much greater precision than other types of data, thus in stock synthesis, the level of fishing mortality is calculated so that the estimated catch biomass matches the observed catch biomass; and 3) Fishing mortality is separable into a year-dependent factor and an age-dependent factor.

In addition to these basic assumptions, the following assumptions specific to Atka mackerel were used in this configuration of stock synthesis: 1) Natural mortality is equal to 0.3 and is constant for all ages and years; 2) There are 2 time series of survey data. Survey data which exclude the 1-100 m depth strata in the Southwest region represent an index of relative abundance, and the absolute estimates of abundance include all data from the 1986, 1991, 1994, 1997, and 2000 surveys. 3) Survey catchability associated with estimates of absolute biomass is fixed at 1.0, and the catchability of the relative index of abundance is estimated within the model. 4) Survey selectivities are estimated from the survey age compositions; and 5) There is 1 fishery which is separated into 2 time periods 1972-1983 and 1984-2000. Thus, the fishery selectivity-at-age vectors are estimated for two different time periods. The rationale for this is that prior to 1984 the fishery basically consisted of fish 2-7 years old and was harvested by the foreign fishery. The oldest fish during this time period was 9 years old (Table 13.3). After 1983, fish greater than 7 years old appeared in the fishery (maximum of 15 years old from the 1994 fishery), and the fishery was prosecuted by domestic fishermen.

Exploratory model runs were made incorporating a third time period with the years 1999 and 2000 to explore the impacts of Steller sea lion regulations. Preliminary results showed lower selectivity at age after age 5, and similar biomass and recruitment trends with a marginal increase in the overall fit of the test model compared to the standard assessment model. Initial results based on only 2 years of fishery data were considered too preliminary. A new model will be presented next year that incorporates the 2001 fishery age data and more fully explores the addition of a third time period to look at the impacts of the recent Steller sea lion regulations.

13.4.3 Model Components

The likelihood components and the corresponding emphasis factors used in this analysis are listed below:

Likelihood component	Emphasis
Catch biomass	1
Catch age composition	1
Catch length composition	1
Survey biomass (indices)	1
Survey age comp. (indices)	1
Survey biomass (absolute)	1
Survey age comp. (absolute)	1
Stock recruitment-individual	1
Stock recruitment-mean	1

In previous assessments, survey estimates of absolute biomass had a high emphasis (10) in order to tune the model to those levels of abundance. In the 1996 assessment, a sensitivity analysis of the absolute survey emphasis factor was conducted which led to the selection of an emphasis of 1 for absolute survey biomass (Lowe and Fritz 1995). The stock recruitment-individual component relates to the deviations between the individual recruitment estimates and the predicted values from the stock recruitment curve. The stock recruitment-mean component relates to the deviation between the stock recruitment curve parameters and the mean and variance of the individual recruitment estimates. The stock recruitment-mean component ensures that the expected value of the recruitment curve is consistent with the average of the individual recruitment estimates. In previous assessments with a single stock recruitment component, this component was de-emphasized (0.01) in order to allow for individual recruitment variability each year. Adding emphasis on the former stock recruitment component was overly restrictive on allowing for individual recruitment variability, e.g., with higher stock recruitment emphasis, recruitment variability approached zero. The stock recruitment mean component allows the underlying model to remain consistent with the average estimated recruitment without sacrificing recruitment variability. Thus, the emphasis on the two stock recruitment components were set to 1.

13.4.4 Parameters

13.4.4.1 Parameters Estimated Independently

Natural Mortality

Natural mortality (*M*) is a very difficult parameter to estimate. The regression model of Hoenig (1983) which relates total mortality as a function of maximum age, was used to estimate *M*:

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

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 this assessment.

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). Differential mortality at age was explored in the 1999 assessment (Lowe and Fritz, 1998), and is summarized in Section 13.5 Model Evaluation.

<u>Length and Weight at Age</u>

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). 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 were analyzed by six areas. It appeared that length at age was smallest in the west and largest in the east.

Analysis of variance (ANOVA) was used to evaluate these differences statistically. The analyses indicated that length at age did not differ significantly by sex, so that factor was ignored in further analyses. Results showed that the area and age effects were both significant, but the year effect was not quite significant. The area effect appeared much stronger than the age effect and all interactions were significant.

Further analysis to determine whether the area differences could be expected to remain consistent over the years demonstrated that the differences in growth between areas is probably a real phenomenon rather than just a chance sampling of years.

Kimura and Ronholt (1988) estimated parameters of the von Bertalanffy length-age equation and a weight-length relationship using Aleutian Islands survey data from the 1980, 1983, and 1986 surveys. Sexes were combined in the analysis as sex was not determined to be an important differentiating variable for Atka mackerel growth. These parameters have also 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
Early surveys			
Areas combined	41.4	0.311	-1.23
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 combined 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 (Figure 13.10).

The weight-length relationships determined from the early (1980, 1983 and 1986) and recent (1986, 1991, and 1994) surveys are similar:

weight (kg) = 4.98E-06 * length (cm) $^{3.2403}$ (early surveys; N=899)
weight (kg) = 9.08E-06 * length (cm) $^{3.0913}$ (recent surveys; N=1,052)

Weight-length data collected from the 1990 to 1996 domestic fisheries were also used to estimate a weight-length relationship:

weight (kg) = 3.72E-05 * length (cm) $^{2.6949}$ (N=4,041).

The observed differences in the weight-length relationships from the survey and recent 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 recent fishery data were collected primarily in winter, when gonad weight would be a smaller percentage of total weight than in summer.

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 subareas:

	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 13.7.

13.4.4.2 Parameters Estimated Conditionally

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

Fishing Mortality

The time series of fishing mortalities ($F_{ya} = f_y s_a$) on fully selected age groups ($s_a = 1$) are estimated within the model. The level of the annual fishing mortality factor (f_y) is adjusted within the model so that the estimated catch biomass matches the observed catch biomass.

Selectivity

The patterns of selectivity-at-age of the 2 time series of survey data are modeled as the product of 2 logistic functions:

$$S_a = \frac{T_1}{\left(1 + e^{-P_1(a - P_2)}\right)\left(1 + e^{P_3(a - P_4)}\right)}$$

where s_a is selectivity at age, P_1 relates to the slope of the first function, P_2 is the inflection age for the first function, P_3 relates to the slope of the second function, P_4 is the inflection age of the second function, and T_1 is a function of P_1, P_2, P_3, and P_4 which scales maximum selectivity to 1.

The fishery selectivity pattern (which is estimated for 2 time periods) is a 7-parameter dome-shaped relationship, which in addition to using the 4 parameters above, specifies a transition age at which the transition from the ascending to the descending side of the function occurs, a selectivity at the minimum age, and a selectivity at the maximum age. The following parameters are allowed to change between time periods: the transition age, the selectivity of the maximum age, the inflection age of the descending limb, and the slope of the descending limb.

Survey Catchability

Catch-per-unit-effort for survey *j* in year *y* (G_{yj}), is expected to be proportional to the model's estimate of available biomass, B_{yj}, at the time of the survey:

$$G_{yj} = Q_j B_{yj}$$

where Q_j is the catchability coefficient. For surveys that are expanded to a measurement of absolute biomass, the scaling factor (catchability coefficient) is assumed to be known. In the case where survey CPUE is interpreted as a relative index of population biomass, the scaling factor is calculated so that the mean log deviation is zero:

$$Q_j = \exp\left(\frac{\sum_y \ln\left(G_{yj} / \hat{G}_{yj}\right)}{n} \right)$$

where the summation is over years (*y*) and *n* is the number of years. Catchability for the absolute abundance survey time series is assumed to be 1.0, and catchability for the relative index survey time series is estimated within the model.

13.5 MODEL EVALUATION

13.5.1 Past Assessment Model Evaluations

The sensitivity of the model output (total and component likelihoods, ending biomass, and recruitment and biomass trends) to changes in three key model elements was explored in the 1996 assessment (Lowe and Fritz 1995). The three elements were the selectivity at age of both the fishery and absolute surveys, the natural mortality estimate, and the emphasis factor on the absolute survey biomass component.

