16. ASSESSMENT OF GULF OF ALASKA ATKA MACKEREL

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EXECUTIVE SUMMARY

Relative to the November 2007 SAFE report, (GOA Atka mackerel are assessed biennially), the following substantive changes have been made in the current draft of the Atka mackerel chapter:

Changes in the Input Data

1. Catch data are updated.
2. Length data from the 2007, 2008, and preliminary 2009 GOA fisheries are presented.
3. Age data from the 2007 and 2008 GOA fisheries are presented.
4. Age data from the 2007 GOA bottom trawl survey are presented.
5. Biomass estimates from the 2009 GOA bottom trawl survey are presented.
6. Length frequency data from the 2009 GOA bottom trawl survey are presented.

Changes in the Assessment Methodology

There are no changes to the assessment methodology. Gulf of Alaska Atka mackerel have been managed under Tier 6 specifications since 1996 due to lack of reliable estimates of current biomass. In the 2007 assessment, Tier 5 calculations of ABC and OFL (based on 2007 survey biomass estimates) were presented for consideration. The Plan Team, SSC, and Council agreed with the authors that there is no reliable estimate of Atka mackerel biomass and recommended continuing management under Tier 6. This year, we again present Tier 6 recommendations, but do not present Tier 5 calculations of ABC and OFL given the extreme variances associated with the 2009 survey biomass estimates.

Changes in Assessment Results

Since 2006, the maximum permissible ABC has been 4,700 t under Tier 6 and the ABCs have been set at this level. The 2006-2008 TACs were set at 1,500 t to accommodate an increase in GOA Atka mackerel catches, and still allow for bycatch in other directed fisheries and minimize targeting. The 2009 TAC was set at 2,000 t to accommodate an increase in GOA bycatch of Atka mackerel. Given the very patchy distribution of GOA Atka mackerel, which results in highly variable estimates of abundance and the extreme variance associated with the 2009 survey biomass estimate (Gulf-wide *CV* of 83%), we continue to recommend that GOA Atka mackerel be managed under Tier 6. **We recommend a 2010 ABC for GOA Atka mackerel equal to the maximum permissible value of 4,700 t. The 2010 OFL is 6,200 t under Tier 6.**

Prudent management is still warranted and the rationale as given in the past for a TAC to provide for anticipated bycatch needs of other fisheries, principally for rockfish, Pacific cod, and pollock, and to only allow for minimal targeting should still be considered. The 2006-2008 TACs for GOA Atka mackerel were 1,500 t and the 2009 TAC was set at 2,000 t. It should be noted that the 2008 and 2009 catches exceeded the TAC in those years.

Summary

Tier 6	Last year's projection		This year's projection	
M = 0.3	2009	2010	**2010**	2011
$B_{40\%}$ (t)	NA	NA	NA	NA
Female Spawning Biomass (t)	NA	NA	NA	NA
Maximum permissible F_{ABC}	Unknown	Unknown	Unknown	Unknown
F_{ABC}	Unknown	Unknown	Unknown	Unknown
F_{OFL}	Unknown	Unknown	Unknown	Unknown
ABC (t, 0.75 x ave. catch 1978-95)	4,700	4,700	**4,700**	4,700
OFL (t, ave. catch 1978-95)	6,200	6,200	**6,200**	6,200

Response to SSC comments

Comments Specific to the Atka Mackerel Assessment

From the December 2008 minutes: *"The SSC recommends that stock assessment authors explore connections of this stock with the Bering Sea and also whether this stock should be moved to Tier 5 in the future"*. A discussion of stock structure information specifically focused on the connectivity of BSAI and GOA Atka mackerel is presented in the introduction. A discussion of the extreme variances associated with GOA survey biomass estimates which result in unreliable abundance estimates for Tier 5 calculations, is presented in the Overfishing Level and Maximum Permissible ABC section.

SSC Comments on Assessments in General

There were no SSC comments on assessments in general that applied to the GOA Atka mackerel assessment.

Introduction

Distribution

Atka mackerel (*Pleurogrammus monopterygius*) are distributed along the continental shelf in areas 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 (Rutenberg 1962). Moving eastward, they are distributed throughout the Komandorskiye and Aleutian Islands, north to the Pribilof Islands in the eastern Bering Sea, and eastward through the Gulf of Alaska to southeast Alaska.

An Atka mackerel population existed in the Gulf of Alaska (GOA) primarily in the Kodiak, Chirikof, and Shumagin areas, and supported a large foreign fishery through the early 1980s. By the mid-1980s, this fishery, and presumably the population, had all but disappeared. Evidence of low population levels was supported by Atka mackerel bycatch in other fisheries of less than 5 t from 1986 to 1988 (Table 16.1). The decline of the GOA Atka mackerel fishery suggests that the area may be the edge of the species' range. During periods of high recruitment in the Aleutian Islands, it is thought that juvenile Atka mackerel may move into the Gulf of Alaska under favorable conditions (Ronholt 1989, Lowe *et al.* 2005). Recently, Atka mackerel have been detected by the summer trawl surveys primarily in the Shumagin (Western) area of the Gulf of 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 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 16.6 (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).

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 2008).

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. 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

Diets of commercially important groundfish species in the Gulf of Alaska during the summer of 1990 were analyzed by Yang (1993). Although Atka mackerel were not sampled as a predator species, it can be inferred that the major prey items of Gulf of Alaska Atka mackerel would likely be euphausiids and copepods as found in Aleutian Islands Atka mackerel (Yang, 1999). The abundance of Atka mackerel in the Gulf of Alaska is much lower compared to the Aleutian Islands. Atka mackerel only showed up as a minor component in the diet of arrowtooth flounder in the Gulf of Alaska (Yang, 1993). Adult Atka mackerel in the Aleutians are consumed by a variety of piscivores, including groundfish (e.g., Pacific cod and arrowtooth flounder, Livingston *et al.*, unpubl. manuscr.), marine mammals (e.g., northern fur seals and Steller sea lions, Kajimura 1984, NMFS 1995, Sinclair and Zeppelin 2002), and seabirds (e.g., thick-billed murres, tufted puffins, and short-tailed shearwaters, Springer *et al.* 1999).

Nichol and Somerton (2002) examined the diurnal vertical migrations of Atka mackerel using archival tags and related these movements to light intensity and current velocity. Atka mackerel displayed strong diel behavior, with vertical movements away from the bottom occurring almost exclusively during daylight hours, presumably for feeding, and little to no movement at night (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 Aleutian Islands. 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. 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 (western Aleutian Islands) but not at Seguam Pass (eastern Aleutian Islands). 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.

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 GOA, 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, 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

Gulf of Alaska Atka mackerel are managed as a Gulf-wide species and managed separately from the Bering Sea/Aleutian Islands. Considerations, discussed above, suggest that continued separate assessment and management of GOA Atka mackerel is prudent and precautionary.

