Stock Assessment of Aleutian Islands Atka Mackerel

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EXECUTIVE SUMMARY

Summary of Major Changes

Relative to the November 2001 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 2001 fishery age composition data were included.
3) The 2002 Aleutian Islands survey biomass estimates were incorporated.

Changes in the Assessment Methodology

1) The 2002 BSAI Atka mackerel stock assessment uses a new modeling approach implemented through the "Stock Assessment Toolbox" (SAT).
2) The assessment model constructed with SAT uses the ADModel Builder software.
3) The selectivity relationship is modeled with a smoothed non-parametric relationship with penalties controlling the degree of change and curvature.
4) Selectivity is allowed to vary annually, and a penalty was imposed on sharp shifts in selectivity between ages.
5) A reparameterized form for the Beverton-Holt stock recruitment relationship based on Francis (1992) was used.

Changes in Assessment Results

1) The mean recruitment from the stochastic projections is 467 million recruits, which gives an estimated $B_{40\%}$ level of 177,900 mt.
2) The projected female spawning biomass for 2003 under an $F_{40\%}$ harvest strategy is estimated at 212,400 mt; BSAI Atka mackerel are in Tier 3a
3) The projected age 3+ biomass at the beginning of 2003 is estimated at 358,300 mt.
4) The addition of the 2001 fishery age composition showed the presence of the above average 1998 year class.
5) The projected 2003 yield at $F_{40\%}$= 0.66 is 82,800 mt.
6) The projected 2003 overfishing level at $F_{35\%}$ (F = 0.84) is 99,700 mt.

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

The SSC noted that "…use of $F_{52\%}$ as a precautionary approach is somewhat problematic. A decision theoretic risk analysis such as that performed in the sablefish assessment might produce a precautionary ABC of greater utility".

Due to the preliminary nature of current model explorations with priors on M and q, we were not able to conduct a complete decision theoretic risk analysis. However, we present alternative 2003 yields for consideration, including the "constant-buffer" scheme of Dorn et al. (2001), and a "cap" level where yield in the upcoming year remains at or below the current estimate of the long-term expected yield under a precautionary harvest policy.

14.1 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 (Gorbunova 1962). The first *in situ* observations of spawning habitat in Seguam Pass were documented in August, 1999. Atka mackerel nests, nest-guarding males, and spawning females were observed and verified with underwater video and SCUBA diving observations[1].

Nichol and Somerton (2002) examined the diurnal vertical migrations of Atka mackerel using archival tags, and related these movements to light intensity and current velocity. Atka mackerel displayed strong diel behavier, with vertical movements away from the bottom occurring almost exclusively during daylight hours and little to no movement at night.

Little is known of the life history of young Atka mackerel prior to their appearance in trawl surveys and the fishery at about age 2-3 years. Adult Atka mackerel in the Aleutians consume a variety of prey, but principally calanoid copepods and euphausiids, and are consumed by a variety of piscivores, including groundfish (e.g., Pacific cod and arrowtooth flounder, Livingston et al. unpubl. manuscr.), marine mammals (e.g., northern fur seals and Steller sea lions, Kajimura 1984, NMFS 1995), and seabirds (e.g., tufted puffins, Byrd et al. 1992).

A morphological and meristic study suggested that there may be separate populations in the Gulf of Alaska and the Aleutian Islands (Levada 1979). This study was based on comparisons of samples

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[1] Lauth, Robert. 2000. Resource Assessment and Conservation Engineering Div., Alaska Fish. Sci. Center, 7600 Sand Point Way NE, Seattle, WA 98115. Personal commun.

collected off Kodiak Island in the central Gulf, and the Rat Islands in the Aleutians. Lee (1985) also conducted a morphological study of Atka mackerel from the Bering Sea, Aleutian Islands and Gulf of Alaska. The data showed some differences (although not consistent by area for each characteristic analyzed), suggesting a certain degree of reproductive isolation. However, results from a genetics study comparing Atka mackerel samples from the western Gulf of Alaska with samples from the eastern, central, and western Aleutian Islands showed no evidence of discrete stocks (Lowe et al. 1998). Between-sample variation was extremely low among the four samples indicating that a large amount of gene flow is occurring throughout the range. It is presumed that gene flow is occurring during the larval, pelagic stage, and that the localized aggregations reflect the distribution of surviving, settled larvae and juveniles. Differences in growth rates consistently observed throughout their Alaskan range are believed to be phenotypic characteristics reflecting differences in the local environment.

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.

14.2 Fishery

14.2.1 Catch history

Annual catches of Atka mackerel in the eastern Bering Sea (EBS) and Aleutian Islands (AI) regions increased during the 1970s reaching an initial peak of over 24,000 mt in 1978 (see BSAI SAFE Table 3). Atka mackerel became a reported species group in the BSAI Fishery Management Plan in 1978. Catches (including discards) 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 14.1. Table 14.2 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.

14.2.2 Description of the Directed Fishery

The patterns of the Atka mackerel fishery generally reflect the behavior of the species: (1) the fishery is highly localized and usually occurs in the same few locations each year; (2) the schooling semi-pelagic nature of the species makes it particularly susceptible to trawl gear fished on the bottom; and (3) trawling occurs almost exclusively at depths less than 200 m. In the early 1970s, most Atka mackerel catches were made in the western Aleutian Islands (west of 180°W longitude). In the late 1970s and through the 1980s, fishing effort moved eastward, with the majority of landings occurring near Seguam and Amlia Islands. In 1984 and 1985 the majority of landings came from a single 1/2°latitude by 1° longitude block bounded by 52°30'N, 53°N, 172°W, and 173°W in Seguam Pass (73% in 1984, 52% in 1985). Areas fished by the Atka mackerel fishery from 1977 to 1992 are displayed in Fritz (1993). Areas of 2002 fishery operations are shown in Figure 14.1.

14.2.3 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 14.1). 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. 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. The 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. The injunction was lifted for the 2001 fishery.

14.2.4 Bycatch and Discards

Atka mackerel are not commonly caught as bycatch in other directed fisheries. The largest amounts of discards of Atka mackerel, which are likely under-size fish, occur in the directed Atka mackerel trawl fishery. Atka mackerel are also caught as bycatch in the trawl Pacific cod and rockfish fisheries. The directed Atka mackerel fishery has had low bycatch rates of rockfish (1-5% of the total Atka mackerel catch) and slightly higher bycatch rates of cod (3-15%). There were reports of high discard rates of northern rockfish in the 2001 Atka mackerel fishery. While the 2001 discard of northern rockfish as a total of the Atka mackerel catch was low (1.8%), the actual amount of northern discards (1,037 mt) was about 15% of the 2001 BSAI northern TAC (6,760 mt). The amount of northern rockfish discarded in the Atka mackerel fisheries in 2000 and 2001 were 1,398 and 1,037 mt, 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	
2001*	Atka mackerel	3,832	55,744	59,567	6.4
	All others	551	1,217	1,768	
	All	4,384	56,961	61,344	

*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%
2001			
Retained (mt)	7,632	28,678	19,333
Discarded (mt)	54	3,102	676
Rate	1%	10%	3%

14.2.5 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 2000-2002 fisheries by location are shown in Figures 14.2, 14.3, & 14.5. Length frequency distributions from the 2000 fishery by area and season fished are shown in Figure 14.2. 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.

Length frequency distributions from the 2001 fishery by area and season fished are shown in Figure 14.3. 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 were comprised of 3-year-old fish of the 1998 year class. The recruitment of the 1998 year class was confirmed by the 2001 age composition data (Figure 14.4) which was dominated by the 1995 and 1998 year classes.

Preliminary length frequency distributions from the 2002 fishery by area and season fished are shown in Figure 14.5. Differences in the distributions between the A- and B-seasons are most notable for the Near Islands, Kiska, Petral Bank and Seguam Bank. Fish from Petral Bank were significantly smaller compared to the other areas and also smaller relative to the Petral Bank distributions for 2000 and 2001.

14.2.6 Steller Sea Lions and Atka mackerel Fishery Interactions

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 14.1). 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 2002).

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 14.2.3) 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 tagging surveys have been conducted in August 2000, 2001 and 2002 in the trawl exclusion zone and open area of 541. Additionally, tagging work was extended to Tanaga Pass (area 542) in 2002. These surveys were followed by tag recovery surveys conducted in the trawl exclusion zone of 541 in September 2000, 2001, and 2002, and in the trawl exclusion zone of 542 in September 2002.

14.3 Data

14.3.1 Fishery Data

Fishery data consist of total catch biomass from 1977 to 2002 (Table 14.1), and the age composition of the catch from 1977-2001 (Table 14.3). Catch-at-age (in numbers) was estimated using the length frequencies described above and age-length keys. The formulas used are described by Kimura (1989). As with the length frequencies, the age data for 1980-1981, 1989, 1992-1993, and 1997 presented problems. The commercial catches in 1980 and 1981 were not sampled for age structures, and there were too few age structures collected in 1989, 1992,1993, and 1997 to construct age-length keys. Kimura and Ronholt (1988) used the 1980 survey age-length key 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. The catch-at-age data does not include these years, which did not present a problem for the SAT model.

The most salient features of the estimated catch-at-age (Table 14.3) 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 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 14.3). The most recent 2001 fishery age data show the first appearance in the fishery of the 1998 year class, and the 1995 year class still appears in large numbers (Table 14.3 and Figure 14.4). Preliminary indications are that the 1998 year class is a very strong year class.

14.3.2 Survey Data

Atka mackerel are a difficult species to survey because: (1) they do not have a swim bladder, making them poor targets for hydroacoustic surveys; (2) they prefer hard, rough and rocky bottom which makes sampling with survey bottom trawl gear difficult; and (3) their schooling behavior and patchy distribution result in survey estimates with large variances. Despite these shortcomings, the U.S.-Japan cooperative trawl surveys conducted in 1980, 1983, 1986, and the 1991, 1994, 1997, 2000, and 2002 domestic 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 14.4). 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 14.4), or 77% of the total biomass of Atka mackerel in the Aleutian Islands. This was a 403,000 mt increase over the 1983 biomass estimate for the same stratum-depth interval. The 1986 biomass estimate is associated with a large coefficient of variation (0.63). Due to differences in areal and depth coverage of the surveys, it is not clear how this biomass estimate compares to earlier years.

The most recent biomass estimate from the 2002 Aleutian Islands bottom trawl survey is 772,798 mt, up 51% relative to the 2002 survey estimate (Table 14.5). Previous to this, the 2000 Aleutian Islands bottom trawl survey biomass estimate of 510,857 mt increased about 40% relative to the 1997 survey. The breakdown of the Aleutian biomass estimates by area corresponds to the management sub-districts (541-Eastern, 542-Central, and 543-Western). The increase in biomass in the 2002 survey is mainly attributed to the increase in biomass found in the Eastern area (190,817 mt); in the 2000 survey, biomass in the Eastern area was slightly less than 1000 mt. Relative to the 2000 survey, the 2002 biomass estimates are up 41% in the Western area, down 1% in the Central area, and up 20,597% in the Eastern area (Figure 14.6). The 95% confidence interval about the mean total 2002 Aleutian biomass estimate is 417,072-1,128,523 mt. The coefficient of variation (*CV*) of the 2002 mean Aleutian biomass is 20%, consistent with the *CV*s from the 1997 and 2000 surveys, as are the CVs by area for these surveys (Table 14.5).

The distribution of biomass in the Western, Central, and Eastern Aleutians, and the southern Bering Sea shifted between each of the 1991, 1994, 1997, 2000 and 2002 surveys, and most dramatically in area 541 in the 2000 survey (Figure 14.6). 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). This occurred again in 1997 (95,700 mt) and most recently in 2002 (59,883 mt, Table 14.5). These biomass estimates are a result of large catches from a single haul encountered north of Akun Island in all three surveys. In both 1991 and 1994, the Western area contributed approximately half of the total estimated Aleutian biomass, but dropped to 37% in 1997. The proportion of biomass in the Western area has remained fairly stable since 1997. In 1994, 14% of the Aleutian biomass was found in the Central area compared to 40% in 1991 and up to 65% 2000 survey. The most recent 2002 survey showed the Central area contributing 42% of the Aleutian biomass.

The contribution of Eastern area biomass from the 2002 survey (25%). The 2000 Eastern area biomass estimate (900 mt) was the lowest of all surveys, contributing only 0.2% of the total 2000 Aleutian biomass and represented a 98% decline relative to the 1997 survey. The extremely low 2000 biomass estimate for the Eastern area has not been reconciled, but there are several factors that may have had a significant impact on the distribution of Atka mackerel that were discussed in Lowe et al. (2001). We note that the distribution of Atka mackerel in the Eastern area is patchier; the area specific variances for the Eastern area have always been high relative to the Central and Western areas. Lowe et al. (2001) suggest that a combination of these factors coupled with the typically patchier distribution of 541 Atka mackerel may have impacted the distribution of the fish such that they were not available at the surveyed stations at the time of the survey in the Eastern area.

Areas with large catches of Atka mackerel during the 2000 survey, included Tanaga Pass, south of Amchitka Island, Buldir Island, and Stalemate Bank (Figure 14.7). In the 2002 survey, areas with large catches were located north of Akun Island, Segaum Pass, Tanaga Pass, south of Amchitka Island, Kiska Island, Buldir Island, and Stalemate Bank (Figure 14.7). In the 2002 survey, Atka mackerel were caught with much less patchily distributed relative to previous surveys and were encountered in 55% of the hauls, which is the highest rate of encounter in the survey time series.

The average bottom temperatures measured in the 2000 survey were the lowest of any of the Aleutian surveys, particularly in depths less than 200 m where 99% of the Atka mackerel are caught in the surveys (pers. comm, Harold Zenger, AFSC, Figure 14.8). The average bottom temperatures measured in the 2002 survey were the second lowest of the Aleutian surveys, but significantly higher than the 2000 survey and very similar to the 1994 survey.

There is greater confidence in Atka mackerel biomass estimates from bottom trawl surveys of the groundfish community of the Aleutian Islands (AI) than the Gulf of Alaska (GOA). First, the coefficients of variation of the mean Atka mackerel biomass estimates have been considerably smaller from the recent AI surveys than the recent GOA surveys: 0.29, 0.28 and 0.20 from the 1997, 2000, and 2002 AI surveys, respectively, compared with 0.61, 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%, 33%, and 55% of the hauls in the 1991, 1994, 1997, 2000 and 2002 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 2000 and 2002 bottom trawl surveys revealed a strong east-west gradient in Atka mackerel size, with the smallest fish in the west and progressively larger fish to the east (Figure 14.9). This pattern is also apparent in the fishery data (Figures 14.2-14.5). The 2000 survey found smaller fish in the Western area than did the fishery and the 2002 survey (Figure 14.9). The length distributions of fish in the 2002 survey were somewhat smaller in the Central and Western area compared to the 2002 fishery. Differences in the timing and location of survey and fishery catches may account for the observed differences in Atka mackerel sizes encountered in the east. Smaller sample sizes in these regions may also be a factor. The fishery is currently excluded from Seguam Pass (10 and 20 nm trawl exclusion zones) and fishes almost exclusively southeast of the pass in winter. Recent surveys, conducted in summer, have been unsuccessful in capturing Atka mackerel southeast of the pass in the summer, but have found large fish inside the pass. In general, the observed differences in fish size between the fishery and survey may be due to differences in timing and distribution of the fishery and survey, and related to inshore movements of the reproductive (i.e., larger-sized) fish in summer for spawning. In winter, the population 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 14.10a). The 2002 survey length frequency distributions show bimodal distributions with modes at 27-28 cm which are likely the 1998 year class.

Survey Age Frequencies

The age compositions from the 1991, 1994, 1997 and 2000 Aleutian surveys are shown in Figure 14.10. 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 14.10b). 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

A partial time series of relative indices from the 1980, 1983, 1986, and 1991 Aleutian Islands surveys had previously been used in the stock synthesis assessment. The relative indices of abundance excluded biomass from the 1-100 m depth strata of the Southwest Aleutian Islands region (west of 180°) due to the lack of sampling in this strata in some years. Because the excluded area and depth strata have consistently been found to be areas of high Atka mackerel biomass in later surveys, it was determined that the indices did not provide useful additional information to the model. Analyses to determine the impact of omitting the relative time series in the SAT model showed that results without the relative index are more conservative. The SAT model results corroborated previous assessments which explored the impact of incorporating the early survey index (Lowe 1991). That is, synthesis results showed that including the survey index resulted in higher historical biomass estimates.

14.4 Analytic approach

The 2002 BSAI Atka mackerel stock assessment uses a new modeling approach implemented through the "Stock Assessment Toolbox" (here referred to as SAT). An introduction to SAT and preliminary model runs were presented in September 2002. The SAT is the result of an initiative by the NOAA Fisheries Office of Science and Technology dating back to 1998 and has been adopted in a number of stock assessment settings on the U.S. east coast (Pamela Mace, NMFS, pers. comm.). The toolbox initiative was seen as a way to provide some facility for assessments similar to Methot's stock synthesis approach but with many enhancements that are discussed below.

The conceptual model is similar to the stock synthesis application (Methot 1989, 1990; Fournier and Archibald 1982) first developed for Aleutian Islands Atka mackerel in 1991 (Lowe 1991). Motivation for changing the software is primarily to provide improved algorithms for estimation and better evaluations of assessment uncertainty. The SAT is developed using ADModel Builder language (ADMB, Fournier 1998) and provides many improvements. In particular, past attempts at exploring alternative models for examining fishery and survey selectivities, natural mortality (M), and survey catchability (q) are greatly improved using the ADMB software. Often, selectivity parameters, M, and q present difficult challenges due to their high correlations. Previous assessments demonstrated these difficulties (e.g., Lowe and Fritz 1998). In addition, the specification of catchability in synthesis assumes equivalent standard errors for the survey time series, an assumption that is not commonly met, particularly for Atka mackerel. Finally, in past assessments, calculation of standard errors for key model results (e.g., recruitment, biomass, F_{msy} – related quantities) were not readily available.

The abundance, mortality, recruitment, and selectivity of Atka mackerel were assessed with a stock assessment model constructed with SAT as implemented using the ADMB software. The ADMB is a C++ software language extension and automatic differentiation library. It allows for estimation of large numbers of parameters in non-linear models using automatic differentiation software developed into C++ libraries (Fournier 1998). The optimizer in ADMB is a quasi-Newton routine (Press et al. 1992). The model is determined to have converged when the maximum parameter gradient is less than a small constant (set to 1×10^{-7}). A feature of ADMB and SAT is that it includes post-convergence routines to calculate standard errors (or likelihood profiles) for quantities of interest.

14.4.1 Model structure

The SAT model models catch-at-age with the standard catch equation. The population dynamics follows numbers-at-age over the period of catch history (here 1977-2002) with natural and age-specific fishing mortality occurring throughout the 15-age-groups that are modeled (ages 1-15+). Age 1 recruitment in each year is estimated as deviations from a mean value expected from an underlying stock-recruitment curve (or simple mean). As 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 a penalized log-likelihood. This overall log-likehood (*L*) is the weighted sum of the calculated log-likelihoods for each data component and model penalties. The component weights are inversely proportional to the specified (or in some cases, estimated) variances Appendix Tables A-1 – A-3 provide a description of the variables used, and the basic equations describing the population dynamics of Atka mackerel as they relate to the available data. The quasi[2] likelihood components and the distribution assumption of the error structure are given below:

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

14.4.2 Parameters

Parameters estimated independently

Natural Mortality

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

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

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

An analysis was undertaken to explore alternative methods to estimate natural mortality for Atka mackerel (Lowe and Fritz, 1997). Several methods were employed based on correlationsof *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

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

the surveys. Natural mortality estimates derived from fishery data ranged from 0.05 to 1.13 with a mean of 0.53. Natural mortality estimates, excluding those based on fishery data, ranged from 0.12 to 0.74 with a mean value of 0.34. The current assumed value of 0.3 is consistent with these values. Also, a value of 0.3 is consistent with values of M derived by the methods of Hoenig (1983) and Rikhter and Efanov (1976) which do not rely on growth parameters (Lowe and Fritz, 1997).

