16. Assessment of the Atka mackerel stock in the Bering Sea/Aleutian Islands

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Executive Summary

Relative to the November 2009 SAFE report, the following substantive changes have been made in the assessment of Atka mackerel.

Summary of Changes in Assessment Inputs

1. Fishery catch data were updated.
2. The 2009 fishery age composition data were added.
3. 2009 fishery catch- and weight-at-age values were added.
4. The 2010 Aleutian Islands survey data were included (biomass, length and age compositions, weight-at-age values).
5. The 2010 selectivity vector (equivalent to the estimated vector for 2000-2009) was used for projections.
6. For 2011 and 2012 we assume that 64% of the BSAI-wide ABC is likely to be taken under proposed Steller Sea Lion Reasonable and Prudent Alternatives (SSL RPAs). This percentage was applied to the 2011 maximum permissible ABC, and that amount was assumed to be caught in order to estimate the 2012 ABCs and OFL values.
7. The apportionment scheme which is based on the most recent 4-survey weighted average is updated to include the 2010 survey biomass distribution (2002, 2004, 2006, 2010).
8. The distribution of survey biomass for area 541 used in the apportionment calculations has been updated to include the southern Bering Sea area which is consistent with the assessment and fishery management of that area for Atka mackerel.

Summary of Changes in the Assessment Methodology

The general modeling approach remained unchanged this year. However, a refinement was made to the change-points (shift to one year later) for the blocks of years with constant selectivity which correspond approximately to the foreign fishery, the joint venture fishery, the domestic fishery prior to Steller sea lion regulations, and the domestic fishery post Steller sea lion regulations.

Summary of Assessment Results

Quantity/Status	Last year 2010	Last year 2011	This year **2011**	This year 2012
M (natural mortality)	0.30	0.30	**0.30**	0.30
Specified/recommended Tier	3a	3a	**3a**	3a
Projected biomass (ages 3+)	388,500		**437,600**	
Female spawning biomass (t)				
Projected	111,300	96,600	**146,000**[1]	130,500[1]
$B_{100\%}$	237,800	237,800	**261,100**	261,100
$B_{40\%}$	95,100	95,100	**104,400**	104,400
$B_{35\%}$	83,200	83,200	**91,400**	91,400
F_{OFL}	0.511	0.511	**0.468**	0.468
$maxF_{ABC}$ (maximum allowable = $F_{40\%}$)	0.417	0.417	**0.384**	0.384
Specified/recommended F_{ABC}	0.417	0.417	**0.384**	0.384
Specified/recommended OFL (t)	88,200	76,200	**101,200**	92,200[1]
Specified/recommended ABC (t)	74,000	65,000	**85,300**	77,900[1]
Is the stock being subjected to overfishing?	No	No	**No**	No
Is the stock currently overfished?	No	No	**No**	No
Is the stock approaching a condition of being overfished?	No	No	**No**	No

[1] These values were calculated assuming reduced catch levels under proposed SSL RPAs.

1. The addition of the 2009 fishery age composition and the 2010 survey age composition impacted the estimated magnitude of the 1999 and 2000 year classes which both increased 17%, the 2001 year class which increased 22%, and the magnitude of the 2006 year class which increased 12% relative to last year's assessment.
2. The mean recruitment (1978-2008) from the stochastic projections is 550 million recruits (10% higher than last year's mean estimate for 1978-2007), which gives an estimated $B_{40\%}$ level of 104,400 t and an estimated $B_{35\%}$ level of 91,400 t, up about 10% from last year's estimates of $B_{40\%}$ and $B_{35\%}$.
3. The projected female spawning biomass for 2011 is estimated at 146,000 t which is 56% of unfished spawning biomass and above $B_{40\%}$ (104,400 t), thereby placing BSAI Atka mackerel in Tier 3a. The 2011 estimate of spawning biomass is up about 31% from last year's estimate for 2010. It should be noted that the projected female spawning biomass estimates for 2011 and 2012 assumed reduced catches under proposed SSL RPAs.
4. The projected age 3+ biomass at the beginning of 2011 is estimated at 437,600 t, up about 13% from last year's estimate for 2010.
5. The current selectivity-at-age vector used for projections differs slightly (slightly higher selectivity for ages 3-6 and lower selectivity after age 7) from the fishery selectivity pattern used in last year's projections. This change in selectivity resulted in an 8% decrease in this year's estimates of $F_{40\%}$ and $F_{35\%}$ relative to last year's estimates.
6. The projected 2011 yield at $F_{40\%} = 0.384$ is 85,300 t, which is 15% higher than last year's estimate for 2010. Despite the decrease in the estimate of $F_{40\%}$, the biomass estimates are up relative to last year's projections, resulting in increased $F_{40\%}$ yields.
7. The projected 2011 overfishing level at $F_{35\%}$ (F = 0.468) is 101,200 t, which is 15% higher than last year's estimate for 2010.

Apportionment

The apportionments of the 2011 and 2012 recommended ABCs based on the most recent 4-survey weighted average are:

	2011 (t)	2012 (t)
Eastern (541+S.BSea)	40,300	36,800
Central (542)	24,000	21,900
Western (543)	21,000	19,200
Total	85,300	77,900

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

SSC Comments on Assessments in General

From the December 2009 SSC minutes: *"The SSC notes that the Aleutian Island bottom trawl survey was last conducted in 2006. Several stocks in the Aleutian Islands are in Tier 5 and above. However, reliable biomass estimates are required in order to maintain Tier 5 and higher status. If the Aleutian Island bottom trawl survey is not conducted in 2010, this may jeopardize the current tier status of these stocks. Additionally, the bottom trawl survey is an important source of ecosystem information for this important region. Thus, the SSC places a high priority on conducting a survey in 2010."* The Aleutian Islands survey was conducted in 2010 and results from this survey (including the age composition) were incorporated into the current assessment. The age composition from the 2010 survey provided important year class strength information, corroborating an above average 2006 year class and providing preliminary indications of an above average 2007 year class.

Comments Specific to the Atka Mackerel Assessment

From the December 2009 SSC minutes*: "The current area apportionment of Atka mackerel in the AI is based on a weighted average of the biomass from surveys conducted in 2000, 2002, 2004 and 2006 (page 1002 of the SAFE chapter). With the upcoming release of the status quo Biological Opinion for Steller Sea Lions and consequent renewed interest in Atka mackerel, up-to-date biomass and distribution data for one of their major prey items would seem prudent, even given the known issues of survey adequacy for Atka mackerel. Thus, we reiterate the importance of conducting an Aleutian Islands bottom trawl survey in 2010."* The current assessment recommends an updated apportionment based on a weighted average of the biomass from surveys conducted in 2002, 2004, 2006, and 2010. In addition, the apportionments were revised to include biomass from the southern Bering Sea as part of area 541. This is consistent with the assessment which includes Bering Sea/Aleutian Islands data and the fishery management of area 541 which includes the southern Bering Sea for Atka mackerel.

"The SSC asks that the diet data in Figure 16.25 be updated with data more recent than 1995. We also note that the two pie charts in that figure are reversed (predator pie chart should be chart B)". The pie charts in Figure 16.25 have been reversed so that they correspond to the caption. We agree that the prey and predator data need to be updated for Atka mackerel. Available updated diet data will be incorporated into the next assessment. Updating the predator data is hindered by the lack of funding for analysis of Aleutian Islands food habit data in general. We will provide updates to the extent possible in the next assessment.

16.1 Introduction

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

Distribution

Atka mackerel (*Pleurogrammus monopterygius*) are widely distributed along the continental shelf across the North Pacific Ocean and Bering Sea from Asia to North America. On the Asian side they extend from the Kuril Islands to Provideniya Bay (Rutenburg 1962); moving eastward, they are distributed throughout the Komandorskiye and Aleutian Islands, north along the eastern Bering Sea shelf, and through the Gulf of Alaska to southeast Alaska.

Early life history

Atka mackerel are a substrate-spawning fish with male parental care. Single or multiple clumps of adhesive eggs are laid on rocky substrates in individual male territories within nesting colonies where males brood eggs for a protracted period. Nesting colonies are widespread across the continental shelf of the Aleutian Islands and western GOA down to bottom depths of 144 m (Lauth *et al*. 2007b). Historical data from ichthyoplankton tows done on the outer shelf and slope off Kodiak Island in the 1970's and 1980's (Kendall and Dunn 1985) suggest that nesting colonies may have existed at one time in the central Gulf of Alaska. Possible factors limiting the upper and lower depth limit of Atka mackerel nesting habitat include insufficient light penetration and the deleterious effects of unsuitable water temperatures, wave surge, or high densities of kelp and green sea urchins (Gorbunova 1962, Lauth *et al.* 2007b, Zolotov 1993).

Incubation times for developing eggs decrease logarithmically with an increase in water temperature and range from 39 days at a water temperature of 12.2° to 169 days at 1.6 °C, however, an incubation water temperature of 15°C was lethal to developing embryos (Guthridge and Hillgruber 2008). In the eastern and central Aleutian Islands, larvae hatch from October to January with maximum hatching in late November (Lauth *et al.* 2007a). After hatching, larvae are neustonic and about 10 mm in length (Kendall and Dunn 1985). Along the outer shelf and slope of Kodiak Island, larvae caught in the fall were about 10.3 mm compared to larvae caught the following spring which were about 17.6 (Kendall and Dunn 1985). Larvae and fry have been observed in coastal areas and at great distances offshore (>500 km) in the Bering Sea and North Pacific Ocean (Gorbunova 1962, Materese *et al*. 2003, Mel'nikow and Efimkin 2003).

The Bering-Aleutian Salmon International Survey (BASIS) project studies salmon during their time at the high seas, and has conducted standardized surveys of the upper pelagic layer in the eastern Bering Sea (EBS) shelf using a surface trawl. In addition to collecting data pertaining to salmon species, BASIS also collected and recorded information for many other Alaskan fish species, including juvenile Atka mackerel. The EBS shelf was sampled during the mid-August through September time period from 2004 to 2006 and juvenile Atka mackerel with lengths ranging from 150-200 mm were distributed along the outer shelf in the southern EBS shelf and along the outer middle shelf between St. George and St Matthew Islands (Appendix B in Lowe et al. 2007). The fate or ecological role of these juveniles is unknown since adult Atka mackerel are much less common or absent in annual standardized bottom trawl surveys in the EBS shelf (Lauth and Acuna 2009)

Reproductive ecology

Atka mackerel have a promiscuous mating system involving elaborate color patterns and social behaviors with the reproductive cycle consisting of three phases: 1) establishing territories; 2) spawning, and 3) brooding (Lauth *et al*. 2007a). In early June, a fraction of the adult males end schooling and diurnal behavior and begin aggregating and establishing territories on rocky substrate in nesting colonies (Lauth *et al*. 2007a). The widespread distribution and broad depth range of nesting colonies suggests that previous conjecture of a concerted nearshore spawning migration by males in the Aleutian Islands is not accurate (Lauth *et al.* 2007b). Geologic, oceanographic, and biotic features vary considerably among nesting colonies, however, nesting habitat is invariably rocky and perfused with moderate or strong currents (Lauth *et al.* 2007b). Many nesting sites in the Aleutian Islands are inside fishery trawl exclusion zones which may serve as *de facto* marine reserves for protecting Atka mackerel (Cooper and McDermott 2010b).

The spawning phase begins in late July, peaks in early September, and ends in mid-October (Lauth *et al*. 2007a). Mature females spawn an average of 4.6 separate batches of eggs during the 12-week spawning period or about one egg batch every 2.5 weeks (McDermott *et al*. 2007). After spawning ends, territorial males with nests continue to brood egg masses until hatching. Higher water temperatures in the range of water temperatures observed in nesting colonies, (3.9°C to 10.5°C, Gorbunova 1962, Lauth *et al*. 2007b), can result in long incubation times extending the male brooding phase into January or February (Lauth *et al*. 2007a).

Prey and predators

Adult Atka mackerel in the Aleutians consume a variety of prey, but principally calanoid copepods and euphausiids (Yang 1999), and are consumed by a variety of piscivores, including groundfish (e.g., Pacific cod and arrowtooth flounder, Livingston *et al.* unpubl. manuscr.), marine mammals (e.g., northern fur seals and Steller sea lions, Kajimura 1984, NMFS 1995, Sinclair and Zeppelin 2002), and seabirds (e.g., thick-billed murres, tufted puffins, and short-tailed shearwaters, Springer *et al.* 1999).

Predation on Atka mackerel eggs by cottids and other hexagrammids is prevalent during the spawning season as is cannibalism by other Atka mackerel of both sexes (heterocannibalism) and by males from their own nest (filial cannibalism; Canino *et al*. 2010, Yang 1999, Zolotov 1993). Filial egg cannibalism is a common phenomenon in species with extended paternal care.

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

Stock structure

A morphological and meristic study suggests there may be separate populations in the Gulf of Alaska and the Aleutian Islands (Levada 1979). This study was based on comparisons of samples collected off Kodiak Island in the central Gulf, and the Rat Islands in the Aleutians. Lee (1985) also conducted a morphological study of Atka mackerel from the Bering Sea, Aleutian Islands and Gulf of Alaska. The data showed some differences (although not consistent by area for each characteristic analyzed), suggesting a certain degree of reproductive isolation. Results from an allozyme genetics study comparing Atka mackerel samples from the western Gulf of Alaska with samples from the eastern, central, and western Aleutian Islands showed no evidence of discrete stocks (Lowe *et al.* 1998). A survey of genetic variation in Atka mackerel using microsatellite DNA markers provided little evidence of genetic structuring over the species range, although slight regional heterogeneity was evident in comparisons between some areas (Canino *et al*. 2010). Samples collected from the Aleutian Islands, Japan, and the Gulf of Alaska did not exhibit genetic isolation by distance or a consistent pattern of differentiation. Examination of these results over time (2004, 2006) showed temporal stability in Stalemate Bank but not at Seguam Pass. These results indicate a lack of structuring in Atka mackerel over a large portion of the species range, perhaps reflecting high dispersal, a recent population expansion and large effective population size, or some combination of all these factors (Canino *et al*. 2010).

The question remains as to whether the Aleutian Island (AI) and Gulf of Alaska populations of Atka mackerel should be managed as a unit stock or separate populations given that there is a lack of consistent genetic stock structure over the species range. There are significant differences in population size, distribution, recruitment patterns, and resilience to fishing suggesting that management as separate stocks is appropriate. Bottom trawl surveys and fishery data suggest that the Atka mackerel population in the GOA is smaller and much more patchily distributed than that in the AI, and composed almost entirely of fish >30 cm in length. There are also more areas of moderate Atka mackerel density in the AI than in the GOA. The lack of small fish in the GOA suggests that Atka mackerel recruit to that region differently than in the AI. Nesting sites have been located in the Gulf of Alaska in the Shumagin Islands (Lauth *et al.* 2007a), and historical ichthyoplankton data from the 1970's around Kodiak Island indicate there was a spawning and nesting population even further to the east (Kendall and Dunn 1985), but the source of these spawning populations is unknown. They may be migrant fish from strong year classes in the Aleutian Islands or a self-perpetuating population in the Gulf, or some combination of the two. The idea that the western GOA is the eastern extent of their geographic range might also explain the greater sensitivity to fishing depletion in the GOA as reflected by the history of the GOA fishery since the early 1970s. Catches of Atka mackerel from the GOA peaked in 1975 at about 27,000 t. Recruitment to the AI population was low from 1980-1985, and catches in the GOA declined to 0 in 1986. Only after a series of large year classes recruited to the AI region in the late 1980s, did the population and fishery reestablish in the GOA beginning in the early 1990s. After passage of these year classes through the population, the GOA population, as sampled in the 1996 and 1999 GOA bottom trawl surveys, has declined and is very patchy in its distribution. Most recently, the strong 1998 and 1999 year classes documented in the Aleutian Islands showed up in the Gulf of Alaska. Leslie depletion analyses using historical AI and GOA fishery data suggest that catchability increased from one year to the next in the GOA fished areas, but remained the same in the AI areas (Lowe and Fritz 1996; 1997). These differences in population resilience, size, distribution, and recruitment support separate assessments and management of the GOA and AI stocks and a conservative approach to management of the GOA portion of the population.

Management units

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

16.2 Fishery

16.2.1 Catch history

Annual catches of Atka mackerel in the eastern Bering Sea (EBS) and Aleutian Islands (AI) regions increased during the 1970s reaching an initial peak of over 24,000 t in 1978 (see BSAI SAFE Table 3). Atka mackerel became a reported species group in the BSAI Fishery Management Plan in 1978. Catches (including discards and community development quota [CDQ] catches), corresponding Acceptable Biological Catches (ABC), Total Allowable Catches (TAC), and Overfishing Levels (OFL) set by the North Pacific Fishery Management Council (Council) from 1978 to the present are given in Table 16.1.

From 1970-1979, Atka mackerel were landed off Alaska exclusively by the distant water fleets of the U.S.S.R., Japan and the Republic of Korea. U.S. joint venture fisheries began in 1980 and dominated the landings of Atka mackerel from 1982 through 1988. Total landings declined from 1980-1983 primarily due to changes in target species and allocations to various nations rather than changes in stock abundance. Catches increased quickly thereafter, and from 1985-1987 Atka mackerel catches averaged 34,000 t annually, dropping to a low of 18,000 t in 1989. The last joint venture allocation of Atka mackerel off Alaska was in 1989, and since 1990, all Atka mackerel landings have been made by U.S. fishermen. Beginning in 1992, TACs increased steadily in response to evidence of a large exploitable biomass, particularly in the central and western Aleutian Islands.

16.2.2 Description of the Directed Fishery

The patterns of the Atka mackerel fishery generally reflect the behavior of the species: (1) the fishery is highly localized and usually occurs in the same few locations each year; (2) the schooling semi-pelagic nature of the species makes it particularly susceptible to trawl gear fished on the bottom; and (3) trawling occurs almost exclusively at depths less than 200 m. In the early 1970s, most Atka mackerel catches were in the western Aleutian Islands (west of 180°W longitude). In the late 1970s and through the 1980s, fishing effort moved eastward, with the majority of landings occurring near Seguam and Amlia Islands. In 1984 and 1985 the majority of landings came from a single 1/2° latitude by 1° longitude block bounded by 52°30'N, 53°N, 172°W, and 173°W in Seguam Pass (73% in 1984, 52% in 1985). Areas fished by the Atka mackerel fishery from 1977 to 1992 are displayed in Fritz (1993). Areas of 2010 fishery operations are shown in Figure 16.1.

16.2.3 Management History

Prior to 1992, ABCs were allocated to the entire Aleutian management district with no additional spatial management. However, because of increases in the ABC beginning in 1992, the Council recognized the need to disperse fishing effort throughout the range of the stock to minimize the likelihood of localized depletions. In 1993, an initial Atka mackerel TAC of 32,000 t was caught by 11 March, almost entirely south of Seguam Island. This initial TAC release represented the amount of Atka mackerel that the Council thought could be appropriately harvested in the eastern portion of the Aleutian Islands subarea (based on the assessment for the 1993 fishery; Lowe 1992). In mid-1993, however, Amendment 28 to the Bering Sea/Aleutian Islands (BSAI) Fishery Management Plan became effective, dividing the Aleutian subarea into three districts at 177°W and 177°E for the purposes of spatially apportioning TACs (Figure 16.1). On 11 August 1993, an additional 32,000 t of Atka mackerel TAC was released to the Central (27,000 t) and Western (5,000 t) districts. Since 1994, the BSAI Atka mackerel TAC has been allocated to the three regions based on the average distribution of biomass estimated from the Aleutian Islands bottom trawl surveys. Table 16.2 gives the time series of BSAI Atka mackerel catches, corresponding ABC and TAC by region.

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

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

Most recently, the Draft 2010 Biological Opinion has found that the fisheries for Alaska groundfish in the Bering Sea and Aleutian Islands and Gulf of Alaska, and the cumulative effects of these fisheries, are likely to jeopardize the continued existence of the western distinct population segment (DPS) of Steller sea lions, and also likely to adversely modify the designated critical habitat of the western DPS of Steller sea lions. Because this Biological Opinion has found jeopardy and adverse modification of critical habitat, the agency is required to implement reasonable and prudent alternatives (RPAs) to the proposed actions (the fisheries). The Draft Biological Opinion includes proposed RPAs which require changes in groundfish fishery management in Management Sub-areas 543, 542, and 541 in the Aleutian Islands Management Area. NOAA Fisheries intends to complete the final Biological Opinion and to implement the direct final rule measures before the start of the 2011 fishery in January.

Amendment 80 to the BSAI Groundfish FMP was adopted by the Council in June 2006 and implemented for the 2008 fishing year. This action allocates several BSAI non-pollock trawl groundfish species among trawl fishery sectors, and facilitates the formation of harvesting cooperatives in the non-American Fisheries Act (non-AFA) trawl catcher/processor sector. Bering Sea/Aleutian Islands Atka mackerel is one of the groundfish species directly affected by Amendment 80. In addition, a Best Practices Cooperative has been formed under Amendment 80 which includes most of the participants in the BSAI Atka mackerel fishery.

16.2.4 Bycatch and Discards

Atka mackerel are not commonly caught as bycatch in other directed Aleutian Islands fisheries. The largest amounts of discards of Atka mackerel, which are likely under-size fish, occur in the directed Atka mackerel trawl fishery. Atka mackerel are also caught as bycatch in the trawl Pacific cod and rockfish fisheries. Northern and light dusky rockfish are caught in the Aleutian Islands Atka mackerel fishery. While the 2008 and 2009 discards of northern rockfish as a total of the Atka mackerel catch were 5 and 4%, respectively, the actual amount of northern catches (discards and retained) accounts for a large portion of the AI northern TAC. The 2008 fishery caught 2,722 t of northern rockfish, about 33% of the 2008 AI northern TAC. The 2009 Atka mackerel fishery caught 2,700 t of northern rockfish which accounted for 38% of the northern TAC.

Discard data have been available for the groundfish fishery since 1990. Discards of Atka mackerel for 1990-1999 have been presented in previous assessments (Lowe *et al.* 2003). Aleutian Islands Atka mackerel discard data from 2000 to the present are given in Table 16.3.

The discards and discard rate of Atka mackerel in the Atka mackerel fishery increased dramatically in 2002 (Table 16.3). The 2002 fishery caught large numbers of 3 and 4 year olds from the 1998 and 1999 year classes. Small fish from the very large 1999 year class may have contributed to the increased discarding in the 2002 fishery. The discards and discard rate increased again in 2003; the 2003 fishery caught large numbers of 3 and 4 year olds from the 1999 and 2000 year classes, and small fish from the 2000 year class may have contributed to the increased discarding in the 2003 fishery. The 2004 discard rate decreased despite the appearance of the above average 2001 year class; the 2004 fishery appeared to have retained larger numbers of 3-year old fish than previous years (Lowe *et al.* 2005). The discard rate decreased dramatically in 2005. The 2006 discard rate continued to decline, and rates have been 2-3% until 2009 when the discard rate increased to nearly 4% (Table 16.3). The increase in 2009 may be due to large numbers of small fish from the 2007 year class.

Until 1998, discard rates of Atka mackerel by the target fishery have generally been greatest in the western AI (543) and lowest in the east (541, Lowe *et al.* 2003). After 1998 and up until 2003, discard rates have been higher in the central AI (542) and have remained lowest in the east (subarea 541, Table 16.4). However, in 2003, the discard rate in the eastern (541) and western AI (543) nearly doubled, and the western rate exceeded the central area rate (Table 16.4). In the 2004 fishery, the discard rates decreased in both the central and western Aleutians (542 & 543) while the eastern rate increased again. The 2005 discard rates dropped significantly in all three areas, contributing to the large overall drop in the 2005 discard rate shown above. Discard rates have continued to decrease in eastern AI (541) since 2005 (Table 16.4).

16.2.5 Fishery Length Frequencies

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

Atka mackerel length distributions from the 2009 and preliminary 2010 fisheries by management area are shown in Figures 16.2 and 16.3, respectively. The modes at about 37-43 cm in the 2009 BSAI fishery length distributions represent the 2006 year class (Figure 16.4). The available 2010 fishery data are presented and should be considered preliminary (Figure 16.3). Preliminary data from the 2010 BSAI fisheries showed similar distributions to the 2009 distributions with modes at about 36-42 cm (Figure 16.3).