Fishery

Catch History and Fishery Management

Prior to the mid-1980s, Atka mackerel were fished exclusively by foreign vessels, primarily from the Soviet Union. Landings were about 19,500 t in 1977 and 1978, then dropped to less than 5 t in 1986 (Table 16.1). Some joint venture operations participated in this fishery from 1983 to 1985. All landings since then have been taken by the domestic fishery.

In 1988, Atka mackerel were combined in the Other Species category due to low abundance and the absence of a directed fishery for the previous several years. However, beginning in 1990, Atka mackerel were targeted in the western Gulf of Alaska. From 1990-1993, catches of the Other Species category in the GOA were dominated by Atka mackerel, primarily from the Western GOA regulatory area. Atka mackerel were separated from the other species category and became a separate target category in the GOA in 1994, after approval of Amendment 31 to the Fishery Management Plan for the Groundfish Fishery of the Gulf of Alaska. Catches of Atka mackerel by GOA management areas since 1990 have been:

Gulf of Alaska (GOA) Catches (t) by Management Areas

Year	Western	Central	Eastern	Total
1990a	1,416	0	0	1,416
1991	3,249	9	0	3,258
1992	13,785	49	0	13,834
1993	4,867	2,143	0	7,010
1994	2,661	877	0	3,538
1995	329	370	2	701
1996	1,577	9	0	1,586
1997	321	8	2	331
1998	279	38	0	317
1999b	-	-	-	262
2000	-	-	-	170
2001	-	-	-	76
2002	-	-	-	85
2003	-	-	-	578
2004	-	-	-	819
2005	-	-	-	799
2006	-	-	-	876
2007	-	-	-	1,459
2008	-	-	-	2,109
2009c	-	-	-	2,204

a/ Actual observed catch
b/ From 1999 to the present TAC has been set GOA-wide; catches not available by regulatory area from the NMFS Alaska Regional Office.
c/ 2009 data as of 14-OCT-09 from NMFS Alaska Regional Office. Available at http://www.fakr.noaa.gov/2009/car110_goa.pdf

The 1990 catch of 1,416 t is a minimum estimate, since this was the tonnage actually observed by domestic observers. The Alaska Regional Office's estimate of catch for 1990 is underestimated, as Gulf of Alaska Atka mackerel catches were incorrectly being reported as landed in the Aleutian Islands (G. Tromble, Regional Office, Juneau, Alaska, *pers. comm.*). Total catches of Atka mackerel were small until 1992, when approximately 14,000 t were taken in the Shumagin area. In 1994, when Atka mackerel was taken out of the Other Species category and assigned a target species, the North Pacific Fishery Management Council (Council) assigned a Gulf-wide Atka mackerel ABC and TAC of 4,800 and 3,500 t, respectively (Table 16.1). For 1995 and 1996, the Council approved a Gulf-wide ABC and a total TAC of 3,240 t for Gulf of Alaska Atka mackerel (Table 16.1). For purposes of data collection and effort

dispersion, 2,310 t was allocated to the Western or Shumagin subarea (Area 610), 925 t was allocated to the Central, or the combined Chirikof and Kodiak subareas (Areas 620 and 630), and 5 t was assigned to the Eastern GOA (Areas 640 and 650). The Western subarea (Area 610) was not opened to the directed Atka mackerel fishery in 1995 because the overfishing level for Pacific ocean perch (POP) was nearly reached; Atka mackerel fisheries have had significant bycatch of POP. In 1996, the fishery in the Western subarea was restricted to a 12-h opening on July 1, again due to concerns about the POP bycatch exceeding the POP TAC and approaching the overfishing level; about 1,600 t of Atka mackerel were caught. The 1996 Central POP catch exceeded the Central area POP overfishing level, thus there was no opening for the directed Atka mackerel fishery in that area. Since 1996 the Atka mackerel fishery has been managed as a bycatch-only fishery with Gulf-wide TACs of 1,000 t in 1997 and 600 t for the years 1998 to 2005.

The catch of GOA Atka mackerel jumped dramatically in 2003 to 578 t. Previous to this, catches were less than 100 t in 2001 and 2002 (Table 16.1). The 2004 Gulf-wide Atka mackerel catch of 819 t, exceeded the TAC (600 t) for Atka mackerel for the first time since this quota was implemented in 1998. The 2005 catch (799 t) also exceeded the 2005 Atka mackerel TAC. This increase of Atka mackerel in the GOA coincided with local sports fishermen reporting catches of Atka mackerel for the first time off Resurrection Bay and as far as Southeast Alaska in 2003. The 1999 year class has been documented as a very strong year class in the Aleutian Islands (Lowe *et al.* 2005). Twenty-seven Atka mackerel were sampled for otoliths by observers in the 2003 Gulf of Alaska fisheries. All 27 fish were aged and determined to be 4-year olds of the 1999 year class. Fifty-three and 82 otoliths respectively, were aged from the 2007 and 2008 GOA fisheries. The 1999 year class continues to dominate the age composition of GOA Atka mackerel.

Figure 16.1 shows the 2008 and preliminary 2009 distributions of observed catches of Atka mackerel in the Gulf of Alaska summed by 20 km areas. Most of these catches occurred during July through October. Open circles represent observed catches greater than 1 t. Large catches were taken in the Shumagin (610) area and to some extent in the Chirikof (620) area. Under the Rockfish Program catcher processors who historically would move out of 610 after the POP fishery closed, are now remaining in the area and targeting northern and pelagic shelf rockfish. This is contributing to greater catches (much of it discarded) of Atka mackerel.

Description of the Directed Fishery

There has not been a directed fishery for Atka mackerel since 1996. A discussion of the directed fishery for the years 1990-1994 is given in Lowe and Fritz (2001).

Bycatch and Discards
A discussion of the historical amount of Atka mackerel retained and discarded by target fishery and area in the Gulf of Alaska in 1994 and 1995 has been given in previous assessments (Lowe and Fritz 2001). The 2003 to 2008 levels of Gulf of Alaska Atka mackerel retained and discarded are given below:

Year	Fishery	Discarded (t)	Retained (t)	Total (t)
2003	Rockfish	218	210	428
	All others	36	118	154
	All	254	329	583
2004	Rockfish	259	461	720
	All others	70	29	99
	All	329	490	819
2005	Rockfish	101	617	718
	All others	54	27	81
	All	155	644	799
2006	Rockfish	337	442	779
	All others	43	56	100
	All	381	498	879
2007	Rockfish	334	760	1,094
	All others	231	135	366
	All	564	895	1,459
2008	Rockfish	973	772	1,745
	All others	350	15	365
	All	1,324	787	2,110

The 2003 through 2008 data indicated that most of the Atka mackerel bycatch in the GOA, which was coming out of the Shumagin and Chirikof areas, was taken in the rockfish fisheries. The amount of Atka mackerel retained in the rockfish fishery more than doubled in 2004. There appears to have been targeted fishing on Atka mackerel since 2003. In 2003 the flatfish and Pacific cod fisheries retained significant amounts of Atka mackerel. In 2007 the pollock and flatfish fisheries retained Atka mackerel. For the most part, there has been very little Atka mackerel retained by fisheries, other than rockfish, since 2003.