In the current assessment, a natural mortality value of 0.3 was used for Models 1-9.Those models assume a fixed, constant value of M. Models 10-14 allow M to be estimated within the Models 10, 11 and 14 assume an informative prior for M with a mean of 0.3 and a coefficient of variation (CV) of 0.05. Models 12 and 13 assume a diffuse prior for M with a mean of 0.3 and a CV of 0.18. This CV was selected based on a subjective evaluation which assumes the probability of M being less than 0.2 and greater than 0.45 is about 1.5%.

Length and Weight at Age

Atka mackerel exhibit large annual and geographic variability in length at age. Because survey data provide the most uniform sampling of the Aleutian Islands region, data from these surveys were used to evaluate variability in growth (Kimura and Ronholt 1988, Lowe et al. 1998). Kimura and Ronholt (1988) conducted an analysis of variance on length-at-age data from the 1980, 1983, and 1986 U.S.-Japan surveys, and the U.S.-U.S.S.R. surveys in 1982 and 1985, stratified by six areas. Results showed length at age was smallest in the west and largest in the east. More recent analyses by Lowe et al. (1998) corroborated differential growth in three sub-areas of the Aleutian Islands and the Western Gulf of Alaska.

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

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

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

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

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

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

The observed differences in the weight-length relationships from the survey and fishery data, particularly in the exponent of length, probably reflect the differences in the timing of sample collection. The survey data were all collected in summer, the spawning period of Atka mackerel when gonad weight would contribute the most to total weight. The fishery data were collected primarily in winter, when gonad weight would be a smaller percentage of total weight than in summer. The average weights-at-age used in the model are given in Table 14.6.

Maturity at Age

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

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

The maturity schedules are given in Table 14.7.

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

Fishing mortality is parameterized to be separable with a year component and an age (selectivity) component in all models except the VPA-type model (Model 6). See Section 14.5 for a description of the models. The selectivity relationship is modeled with a smoothed non-parametric relationship that can take on any shape (with penalties controlling the degree of change and curvature specified by the user; Table A-2). Selectivity is conditioned so that the mean value over all ages will be equal to one. To provide regularity in the age component, a penalty was imposed on sharp shifts in selectivity between ages using the squared second differences. In addition, the age component parameters are assumed constant for the last 6 age groups (ages 10-15). Asymptotic growth is reached at about age 9 to 10 years. Thus, it seemed reasonable to assume that selectivity of fish older than age 10 would be the same. Finally, depending on the model configuration, selectivity was allowed to vary over time. Two types of controls are allowed in configuring the model: selecting the year or years where the selectivity change is allowed to occur and selecting the degree to which selectivity is allowed to change. Both of these features are explored in the set of model configurations evaluated below.

Survey Catchability

For the bottom trawl survey, survey catchability-at-age follows a parameterization similar to the fishery selectivity-at-age presented above (except with no allowance for time-varying selectivity). Here we specified that the average selectivity-at-age for the survey is equal to 1 over ages 4-10. This was done to provide a standardized view of the ages over which catchability applies. Models 1-10 assume a fixed value of 1.0 for the catchability coefficient. Models 11-14 explore the use of a prior on catchability, with a mean of 1.0 and *CVs* of either 0.1 or 0.2.

Recruitment

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

14.5 Model Evaluation

To examine model assumptions, data sensitivities and uncertainty, we evaluated 14 different model configurations (Table 14.8). Model exploration focused on the estimation of fishery selectivity-at-age, natural mortality, and survey catchability-at-age. A summarized list of the models follows:

Model 1 Sept. Model. This is the preliminary model configuration presented in September 2002 to introduce the SAT, but did not include a desired feature of time-varying selectivity and had a very high (artificial) constraint on the fishery and survey selectivity curvature. This model was included as a means to link relationships between past assessments and the new model configurations.

Model 2 Baseline Model. This model is intended to most closely reflect the former stock synthesis model configuration: fishery selectivity-at-age is allowed to change to a large degree (low constraint on fishery selectivity curvature), and is also allowed to change in 1984 and to a lesser degree in 1999, to reflect the shift from a foreign to a domestic fishery (~1984) and the implementation of Steller sea lion regulations in 1999.

Model 3 As Baseline Model but with a moderate constraint on the fishery selectivity-at-age curvature.

Model 4 As Baseline Model but with a high constraint on the fishery selectivity-at-age curvature.

Model 5 Moderate constraint on the fishery selectivity-at-age curvature, and selectivity-at-age is allowed to change *each* year with a moderate constraint.

Model 6 VPA-Type Model. That is, a very low constraint on the fishery selectivity-at-age curvature, and selectivity-at-age is allowed to change *each* year with a low constraint.

Model 7 Reference Model, moderate constraint on the fishery selectivity-at-age curvature, and selectivity-at-age is allowed to change *each* year with a low constraint.

Model 8 Med.-high constraint on the fishery selectivity-at-age curvature, and selectivity-at-age is allowed to change *each* year with a low constraint.

Model 9 High constraint on the fishery selectivity-at-age curvature, and selectivity-at-age is allowed to change *each* year with a low constraint.

Model 10 As Reference Model, but estimating M with an informative prior.

Model 11 As Model 10, but also estimating survey catchability (q) with a moderate prior.

Model 12 As Reference Model, but estimating *M* with a diffuse prior and estimating *q* with a moderate prior.

Model 13 As Reference Model, but estimating *M* and *q* with diffuse priors.

Model 14 As Reference Model, but estimating *M* with an informative prior and estimating *q* with a diffuse prior.

The models can be categorized as follows:

Sept. Model 1 Same as model presented at September Plan Team meeting.

Models 2-4 Explore different levels of constraints on the fishery selectivity-at-age curvature.

Models 5-9 Explore different levels of constraints on the fishery selectivity-at-age curvature in conjunction with allowing selectivity-at-age to change each year.

Models 10-14 Configured as the Reference Model (7) and explore the use of priors on *M* and *q*.

Key results from the models are given in Table 14.9. The Baseline Model 2 from the Model 2-4 group had the best fit (i.e., lower –ln(likelihood function). The limited time-varying selectivity-at-age for Model 2 is shown in Figure 14.11. There is an abrupt change in selectivity in 1984 and very little change noted in 1999, the only 2 years where selectivity is allowed to change. Prior to 1984, selectivity drops abruptly to almost zero after age 7. For Atka mackerel, the estimated selectivity patterns are particularly important in describing their dynamics. There are two features to these selectivity patterns that we believe can be improved upon: 1) the abrupt transitions between ages; and 2) and the lack of differential selectivity for other years.

Models 5-9 allow time-varying selectivity with different levels of constraint on the fishery selectivity-at-age curvature. Model 6, which is essentially a non-separable VPA-type model, had the best fit, but biologically unreasonable selectivity-at-age assumptions (Figure 14.12). The implications of sharp increases and decreases in selectivity between ages are low estimates of historical fishing mortality and a much higher estimate of current biomass. Model 7 had the best fit of the separable models in the group. The moderate constraint on the selectivity-at-age curvature provided biologically reasonable selectivity assumptions that fit the data well. The low constraint on the time component of selectivity allows the model to capture important differences noted through about 1990 (Figure 14.13).

The impact of the different selectivity assumptions between the synthesis model and Model 7 are particularly notable when comparing the difference in magnitude in estimates of $F_{40\%}$ from the current assessment (0.66), relative to the previous synthesis estimate (0.35). The estimate of $F_{40\%}$ is computed based on the most recent selectivity, i.e., the 2002 estimated selectivity for SAT, and an estimated "average" selectivity for the years 1985-2000 for synthesis. These selectivity patterns are compared in Figure (14.14). Fish older than age 9 make up a very small percentage of the population each year (Table 14.10), and the differences in the selectivity assumptions for the older ages are not likely to have a large impact. However, the differences in selectivity for ages 3-6 have a significant impact. It is important to note that the maturity-at-age vector is nearly identical to the former synthesis fishery selectivity. Thus, the current SAT selectivity indicates that the current fishery is harvesting the older, mature population, which translates into much higher reference rates (e.g. $F_{40\%}$ and $F_{35\%}$). We believe the higher selectivities estimated for ages 3-6 in the synthesis model did not appropriately represent the recent fishery, and were an artifact of the model configuration. That is, the former synthesis selectivity configuration allowed time varying selectivity, but the differences were only implemented in the parameters for the descending limb. The synthesis selectivity assumption for the ascending limb is essentially an "average" over the entire time series. The much higher selectivities for ages 3-6 accommodate the fishery age compositions for the early part of the time series (Table 14.11, Figure 14.13).

Model 13 (diffuse priors on both *M* and *q*) of the Model 10-14 group had the best fit. Estimates of *M* for this group range from 0.45 to 0.55 (Model 13). These estimates are substantially higher than the estimates presented in section 14.4.2 . Also, these estimates are much higher than for other groundfish stocks in this region. For example, the estimate of EBS pollock *M* is 0.45 for age 2 fish and 0.3 for ages 3+. The estimate of *M* for Bering Sea/Aleutian Island Pacific cod is 0.37. Estimates of *q* range from 0.779 (Model 13) to 0.985. The high estimates of *M* result in very high estimates of reference fishing mortality rates (e.g., the $F_{40\%}$ fishing mortality rate ranges from 1.813 to 3.806). Similarly, estimates of the 2002 biomass range from 968,500 mt to nearly 2 million mt. Therefore, accepting the results from Models 10-14 at this time may be premature. Further explorations are needed to configure appropriate models with priors on *M* and *q*, perhaps using methods such as Hoenig's and others to illicit appropriate prior distributions. We consider the fixed values of *M* and *q* at 0.3 and 1.0, respectively, to be reasonable and conservative alternatives for ABC recommendations.

We chose Model 7 as our Reference Model based on the following features: 1) fixed value of *M* of 0.3, 2) fixed value of *q* of 1.0, 3) moderate constraint on the fishery selectivity-at-age curvature, 4) allows for differential selectivity each year, and 5) overall best fit of the separable models 5-9. The overall selectivity pattern estimated by synthesis in previous assessments, including the abrupt changes in selectivity between adjacent ages, can be attributed to "parameter drift". That is, certain combinations of selectivity parameters can render other selectivity parameters as having no effect on the likelihood. This can cause these patterns to arise even though they are not easily rationalized from a biological or mechanistic basis. We feel that the gradual transition of selectivity between ages, and the time-varying selectivity is a more appropriate model configuration to explain the dynamics of the Atka mackerel fishery. We believe that the Reference Model significantly improves upon the selectivity assumptions of the Baseline Model, and is a conservative and reasonable representation of BSAI Atka mackerel dynamics given the uncertainty in the estimation of *M* and *q*.

14.6 Model Results

The results discussed below are based on Reference Model 7.

14.6.1 Selectivity

The estimated selectivity at age schedules for the fishery and survey are shown in Figures 14.14 and 14.15, respectively, and given in Table 14.11. The fishery catches consist of fish 3-12 years old, although a 15-year-old fish was found in the 1994 fishery. Previous assessments estimated selectivity for the fishery, with 2 separate dome-shaped patterns with steep ascending and descending limbs reflecting the early foreign and later domestic fisheries (Figure 13.11 in Lowe et al. 2001). Under the current model specification, a dome-shaped fishery selectivity pattern is still evident through 1991 (Figure 14.13). After 1991, fishery selectivity patterns are fairly similar with gradual transitions, particularly between the ages of 3-9. The implementation of Steller sea lion regulations in 1999 did not have a notable effect on the estimation of selectivity. It is evident that the former selectivity assumptions masked notable annual changes before 1992.

Survey catches were mostly comprised of fish 3-9 years old . A 14-year old fish was found in the 1994 survey and a 15-year old fish was found in the 2000 survey, accounting for a drop in selectivity to zero at age 15 under the former stock synthesis model specification (Figure 13.11 in Lowe et al 2001). The current configuration estimates a smoothed dome-shaped selectivity pattern (Figure 14.15). Under stock synthesis, there was a plateau-shaped "curve" for the survey which we believe was an artifact of the model's limited flexibility in modeling selectivity. Model fits to the survey data are still challenging, but we believe the current selectivity assumptions to be more reasonable and the fits to the survey age composition are improved.

14.6.2 Abundance Trend

The estimated time series of total biomass with approximate upper and lower 95% confidence limits are shown in Figure 14.16 and given in Table 14.12. For comparison, the time series of 3+ biomass from the SAT model and last year's assessment are also plotted (Figure 14.17). The corresponding time series of total numbers at age are given in Table 14.10.

A comparison of the age 3+ biomass trend from the SAT model and the previous synthesis model (Figure 14.17), indicates that biomass increased during the late 70s and early 80s and again in the early 90s. However, historic biomass levels differ considerably between the years 1980 and 1998. These differences in biomass levels are attributed to the higher fishing mortalities estimated by SAT, stemming from the different patterns in selectivity assumptions. An evaluation of the differences in results between the stock synthesis and the SAT models (Sept. assessment, Lowe and Ianelli 2002) supports our suggestion that the different selectivity patterns are the reason for the different results between the two models. Recent biomass levels are more similar after 1998. The SAT model estimate of 2002 age 3+ biomass of 384,500 mt is within 13% of the projected 2002 age 3+ biomass from last year's stock synthesis model. It should be noted that the current stock assessment includes the 2001 fishery age composition which was not available for the 2001 stock synthesis assessment. The inclusion of the current fishery age composition data in the SAT model largely contributes to the elevated recent biomass levels, which are more similar to levels estimated with the former synthesis model. A comparison of current biomass levels from the SAT and synthesis models without the 2001 fishery data (Sept. assessment, Lowe and Ianelli 2002), showed a much lower 2002 SAT biomass level relative to the synthesis model results. The stock has shown a declining trend since 1991 which ended in 2000, after which the stock showed a large increase in biomass in 2001.

14.6.3 Recruitment Trend

The estimated time series of age 1 recruits are shown in Figure 14.18. and given in Table 14.13 (along with age-2 values). The strong 1977 year class is most notable, similar in magnitude to the value currently estimated for the 1988 year class. In previous assessments, the stock synthesis model had estimated very high levels of recruitment from strong year classes prior to 1995 (Figure 14.19). Estimates of recruitment from the SAT model relative to the synthesis model are more moderate, and after 1994 are very similar in magnitude. The current model estimates above average (greater than 20% of the mean) recruitment from the 1977, 1986, 1988, 1992, 1995, and 1998 year classes (Figure 14.18). The addition of the 2001 age fishery age composition data shows the most recent above average 1998 year class which showed up in the 2001 fishery length frequency data and the 2000 survey age data (Lowe et al. 2001). The 1998 year class is estimated to be the third largest year class in the time series, after the 1977 and 1988 year classes. The average estimated recruitment from the time series 1978-2000 is 467 million fish and the median is 329 million fish (Figure 14.18). The entire time series of recruitments (1977-2000) includes the 1975-1998 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 (1977-1998 year classes). Projections of biomass are based on estimated recruitments from 1978-1999 using a stochastic projection model described below.

14.6.4 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 14.14 and shown in Figure 14.20.

14.6.5 Model Fit

Comparing the Reference Model with the other separable Models within the Model 5-9 group (excluding Model 6) shows an improved overall goodness of fit (i.e., a lower –ln(likelihood) function; Table 14.9). The coefficient of variation or *CV* (reflecting uncertainty) about the 2002 biomass estimate is 22% and the *CV* on the strength of the 1998 year class is 52% (Table 14.9). Overall estimated recruitment variability for BSAI Atka mackerel is high (0.545 for the Reference Model). Sample size values were fixed at 100 for the fishery data, and 50 for the bottom trawl survey data. The model estimated an average fishery effective sample size (*N*) of 117, which compares well with the fixed value, however the average survey effective *N* was estimated to be 39. The overall residual mean square error (RSME) for the survey is estimated at 0.391 (Table 14.9). The RSME is in line with estimates of sampling-error *CV*s for the survey which range from 15-63% and average 31% over the time series. The sampling-error variances should be considered as minimal estimates. Other sources of uncertainty (e.g., due to spatial variability and environmental conditions) can inflate the uncertainty associated with survey biomass estimates.

Figure 14.21 compares the observed and estimated survey biomass abundance values. The model fit the 1986 and 2002 survey estimates very poorly. The catch-at-age data do not show another strong year class following the 1977 year class that would allow the model to achieve a better fit to the 1986 survey estimate. This lack of fit is confounded by the large coefficient of variation associated with the 1986 biomass estimate (63%). The large decrease in biomass from the 1994 to 1997 surveys appears to be consistent with recruitment patterns, while the large increase in biomass from the 2000 to 2002 surveys appears to be inconsistent with the recent recruitment patterns. Although the 1998 year class appears to be above average, the 51% increase in biomass observed between the 2000 and 2002 surveys appears to be inconsistent with the other data. In fact, the model prediction is slightly lower than the lower 95% confidence bound (based on sampling error alone) for the 2002 survey (Figure 14.21). We therefore evaluated a model run where we artificially reduced the uncertainty of the 2002 survey estimate by a factor of 3 and tuned the model. This resulted in a near perfect fit to the 2002 survey estimate but substantially degraded the fit to the fishery age composition data. It also increased the estimate of current stock size by over 50% and the projected maximum permissible ABC for 2003 by over 65% compared to Model 7. Based on this, we felt that the lack of fit to the recent estimate was reasonable in a statistical sense and also provided an extra measure of precaution.

The fits to the fishery and survey age compositions for Model 7 are depicted in Figures 14.22 and 14.23. The model fits the fishery age composition data quite well and the survey age composition data slightly less so. This reflects the fact that the sample sizes for age and length composition data are higher for the fishery than the survey. These figures also highlight the patterns in changing age compositions over time. Note that the older age groups in the fishery age data are largely absent until around 1985 when the 1977 year class appears. It is also interesting to note that in the 2000 survey they found much larger than expected number of 2-year old fish (1998 year class) for which the selectivity is estimated to be relatively low (0.18). The expected 3-year olds (1997 year class) in 2000 were somewhat lower than expected even though the estimated selectivity is about 65% (Figure 14.15).

14.7 Projections and harvest alternatives

14.7.1 Reference fishing mortality rates and yields

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC (*max* F_{ABC}). The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. The overfishing and maximum allowable ABC fishing mortality rates are given in terms of percentages of unfished female spawning biomass ($F_{SPR\%}$), on fully selected age groups. The associated long-term average female spawner biomasses that would be expected under average estimated recruitment from 1978-2000 (467 million age 1 recruits) and F equal to $F_{40\%}$ and $F_{35\%}$ are denoted $B_{40\%}$ and $B_{35\%}$, respectively. The Tiers require reference point estimates for biomass level determinations. We present the following reference points for BSAI Atka mackerel for Tier 3 of Amendment 56. For our analyses, we selected the following values from Reference Model 7 results computed based on recruitment from post-1976 spawning events:

$B_{100\%}$ = 444,700 mt female spawning biomass

$B_{40\%}$ = 177,900 mt female spawning biomass

$B_{35\%}$ = 155,700 mt female spawning biomass

14.7.2 Specification of OFL and Maximum Permissible ABC

For the Reference Model 7, the projected year 2003 female spawning biomass (SB_{03}) is estimated to be 212,400 mt under the maximum allowable ABC harvest strategy ($F_{40\%}$). (It should be noted that for BSAI Atka mackerel, projected female spawning biomass calculations depend on the harvest strategy because spawning biomass is estimated at peak spawning (August), thus projections incorporate 7 months of the specified fishing mortality rate). The projected 2003 female spawning biomass is well above the $B_{40\%}$ value of 177,900 mt, placing BSAI Atka mackerel in Tier 3a. The maximum permissible ABC and OFL values under Tier 3a are:

Harvest Strategy	FSPR%	Fishing Mortality Rate	2003 Projected yield (mt)
max F_{ABC}	*F40% %*	0.66	82,800
F_{OFL}	*F35%%*	0.84	99,700

14.7.3 ABC Considerations and Recommendation

ABC Considerations

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

1) Stock size as estimated by the age structured model declined approximately 43% over a 9-year period from 1991 to 1999.