16.2.6 Steller Sea Lions and Atka mackerel Fishery Interactions

Since 1979, the Atka mackerel fishery has occurred largely within areas designated in 1993 as Steller sea lion critical habitat (20 nm around rookeries and major haulouts). While total removals from critical habitat may be small in relation to estimates of total Atka mackerel biomass in the Aleutian region, fishery harvest rates in localized areas may have been high enough to affect prey availability of Steller sea lions (Section 12.2.2 of Lowe and Fritz 1997). The localized pattern of fishing for Atka mackerel apparently does not affect fishing success from one year to the next since local populations in the Aleutian Islands appear to be replenished by immigration and recruitment. However, this pattern could have created temporary reductions in the size and density of localized Atka mackerel populations which may have affected Steller sea lion foraging success during the time the fishery was operating and for a period of unknown duration after the fishery closed. As a consequence, the NPFMC passed regulations in 1998 and 2001 (described above in Section 16.2.3) to disperse fishing effort temporally and spatially as well as reduce effort within Steller sea lion critical habitat.

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

16.3 Data

16.3.1 Fishery Data

Fishery data consist of total catch biomass from 1977 to 2009 and partial 2010 catch data (Table 16.1). Also, length measurements collected by observers and otoliths read by the AFSC Age and Growth Lab (Table 16.5) were used to create age-length keys to determine the age composition of the catch from 1977-2009 (Table 16.6). In previous assessments (prior to 2008), the catch-at-age in numbers was compiled using total annual BSAI catches and global (Aleutian-wide) year-specific age-length keys. The formulas used are described by Kimura (1989). As with the length frequencies, the age data for 1980-1981 and 1989 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 to construct a reasonable age-length key. Kimura and Ronholt (1988) used the 1980 survey age-length key to estimate the 1980 commercial catch age distribution, and these data were further used to estimate the 1981 commercial catch age distribution with a mixture model (Kimura and Chikuni 1987). However, this method did not provide satisfactory results for the 1989 catch data and that year has been excluded from the analyses (Lowe *et al*. 2007).

An alternative approach to compiling the catch-at-age data was adopted in the 2008 assessment in response to issues raised during the 2008 Center for Independent Experts (CIE) review of the Aleutian Islands Atka mackerel and pollock assessments. This method uses stratified catch by region (Table 16.2) and compiles (to the extent possible) region-specific age-length keys stratified by sex. This method also accounts for the relative weights of the catch taken within strata in different years. This approach was applied to catch-at-age data after 1989 (the period when consistent observer data were available) and follows the methods described by Kimura (1989) and modified by Dorn (1992; Table 16.6). Briefly, length-stratified age data are used to construct age-length keys for each stratum and sex. These keys are then applied to randomly sampled catch length frequency data. The stratum-specific age composition estimates are then weighted by the catch within each stratum to arrive at an overall age composition for each year. In summary, estimates of the proportion of catch-at-age are derived from the mean of the bootstrap sampling of the revised catch-at-age estimates. The bootstrap method also allows evaluation of sample-size scalings that better reflect inter-annual differences in sampling and observer coverage. Since body mass is applied in this estimation, stratum-weighted mean weights-at-age are available with the estimates of catch-at-age. The three strata for the Atka mackerel coincide with the three management areas (eastern, central, and western regions of the Aleutian Islands). This method was used to derive the age compositions for 1990-2009 (the period for which all the necessary information is readily available). Prior to 1990, the catch-age composition estimates remain the same as in previous assessments.

The most notable features of the estimated catch-at-age data (Table 16.6) are the strong 1975, 1977, 1999, 2000, and 2001 year classes, and large numbers of the 2006 year class which showed up in the 2009 fishery. The 1975 year class appeared strong as 3 and 4-year-olds in 1978 and 1979. It is unclear why this year class did not continue to show up strongly after age 4. The 1977 year class appeared strong through 1987, after entering the fishery as 3-year-olds in 1980. The 2002 fishery age data showed the first appearance in the fishery of the strong 1999 year class, and the 2003 and 2004 fishery data showed the first appearance of large numbers from the 2000 and 2001 year classes, respectively. The 2009 fishery data was dominated by 3-year-olds of the 2006 year class, and continued to show the presence of the 2001 year class (Table 16.6 and Figure 16.4). The progression of the 2001 year class is clearly evident in the modes of the 2007, 2008, and 2009 fishery age data (Figure 16.4).

Atka mackerel are a summer-fall spawning fish that do not appear to lay down an otolith annulus in the first year (Anderl *et al.*, 1996). For stock assessment purposes, one year is added to the number of otolith hyaline zones determined by the Alaska Fisheries Science Center Age and Growth Unit. All age data presented in this report have been corrected in this way.

16.3.2 Survey Data

Atka mackerel are a difficult species to survey because: (1) they do not have a swim bladder, making them poor targets for hydroacoustic surveys; (2) they prefer hard, rough and rocky bottom which makes sampling with survey bottom trawl gear difficult; and (3) their schooling behavior and patchy distribution result in survey estimates with large variances. Despite these shortcomings, the U.S.-Japan cooperative trawl surveys conducted in 1980, 1983, 1986, and the 1991, 1994, 1997, 2000, 2002, 2004, 2006, and 2010 domestic trawl surveys, provide the only direct estimates of population biomass from throughout the Aleutian Islands region. Furthermore, the biomass estimates from the early U.S-Japan cooperative surveys are not directly comparable with the biomass estimates obtained from the U.S. trawl surveys because of differences in the net, fishing power of the vessels, and sampling design (Barbeaux *et al.* 2003).

Aleutian Islands trawl survey biomass estimates of Atka mackerel varied from 63,215 t in 1980 to 489,486 t in 1983, and 1,21,148 t in 1986 (Table 16.7). 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 1,011,991 t in the Central Aleutians (Table 16.7), or 90% of the total biomass of Atka mackerel in the Aleutian Islands. This was a 908,403 t increase over the 1983 biomass estimate for the same stratum-depth interval. The 1986 biomass estimate is associated with a large coefficient of variation (0.80). Due to differences in area and depth coverage of the surveys, it is not clear how this biomass estimate compares to earlier years.

The most recent Aleutian Islands biomass estimate from the 2010 Aleutian Islands bottom trawl survey is 844,571 t, up 16% relative to the 2006 survey estimate (no survey was conducted in 2008, Table 16.8). 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 2010 survey is largely a result of the increase in biomass found in the Western area (252,819 t in 2010 up from 100,693 t in 2006), despite a large decrease in the Central area. Relative to the 2006 survey, the 2010 biomass estimates are up 151% in the Western area, down 29% in the Central area, and up 13% in the Eastern area (Figure 16.5). The 95% confidence interval about the mean total 2010 Aleutian biomass estimate is **162,039-1,527,102 t**. The coefficient of variation (*CV*) of the 2010 mean Aleutian biomass is 40% (Table 16.8).

The distribution of biomass in the Western, Central, and Eastern Aleutians and the southern Bering Sea shifted between each of the surveys, and most dramatically in area 541 in the 2000 survey (Figure 16.5). The 2000 Eastern Aleutian area biomass estimate (900 t) was the lowest of all surveys, contributing only 0.2% of the total 2000 Aleutian biomass and represented a 98% decline relative to the 1997 survey. The extremely low 2000 biomass estimate for the Eastern area has not been reconciled, but there are several factors that may have had a significant impact on the distribution of Atka mackerel that were discussed in Lowe *et al.* (2001). We note that the distribution of Atka mackerel in the Eastern area is generally patchier, and up until the 2004 survey, the area-specific variances for the Eastern area have always been high relative to the Central and Western areas. Lowe *et al.* (2001) suggest that a combination of several factors coupled with the typically patchier distribution of Atka mackerel in area 541 may have impacted the distribution of the fish such that they were not available at the surveyed stations at the time of the 2000 survey.

The 2010 survey showed that the Eastern area contributed 47% of the total biomass which is nearly identical to the proportion detected in the 2006 survey, and represents the largest proportions in the time series (Table 16.8).

In 1994 for the first time since the initiation of the Aleutian triennial surveys, a significant concentration of biomass was detected in the southern Bering Sea area (66,603 t). This occurred again in 1997 (95,680 t), 2002 (59,883 t), and 2004 survey (267,556 t, Table 16.8). These biomass estimates are a result of large catches from a single haul encountered north of Akun Island in all four surveys. In addition, large catches of Atka mackerel in the 2004 survey were also encountered north of Unalaska Island, with a particularly large haul in the northwest corner of Unalaska Island (Figure 16.6). The 2004 southern Bering Sea strata biomass estimate of 267,556 t is the largest biomass encountered in this area in the survey time series. The *CV* of the 2004 southern Bering Sea estimate is 43%, much lower than previous years as several hauls contributed to the 2004 estimate. The 2006 survey estimated only 12,284 t of biomass (*CV*=44%) from the southern Bering Sea area. Most recently, the 2010 survey estimated 102,755 t of biomass in the southern Bering Sea (*CV*=86%). As in past surveys, this biomass estimate is the result of a large catch from a single haul encountered north of Akun Island.

Areas with large catches of Atka mackerel during the 2004 survey included north of Akun Island and Unalaska Islands, Seguam Pass, Tanaga Pass, Kiska Island, Buldir Island, and Stalemate Bank (Figure 16.6). Similar to the 2004 survey, areas with large catches of Atka mackerel in the 2006 survey included Seguam Pass, Tanaga Pass, Kiska Island, and Stalemate Bank (Figure 16.6). In the most recent 2010 survey, areas of large catches included north of Akun Island, northwest of the Islands of Four Mountains, Seguam Pass, Kiska Island, Buldir Island, and Stalemate Bank (Figure 16.6). In the 2002, 2004, 2006, and 2010 surveys Atka mackerel were much less patchily distributed relative to previous surveys and were encountered in 55, 60, 51, and 57% of the hauls respectively, which are the highest rates of encounters in the survey time series.

The average bottom temperatures measured in the 2000 survey were the lowest of any of the Aleutian surveys, particularly in depths less than 200 m where 99% of the Atka mackerel are caught in the surveys (Figure 16.7). The average bottom temperatures measured in the 2002 survey were the second lowest of the Aleutian surveys, but significantly higher than the 2000 survey and very similar to the 1994 survey. The average bottom temperatures measured in the 2006 and 2010 surveys were slightly above the 2002 survey and very similar to the 1994 survey temperatures (Figure 16.7).

There is greater confidence in Atka mackerel biomass estimates from bottom trawl surveys of the groundfish community of the Aleutian Islands (AI) than the Gulf of Alaska (GOA). First, the coefficients of variation (*CV*) of the mean Atka mackerel biomass estimates have been considerably smaller from recent AI surveys compared to recent GOA surveys: 0.20, 0.17, and 0.28 from the 2002, 2004, 2006 AI surveys, respectively, compared with 1.00, 0.35, 0.50, and 0.46 from the 2001, 2003, 2005, and 2007 GOA surveys. However, it is noted that the most recent 2010 survey was associated with a *CV* of 40%, which is the highest *CV* in the domestic trawl survey time series. 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 55%, 60, 51, and 57%% of the hauls in the 2002, 2004, 2006, and 2010 AI surveys, compared to 10%, 44%, 29%, and 20% of the hauls in the Shumagin area in the 2001, 2003, 2005, and 2007 GOA surveys, respectively. For these reasons we utilize bottom trawl surveys to assess the relative abundance of Atka mackerel in the Aleutian Islands, but do not consider the highly variable estimates of biomass from the GOA surveys useful for tracking abundance trends.

Survey Length Frequencies

The 2000, 2002, 2004, and 2006 bottom trawl surveys and the fishery catch data revealed a strong east-west gradient in Atka mackerel size, with the smallest fish in the west and progressively larger fish to the east, (Figure 16.8 in Lowe *et al.* 2003, 2005, 2009). The 2010 survey length frequency distributions also show a strong east-west gradient in Atka mackerel size (Figure 16.8). The 2010 survey length frequency distributions from the Eastern area showed a mode of fish at 44 cm, larger than the Central and Western fish, and similar to the size distribution of fish sampled from the southern Bering Sea with a mode of 45 cm (Figure 16.8).

Survey Age Frequencies

The age compositions from the 2004, 2006, and 2010 Aleutian surveys are shown in Figure 16.9. The 2004 survey age data is basically comprised of 3, 4, and 5-year olds of the 1999, 2000, and 2001 year classes, and is dominated by 3-year olds of the 2001 year class (Figure 16.9). The 2006 survey still indicated large numbers from the 1999 year class and a very low number of fish from the 2002 year class. The fishery catch data also confirmed very low numbers of the 2002 year class. The 2006 survey and fishery saw an unusually high number of 2 year olds from the 2004 year class (Figure 16.9 and Table 16.6). The 2007 fishery data confirmed a large number of 3 year olds from the 2004 year class. The most recent 2010 survey age composition is dominated by 3 and 4-year olds of the 2006 and 2007 year classes. The 2009 fishery data confirmed the strong presence of the 2006 year class in fishery catches. The mean ages of the 2004, 2006, and 2010 surveys are 4.2, 5.3, and 5.3 years, respectively.

Survey Abundance Indices

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

Analyses to determine the impact of omitting the relative time series showed that results without the relative index are more conservative (Lowe *et al*. 2002).

16.4 Analytic approach

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

The Assessment Model for Alaska is developed using ADModel Builder language (Fournier 1998) and follows from the structure presented in Ianelli and Fournier (1998). ADMB is a C++ software language extension and automatic differentiation library that is now freely available. It allows for estimation of large numbers of parameters in non-linear models using automatic differentiation.

[1] AMAK. 2005. A statistical catch at age model for Alaska, version 1.07.1. NOAA Fisheries Toolbox. NEFSC, Woods Hole, MA. Updated 2010 version available on request to authors.

16.4.1 Model structure

The AMAK models catch-at-age with the standard Baranov catch equation. The population dynamics follows numbers-at-age over the period of catch history (here 1977-2010) with natural and age-specific fishing mortality occurring throughout the 11-age-groups that are modeled (1-11+). Age 1 recruitment in each year is estimated as deviations from a mean value expected from an underlying stock-recruitment curve. Deviations between the observations and the expected values are quantified with a specified error model and cast in terms of a penalized log-likelihood. The overall log-likelihood (*L*) is the weighted sum of the calculated log-likelihoods for each data component and model penalties. The component weights are inversely proportional to the specified (or in some cases, estimated) variances. Appendix Tables A-1 – A-3 provide a description of the variables used, and the basic equations describing the population dynamics of Atka mackerel as they relate to the available data. The quasi[2] likelihood components and the distribution assumption of the error structure are given below:

Data component	**Years of data**	**Likelihood form**	***CV* or sample size (*N*)**
Catch biomass	1977-2010	Lognormal	*CV*=5%
Fishery catch age composition	1977-2010	Multinomial	Year specific *N*=25-234
Survey biomass	1991, 1994, 1997 2001, 2004, 2006, 2010	Lognormal	Average *CV*=26%
Survey age composition	1986, 1991, 1994, 1997 2001, 2004, 2006, 2010	Multinomial	*N*=50
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	

The age-composition components are heavily influenced by the sample size assumptions specified for the multinomial likelihood. Since sample variances of our catch-at-age estimates are available (Dorn 1992), "effective sample sizes" ($\dot{N}_{i,j}$) can be derived as follows (where *i* indexes year, and *j* indexes age):

$$\dot{N}_{i,j} = \frac{p_{i,j}\left(1-p_{i,j}\right)}{\mathrm{var}\left(p_{i,j}\right)}$$

where $p_{i,j}$ is the proportion of Atka mackerel in age group *j* in year *i* plus an added constant of 0.01 to provide some robustness. The variance of $p_{i,j}$ was obtained from the estimates of variance in catch-at-age. Thompson and Dorn (2003, p. 137) and Thompson (AFSC pers. comm.) note that the above is a random variable that has its own distribution. Thompson and Dorn (2003) show that the harmonic mean of this distribution is equal to the true sample size in the multinomial distribution. This property was used to obtain sample size estimates for the (post 1989) fishery numbers-at-age estimates (scaled to have a mean of 100; earlier years were set to constant values):

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

1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
25	25	25	25	50	50	50	50	50	50	50	50
1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
47	35	10	10	66	59	117	16	82	219	234	104
2002	2003	2004	2005	2006	2007	2008		2009			
136	133	133	89	117	89	144		150			

An ageing error conversion matrix is used in the assessment model to translate model population numbers at age to expected fishery catch at age. We estimated this matrix using an ageing error model fit to the observed percent agreement at ages 2 through 10. Mean percent agreement is close to 100% at age 2 and declines to 54% at age 10. Annual estimates of percent agreement are variable, but show no obvious trend, hence a single conversion matrix for all years in the assessment model was adopted. The model is based on a linear increase in the standard deviation of ageing error and the assumption that ageing error is normally distributed. The model predicts percent agreement by taking into account the probability that both readers are correct, both readers are off by one year in the same direction, and both readers are off by two years in the same direction. The probability that both readers agree and were off by more than two years was considered negligible.

Parameters estimated independently

Natural Mortality

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

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

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

An analysis was undertaken to explore alternative methods to estimate natural mortality for Atka mackerel (Lowe and Fritz, 1997). Several methods were employed based on correlations of *M* with life history parameters including growth parameters (Alverson and Carney 1975, Pauly 1980, Charnov 1993), longevity (Hoenig 1983), and reproductive potential (Roff 1986, Rikhter and Efanov 1976). Atka mackerel appear to be segregated by size along the Aleutian chain. Thus, natural mortality estimates based on growth parameters would be sensitive to any sampling biases that could result in under- or over-estimation of the von Bertalanffy growth parameters. Fishery data collections are more likely to be biased as the fishery can be more size selective and concentrates harvests in specific areas as opposed to the surveys. Natural mortality estimates derived from fishery data ranged from 0.05 to 1.13 with a mean of 0.53. Natural mortality estimates, excluding those based on fishery data, ranged from 0.12 to 0.74 with a mean value of 0.34. The current assumed value of 0.3 is consistent with these values. Also, a value of 0.3 is consistent with values of *M* derived by the methods of Hoenig (1983) and Rikhter and Efanov (1976) which do not rely on growth parameters (Lowe and Fritz, 1997).

The 2003 assessment explored the use of priors on *M*, resulting in drastically inflated biomass levels (Figure 16.11 in Lowe *et al.* 2003). Independent studies are being conducted outside the assessment which may provide further information to configure appropriate prior distributions for *M*. In the current assessment, a natural mortality value of 0.3 was used in the assessment model.

Length and Weight at Age

Atka mackerel exhibit large annual and geographic variability in length at age. Because survey data provide the most uniform sampling of the Aleutian Islands region, data from these surveys were used to evaluate variability in growth (Kimura and Ronholt 1988, Lowe *et al.* 1998). Kimura and Ronholt (1988) conducted an analysis of variance on length-at-age data from the 1980, 1983, and 1986 U.S.-Japan surveys, and the U.S.-U.S.S.R. surveys in 1982 and 1985, stratified by six areas. Results showed that length at age did not differ significantly by sex, and was smallest in the west and largest in the east. More recent analyses by Lowe *et al.* (1998) corroborated differential growth in three sub-areas of the Aleutian Islands and the Western Gulf of Alaska. Based on the work of Kimura and Ronholt (1988), and annual examination of length and age data by sex which has found no differences, growth parameters are presented for combined sexes. Parameters of the von Bertalanffy length-age equation and a weight-length equation have been calculated for (1) the combined 1986, 1991, and 1994 survey data for the entire Aleutians region, and for the Eastern (541) and combined Central and Western (542 and 543) subareas, and (2) the combined 1990-96 fishery data for the same areas:

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

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

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.

Year-specific weight-at-age estimates are used in the model to scale fishery and survey catch-at-age (and the modeled numbers-at-age) to total catch biomass and are intended to represent the average weight-at-age of the catch. Separate annual survey weights-at-age are complied for expanding modeled numbers into –age-selected- survey biomass levels (Table 16.9). Specifically, survey estimates of length-at-age were obtained using year-specific age-length keys. Weights-at-age were estimated by multiplying the length distribution at age from the age-length key, by the mean weight-at-length from each year-specific data set (DeRobertis and Williams 2008). In addition, a single vector of weight-at-age values based on the 2004, 2006, and 2010 surveys is used to derive population biomass from the modeled numbers-at-age in order to allow for better estimation of current biomass (Table 16.9).

The fishery weight-at-age data presented in previous assessments (prior to 2008) were compiled based on unweighted, unstratified (Aleutian-wide) fishery catch-age samples to construct the year-specific age-length keys (see Table 16.8 in Lowe *et al*. 2007). Beginning with the 2008 assessment, the weights-at-age for the post 1989 fishery reflect stratum-weighted values based on the relative catches. The fishery weight-at-age data presented in Table 16.9 for 1990 to 2009, were compiled using the two-stage catch-estimation scheme described above in the Fishery Data section. Prior to 1990, the fishery weight-at-age estimates are as in previous assessments and given in Table 16.9.

Maturity at Age and Length

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

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

The maturity schedules are given in Table 16.10. Cooper and McDermott (2010a) examined spatial and temporal variation in Atka mackerel female maturity at length and age. Maturity at length data varied significantly between different geographic areas and years, while maturity at age data failed to indicate differences and corroborated the age at 50% maturity determined by McDermott and Lowe (1997).

Parameters estimated conditionally

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

Fishing Mortality

Fishing mortality is parameterized to be separable with a year component and an age (selectivity) component in all models. The selectivity relationship is modeled with a smoothed non-parametric relationship that can take on any shape (with penalties controlling the degree of change and curvature specified by the user; Table A-2). Selectivity is conditioned so that the mean value over all ages will be equal to one. To provide regularity in the age component, a moderate penalty was imposed on sharp shifts in selectivity between ages using the sum of squared second differences (log-scale). In addition, the age component parameters are assumed constant for ages 10 and older. 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. Prior to the 2008 assessment, selectivity had been allowed to vary annually with a low constraint as described in the 2002 assessment (Lowe *et al*. 2002). As suggested by the 2008 CIE reviewers, we adopted a new model configuration with blocks of years with constant selectivity which correspond approximately to the foreign fishery, the joint venture fishery, the domestic fishery prior to Steller sea lion regulations, and the domestic fishery post Steller sea lion regulations. This model configuration, with a refinement to the change-points in the fishery selectivity blocks is used in the current assessment. See Model Evaluation (below) for a discussion of the shift in the blocks of years with constant selectivity.

Survey Selectivity and Catchability

For the bottom trawl survey, selectivity-at-age follows a parameterization similar to the fishery selectivity-at-age presented above (except with no allowance for time-varying selectivity). Here we specified that the average selectivity-at-age for the survey is equal to 1 over ages 4-10. This was done to standardize the ages over which selectivity most reasonably applies.

The 2003 assessment explored the use of a prior on survey catchability (q) through AMAK with mixed results that were difficult to interpret biologically (Lowe *et al.* 2003). In the 2004 assessment we presented a model (Model 4, Lowe *et al.* 2004), with a moderate prior on q (mean = 1.0, $\sigma^2 = 0.2^2$) which was accepted and used as the basis for the ABC and OFL specifications since 2004. Our assumptions on survey catchability have not changed for the current assessment.

Recruitment

The Beverton-Holt form of stock recruitment relationship based on Francis (1992) was used (Table A-2). Values for the stock recruitment function parameters α and β are calculated from the values of R_0 (the number of 0-year-olds in the absence of exploitation and recruitment variability) and the "steepness" of the stock-recruit relationship (h, Table A-2). The "steepness" parameter is the fraction of R_0 to be expected (in the absence of recruitment variability) when the mature biomass is reduced to 20% of its pristine level (Francis 1992). Past assessments have assumed a value of 0.8. A value of h = 0.8 implies that at 20% of the unfished spawning stock size, an expected value of 80% of the unfished recruitment level will result. Model runs exploring other values of h and the use of a prior on h were explored in previous assessments (Lowe *et al.* 2002), but were found to have little or no bearing on the stock assessment results and were not carried forward for further evaluation at the time. As in past years, we assumed h = 0.8 for all model runs since previous work showed that assessment results were insensitive to this assumption (and given the Tier 3 status does not affect future projections).

16.5 Model Evaluation

In response to issues raised during the 2008 Center for Independent Experts (CIE) review of the Aleutian Islands Atka mackerel and pollock assessments, we changed a number of aspects of the input data and made refinements to the model configuration in the 2008 assessment. In summary, these changes focused on a more consistent approach to include survey data, the incorporation of a lower age+ bin (11+), calculated samples sizes for fishery catch-at-age data, revised compilation of catch- and weight-at-age data using a two-stage catch-estimation scheme based on stratified (by area) catch biomass and catch-at-age fishery samples, inclusion of an age-misclassification matrix, and incorporating blocks of years with constant selectivity. These changes were evaluated in a step-wise fashion and presented in Lowe *et al*. (2008).