Fishery Length Frequencies
Atka mackerel length distributions from the 1990-1994 fisheries are discussed in previous assessments (Lowe and Fritz 2001). Fishery observers sampled significant numbers of fish for length data from the 2007-2009 fisheries. Lengths ranged from 41-51 cm with modes at 45-46 cm (Figure 16.2).

Fishery Age Frequencies
There is only very limited age data available from the historical fisheries that were actively targeting Atka mackerel, i.e., 1990 Davidson Bank fishery, the 1992 Umnak Island fishery, and the 1994 fishery which operated off Umnak Island, Davidson Bank and Shumagin Bank. These data are discussed in Lowe and Fritz (2001).

The very strong 1999 year class still dominates the GOA Atka mackerel catch-age distributions. Fifty-three Atka mackerel otoliths from the 2007 Gulf of Alaska fisheries were aged and 38% were determined to be 8-year-olds of the 1999 year class. Forty-one percent of the 99 otoliths aged from the 2008 Gulf of Alaska Fisheries were determined to be 9-year-olds of the 1999 year class (Figure 16.3). It is interesting

to note the appearance of 2-year-olds in the 2008 GOA catches. Preliminary data suggests the 2006 year class may be above average in the Aleutian Islands (Lowe *et al*. 2009).

Fishery and Steller Sea Lions

The western stock of Steller sea lions, which ranges from Cape Suckling (at 144°W) west through the Aleutian Islands and into Russia, is currently listed as endangered under the Endangered Species Act (ESA), and has been listed as threatened since 1990. In 1991 and 1992, 10 nm annual trawl exclusion zones were established around all rookeries west of 150°W (Figure 16.1); in 1992 and 1993, 20 nm trawl exclusion zones were established around 6 rookeries in the eastern Aleutian Islands that are operational only during the BSAI pollock A-season. In 1993, NMFS designated Steller sea lion critical habitat, which includes a 20 nm aquatic zone around all rookeries and major haulouts west of 144°W, and three foraging areas, one of which contains Shelikof Strait. Sea lion food habits data collected in the Aleutian Islands revealed that Atka mackerel was the most common prey of Steller sea lions throughout the year (NMFS 1995, Sinclair and Zeppelin 2002).

From 1977 to 1984 and in 1990, up to 11% of the annual Gulf of Alaska Atka mackerel harvest was caught within 20 miles of all Gulf of Alaska sea lion rookeries and major haulouts, reflecting the offshore distribution of the fishery. In 1991-1993, however, the fishery moved closer to shore, and this percentage increased to 82-98%, almost all of which was caught between 10-20 nm of Steller sea lion rookeries on Ogchul and Adugak Islands (near Umnak Island), and Atkins and Chernabura Islands in the Shumagin Islands.

Leslie depletion estimates of local fishery harvest rates were computed to be much greater than estimated Gulf-wide harvest rates (Lowe and Fritz 1996; 1997). This raised concerns about how the fishery may have affected food availability, foraging success, and the potential for recovery of the Steller sea lion population. There has not been a directed Gulf of Alaska Atka mackerel fishery since 1996. Steller Sea Lion Protection measures prohibit directed fishing for Atka mackerel in the GOA. In June 1998, the Council passed a fishery regulatory amendment which proposed a four-year timetable to temporally and spatially disperse and reduce the level of Atka mackerel fishing within Steller sea lion critical habitat in the Bering Sea/Aleutian Islands. The 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. The management of the Bering Sea/Aleutian Islands Atka mackerel fishery is detailed in Lowe *et al.* (2009).

Survey Data

Absolute Abundance and Survey Biomass

Bottom trawl surveys of the Gulf of Alaska groundfish community have been conducted every three years since 1984 and biennially since 1999 using an area-depth stratified and area-swept design. In 1999, the same GOA survey design was maintained, but effort allocation was shifted to provide more even coverage within depth strata. Atka mackerel are a very 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 the standard survey bottom trawl gear difficult; and (3) their schooling behavior and patchy distribution (particularly in the GOA), makes the species susceptible to large variances in catches which greatly affect area-swept estimates of biomass.

The general groundfish surveys of the Gulf of Alaska are particularly problematic for Atka mackerel given the characteristics described above. In 1996, a meaningful estimate of biomass could not be determined from the data due to extreme variances. Over 98% of the Atka mackerel caught in the 1996 survey were encountered in a single haul within a large stratum, which yielded a large stratum biomass with an extremely large confidence interval.

Although estimates of abundance from earlier surveys have been presented in previous assessments, they were also compromised by the problem of large confidence intervals, although not to the same degree as observed in 1996. Similar to the 1996 survey, virtually all the GOA Atka mackerel biomass from the 2001 survey was encountered in a single haul south of the Islands of Four Mountains at about 170°W. The 2003 Gulf of Alaska bottom trawl survey encountered the highest percentage of hauls with Atka mackerel catch since 1990. Catches were less patchy relative to previous surveys, and observations extended well into the central Gulf of Alaska and even into the Yakutat area. This is coincident with dramatically increased catches of Atka mackerel in other directed fisheries, and reports from local sports fishermen of catches of Atka mackerel in the central Gulf and even off Southeast Alaska. The 2005 survey encountered fewer hauls with Atka mackerel catch (relative to the 2003 survey), and observations extended only into the Chirikof area (Figure 16.4). The 2007 survey encountered even fewer hauls with Atka mackerel catch (relative to the 2005 survey), and most of the observations were from the Shumagin area. The most recent 2009 survey showed that over 95% of the GOA Atka mackerel biomass was caught in 2 hauls off Sanak Island in the 1-100 m depth strata (Figure 16.4). Bottom trawl survey information is presented for 2005, 2007, and 2009 for consideration (Table 16.2).

Atka mackerel have been inconsistently caught in the GOA surveys, appearing in 10%, 44%, 29%, 20% and 24% of the hauls in the Shumagin area in the 2001, 2003, 2005, 2007, and 2009 GOA surveys, respectively. What can be concluded from this is that the general groundfish GOA bottom trawl survey, as it has been designed and used since 1984, does not assess GOA Atka mackerel well, and the resulting biomass estimates are not considered consistent reliable indicators of absolute abundance or indices of trend.

Most of the GOA Atka mackerel biomass (96%, 98% and 99.6% in 2005, 2007, and 2009 respectively) is distributed within the Shumagin area of the western GOA (Area 610, Figure 16.4; Table 16.2). Atka mackerel were encountered in 24% of the hauls conducted in the Shumagin area in the 2009 survey. The 2009 estimate of Atka mackerel biomass in the Shumagin area is 135,100 t, with a coefficient of variation (*CV*) of 84%, reflecting a variance of 12.8 million (Table 16.2).