Estimates of selectivity and natural mortality are confounded parameters. In the 1996 stock assessment, no maxima in relative likelihoods were observed when fishery (or survey) terminal (oldest age) selectivity varied from 0.1 to 1, while at the same time fixing the survey (or fishery) terminal selectivity at 0.1 and allowing the model to estimate *M* (Lowe and Fritz 1995). In both cases, the ability of the model to fit the catch or survey age composition degraded and *M* increased to > 0.4 with increasing terminal selectivities. Thompson (1994) showed that fixing *M* at it's expected value is generally a safer strategy than allowing *M* to be estimated by assuming asymptotic selectivity. Based on these sensitivity analyses, it was determined that the model structure that best fit the data (highest total likelihoods) and provided the most reasonable biomass trend was one that had dome-shaped selectivities for both the surveys and fisheries (Lowe and Fritz, 1995).

There are rationale based on Atka mackerel life history characteristics and the operation of the fishery for survey and fishery dome-shaped selectivities for Atka mackerel. The surveys have been conducted solely in the summer, when some mature Atka mackerel move into shallow waters for spawning (Zolotov 1993;

Fritz and Lowe 1998). Consequently, nest-guarding males and spawning females, the largest and oldest part of the population, would likely be less available to the survey trawl gear (due to difficulties in sampling the nearshore rocky, high current areas utilized by spawning Atka mackerel) than the smaller and younger portions of the population. Spawning and nest-guarding were observed (by divers and in *in situ* video) off Seguam Island in August 1999 and 2000 (pers. comm., Robert Lauth, AFSC). This could lead to the estimation of dome-shaped survey selectivities. With regard to the fisheries, the early fisheries (1977-83) were also conducted solely in the summer; hence, much of the same rationale used to explain the dome-shaped survey selectivities applies to the early fisheries. The late fisheries (1984-present) have the highest selectivities on fish older than 8 years relative to the surveys and the early fishery. This could be attributed to increased fishing effort in winter, when the Atka mackerel population appears to be less segregated by sex and age than in summer. While this would tend to increase the selectivities on the older fish, there is still considerable summer fishing data from 1984 to the present averaged into the estimation of a single fishery selectivity curve from this period which could lead to dome-shaped selectivity.

At the time of development of the first stock synthesis model (Lowe, 1991), only the 1986 and 1991 biomass estimates were available and were weighted heavily (emphasis factor of 10) to insure that the model would closely approximate these levels; stock synthesis could not simultaneously fit both the 1986 and 1991 survey biomass estimates (Lowe, 1991). A subsequent re-analysis of the absolute survey biomass emphasis factor (which included the 1994 survey biomass estimate) showed that increasing the emphasis factor from 1 to 10 had a negligible effect on the model fit and only a small effect on ending biomass, thus the emphasis on the absolute survey time series was set at 1 (Lowe and Fritz 1995).

13.5.2 Evaluation of Current Model

An evaluation of alternative models was undertaken in the 1999 assessment (Section 12.5.2 in Lowe and Fritz, 1998). The 1998 baseline model configuration (described above in Section 13.5.1) denoted Model A, included fishery data from 1997 and 1998. Three alternative models were explored which analyzed: changing the starting year (Model B), estimating survey catchability of the absolute abundance time series (Model C), and differential natural mortality at age (Model D). A summary of the evaluation follows.

The estimation of survey catchability and natural mortality (Models C and D, respectively) had a significant impact on ending biomass (Lowe and Fritz, 1998). The estimation of catchability in synthesis is problematic in that 1) it is highly confounded with selectivity, and 2) the estimation of catchability assumes equivalent standard errors for the survey time series, an assumption which is not met. The estimation of natural mortality in synthesis is also problematic due to the confounding of selectivity and natural mortality. These issues and the added uncertainty they present are currently being explored with alternative models.

Model B was selected as the final model configuration based on the assumptions that constant natural mortality equal to 0.3 and absolute survey catchability of 1.0 are reasonable given the current difficulties in estimating M and Q simultaneously with selectivity (Lowe and Fritz, 1998). Model B was updated in the current assessment with 2000 fishery catch biomass and age composition.

13.6 MODEL RESULTS

13.6.1 Selectivity

The estimated selectivity at age schedules for the fishery and surveys are shown in Figure 13.11 and given in Table 13.8. The fishery basically consists of fish 3-12 years old, although a 15-year-old fish was found in the 1994 fishery. Estimated selectivity for the fishery and particularly for the survey data, are dome-shaped with steep ascending and descending limbs (Figure 13.11). Survey catches were mostly comprised of fish 3-8 years old (Figure 13.11). A 14-year old fish was found in the 1994 survey and a 15-year old fish was found in the 2000 survey, accounting for the low selectivity out to age 15 for the absolute surveys (Figure 13.11c). The estimated selectivities of 3-year-old fish from the 2 types of survey data are quite different (Figure 13.11b,c). Data from the 1-100 m depth interval apparently included a large number of 3-year-olds, as the selectivities at this age showed the most notable difference. The estimated survey catchability for the relative index survey was 0.85.

13.6.2 Abundance Trend

The estimated time series of biomass for ages 3+ are shown in Figure 13.12 and given in Table 13.9. The corresponding time series of total numbers at age are given in Table 13.10. The biomass trend increases during the late 70s and early 80s and again in the early 90s (Figure 13.12). The stock has been on a fairly steep declining trend since 1991.

The current assessment's estimated biomass trend is lower in magnitude after about 1989, relative to the trend estimated in the 2000 assessment (Figure 13.12). The addition of the 2000 fishery age composition resulted in downward revised estimates of recruitment starting in about 1990 (see Recruitment Trend below), which translated to lower estimates of biomass. Last year's assessment projected the 2001 age 3+ biomass to be 553,000 mt which compares to the estimated 2001 age 3+ biomass of 426,000 mt from the current assessment. The revised magnitude (25% lower) of the previously estimated above average 1995 year class is probably a large factor in the significantly lower estimates of current biomass.

13.6.3 Recruitment Trend

The estimated time series of age 2 recruits are shown in Figures 13.13 and 13.14 and given in Table 13.11. The strong 1977 year class is most notable followed by the 1988 year class. The model estimates above average (greater than 20% of the mean) recruitment from the 1984-86, 1988, and 1992 year classes (Figure 13.13). This is corroborated by the catch-at-age data which showed large numbers of 4-year-old fish recruiting to the 1988, 1989, 1990, 1992, and 1996 fisheries. The addition of the 2000 fishery age composition resulted in lower (relative to the 2000 assessment) estimates of recruitment since 1989, particularly impacting the estimates of the strong 1988 and 1992 year classes (Figure 13.13). The 1995 year class which had previously been estimated to be an above average year class, is now estimated to be within 20% of the average recruitment value and is considered to be an average year class.

The average estimated recruitment from the time series 1979-1999 is 502 million fish and the median is 359 million fish (Figure 13.13). The entire time series of recruitments (1977-1999) includes the 1975-1997 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 (1977-1997 year classes) for the years 1979-1999.

Projections of biomass are based on estimated recruitments from 1979-1999 using a stochastic projection model described below.

13.6.4 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 13.12.

13.6.5 Model Fit

Figure 13.15 compares the observed (a) relative and (b) absolute abundance values from the surveys with the model estimates of survey abundance values (observed versus expected). Stock synthesis applies the estimated survey selectivities to the population estimates to provide the expected values of survey abundance. The population estimates are also depicted for comparison to absolute estimates of biomass from the surveys (Figure 13.15b). The 1986, 1991, 1994, 1997, and 2000 observed trawl survey biomass estimates represented 75, 60, 61, 54, and 105% respectively, of the population estimates.

The model fit the 1986 and 1991 survey estimates poorly compared to the more recent 1994 and 1997 surveys (Figure 13.15b). 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. From 1986 to 1991, the population is estimated to have increased at a greater rate than shown by the surveys (Figure 13.15b). This lack of fit is confounded by the large coefficient of variation associated with the 1986 biomass estimate. 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 1997 to 2000 surveys appears to be inconsistent with the recent recruitment patterns. The magnitude of the 1995 year class was revised downward with the addition of the 2000 fishery age composition. This year class now appears to be about average in size. The lack of a recent strong year class is inconsistent with the large increase in survey biomass observed in 2000.