The changes to the input data allowed for a more consistent approach and the change in the model configuration of fishery selectivity allowed for much greater parsimony with slight improvements to survey biomass fit at the cost of only a slight decrease in fishery age composition fits (Lowe *et al*. 2008). The revised model configuration assumed blocks of years with constant selectivity corresponding approximately to the foreign fishery, the joint venture fishery, the domestic fishery prior to Steller sea lion regulations, and the domestic fishery post Steller sea lion regulations. This model configuration was accepted by the SSC and used to set the 2009 and 2010 BSAI Atka mackerel ABCs and OFLs. In the current assessment we use the same model configuration, however we explore the impact of a shift in the change-points for the blocks of years with constant selectivity (shift 1 year earlier, and shift 1 year later).

Key results from the model runs with the 1 year shifts compared to status quo (last year's model) are presented in Table 16.11. The best overall -log likelihood fit was achieved with a shift in the blocks 1 year later. This improvement was attributed to an improved fit to the fishery age compositions relative to a shift 1 year earlier and status quo. The refined model with a shift 1 year later had the lowest AIC value and was selected as our preferred configuration. The revised blocks with a shift 1 year later correspond approximately to the foreign fishery (1977-1984), the joint venture fishery (1985-1992), the domestic fishery prior to Steller sea lion regulations (1993-1999), and the domestic fishery post Steller sea lion regulations (2000-2010).

Key results from the 2009 Model and the 2010 Model incorporating refinements to the change-points for the fishery selectivity blocks are given in Table 16.12.

16.6 Model Results

The results discussed below are based on the 2010 Model with updated fishery catch- and weight-at-age values, 2009 fishery data, 2010 Aleutian Islands survey data, 4 time periods each with constant selectivity, and other minor changes including refinements to the change-points in the fishery selectivity as described above.

16.6.1 Selectivity

For Atka mackerel, the estimated selectivity patterns are particularly important in describing their dynamics. Previous assessments have focused on the transitions between ages and time-varying selectivity (Lowe *et al.* 2002). The current assessment estimates selectivity at age schedules for 4 time periods in the fishery and a single selectivity pattern for the survey (Figures 16.10-16.13, Table 16.13).

The fishery catches essentially consist of fish 3-11 years old, although a 15-year-old fish was found in the 1994 fishery. The fishery exhibits a slight dome-shaped selectivity pattern which is more pronounced prior to 1992 during the foreign and joint venture fisheries blocks (1977-1984 and 1985-1992, Figures 16.10-16.11). After 1992, fishery selectivity patterns are divided into 2 blocks of years (1993-1999, 2000-2010) each with constant selectivity. The patterns between these two blocks are fairly similar but do show slight differences at ages 3-7 and more notable differences at age 8 and older. Fish older than age 9 make up a very small percentage of the population each year, and the differences in the selectivity assumptions for the older ages are not likely to have a large impact. However, differences in selectivity for ages 3-8 can have a significant impact. The recent pattern for the years 2000-2010 reflects the large numbers of fish from the 1999, 2000, 2001, and 2006 year classes (Figure 16.11, Table 16.6). The age at 50% selectivity is estimated at about age 4 for both time periods (Figure 16.11). It is important to note the maturity-at-age vector (age at 50% maturity is 3.6 years, Figure 16.11). The estimated selectivity patterns since 1991 indicate the fishery is harvesting mature older fish relative to the foreign and joint venture fisheries. The estimated fishery selectivity patterns from the most recent time period from the current assessment are compared with the recent period from last year's assessment and are very similar (Figure 16.12). Relative to last year, the current estimated fishery selectivity shows slight differences with higher selectivity between the ages of 3 and 7, and lower selectivity after age 8. This is a reflection of the large numbers of 3 year olds (2006 year class) observed in the 2009 fishery catches, and the decreased presence of the 1999 year class in the fishery catches.

Survey catches are mostly comprised of fish 3-9 years old. However, the 2010 survey showed significant numbers of 9-11 year olds of the 1999, 2000, and 2001 year classes. A 14-year old fish was found in the 1994 survey and a 15-year old fish was found in the 2000 survey. The current configuration estimates a smoothed nearly asymptotic pattern (Figure 16.13), which differs from last year's estimate which exhibited a slightly dome-shaped selectivity pattern (Figure 16.13 in Lowe *et al*. 2009). Relative to last year, the current estimated survey selectivity pattern is nearly identical for ages 1-7. However, after age 7, the updated pattern shows higher selectivity reflecting the continued strong presence of the 1999, 2000, and 2001 year classes as 9-11 year olds (Figure 16.9).

16.6.2 Abundance Trend

The estimated time series of total numbers at age are given in Table 16.14. The estimated time series of total biomass (ages 1+) with approximate upper and lower 95% confidence limits are shown in Figure 16.14 and given in Table 16.15. A comparison of the spawning biomass trend from the current and previous assessments (Figure 16.15, Table 16.15) indicates consistent trends throughout the time series, i.e., biomass increased during the early 80s and again in the late 80s to early 90s. After the estimated peak spawning biomass in 1993, spawning biomass declined for nearly 10 years until 2001, thereafter, spawning biomass began a steep increase which continued to 2005. The estimated historical biomass levels prior to 1989 are higher relative to last year's assessment. This is attributed to a small increase in the estimated magnitude of the 1977 year class. Although the increase in magnitude of the 1977 year class was small (8%), this year class was a dominant year class in the time series and was persistently observed for several years. The estimated biomass levels after 1997 in the current assessment are higher than previously projected. This is attributed to revised estimates of recruitment from the 1999, 2000, 2001, and 2006 year classes which increased by 17%, 17%, 22%, and 12%, respectively (Table 16.16, Figure 16.16a).

16.6.3 Recruitment Trend

The estimated time series of age 1 recruits from the current assessment and the 2007 assessment is shown in Figure 16.16a and given in Table 16.16. The strong 1999 year class is most notable in the current assessment, followed by the 1977, 1989, and 2001 year classes. The addition of the 2009 fishery and 2010 survey age composition data impacted the estimated magnitude of the 2006 and 2007 year class which increased 12 and 53% respectively, relative to last year's assessment (Figure 16.16a). Although, the estimated magnitude of the 2007 year class increased 53%, they were only observed as 3-year olds in the 2010 survey and are associated with a high degree of variability. The 2009 fishery data was dominated by 3-year-olds of the 2006 year class, and continued to show the presence of the 2001 year class (Table 16.6 and Figure 16.4). The 2010 survey data are dominated by the 2006 and 2007 year classes and continued to show the presence of the 1999, 2000, and 2001 year classes (Figure 16.9). The 1999 and 2001 year classes are estimated to be two of the four largest year classes in the time series (approximately 1.3 and 1.4 billion recruits, respectively) due to the persistent observations of these year classes in the 2009 fishery and the 2010 survey (Figures 16.4 and 16.9). The current assessment estimates above average (greater than 20% of the mean) recruitment from the 1977, 1988, 1992, 1995, 1998, 1999, 2000, 2001, 2006 and 2007 year classes (Figure 16.16a).

The average estimated recruitment from the time series 1978-2008 is 550 million fish and the median is 387 million fish (Table 16.16). The entire time series of recruitments (1977-2009) includes the 1976-2008 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 (1977-2007 year classes). Projections of biomass are based on estimated recruitments from 1978-2008 using a stochastic projection model described below.

16.6.4 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 16.17 and shown in Figure 16.17.

16.6.5 Model Fit

A summary of key results from the 2010Model are presented in Table 16.12. The coefficient of variation or *CV* (reflecting uncertainty) about the 2010 biomass estimate is 19% and the *CV*s on the strength of the 1999 and 2001 year classes at age 1 are 19 and 22%, respectively (Table 16.12). Overall estimated recruitment variability for BSAI Atka mackerel is high (0.639). Sample size values were calculated for the fishery data and fixed at 50 for the bottom trawl survey data. The model estimated an average fishery effective sample size (*N*) of 124 and average survey effective *N* of 51, which compares well with the fixed value. The overall residual mean square error (RMSE) for the survey is estimated at 0.208 (Table 16.12). The RMSE is in line with estimates of sampling-error *CV*s for the survey which range from 14-40% and average 26% 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 16.18 compares the observed and estimated survey biomass abundance values for the Bering Sea/Aleutian Islands. The large decrease in biomass indicated by the 1994 and 1997 surveys followed by the large increases in biomass from the 2000 and 2002 surveys appear to be consistent with recruitment patterns. However, the large increase observed in the 2004 survey could not be fit. In the 2004 survey, an unusually high biomass (270,000 t) was estimated for the southern Bering Sea area. This value represented 30% of the entire 2004 BSAI survey biomass estimate. The 2006 survey indicates a downward trend which is consistent with the population age composition at the time. The most recent 2010 survey biomass estimate indicates a large increase that was not predicted by the assessment model. The 2010 survey biomass estimate for the southern Bering Sea was also unusually high (102,800 t) and represented a 735% increase over the 2006 southern Bering Sea estimate. We note that the model's predicted survey biomass trend is very conservative relative to the recent (2000, 2002, 2004, 2006, and 2010) observed bottom trawl survey biomass values (Figure 16.18).

The fits to the survey and fishery age compositions for the 2010 Model are depicted in Figures 16.19 and 16.20, respectively. The model fits the fishery age composition data well particularly after 1995, and the survey age composition data less so. This reflects the fact that the sample sizes for age and length composition data are higher for the fishery in some years 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. We also note that the 2009 fishery observed slightly greater numbers than expected of 3-year olds of the 2006 year class, and significantly fewer numbers than expected of the 4, 5, and 6-year olds of the 2005, 2004, and 2003 year classes (Figure 16.20). Recent fishery age composition fits may indicate the need for another change-point for the recent (2000-2009) selectivity block.

16.7 Projections and harvest alternatives

16.7.1 Amendment 56 Reference Points

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC (*max* F_{ABC}). The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. The overfishing and maximum allowable ABC fishing mortality rates are given in terms of percentages of unfished female spawning biomass ($F_{SPR\%}$), on fully selected age groups. The associated long-term average female spawning biomass that would be expected under average estimated recruitment from 1978-2008 (550 million age 1 recruits) and *F* equal to $F_{40\%}$ and $F_{35\%}$ are denoted $B_{40\%}$ and $B_{35\%}$, respectively. The Tiers require reference point estimates for biomass level determinations. We present the following reference points for BSAI Atka mackerel for Tier 3 of Amendment 56. For our analyses, we computed the following values from the 2010 Model results based on recruitment from post-1976 spawning events:

$B_{100\%}$ = 261,100 t female spawning biomass
$B_{40\%}$ = 104,400 t female spawning biomass
$B_{35\%}$ = 91,400 t female spawning biomass

16.7.2 Specification of OFL and Maximum Permissible ABC

In the current assessment, the 2010 Model is configured with 4 time periods of constant selectivity. The last time period (2000-2009) reflects the domestic fishery after implementation of Steller sea lion protection measures. This selectivity pattern is shown in Figure 16.12 and used for projection purposes. The following rates are based on the 2000-2009 selectivity pattern estimated by the 2010 Model:

Full selection *F*s	
F_{2010}	0.311
$F_{40\%}$	0.384
$F_{35\%}$	0.468
$F_{2010}/F_{40\%}$	0.810

For specification purposes to project the 2011 ABC, we assumed that the full TAC would be taken in 2010 (74,000 t). For projecting to 2012, an expected catch in 2011 is required. Typically this value is set to a recommended ABC, in this case the 2011 recommended ABC (85,300 t). However, recognizing that the proposed Steller Sea Lion RPA's will likely be in effect in 2011, it may be more prudent to assume the stock-wide catch based on a reduced overall BSAI-wide Atka mackerel catch for 2011. To arrive at such a reduction we assumed that only trace amounts of Atka mackerel (as bycatch in other fisheries) would be taken from Area 543 (Western Aleutian Islands) and about half of the allocation to Area 542 (Central Aleutian Islands) would be taken. We estimated that about 64% of the BSAI-wide ABC is likely to be taken. This percentage was applied to the maximum permissible 2011 ABC and that amount was assumed to be caught in order to estimate the 2012 ABC and OFL values.

It is important to note 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. For the 2010 Model, the projected year 2011 female spawning biomass (SSB_{10}) is estimated to be 146,000 t under an assumed 2010 catch of 74,000 t and reduced 2011 catch reflecting the RPA adjustment to the 2011 ABC. The projected 2011 female spawning biomass estimate is above the $B_{40\%}$ value of 104,400 t, placing BSAI Atka mackerel in **Tier 3a**. The maximum permissible ABC and OFL values under **Tier 3a** are:

Year	Catch	ABC	OFL	SSB
2011	54,600	85,300	101,200	146,000
2012	50,000	77,900	92,200	130,500

Note that the 2011 and 2012 maximum permissible $F_{ABC} = F_{40\%}$ = 0.384 and $F_{OFL}=F_{35\%}$ = 0.468; also, catches in 2011 and 2012 are less than the recommended ABCs to reflect expected catch reductions under Steller Sea Lion RPAs.

16.8 ABC Recommendation

Observations and characterizations of uncertainty in the Atka mackerel assessment are noted for ABC considerations.

1) Trawl survey estimates of Aleutian Islands biomass are highly variable; the 2000, 2002, and 2004 survey estimates showed 40, 50, and 15% increases respectively. The 2006 survey estimate of

Aleutian Islands biomass decreased 18% relative to the 2004 survey. The 2008 survey was not conducted. The most recent 2010 survey increased 16% relative to the 2006 survey.

2) Under an $F_{40\%}$ harvest strategy with no SSL RPA catch reductions, 2011 female spawning biomass is projected to be above $B_{40\%}$ but drop below in 2013 to 2016 (Figure 16.21 and Table 16.18 Scenario 1). Under an $F_{40\%}$ harvest strategy and assuming SSL RPA catch reductions, 2011 female spawning biomass is projected to be above $B_{40\%}$ for the full time series (2011-2023, Table 16.18 Scenario 2).
3) The model's predicted survey biomass trend is very conservative relative to 2000, 2002, 2004, 2006 and 2010 observed bottom trawl survey biomass values (Figure 16.18).
4) The 2009 fishery data is dominated by 3-year-olds of the 2006 year class, and continued to show the presence of the strong 2001 year class (Table 16.6 and Figure 16.4).

5) The 2010 survey age composition is dominated by 3 and 4-year olds of the 2006 and 2007 year classes. The bottom trawl surveys have been a consistently good indicator of incoming year class strengths.

6) Currently we estimate the 1999 year class to be the largest in the time series (but with a moderate degree of uncertainty: *CV*=19%).

We believe the current model configuration provides an improved assessment of BSAI Atka mackerel relative to past model configurations. Given the current stock size, the appearance of three consecutive strong year classes which still persist in the population, an above average 2006 year class, and preliminary indications of an above average 2007 year class, the maximum permissible is precautionary and acceptable for Atka mackerel. We note that the maximum permissible reference fishing mortality rate (F_{ABC}) is higher than the natural mortality rate. This is a due to the fact that estimated fishery selectivity-at-age is significantly older than the maturity-at-age. That is, the fishery targets the older mature portion of the population that have had opportunities to spawn. Actual fishing mortality rates have been below F_{ABC} . For perspective, a plot of relative harvest rate ($F_t / F_{35\%}$) versus relative female spawning biomass ($B_t/B_{35\%}$) is shown in Figure 16.22. For most of the time series (including the 2010 data point), the current assessment estimates that relative harvest rates have been below 1, and the relative spawning biomass rates have been greater than 1.0 (Figure 16.22).

The probability of female spawning biomass dropping below $B_{20\%}$ in the next five years is very low (Figure 16.23).

The 2011 yield associated with the maximum permissible $F_{40\%}$ fishing mortality rate of 0.384 is 85,300 t, which is our 2011 ABC recommendation for BSAI Atka mackerel.

The 2012 yield associated with the maximum permissible F_{ABC} fishing mortality rate of 0.384 and assuming 2011 catch reductions, is 77,900 t, which is our 2012 ABC recommendation for BSAI Atka mackerel.

The 2011 ABC recommendation represents a 15% increase from the Council's 2010 ABC. This is consistent with higher estimates of the magnitude of the 1999, 2000, 2001, and 2006 year classes.

16.8.1 Area Allocation of Harvests

Amendment 28 of the Bering Sea/Aleutian Islands Fishery Management Plan divided the Aleutian subarea into 3 districts at 177° E and 177° W longitude, providing the mechanism to apportion the Aleutian Atka mackerel TACs. The Council used a 4-survey (2000, 2002, 2004, and 2006) weighted average to apportion the 2010 ABC. The rationale for the weighting scheme was described in Lowe *et* *al.* (2001). The 2010 survey provides updated information for the apportionment, and we drop the 2000 survey and incorporate the 2010 survey distribution. In addition, the distribution of survey biomass used in the apportionment calculations has been updated to include the southern Bering Sea area in area 541. This is consistent with the assessment and fishery management of area 541 for Atka mackerel. The data used to derive the percentages for the weighting scheme are given below:

	2002	2004	2006	2010	2010 Apportionment	Recommended 2011 & 2012 Apportionment
541[1]	30.26%	44.20%	48.91%	52.57%	32.2%	**47.27%**
542	38.94%	23.27%	37.51%	20.74%	40.0%	**28.09%**
543	30.80%	32.52%	13.58%	26.69%	27.8%	**24.64%**
Weights	8	12	18	27		

[1]Includes eastern Aleutian Islands and southern Bering Sea areas.

The apportionments of the 2011 and 2012 recommended ABCs based on the most recent 4-survey weighted average are:

	2011	2012
Eastern (541)	40,300	36,800
Central (542)	24,000	21,900
Western (543)	21,000	19,200
Total	85,300	77,900

16.9 Standard Harvest Scenarios and Projection Methodology

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

For each scenario, the projections begin with the vector of 2010 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2011 using a fixed value of natural mortality of 0.3, the recent schedule of selectivity estimated in the assessment (in this case the 2000-2009 selectivity), and the best available estimate of total (year-end) catch for 2010 (in this case assumed equal to the 2010 TAC of 74,000 t). In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning (August) and the maturity and population weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 500 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in a Supplemental Environmental Impact Statement prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2011, are as follows ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

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

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2011 recommended in the assessment to the *max* F_{ABC} for 2011. (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). *Note: We used this scenario to project the BSAI stock assuming catch reductions that may occur under proposed SSL RPAs.*

Scenario 3: In all future years, F is set equal to the 2006-2010 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

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

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

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

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in 2010 or 2) above ½ of its MSY level in 2010 and above its MSY level in 2020 under this scenario, then the stock is not overfished.)

Scenario 7: In 2011 and 2012, 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 2023 under this scenario, then the stock is not approaching an overfished condition.)

16.9.1 Status determination

The projections of female spawning biomass, fishing mortality rate, and catch corresponding to the seven standard harvest scenarios are shown in Table 16.18. Harvest scenarios #6 and #7 are intended to permit determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock that is below its MSST is defined to be *overfished*. Any stock that is expected to fall below its MSST in the next two years is defined to be *approaching* an overfished condition. Harvest scenarios #6 and #7 are used in these determinations as follows:

Is the stock overfished? This depends on the stock's estimated spawning biomass in 2010:

a) If spawning biomass for 2010 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b) If spawning biomass for 2010 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c) If spawning biomass for 2010 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest scenario #6 (Table 16.18). If the mean spawning biomass for 2020 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest scenario #7:

a) If the mean spawning biomass for 2013 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

b) If the mean spawning biomass for 2013 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c) If the mean spawning biomass for 2013 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2023. If the mean spawning biomass for 2023 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

In the case of BSAI Atka mackerel, spawning biomass for 2010 is estimated to be above $B_{35\%}$. Therefore, the stock is above its MSST and is not overfished. Mean spawning biomass for 2013 under scenario 7 in Table 16.18 is above $B_{35\%}$ therefore, the stock is not approaching an overfished condition.

16.10 Ecosystem Considerations

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

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

16.10.1 Ecosystem effects on BSAI Atka mackerel

Prey availability/abundance trends

Figure 16.24 shows the food web of the Aleutian Islands summer survey region, based on trawl survey and food habits data, with an emphasis on the predators and prey of Atka mackerel (see the current Ecosystem Assessment's ecosystem modeling results section for a description of the methodology for constructing the food web).

Adult Atka mackerel in the Aleutians consume a variety of prey, but are primarily zooplanktivors, consuming mainly euphausiids and calanoid copepods (Yang 1996, Yang 2003). Food habits data from 1990-1994 indicates that Atka mackerel feed on calanoid copepods (40%) and euphausiids (25%) followed by squids (10%), juvenile pollock (6%), and finally a range of zooplankton including fish larvae, benthic amphipods, and gelatinous filter feeders (Fig. 16.25a). While Figure 16.25a shows an aggregate diet for the Aleutians management regions, Atka mackerel diet data also show a longitudinal gradient, with euphausiids dominating diets in the east and copepods and other zooplankton dominating in the west. Greater piscivory, especially on myctophids, occurs in the island passes (Ortiz, 2007) Monitoring trends in Atka mackerel prey populations may, in the future, help elucidate Atka mackerel population trends. However, there is no long-term time series of zooplankton, squid, or small forage fish abundance information available.

Some preliminary results of sensitivity analysis suggest that Atka mackerel foraging in the Aleutian Islands may have a relatively strong competitive effect on walleye pollock distribution and abundance, as opposed to the Bering Sea where pollock may be more bottom-up (prey) controlled, or the Gulf of Alaska where pollock may be top-down (predator) controlled (Aydin *et al*. 2007). Since these sensitivity analyses treat the Aleutian Islands as a single “box model”, it is possible that this is a mitigating or underlying factor for the geographical separation between Atka mackerel and pollock as a partitioning of foraging habitat.

Predator population trends

Atka mackerel are consumed by a variety of piscivores, including groundfish (e.g., Pacific cod, Pacific halibut, and arrowtooth flounder, Livingston *et al.* unpubl. manuscr.), marine mammals (e.g., northern fur seals and Steller sea lions, Kajimura 1984, NMFS 1995, Sinclair and Zeppelin 2002), skates, and seabirds (e.g., thick-billed murres, tufted puffins, and short-tailed shearwaters, Springer *et al.* 1999). Apportionment of Atka mackerel mortality between fishing, predation, and unexplained mortality, based on the consumption rates and food habits of predators averaged over 1990-1994 is shown in Figure 16.26. During these years, approximately 20% of the Atka mackerel exploitation rate (as calculated by stock assessment) was due to the fishery, 62% due to predation, and 18% “unexplained”, where “unexplained” is the difference between the stock assessment total mortality and the sum of fisheries exploitation and quantified predation. This unexplained mortality may be due to data uncertainty, or Atka mackerel mortality due to disease, migration, senescence, etc.

Of the 62% of mortality due to predation, a little less than half (25% of total) is due to Pacific cod predation, and one quarter (15% of total) due to Steller sea lion predation, with the remainder spread across a range of predators (Figure 16.25b), based on Steller sea lion diets published by Merrick *et al.* (1997) and summer fish food habits data from the REEM food habits database.

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

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

Changes in habitat quality

<u>Climate</u>

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

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

The 2000 Aleutian Islands summer bottom temperatures indicated that 2000 was the coldest year followed by summer bottom temperatures from the 2002 survey, which indicated the second coldest year (Figure 16.7). The 2004 AI summer bottom temperatures indicated that 2004 was an average year, while the 2006 and 2010 bottom temperatures were slightly below average. Bottom temperatures could possibly affect fish distribution, but there have been no directed studies, and there is no time series of data which demonstrates the effects on AI Atka mackerel.

16.10.2 Atka mackerel fishery effects on the ecosystem

Atka mackerel fishery contribution to bycatch

The levels of bycatch in the Atka mackerel fishery of prohibited species, forage fish, HAPC biota, marine mammals, birds, and other sensitive non-target species is relatively low except for the species which are noted in Table 16.19 and discussed below.

The Atka mackerel fishery has very low bycatch levels of some species of HAPC biota, e.g. seapens and whips. The bycatch of sponges and coral in the Atka mackerel fishery is highly variable. It is notable that in the last 3 years (2007-2009), the Atka mackerel fishery has taken on average about 52 and 25%, respectively of the total Aleutian Islands sponge and coral catches. It is unknown if the absolute levels of sponge and coral bycatch in the Atka mackerel fishery are of concern.

The bycatch of skates, which are considered a sensitive or vulnerable species based on life history parameters, is noted in Table 16.19. Skate bycatch in the Aleutian Islands Atka mackerel fishery is variable and has averaged 158 t in the last 3 years (2007-2009). Over this same time period, the Atka mackerel fishery has taken an average of 13% of the total Aleutian Islands skate bycatch. It is unknown if the absolute levels of skate bycatch in the Atka mackerel fishery are of concern.