2) Trawl survey estimates of biomass are highly variable; the 1997 Aleutian trawl survey biomass estimate was about 40% lower than the 1994 survey estimate, the 2000 and 2002 survey estimates showed 40 and 50% increases respectively, that could not be fit by the stock assessment model.

3) Under an $F_{40\%}$ harvest strategy, 2003 female spawning biomass is projected to be above $B_{40\%}$, but drop below by 2004.

The following considerations are from the current assessment:

4) The uncertainty about the estimate of the 2003 $F_{40\%}$ catch is modest with a *CV* of 31%. The SAT model provides estimates of the standard errors for key output parameters, which we consider a good first approximation of assessment uncertainty and useful for evaluation of abundance patterns.

5) The model's predicted survey biomass trend is extremely conservative relative to the recent (2000 and 2002) observed survey biomass values. The residuals are highly positive. The impact is that the abundance trend is conservative relative to the trend indicated by the bottom trawl survey.

6) The 2001 fishery age composition data show the first appearance in the fishery of the 1998 year class. This year class was also prominent in the 2000 survey age composition data. Currently we estimate the 1998 year class to be the third largest in the time series (*CV*=52%).

ABC Recommendation

We believe the current model configuration as implemented with the ADMB software provides an improved assessment of BSAI Atka mackerel. In particular, we believe the important selectivity assumptions in describing the population dynamics of Atka mackerel are more sensible from a biological and mechanistic standpoint. However, given the factors listed above, we felt that an added conservation measure may be warranted for other considerations. For this reason, we implemented the "constant-buffer" scheme of Dorn et al. (2001). This gave a 2003 yield of 79,600 mt compared to a maximum permissible ABC of 82,800 mt. We noted that the long-term expected catch under the "constant buffer" scheme was about 63,000 mt. As yet a more conservative option, we chose to examine a projection where the 2003 catch was fixed at 63,000 mt. This scenario (as expected) reduced the probability of the biomass dropping below $B_{40\%}$ (Figure. 14.24). This approach we consider as a "cap" where the yield in the upcoming quota year remains at or below the current estimate of the long-term expected yield under a precautionary harvest policy (e.g., as under Tier 3 of Amendment 56). These alternatives are offered as a means for added conservation to encompass other considerations. However, given the current stock size, from a biological perspective (for Atka mackerel) the maximum permissible is acceptable.

The associated 2003 yield associated with the maximum permissible $F_{40\%}$ fishing mortality rate of 0.66 is 82,800 mt, which is our 2003 ABC recommendation for BSAI Atka mackerel.

We note that the ABC recommendation represents a 69% increase over the 2002 ABC which was based on an $F_{52\%}$ harvest strategy. However, given the positive signs from the last two surveys and the fact that the model prediction is substantially below these survey biomass estimates, and the incoming 1998 year class, this level of increase is likely to be precautionary. That is, as the age-composition information from the 2002 survey becomes available along with other data in the coming years, we expect that our current biomass estimate is more likely to be higher rather than lower. Nonetheless, alternative prudent yield levels warrant consideration and include the "constant buffer" scheme value of 79,600 mt and the "cap" level of 63,000 mt. Note that the cap level is nearly two standard deviations below the maximum permissible $F_{40\%}$ value.

14.7.4 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 a 4-survey weighted average to apportion the 2001 ABC. The rationale for the weighting scheme is described in Lowe et al. (2001).

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

	1994	1997	2000	2002	2002 TAC apportionment	4-survey weighted average
541	34.6%	12.3%	0.20%	24.7%	11.2%	**16.8%**
542	14.0%	51.0%	64.6%	42.3%	48.5%	**46.6%**
543	51.4%	36.4%	35.2%	33.0%	40.2%	**36.5%**
Weights	8	12	18	27		

The apportionment of 82,800 mt based on the most recent 4-survey weighted average is:

Eastern (541)	13,900 mt
Central (542)	38,600 mt
Western (543)	30,300 mt

14.7.5 Standard Harvest Scenarios and Projection Methodology

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

For each scenario, the projections begin with the vector of 2002 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2003 using a fixed value of natural mortality of 0.3, the schedules of selectivity estimated in the assessment, and the best available estimate of total (year-end) catch for 2002. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning (August) and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2003, are as follow (A "*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2003 recommended in the assessment to the *max* F_{ABC} for 2003. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 1997-2001 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

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

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

Scenario 6: In all future years, F is set equal to FOFL. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in 2003 or 2) above ½ of its MSY level in 2003 and above its MSY level in 2013 under this scenario, then the stock is not overfished.)

Scenario 7: In 2003 and 2004, 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 2015 under this scenario, then the stock is not approaching an overfished condition.)

14.7.6 Projections and status determination

The projected age 3+ biomass at the beginning of 2003 is 358,300 mt, and the projected 2003 female spawning biomass is 212,400 mt. The projected yields, female spawning biomass, and the associated fishing mortality rates for the seven harvest strategies are shown in Table 14.15. Under a harvest strategy of $F_{40\%}$ (Scenario 1), female spawning biomass is projected to be above $B_{40\%}$ in 2003, but drop slightly (less than 5%) below in 2004. Female spawning biomass is also projected to drop below $B_{40\%}$ when fishing at F_{OFL} (Scenarios 6 & 7, Table 14.15). It should be noted that in the projections, the fishing mortality rates are prescribed on the basis of the harvest scenario and the spawning biomass in each year. Thus, fishing mortality rates may not be constant within the projection if spawning biomass drops below $B_{40\%}$ in any run.

The associated long-term average female spawner biomass that would be expected under average estimated recruitment from 1978-1999 (467 million recruits) and $F = F_{35\%}$, denoted $B_{35\%}$ is estimated to be 155,700 mt. This value ($B_{35\%}$), is used in the status determination criteria. Female spawning biomass for 2003 (212,400 mt) is projected to be above $B_{35\%}$ thus, the BSAI Atka mackerel stock is determined to be *above* its minimum stock size threshold (MSST) and is *not overfished*. Female spawning biomass for 2015 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*.

14.8 Future considerations

The toolbox provides a relatively easy interface to a powerful assessment model similar in flavor to stock synthesis. Enhancements under the toolbox include the facility to evaluate estimates of uncertainty, and to provide a more robust estimation method with less chance for false convergence. This is due to the fact that the toolbox model is constructed using automatic differentiation algorithms so that the needed derivatives can be easily (and automatically) computed for maximizing the likelihood of a model given a set of data. Additionally, prior specifications of natural mortality and survey catchability are easily implemented and will assist in doing a more thorough risk assessment for making ABC recommendations (e.g., as in the Pacific. cod assessment, Thompson et al. 1998, but with greater facility). Finally, evaluation of stock-recruitment relationships are easier, as are catch projections for MSST and overfishing determinations.

Future considerations include: 1) a complete risk-averse evaluation of key model uncertainties related to natural mortality and survey catchability, 2) exploring time-varying selectivity for the survey, 3) exploration of differential natural mortality at age, and 4) continued evaluation of model sensitivity to a number of input specifications.

14.9 Acknowledgements

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14.10 Summary

2003 (Tier 3a)			
Maximum permissible ABC:	$F_{40\%}$ = 0.66	yield =	82,800 mt
Recommended ABC:	$F_{40\%}$ = 0.66	yield =	82,800 mt
Overfishing (OFL):	$F_{35\%}$ = 0.84	yield =	99,700 mt
Equilibrium female spawning biomss			
$B_{100\%}$	= 444,700 mt		
$B_{40\%}$	= 177,900 mt		
$B_{35\%}$	= 155,700 mt		
Projected 2003 biomass			
Age 3+ biomass	= 358,300 mt		
Female spawning biomass	= 212,400 mt		

14.11 Literature cited

Alverson, D.L., and M.J. Carney. 1975. A graphic review of the growth and decay of population cohorts. J. Cons. Int. Explor. Mer 36:133-143.

Anderl, D.M., A. Nishimura, and S.A. Lowe. 1996. Is the first annulus on the otolith of the Atka mackerel, Pleurogrammus monopterygius, missing? Fish. Bull. 94:163-169.

Byrd, G. V., J. C. Williams, and R. Walder. 1992. Status and biology of the tufted puffin in the Aleutian Islands, Alaska, after a ban on salmon driftnets. U. S. Fish and Wildlife Service, Alaska Maritime National Wildlife Refuge, Aleutian Islands Unit, PSC 486, Box 5251, FPO AP 96506-5251, Adak, Alaska.

Charnov, E.L. 1993. Life history invariants some explorations of symmetry in evolutionary ecology. Oxford University Press Inc., New York. 167p.

Deriso, R.B., T.J. Quinn II, and P.R. Neal. 1985. Catch-age analysis with auxiliary information. Can. J. Fish. and Aquat. Sci. 42:815-824.

Dorn, M.W., A.B. Hollowed, E. Brown, B. Megrey, C. Wilson and J. Blackburn. 2001. Assessment of the walleye pollock stock in the Gulf of Alaska. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Gulf of Alaska. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Fournier, D. 1998. An Introduction to AD model builder for use in nonlinear modeling and statistics. Otter Research Ltd. PO Box 2040, Sidney BC V8L3S3, Canada, 53p.

Fournier, D., and C. P. Archibald. 1982. A general theory for analyzing catch at age data. Can. J. Fish. Aquat. Sci. 39:1195-1207.

Francis, R.I.C.C. 1992. Use of risk analysis to assess fishery management strategies: a case study using orange roughy (*Hoplostethus atlanticus*) on the Chatham Rise, New Zealand. Can. J. Fish. Aquat. Sci. 49: 922-930.

Fritz, L. W. 1993. Trawl locations of walleye pollock and Atka mackerel fisheries in the Bering Sea, Aleutian Islands, and Gulf of Alaska from 1977-1992. AFSC Processed Report 93-08, NMFS, 7600 Sand Point Way, NE, Seattle, WA 98115. 162 pp.

Fritz, L.W., and S.A. Lowe. 1998. Seasonal distributions of Atka mackerel (Pleurogrammus monopterygius) in commercially-fished areas of the Aleutian Islands and Gulf of Alaska. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-92. 29p.

Gorbunova, N.N. 1962. Razmnozhenie i razvite ryb semeistva terpugovykh (Hexagrammidae) (Spawning and development of greenlings (family Hexagrammidae)). Tr. Inst. Okeanol., Akad. Nauk SSSR 59:118-182. In Russian. (Trans. by Isr. Program Sci. Trans., 1970, p. 121-185 in T.S. Rass (editor), Greenlings: taxonomy, biology, interoceanic transplantation; available from the U.S. Dep. Commer., Natl. Tech. Inf. Serv., Springfield, VA., as TT 69-55097).

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. 82: 898-903.

Kajimura, H. 1984. Opportunistic feeding of the northern fur seal Callorhinus ursinus, in the eastern north Pacific Ocean and eastern Bering Sea. NOAA Tech. Rept. NMFS SSRF-779. USDOC, NOAA, NMFS, 49 pp.

Kimura, D.K. 1989. Variability in estimating catch-in-numbers-at-age and its impact on cohort analysis. P.57-66, In Effects of ocean variability on recruitment and evaluation of parameters used in stock assessment models, R.J. Beamish and G.A. McFarlane (editors), Can. Spec. Pub. Fish. Aquat. 108.

Kimura, D.K., and S. Chikuni. 1987. Mixtures of empirical distributions: an iterative application of the age-length key. Biometrics 43: 23-35.

Kimura D.K. and L.L. Ronholt. 1988. In R.G. Bakkala (editor), Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1987, p. 143-171. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-139.

Lee, J.U. 1985. Studies on the fishery biology of the Atka mackerel Pleurogrammus monopterygius (Pallas) in the north Pacific Ocean. Bull. Fish. Res. Dev. Agency, 34, pp.65-125.

Levada, T.P. 1979. Comparative morphological study of Atka mackerel. Pac. Sci. Res. Inst. Fish. Oceanogr. (TINRO), Vladivostok, U.S.S.R., Unpublished manuscript.

Livingston, P.A., M-S. Yang and G.M. Lang. Unpublished manuscript. Comparison of the role of walleye pollock in groundfish food webs of the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska. NMFS. Alaska Fisheries Science Center, 7600 Sand Point Way NE., Seattle, WA 98115.

Lowe, S. A. 1991. Atka Mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions as Projected for 1992. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Lowe, S. A. 1992. Atka Mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions as Projected for 1993. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Lowe, S.A., D.M. Van Doornik, and G.A. Winans. 1998. Geographic variation in genetic and growth patterns of Atka mackerel, Pleurogrammus monopterygius (Hexagrammidae), in the Aleutian archipelago. Fish. Bull. U.S. 96:502-515.

Lowe, S. and J. Ianelli. 2002. An Application of a NOAA Fisheries Toolbox stock assessment model to Aleutian Islands Atka mackerel. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Lowe, S.A. and L.W. Fritz. 1997. Atka mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions as Projected for 1999. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Lowe, S.A. and L.W. Fritz. 1998. Atka mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions as Projected for 1999. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Lowe, S.A., L.W. Fritz and H. Zenger. 2000. Atka mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Lowe, S.A., R.F. Reuter and H. Zenger. 2001. Atka mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

McDermott, S.F. and S.A. Lowe. 1997. The reproductive cycle of Atka mackerel, Pleurogrammus monopterygius, in Alaska waters. Fish. Bull. U.S. 95:231-333.

Methot, R.D. 1989. Synthetic estimates of historical abundance and mortality for northern anchovy. In E. Edwards and B. Megrey (eds.) Mathematical analysis of fish stock dynamics: reviews and current applications. Amer. Fish. Soc. Symposium 6:66-82.

Methot, R.D. 1990. Synthesis model: An adaptable framework for analysis of diverse stock assessment data. INPFC Bull. 50:259-277.

Morris, B.F. 1981. An assessment of the living marine resources of the central Bering Sea and potential resource use conflicts between commercial fisheries and Petroleum development in the Navarin Basin, Proposed sale No. 83. Anchorage, AK: USDOC, NOAA, NMFS, Environmental Assessment Division.

Morris, B.F., M.S. Alton, and H.W. Braham. 1983. Living marine resources of the Gulf of Alaska: A resource assessment for the Gulf of Alaska/Cook Inlet proposed oil and gas lease sale no. 88. Seattle, WA: USDOC, NOAA, NMFS.

Musienko, L.N. 1970. Razmnozheine i razvitie ryb Beringova morya (Reproduction and development of Bering Sea fishes). Tr. Vses. Nauchno-issled. Inst. Morsk. Rybn. Koz. Okeanogr. 70: 161-224 In P.A. Moiseev (ed.), Soviet fisheries investigations in the northeastern Pacific, Pt. 5, Avail. Natl. Tech. Info. Serv., Springfield, VA as TT 74-50127.

Nichol D.G., Somerton D.A. 2002. Diurnal vertical migration of the Atka mackerel *Pleurogrammus monopterygius* as shown by archival tags. Mar Ecol Prog Ser 239: 193-207.

NMFS. 1995. Status review of the Unites States Steller sea lion (Eumetopias jubatus) population. National Marine Mammal Laboratory, Alaska Fishery Science Center, National Marine Fisheries Service, 7600 Sand Point Way, NE, Seattle, WA 98115.

Pauly, D. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. Int. Explor. Mer 39(2):175-192.

Rikhter, V.A., and V.N. Efanov. 1976. On one of the approaches to estimation of natural mortality of fish populations. ICNAF Res. Doc. 76/VI/8. Serial N. 3777. 13p.

Roff, D.A. 1986. The evolution of life history parameters in teleosts. Can. J. Fish. Aquat. Sci. 41:989-1000.

Sinclair E.H. and T.K. Zeppelin 2002. Seasonal and spatial differences in diet in the western stock of Steller sea lions (*Eumetopias jubatus*). Journal of Mammalogy 83(4).

Press, W.H., S.A. Teukolsky, W.T. Vetterling, and B.P. Flannery. 1992. Numerical recipes in C. Second ed. Cambridge University Press. 994p.

Thompson, G.G. and M.W. Dorn. 1998. Pacific Cod. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions as Projected for 1999. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Zolotov, O.G. 1993. Notes on the reproductive biology of Pleurogrammus monopterygius in Kamchatkan waters. J. of Ichthy. 33(4), pp. 25-37.

Tables

Table 14.1. 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.

	Eastern Bering Sea				Aleutian Islands Region				BSAI	
Year	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	0	0	a	a	a	0	56,634	56,634	56,634	69,300
2002[c]	0	0	a	a	a	0	42,055	42,055	42,055	49,000

Catch table footnotes:
a) Eastern Bering Sea catches included with Aleutian Islands.
b) Atka mackerel was not a reported species group until 1978
c) 2002 data as of 10/12/02 from NMFS Alaska Regional Office

Table 14.2 Research catches (mt) of Atka mackerel from NMFS trawl surveys in the Aleutian Islands.

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

Table 14.3 Estimated catch-in-numbers at age (in millions) of Atka mackerel from the Aleutian Islands. These data were used to tune the age-structured analysis.

Age	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1977	6.83	31.52	20.06	15.11	1.22	0.39	0.20	---	---	---	---	---	---	---
1978	2.70	60.16	15.57	9.22	3.75	0.59	0.34	0.11	---	---	---	---	---	---
1979	0.01	4.48	26.78	13.00	2.20	1.11	---	---	---	---	---	---	---	---
1980	---	12.68	5.92	7.22	1.67	0.59	0.24	0.13	---	---	---	---	---	---
1981	---	5.39	17.11	0.00	1.61	8.10	---	---	---	---	---	---	---	---
1982	---	0.19	2.63	25.83	3.86	0.68	---	---	---	---	---	---	---	---
1983	---	1.90	1.43	2.54	10.60	1.59	---	---	---	---	---	---	---	---
1984	0.09	0.98	7.30	7.07	10.79	21.78	2.21	0.96	---	---	---	---	---	---
1985	0.63	15.97	8.79	9.43	6.01	5.45	11.69	1.26	0.27	---	---	---	---	---
1986	0.37	11.45	6.46	4.42	5.34	4.53	5.84	9.91	1.04	0.85	---	---	---	---
1987	0.56	10.44	7.60	4.58	1.89	2.37	2.19	1.71	6.78	0.53	0.22	---	---	---
1988	0.40	9.97	22.49	6.15	1.80	1.54	0.63	0.96	0.20	0.44	0.04	---	---	---
1989[a]														
1990	---	4.05	12.06	6.79	2.49	0.89	0.19	0.13	0.05	0.02	0.04	0.16	0.03	---
1991	---	1.96	5.58	10.11	5.90	3.06	1.29	0.27	0.41	0.40	0.09	---	---	---
1992[a]														
1993[a]														
1994	0.03	9.57	6.95	24.00	39.77	4.57	9.42	6.59	4.26	0.61	0.27	0.00	0.00	0.03
1995	0.24	19.04	41.27	9.78	14.85	27.63	3.57	4.01	5.36	2.04	---	---	---	---
1996	0.03	3.45	65.69	22.31	12.77	20.87	31.93	3.02	3.60	2.64	0.51	0.05	---	---
1997[a]														
1998	---	11.34	18.95	17.30	31.93	11.65	4.15	3.83	5.58	0.47	0.85	0.76	---	---
1999	1.22	1.02	38.78	9.74	7.77	11.17	4.49	1.57	1.06	1.13	0.16	0.13	---	---
2000	0.56	7.74	5.11	23.73	6.94	3.80	7.41	1.89	0.81	0.53	0.32	0.32	---	---
2001	1.55	20.31	11.06	7.17	23.74	6.70	3.98	3.80	0.72	0.33	0.078	0.10	---	---

[a] Too few fish were sampled for age structures in 1989, 1992, 1993, and 1997 to construct age-length keys (see Section 14.3.1).