The fits to the fishery and survey age compositions are depicted in Figure 13.16, and show relatively good fits each year. It is interesting to note that the 2000 survey saw a much larger than expected number of 2-year old fish (1998 year class) for which the selectivity is estimated to be very low (0.14), and a much poorer than expected showing of 3-year old (1997 year class) fish which are estimated to be fully selected (Figure 13.16c).

13.7 HARVEST ALTERNATIVES AND PROJECTIONS

13.7.1 Reference Fishing Mortality Rates and Yields

The overfishing and maximum allowable ABC fishing mortality rates (F_{OFL} and *max* F_{ABC}, respectively) are given in terms of percentages of unfished female spawning biomass per recruit ($F_{SPR\%}$), on fully selected age groups. The associated long-term average female spawner biomass that would be expected under average estimated recruitment from 1979-1999 (502 million recruits) and $F = F_{40\%}$, denoted $B_{40\%}$, is estimated to be 124,500 mt. The projected 2002 female spawning biomass (SB_{02}) under the recommended ABC harvest strategy is 118,000 mt. This differs from the projected 2002 female spawning biomass (SB_{01}) under the maximum allowable ABC harvest strategy (*max* F_{ABC}) of 113,100 mt. The reason for the difference in projected 2002 female spawning biomass depending on the harvest strategy, is that spawning biomass is estimated at peak spawning (August), thus the projection incorporates 7 months of the specified fishing mortality rate. Under either harvest strategy, projected 2002 female spawning biomass is below $B_{40\%}$. Atka mackerel are now in Tier 3b for the first time, and the F_{OFL} and the *max* F_{ABC} are adjusted $F_{35\%}$ and $F_{40\%}$ rates, denoted $F_{35\%adj}$ and $F_{40\% adj}$, respectively.

If a projection is made under the *max* F_{ABC} strategy, $F_{OFL} = F_{35\% adj} = 0.37$, and *max* $F_{ABC} = F_{40\% adj} = 0.32$. Projected 2002 yields associated with $F_{OFL\ adj}$ and *max* $F_{ABC\ adj}$ are 82,300 and 71,300 mt, respectively.

Tier 3b

Harvest Strategy	$F_{SPR\%}$	**Fishing Mortality Rate**	**2001 Projected Yield (mt)**
F_{OFL}	$F_{35\% adj}$	0.37	82,300
max F_{ABC}	$F_{40\% adj}$	0.32	71,300

The harvest strategy used by the SSC to set the 1999, 2000, and 2001 Atka mackerel ABCs is given below with the projected 2002 yield:

Tier 3b

Harvest Strategy	$F_{SPR\%}$	**Fishing Mortality Rate**	**2001 Projected Yield (mt)**
F_{ABC}	$F_{52\%}$	0.21	49,000

13.7.2 <u>ABC Considerations</u>

Several observations and characterizations of uncertainty in the Atka mackerel assessment have been noted for ABC considerations since 1997. These concerns are repeated below:

1) Stock size as estimated by the age structured model has declined approximately 63% since 1991;

2) Trawl survey estimates of biomass are highly variable; the 1997 Aleutian trawl survey biomass estimate was about 50% lower than the 1994 survey estimate, and the most recent 2000 survey estimate showed a 39% increase that could not be fit by the stock assessment model.

3) Under an $F_{40\%adj}$ harvest strategy, 2002 female spawning biomass is projected to be below $B_{40\%}$ (and within 4% of $B_{35\%}$) and remain below $B_{40\%}$ until 2005.

The last concern stems from the current assessment:

4) The hindcast of biomass from the current assessment yielded lower estimates of current biomass than the previous assessments due to lower estimates of recruitment from recent strong year classes. In particular, the 1995 year class which had previously been estimated to be an above average year class, is now estimated to be within 20% of the average recruitment value and is considered to be an average year class. Although there were large numbers of 2 year old fish of the 1998 year class encountered by the 2000 survey, it is still too early to determine the magnitude of this year class and an average size 1998 year class was assumed in the model for the biomass projection.

The 2002 yield associated with the maximum allowable $F_{40\%\ adj}$ rate is 71,300 mt, a 3% increase over the 2000 TAC (based on an $F_{52\%}$ rate). This does not seem prudent given the concerns listed above, the difficulties in characterizing the true range of uncertainty in the Atka mackerel assessment, the downward revision in the magnitude of recent year class strengths, and the unknown impacts of future harvests as the fishery shifts to new areas. **We recommend a 2002 ABC of 49,000 mt based on the $F_{52\%}$ harvest strategy used since 1999 to set ABC.** Short-term projections under an average fishing mortality rate equal to $F_{52\%}$ = 0.21 show that female spawning biomass will increase above the estimated $B_{40\%}$ spawning biomass by 2003.

13.7.3 Projections

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 Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2001 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2002 using constant natural mortality of 0.3, and the schedules of selectivity estimated in the assessment. 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 for 1979-1999 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 2002, are as follow ("*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}.

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 2002 recommended in the assessment to the *max* F_{ABC} for 2002.

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}.

Scenario 4: In all future years, F is set equal to the 1996-2000 average F.

Scenario 5: In all future years, F is set equal 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 above ½ of its MSY level in 2002 and above its MSY level in 2012 under this scenario, then the stock is not overfished.)

Scenario 7: In 2002 and 2003, 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 2014 under this scenario, then the stock is not approaching an overfished condition.)

The projected biomass of ages 3+ at the beginning of 2002 is 439,700 mt. The projected yields, female spawning biomass, and associated fishing mortality rates for the seven harvest strategies are shown in Table 13.13. Under a harvest strategy of $F_{40\%\,adj}$ (Scenario 1), female spawning biomass is projected to be below $B_{40\%}$ in 2002, and remain so until 2005. Female spawning biomass is also projected to drop below $B_{40\%}$ when fishing at F_{OFL} (Scenarios 6 & 7, Table 13.13). The other harvest strategies project female spawning biomass to increase above $B_{40\%}$ by 2003. 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. Figure 13.17 illustrates 5-year projections for $F = F_{40\%\,adj}$ (Scenario 1), $F = F_{ABC}$ (Scenario 2), and $F = F_{OFL} = F_{35\%\,adj}$ (Scenario 6). The associated long-term average female spawner biomass that would be expected under average estimated recruitment from 1979-1999 (502 million recruits) and $F = F_{35\%}$, denoted $B_{35\%}$, is estimated to be 109,000 mt. This value ($B_{35\%}$), which is used in the status determination criteria (Section 13.7.4), is provided as a reference level along with $B_{40\%}$ (Figure 13.17).

13.7.4 ABC Recommendation, Overfishing Level, and Status Determination

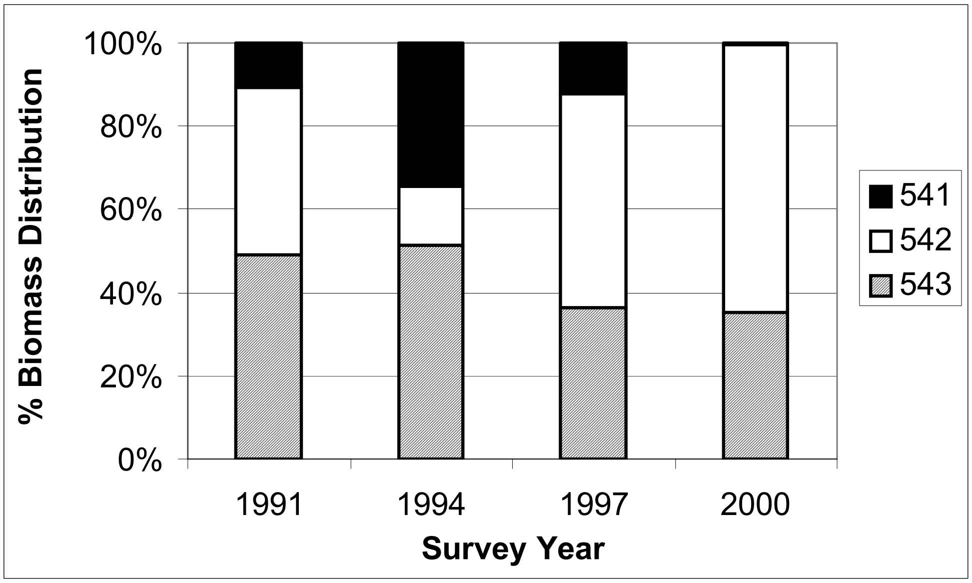
Short-term stochastic projections under an average fishing mortality rate of $F_{ABC} = 0.21$, result in female spawning biomass increasing above $B_{40\%}$ by 2003, compared to harvesting at $F_{40\%\ adj}$ in which projected female spawning biomass remains below $B_{40\%}$ until 2005. Based on a comparison of the $F_{40\%\ adj}$ strategy versus an $F = 0.21$ in the projections, and given the ABC considerations described above, we recommend that $F_{ABC} = 0.21$. The 2002 projections assuming fishing at the recommended F_{ABC} places Atka mackerel in Tier 3b. **The associated 2002 yield with a fishing mortality rate of 0.21 is 49,000 mt, which is our 2002 ABC recommendation for BSAI Atka mackerel.**