The bycatch of sculpin is notable and has averaged about 570 t from 2007 to 2009. This level of bycatch represents an average of 53% of the total Aleutian Islands sculpin bycatch. It is unknown if the absolute levels of sculpin bycatch in the Atka mackerel fishery are of concern.

Fishing gear effects on spawning and nesting habitat

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

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

Concentration of Atka mackerel catches in time and space

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

Atka mackerel fishery effects on amount of large size Atka mackerel

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

Atka mackerel fishery contribution to discards and offal production

There is no time series of the offal production from the Atka mackerel fishery. The Atka mackerel fishery has contributed on average about 1,180 t of non-target discards in the Aleutian Islands from 2007 to 2009. Most of the Atka mackerel fishery discards of target species are comprised of small Atka mackerel. The average discards of Atka mackerel in the Atka mackerel fishery have been about 1,800 t over 2007-2009.

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

The effects of the fishery on the age-at-maturity and fecundity of Atka mackerel are unknown. Studies were conducted to determine age-at-maturity (McDermott and Lowe 1997, and Cooper and McDermott 2010a) and fecundity (McDermott 2003, McDermott *et al*. 2007) of Atka mackerel. These are recent studies and there are no earlier studies for comparison on fish from an unexploited population. Further studies would be needed to determine if there have been changes over time and whether changes could be attributed to the fishery.

16.11 Data gaps and research priorities

Regional and seasonal food habits data for Aleutian Islands is very limited. No time series of information is available on copepod and euphausiid abundance in the Aleutian Islands which would provide information on prey availability and abundance trends. Studies to determine the impacts of environmental indicators such as temperature regime on Atka mackerel are needed. Further studies to determine whether there have been any changes in life history parameters over time (e.g. fecundity, and weight- and length-at-age) would be informative. More information on Atka mackerel habitat preferences would be useful to improve our understanding of Essential Fish Habitat (EFH), and improve our assessment of the impacts to habitat due to fishing. Better habitat mapping of the Aleutian Islands would provide information for survey stratification and the extent of trawlable and untrawlable habitat.

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16.14 Tables

Table 16.1 Time series of Bering Sea/Aleutian Islands Atka mackerel catches (including discards and CDQ catches), corresponding Acceptable Biological Catches (ABC), Total Allowable Catches (TAC), and Overfishing Levels (OFL) set by the North Pacific Fishery Management Council from 1978 to the present. Catches, ABCs, TACs, and OFLs are in metric tons.

Year	Catch	ABC	TAC	OFL
1977	21,763	a	a	
1978	24,249	24,800	24,800	
1979	23,264	24,800	24,800	
1980	20,488	24,800	24,800	
1981	19,688	24,800	24,800	
1982	19,874	24,800	24,800	
1983	11,726	25,500	24,800	
1984	36,055	25,500	23,130	
1985	37,860	37,700	37,700	
1986	31,990	30,800	30,800	
1987	30,061	30,800	30,800	
1988	22,084	21,000	21,000	
1989	17,994	21,000	20,285	
1990	22,205	24,000	21,000	
1991	24,523	24,000	24,000	
1992	49,441	43,000	43,000	435,000
1993	66,006	117,100	64,000	771,000
1994	69,591	122,500	68,000	484,000
1995	81,554	125,000	80,000	335,000
1996	103,867	116,000	106,157	164,000
1997	65,839	66,700	66,700	81,600
1998	57,096	64,300	64,300	134,000
1999	53,644	73,300	66,400	148,000
2000	47,229	70,800	70,800	119,000
2001	61,560	69,300	69,300	138,000
2002	45,294	49,000	49,000	82,300
2003	59,350	63,000	60,000	99,700
2004	60,564	66,700	63,000	99,700
2005	62,014	124,000	63,000	78,500
2006	61,883	110,200	63,000	147,000
2007	58,831	74,000	63,000	86,900
2008	58,088	60,700	60,700	71,400
2009	72,806	83,800	76,400	99,400
2010[b]	68,631	74,000	74,000	88,200

a) Atka mackerel was not a reported species group until 1978.
b) 2010 data as of 11/06/10. Available at http://www.fakr.noaa.gov/2010/car110_bsai_with_cdq.pdf (the model assumed catch equal to TAC for 2010, 74,000 t)

Sources: compiled from NMFS Regional Office web site and various NPFMC reports.

Table 16.2 Time series of Bering Sea/Aleutian Islands Atka mackerel catches (including discards and CDQ catches) by region, corresponding Acceptable Biological Catches (ABC), and Total Allowable Catches (TAC) set by the North Pacific Fishery Management Council from 1994 to the present. Apportioned catches prior to 1994 were assumed as the average apportionment for the years 1994-1998. Catches, ABCs, and TACs are in metric tons.

Year	Eastern (541)	Central (542)	Western (543)	Total	Year	Eastern (541)	Central (542)	Western (543)	Total
1990 Catch	5,116	11,058	6,032	22,206	2001 Catch	8,424	32,829	20,309	61,563
ABC				24,000	ABC	7,800	33,600	27,900	69,300
TAC				21,000	TAC	7,800	33,600	27,900	69,300
1991 Catch	6,154	11,761	8,711	26,626	2002 Catch	4,920	22,291	18,077	45,288
ABC				24,000	ABC	5,500	23,800	19,700	49,000
TAC				24,000	TAC	5,500	23,800	19,700	49,000
1992 Catch	11,217	21,438	15,878	48,532	2003 Catch	10,725	25,435	17,885	54,045
ABC				43,000	ABC	10,650	29,360	22,990	63,000
TAC				43,000	TAC	10,650	29,360	19,990	60,000
1993 Catch	15,256	29,156	21,594	66,006	2004 Catch	10,838	30,169	19,554	60,562
ABC				117,100	ABC	11,240	31,100	24,360	66,700
TAC				64,000	TAC	11,240	31,100	20,660	63,000
1994 Catch	15,106	28,871	21,383	65,360	2005 Catch	7,200	35,069	19,743	62,012
ABC	13,475	55,125	53,900	122,500	ABC	24,550	52,830	46,620	124,000
TAC	13,475	44,525	10,000	68,000	TAC	7,500	35,500	20,000	63,000
1995 Catch	14,201	50,386	16,967	81,554	2006 Catch	7,421	39,836	14,637	61,894
ABC	13,500	55,900	55,600	125,000	ABC	21,780	46,860	41,360	110,200
TAC	13,500	50,000	16,500	80,000	TAC	7,500	40,000	15,500	63,000
1996 Catch	28,173	33,523	42,246	103,942	2007 Catch	22,943	26,723	9,097	58,763
ABC	26,700	33,600	55,700	116,000	ABC	23,800	29,600	20,600	74,000
TAC	26,700	33,600	45,857	106,157	TAC	23,800	29,600	9,600	63,000
1997 Catch	16,315	19,990	29,537	65,842	2008 Catch	19,118	22,329	16,643	58,090
ABC	15,000	19,500	32,200	66,700	ABC	19,500	24,300	16,900	60,700
TAC	15,000	19,500	32,200	66,700	TAC	19,500	24,300	16,900	60,700
1998 Catch	12,271	20,209	24,617	57,097	2009 Catch	26.417	30,070	16,319	72,806
ABC	14,900	22,400	27,000	64,300	ABC	27,000	33,500	23,300	83,800
TAC	14,900	22,400	27,000	64,300	TAC	27,000	32,500	16,900	76,400
1999 Catch	17,453	22,419	16,366	56,237	2010 Catch	23,592	26,387	18,650	68,631
ABC	17,000	25,600	30,700	73,300	ABC	23,800	29,600	20,600	74,000
TAC	17,000	22,400	27,000	66,400	TAC	23,800	29,600	20,600	74,000
2000 Catch	14,344	22,383	10,503	47,230					
ABC	16,400	24,700	29,700	70,800					
TAC	16,400	24,700	29,700	70,800					

* 2010 data as of 11/06/10. Available at http://www.fakr.noaa.gov/2010/car110_bsai_with_cdq.pdf

Table 16.3 Discard data for Aleutian Islands Atka mackerel from the Atka mackerel fishery and all other fisheries combined (All others), for the years 2000 to the present. Discards of Atka mackerel for 1990-1999 have been presented in previous assessments (Lowe *et al.* 2003).

Year	Fishery	Discarded (t)	Retained (t)	Total (t)	Discard Rate (%)
2000	Atka mackerel	2,388	43,977	46,365	5.1
	All others	201	272	473	
	All	2,589	44,249	46,838	
2001	Atka mackerel	3,832	55,744	59,567	6.4
	All others	551	1,217	1,768	
	All	4,384	56,961	61,344	
2002	Atka mackerel	7,125	36,112	43,237	16.5
	All others	239	1,205	1,443	
	All	7,364	37,317	44,680	
2003	Atka mackerel	9,209	41,994	51,203	18.0
	All others	709	1,076	1,785	
	All	9,918	43,070	52,988	
2004	Atka mackerel	6,709	45,841	52,550	12.8
	All others	448	407	855	
	All	7,157	46,248	53,405	
2005	Atka mackerel	2,403	55,359	57,762	4.2
	All others	264	448	712	
	All	2,668	55,806	58,474	
2006	Atka mackerel	1,558	56,603	58,161	2.7
	All others	326	232	558	
	All	1,884	56,835	58,719	
2007	Atka mackerel	1,595	53,593	55,188	2.9
	All others	73	474	554	
	All	1,668	54,067	55,735	
2008	Atka mackerel	1,087	53,757	54,483	2.0
	All others	72	2,774	2,846	
	All	1,159	56,531	57,690	
2009	Atka mackerel	2,618	67,116	69,733	3.8
	All others	283	2,546	2,829	
	All	2,901	69,661	72,563	

Table 16.4 Discard data for Aleutian Islands Atka mackerel from the Atka mackerel fishery by Aleutian Islands subareas for the years 2000 to the present.

		Aleutian Islands Subarea		
Year		**541**	**542**	**543**
2000	Retained (t)	13,798	20,720	9,458
	Discarded (t)	163	1,484	742
	Rate	***1%***	***7%***	***7%***
2001	Retained (t)	7,632	28,678	19,333
	Discarded (t)	54	3,102	676
	Rate	***1%***	***10%***	***3%***
2002	Retained (t)	3,607	17,156	15,348
	Discarded (t)	213	4,827	2,085
	Rate	***6%***	***22%***	***12%***
2003	Retained (t)	5,626	22,566	14,877
	Discarded (t)	709	4,998	4,210
	Rate	***11%***	***18%***	***22%***
2004	Retained (t)	3,161	26,560	16,527
	Discarded (t)	520	3,610	3,027
	Rate	***14%***	***12%***	***15%***
2005	Retained (t)	3,356	33,598	18,852
	Discarded (t)	305	1,472	891
	Rate	***8%***	***4%***	***5%***
2006	Retained (t)	4,013	38,447	14,374
	Discarded (t)	232	1,389	263
	Rate	***5%***	***4%***	***2%***
2007	Retained (t)	19,752	25,475	8,847
	Discarded (t)	169	1,248	251
	Rate	***1%***	***5%***	***3%***
2008	Retained (t)	18,701	21,725	16,105
	Discarded (t)	18	745	395
	Rate	***0.1%***	***3%***	***2%***
2009	Retained (t)	25,734	28,349	15,578
	Discarded (t)	439	1,722	741
	Rate	***2%***	***6%***	***5%***

Table 16.5 Numbers of Atka mackerel length-weight data, length frequency, and aged samples based on NMFS observer data 1990-2009.

Year	Number of length-weight samples	Length frequency records	Number of aged samples
1990	731	8,618	718
1991	356	7,423	349
1992	90	13,532	86
1993	58	12,476	58
1994	913	13,384	837
1995	1,054	19,653	972
1996	1,039	24,758	680
1997	126	13,412	123
1998	733	15,060	705
1999	1,633	12,349	1,444
2000	2,697	9,207	1,659
2001	3,332	11,600	935
2002	3,135	12,418	820
2003	4,083	13,740	1,008
2004	4,205	14,239	870
2005	4,494	13,142	1,024
2006	4,194	13,598	980
2007	2,100	11,841	884
2008	1,882	19,831	922
2009	2,374	15,207	971

Table 16.6 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+
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	0.75
1988	0.40	9.97	22.49	6.15	1.80	1.54	0.63	0.96	0.20	0.48
1989[a]										
1990	1.74	7.62	13.15	4.78	1.77	0.81	0.11	0.09	0.03	0.17
1991	0.00	4.15	6.49	7.78	5.71	3.94	1.04	0.18	0.35	0.22
1992	0.00	0.93	20.82	2.97	1.40	0.62	0.00	0.00	0.00	0.00
1993	0.00	13.55	18.33	38.88	12.16	6.76	4.17	0.61	0.59	0.00
1994	0.05	9.16	6.83	23.13	36.00	4.64	8.21	5.27	3.04	0.61
1995	0.13	20.65	33.67	9.81	18.78	33.09	4.01	5.84	7.90	2.98
1996	0.02	3.65	63.55	21.94	14.14	19.44	31.59	2.85	3.37	2.53
1997	0.00	17.11	4.66	66.28	3.72	1.56	0.67	3.56	0.36	0.00
1998	0.00	11.15	15.73	15.24	25.07	11.21	4.02	3.55	5.28	1.85
1999	1.17	1.08	38.31	8.85	7.09	9.93	5.24	1.80	1.49	1.79
2000	0.54	8.91	6.40	26.59	7.53	4.33	8.33	1.93	0.78	1.01
2001	1.87	20.59	13.57	8.68	27.20	8.16	4.60	3.86	0.78	0.50
2002	1.94	22.68	25.37	7.88	3.89	16.20	3.23	1.56	1.67	0.53
2003	0.78	19.96	49.54	20.63	5.95	3.27	7.02	0.78	0.49	0.85
2004	0.09	20.44	31.49	44.20	12.32	2.40	1.56	2.21	0.00	0.39
2005	1.43	3.96	35.31	27.23	28.97	9.68	1.54	0.25	0.85	0.00
2006	3.56	16.74	5.66	33.56	20.27	22.62	4.12	0.56	0.36	0.26
2007	2.25	19.63	11.63	5.39	19.94	15.90	12.46	2.69	0.77	0.08
2008	5.49	13.29	16.90	7.61	6.29	20.04	10.53	11.63	1.64	0.54
2009	4.69	31.92	15.73	20.00	8.81	8.56	16.59	8.24	8.71	1.79

[a] Too few fish were sampled for age structures in 1989 to construct an age-length key (see Section 16.3.1).

Table 16.7 Atka mackerel estimated biomass in metric tons from the U.S.-Japan cooperative bottom trawl surveys, by subregion, depth interval, and survey year, with the corresponding Aleutian-wide coefficients of variation (*CV*).

			Biomass	
Area	Depth (m)	1980	1983	1986
Aleutian	1-100	193	239,502	1,013,678
	101-200	62,376	247,256	107,092
	201-300	646	2,565	368
	301-500	0	164	10
	Total	63,215	489,487	1,121,148
	CV	0.80	0.24	0.80
Western	1-100	193	49,115	1,675
543	101-200	692	124,806	40,675
	201-300		1,559	111
	301-500	0	164	0
	Total	885	175,644	42,461
Central	1-100	0	103,588	1,011,991
542	101-200	58,666	1,488	20,582
	201-300	504	303	36
	301-500	0	0	10
	Total	59,170	105,379	1,032,619
Eastern	1-100		86,800	11
541	101-200	3,018	120,962	45,835
	201-300	143	703	222
	301-500	0	0	0
	Total	3,161	208,465	46,068
Southern	1-100	6	0	429
Bering Sea	101-200	20,239	9	5
	201-300	2	0	1
	301-500		0	0
	Total	20,247	9	435

Table 16.8 Aleutian Islands Atka mackerel survey biomass by bottom-depth category by region and subareas including area percentages (for each year) and coefficients of variation (*CV*) for 1991, 1994, 1997, 2000, 2002, 2004, 2006, and 2010.

Area	Depth (m)	Biomass (t) 1991	1994	1997	2002	2004	2006	2010
Aleutian Islands	1-100	429,826	145,000	188,504	326,582	393,594	364,490	200,108
	101-200	293,554	455,452	177,663	393,055	488,534	326,136	643,793
	201-300	538	1,688	127	48,630	7,362	38,249	647
	301-500	-	22	20	221	288	61	22
	Total	723,918	602,161	366,314	768,488	889,778	728,935	844,571
	Area % of Total	100%	100%	100%	100%	100%	100%	100%
	CV	*15%*	*33%*	*29%*	*20%*	*17%*	*28%*	*40%*
Western 543	1-100	168,968	93,847	90,824	51,921	140,669	64,429	56,621
	101-200	185,748	214,228	43,478	154,820	229,675	35,926	196,049
	201-300	304	1,656	63	48,367	6,033	318	132
	301-500	-	6	-	8	36	21	17
	Total	355,020	309,737	134,364	255,115	376,414	100,693	252,819
	Area % of Total	49.0%	51.4%	36.7%	33.0%	42.0%	13.8%	29.9%
	CV	18%	55%	56%	31%	24%	35%	59%
Central 542	1-100	187,194	50,513	70,458	122,502	198,501	192,832	101,463
	101-200	104,413	33,517	116,295	199,743	70,267	85,102	94,804
	201-300	71	13	53	169	358	103	209
	301-500	-	3	6	143	194	-	-
	Total	291,679	84,046	186,813	322,556	269,320	278,036	196,476
	Area % of Total	40.3%	14.0%	64.6%	42.3%	30.4%	38.1%	23.3%
	CV	18%	48%	34%	24%	34%	24%	28%
Eastern 541	1-100	73,663	641	27,222	152,159	54,424	107,230	42,025
	101-200	3,392	207,707	17,890	38,492	188,592	205,108	352,939
	201-300	163	19	11	94	971	37,829	306
	301-500	-	12	14	71	57	40	5
	Total	77,218	208,379	45,137	190,817	244,043	350,206	395,275
	Area % of Total	10.7%	34.6%	12.3%	24.7%	27.5%	48.0%	46.8%
	CV	83%	44%	68%	58%	33%	55%	75%
Bering Sea	1-100	47	66,562	95,672	59,682	124,896	10,284	97,543
	101-200	3	30	9	103	142,616	176	4,870
	201-300	11	3	-	98	39	1,842	323
	301-500	-	8	-	-	4	6	19
	Total	61	66,603	95,680	59,883	267,556	12,308	102,755
	CV	37%	99%	99%	99%	43%	44%	86%

Table 16.9 Year-specific fishery and survey and the population weight-at-age (kg) values used to obtain expected survey and fishery catch biomass and population biomass. The population weight-at-age values are derived from the Aleutian trawl survey from the years 2004, 2006, and 2010. The 2010 fishery weight-at-age values are the average of the last ten years (2000-2009).

		Age										
	Year	1	2	3	4	5	6	7	8	9	10	11+
Survey	1991	0.045	0.185	0.449	0.637	0.652	0.751	0.811	0.693	1.053	1.764	0.878
	1994	0.045	0.177	0.450	0.653	0.738	0.846	0.941	0.988	0.906	0.907	0.516
	1997	0.045	0.191	0.486	0.686	0.753	0.805	0.887	0.970	0.919	1.375	0.935
	2000	0.045	0.130	0.387	0.623	0.699	0.730	0.789	0.810	0.792	0.864	0.871
	2002	0.045	0.139	0.342	0.615	0.720	0.837	0.877	0.773	0.897	0.955	1.084
	2004	0.045	0.138	0.333	0.497	0.609	0.739	0.816	0.956	0.928	0.745	0.824
	2006	0.045	0.158	0.332	0.523	0.516	0.675	0.764	0.719	0.855	1.653	0.991
	2010	0.045	0.161	0.369	0.633	0.667	0.744	0.974	1.075	0.981	1.041	1.244
Ave 2004, 2006, 2010		0.045	0.153	0.345	0.551	0.597	0.719	0.851	0.917	0.922	1.146	1.019
Fishery	1977	0.069	0.132	0.225	0.306	0.400	0.470	0.507	0.379	0.780	0.976	1.034
Foreign	1978	0.069	0.072	0.225	0.300	0.348	0.388	0.397	0.371	0.423	0.976	1.034
	1979	0.069	0.496	0.319	0.457	0.476	0.475	0.468	0.546	0.780	0.976	1.034
	1980	0.069	0.365	0.317	0.450	0.520	0.585	0.630	0.546	0.780	0.976	1.034
	1981	0.069	0.365	0.317	0.450	0.520	0.585	0.630	0.546	0.780	0.976	1.034
	1982	0.069	0.365	0.273	0.443	0.564	0.695	0.795	0.546	0.780	0.976	1.034
	1983	0.069	0.365	0.359	0.499	0.601	0.686	0.810	0.546	0.780	0.976	1.034
	1984	0.069	0.297	0.410	0.617	0.707	0.777	0.802	0.890	0.910	0.976	1.034
	1985	0.069	0.302	0.452	0.552	0.682	0.737	0.775	0.807	1.007	1.011	1.034
	1986	0.069	0.146	0.334	0.528	0.546	0.786	0.753	0.829	0.858	0.954	0.979
	1987	0.069	0.265	0.435	0.729	0.908	0.859	0.964	1.023	1.054	1.088	1.105
	1988	0.069	0.196	0.351	0.470	0.564	0.624	0.694	0.783	0.818	0.850	1.017
Domestic	1989	0.069	0.295	0.440	0.577	0.739	0.838	0.664	0.817	0.906	1.010	0.951
	1990	0.069	0.362	0.511	0.728	0.877	0.885	0.985	1.386	1.039	1.445	1.442
	1991	0.069	0.230	0.207	0.540	0.729	0.685	0.655	0.755	1.014	0.743	1.021
	1992	0.069	0.230	0.390	0.607	0.715	0.895	0.973	0.839	0.865	0.916	1.010
	1993	0.069	0.230	0.572	0.626	0.682	0.773	0.826	0.782	1.041	0.812	1.010
	1994	0.069	0.150	0.363	0.568	0.649	0.697	0.777	0.749	0.744	0.736	0.922
	1995	0.069	0.092	0.228	0.520	0.667	0.687	0.691	0.707	0.721	0.641	0.909
	1996	0.069	0.188	0.294	0.474	0.633	0.728	0.743	0.770	0.799	0.846	0.973
	1997	0.069	0.230	0.397	0.664	0.686	0.862	0.904	0.971	0.884	0.951	1.108
	1998	0.069	0.230	0.296	0.494	0.580	0.644	0.682	0.775	0.707	0.798	0.858
	1999	0.069	0.240	0.406	0.568	0.707	0.755	0.839	0.979	1.170	1.141	0.961
	2000	0.069	0.215	0.497	0.594	0.689	0.734	0.778	0.854	0.813	0.904	0.988
	2001	0.069	0.224	0.418	0.563	0.719	0.765	0.841	0.826	0.946	0.912	1.109
	2002	0.069	0.253	0.293	0.459	0.600	0.601	0.723	0.722	0.791	0.851	0.940
	2003	0.069	0.208	0.304	0.420	0.539	0.667	0.747	0.731	0.669	0.824	0.996
	2004	0.069	0.176	0.316	0.444	0.567	0.624	0.679	0.810	0.728	0.916	1.015
	2005	0.069	0.247	0.406	0.480	0.536	0.558	0.657	0.966	1.184	0.942	1.010
	2006	0.069	0.265	0.393	0.503	0.551	0.613	0.647	0.714	0.848	0.856	0.984
	2007	0.069	0.247	0.437	0.547	0.715	0.697	0.768	0.778	0.776	1.272	1.034
	2008	0.069	0.264	0.388	0.540	0.614	0.727	0.719	0.700	0.798	0.786	0.998
	2009	0.069	0.215	0.395	0.494	0.605	0.667	0.734	0.745	0.770	0.816	0.813
	2010	0.069	0.231	0.385	0.504	0.614	0.665	0.729	0.785	0.832	0.908	0.989

Table 16.10 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				
Length (cm)	541	542	543	Age	Proportion 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 16.11 Evaluation of modifying the change-points for fishery selectivity. The last configuration shown in the last column was carried forward for the 2010 Model.