Table 14.4 Atka mackerel estimated biomass in metric tons from the bottom trawl survey, by subregion, depth interval, and survey year, with the corresponding coefficients of variation.

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

Table 14.5 Atka mackerel biomass (mt), and the percentage distribution and coefficients of variation by management area from the bottom trawl surveys in the Aleutian Islands in 1991, 1994, 1997, 2000, and 2002. Biomass is also reported by survey depth interval.

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

Table 14.6 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	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Survey	0.184	0.398	0.549	0.656	0.732	0.785	0.823	0.85	0.869	0.882	0.892	0.899	0.903	0.907
Fishery	0.128	0.421	0.66	0.756	0.794	0.81	0.816	0.818	0.819	0.82	0.82	0.82	0.82	0.82

Table 14.7 Schedules of age and length specific maturity of Atka mackerel from McDermott and Lowe (1997) by Aleutian Islands subareas. Eastern - 541, Central - 542, and Western - 543.

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

Table 14.8 Summary of key changes between different Atka mackerel model configurations.

Model	Age component of selectivity constraint	Fishery selectivity change frequency (over time)	Time component fishery selectivity constraint	Est M?	Est Q?	M Prior	Q Prior
Sept	Very High	None	NA	No	No	NA	NA
2	Low	2 times (1984 & 1999)	Low & medium	No	No	NA	NA
3	Medium	2 times (1984 & 1999)	Low & medium	No	No	NA	NA
4	High	2 times (1984 & 1999)	Low & medium	No	No	NA	NA
5	Medium	All years	Medium	No	No	NA	NA
6	Low	All years	Low	No	No	NA	NA
7	Medium	All years	Low	No	No	NA	NA
8	Med-High	All years	Low	No	No	NA	NA
9	High	All years	Low	No	No	NA	NA
10	Medium	All years	Low	Yes	No	Inform	NA
12	Medium	All years	Low	Yes	Yes	Inform	Moderate
13	Medium	All years	Low	Yes	Yes	Diffuse	Moderate
14	Medium	All years	Low	Yes	Yes	Diffuse	Diffuse

Table 14.9. Estimates of key results for some of the Atka mackerel models evaluated for this assessment. Coefficients of variation (*CV*) of values appearing directly above are given in parentheses.

	Sept.	Baseline					Reference							
	Model_1	Model_2	Model_3	Model_4	Model_5	Model_6	Model_7	Model_8	Model_9	Model_10	Model_11	Model_12	Model_13	Model_14
Fishing mortalities (full selection)														
F 2002	0.238	0.217	0.225	0.262	0.397	0.253	0.373	0.640	0.831	0.354	0.346	0.341	0.275	0.332
F 2002/$F_{40\%}$ %	0.588	0.524	0.535	0.592	0.647	0.436	0.562	0.725	0.841	0.192	0.189	0.091	0.072	0.183
$F_{40\%}$ %	0.405	0.414	0.420	0.443	0.615	0.580	0.663	0.882	0.989	1.847	1.835	3.750	3.806	1.813
CV	(16%)	(19%)	(21%)	(26%)	(33%)	(33%)	(46%)	(46%)	(45%)	(53%)	(53%)	(59%)	(59%)	(53%)
$F_{35\%}$%	0.488	0.501	0.511	0.543	0.772	0.715	0.836	1.119	1.253	2.347	2.331	4.772	4.839	2.302
CV	(17%)	(20%)	(22%)	(27%)	(35%)	(36%)	(48%)	(48%)	(47%)	(53%)	(54%)	(59%)	(60%)	(54%)
Stock abundance														
Initial Biomass (1977)	332,480	267,970	244,020	201,020	226,790	517,920	281,460	181,760	154,210	658,430	667,930	1,215,600	1,507,300	686,180
CV	(18%)	(22%)	(22%)	(23%)	(22%)	(19%)	(21%)	(19%)	(11%)	(25%)	(26%)	(35%)	(43%)	(29%)
2002 total biomass	524,420	562,490	540,910	482,270	445,930	679,840	497,540	393,700	344,790	968,470	981,020	1,645,400	1,997,900	1,005,200
CV	(19%)	(20%)	(20%)	(25%)	(25%)	(15%)	(22%)	(28%)	(30%)	(21%)	(23%)	(31%)	(38%)	(26%)
2003 Age 3+ biomass	388,822	421,616	398,603	346,245	315,398	521,409	358,303	268,690	226,680	749,359	759,684	1,306,767	1,596,050	779,576
1998 year class (at age 1)	786	925	944	880	799	926	850	725	646	2,287	2,320	4,978	6,289	2,382
CV	(47%)	(52%)	(51%)	(55%)	(57%)	(48%)	(52%)	(61%)	(65%)	(62%)	(64%)	(87%)	(102%)	(69%)
Recruitment Variability	0.604	0.642	0.641	0.648	0.593	0.422	0.545	0.616	0.647	0.494	0.494	0.483	0.480	0.493
Projected catch (unadjusted)														
F50% 2003 catch	55,904	63,338	62,097	55,660	50,152	77,882	56,769	42,133	35,361	141,390	143,530	258,380	317,370	147,650
CV	(26%)	(27%)	(28%)	(33%)	(36%)	(25%)	(32%)	(42%)	(47%)	(30%)	(32%)	(36%)	(42%)	(34%)
F40% 2003 catch	76,485	87,412	86,075	78,013	72,760	109,620	82,749	62,268	52,327	200,310	203,240	354,070	432,230	208,860
CV	(26%)	(27%)	(28%)	(33%)	(36%)	(25%)	(31%)	(41%)	(45%)	(29%)	(30%)	(34%)	(40%)	(33%)
F35% 2003 catch	89,528	102,750	101,410	92,387	87,489	130,360	99,655	75,221	63,161	235,210	238,590	408,210	496,820	245,090
CV	(26%)	(27%)	(28%)	(33%)	(35%)	(25%)	(31%)	(40%)	(45%)	(28%)	(30%)	(34%)	(39%)	(32%)
Survey catchability	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.985	0.930	0.779	0.959
Natural mortality	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.446	0.447	0.553	0.572	0.449
Fishery Average Effective N	63	68	66	67	98	467	117	94	80	111	110	108	107	110
Survey Average Effective N	33	61	57	42	38	53	39	39	39	41	41	42	42	41
RMSE Survey	0.376	0.373	0.394	0.483	0.497	0.219	0.391	0.606	0.693	0.205	0.204	0.184	0.176	0.203
Number of Parameters	110	124	124	124	354	354	354	354	354	355	356	356	356	356
-log likelihoods														
Survey index	5.34	3.56	3.28	4.03	5.18	2.39	3.85	7.12	8.66	1.85	1.82	1.80	1.59	1.79
Catch biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fishery age comp	196.56	157.03	175.98	191.28	173.64	57.00	147.48	177.49	199.77	142.49	142.51	141.04	140.79	142.54
Survey age comp	37.12	25.40	25.07	29.11	32.32	33.44	33.04	31.82	31.88	33.60	33.57	33.45	33.00	33.52
Sub total	239.02	185.98	204.33	224.42	211.13	92.83	184.37	216.44	240.31	177.93	177.90	176.29	175.37	177.85
-log Penalties														
Recruitment	-0.337	1.206	1.170	1.472	-0.855	-9.707	-3.048	0.118	1.395	-5.573	-5.603	-6.152	-6.339	-5.657
Selectivity constraint	35.568	0.369	25.583	36.931	69.968	3.030	79.878	86.418	89.045	81.091	81.138	81.855	82.269	81.225
Fishing mortality penalty	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Prior	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4.268	4.338	1.230	1.759	4.462
Total	513.278	373.538	435.411	487.249	491.381	178.982	445.562	519.407	571.053	435.652	435.680	429.504	428.436	435.728

Table 14.10. Estimated Atka mackerel numbers at age in millions, 1977-2002 based on Model 7.

	1	2	3	4	5	6	7	8	9	10+	Total	% of 10+
1977	208	221	176	50	38	21	19	17	14	49	812	6%
1978	1124	153	160	118	30	22	13	13	12	45	1689	3%
1979	327	830	111	107	74	18	14	9	9	40	1537	3%
1980	213	242	608	78	67	45	11	9	6	34	1313	3%
1981	246	157	178	437	53	43	29	7	6	29	1185	2%
1982	165	182	116	129	309	37	29	18	5	25	1014	2%
1983	242	122	134	85	93	211	25	20	13	22	967	2%
1984	329	179	90	99	62	66	148	18	15	25	1031	2%
1985	501	244	132	65	68	40	40	92	12	28	1221	2%
1986	476	371	178	90	41	41	24	25	58	26	1330	2%
1987	632	352	272	126	60	26	25	14	15	53	1575	3%
1988	395	468	259	193	84	38	16	16	9	42	1520	3%
1989	1111	293	345	186	130	56	26	11	11	35	2204	2%
1990	507	823	216	251	131	89	38	18	8	32	2114	2%
1991	269	375	608	157	174	89	62	27	13	28	1803	2%
1992	528	199	278	446	111	118	60	42	19	29	1829	2%
1993	762	391	147	202	312	73	73	37	26	30	2052	1%
1994	282	563	288	106	140	201	43	42	21	32	1719	2%
1995	313	209	415	207	72	87	119	25	24	30	1500	2%
1996	694	231	153	292	128	42	50	66	14	28	1698	2%
1997	157	513	169	107	177	70	21	22	28	18	1283	1%
1998	322	116	376	120	71	105	37	10	11	22	1189	2%
1999	850	238	85	269	79	41	57	20	5	16	1660	1%
2000	288	629	175	60	171	47	23	32	11	11	1446	1%
2001	313	213	463	125	40	105	27	13	17	12	1329	1%
2002	343	231	156	326	81	23	55	13	6	15	1251	1%

Table 14.11. 1977-2002 estimates of Atka mackerel fishery (over time) and survey selectivity for Model 7. These are full-selection (maximum value = 1.0) estimates.

	Age														
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1977	0.02	0.11	0.41	0.88	1.00	0.72	0.45	0.30	0.21	0.18	0.18	0.18	0.18	0.18	0.18
1978	0.02	0.11	0.49	0.82	1.00	0.85	0.58	0.38	0.26	0.21	0.21	0.21	0.21	0.21	0.21
1979	0.01	0.05	0.26	0.80	1.00	0.85	0.60	0.39	0.26	0.21	0.21	0.21	0.21	0.21	0.21
1980	0.01	0.05	0.22	0.62	1.00	0.96	0.80	0.55	0.35	0.25	0.25	0.25	0.25	0.25	0.25
1981	0.01	0.03	0.14	0.28	0.37	0.63	1.00	0.56	0.28	0.18	0.18	0.18	0.18	0.18	0.18
1982	0.01	0.03	0.10	0.33	0.89	1.00	0.66	0.40	0.26	0.20	0.20	0.20	0.20	0.20	0.20
1983	0.01	0.04	0.15	0.38	0.69	1.00	0.87	0.49	0.30	0.24	0.24	0.24	0.24	0.24	0.24
1984	0.01	0.03	0.14	0.42	0.76	1.00	0.92	0.64	0.41	0.30	0.30	0.30	0.30	0.30	0.30
1985	0.01	0.06	0.40	0.84	1.00	1.00	0.92	0.79	0.65	0.54	0.54	0.54	0.54	0.54	0.54
1986	0.01	0.04	0.23	0.49	0.69	0.83	0.96	1.00	0.83	0.64	0.64	0.64	0.64	0.64	0.64
1987	0.01	0.04	0.24	0.55	0.76	0.84	0.93	1.00	0.98	0.94	0.94	0.94	0.94	0.94	0.94
1988	0.01	0.05	0.32	0.99	1.00	0.86	0.82	0.77	0.74	0.68	0.68	0.68	0.68	0.68	0.68
1989	0.01	0.04	0.20	0.58	0.94	1.00	0.88	0.75	0.67	0.63	0.63	0.63	0.63	0.63	0.63
1990	0.00	0.03	0.23	0.79	1.00	0.78	0.64	0.57	0.54	0.53	0.53	0.53	0.53	0.53	0.53
1991	0.00	0.02	0.09	0.42	0.88	1.00	0.84	0.70	0.61	0.58	0.58	0.58	0.58	0.58	0.58
1992	0.01	0.03	0.10	0.30	0.66	0.95	1.00	0.96	0.91	0.87	0.87	0.87	0.87	0.87	0.87
1993	0.01	0.03	0.09	0.26	0.55	0.88	1.00	0.98	0.97	0.99	0.99	0.99	0.99	0.99	0.99
1994	0.01	0.02	0.10	0.31	0.64	0.82	0.85	0.95	1.00	0.98	0.98	0.98	0.98	0.98	0.98
1995	0.00	0.03	0.14	0.47	0.63	0.68	0.75	0.82	0.90	1.00	1.00	1.00	1.00	1.00	1.00
1996	0.00	0.02	0.10	0.36	0.54	0.71	0.90	1.00	0.96	0.93	0.93	0.93	0.93	0.93	0.93
1997	0.01	0.02	0.08	0.24	0.47	0.71	0.85	0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1998	0.00	0.02	0.08	0.30	0.59	0.77	0.86	0.92	0.97	1.00	1.00	1.00	1.00	1.00	1.00
1999	0.00	0.02	0.12	0.45	0.67	0.78	0.84	0.93	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2000	0.00	0.02	0.12	0.36	0.63	0.79	0.90	1.00	0.98	0.94	0.94	0.94	0.94	0.94	0.94
2001	0.01	0.03	0.12	0.31	0.58	0.82	0.97	1.00	0.94	0.89	0.89	0.89	0.89	0.89	0.89
2002	0.01	0.03	0.10	0.26	0.51	0.78	0.95	1.00	0.96	0.92	0.92	0.92	0.92	0.92	0.92
Survey	0.03	0.16	0.57	0.91	0.99	0.98	1.00	0.92	0.74	0.66	0.66	0.66	0.66	0.66	0.66

Table 14.12. Model 7 estimates of Atka mackerel biomass with approximate lower and upper 95% confidence bounds for age 1+ biomass. Also included is the age 3+ biomass.

	Total Biomass (Age 1+)			Biomass
Year		LCI	UCI	Age 3+
1977	281,460	161,520	401,400	221,470
1978	384,110	232,322	535,898	234,505
1979	383,330	229,038	537,622	224,903
1980	495,080	304,756	685,404	413,785
1981	540,360	337,520	743,200	437,183
1982	499,160	312,258	686,062	411,081
1983	455,370	286,506	624,234	382,425
1984	425,190	273,124	577,256	344,971
1985	402,380	261,418	543,342	303,778
1986	401,360	267,550	535,170	289,101
1987	458,710	327,776	589,644	326,024
1988	496,750	371,632	621,868	362,386
1989	626,780	507,632	745,928	435,913
1990	660,910	550,336	771,484	455,770
1991	742,510	633,904	851,116	615,033
1992	787,760	678,204	897,316	637,109
1993	749,430	642,360	856,500	563,507
1994	670,130	565,882	774,378	527,414
1995	653,370	538,964	767,776	550,782
1996	615,190	487,296	743,084	466,733
1997	486,210	360,824	611,596	369,263
1998	486,310	339,826	632,794	404,857
1999	500,360	332,384	668,336	342,854
2000	450,990	282,974	619,006	312,197
2001	506,110	302,550	709,670	413,724
2002	497,540	282,000	713,080	384,510
2003				358,303

Table 14.13 Estimates of age-1 and age-2 Atka mackerel recruitment (in millions) based on Model 7.

Year	Age 1 Recruits
1977	208.0
1978	1,124.0
1979	327.0
1980	212.6
1981	245.7
1982	164.7
1983	242.2
1984	329.2
1985	501.4
1986	476.1
1987	632.4
1988	395.4
1989	1,110.9
1990	506.9
1991	268.9
1992	528.3
1993	761.7
1994	282.0
1995	312.6
1996	693.6
1997	156.7
1998	321.8
1999	850.4
2000	288.0
Ave 78-00	466.6
Med 78-00	329.2

Table 14.14. Estimates of full-selection fishing mortality rates and exploitation rates for Atka mackerel based on Model 7 results.

Year	F^a	Catch/Biomass Rate[b]
1977	0.238	0.098
1978	0.210	0.103
1979	0.200	0.103
1980	0.139	0.050
1981	0.166	0.045
1982	0.090	0.048
1983	0.054	0.031
1984	0.190	0.105
1985	0.201	0.125
1986	0.221	0.111
1987	0.188	0.092
1988	0.098	0.061
1989	0.082	0.041
1990	0.083	0.049
1991	0.106	0.043
1992	0.185	0.079
1993	0.250	0.117
1994	0.278	0.132
1995	0.374	0.148
1996	0.556	0.223
1997	0.474	0.178
1998	0.407	0.138
1999	0.342	0.156
2000	0.298	0.136
2001	0.419	0.137
2002	0.373	0.124

[a] Full-selection fishing mortality rates.
[b] Catch/biomass rate is the ratio of catch to beginning year age 3+ biomass.
[c] The 2002 catch/biomass rate is based on catch as of 10/12/02

Table 14.15. Projections of Model 7 spawning biomass, *F* and catch for Atka mackerel for the 7 scenarios. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 444,700, 177,900, and 155,700 mt, respectively. Fishing mortality rates given are based on the *average* fishing mortality over all ages.