Survey Length Frequencies

Length frequency distributions from the 2005, 2007, and 2009 surveys are shown in Figure 16.5. The distributions of fish from the surveys fall mainly between 40 and 50 cm with modes at 43 cm in 2005, 44 cm in 2007, and 44-48 cm in 2009, reflecting the growth of the 1999 year class (Figure 16.5). It is interesting to note that the length frequency distributions of males and females differ slightly in the GOA surveys. The female length frequency distributions show a slightly greater proportion of large fish, while the male distributions show slightly greater proportions of small fish, particularly in the 2009 survey (Figure 16.5). This has not been observed in the Aleutian Islands surveys; the male and female length frequency distributions are not differentiable and survey length frequency distributions are presented for combined sexes (Lowe *et al.* 2009).

Survey Age Frequencies

Historical survey age data from the Gulf of Alaska trawl survey are only available from 1993 (Figure 10.11 in Lowe and Fritz 2001). The 1993 survey showed a mode of 5-year-olds from the 1988 year class which has also been documented as a strong year class in the Aleutian Islands (Lowe *et al.* 2005).

The 2005 and 2007 Gulf of Alaska surveys were able to sample Atka mackerel, and 315 and 143 otoliths were aged from the 2005 and 2007 surveys, respectively (Figure 16.6). The survey age data show that survey catches were comprised mainly of the 1999 year class (66% in 2005 and 50% in 2007). The 1999 year class is documented to be well above average in the Aleutian Islands assessment (Lowe *et al.* 2009).

Biological Parameters

Natural Mortality, Age of Recruitment, and Maximum Age

A natural mortality rate of 0.3 is assumed for Gulf of Alaska Atka mackerel based on analyses of natural mortality for Aleutian Islands Atka mackerel. The value of 0.3 was calculated with the method of Hoenig (1983) and is described in Lowe *et al*. (2009).

A qualitative look at the sparse GOA fishery age data shows recruitment patterns similar to the Aleutian Islands fishery. The age of first recruitment appears to be 2-3 years, and full recruitment at 4 years (Lowe and Fritz 2001). This pattern becomes somewhat obscured when a strong year class dominates the distributions.

The maximum age seen in the Gulf of Alaska fishery is 13 years (1990 fishery). This compares with a maximum age of 15 years for the Aleutian Islands.

Length and Weight at Age

Parameters of the von Bertalanffy length-age equation and a weight-length relationship were calculated from the combined 1990, 1992, and 1994 fishery data. Sexes were combined to provide an adequate sample size. The estimated von Bertalanffy growth parameters are:

L_∞ = 54.56 cm
K = 0.22
t_0 = -2.78 yr

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

The weight-length relationship was determined to be:

Weight (kg) = 4.61E-05*Length (cm) 2.698.

Growth parameters were also estimated from data collected during the 1993 Gulf of Alaska survey. As in the Aleutians, the survey tends to select for smaller fish-at-age than the fishery. The estimated von Bertalanffy parameters from the 1993 survey are:

L_∞ = 47.27 cm
K = 0.610
t_0 = 0.38 yr.

The estimated weight-length relationship is:

Weight (kg) = 1.55E-05*Length (cm) 2.979.

The age-length and weight-length schedules for the fishery and survey are given in Table 16.3.

Maturity at Length and Age

Female maturity-at-length and age were determined for Gulf of Alaska Atka mackerel (McDermott and Lowe 1997). The maturity schedules are given in Table 16.4. The age-at-50% maturity is 3.6 years and length-at-50% maturity in the Gulf of Alaska is 38.2 cm. Cooper and McDermott (2008) 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).

Selectivity at Age

The small amount of age data for Gulf of Alaska Atka mackerel show similar selectivity patterns as seen in the Aleutian Islands survey and fishery data. The fishery data tend to show older fish than the survey samples. The oldest age from the 1993 GOA survey was 9 years old and the age distribution consisted of mostly 2 to 6-year-olds (Lowe and Fritz 2001). Recent age data from the GOA fisheries (2007 and 2008) and survey (2007) show a limited distribution of ages (Figures 16.3 and 16.6). Current catches of GOA Atka mackerel are mainly comprised of a single cohort, the very strong 1999 year class.

Overfishing Level and Maximum Permissible ABC

As discussed above, bottom trawl survey information from the GOA surveys is presented for consideration. The 2009 survey estimated a GOA Atka mackerel biomass of 135,100 t for the Shumagin area with a *CV* of 84%. This represents 99.6% of the Gulf-wide Atka mackerel biomass estimate. Over 95% of the Shumagin area biomass was caught in 2 hauls off Sanak Island in the 1-100 m depth strata. Given the extreme variance associated with the GOA survey biomass estimates, we do not believe they provide reliable estimates for determination of OFL and maximum permissible ABC.

If there is no reliable estimate of current biomass, then Tier 6 of Amendment 56 of the GOA FMP defines the overfishing level (OFL) as the average catch from 1978-95, and the maximum permissible ABC as 0.75 of the OFL. The average annual catch from 1978-95 is 6,200 t, which is the overfishing level, and the maximum permissible ABC is 4,700 t under Tier 6.

ABC Considerations and Recommendation

Since 1996, GOA Atka Mackerel has been managed under Tier 6 specifications due to lack of reliable estimates of current biomass. The maximum permissible ABC has been 4,700 t. The biomass estimates from the 2007 and 2009 surveys are highly variable with Gulf-wide *CV*s of 46 and 83%, respectively. The biomass has been mostly observed in the Shumagin area (98 and 99.6% of the Gulf-wide estimates in the 2007 and 2009 surveys, respectively). Given the extreme patchy distribution of GOA Atka mackerel which results in highly variable estimates of abundance, we continue to recommend that GOA Atka mackerel be managed under Tier 6.

The GOA fishery and survey catches are mainly comprised of a single cohort (the 1999 year class) which has been documented as well above average in the Aleutian Islands (Lowe *et al.* 2009). There does not appear to be an expanded population with a broad distribution of age classes, and speculation is that this is overflow from the Aleutian Islands population.

For the above reasons, we continue to recommend that GOA Atka mackerel be managed under **Tier 6, and recommend a 2010 ABC for GOA equal to the maximum permissible value of 4,700 t.** T**he 2010 OFL is 6,200 t under Tier 6.**

Prudent management is still warranted and the rationale as given in the past for a TAC to provide for anticipated bycatch needs of other fisheries, principally for Pacific cod, rockfish and pollock, and to only allow for minimal targeting should still be considered. The 2009 TAC for GOA Atka mackerel was 2,000 t.