	Shift block 1 yr earlier	Status quo block	Shift block 1 yr later
Fishery Average Effective N	128	129	124
Survey Average Effective N	53	52	51
RMSE Survey	0.219	0.206	0.208
-log Likelihoods			
Survey index	5.06	4.71	4.84
Catch biomass	0.09	0.09	0.10
Fishery age comp	175.46	174.15	167.29
Survey age comp	46.39	46.16	46.73
Sub total	226.99	225.11	218.96
-log Penalties			
Recruitment	16.972	16.772	16.417
Selectivity constraint	55.140	55.719	57.924
Priors	4.212	3.906	4.133
Total	303.314	301.506	297.434
Number of Parameters	161	161	161
AIC	928.628	925.012	916.868

Table 16.12 Estimates of key results from AMAK for Bering Sea/Aleutian Islands Atka mackerel from last year's assessment (2009Model) and the current assessment (2010Model). The 2010Model results include 2009 fishery catch and age data, 2010 survey catch and age data, and a shift 1 year later in the change-points for the constant selectivity blocks. Coefficients of variation (*CV*) for some key reference values appearing directly below, are given in parentheses.

Assessment Model	**2009Model**	**2010Model**
Model setup		
Survey catchability	1.59	1.57
Steepness	0.80	0.80
SigmaR	0.6	0.6
Natural mortality	0.300	0.300
Fishery Average Effective *N*	125	124
Survey Average Effective *N*	53	51
RMSE Survey	0.212	0.208
-log Likelihoods		
Number of Parameters	140	161
Survey index	5.87	4.84
Catch biomass	0.10	0.10
Fishery age comp	161.75	167.29
Survey age comp	40.12	46.73
Sub total	209.84	218.96
-log Penalties		
Recruitment	15.381	16.417
Selectivity constraint	46.609	57.924
Fishing mortality penalty	0.000	0.001
Prior	4.431	4.133
Total	274.264	297.434
Fishing mortalities (full selection)		
F 2010		0.311
F 2010/*F* 40%		0.810
F 40%	0.417	0.384
*F*35%	0.511	0.468
Stock abundance		
Initial Biomass (t, 1977)	319,410	345,860
CV	(14%)	(14%)
2010 total biomass (t)	474,750	596,750
CV	(24%)	(19%)
1999 year class (millions at age 1)	1,216	1,425
CV	(21%)	(19%)
2001 year class (millions at age 1)	861	1,051
CV	(27%)	(22%)
Recruitment Variability	0.639	0.639

Table 16.13 Estimates of Atka mackerel fishery (over time, 1977-2010) and survey selectivity at age. These are full-selection (maximum = 1.0) estimates.

	Age										
Year	1	2	3	4	5	6	7	8	9	10	11+
1977	0.004	0.039	0.321	0.718	1.000	0.960	0.853	0.699	0.599	0.533	0.533
1978	0.004	0.039	0.321	0.718	1.000	0.960	0.853	0.699	0.599	0.533	0.533
1979	0.004	0.039	0.321	0.718	1.000	0.960	0.853	0.699	0.599	0.533	0.533
1980	0.004	0.039	0.321	0.718	1.000	0.960	0.853	0.699	0.599	0.533	0.533
1981	0.004	0.039	0.321	0.718	1.000	0.960	0.853	0.699	0.599	0.533	0.533
1982	0.004	0.039	0.321	0.718	1.000	0.960	0.853	0.699	0.599	0.533	0.533
1983	0.004	0.039	0.321	0.718	1.000	0.960	0.853	0.699	0.599	0.533	0.533
1984	0.004	0.039	0.321	0.718	1.000	0.960	0.853	0.699	0.599	0.533	0.533
1985	0.003	0.037	0.371	0.991	1.000	0.953	0.914	0.863	0.819	0.766	0.766
1986	0.003	0.037	0.371	0.991	1.000	0.953	0.914	0.863	0.819	0.766	0.766
1987	0.003	0.037	0.371	0.991	1.000	0.953	0.914	0.863	0.819	0.766	0.766
1988	0.003	0.037	0.371	0.991	1.000	0.953	0.914	0.863	0.819	0.766	0.766
1989	0.003	0.037	0.371	0.991	1.000	0.953	0.914	0.863	0.819	0.766	0.766
1990	0.003	0.037	0.371	0.991	1.000	0.953	0.914	0.863	0.819	0.766	0.766
1991	0.003	0.037	0.371	0.991	1.000	0.953	0.914	0.863	0.819	0.766	0.766
1992	0.003	0.037	0.371	0.991	1.000	0.953	0.914	0.863	0.819	0.766	0.766
1993	0.002	0.016	0.112	0.471	0.660	0.766	0.840	1.000	0.972	0.938	0.938
1994	0.002	0.016	0.112	0.471	0.660	0.766	0.840	1.000	0.972	0.938	0.938
1995	0.002	0.016	0.112	0.471	0.660	0.766	0.840	1.000	0.972	0.938	0.938
1996	0.002	0.016	0.112	0.471	0.660	0.766	0.840	1.000	0.972	0.938	0.938
1997	0.002	0.016	0.112	0.471	0.660	0.766	0.840	1.000	0.972	0.938	0.938
1998	0.002	0.016	0.112	0.471	0.660	0.766	0.840	1.000	0.972	0.938	0.938
1999	0.002	0.016	0.112	0.471	0.660	0.766	0.840	1.000	0.972	0.938	0.938
2000	0.001	0.022	0.233	0.528	0.696	0.809	1.000	0.963	0.864	0.774	0.774
2001	0.001	0.022	0.233	0.528	0.696	0.809	1.000	0.963	0.864	0.774	0.774
2002	0.001	0.022	0.233	0.528	0.696	0.809	1.000	0.963	0.864	0.774	0.774
2003	0.001	0.022	0.233	0.528	0.696	0.809	1.000	0.963	0.864	0.774	0.774
2004	0.001	0.022	0.233	0.528	0.696	0.809	1.000	0.963	0.864	0.774	0.774
2005	0.001	0.022	0.233	0.528	0.696	0.809	1.000	0.963	0.864	0.774	0.774
2006	0.001	0.022	0.233	0.528	0.696	0.809	1.000	0.963	0.864	0.774	0.774
2007	0.001	0.022	0.233	0.528	0.696	0.809	1.000	0.963	0.864	0.774	0.774
2008	0.001	0.022	0.233	0.528	0.696	0.809	1.000	0.963	0.864	0.774	0.774
2009	0.001	0.022	0.233	0.528	0.696	0.809	1.000	0.963	0.864	0.774	0.774
2010	0.001	0.022	0.233	0.528	0.696	0.809	1.000	0.963	0.864	0.774	0.774
Survey	0.033	0.171	0.536	0.809	0.828	0.871	0.969	1.000	0.957	0.930	0.930

Table 16.14 Estimated Atka mackerel numbers at age in millions, 1977-2010.

	Age										
Year	1	2	3	4	5	6	7	8	9	10	11+
1977	222	368	216	68	45	22	19	17	14	12	67
1978	1349	164	270	149	43	27	13	11	11	9	52
1979	336	998	120	185	92	25	15	8	7	7	39
1980	211	249	735	85	123	59	16	10	5	5	31
1981	237	156	183	527	58	82	39	11	7	4	25
1982	156	176	116	133	370	40	56	27	8	5	21
1983	221	116	130	84	94	256	28	40	19	5	18
1984	305	164	86	95	60	67	182	20	28	14	17
1985	434	226	121	61	64	39	43	120	13	19	21
1986	377	321	166	84	38	40	25	27	77	9	27
1987	535	279	236	116	53	24	25	16	18	50	23
1988	343	396	206	167	76	35	16	17	10	12	49
1989	1289	254	292	147	111	50	23	11	11	7	41
1990	569	955	188	211	102	77	35	16	7	8	34
1991	280	422	706	136	148	71	54	25	11	5	30
1992	497	207	311	506	92	100	49	37	17	8	24
1993	899	368	153	223	341	62	68	33	25	12	22
1994	307	665	272	111	150	220	39	42	20	15	21
1995	327	228	491	195	73	94	134	24	24	11	21
1996	879	242	168	348	121	42	52	72	12	12	17
1997	162	650	178	117	203	64	21	25	32	5	13
1998	293	120	479	127	75	122	37	12	13	17	10
1999	693	217	88	340	79	43	68	20	6	7	14
2000	1425	513	160	63	221	49	26	40	11	3	12
2001	938	1055	378	112	41	138	30	15	23	7	10
2002	1051	694	776	260	70	25	79	16	8	13	9
2003	229	778	512	546	171	44	15	47	10	5	14
2004	361	170	574	361	361	109	28	9	28	6	12
2005	545	267	125	406	241	234	69	17	6	18	11
2006	387	403	197	89	272	156	148	42	10	4	19
2007	871	286	298	139	59	175	98	90	26	6	14
2008	680	645	211	211	93	38	111	60	55	16	13
2009	288	504	475	149	139	59	24	66	36	34	18
2010	302	214	370	327	93	83	34	13	36	20	30

Table 16.15 Estimates of Atka mackerel biomass in metric tons with approximate lower and upper 95% confidence bounds for age 1+ biomass (labeled as LCI and UCI). Also included are age 3+ and female spawning biomass in metric tons from the current assessment compared to last year's (2009) assessment.

	Current assessment age 1+ biomass (t)			*Age 3+ biomass (t)*		*Female spawning biomass (t)*	
Year	Estimate	LCI	UCI	Current	2009	Current	2009
1977	345,860	246,760	444,960	207,084	191,555	81,286	74,652
1978	399,970	279,478	520,462	208,888	192,288	82,219	76,051
1979	458,220	313,708	602,732	244,217	223,316	90,213	83,929
1980	528,070	358,762	697,378	427,308	391,133	107,100	100,130
1981	561,550	378,528	744,572	440,166	401,618	156,700	146,320
1982	503,200	337,226	669,174	419,272	381,399	163,980	154,000
1983	461,440	308,496	614,384	404,529	367,065	156,530	143,280
1984	437,440	296,026	578,854	409,682	373,211	140,840	123,980
1985	397,810	268,994	526,626	346,295	315,403	115,880	99,256
1986	375,100	257,374	492,826	295,698	267,676	96,789	84,224
1987	392,640	278,008	507,272	393,395	362,031	96,056	84,330
1988	411,150	307,032	515,268	310,026	288,785	99,754	92,327
1989	470,950	376,196	565,704	423,352	408,908	109,130	104,550
1990	564,040	476,334	651,746	532,675	514,744	125,500	122,920
1991	650,340	567,280	733,400	476,412	467,844	144,150	142,770
1992	692,540	612,492	772,588	709,584	703,143	185,790	185,420
1993	667,550	595,250	739,850	647,480	640,059	186,140	188,830
1994	647,030	578,208	715,852	519,579	507,772	164,850	164,290
1995	630,020	560,706	699,334	480,009	464,094	148,660	143,660
1996	580,110	509,042	651,178	451,182	430,144	135,840	129,560
1997	489,780	418,786	560,774	434,407	403,607	115,240	109,270
1998	484,910	408,576	561,244	393,841	356,168	109,180	99,371
1999	464,270	385,242	543,298	422,599	371,988	119,320	105,730
2000	483,670	400,910	566,430	382,709	330,043	107,400	92,882
2001	597,320	496,838	697,802	432,937	369,679	102,530	84,638
2002	738,350	611,596	865,104	499,470	419,912	129,140	106,110
2003	825,630	680,116	971,144	577,199	481,851	180,400	150,830
2004	810,410	659,004	961,816	678,833	556,197	210,790	176,260
2005	756,110	603,156	909,064	602,456	479,933	224,660	180,850
2006	668,560	519,484	817,636	524,304	414,201	196,170	149,980
2007	633,860	474,596	793,124	557,722	454,042	171,270	126,410
2008	632,650	453,400	811,900	471,961	409,970	155,990	119,350
2009	630,860	427,520	834,200	520,260	455,334	142,290	113,790
2010	596,750	375,050	818,450	532,415	388,468	145,910	111,300
2011				437,572		137,313	

Table 16.16 Estimates of age-1 Atka mackerel recruitment (millions of recruits).

	Age 1 Recruits	
Year	Current	2009
1977	222	205
1978	1,349	1,245
1979	336	308
1980	211	196
1981	237	218
1982	156	152
1983	221	211
1984	305	284
1985	434	423
1986	377	373
1987	535	554
1988	343	328
1989	1,289	1,298
1990	569	566
1991	280	268
1992	497	460
1993	899	861
1994	307	280
1995	327	294
1996	879	780
1997	162	134
1998	293	258
1999	693	609
2000	1,425	1,216
2001	938	804
2002	1,051	861
2003	229	175
2004	361	324
2005	545	539
2006	387	460
2007	871	692
2008	680	317
2009	288	
Ave 78-08	554	
Med 78-08	387	

Table 16.17 Estimates of full-selection fishing mortality rates and exploitation rates for Atka mackerel.

Year	*F*[a]	Catch/Biomass Rate[b]
1977	0.221	0.105
1978	0.252	0.116
1979	0.153	0.095
1980	0.104	0.048
1981	0.075	0.045
1982	0.066	0.047
1983	0.042	0.029
1984	0.139	0.088
1985	0.166	0.109
1986	0.169	0.108
1987	0.121	0.076
1988	0.108	0.071
1989	0.066	0.043
1990	0.057	0.042
1991	0.087	0.056
1992	0.096	0.068
1993	0.207	0.102
1994	0.255	0.126
1995	0.387	0.170
1996	0.508	0.230
1997	0.316	0.152
1998	0.380	0.145
1999	0.282	0.133
2000	0.239	0.123
2001	0.316	0.142
2002	0.224	0.091
2003	0.213	0.094
2004	0.195	0.089
2005	0.191	0.103
2006	0.206	0.118
2007	0.193	0.105
2008	0.225	0.123
2009	0.314	0.140
2010[c]	0.311	0.139

a Full-selection fishing mortality rates.
b Catch/biomass rate is the ratio of catch to beginning year age 3+ biomass.
c The 2010 catch/biomass rate is based on 2010 TAC.

Table 16.18 Projections of female spawning biomass in metric tons, full-selection fishing mortality rates (*F*) and catch in metric tons for Atka mackerel for the 7 scenarios. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 261,100, 104,400, and 91,400 t, respectively. Scenario 2 assumes reduced catch levels under proposed Steller Sea Lion RPAs.

	$B_{100\%}$	$B_{40\%}$	$B_{35\%}$	B_{2011}	$B_{2011}/B_{100\%}$		
	261,100	104,400	91,400	146,000	0.559		
Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2010	74,000	74,000	74,000	74,000	74,000	74,000	74,000
2011	85,343	54,608	36,200	22,606	0	101,214	85,343
2012	71,206	49,926	34,857	22,587	0	79,418	71,206
2013	58,248	46,971	34,144	22,798	0	58,799	67,646
2014	55,818	45,639	34,706	23,597	0	58,410	61,842
2015	57,887	46,251	35,518	24,353	0	61,842	63,115
2016	60,452	47,776	36,615	25,232	0	64,945	65,376
2017	62,630	49,609	38,068	26,384	0	67,078	67,207
2018	63,842	50,845	39,139	27,271	0	68,143	68,177
2019	64,420	51,548	39,764	27,815	0	68,566	68,576
2020	65,035	52,122	40,238	28,219	0	69,128	69,130
2021	65,551	52,630	40,701	28,607	0	69,748	69,749
2022	65,541	52,779	40,908	28,817	0	69,600	69,600
2023	65,149	52,720	40,946	28,901	0	69,059	69,059
Fishing M	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2010	0.311	0.311	0.311	0.311	0.311	0.311	0.311
2011	0.384	0.234	0.151	0.093	0.000	0.468	0.384
2012	0.384	0.234	0.151	0.093	0.000	0.461	0.384
2013	0.352	0.234	0.151	0.093	0.000	0.389	0.417
2014	0.338	0.227	0.151	0.093	0.000	0.382	0.393
2015	0.340	0.225	0.151	0.093	0.000	0.390	0.394
2016	0.345	0.226	0.151	0.093	0.000	0.398	0.399
2017	0.349	0.227	0.151	0.093	0.000	0.403	0.404
2018	0.350	0.227	0.151	0.093	0.000	0.405	0.405
2019	0.352	0.228	0.151	0.093	0.000	0.407	0.407
2020	0.353	0.228	0.151	0.093	0.000	0.408	0.408
2021	0.354	0.229	0.151	0.093	0.000	0.409	0.409
2022	0.354	0.229	0.151	0.093	0.000	0.409	0.409
2023	0.353	0.229	0.151	0.093	0.000	0.407	0.407
Spawning biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2010	145,875	145,875	145,875	145,875	145,875	145,875	145,875
2011	137,313	145,976	151,033	154,707	160,713	132,723	137,313
2012	111,865	130,532	142,364	151,411	167,034	103,039	111,865
2013	96,567	119,063	135,399	148,535	172,503	87,700	93,917
2014	96,205	119,529	138,412	154,533	185,451	88,121	90,839
2015	99,752	123,470	143,586	161,680	197,726	91,786	92,859
2016	103,801	128,976	150,635	170,794	212,132	95,298	95,707
2017	105,422	132,045	155,043	176,873	222,606	96,363	96,508
2018	106,563	134,204	158,131	181,101	230,015	97,141	97,186
2019	107,094	135,624	160,452	184,496	236,498	97,419	97,432
2020	107,925	137,270	162,998	188,076	243,081	98,063	98,065
2021	108,880	138,845	165,244	191,074	248,350	98,849	98,849
2022	108,695	139,109	166,021	192,434	251,539	98,547	98,547
2023	108,292	138,906	166,139	192,941	253,384	98,132	98,132

Table 16.19 Ecosystem effects

Ecosystem effects on Atka mackerel			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Zooplankton	Stomach contents, ichthyoplankton surveys	None	Unknown
Predator population trends			
Marine mammals	Fur seals declining, Steller sea lions declining in western AI	Possibly lower mortality on Atka mackerel	No concern
Birds	Stable, some increasing some decreasing	Affects young-of-year mortality	No concern
Fish (Pacific cod, arrowtooth flounder)	Arrowtooth abundance trends are increasing	Possible increased predation on Atka mackerel	No concern
Changes in habitat quality			
Temperature regime	2010 AI summer bottom temperature slightly below average (excl. 2000)	Could possibly affect fish distribution	Unknown

***The Atka mackerel* effects on ecosystem**			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	Stable, heavily monitored	Likely to be a minor contribution to mortality	Unknown
Forage (including herring, Atka mackerel, cod, and pollock)	Stable, heavily monitored	Bycatch levels small relative to forage biomass	Unknown
HAPC biota (seapens/whips, corals, sponges, anemones)	Low bycatch levels of seapens/whips, sponge and coral catches are variable	Unknown	Possible concern for sponges and corals
Marine mammals and birds	Very minor direct-take	Likely to be very minor contribution to mortality	No concern
Sensitive non-target species	Skate catches are variable and have averaged 158 t from 2007-2009, which is about 13% of the AI skate catch over this time period	Data limited, need species-specific catch information	Possible concern
Other non-target species	Sculpin catches are variable and have averaged about 570 t over the 2007-2009 time period	Unknown	Unknown
Fishery concentration in space and time	Steller sea lion protection measures spread out Atka mackerel catches in time and space. Fishery has expanded and concentrates in other areas outside of critical habitat	Mixed potential impact (fur seals vs Steller sea lions). Areas outside of critical habitat may be experiencing higher exploitation rates.	Possible concern
Fishery effects on amount of large size target fish	Depends on highly variable year-class strength	Natural fluctuation	Probably no concern
Fishery contribution to discards and offal production	Offal production—unknown The Atka mackerel fishery contributes an average of 1,180 and 1,800 t of the total AI trawl non-target and Atka mackerel discards, respectively.	The Atka mackerel fishery is one of the few trawl fisheries operating in the AI. Numbers and rates should be interpreted in this context.	Unknown
Fishery effects on age-at-maturity and fecundity	Unknown	Unknown	Unknown

16.15 Figures

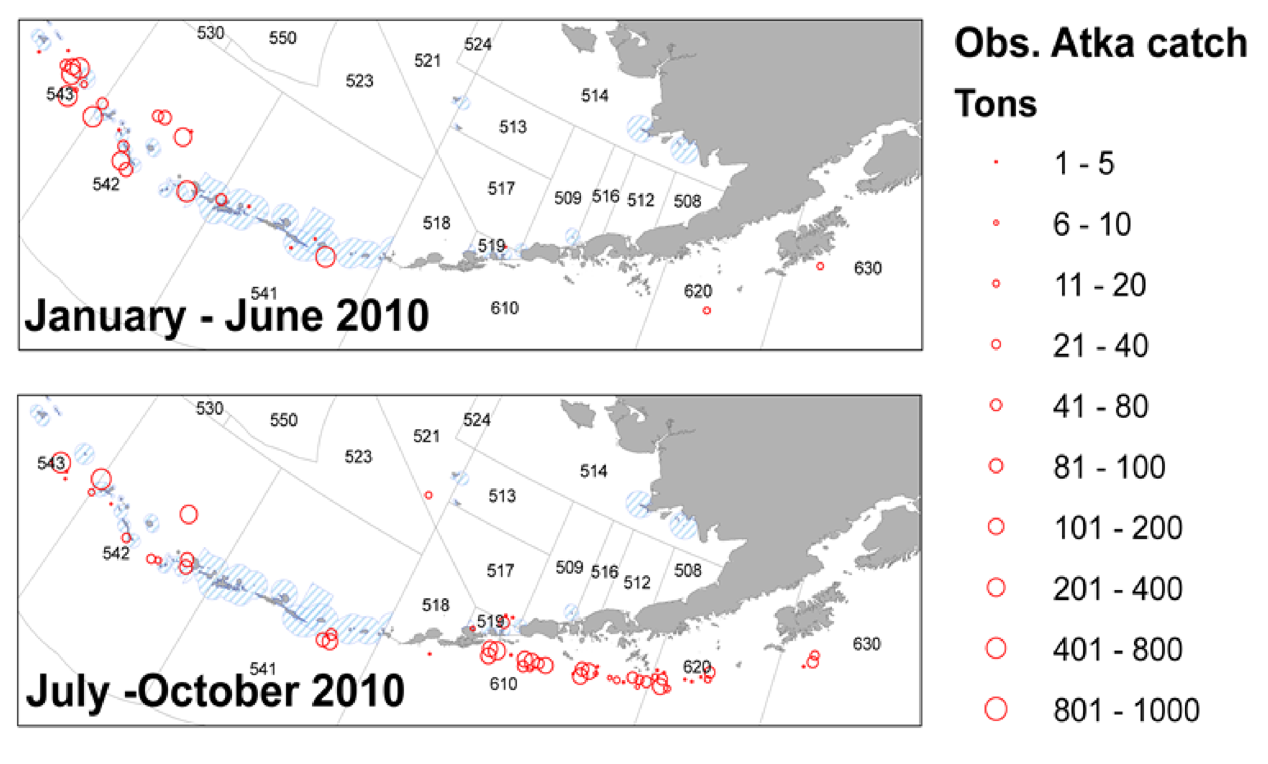


Figure 16.1 Observed catches of Atka mackerel summed for 20 km^2 cells for 2010 (January – June, top panel; and from July-October, bottom panel) where observed catch per haul was greater than 1 t. Shaded areas represent 10 and 20 nm Steller sea lion areas

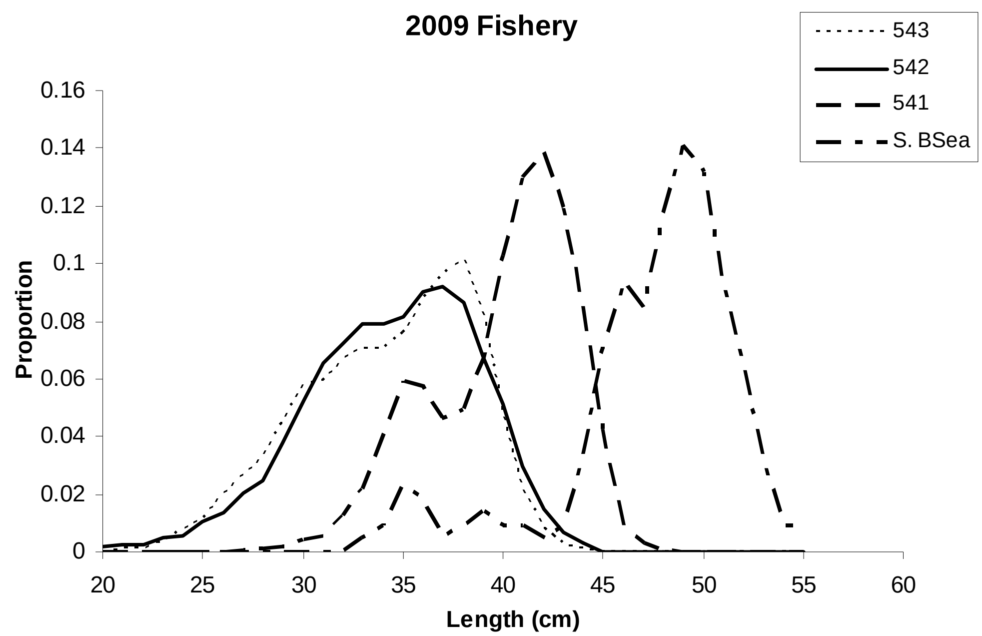


Figure 16.2 2009 Atka mackerel fishery length-frequency data by area fished (see Figure 16.1). Numbers refer to management areas.