Sp.Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2002	236,910	236,910	236,910	236,910	236,910	236,910	236,910
2003	212,423	212,423	235,650	232,276	262,002	201,405	212,423
2004	169,704	169,704	213,213	206,063	276,375	154,855	169,704
2005	156,410	156,410	204,143	194,926	293,824	143,097	150,696
2006	166,672	166,672	215,671	204,844	324,012	153,491	155,852
2007	178,862	178,862	231,499	219,298	355,454	164,065	164,668
2008	185,345	185,345	242,622	229,429	381,059	168,746	168,834
2009	186,659	186,659	247,733	233,864	399,220	168,916	168,902
2010	185,702	185,702	249,024	234,738	411,326	167,577	167,562
2011	185,201	185,201	249,564	235,049	420,254	167,072	167,067
2012	185,639	185,639	250,513	235,895	427,602	167,563	167,562
2013	186,473	186,473	251,700	237,035	433,731	168,355	168,355
2014	187,054	187,054	252,638	237,934	438,586	168,837	168,837
2015	185,729	185,729	251,565	236,817	440,490	167,496	167,496
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2002	0.251	0.251	0.251	0.251	0.251	0.251	0.251
2003	0.447	0.447	0.224	0.254	0.000	0.564	0.447
2004	0.425	0.425	0.224	0.254	0.000	0.488	0.425
2005	0.389	0.389	0.222	0.254	0.000	0.447	0.473
2006	0.394	0.394	0.216	0.254	0.000	0.466	0.472
2007	0.403	0.403	0.217	0.254	0.000	0.482	0.484
2008	0.410	0.410	0.218	0.254	0.000	0.492	0.493
2009	0.412	0.412	0.219	0.254	0.000	0.495	0.495
2010	0.411	0.411	0.219	0.254	0.000	0.492	0.492
2011	0.411	0.411	0.219	0.254	0.000	0.491	0.491
2012	0.412	0.412	0.219	0.254	0.000	0.492	0.492
2013	0.412	0.412	0.219	0.254	0.000	0.492	0.492
2014	0.412	0.412	0.219	0.254	0.000	0.493	0.493
2015	0.412	0.412	0.219	0.254	0.000	0.493	0.493
Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2002	47,585	47,585	47,585	47,585	47,585	47,585	47,585
2003	82,790	82,790	45,383	50,966	0	99,707	82,790
2004	68,013	68,013	45,889	50,317	0	70,230	68,013
2005	55,012	55,012	43,702	47,432	0	56,427	64,631
2006	54,811	54,811	42,240	46,280	0	58,203	60,777
2007	58,754	58,754	44,013	47,831	0	63,333	64,085
2008	62,707	62,707	46,770	50,388	0	67,258	67,434
2009	64,409	64,409	48,796	52,331	0	68,503	68,524
2010	64,597	64,597	49,778	53,246	0	68,121	68,115
2011	64,369	64,369	50,124	53,542	0	67,734	67,730
2012	64,430	64,430	50,340	53,672	0	67,799	67,798
2013	64,600	64,600	50,544	53,855	0	68,080	68,080
2014	64,768	64,768	50,716	54,023	0	68,230	68,230
2015	64,712	64,712	50,695	54,029	0	68,092	68,093

Figures

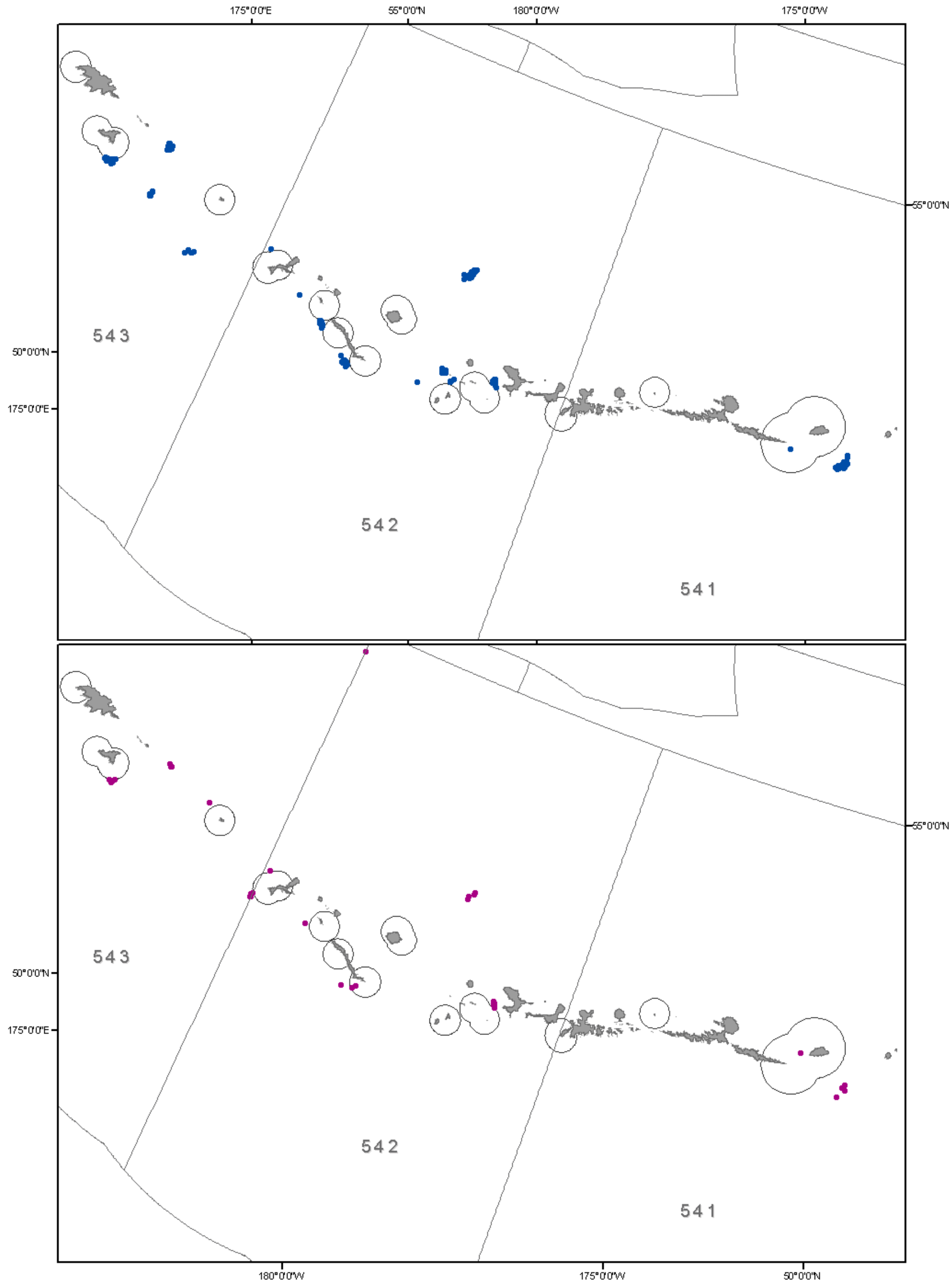


Figure 14.1. Atka mackerel fishery distributions for the 2002 A- (top) and B- (bottom) season fisheries relative to 10-nm Steller sea lion rookery areas.

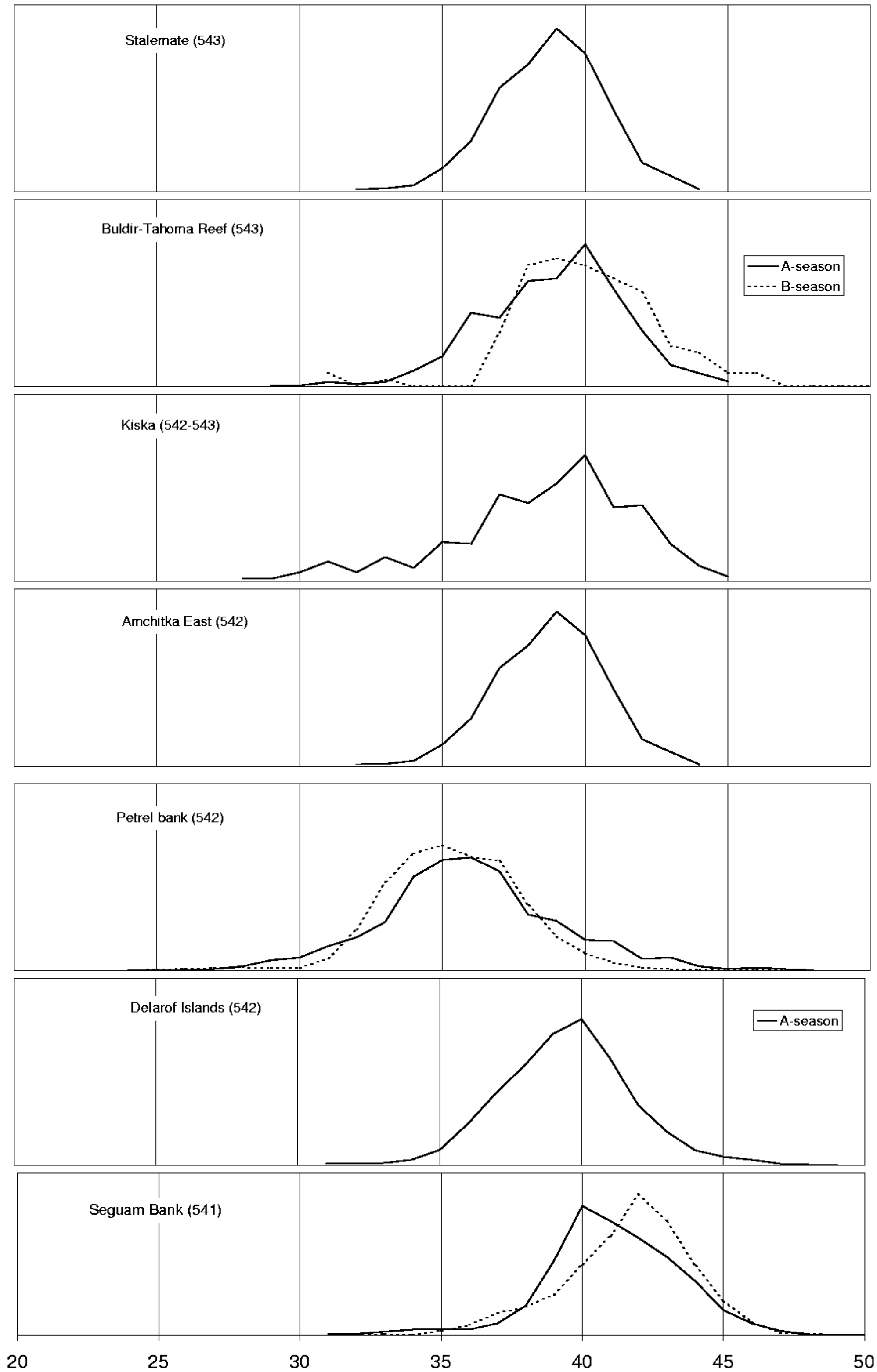


Figure 14.2. 2000 Atka mackerel fishery length-frequency by area fished. (see Figure 14.1). Numbers refer to management areas.

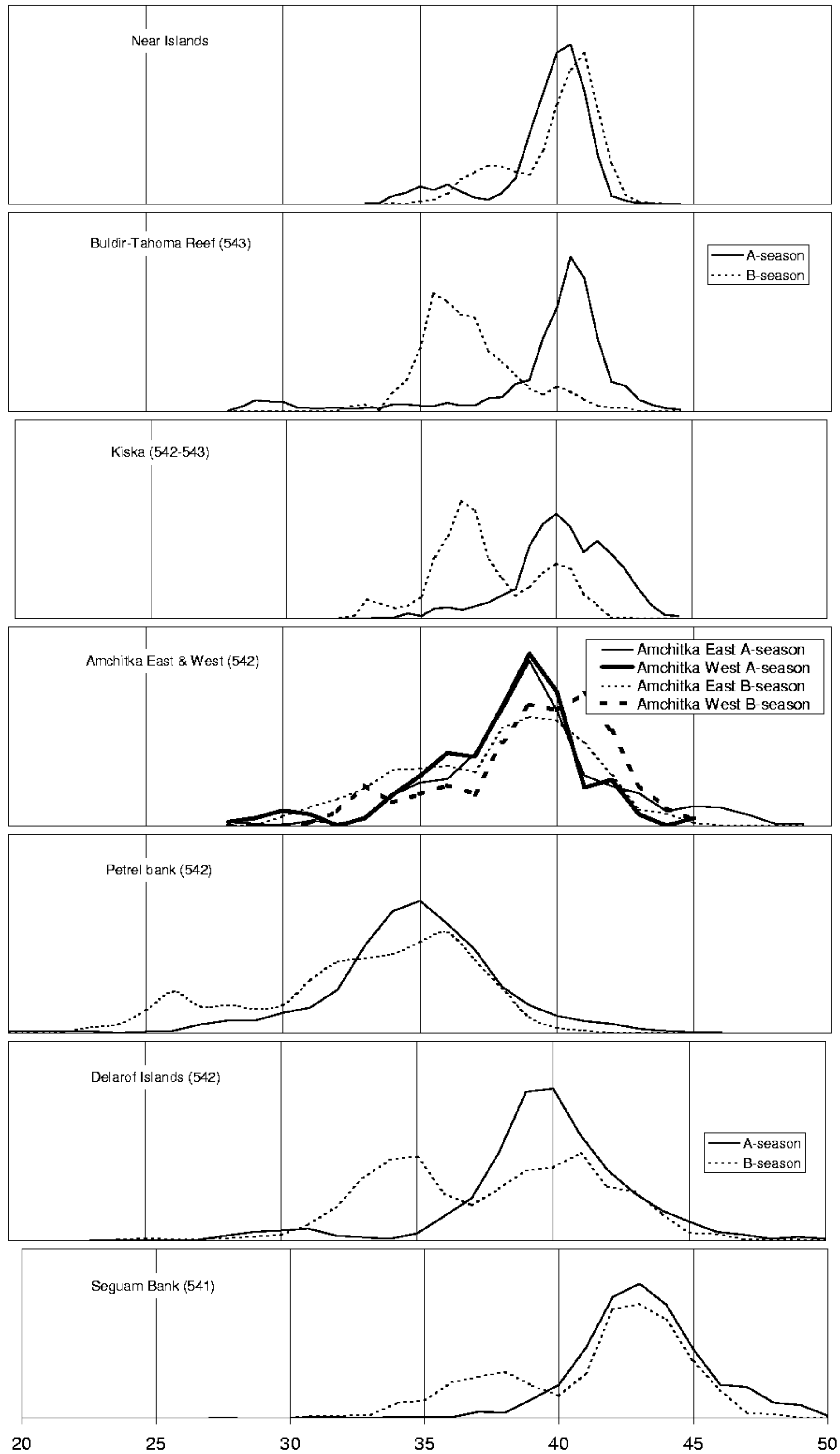


Figure 14.3. 2001 Atka mackerel fishery length-frequency by area fished. (see Figure 14.1). Numbers refer to management areas.

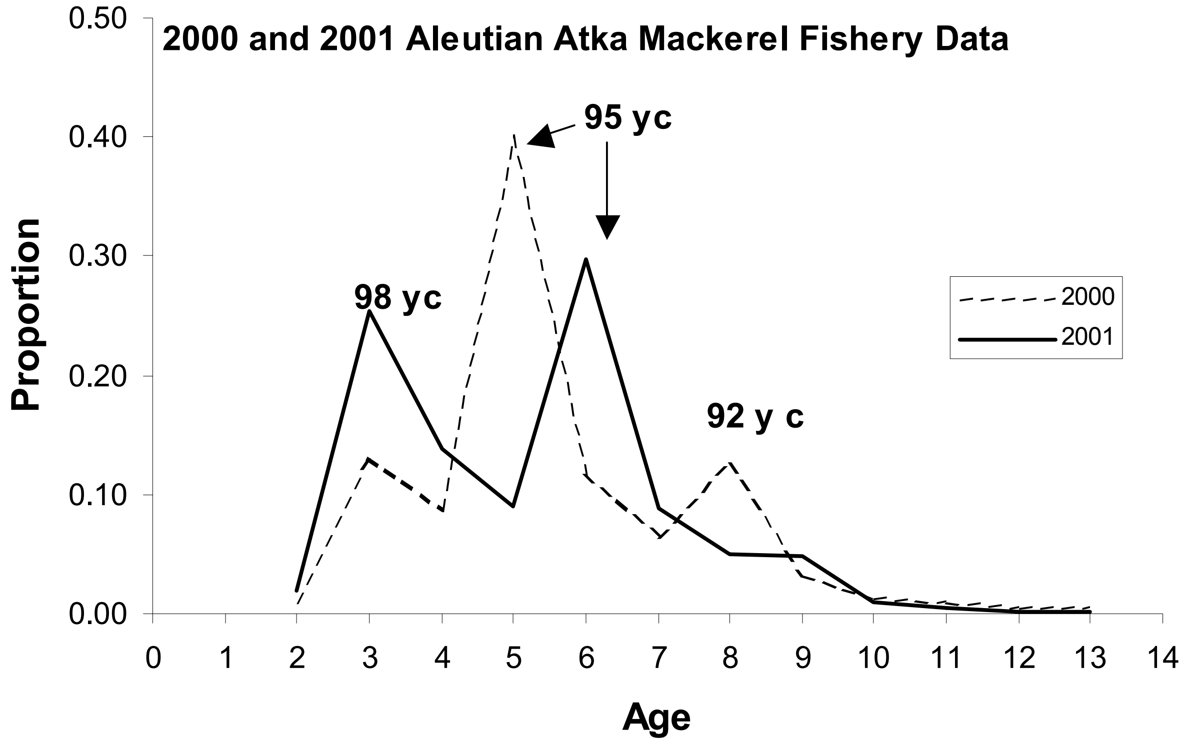


Figure 14.4. 2000 and 2001 Aleutian Atka mackerel fishery age compositon data.

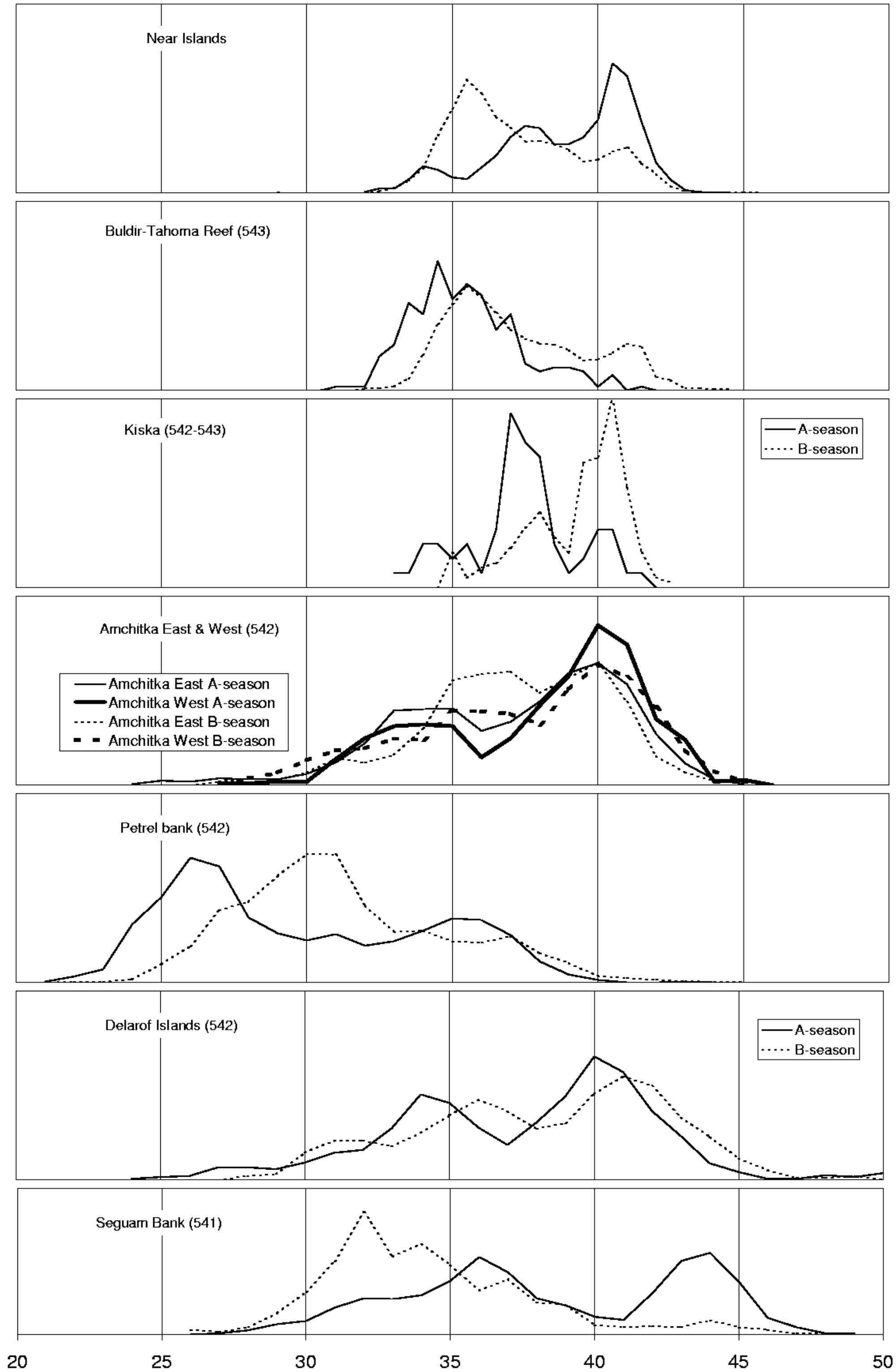


Figure 14.5. 2002 Atka mackerel fishery length-frequency (as of Oct. 28) by area fished. (see Figure 14.1). Numbers refer to management areas.