The $F_{35\%\ adj}$ overfishing level is 82,300 mt. The estimated $B_{35\%}$ female spawner biomass is 109,000 mt. Female spawning biomass for 2002 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 2014 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*.

13.7.5 Apportionment of Catch

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 the average of the 1994 and 1997 survey biomass distributions of Atka mackerel to apportion the 1999 and 2000 ABCs, and a new 4-survey weighted average to apportion the 2001 ABC. The rationale for the new weighting scheme is given below.

The triennial Aleutian trawl survey occurs every three years in the summer months. The historical pattern or rather lack of pattern in the Atka mackerel biomass distribution likely indicates a high degree of observation and process error. The sensitivity of the 2000 biomass distribution to an extremely large decline in biomass in the Eastern Aleutians (541) is also a concern.



	1991	1994	1997	2000	2000 TAC Apportionment (ave. 1994 & 1997)	4 survey unweighted average	4 survey weighted average
543	49.0%	51.4%	36.4%	35.2%	42%	43.0%	**40.2%**
542	40.3%	14.0%	51.0%	64.6%	35%	42.5%	**48.5%**
541	10.7%	34.6%	12.3%	0.2%	23%	14.5%	**11.2%**
Weights	8	12	18	27			

As a more robust way of apportioning biomass, we suggested using a longer term weighted average. A four-survey average (1991, 1994, 1997, and 2000) was suggested to capture changes in the average biomass distribution. A weighted average with the highest weights given to the most recent survey year was also recommended to adapt to current information and the possibility of autocorrelation, that is, the tendency for the true biomass distribution to be similar from one year to the next

Following the apportionment method used for GOA rockfish, we assumed that observation error contributed at least 2/3 of the total variability in predicting the distribution of biomass; (the survey variability for Atka mackerel is similar to the level of survey variability estimated for most rockfish, Appendix 2 in Lowe et al. 2000), thus the weight of a prior survey should be 2/3 the weight of the subsequent survey. This resulted in weights of 8:12:18:27 for the 1991, 1994, 1997, and 2000 surveys, respectively.

ABC Apportionment of 49,000 mt	
	4 survey weighted[1] average
543	19,700
542	23,800
541	5,500
Total	49,000

[1]The weighting scheme is based on the assumption that survey error (measurement error) contributes 2/3 of the total variability in predicting biomass distribution, and the weight of a prior survey should be 2/3 the weight of the subsequent survey.

The apportionment based on the 4 survey weighted average is the recommendation for the 2002 ABC: **19,700 mt for 543, 23,800 mt for 542, and 5,500 mt for 541.**

13.8 SUMMARY

$M = 0.30$

2001:	F_{ABC} = 0.23	yield =	69,300 mt

2002 (Tier 3b)

Maximum permissible ABC	$F_{40\%\ adj}$ = 0.32	yield =	71,300 mt
Recommended ABC:	$F_{ABC\%}$ = 0.21	yield =	49,000 mt
Overfishing F_{OFL} :	$F_{35\%\ adj}$ = 0.37	yield =	82,300 mt

$B_{40\%}$ female spawning biomass	= 124,500 mt
$B_{35\%}$ female spawning biomass	= 109,000 mt

Projected 2002 3+ biomass	= 439,700 mt
Projected 2002 female spawning biomass	= 118,000 mt

Note: The *F* values are the full-selection fishing mortality rates.

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Table 13.1. Atka mackerel catches (including discards) 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.

Year	Eastern Bering Sea				Aleutian Islands Region				EBS-AI	
	Foreign	Domestic JVP	Domestic DAP	Total	Foreign	Domestic JVP	Domestic DAP	Total	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	57,177	57,177	57,177	64,300
1999	0	0	a	a	0	0	53,643	53,643	53,643	66,400
2000	0	0	a	a	0	0	42,440	42,440	42,440	70,800
2001[c]	0	0	a	a	a	0	55,961	55,961	55,961	69,300

Catch table footnotes:

a) Eastern Bering Sea catches included with Aleutian Islands.

b) Atka mackerel was not a reported species group until 1978

c) 2001 data as of 10/4/01 from NMFS Alaska Regional Office Home Page.

Table 13.2 Research catches (mt) of Atka mackerel from NMFS trawl surveys in the Aleutian Islands.

Year	Aleutian Islands
1977	
1978	
1979	
1980	47.9
1981	3.9
1982	0.9
1983	151.4
1984	
1985	
1986	130.2
1987	
1988	
1989	
1990	
1991	77.1
1992	
1993	
1994	146.5
1995	
1996	
1997	85.2
1998	
1999	

Table 13.3 Estimated catch-in-numbers at age (in millions) of Atka mackerel from the Aleutian Islands.

	Year																							
Age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
2	6.827	2.702	0.011	---	---	---	---	0.094	0.627	0.369	0.563	0.400	0.190	---	---	0.231	0.764	0.025	0.238	0.029	1.705	---	1.221	0.558
3	31.522	60.155	4.477	12.681	5.393	0.188	1.900	0.977	15.971	11.454	10.441	9.966	3.230	4.047	1.957	2.726	2.366	9.572	19.042	3.449	4.386	11.340	1.015	7.742
4	20.056	15.573	26.778	5.920	17.106	2.629	1.433	7.295	8.787	6.457	7.602	22.487	7.931	12.055	5.576	29.183	12.281	6.949	41.265	65.693	11.441	18.946	38.782	5.107
5	15.113	9.221	13.000	7.220	0.002	25.828	2.535	7.070	9.428	4.423	4.582	6.148	8.378	6.790	10.112	7.501	36.479	23.997	9.776	22.307	35.696	17.302	9.735	23.734
6	1.223	3.750	2.197	1.665	1.612	3.861	10.596	10.793	6.010	5.335	1.891	1.797	3.088	2.490	5.901	13.470	7.823	39.771	14.849	12.765	13.612	31.933	7.773	6.939
7	0.393	0.592	1.109	0.591	8.104	0.676	1.587	21.775	5.453	4.531	2.373	1.535	1.355	0.893	3.064	7.582	13.636	4.573	27.633	20.870	3.955	11.651	11.167	3.800
8	0.197	0.343	---	0.240	---	---	---	2.212	11.685	5.841	2.192	0.627	0.471	0.189	1.285	5.756	6.796	9.416	3.565	31.928	4.023	4.153	4.494	7.412
9	---	0.106	---	0.131	---	---	---	0.957	1.263	9.912	1.708	0.959	0.408	0.134	0.269	1.792	5.103	6.588	4.007	3.023	8.637	3.834	1.573	1.892
10	---	---	---	---	---	---	---	---	0.269	1.036	6.777	0.202	0.206	0.054	0.406	0.668	1.559	4.257	5.361	3.603	1.598	5.579	1.061	0.808
11	---	---	---	---	---	---	---	---	---	0.846	0.530	0.437	0.156	0.016	0.397	0.215	0.563	0.612	2.044	2.635	2.416	0.473	1.130	0.533
12	---	---	---	---	---	---	---	---	---	---	0.220	0.040	0.521	0.038	0.087	0.165	0.172	0.267	---	0.506	1.118	0.851	0.156	0.324
13	---	---	---	---	---	---	---	---	---	---	---	---	0.031	0.164	---	0.068	0.119	0.000	---	0.047	0.708	0.761	0.128	0.319
14	---	---	---	---	---	---	---	---	---	---	---	---	0.038	0.032	---	0.033	0.037	0.000	---	---	0.141	---	---	
15	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	0.033	---	---	---	---	---	---

Table 13.4 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.