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. Steller sea lion food habits data from the western Gulf of Alaska are relatively sparse, so it is not known how important Atka mackerel is to sea lions in this area. The close proximity of fishery locations to sea lion rookeries in the western Gulf suggests that Atka mackerel could be a prey item at least during the summer. Analyses of fishery CPUE revealed that the fishery may create temporary localized depletions of Atka mackerel and that these depletions may last for

weeks after the vessels have left the area. This supports the argument already made above in the ABC section for a conservative harvest policy for Atka mackerel in the Gulf of Alaska.

Ecosystem effects on GOA Atka mackerel

Prey availability/abundance trends

Atka mackerel are primarily zooplanktivores, consuming mainly euphausiids and calanoid copepods (Yang 1996, Yang and Nelson 2000, Yang 2003, Yang *et al.* 2006). Other zooplankton prey include larvaceans, gastropods, jellyfish, pteropods, amphipods, isopods, and shrimp (Yang and Nelson 2000, Yang 2003, Yang *et al.* 2006). Atka mackerel also consume fish, such as sculpins, juvenile Pacific halibut, eulachon, Pacific sand lance, juvenile Kamchatka flounder, juvenile pollock, and eelpouts, in small proportions relative to zooplankton (Yang and Nelson 2000, Yang *et al.* 2006, Aydin *et al.* 2007). The proportions of these various prey groups consumed by Atka mackerel vary with year and location (Yang and Nelson 2000). The diet of Atka mackerel in the GOA differs from their more diverse diet at the core of their range in the western Aleutian Islands, where they feed on copepods, polychaetes, deepwater mytophids, squids, and other invertebrates (Ortiz, 2007).

Monitoring trends in Atka mackerel prey populations may, in the future, help elucidate Atka mackerel population trends. There is no long-term time series of zooplankton biomass information available; however, there are six years (1998-2003) of zooplankton information along the Seward hydrographic line (extending offshore from the mouth of Resurrection Bay). This data shows that zooplankton composition and biomass varies with year, season, and the location of the front between the nearshore Alaska coastal current and the further offshore Alaska stream (Coyle and Pinchuk 2006). The time series of euphausiid biomass indicates that they were more abundant in 2002 and 2003, both inshore and offshore of the shelf-break front than in previous years (Coyle and Pinchuk 2006). The primary euphausiids species found offshore is *Euphausia pacifica*, whereas, inshore of the front, *Thysanoessa inermis* and *T. spinifera* are the dominant euphausiids species (Coyle and Pinchuk 2006). Both *E. pacifica* and *T. inermis* are consumed by GOA Atka mackerel (Yang 1999).

Predator population trends

Adult Atka mackerel are not currently a significant prey fish for other commercially important groundfish in the Gulf of Alaska. They are consumed occasionally by several piscivorous species in the western Gulf, such as arrowtooth flounder (ATF), Pacific halibut, and Pacific cod (Yang and Nelson 2000), at fork lengths ranging from 1-50cm, though primarily between 20-26cm fork length. The occasional nature of their consumption is probably due to their relative lack of abundance in the Gulf rather than a lack of preference on the part of the predators; they are a critical food resource for piscivorous species in the western Aleutian Islands where they are a dominant groundfish species. Additional species which feed on Atka mackerel include Steller sea lions, Northern fur seals (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).

The overall biomass of major Atka mackerel groundfish predators (ATF, Pacific cod, and halibut) has increased dramatically since the late 1970s (Figure 16.7). GOA ATF biomass started increasing in 1976 and continues to increase (Turnock *et al.* 2005). GOA Pacific cod biomass increased from the early 1970s, peaked in 1990, and has since decreased to levels observed in the early 1980s (Thompson *et al.* 2006). Central GOA Pacific halibut biomass increased from the early 1970s to the mid-1990s and has since declined slightly to levels observed in the early 1990s (IPHC, S. Hare, personal communication). The increase in groundfish predator biomass could potentially increase the mortality of Atka mackerel.

The population trends of seabirds in the GOA are mixed with some increasing, some decreasing, and others stable. At selected monitored sites in the central GOA, the majority of seabird populations do not show significant linear trends over time (Dragoo *et al.* 2006, Fitzgerald *et al.* 2006). There are a few populations that have increased over time, however, the majority of diving piscivorous seabird

populations in 2003 that showed a significant population trend over time, showed a decreasing trend (Dragoo *et al.* 2006, Fitzgerald *et al.* 2006). Seabird population trends could potentially affect juvenile Atka mackerel mortality, but this has not been quantified in the GOA.

Trends in Steller sea lion populations are monitored at selected 'trend' sites in Alaska. Steller sea lion non-pup counts decreased sharply in both the central and eastern Gulf of Alaska through 1998 (Sinclair *et al.* 2006). In the eastern Gulf of Alaska, counts increased between 1998 and 2004, but were stable between 2004 and 2006. Since 1998 in the central Gulf of Alaska, counts continued to decline but at a slower rate (Sinclair *et al.* 2006). Atka mackerel comprise a small proportion of the Steller sea lion diet in the central GOA, but about 30% of the diet in the eastern AI/western GOA (Merrick *et al.* 1997). Winship and Trites (2003) estimated that "Steller sea lions in all areas of Alaska consumed a total of 104,000 (±20,600) t of hexagrammid biomass in 1998 (75% of estimated exploitable Atka mackerel biomass dying naturally in the Aleutian Islands, and 181% of fishery catches in the Aleutian Islands and the Gulf of Alaska in 1998)".

Overall, while Steller sea lions, Pacific cod, and arrowtooth flounder are all sources of significant mortality of Atka mackerel in the Aleutian Islands, predatory groundfish play a far larger numerical role than Steller sea lions in the Gulf of Alaska as even occasional predation events by these groundfish may add to a large degree of predator control due to the large and increasing size of their populations.

Changes in habitat quality

Climate

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 GOA.
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). This has not been examined for GOA Atka mackerel.

Bottom temperature

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).

Bottom temperatures, recorded in the GOA bottom trawl survey, were above normal in 1984, 1987, 2001, 2003, and 2005 for depths less than 150 m (Martin 2005). The 1990s were generally cooler than normal and 1999 was the coldest year (Martin 2005). This also coincided with the strongest year class of Atka mackerel in the GOA (1999 year class). One notable trend in the bottom temperatures of the GOA shows that there is a "general warming pattern in depths less than 50 m" (Martin 2005). It is unclear what effect this may have on Atka mackerel nesting sites that are within this depth range.

Atka mackerel fishery effects on the ecosystem

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 whips, sea anemones, ascidians, and bryozoans (Malecha *et al.* 2005, Malecha and Stone 2009). 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. The cumulative and long term effects from historic Atka mackerel fisheries are unknown.