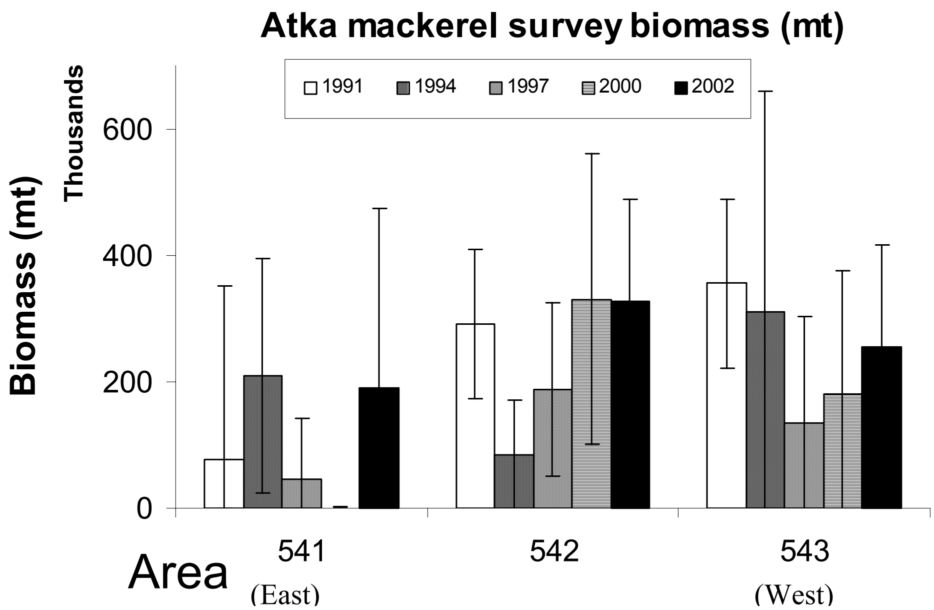


Figure 14.6. Atka mackerel Aleutian survey biomass estimates by area and survey year. Bars represent 95% confidence intervals based on sampling error.

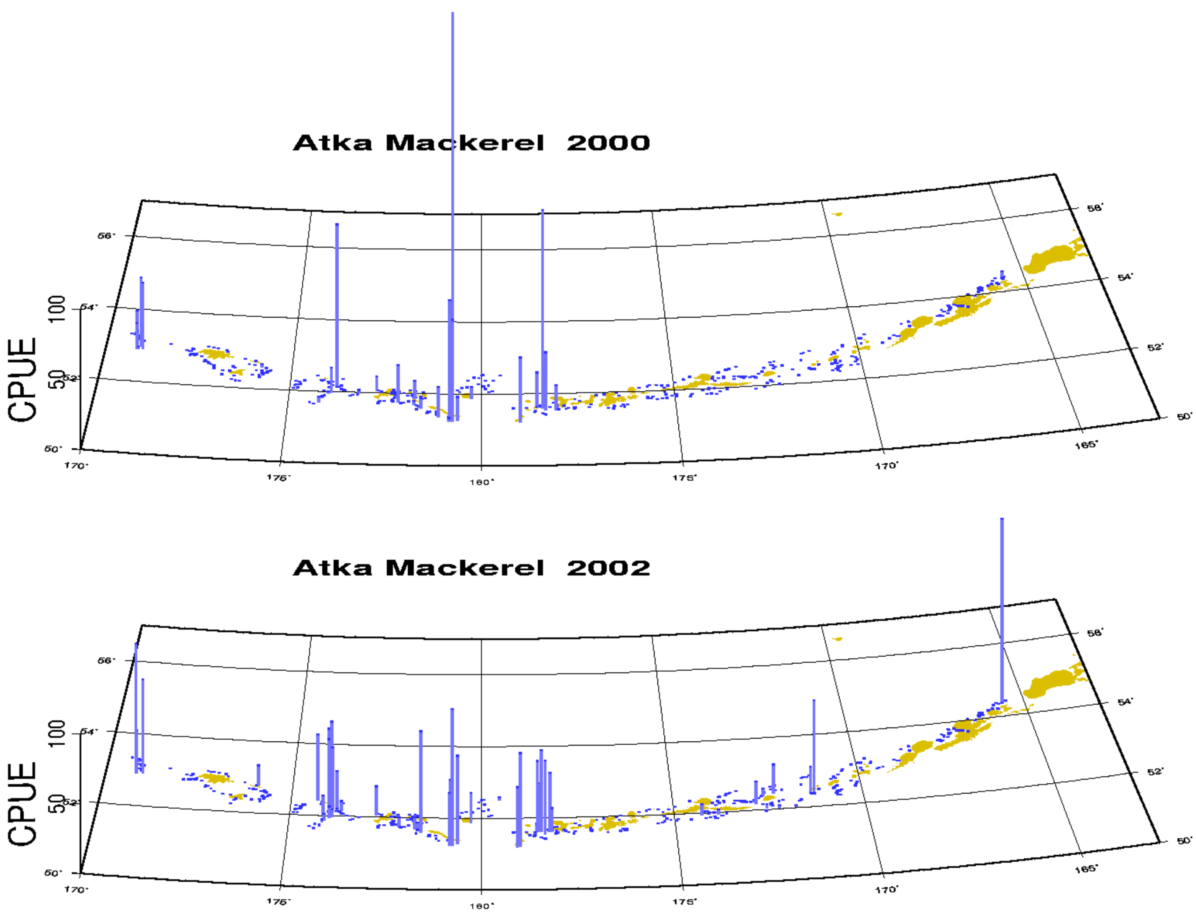


Figure 14.7. Bottom-trawl survey CPUE distributions during the summers of 2000 and 2002.

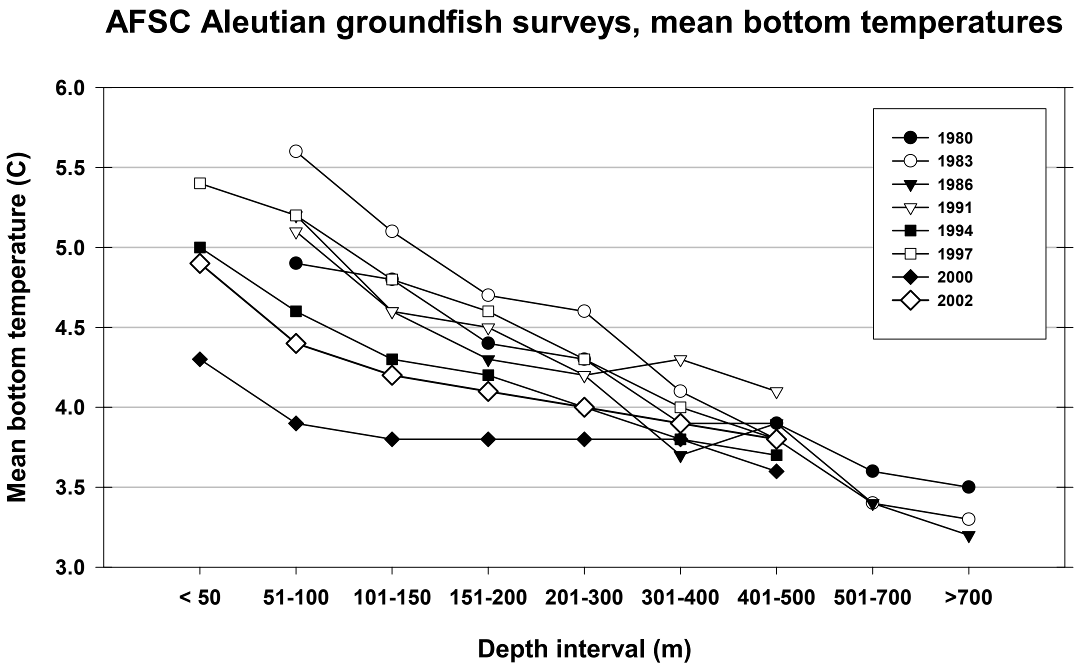


Figure 14.8. Average bottom temperatures by depth interval based on Aleutian Islands summer bottom-trawl surveys since 1980.

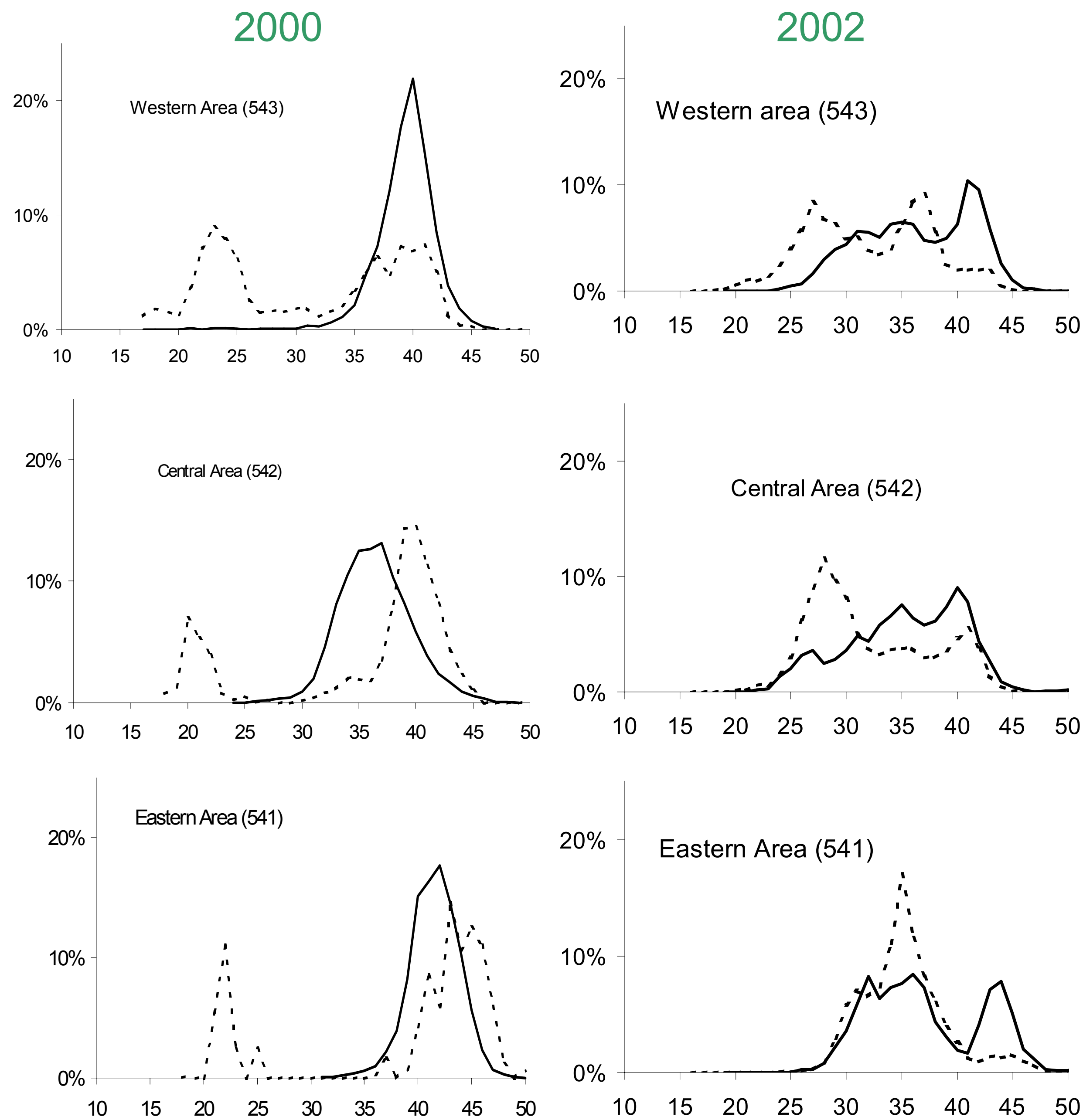


Figure 14.9. Atka mackerel fishery (solid lines) and survey (dashed lines) length frequencies by areas for 2000 and 2002.

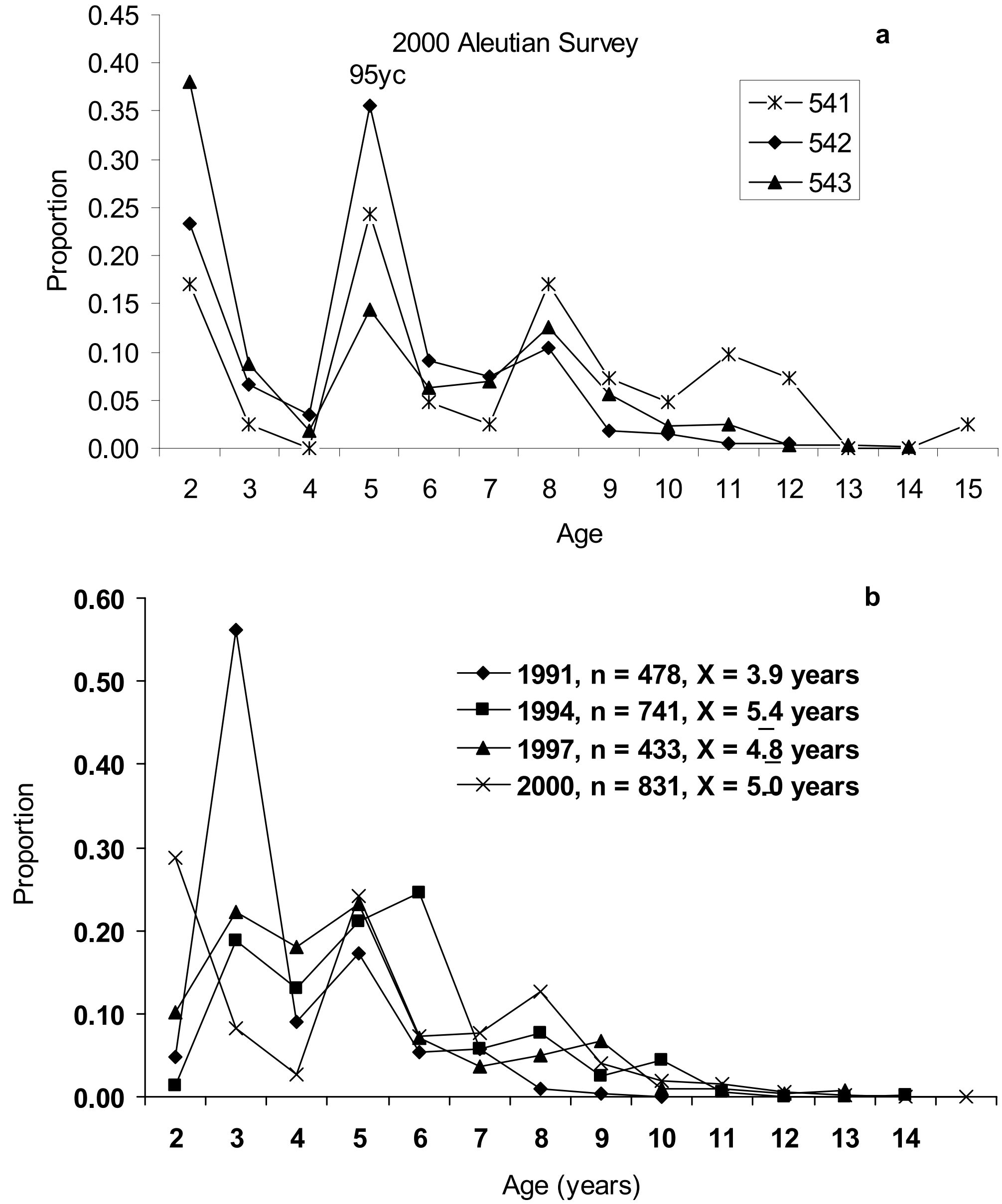


Figure 14.10. Age distributions from the Aleutian Islands region from the 1991, 1994, 1997, and 2000: surveys.

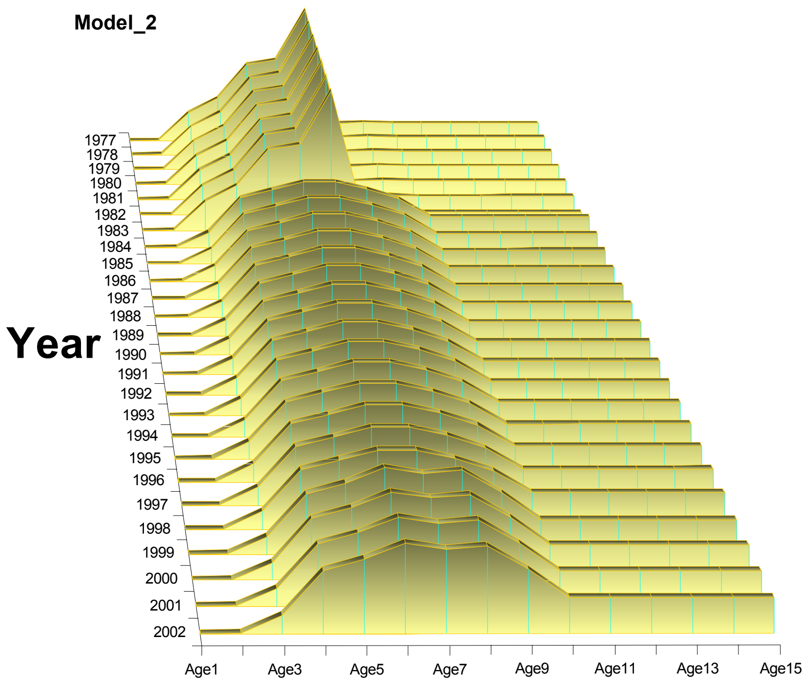


Figure 14.11. Atka mackerel fishery selectivity-at-age estimated for Model 2.

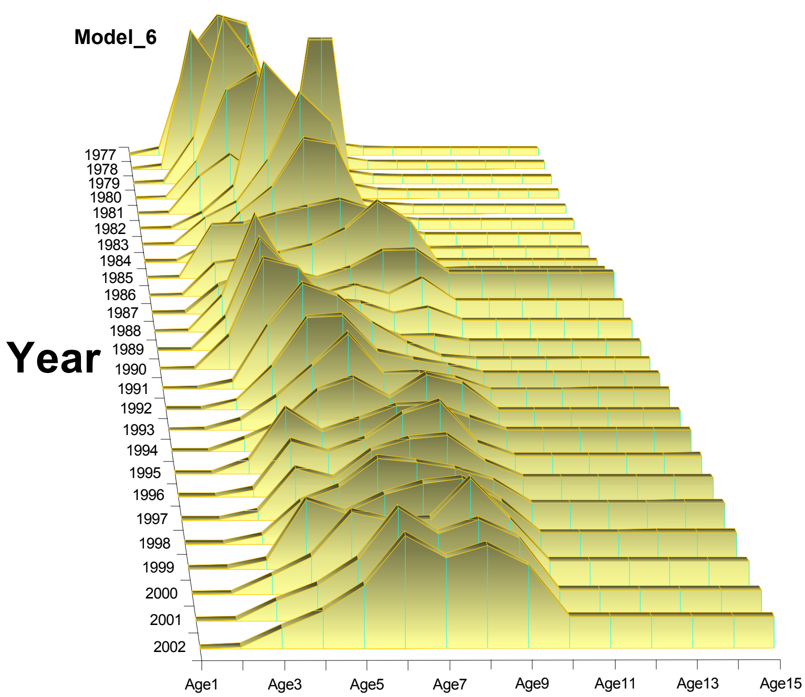


Figure 14.12. Atka mackerel fishery selectivity-at-age estimated for Model 6.