Area	Depth (m)	Biomass (mt) 1980	Biomass (mt) 1983	Biomass (mt) 1986	Coefficient of variation 1980	Coefficient of variation 1983	Coefficient of variation 1986
Aleutian	1-100	48,306	140,552	450,869	1.00	0.26	0.76
	101-200	144,431	162,399	93,501	0.46	0.25	0.30
	201-300	4,296	3,656	331	0.59	0.42	0.57
	301-500	483	172	16	0.77	1.00	0.87
	501-900	13	1	37	0.75	1.00	1.00
	Total	197,529	306,780	544,754	0.42	0.22	0.63
Southwest Aleutian	1-100	95	15,321	418,271	0.00	0.61	0.82
	101-200	75,857	120,991	51,312	0.58	0.41	0.39
	201-300	619	2,304	122	0.61	0.57	0.83
	301-500	105	172	14	0.77	1.00	0.98
	501-900	9	1	0	0.96	1.00	0.00
	Total	76,685	138,789	469,719	0.57	0.36	0.73
Southeast Aleutian	1-100	0	65,814	33	0.00	0.00	0.42
	101-200	21,153	854	89	0.87	0.92	0.90
	201-300	115	202	3	0.14	0.86	0.88
	301-500	16	0	0	0.00	0.00	0.00
	501-900	0	0	0	0.00	0.00	0.00
	Total	21,284	66,870	125	0.86	0.01	0.64
Northwest Aleutian	1-100	0	41,235	32,564	0.00	0.72	0.65
	101-200	382	5,571	211	0.71	0.69	0.54
	201-300	2,524	34	0	0.96	0.69	0.00
	301-500	0	0	0	0.00	0.00	0.00
	501-900	4	0	0	1.12	0.00	0.00
	Total	2,910	46,840	32,775	0.84	0.64	0.65
Northeast Aleutian	1-100	48,211	18,182	1	1.00	1.00	1.00
	101-200	47,039	34,983	44,889	0.98	0.71	0.46
	201-300	1,038	1,116	206	0.65	0.69	0.78
	301-500	362	0	2	1.00	0.00	0.71
	501-900	0	0	37	0.00	0.00	1.00
	Total	96,650	54,281	42,135	0.69	0.57	0.46

Table 13.5 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, and 1997. Biomass is also reported by survey depth interval.

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

Table 13.6 Mean weight-at-age values (kg) for Atka mackerel from the Aleutian trawl surveys and the commercial fishery. The survey weight-at-age vector was derived from the 1986, 1991, and 1994 weight-at-age data; the fishery weight-at-age data was derived from fishery weight-at-age data from 1990 to 1996.

Age	Survey	Fishery
2	0.184	0.128
3	0.398	0.421
4	0.549	0.660
5	0.656	0.756
6	0.732	0.794
7	0.785	0.810
8	0.823	0.816
9	0.850	0.818
10	0.869	0.819
11	0.882	0.820
12	0.892	0.820
13	0.899	0.820
14	0.903	0.820
15	0.907	0.820

Table 13.7 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.

	Proportion mature				
Length (cm)	541	542	543	Age	Proportion mature
25	0.00	0.00	0.00	1	0.00
26	0.00	0.00	0.00	2	0.04
27	0.00	0.01	0.01	3	0.22
28	0.00	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	1.00
32	0.06	0.25	0.24	8	1.00
33	0.11	0.40	0.39	9	1.00
34	0.20	0.58	0.56	10	1.00
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	0.90	0.98	0.98		
40	0.95	0.99	0.99		
41	0.97	0.99	0.99		
42	0.99	1.00	1.00		
43	0.99	1.00	1.00		
44	1.00	1.00	1.00		
45	1.00	1.00	1.00		
46	1.00	1.00	1.00		
47	1.00	1.00	1.00		
48	1.00	1.00	1.00		
49	1.00	1.00	1.00		
50	1.00	1.00	1.00		

Table 13.8 Atka mackerel age specific selectivities (percent) for fishery and survey data as estimated by stock synthesis.

	Age													
	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Fishery (1977-83)	2	31	88	97	100	22	22	22	22	22	22	22	22	22
Fishery (1984-98)	2	18	90	97	100	99	86	74	62	49	37	24	12	0
Survey (indices)	1	16	72	97	100	99	66	3	0	0	0	0	0	0
Survey (absolute)	14	100	100	99	99	99	99	37	28	28	28	28	28	28

Table 13.9 Estimated time series of Atka mackerel female spawning biomass (1000s mt) and age 3+ biomass (1000s mt) as estimated by stock synthesis in the current assessment. Estimated age 3+ biomass from last year's assessments is given for comparison.

	Current Assessment		Last Year's Assessment
Year	Female Spawning Biomass	Age 3+ Biomass	Age 3+ Biomass
1977	61.0	206.9	213.0
1978	73.3	355.7	366.7
1979	108.6	365.5	378.0
1980	158.0	790.6	816.1
1981	244.3	810.8	837.3
1982	270.9	754.0	779.2
1983	251.4	690.6	714.1
1984	219.9	612.2	634.2
1985	187.5	555.7	577.4
1986	173.5	560.7	584.9
1987	188.5	705.8	739.6
1988	232.6	809.2	850.2
1989	279.1	957.3	1011.3
1990	315.0	934.0	988.2
1991	332.9	1139.7	1214.8
1992	356.8	1081.0	1157.3
1993	333.2	928.9	999.7
1994	282.2	842.3	917.0
1995	251.2	870.2	958.5
1996	232.0	730.2	815.5
1997	196.6	578.7	662.0
1998	168.8	584.1	685.8
1999	157.4	473.6	569.6
2000	135.2	407.0	549.2
2001	116.4	425.9	

Table 13.10 Atka mackerel numbers at age as estimated by stock synthesis (millions). Zero values denote less than 1,000 fish.

	Age													
Year	2	3	4	5	6	7	8	9	10	11	12	13	14	15
77	680.8	152.0	46.5	30.5	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	106.0
78	199.8	501.3	102.6	26.5	16.9	0.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0	73.4
79	1666.5	147.5	352.2	65.5	16.6	10.6	0.0	3.0	0.0	0.0	0.0	0.0	0.0	52.3
80	279.1	1232.3	106.2	240.5	44.3	11.2	7.7	0.0	2.1	0.0	0.0	0.0	0.0	37.9
81	217.3	206.6	897.6	75.0	169.1	31.1	8.2	5.6	0.0	1.6	0.0	0.0	0.0	27.7
82	259.2	160.8	151.6	647.3	53.9	121.5	22.9	6.0	4.1	0.0	1.2	0.0	0.0	20.4
83	177.4	191.9	117.9	108.8	463.3	38.6	89.2	16.8	4.4	3.0	0.0	0.8	0.0	15.0
84	300.9	131.4	141.1	85.5	78.8	335.1	28.4	65.8	12.4	3.3	2.2	0.0	0.6	11.1
85	459.0	222.5	95.9	98.2	58.7	54.0	229.6	19.7	45.9	8.7	2.3	1.6	0.0	8.6
86	873.7	339.3	161.6	65.3	65.6	39.1	36.0	155.2	13.5	31.9	6.1	1.7	1.2	6.4
87	713.0	646.0	246.7	110.6	43.9	44.0	26.3	24.5	106.8	9.4	22.5	4.4	1.2	5.6
88	901.7	527.3	471.2	171.1	75.6	30.0	30.1	18.1	17.1	75.2	6.7	16.2	3.2	5.0
89	368.3	667.4	387.4	336.8	121.3	53.6	21.2	21.4	13.0	12.3	54.5	4.9	11.8	6.1
90	1248.9	272.7	491.6	280.2	242.3	87.2	38.5	15.3	15.5	9.4	9.0	39.9	3.6	13.2
91	359.6	924.6	200.8	355.0	201.2	173.9	62.6	27.8	11.1	11.3	6.9	6.6	29.3	12.4
92	210.7	266.2	680.1	144.2	253.3	143.4	124.0	44.9	20.0	8.0	8.2	5.0	4.8	30.8
93	469.4	155.9	194.9	478.8	100.4	176.1	99.8	86.9	31.7	14.2	5.8	5.9	3.7	26.4
94	790.1	347.1	113.5	133.8	323.5	67.7	118.8	68.1	60.0	22.1	10.1	4.1	4.3	22.2
95	190.9	583.8	251.1	75.9	87.6	211.1	44.2	78.8	45.9	41.1	15.4	7.1	3.0	19.6
96	211.3	141.0	419.1	162.6	47.7	54.9	132.4	28.3	51.5	30.6	28.0	10.7	5.1	16.7
97	561.5	155.9	100.2	260.3	97.2	28.4	32.7	81.0	17.8	33.3	20.4	19.1	7.5	16.0
98	74.3	414.5	111.7	64.5	162.4	60.4	17.7	20.8	52.7	11.8	22.6	14.1	13.6	17.3
99	214.2	54.8	296.8	71.6	40.0	100.4	37.4	11.2	13.5	34.9	8.0	15.7	10.0	22.6
100	425.0	158.2	39.3	191.7	44.9	25.0	62.8	23.9	7.3	9.0	23.7	5.6	11.1	24.0
101	425.0	313.8	113.5	25.4	120.1	28.0	15.6	40.1	15.6	4.9	6.1	16.5	4.0	25.9