Trends in fishing effort have changed over time. Bottom trawl fishing effort in the GOA has decreased since 1990 as pollock and Pacific cod total allowable catches have been reduced (Coon 2007a). Pot fishing effort, primarily a Pacific cod fishery, in the GOA has increased since the 1990s (Coon 2007b). The A season fishery begins on January 1st and concludes in early March and the B season fishery opens September 1 lasts 6 weeks or less (Coon 2007b). There is also a state-managed fishery in state waters. The federally-managed pot fishery overlaps temporally with Atka mackerel spawning and nesting times, however, it is thought that the footprint of this fishery is small (Coon 2007b). Hook and line effort decreased in the early 1990s, and has been relatively stable since 2000 (Coon 2007c). The cod longline fishery occurs over gravel, cobble, mud, sand, and rocky bottom, in depths of approximately 45 m to 255 m (Coon 2007c). This fishery generally occurs in the western and central Gulf of Alaska, opening on January 1st and lasting until early March (Coon 2007c). This may, therefore, temporally miss the peak Atka mackerel spawning and nesting period. However, both temporal and spatial overlap with Atka mackerel spawning/nesting habitat and period, and both direct and indirect impacts of fishing gear need to be examined to determine the effects on Atka mackerel habitat.

Concentration of Atka mackerel catches in time and space

There is currently no directed Atka mackerel fishery in the GOA. However, from 1977 to 1984 and in 1990, up to 11% of the annual Gulf of Alaska Atka mackerel harvest was caught within 20 miles of all Gulf of Alaska sea lion rookeries and major haulouts, reflecting the offshore distribution of the fishery. In 1991-1993, the fishery moved closer to shore, and this percentage increased to 82-98%, almost all of which was caught between 10-20 nm of Steller sea lion rookeries on Ogchul and Adugak Islands (near Umnak Island), and Atkins and Chernabura Islands in the Shumagin Islands. Leslie depletion estimates of historic local fishery harvest rates were computed to be much greater than estimated Gulf-wide harvest rates (Lowe and Fritz 1996; 1997). This raised concerns about how the fishery may have affected food availability, foraging success, and the potential for recovery of the Steller sea lion population.

Fishery contribution to bycatch

There has not been a directed Gulf of Alaska Atka mackerel fishery since 1996; however, current trawl fisheries for pollock, cod, and rockfish do retain some levels of Atka mackerel. For a discussion of the contribution to discards and offal production or to bycatch of prohibited species, forage fish, HAPC biota, marine mammals, seabirds, sensitive species or non-target species from these fisheries, the reader should refer to the GOA pollock, Pacific cod, and rockfish assessments.

Fishery effects in age-at-maturity and fecundity
The effects on the amount of large-sized Atka mackerel or on the age-at-maturity and fecundity from the pollock, Pacific cod, and rockfish fisheries are unknown.

Table 16.5 summarizes the ecosystem effects on GOA Atka mackerel and the fishery effects on the ecosystem

Data Gaps and Research Priorities

Regional and seasonal food habits data for Gulf of Alaska Atka mackerel is very limited. Studies to determine the impacts of environmental indicators such as temperature regime, on Atka mackerel are needed. Further studies to determine whether there have been any changes in life history parameters over time (e.g. maturity-at-age, fecundity, weight- and length-at-age) would be informative. 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 Gulf of Alaska would provide information for survey stratification and the extent of trawlable and untrawlable habitat.

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Literature Cited

Aydin, K., S. Gaichas, I. Ortiz, D. Kinzey, and N. Friday. 2007. A comparison of the Bering Sea, Gulf of Alaska, and Aleutian Islands large marine ecosystems through food web modeling. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-178, 298 p.

Bailey, K.M., J.F. Piatt, T.C. Royer, S.A. Macklin, R.K. Reed, M. Shima, R.C. Francis, A.B. Hollowed, D.A. Somerton, R.D. Brodeur, W.J. Ingraham, P.J. Anderson, and W.S. Wooster. 1995. ENSO events in the northern Gulf of Alaska, and effects on selected marine fisheries. Calif. Coop. Oceanic Fish. Invest. Rep. 36:78-96.

Boldt, J.L. (Ed). 2005. Ecosystem indicators for the North Pacific and their implications for stock assessment: Proceedings of first annual meeting of NOAA's Ecological Indicators research program. AFSC Processed Rep.2005-04, Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115.

Coon, C. 2007a. Groundfish bottom trawl fishing effort in the Gulf of Alaska, Bering Sea and Aleutian Islands. In J.L. Boldt (Ed.) Ecosystem Considerations for 2008. September 2007 DRAFT Appendix C of the BSAI\GOA Stock Assessment and Fishery Evaluation Reports. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Coon, C. 2007b. Pot fishing effort in the Gulf of Alaska, Bering Sea, and Aleutian Islands. In J.L. Boldt (Ed.) Ecosystem Considerations for 2008. September 2007 DRAFT Appendix C of the BSAI\GOA Stock Assessment and Fishery Evaluation Reports. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Coon, C. 2007c. Hook and Line (Longline) fishing effort in the Gulf of Alaska, Bering, Sea and Aleutian Islands. In J.L. Boldt (Ed.) Ecosystem Considerations for 2008. September 2007 DRAFT Appendix C of the BSAI\GOA Stock Assessment and Fishery Evaluation Reports. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Cooper, D., and S. McDermott. 2008. Variation in Atka mackerel, *Pleurogrammus monopterygius*, spatial and temporal distribution by maturity stage. Pages 11-42 *in* S. F. McDermott, M. Canino, N. Hillgruber, D. W. Cooper, I. Spies, J. Guthridge, J. N. Ianelli, P. Woods. 2008. Atka mackerel *Pleurogrammus monopterygius* reproductive ecology in Alaska. North Pacific Research Board Final report, 163p.

Coyle, K. O., and A. I. Pinchuk. 2006. Gulf of Alaska zooplankton. In J.L. Boldt (Ed.) Ecosystem Considerations for 2007. Appendix C of the BSAI\GOA Stock Assessment and Fishery Evaluation Reports. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Dragoo, D. E., G. V. Byrd, and D. B. Irons. 2006. Breeding status, population trends and diets of seabirds in Alaska, 2003. U.S. Fish and Wildl. Serv. Report AMNWR 06/13. Homer, Alaska.

Fitzgerald, S., K. Kuletz, M. Perez, K. Rivera, and D. Dragoo. 2006. Seabirds. In J.L. Boldt (Ed.) Ecosystem Considerations for 2007. Appendix C of the BSAI\GOA Stock Assessment and Fishery Evaluation Reports. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Francis, R.C., and S.R. Hare. 1994. Decadal scale regime shifts in the large marine ecosystems of the northeast Pacific: A case for historical science. Fish. Oceanogr. 3(1):279-291.