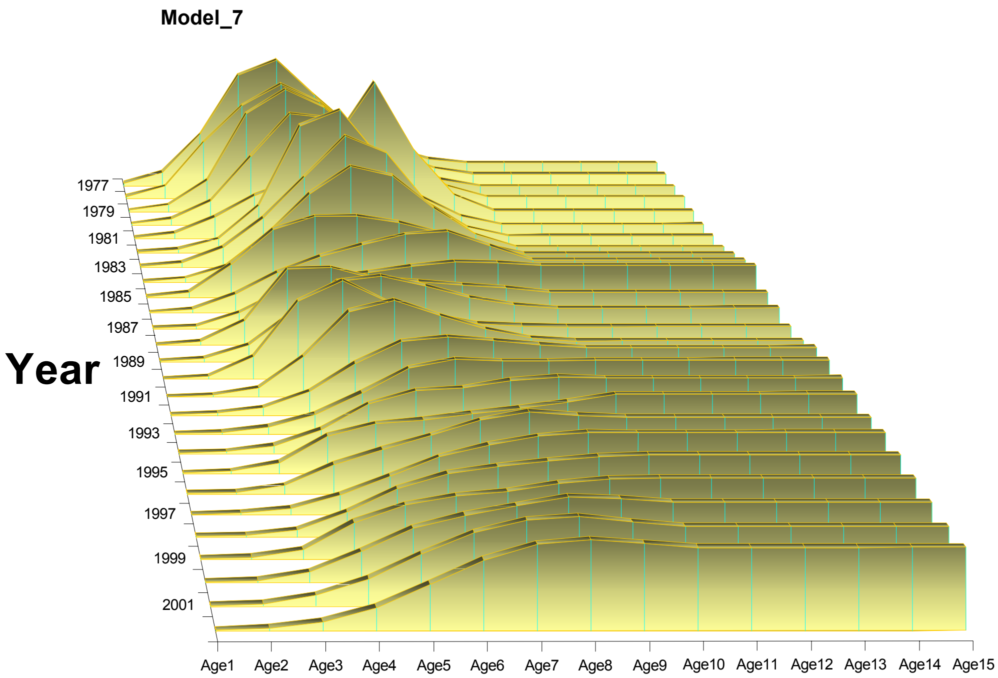


Figure 14.13. Atka mackerel fishery selectivity-at-age estimated for Model 7.

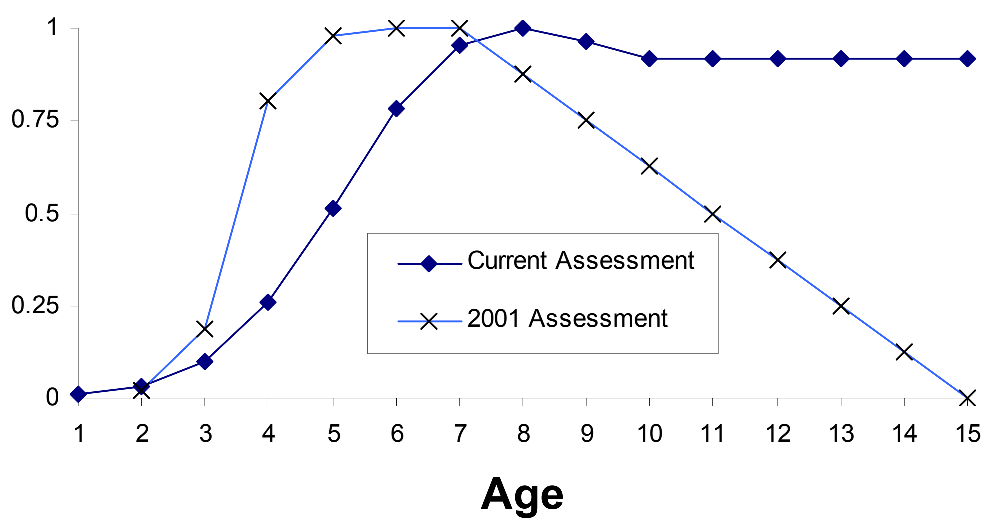


Figure 14.14. Atka mackerel fishery selectivity-at-age estimates used for $F_{40\%}$ calculations (Model 7) in the current assessment compared with Lowe et al. (2001).

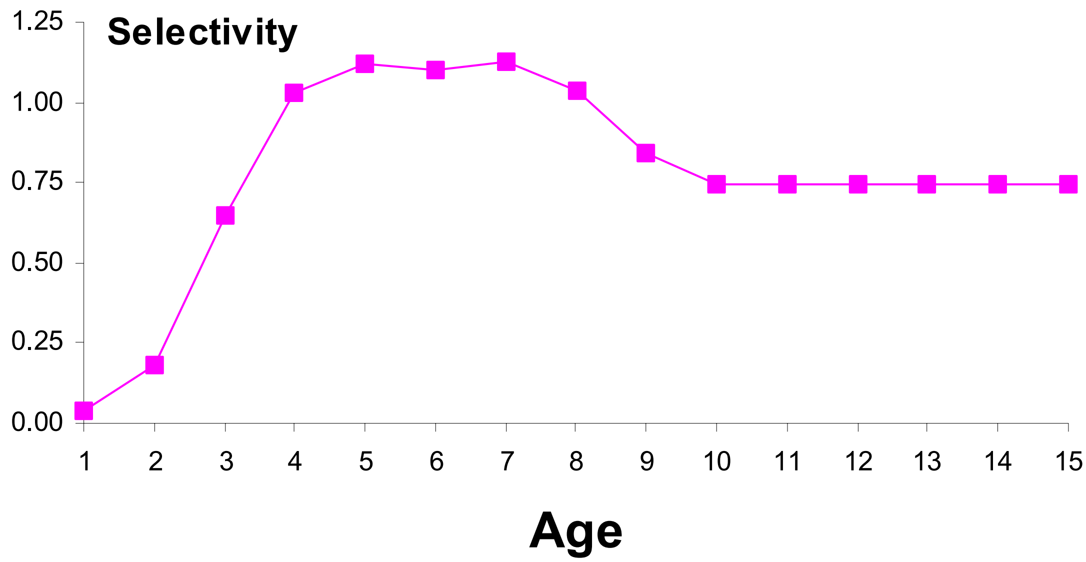


Figure 14.15. Atka mackerel survey selectivity-at-age estimates based on Model 7.

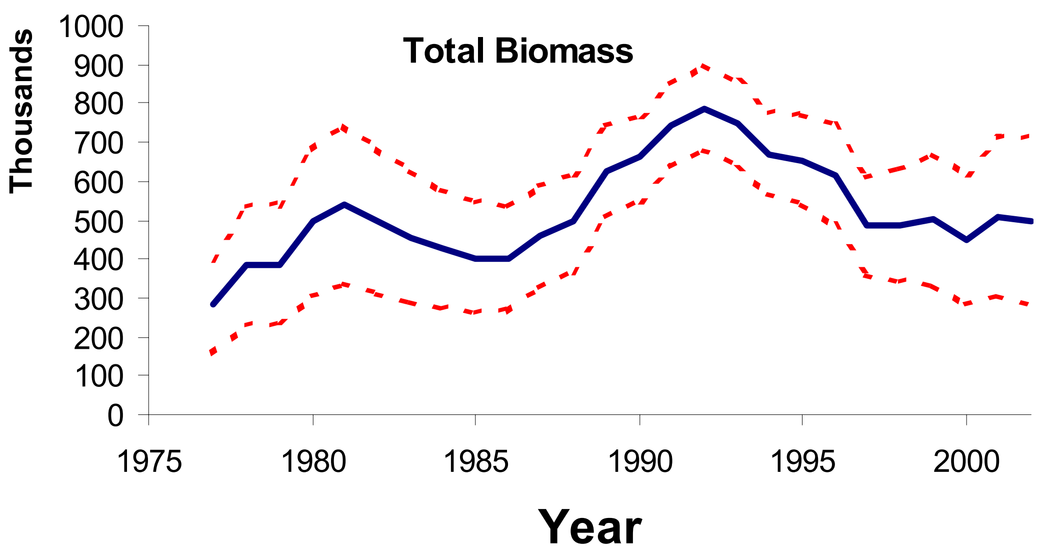


Figure 14.16. Time series of Atka mackerel biomass estimates and approximate 95% confidence bounds based on Model 7.

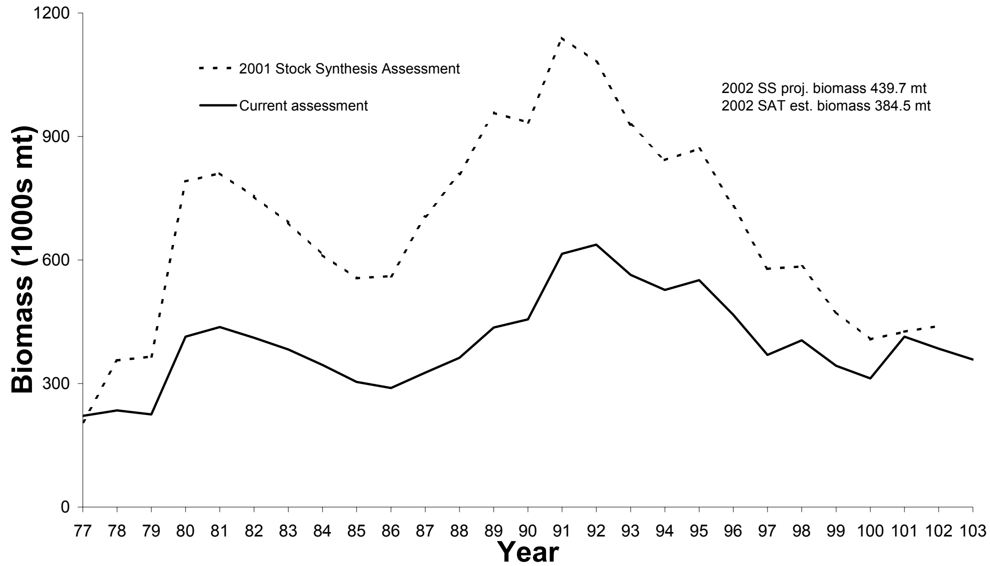


Figure 14.17. Comparison of Lowe et al.'s (2001) assessment of Atka mackerel to the current Model 7 estimate of age 3+ biomass.

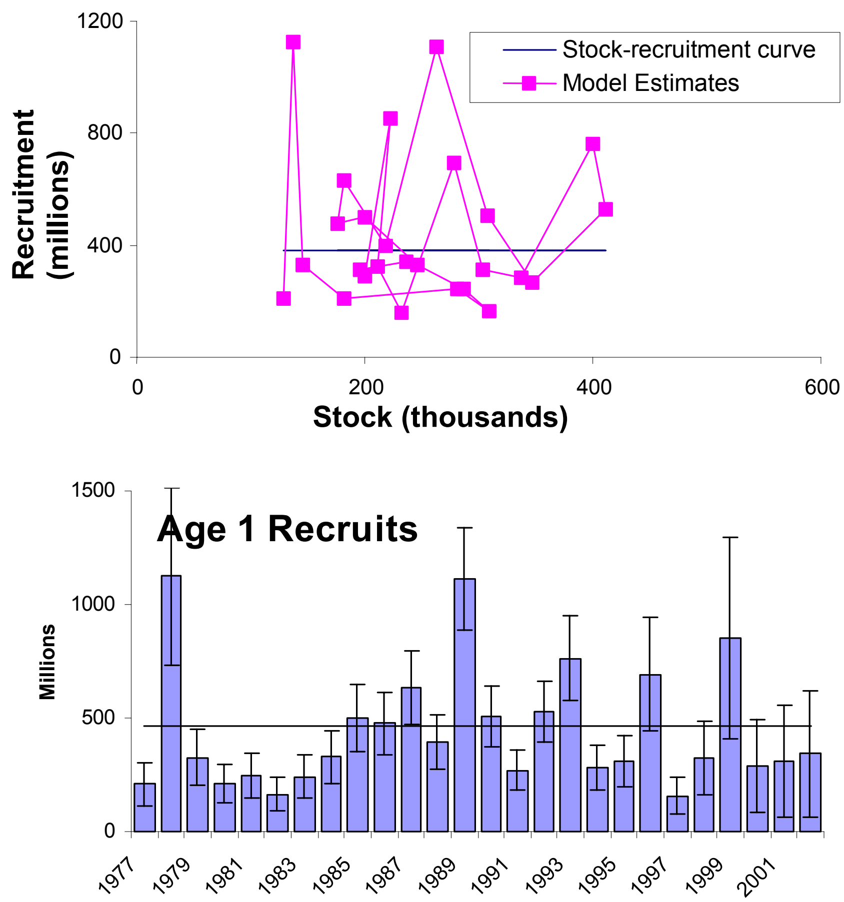


Figure 14.18. Age 1 recruitment (millions) of Atka mackerel as estimated from the current assessment for Model 7.

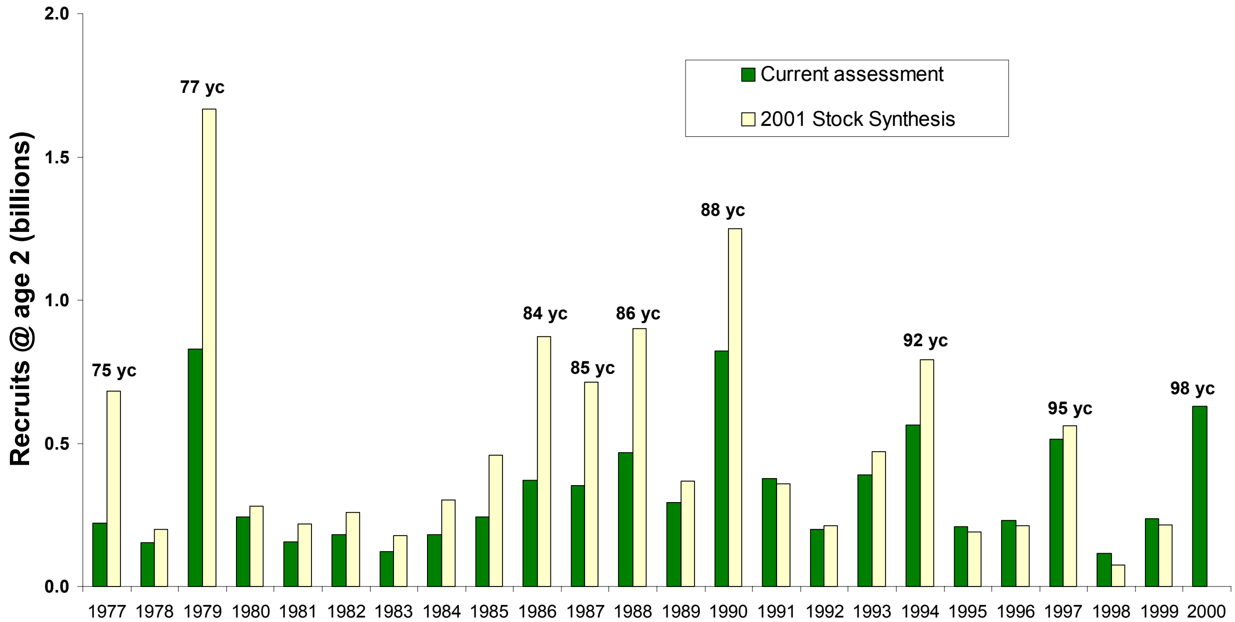


Figure 14.19. Comparison of recruitment (at age 2) from the current assessment (Model 7) and Lowe et al. (2001) estimates for Atka mackerel.

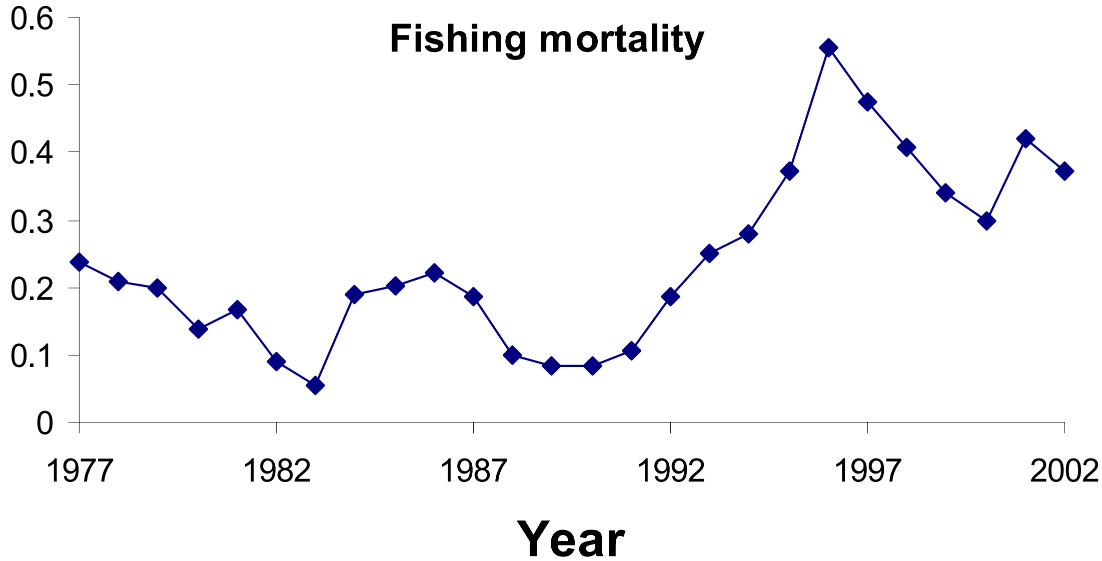


Figure 14.20. Estimated time series of full-selection fishing mortality of Atka mackerel based on Model 7.

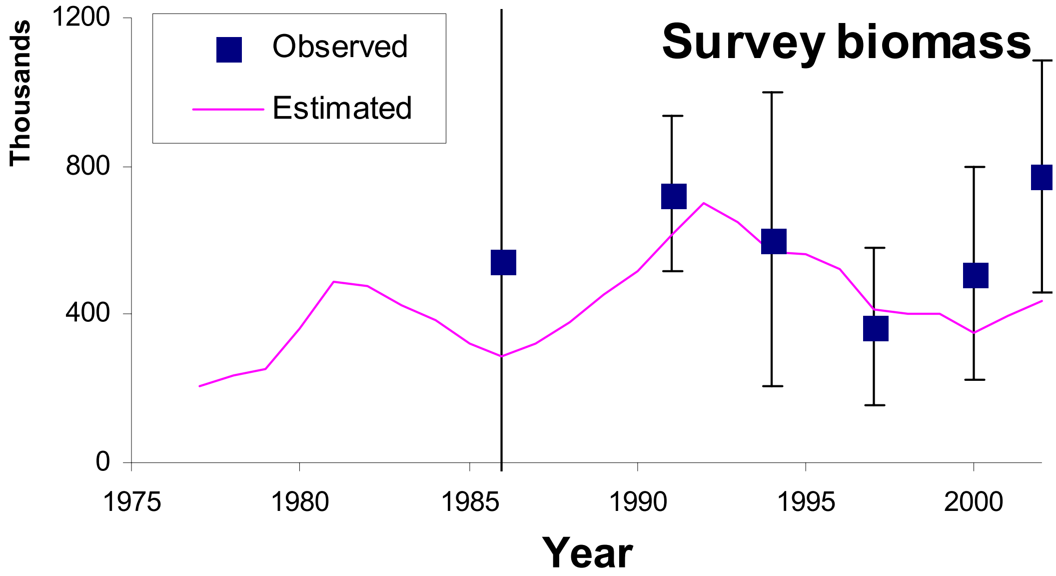


Figure 14.21. Observed and predicted survey biomass for Aleutian Islands Atka mackerel. Error bars represent two standard errors (based on sampling) from the survey estimates.