Table 13.11 Estimated age 2 recruits (millions of Atka mackerel) from the current assessment and last year's assessment.

Year	Current Assessment	Last Year's Assessment
1977	680.8	700.8
1978	199.8	207.8
1979	1666.5	1715.7
1980	279.1	288.4
1981	217.3	224.5
1982	259.2	267.7
1983	177.4	186.1
1984	300.9	313.5
1985	459.0	479.8
1986	873.7	918.0
1987	713.0	749.7
1988	901.6	961.9
1989	368.3	389.3
1990	1248.9	1347.3
1991	359.6	391.5
1992	210.7	229.8
1993	469.4	524.1
1994	790.1	875.5
1995	190.9	220.2
1996	211.3	251.7
1997	561.5	670.7
1998	74.2	100.0
1999	214.4	

Table 13.12 Time series of historical fishing mortality rates for Atka mackerel, and catch/biomass (age 3+) rates estimated by stock synthesis.

Year	F[a]	Catch/Biomass Rate[b]
1977	0.30	0.11
1978	0.17	0.07
1979	0.09	0.06
1980	0.05	0.03
1981	0.03	0.02
1982	0.04	0.03
1983	0.02	0.02
1984	0.08	0.06
1985	0.11	0.07
1986	0.10	0.06
1987	0.08	0.04
1988	0.04	0.03
1989	0.03	0.02
1990	0.03	0.02
1991	0.04	0.02
1992	0.06	0.05
1993	0.09	0.07
1994	0.13	0.08
1995	0.17	0.09
1996	0.22	0.14
1997	0.18	0.11
1998	0.18	0.10
1999	0.17	0.11
2000	0.17	0.10
2001[c]	0.28	0.14

a/ Fishing mortality rate on fully-recruited fish.
b/ Catch/biomass rate is the catch to beginning year biomass (ages 3+) ratio.
c/ The 2000 catch/biomass rate is based on catch as of 10/14/00.

Table 13.13 Projections of Bering Sea/Aleutian Islands Atka mackerel female spawning biomass (1000 mt), yield (1000 mt), and full-selection fishing mortality rate for seven future harvest scenarios The average recruitment from the stochastic projections is 502 million recruits which gives $B_{40\%}$ and $B_{35\%}$ levels (female spawning biomass) of 124,500 and 109,000 mt, respectively.

Scenario 1
Maximum Permissible F_{ABC} (*max* F_{ABC})

Year	Female Spawning biomass	Yield	*F*
2001	116.356	59.984	0.28
2002	113.093	71.353	0.32
2003	116.608	78.565	0.32
2004	122.852	87.461	0.32
2005	127.302	93.418	0.32
2006	129.431	96.238	0.32
2007	130.66	98.229	0.32
2008	131.276	99.518	0.32
2009	131.282	99.962	0.32
2010	131.251	100.143	0.32
2011	131.407	100.858	0.32
2012	130.544	99.334	0.32
2013	130.509	99.483	0.32
2014	130.252	99.183	0.32

Scenario 2
***F* = 0.56 of *max* F_{ABC}**

Year	Female Spawning biomass	Yield	*F*
2001	116.356	59.986	0.28
2002	118.017	48.973	0.21
2003	128.344	59.293	0.22
2004	139.946	67.967	0.22
2005	148.84	73.961	0.22
2006	154.283	77.358	0.22
2007	157.856	79.648	0.22
2008	160.149	81.143	0.22
2009	161.333	81.823	0.22
2010	162.085	82.164	0.22
2011	162.799	82.894	0.22
2012	162.231	82.018	0.22
2013	162.269	82.069	0.22
2014	162.123	81.727	0.22

Scenario 3
50% of *max* F_{ABC}

Year	Female Spawning biomass	Yield	*F*
2001	116.355	59.986	0.28
2002	120.426	37.801	0.16
2003	134.612	47.837	0.17
2004	149.699	55.742	0.17
2005	161.674	61.354	0.17
2006	169.601	64.698	0.17
2007	175.078	66.984	0.17
2008	178.826	68.451	0.17
2009	181.101	69.192	0.17
2010	182.642	69.584	0.17
2011	183.959	70.229	0.17
2012	183.808	69.639	0.17
2013	184.075	69.707	0.17
2014	184.09	69.465	0.17

Scenario 4
F* = to the 1996-2000 average *F

Year	Female Spawning biomass	Yield	*F*
2001	116.356	59.984	0.28
2002	120.834	35.898	0.15
2003	136.394	42.498	0.15
2004	153.31	49.900	0.15
2005	166.977	55.314	0.15
2006	176.317	58.517	0.15
2007	182.934	60.645	0.15
2008	187.612	61.976	0.15
2009	190.635	62.644	0.15
2010	192.765	62.969	0.15
2011	194.56	63.525	0.15
2012	194.768	63.047	0.15
2013	195.267	63.150	0.15
2014	195.443	62.965	0.15

Scenario 5
***F* = 0**

Year	Female Spawning biomass	Yield	*F*
2001	116.356	59.984	0.28
2002	128.36	0	0
2003	157.761	0	0
2004	189.211	0	0
2005	217.222	0	0
2006	239.505	0	0
2007	257.132	0	0
2008	270.902	0	0
2009	281.223	0	0
2010	289.022	0	0
2011	295.252	0	0
2012	298.829	0	0
2013	301.692	0	0
2014	303.635	0	0

Table 13.13 cont. Projections of Bering Sea/Aleutian Islands Atka mackerel female spawning biomass (1000 mt), yield (1000 mt), and full-selection fishing mortality rate for seven future harvest scenarios. The average recruitment from the stochastic projections is 502 million recruits which gives $B_{40\%}$ and $B_{35\%}$ levels (female spawning biomass) of 124,500 and 109,000 mt, respectively.