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

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

Guthridge, J. L. and N. Hillgruber. 2008. Embryonic development of Atka mackerel (*Pleurogrammus monopterygius*) and the effect of temperature. Pages 43-65 *in* S. F. McDermott, M. Canino, N. Hillgruber, D. W. Cooper, I. Spies, J. Guthridge, J. N. Ianelli, P. Woods. 2008. Atka mackerel *Pleurogrammus monopterygius* reproductive ecology in Alaska. North Pacific Research Board Final report, 163p.

Hare, S.R., and N.J. Mantua. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Prog. Oceanogr. 47:103-145.

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

Hollowed, A.B., S.R. Hare, and W.S. Wooster. 2001. Pacific Basin climate variability and patterns of Northeast Pacific marine fish production. Prog. Oceanogr. 49:257-282.

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

Kendall, A.W., and J.R. Dunn. 1985. Ichthyoplankton of the continental shelf near Kodiak Island, Alaska. U.S. Department of Commerce, NOAA Technical Report NMFS 20, 89 p.

Lauth, R. R., J. Guthridge, D. Nichol, S. W. Mcentire, and N. Hillgruber. 2007a. Timing and duration of mating and brooding periods of Atka mackerel (*Pleurogrammus monopterygius*) in the North Pacific Ocean. Fish. Bull., U.S. 105:560-570. http://fishbull.noaa.gov/1054/lauth.pdf

Lauth, R. R., S. W. Mcentire, and H. H. Zenger, Jr. 2007b. Geographic distribution, depth range, and description of Atka mackerel *Pleurogrammus monopterygius* nesting habitat in Alaska. Alaska Fish. Res. Bull. 12:165-186. http://www.adfg.state.ak.us/pubs/afrb/vol12_n2/lautv12n2.pdf

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

Levada, T.P. 1979. Comparative morphological study of Atka mackerel. Pac. Sci. Res. Inst. Fish. Oceanogr.5(TINRO), Vladivostok, U.S.S.R., Unpublished manuscript.

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

Lowe, S. A., and L. W. Fritz. 1996. Atka mackerel *In* Stock Assessment and Evaluation Report for the Groundfish Resources of the Gulf of Alaska as Projected for 1997. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, Alaska, 99510.

Lowe, S. A., and L. W. Fritz. 1997. Atka mackerel. *In* Stock Assessment and Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions as Projected for 1998. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, Alaska, 99510.

Lowe, S. A., and L. W. Fritz. 2001. Atka mackerel. *In* Stock Assessment and Evaluation Report for the Groundfish Resources of the Gulf of Alaska. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, Alaska, 99510.

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

Lowe, S., J. Ianelli, H. Zenger, K. Aydin, and R. Lauth. 2005. Stock assessment of Aleutian Islands Atka mackerel. *In* Stock Assessment and Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, Alaska, 99510.

Lowe, S., J. Ianelli, M. Wilkins, K. Aydin, R. Lauth, and I. Spies. 2009. Stock assessment of Aleutian Islands Atka mackerel. *In* Stock Assessment and Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, Alaska, 99510.

Malecha, P.W. and R.P. Stone. 2009. Response of the sea whip *Halipteris willemoesi* to simulated trawl disturbance and its vulnerability to subsequent predation. Mar. Ecol. Prog. Ser. 388:197-206.

Malecha, P.W., R.P. Stone, and J. Heifetz. 2005. Living substrate in Alaska: Distribution, abundance, and species associations. Pages 289-299 *in* P.W. Barnes and J.P. Thomas, editors. Benthic habitats and the effects of fishing. American Fisheries Society, Symposium 41, Bethesda, Maryland.

Martin, M. 2005. Gulf of Alaska Survey Bottom Temperature Analysis. In J.L. Boldt (Ed.) Ecosystem Considerations for 2006. Appendix C of the BSAI\GOA Stock Assessment and Fishery Evaluation Reports. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Materese, A.C., D. M. Blood, S. J. Piquelle, J. L. Benson. 2003. Atlas of abundance and distribution patterns of ichthyoplankton from the Northeast Pacific Ocean and Bering Sea ecosystems based on research conducted by the Alaska Fisheries Science Center (1972-1996). U.S. Dep. Commer., NOAA Professional Paper, NMFS-1, 281 p.

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

McDermott, S.F., K.E. Pearson and D.R. Gunderson. 2007. Annual fecundity, batch fecundity, and oocyte atresia of Atka mackerel (Pleurogrammus monopterygius) in Alaskan waters. Fish Bull. 105:19-29.

Mel'nikov, I.V. and A. YA. Efimkin. 2003. the young of the northern Atka mackerel Pleurogrammus monopterygius in the epipelagic zone over deep-sea areas of the northern Pacific Ocean. J. Ichthyol. 43: 424-437.

Merrick, R.L., M.K. Chumbley, and G.V. Byrd. 1997. Diet diversity of Steller sea lions (*Eumetopias jubatus*) and their population decline in Alaska: a potential relationship. Can. J. Fish. Aquat. Sci. 54:1342-1348.

Nichol, D.G. and D.A. Somerton. 2002. Diurnal vertical migration of Atka mackerel, *Pleurogrammus monopterygius*, as shown by archival tags.

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

Ortiz, I. 2007. Ecosystem Dynamics of the Aleutian Islands. Ph.D. Thesis. University of Washington, Seattle.

Ronholt, L.L. 1989. Atka mackerel. Pages 93-98 in T.K. Wilderbuer, editor, Condition of groundfish resources of the Gulf of Alaska in 1988. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-F/NWC-165.

Rutenberg, E.P. 1962. Survey of the fishes family Hexagrammidae. Trudy Instituta Okeanologii Akademiya Nauk SSSR 59:3-100. In Russian. (Translated by the Israel Program for Scientific Translations, 1970. Pages 1-103 in T.S. Rass (editor), Greenlings: taxonomy, biology, interoceanic transplantation; available from the U.S. Department of Commerce, National Technical Information Services, Springfield, Virginia, as TT 69-55097).

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

Sinclair, E., J.W. Testa, and L. Fritz. 2006. Marine Mammals. In J.L. Boldt (Ed.) Ecosystem Considerations for 2007. Appendix C of the BSAI\GOA Stock Assessment and Fishery Evaluation Reports. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Springer, A.M., J.F. Piatt, V.P. Shuntov, G.B. Van Vliet, V.L. Vladimirov, A.E. Kuzin, and A.S. Perlov. 1999. Marine birds and mammals of the Pacific subarctic gyres. Prog. Oceanogr. 43:443-487.

Stone, R.P. 2006. Coral habitat in the Aleutian Islands of Alaska: depth distribution, fine-scale species associations, and fisheries interactions. Coral Reefs 25:229-238.