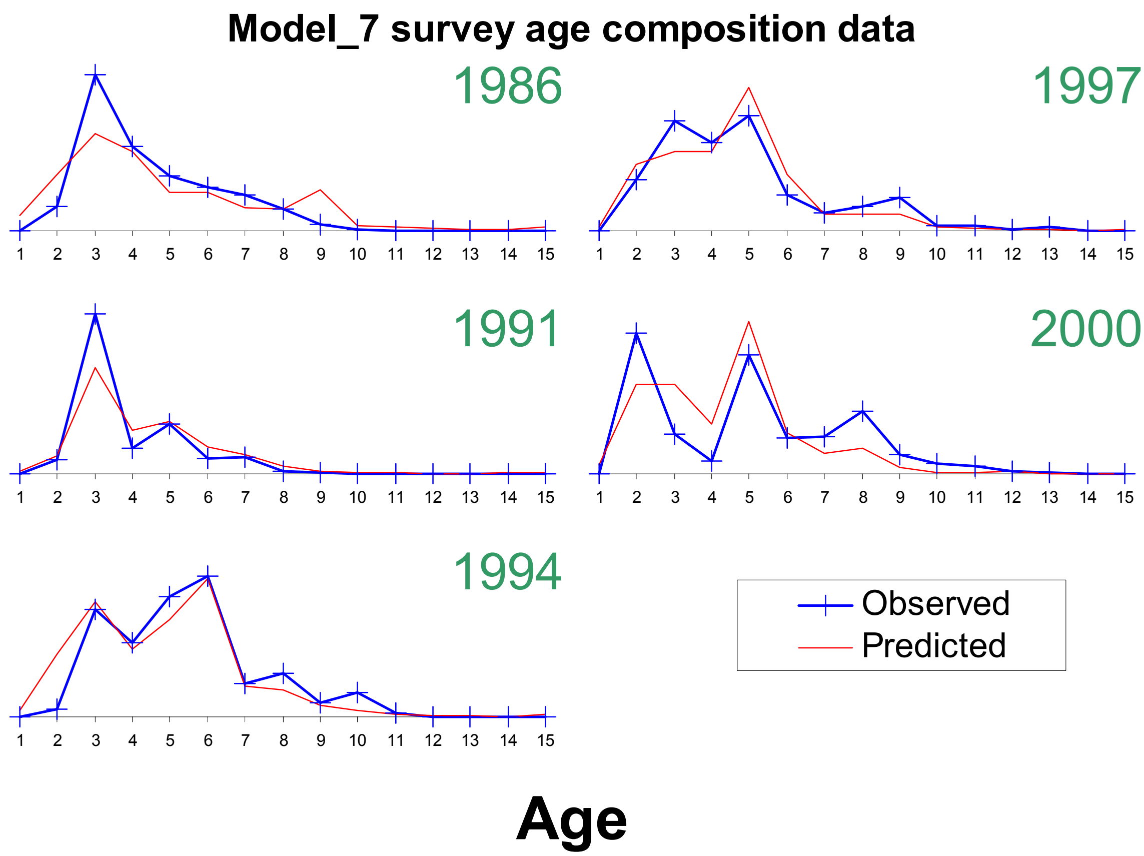


Figure 14.22. Observed and predicted fits to the available survey age composition data for Atka mackerel based on Model 7.

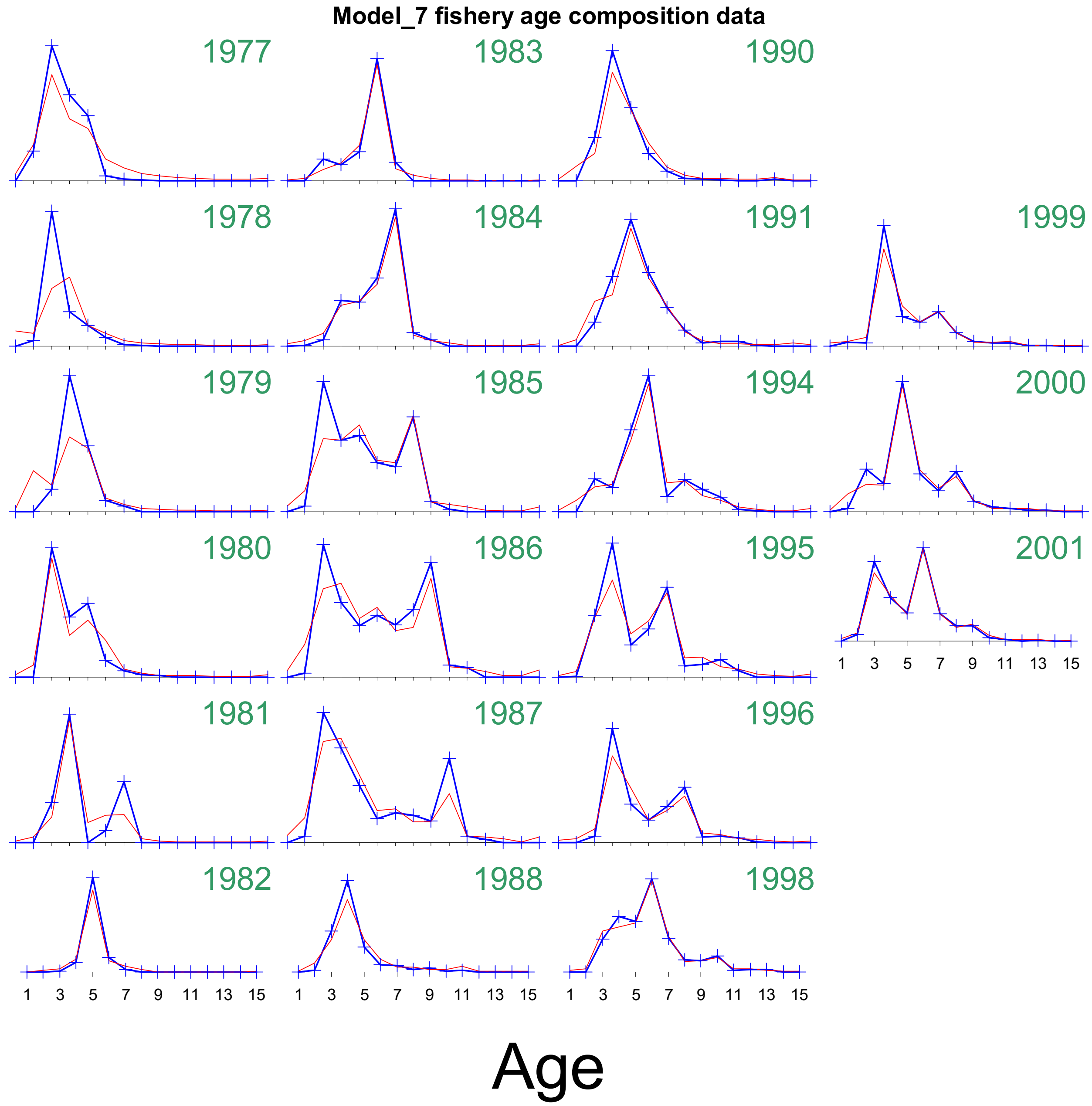
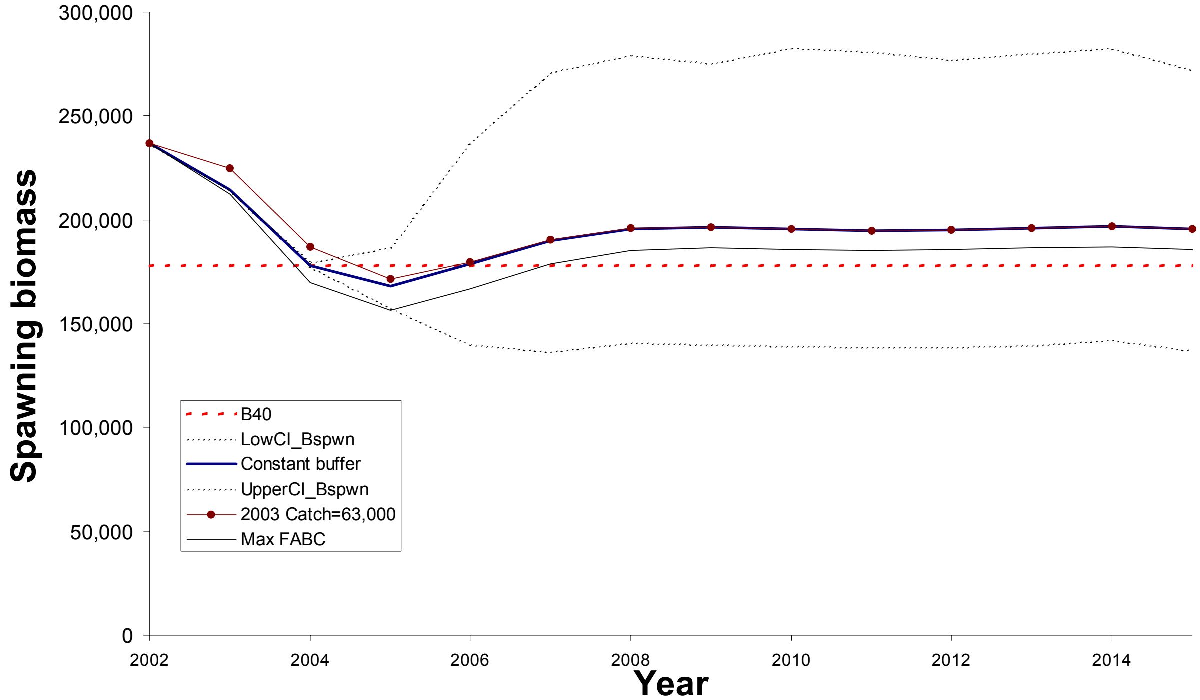


Figure 14.23. Observed and predicted fits to the available fishery age composition data for Atka mackerel based on Model 7. Continuous lines are the model predictions and lines with + symbol are the observed proportions at age.



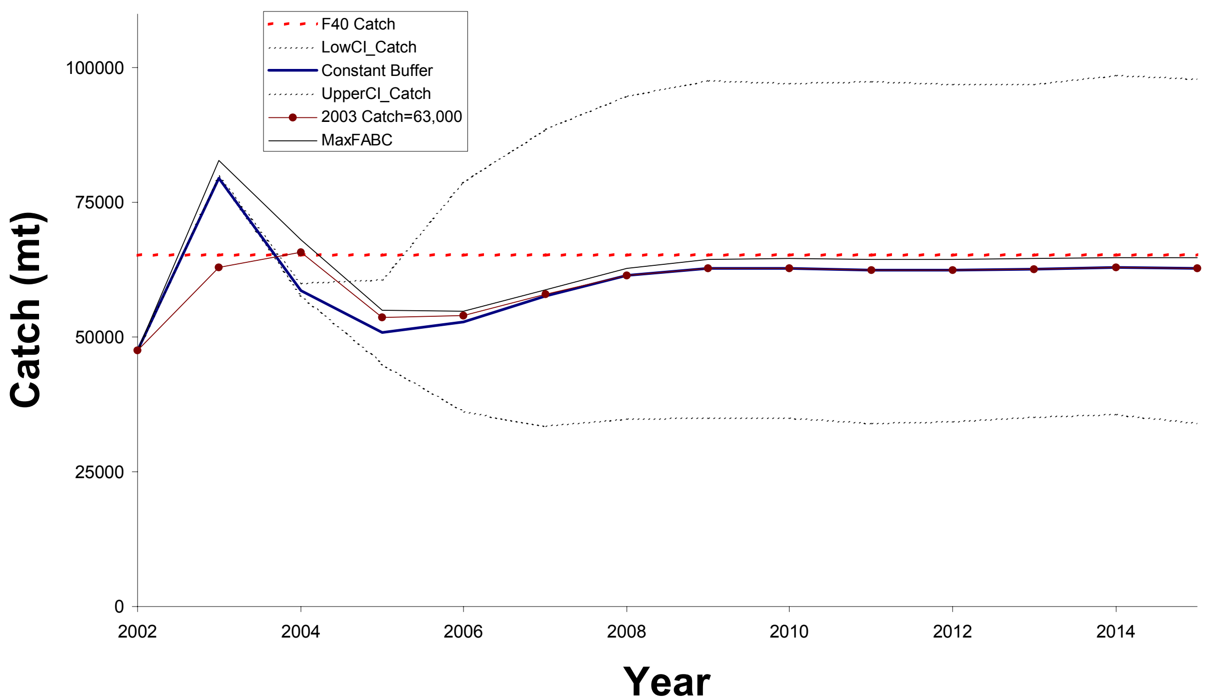


Figure 14.24. Projected spawning biomass (top) and catch (bottom) with the constant-buffer option.

Appendix 14.A

Table A-1. Variable descriptions and model specification.

General Definitions	Symbol/Value	Use in Catch at Age Model
Year index: i = {1977, …., 2002}		i
Age index: j = {1, 2, 3, …, 14, 15^{+}}	j	
Mean weight by age j	W_j	
Maximum age beyond which selectivity is constant	*Maxage*	Selectivity parameterization
Instantaneous Natural Mortality	M	Prior distribution = lognormal(0.3, 0.6^2)
Proportion females mature at age j	p_j	Definition of spawning biomass
Sample size for proportion at age j in year i	T_i	Scales multinomial assumption about estimates of proportion at age
Survey catchability coefficient	q^s	Prior distribution = lognormal(1.0 , 0.2^2)
Stock-recruitment parameters	R_0	Unfished equilibrium recruitment
	h	Stock-recruitment steepness
	σ_R^2	Stock-recruitment variance
Estimated parameters		
$\phi_i(26),\ R_0,\ h,\ \varepsilon_i(40), \sigma_R^2,\ \mu^f,\ \mu^s,\ M,\ \eta_j^s(14),\ \eta_j^f(14), F_{50\%}, F_{40\%}, F_{30\%}, q^s$		

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

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

Description	Symbol/Constraints	Key Equation(s)
Survey abundance index (s) by year	Y_i^s	$\hat{Y}_i^s = q_i^s \sum_{j=1}^{15^+} s_j^s W_{ij} N_{ij}$
Catch biomass by year	C_i	$\hat{C}_i = \sum_j W_{ij} N_{ij} \frac{F_{ij}}{Z_{ij}} \left(1 - e^{-Z_{ij}}\right)$
Proportion at age j, in year i	P_{ij}, $\sum_{j=1}^{15} P_{ij} = 1.0$	$P_{ij} = \frac{N_{ij} s_{ij}^f}{\sum_{k=1}^{15} N_{ik} s_{ik}^f}$
Initial numbers at age	$j = 1$	$N_{1977,1} = e^{\mu_{R1977} + \varepsilon_{1977}}$
	$1 < j < 15$	$N_{1977,j} = e^{\mu_{R1978-j} + \varepsilon_{1978-j}} \prod_{j=1}^{j} e^{-M}$
	$j = 15^+$	$N_{1977,15} = N_{1977,14} \left(1 - e^{-M}\right)^{-1}$
Subsequent years ($i > 1977$)	$j = 1$	$N_{i,1} = \frac{S_{i-1} e^{\varepsilon_i}}{\alpha + \beta S_{i-1,1}}$
	$1 < j < 15$	$N_{i,j} = N_{i-1,j-1} e^{-Z_{i-1,j-1}}$
	$j = 15^+$	$N_{i,15^+} = N_{i-1,14}\, e^{-Z_{i-1,14}} + N_{i-1,15}\, e^{-Z_{i-1,15}}$
Index catchability Mean effect	μ^s, μ^f	$q_i^s = e^{\mu^s}$
Age effect	η_j^s, $\sum_{j=1}^{15^+} \eta_j^s = 0$	$s_j^s = e^{\eta_j^s}$ $j \le$ maxage $s_j^s = e^{\eta_{\text{maxage}}^s}$ $j >$ maxage
Instantaneous fishing mortality		$F_{ij} = e^{\mu_f + \eta_j^f + \phi_i}$
mean fishing effect	μ_f	
annual effect of fishing in year i	ϕ_i, $\sum_{i=1977}^{2001} \phi_i = 0$	
age effect of fishing (regularized) In year time variation allowed	η_{ij}^f, $\sum_{j=1}^{15^+} \eta_{ij} = 0$	$s_{ij}^f = e^{\eta_j^f}$, $j \le$ maxage $s_{ij}^f = e^{\eta_{\text{maxage}}^f}$ $j >$ maxage
In years where selectivity is constant over time	$\eta_{i,j}^f = \eta_{i-1,j}^f$	$i \ne$ change year
Natural Mortality	M	
Total mortality		$Z_{ij} = F_{ij} + M$
Recruitment Beverton-Holt form	μ_{R_i}	$\mu_{R_i} = \frac{\alpha B_i}{\beta + B_i}$, $\alpha = \frac{4hR_0}{5h-1}$ and $\beta = \frac{B_0(1-h)}{5h-1}$ where $B_0 = R_0 \varphi$ $\varphi = \frac{e^{-15M} W_{15} p_{15}}{1 - e^{-M}} + \sum_{j=1}^{15} e^{-M(j-1)} W_j p_j$
Year effect, i = 1977, …, 2002	ε_i, $\sum_{i=1977}^{2002} \varepsilon_i = 0$	$R_i = e^{\mu_{R_i} + \varepsilon_i}$

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

Likelihood /penalty component		Description / notes
Abundance indices	$L_1 = \lambda_1 \sum_i \left(Y_i^s - \hat{Y}_i^s\right)^2 \frac{1}{2\sigma_i^2}$	Survey abundance
Smoother for selectivities	$L_2 = \sum_l \lambda_2^l \sum_{j=1}^{15^+} \left(\eta_{j+2}^l + \eta_j^l - 2\eta_{j+1}^l\right)^2$	Smoothness (second differencing), Note: l={s, or f} for survey and fishery selectivity
Recruitment regularity	$L_3 = \lambda_3 \sum_{i=1977}^{2001} \varepsilon_i^2 \frac{1}{2\sigma_R^2}$	Influences estimates where data are lacking (e.g., if no signal of recruitment strength is available, then the recruitment estimate will converge to median value).
Catch biomass likelihood	$L_4 = \lambda_4 \sum_{i=1977}^{2001} \ln\left(C_i / \hat{C}_i\right)^2$	Fit to survey
Proportion at age likelihood	$L_5 = -\sum_{l,i,j} T_{ij}^l P_{ij}^l \ln\left(\hat{P}_{ij}^l \cdot P_{ij}^l\right)$	l={s, f} for survey and fishery age composition observations
Fishing mortality regularity	$L_6 = \lambda_6 \sum_{i=1977}^{2001} \phi_i^2$	(relaxed in final phases of estimation)
Priors	$L_7 = \left[\lambda_7 \frac{\ln\left(M/\hat{M}\right)^2}{2 \cdot 0.05^2} + \lambda_8 \frac{\ln\left(q/\hat{q}\right)^2}{2 \cdot 0.05^2}\right]$	Prior on natural mortality, and survey catchability (reference case assumption that these are precisely known at 0.3 and 1.0, respectively).
Overall objective function to be minimized	$\dot{L} = \sum_{i=1}^{7} L_i$	