Scenario 6

***F* = F_{OFL}**

Determination if Atka mackerel are overfished

Year	Female Spawning biomass	Yield	*F*
2001	116.356	59.984	0.28
2002	110.637	82.290	0.37
2003	111.216	86.515	0.37
2004	115.353	95.610	0.37
2005	118.077	101.322	0.36
2006	119.021	103.647	0.36
2007	119.522	105.251	0.36
2008	119.649	106.521	0.36
2009	119.383	106.606	0.36
2010	119.241	106.670	0.36
2011	119.313	107.495	0.36
2012	118.418	105.738	0.36
2013	118.386	106.039	0.36
2014	118.094	105.705	0.36

Scenario 7

***F* = to *max* F_{ABC} in 2001 and 2002, and F_{OFL} in all subsequent years.**

Determination if Atka mackerel are approaching an overfished condition

Year	Female Spawning biomass	Yield	*F*
2001	116.586	60.036	0.28
2002	115.148	73.183	0.32
2003	122.030	83.794	0.32
2004	124.008	106.574	0.37
2005	122.430	106.206	0.37
2006	121.429	106.335	0.37
2007	120.781	106.862	0.37
2008	120.104	106.724	0.37
2009	119.724	106.702	0.37
2010	119.653	107.481	0.36
2011	118.661	105.735	0.36
2012	118.559	106.035	0.36
2013	118.218	105.700	0.36
2014	117.924	105.779	0.36

Appendix I – Characteristics of Atka Mackerel trawl data and estimation of stock biomass from surveys

Prepared by M. Elizabeth Conners, AFSC

Stock assessments at the AFSC are based on research surveys conducted by the AFSC's RACE Division. These surveys conduct, as nearly as possible, a randomized sampling survey over the vast areas of the Aleutian Islands (AI), Bering Sea, and Gulf of Alaska. These surveys provide catch and size distribution data for a wide variety of groundfish species, and so must be kept to a general, broadly applicable design. (A survey design "tuned" for one particular species might perform poorly for other species). Because of its particular biology, Atka mackerel has characteristics that make it particularly difficult to assess with a trawl survey using this type of general design. This appendix is included to illustrate the reasons for the high uncertainty associated with survey estimates of Atka mackerel biomass.

Atka mackerel in the AI tend to occur in very dense, spatially discrete schools. Trawl samples that include Atka mackerel tend to have very high catch, indicating that the trawl path intersected a large school of mackerel. The majority of trawls, even those in areas where Atka mackerel are known to occur, miss these dense schools and come up with few or no mackerel in the catch. The reasons for this effect are not fully understood. Schooling behavior of the mackerel, especially in the summer around spawning season, may be an important factor. It is also highly likely that Atka mackerel schools associate with some small-scale habitat features that have not been identified. The location of individual mackerel and mackerel schools can change substantially over day/night and tidal cycles. The inability of trawl gear to sample over very rocky bottom and the difficulty of keeping a trawl net on the bottom also contribute to this effect. The result is that the trawl catches of Atka mackerel tend to be either very high or very low, with the majority of hauls containing few or no Atka mackerel. This type of behavior is found to some extent with almost all fish species, but Atka mackerel represent an extreme case.

To get an idea of the actual distribution of Atka mackerel catch data in the AI, I used the AFSC's RACE Division database, which includes haul-by-haul results of research surveys. This database includes bottom trawl surveys of the Aleutian Islands from 1980 through 2000, including both joint US-Japan surveys conducted in the early 1980's and the triennial NMFS survey conducted in 1991, 1994, 1997, and 2000. The following analysis uses all haul records from the database that were located between 170 W and 170 E; that were randomly-selected bottom trawl stations;

and that were rated as successful haul performance. The raw catch data (Kg/haul) was examined, as well as the catch–per-trawled-area or CPUE data (Kg/Km^2). Figure 1 shows the estimated probability distribution of Atka mackerel catch in Kg/haul over all of the AI survey data. For 56% of the hauls, there were no Atka mackerel present in the catch (haul weight of 0). Another 30% of the time, a few individual mackerel were caught, and the catch weight was between 0 and 100Kg. Catch weights of more than 100Kg but less than 1000 Kg were relatively rare, making up only 5.5% of the hauls. Finally, the upper 8.5% of the hauls reflect a "hit" of schooling Atka mackerel, with catch weights from 1000kg (1 mt) up to 33,335Kg (33.3 mt) in a single haul. When the data are broken down by year or by spatial regions these percentages vary, but the grouping of catches into these general categories persists.

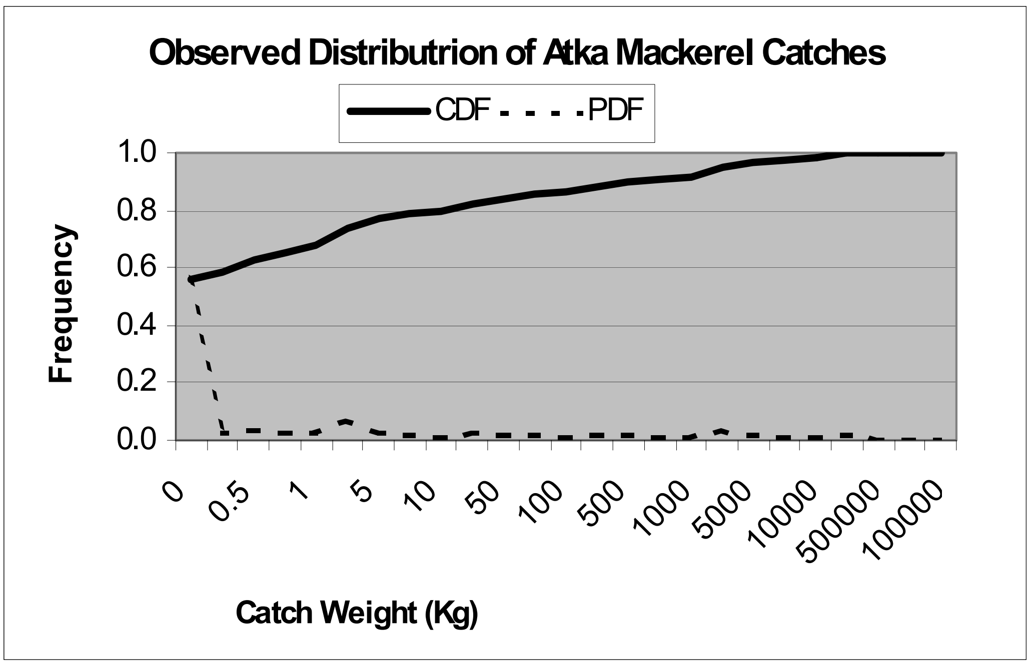

Figure 1. Observed distribution of Atka mackerel trawl catch weights from the Aleutian Islands. This data includes all bottom trawl research survey hauls collected in the AI region from 1980-2000.

In a statistical sense, this distribution is strongly right-skewed, with a high fraction of very low values and a small fraction of very high values. While the arithmetic mean of this distribution is an intermediate value (498 Kg/haul), very few of the individual hauls actually get a catch close to this figure. The arithmetic mean is heavily influenced by the number and magnitude of the few high catches in the "upper tail" of the distribution; if a sample happens to include a higher fraction of "big" hauls than usual, the sample mean will be substantially higher than he true mean. If, by chance, the sample includes fewer of these "big" hauls, then the sample mean will be lower than the true mean. The sample mean only approximates the true mean when the proportion of "big" hauls in the sample is similar to that in the underlying distribution. Table 1 illustrates this effect for a sample size of five hauls. When the underlying distribution has a high proportion of zeros, it is likely that a small sample will get a higher-than normal proportion of zeros, thereby underestimating the true mean. Since the number of hauls at the high end is small, chances that a particular sample will get a large proportion of these hauls, and thus overestimate the true mean, is smaller. The result is that the distribution of the sample mean is right-skewed, with a high probability of low estimates and a small chance of large over-estimates. The more strongly skewed the underlying data distribution is, the more skewed the distribution of the sample mean becomes.

Table 1. Examples of the sensitivity of the sample mean to the proportion of "big" hauls.

Sampled Data Set: [0 0 0 100 0 0 0 0 100 100 0 0 0 0 100 0 0 0 0 0]
(Twenty possible values, 1/4 are "big hauls". True Average is 20)

Sample	**% "Big" in Sample**	**Sample Average**
[0 100 0 100 0]	40%	40
[0 0 0 0	0%	0
[0 0 0 0 100]	20%	20

Sampling theory relies on the fact that this effect can be overcome by using a large sample size. The Central Limit Theorem proves that, for large sample sizes, the distribution of the sample mean is approximately Normally distributed, regardless of the underlying distribution from which the sample is drawn. The definition of "large" depends on the underlying distribution; the more strongly non-Normal the underlying distribution, the larger the sample size needed to give the sample mean a Normal distribution. Using the combined data from all AI surveys, I performed random sampling (with replacement) for a number of sample sizes in order to estimate what "large" might mean for an Atka mackerel survey. Figure 2 shows the distribution of the sample mean over 1000 samples randomly drawn from the combined AI data in Figure 1. Since the distribution being sampled is strongly skewed, a fairly large sample is required before the distribution of the sample mean becomes well-behaved. At sample sizes up to 75 hauls, strong skewness in the underlying distribution creates a skewed distribution of the sample mean. It is not until sample size gets up over 100 hauls that the sample mean approaches an approximately Normal distribution.