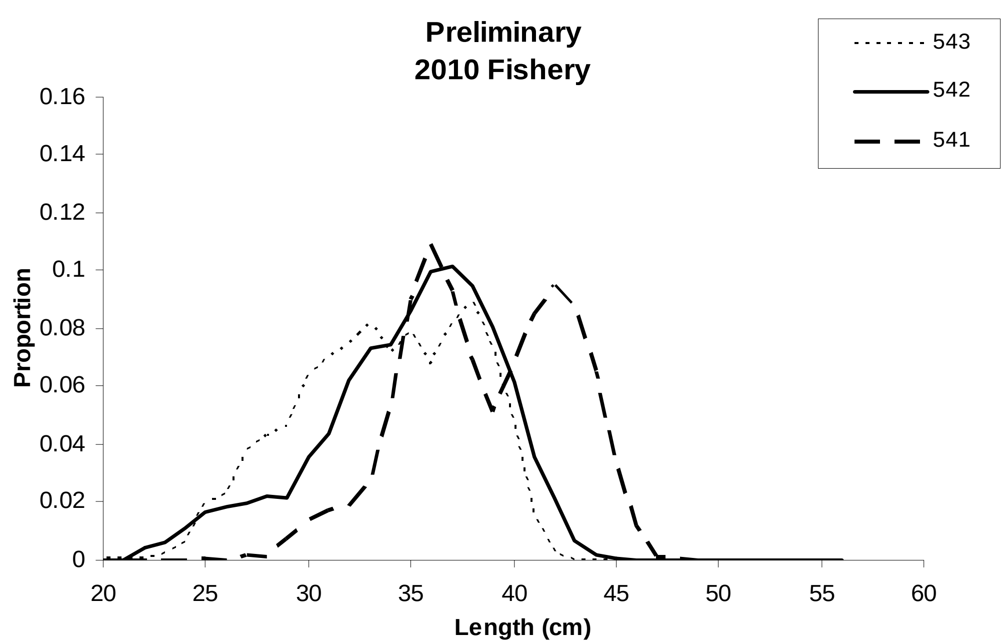


Figure 16.3 Preliminary 2010 Atka mackerel fishery length-frequency data by area fished (see Figure 16.1). Too few fish were measured in area 519 for presentation. Numbers refer to management areas.

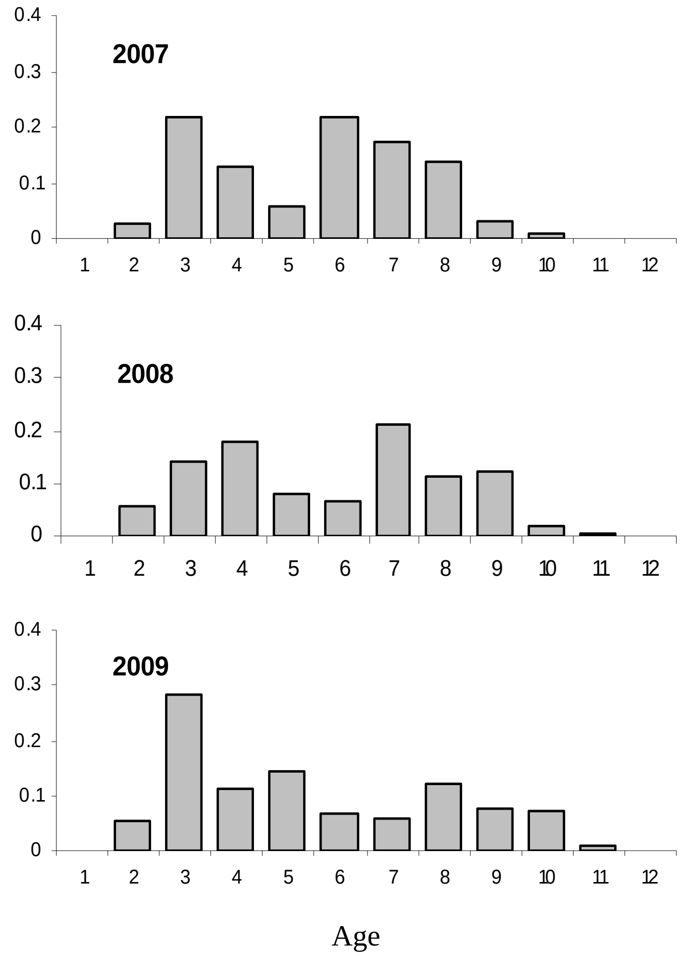


Figure 16.4 Aleutian Islands Atka mackerel fishery age composition data for 2007, 2008, and 2009.

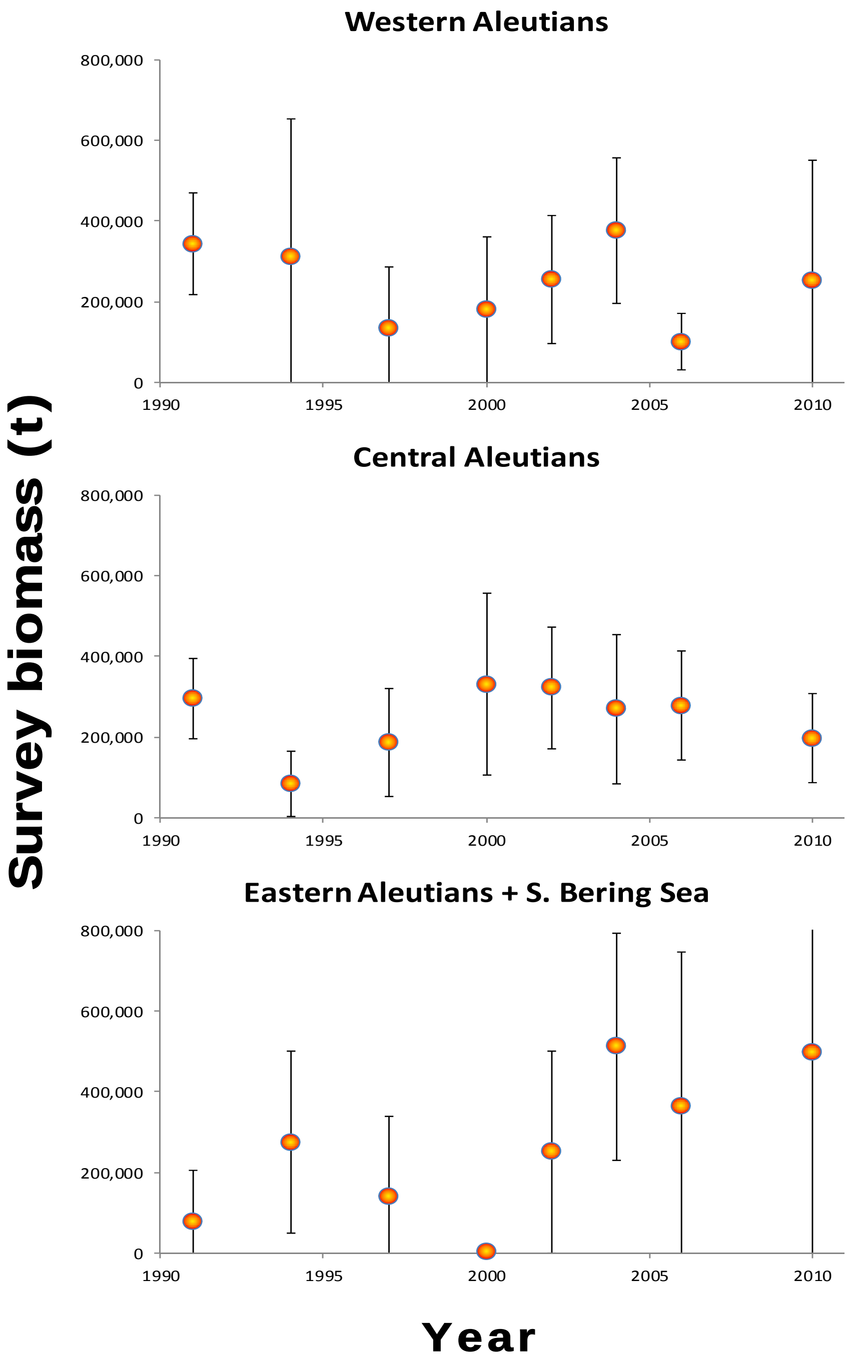


Figure 16.5 Atka mackerel Aleutian Islands survey biomass estimates by area and survey year. Bars represent 95% confidence intervals based on sampling error.

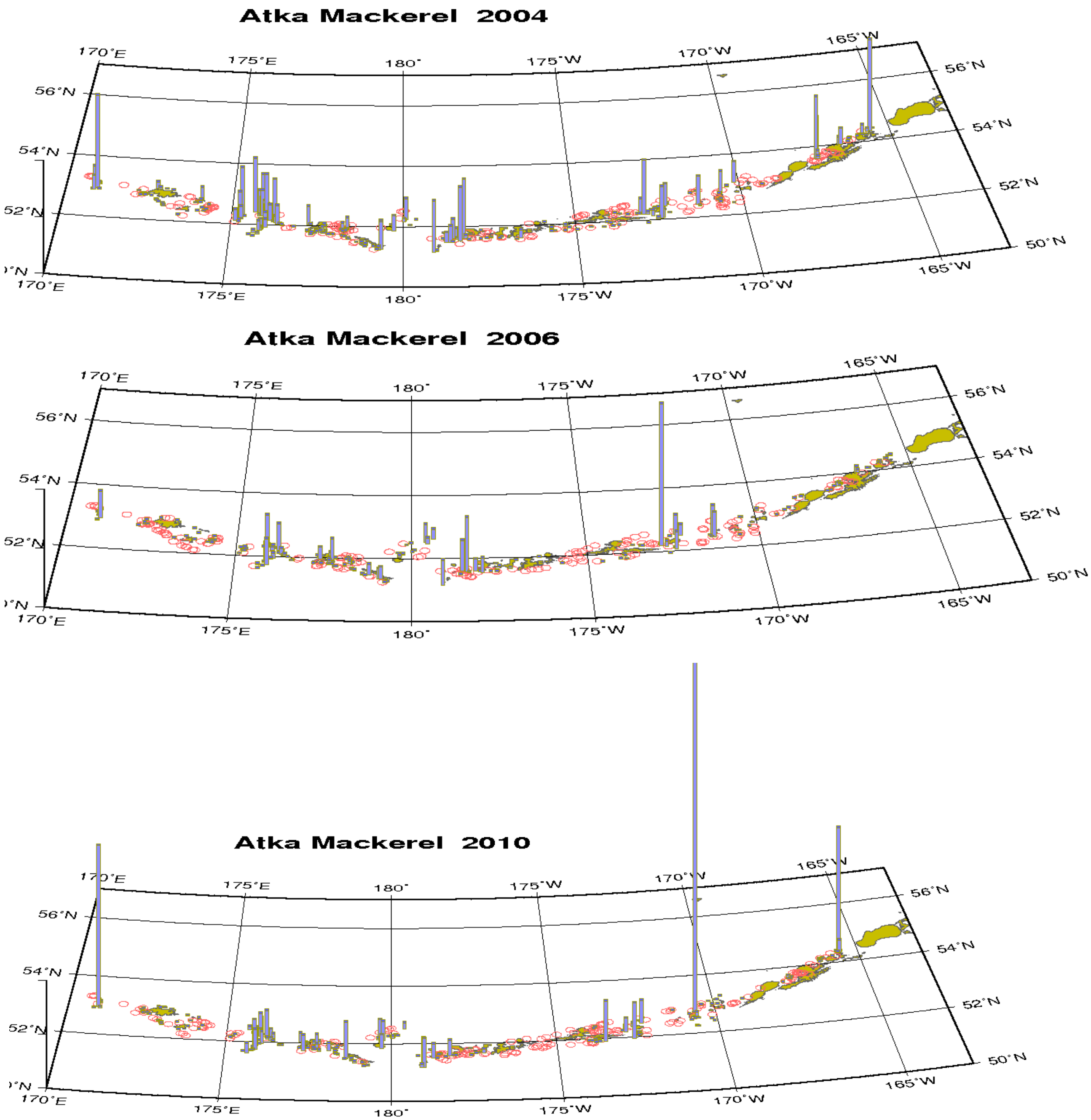


Figure 16.6 Bottom-trawl survey CPUE distributions of Atka mackerel catches during the summers of 2004, 2006, and 2010.

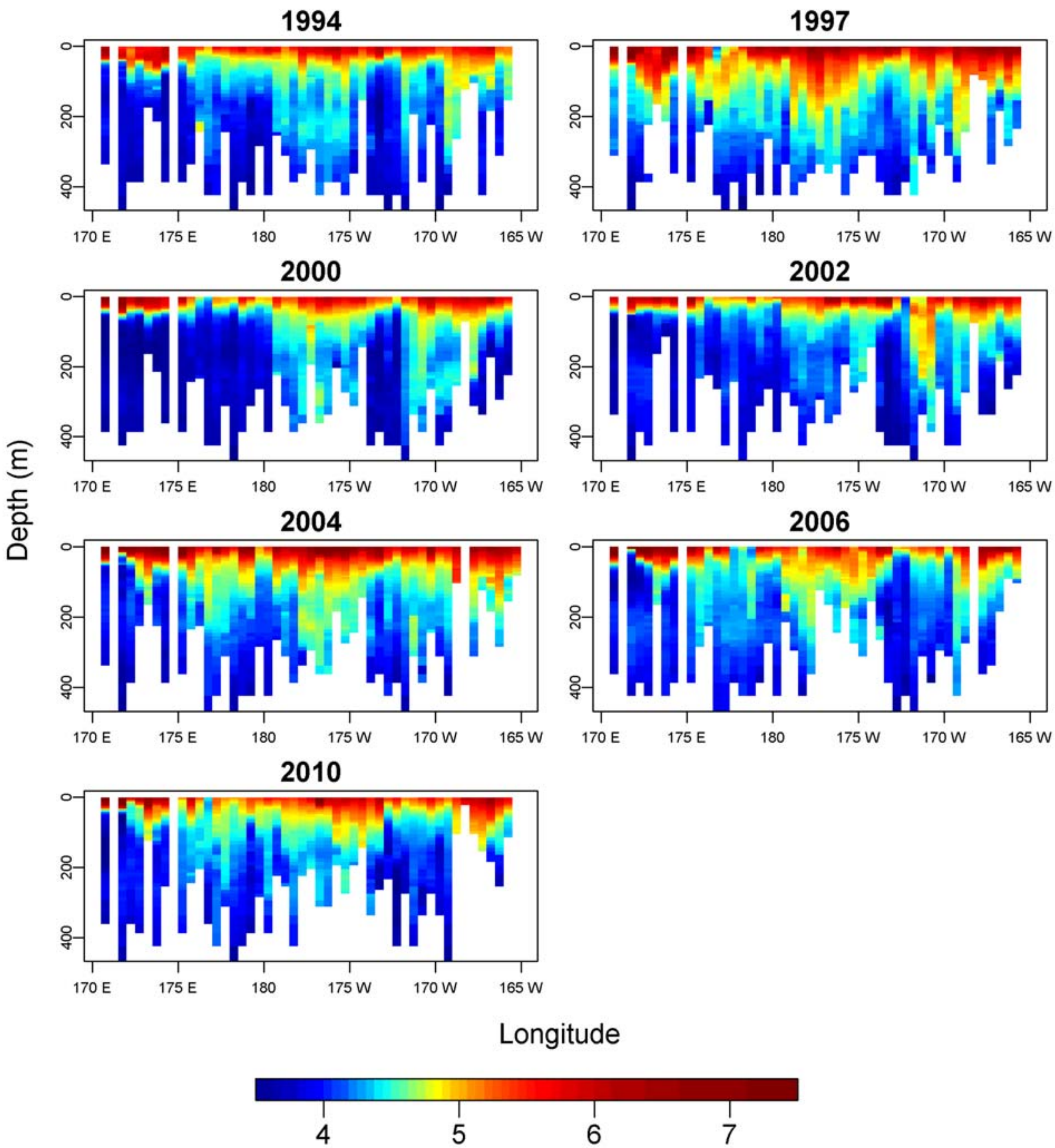


Figure 16.7 Date-adjusted water temperatures by depth interval and longitude based on Aleutian Islands summer bottom-trawl surveys since 1994 (Martin 2010). A full description of the estimation process is given in Martin (2010).

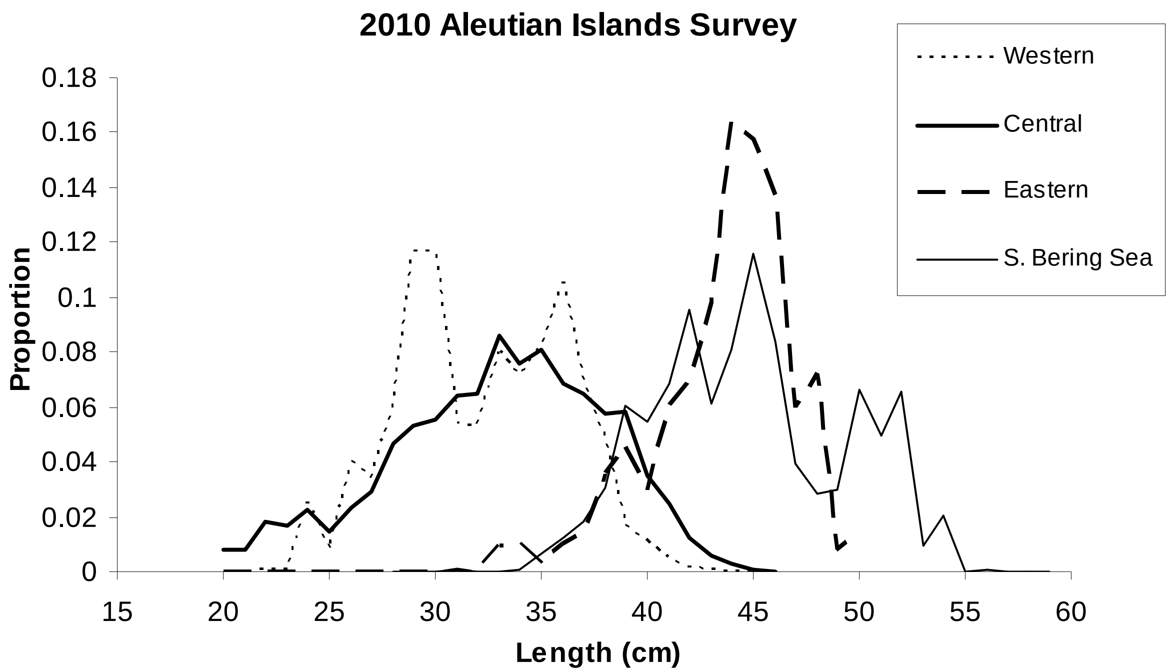


Figure 16.8 Atka mackerel bottom trawl survey length frequency data by subarea from the 2010 Aleutian Island survey.

Figure 16.9 Atka mackerel age distributions from the Aleutian Islands region from the 2004, 2006, and 2010 bottom trawl surveys.

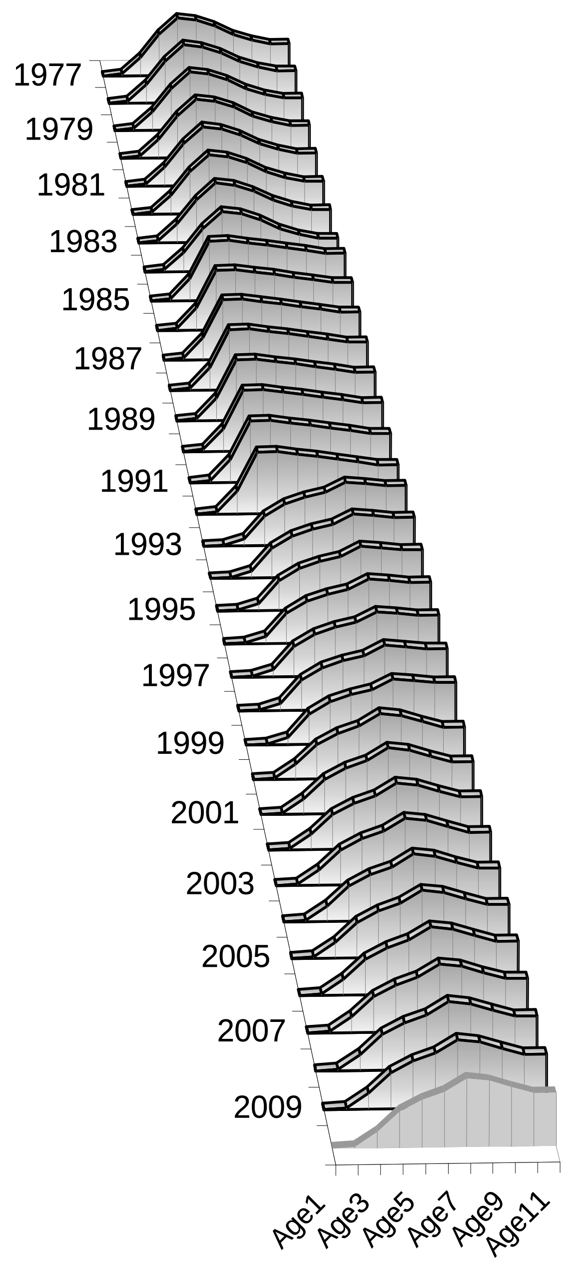


Figure 16.10 BSAI Atka mackerel assessment model configured to have 4 periods of distinct fishery selectivity patterns, 1977-2010.

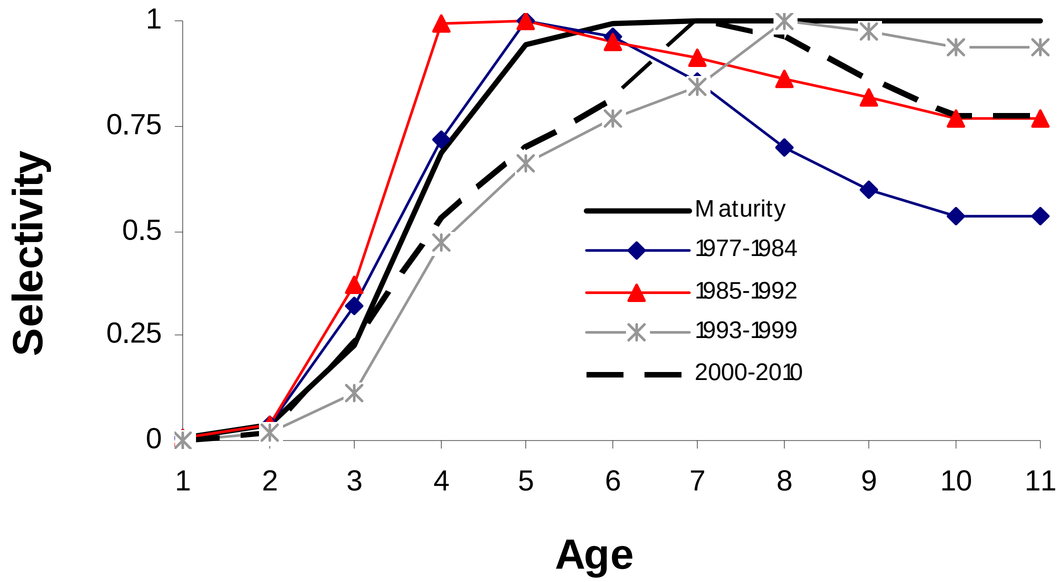


Figure 16.11 Estimated fishery selectivity patterns for the four time periods (1977-1984, 1985-1992, 1993-1999, and 2000-2010) from the current assessment compared with the maturity-at-age estimates for Atka mackerel.