Effect of Sample Size on Distribution of the Sample Mean: Atka Data from AI

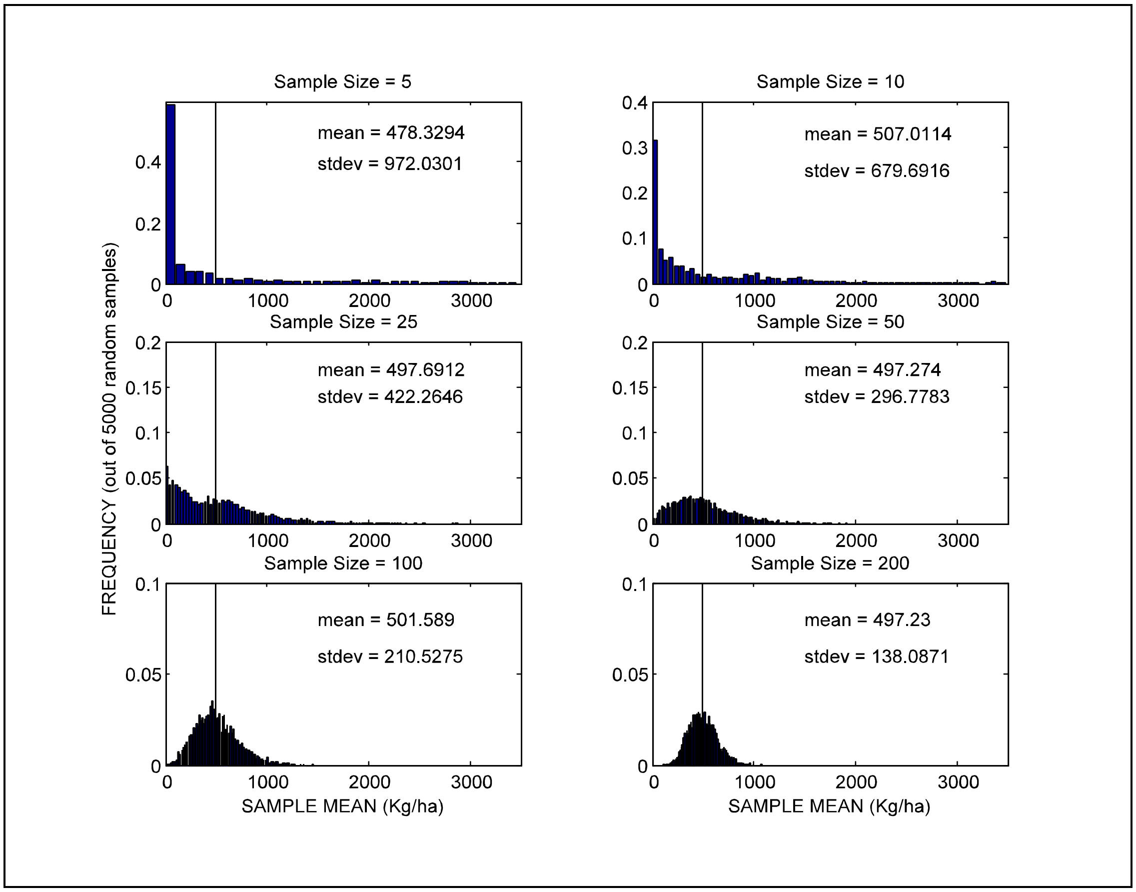

Figure 2. Example of the effect of sample size on the distribution of the sample mean. Samples were drawn from trawl results for all AI surveys 1980-2000, in depths <200m. The vertical line in each graph represents the true mean of 497.65. The mean and standard deviation in each plot are for the distribution of the sample mean. At small sample sizes, the sample mean is an unbiased estimator but has a highly skewed distribution, with a large chance of under-predicting the true mean and a small chance of a large over-prediction.

This skewness of the sample mean at smaller sample sizes effects the survey estimate of biomass. For the AI survey, the study area is divided into strata based on depth, location and regulatory regions. Sample sizes in each stratum typically range from 6-8 (for the deeper strata) up to 20-40 (for the strata containing the majority of fish biomass). As seen in Figure 2, a sample size of 25 still shows strongly skewed distribution of the sample mean. This means that the estimated biomass of Atka mackerel calculated for each stratum (as the mean catch x stratum area) will also have a skewed distribution. The survey estimate for total biomass of Atka Mackerel in the AI is based on combining these stratum estimates. Another sampling simulation (Figure 3) shows an approximate distribution for a stratified biomass estimate, based on stratified sampling from the combined CPUE data (Kg/Km^2). This combined data set and the simulation are based on strata less than 200m deep, since Atka mackerel were rarely found in deeper strata. The allocation of samples to strata used is the same as in the 2000 survey. Samples for all strata were drawn from the same CPUE distribution, although in reality the actual distribution of Atka mackerel biomass is expected to vary by region. The resulting distribution of the estimated total biomass is also right-skewed, with 61% of samples underestimating the true total biomass and 6% overestimating it by a factor of 2 or more. The most common estimate based on stratified sampling is on the order of 2.0 x 105 mt, 26% below the true total for the sampled datset.

AFSC scientists have been concerned about the unusually low estimates of biomass for area 541 in the 2000 survey. The survey sample for the strata in area 541 in 2000 did not include any high catches, and thus the estimated biomass for this region was much smaller than in preceding surveys. This appendix was included to show that such low estimates can result simply from the strongly skewed nature of Atka mackerel catch data.

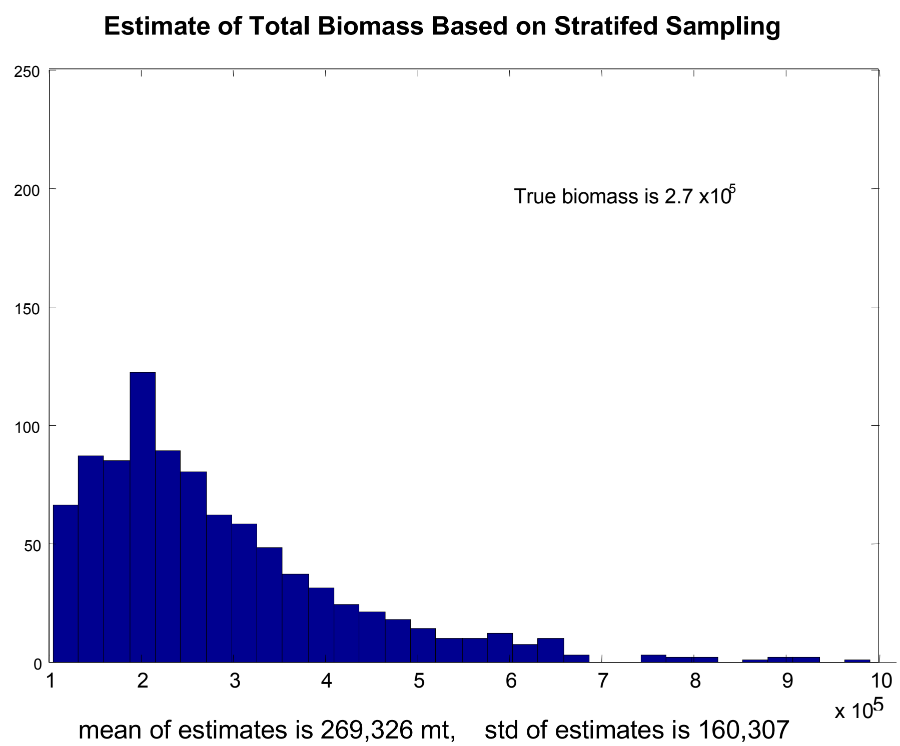

Figure 3. Distribution of the estimated total biomass of Atka Mackerel in AI waters <200m deep, based on stratified random sampling from the combined historical CPUE data.