Figure 16. Estimated fishery selectivity patterns from the most recent time period (2000-2010) from the current assessment and last year's assessment compared with the maturity-at-age estimates for Atka mackerel

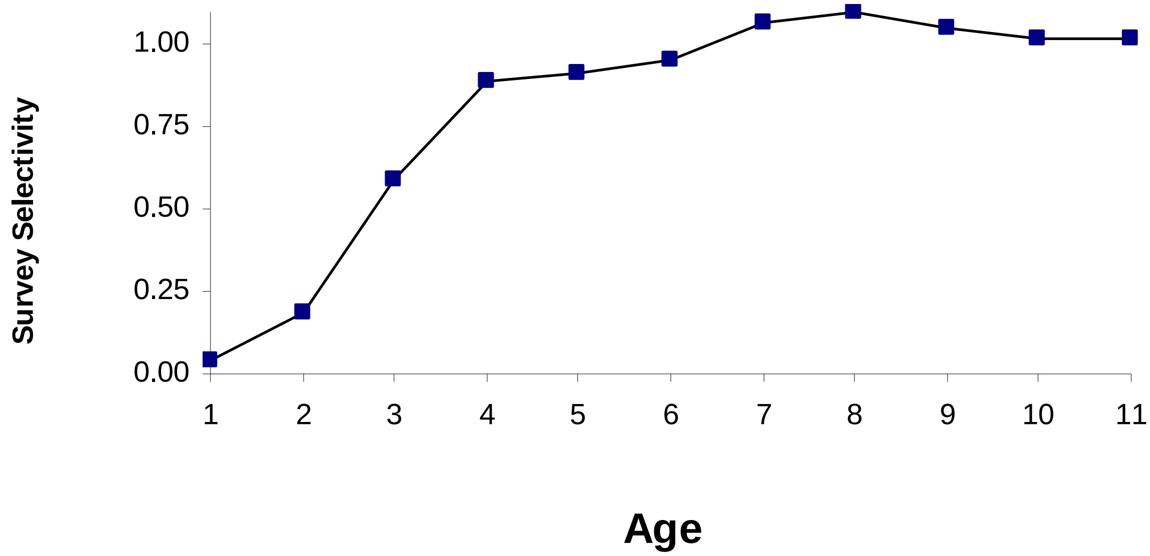


Figure 16.13 Estimated BSAI Atka mackerel survey selectivity-at-age.

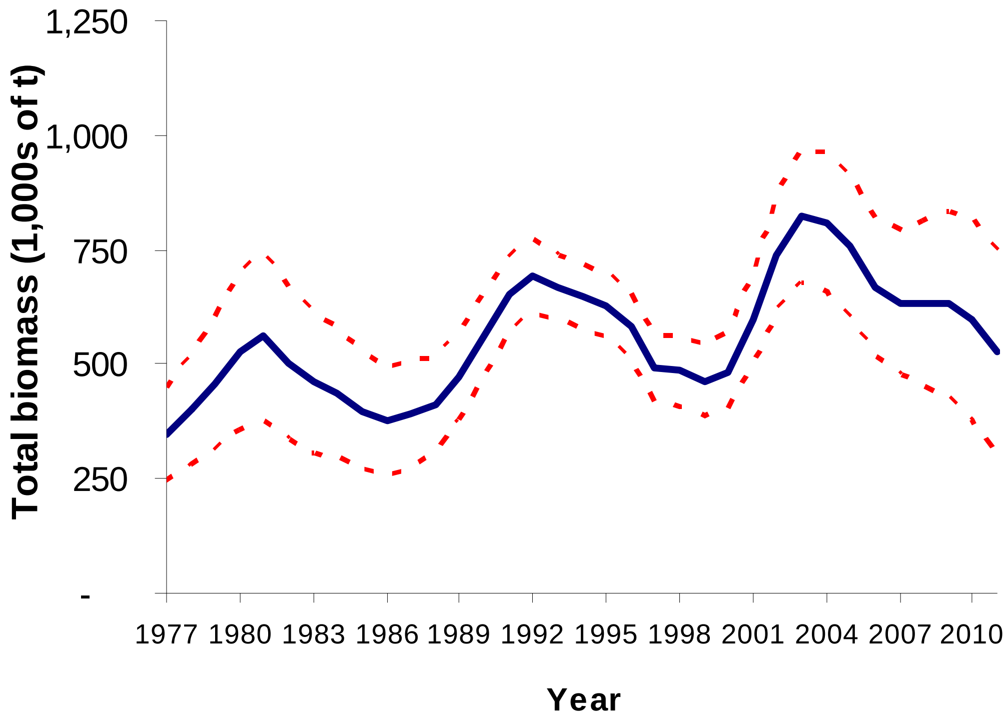


Figure 16.14 Time series of Aleutian Islands Atka mackerel total (age 1+) biomass estimates in thousands of metric tons, and approximate 95% confidence bounds.

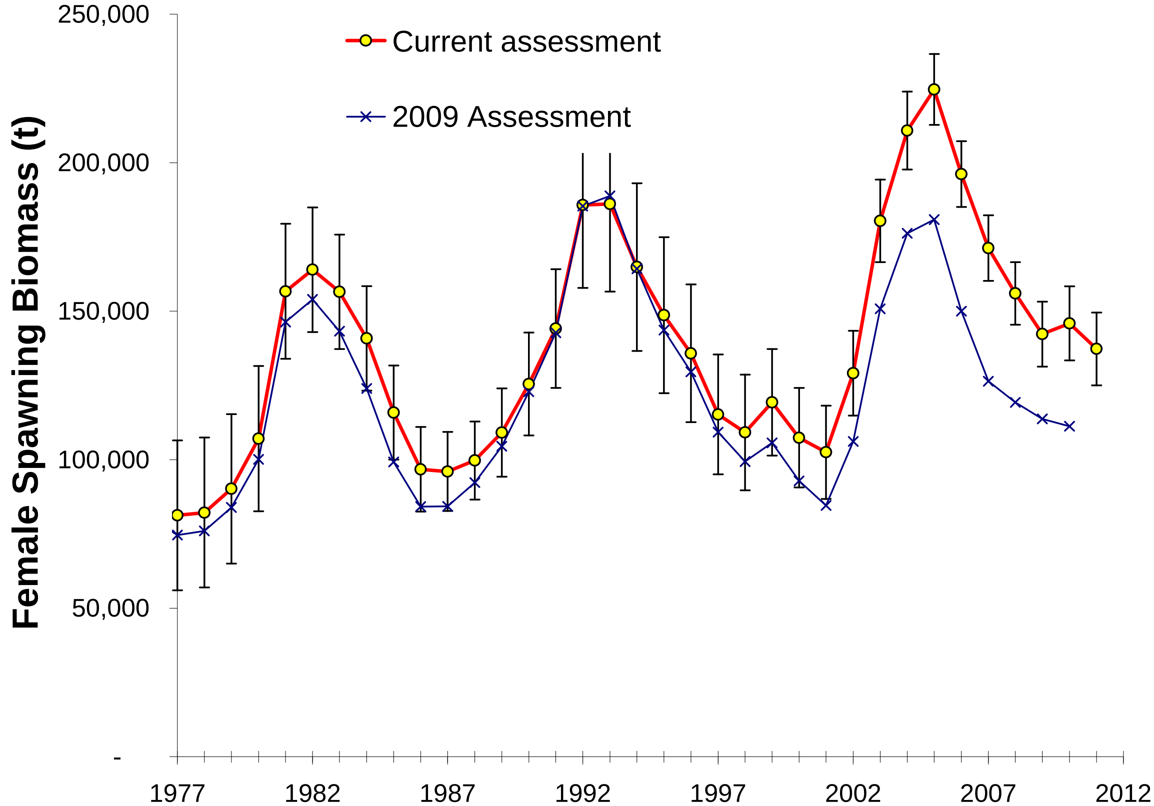


Figure 16.15 Estimated female spawning biomass from the current assessment with approximate ±1 standard errors compared to the 2009 assessment (line, Lowe *et al.* 2009) for BSAI Atka mackerel.

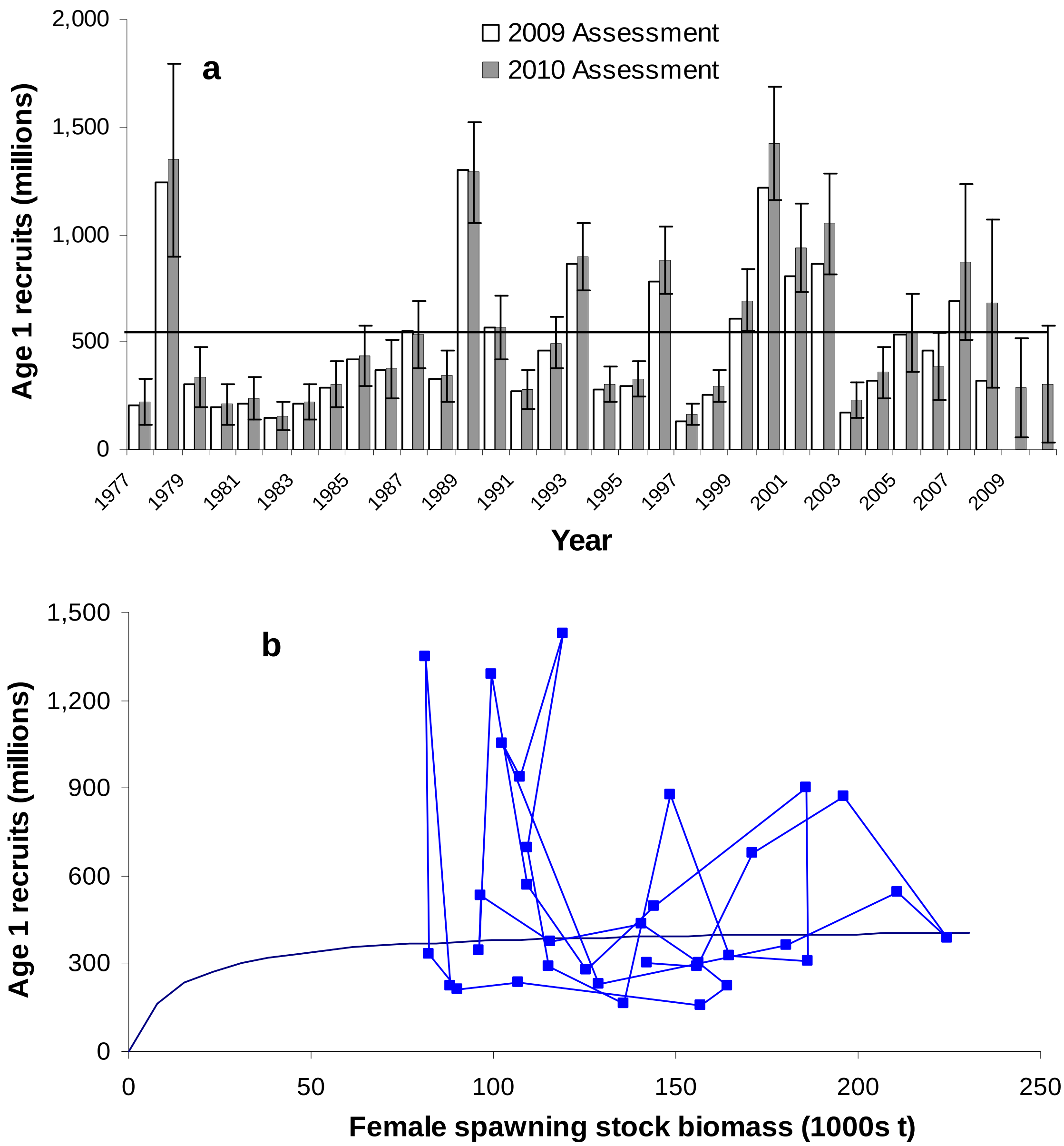


Figure 16.16 a) Age 1 recruitment of Atka mackerel as estimated from the current assessment, with error bars representing two standard errors (top panel) and the solid line indicating average recruitment (550 million) over 1978-2010, and b) estimated female spawning biomass levels in thousands of metric tons (lower panel). Solid line represents the underlying Beverton-Holt stock recruitment curve assumed in the model.

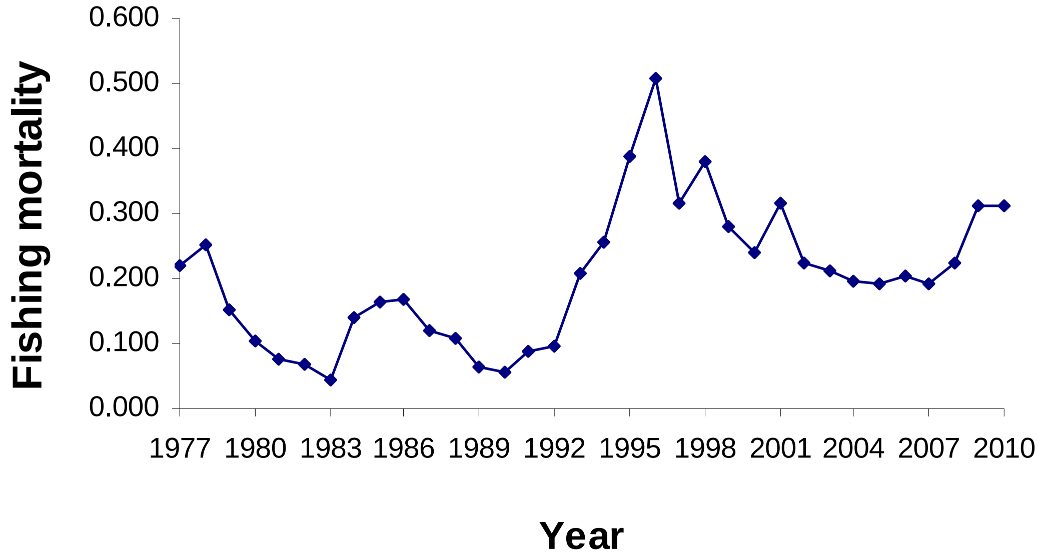


Figure 16.17 Estimated time series of full-selection fishing mortality rates of Atka mackerel, 1977-2010.

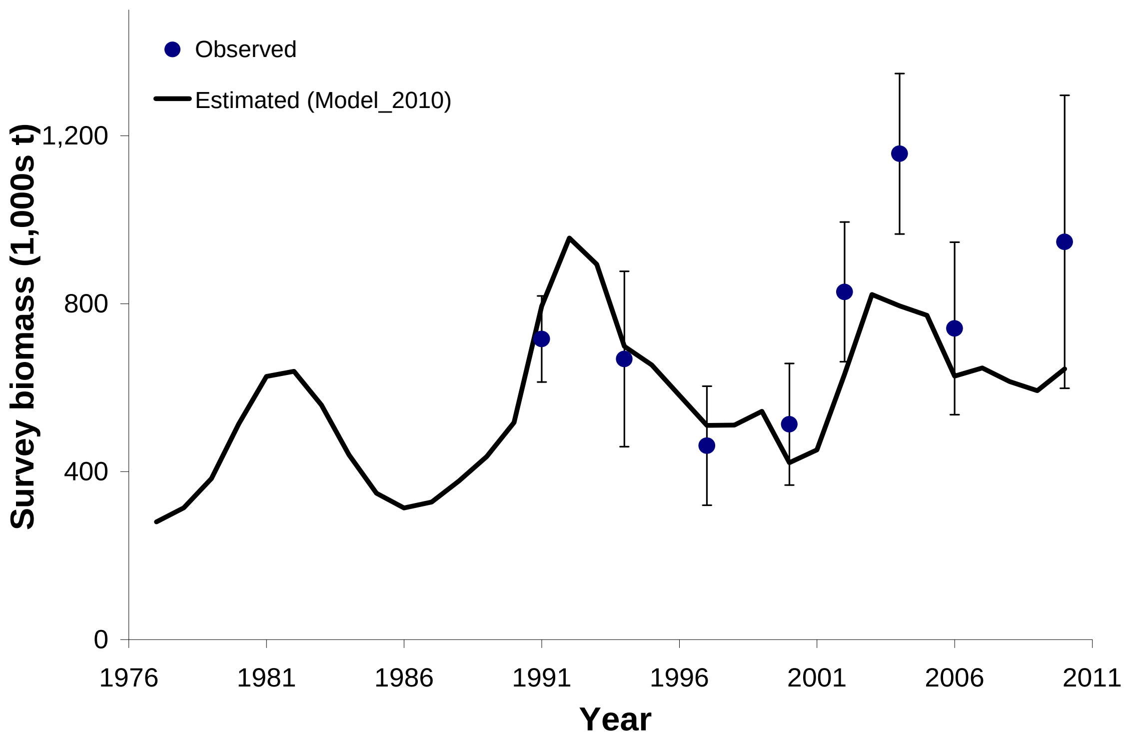


Figure 16.18 Observed and predicted survey biomass estimates in thousands of metric tons for Bering Sea/Aleutian Islands Atka mackerel. Error bars represent two standard errors (based on sampling) from the survey estimates.

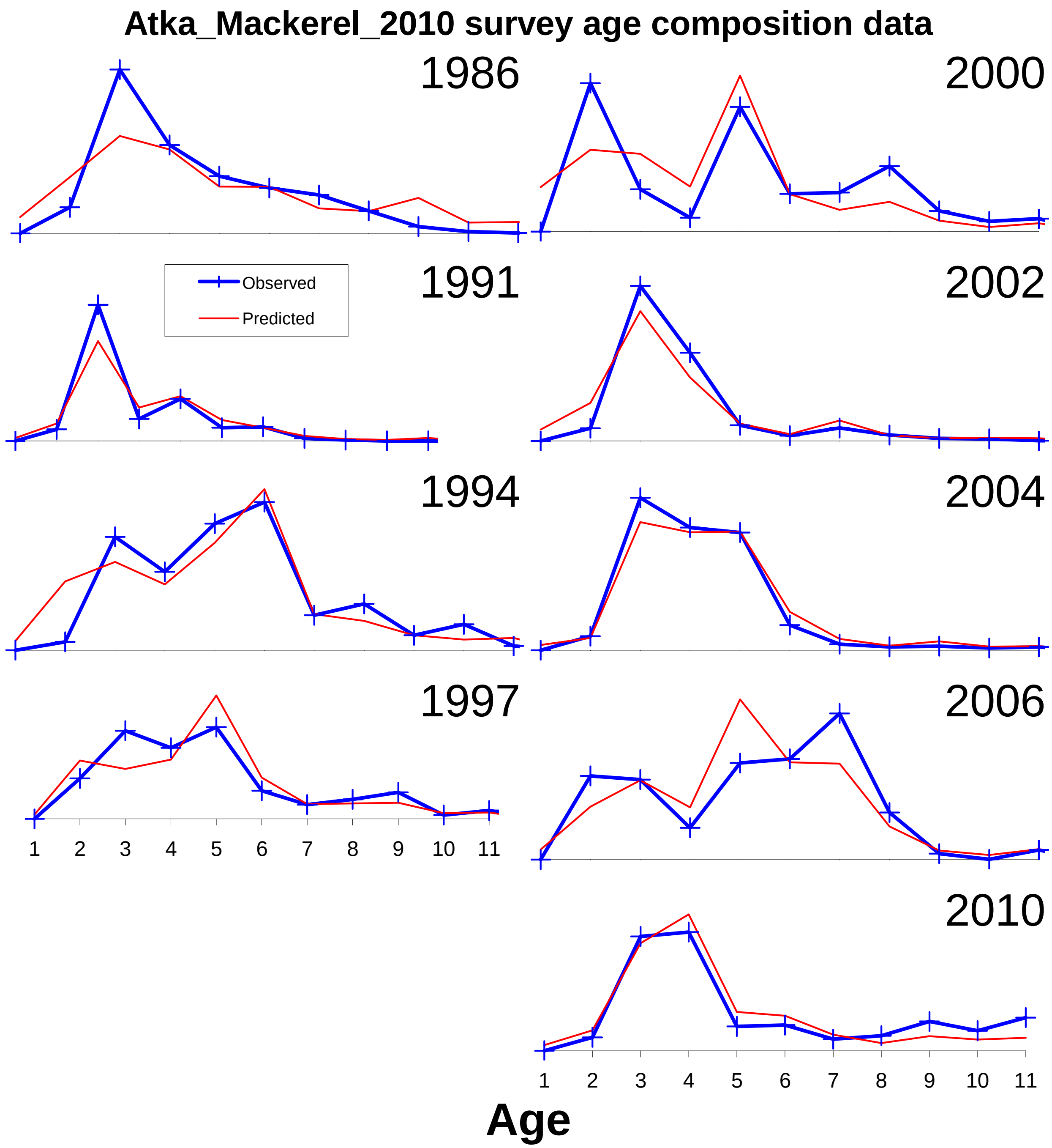


Figure 16.19 Observed and predicted **survey** proportions-at-age for BSAI Atka mackerel. Continuous lines are the model predictions and lines with "+" symbols are the observed proportions at age.

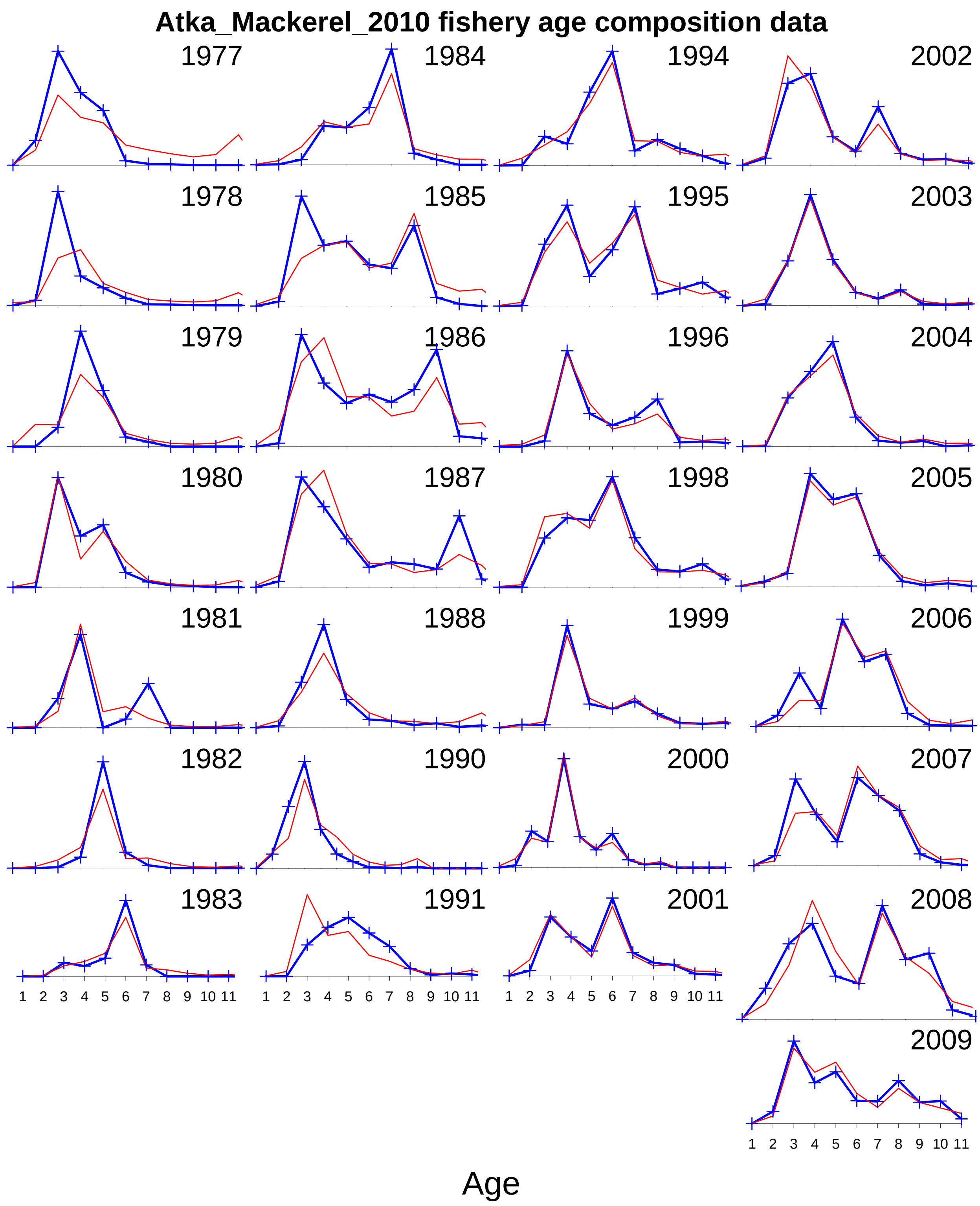
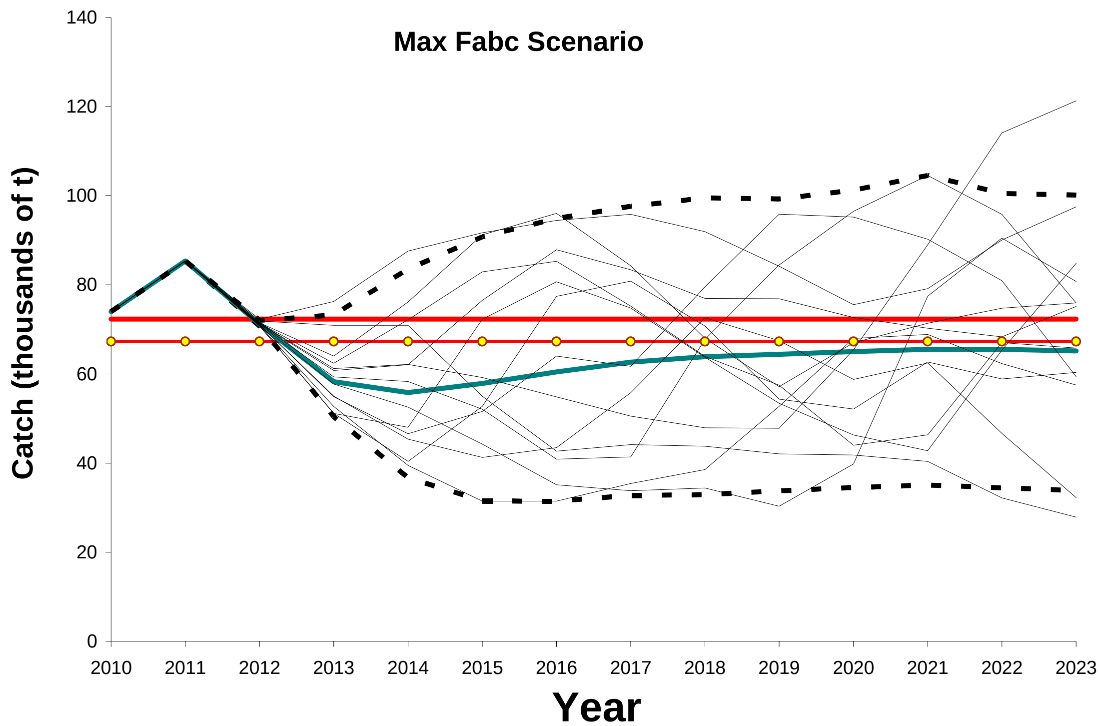


Figure 16.20 Observed and predicted Atka mackerel **fishery** proportions-at-age for BSAI Atka mackerel. Continuous lines are the model predictions and lines with "+" symbol are the observed proportions at age.



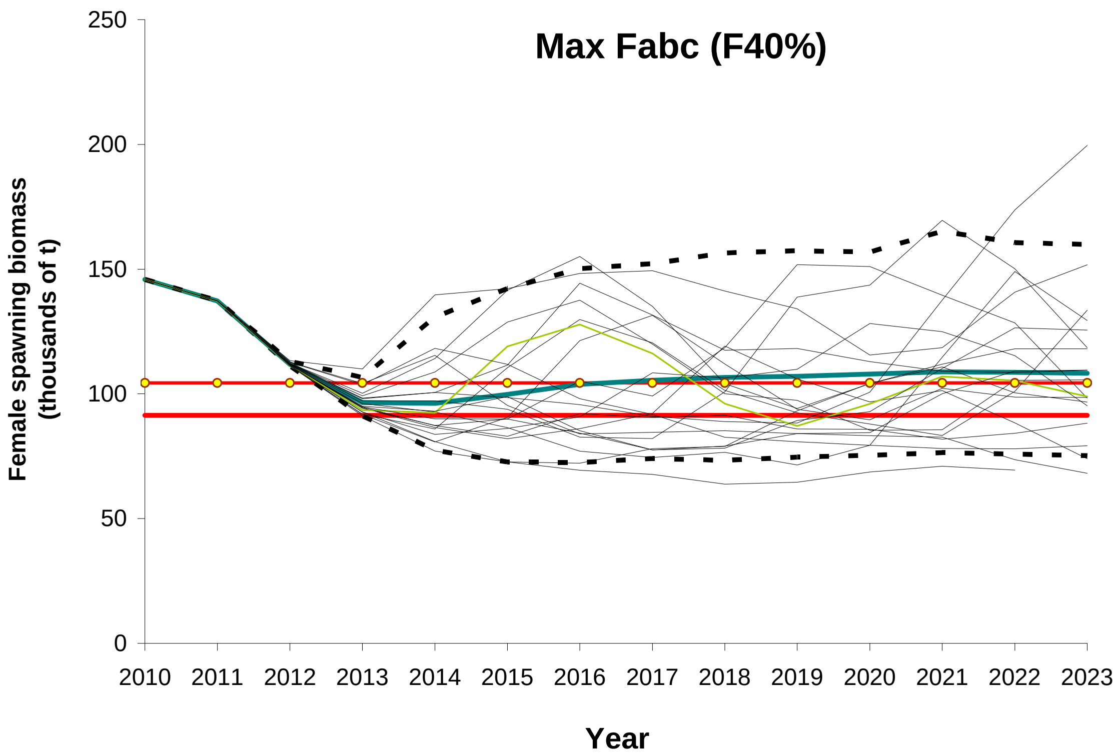


Figure 16.21 Projected catch in (top) and spawning biomass (bottom) in thousands of metric tons under maximum permissible Tier 3a harvest levels. The individual thin lines represent samples of simulated trajectories.

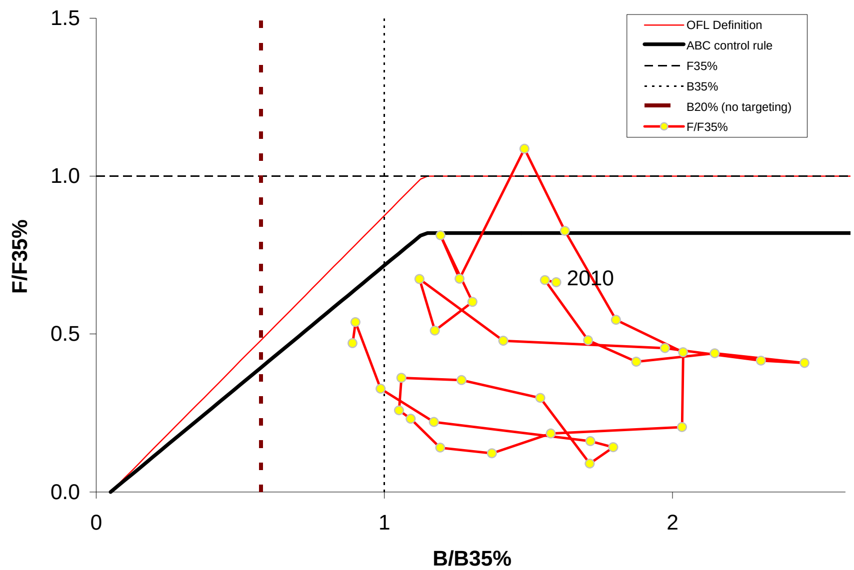


Figure 16.22 Aleutian Islands Atka mackerel spawning biomass relative to $B_{35\%}$ and fishing mortality relative to F_{OFL} (1977-2010). The ratio of fishing mortality to F_{OFL} is calculated using the estimated selectivity pattern in that year. Estimates of spawning biomass and $B_{35\%}$ are based on current estimates of weight-at-age and mean recruitment. Because these estimates change as new data become available, this figure can only be used in a general way to evaluate management performance relative to biomass and fishing mortality reference levels.

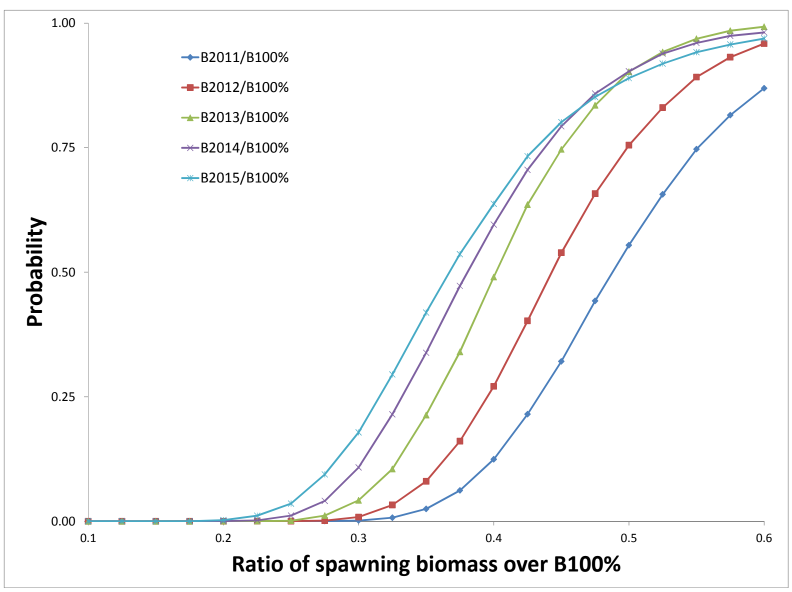


Figure 16.23 Posterior density projections of spawning biomass (relative to $B_{100\%}$) for Aleutian Islands Atka mackerel for the next 5 years under a strict $F_{50\%}$ harvest rate (similar to the fishing mortality rates incurred over the history of Atka mackerel). For the model as configured, this suggest that there is a very low probability that the stock is below $B_{20\%}$ (0.2 on horizontal scale). The joint posterior density was approximated by 1,000,000 MCMC simulations, storing every 200th sample to obtain these marginal cumulative probability estimates.

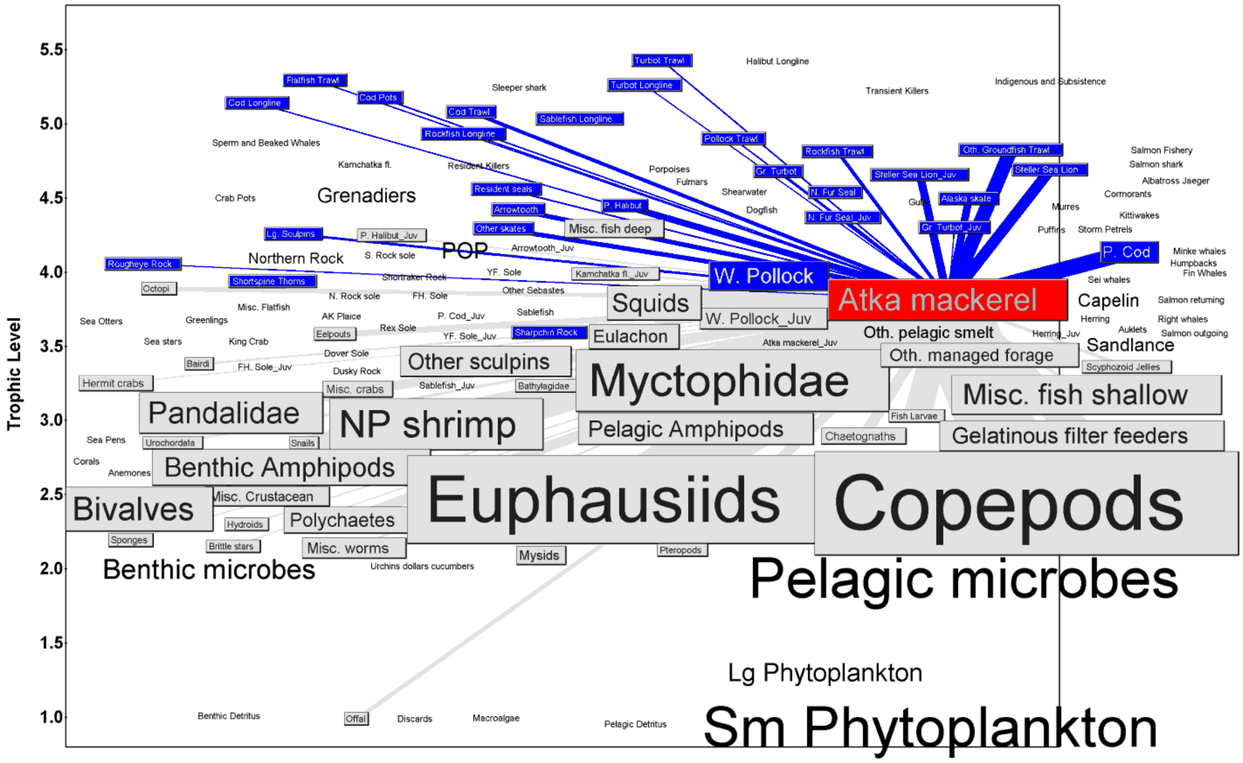
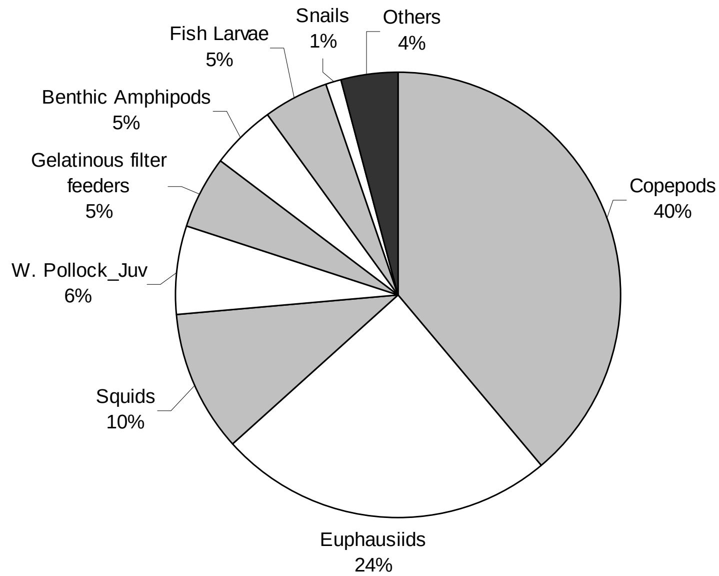
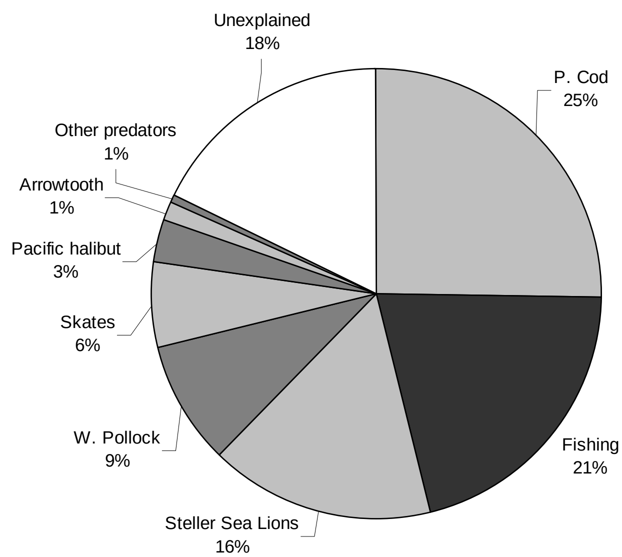


Figure 16.24 The food web of the Aleutian Islands survey region, 1990-1994, emphasizing the position of age 1+ Atka mackerel. Outlined species represent predators of Atka mackerel (dark boxed with light text) and prey of Atka mackerel (light boxes with dark text). Box and text size are proportional to each species' standing stock biomass, while line widths are proportional to the consumption between boxes (t/year). Trophic levels of individual species may be staggered up to +/-0.5 of a trophic level for visibility.



(A)



(B)

Figure 16.25 (A) Diet of age 1+ Atka mackerel, 1990-1994, by percentage wet weight in diet weighted by age-specific consumption rates. (B) Percentage mortality of Atka mackerel by mortality source, 1990-1994. "Unexplained" mortality is the difference between the stock assessment total exploitation rate averaged for 1990-1994, and the predation and fishing mortality, which are calculated independently of the assessment using predator diets, consumption rates, and fisheries catch.

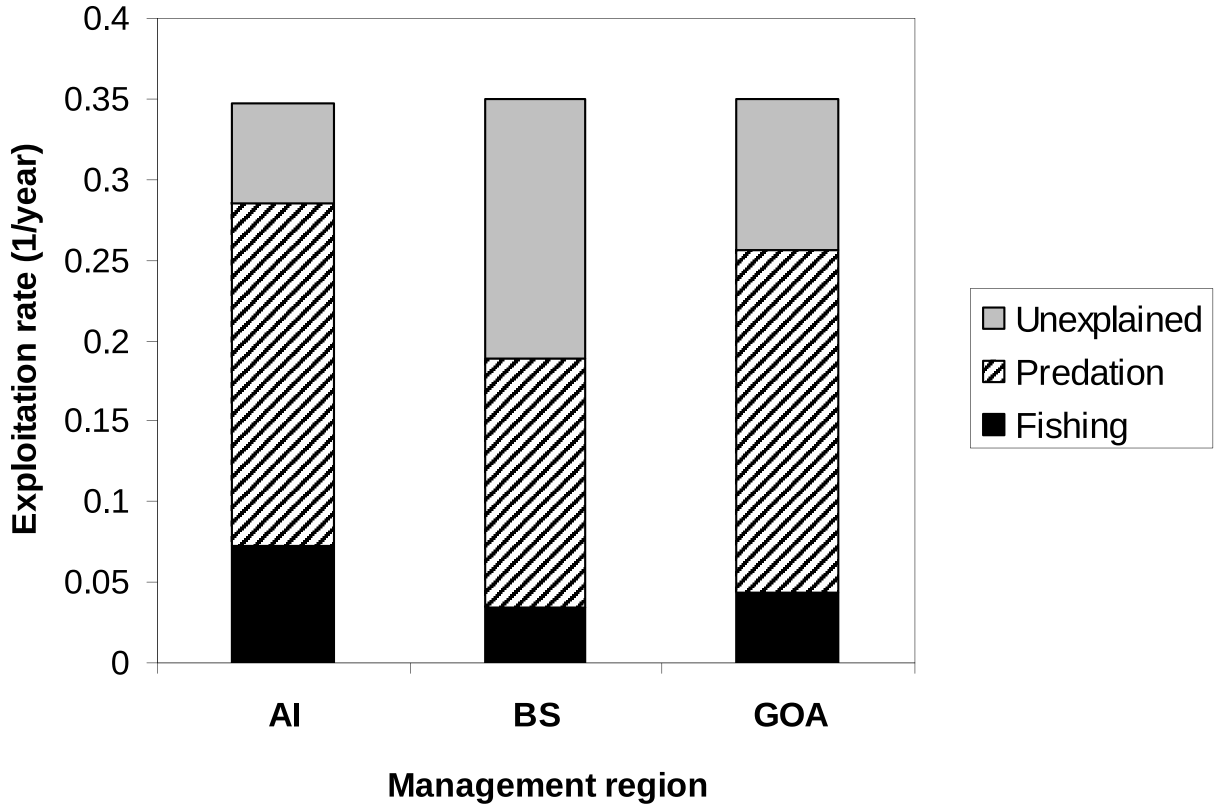


Figure 16.26 Total exploitation rate of age 1+ Atka mackerel, 1990-1994, proportioned into exploitation by fishing (black), predation (striped) and "unexplained" mortality (grey). "Unexplained" mortality is the difference between the stock assessment total exploitation rate averaged for 1990-1994, and the predation and fishing mortality, which are calculated independently of the assessment using predator diets, consumption rates, and fisheries catch.

Appendix 16.A

Table A-1. Variable descriptions and model specification.

General Definitions	Symbol/Value	Use in Catch at Age Model
Year index: i = {1977, …., 2010}	i	
Age index: j = {1, 2, 3, …, A}	j	
Mean weight by age j	W_j	
Maximum age beyond which selectivity is constant	*Maxage*	Selectivity parameterization
Instantaneous Natural Mortality	M	Fixed M=0.30, constant over all ages
Proportion females mature at age j	p_j	Definition of spawning biomass
Sample size for proportion at age j in year i	T_i	Scales multinomial assumption about estimates of proportion at age
Survey catchability coefficient	q^s	Prior distribution = lognormal(1.0 , σ_q^2)
Stock-recruitment parameters	R_0	Unfished equilibrium recruitment
	h	Stock-recruitment steepness
	σ_R^2	Recruitment variance
Estimated parameters		
$\phi_i(34),\ R_0,\ h,\ \varepsilon_i(44),\ \sigma_R^2,\ \mu^f,\ \mu^s,\ M,\ \eta_j^s(10),\ \eta_j^f(10),\ F_{50\%},\ F_{40\%},\ F_{30\%},\ q^s$		

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

Table A-2. Variables and equations describing implementation of the Assessment Model for Alaska (AMAK).

Description	Symbol/Constraints	Key Equation(s)
Survey abundance index (s) by year	Y_i^s	$\hat{Y}_i^s = q_i^s \sum_{j=1}^{A} s_j^s W_{ij} e^{Z_{i,j}\frac{7}{12}} N_{ij}$
Catch-at-age by year	C_{ij}	$\hat{C}_{ij} = N_{ij} \frac{F_{ij}}{Z_{ij}} \left(1 - e^{-Z_{ij}}\right)$
Catch biomass	$\hat{C}_i^B$	$\hat{C}_i^B = \sum_j W_{ij} \hat{C}_{ij}$
Initial numbers at age	$j = 1$	$N_{1977,1} = e^{\mu_R + \varepsilon_{1977}}$
	A $1 < j < A$	$N_{1977,j} = e^{\mu_R + \varepsilon_{1978-j}} \prod_{j=1}^{j} e^{-M}$
Maximum age	$j = A$	$N_{1977,A} = N_{1977,A-1}\left(1 - e^{-M}\right)^{-1}$
Subsequent years ($i > 1977$)	$j = 1$	$N_{i,1} = e^{\mu_R + \varepsilon_i}$
	$1 < j < A$	$N_{i,j} = N_{i-1,j-1} e^{-Z_{i-1,j-1}}$
	$j = A$	$N_{i,15^+} = N_{i-1,14}\, e^{-Z_{i-1,14}} + N_{i-1,15}\, e^{-Z_{i-1,15}}$
Year effect, i = 1967, …, 2008	ε_i, $\sum_{i=1967}^{2010} \varepsilon_i = 0$	$N_{i,1} = e^{\mu_R + \varepsilon_i}$
Index catchability Mean effect	μ^s, μ^f	$q_i^s = e^{\mu^s}$
Age effect	η_j^s, $\sum_{j=1}^{A} \eta_j^s = 0$	$s_j^s = e^{\eta_j^s}$ $j \le$ 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, $\sum_{i=1977}^{2010} \phi_i = 0$	
Age effect of fishing (regularized) in year time variation allowed	η_{ij}^f, $\sum_{j=1}^{A} \eta_{ij} = 0$	$s_{ij}^f = e^{\eta_j^f}$, $j \le$ 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	$\tilde{R}_i$	$\tilde{R}_i = \frac{\alpha B_i}{\beta + B_i}$, $\alpha = \frac{4hR_0}{5h-1}$ and $\beta = \frac{B_0(1-h)}{5h-1}$ where $B_0 = \tilde{R}_0 \varphi$ $\varphi = \frac{e^{-AM} W_A p_A}{1-e^{-M}} + \sum_{j=1}^{A} e^{-M(j-1)} W_j p_j$

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

Likelihood /penalty component		Description / notes
Abundance indices	$L_1 = \lambda_1 \sum_i \ln\left(Y_i^s \big/ \hat{Y}_i^s \right)^2 \frac{1}{2\sigma_i^2}$	Survey abundance
Prior on smoothness for selectivities	$L_2 = \sum_l \lambda_2^l \sum_{j=1}^{A} \left(\eta_{j+2}^l + \eta_j^l - 2\eta_{j+1}^l \right)^2$	Smoothness (second differencing), Note: *l={s,* or *f}* for survey and fishery selectivity
Prior on recruitment regularity	$L_3 = \lambda_3 \sum_{i=1967}^{2010} \varepsilon_i^2$	Influences estimates where data are lacking (e.g., if no signal of recruitment strength is available, then the recruitment estimate will converge to median value).
Catch biomass likelihood	$L_4 = \lambda_4 \sum_{i=1977}^{2010} \ln\left(C_i^B \big/ \hat{C}_i^B \right)^2$	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	$L_6 = \lambda_6 \sum_{i=1978}^{2010} \phi_i^2$	(relaxed in final phases of estimation)
Priors	$L_7 = \left[\lambda_7 \frac{\ln\left(M/\hat{M} \right)^2}{2\sigma_M^2} + \lambda_8 \frac{\ln\left(q/\hat{q} \right)^2}{2\sigma_q^2} \right]$	Prior on natural mortality, and survey catchability (reference case assumption that these are precisely known at 0.3 and 1.0, respectively).
Overall objective function to be minimized	$\dot{L} = \sum_{i=1}^{7} L_i$	