Thompson G.G., M.W. Dorn, and D.G. Nichol. 2006. Assessment of the Pacific cod stock in the Gulf of Alaska. In Plan Team for Groundfish Fisheries of the Gulf of Alaska (compiler), Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Turnock, B.J., T.K. Wilderbuer, and E.S. Brown. 2005. Gulf of Alaska Arrowtooth Flounder stock assessment. In Plan Team for Groundfish Fisheries of the Gulf of Alaska (compiler), Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Winship, A.J., and A.W. Trites. 2003. Prey consumption of Steller sea lions (*Eumetopias jubatus*) off Alaska: How much prey do they require? Fish. Bull. 101:147-167.

Yang, M. S. 1993. Food habits of the commercially important groundfishes in the Gulf of Alaska in 1990. NOAA Technical Memorandum, NMFS-AFSC-22, U.S. Department of Commerce, NOAA. p. 150.

Yang, M-S. 1996. Diets of the important groundfishes in the Aleutian Islands in summer 1991. NOAA Technical Memorandum, NMFS-AFSC-60, U.S. Department of Commerce, NOAA. p. 105.

Yang, M-S. 1999. The trophic role of Atka mackerel, *Pleurogrammus monopterygius*, in the Aleutian Islands area. Fishery Bulletin 97(4):1047-1057.

Yang, M-S. 2003. Food habits of the important groundfishes in the Aleutian Islands in 1994 and 1997. AFSC Processed Rep.2003-07, Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115. p. 233.

Yang, M-S., K. Dodd, R. Hibpshman, and A. Whitehouse. 2006. Food habits of groundfishes in the Gulf of Alaska in 1999 and 2001. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-164, 199 p.

Yang, M-S., and M.W. Nelson. 2000. Food habits of the commercially important groundfishes in the Gulf of Alaska in 1990, 1993, and 1996. NOAA Technical Memorandum, NMFS-AFSC-112, U.S. Department of Commerce, NOAA. p. 174.

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

Tables

Table 16.1 Gulf of Alaska Atka mackerel catches (including discards), and corresponding Acceptable Biological Catches (ABC) and Total Allowable Catches (TAC) set by the North Pacific Fishery Management Council from 1977 to the present. Catches, ABCs, and TACs are in t.

Year	Catch	ABC	TAC
1977	19,455		22,000[e]
1978	19,588		24,800[e]
1979	10,949		26,800[e]
1980	13,166		28,700[e]
1981	18,727		28,700[e]
1982	6,760		28,700[e]
1983	12,260		28,700[e]
1984	1,153		28,700[e]
1985	1,848		5,000[e]
1986	4	4,700	4,678[e]
1987	1	0	240[f]
1988[a]	[b]		
1989	[b]		
1990	1,416[c]		
1991	3,258[c]		
1992	13,834[c]		
1993	5,146[c]		
1994[d]	3,538	4,800	3,500
1995	701	3,240	3,240
1996	1,580	3,240	3,240
1997	331	1,000	1,000
1998	317	600	600
1999	262	600	600
2000	170	600	600
2001	76	600	600
2002	85	600	600
2003	583	600	600
2004	819	600	600
2005	799	600	600
2006	876	4,700	1,500
2007	1,459	4,700	1,500
2008	2,109	4,700	1,500
2009g	2,219	4,700	2,000

a/ Atka mackerel were added to the Other Species category in 1988.
b/ Catches of Atka mackerel were included in the Other Species category.
c/ Catches of Atka mackerel was reported separately for 1990-1993.
d/ Atka mackerel were assigned a target species in 1994.
e/ Reported as OY (Optimum Yield).
f/ Reported as TQ (Target Quota).
g/ 2009 data as of 17-OCT-09 from NMFS Alaska Regional Office. Available at http://www.fakr.noaa.gov/2009/car110_goa.pdf

Table 16.2. Gulf of Alaska Atka mackerel mean biomass estimates (biomass, t), variance, and coefficient of variation (*CV*), by area from the 2003, 2005, 2007, and 2009 Gulf of Alaska bottom trawl surveys. Number of hauls conducted in each area, and number and percentage (%) of hauls with Atka mackerel catch are also given.

	Year	Haul count	Hauls with catch*	% hauls with catch*	Biomass	Biomass variance	*CV*
2003	Shumagin	230	101	44%	59,373	442,743,545	35%
	Chirikof	172	12	7%	421	33,829	44%
	Kodiak	248	35	14%	5,224	9,333,815	58%
	Yakutat	79	9	11%	514	32,642	35%
	Southeast	80	0	--	--	--	--
	Gulf of Alaska	809	157	19%	65,532	452,143,831	32%
2005	Shumagin	180	53	29%	97,233	2,500,113,153	51%
	Chirikof	177	38	21%	2,533	473,332	27%
	Kodiak	293	9	3%	1,147	642,670	70%
	Yakutat	92	0	--	--	--	--
	Southeast	97	0	--	--	--	--
	Gulf of Alaska	839	100	12%	100,913	2,501,229,155	50%
2007	Shumagin	205	42	20%	80,546	1,412,393,581	47%
	Chirikof	199	18	9%	1,562	650,483	52%
	Kodiak	274	11	4%	219	6,124	36%
	Yakutat	76	0	--	--	--	--
	Southeast	66	0	--	--	--	--
	Gulf of Alaska	820	71	9%	82,328	1,413,050,188	46%
2009	Shumagin	196	48	24%	135,089	12,748,474,113	84%
	Chirikof	190	14	7%	224	6,987	37%
	Kodiak	280	21	8%	294	5,497	25%
	Yakutat	83	1	1%	16	266	100%
	Southeast	74	0	--	--	--	--
	Gulf of Alaska	823	84	10%	135,623	12,748,486,855	83%

*Catch of Atka mackerel.

Table 16.3 Atka mackerel age-length and weight-length schedules based on parameters estimated from combined 1990, 1992 and 1994 fishery data and the 1993 survey.

Fishery			Survey		
Age	Length	Weight	Age	Length	Weight
1	30.81	0.48	1	14.89	0.05
2	35.50	0.70	2	29.67	0.38
3	39.26	0.92	3	37.71	0.77
4	42.28	1.12	4	42.08	1.07
5	44.71	1.31	5	44.45	1.26
6	46.65	1.47	6	45.74	1.37
7	48.21	1.60	7	46.44	1.43
8	49.47	1.72	8	46.82	1.47
9	50.47	1.81	9	47.02	1.49
10	51.28	1.89	10	47.14	1.50
11	51.93	1.96	11	47.20	1.50
12	52.45	2.01	12	47.23	1.51
13	52.86	2.05	13	47.25	1.51
14	53.20	2.09	14	47.26	1.51
15	53.47	2.12	15	47.26	1.51

Table 16.4. Schedules of age and length specific maturity from McDermott and Lowe (1997).

Length (cm)	Proportion mature	Age	Proportion mature
20	0	1	0
21	0	2	0.04
22	0	3	0.22
23	0	4	0.69
24	0	5	0.94
25	0	6	0.99
26	0	7	1
27	0	8	1
28	0	9	1
29	0	10	1
30	0		
31	0.01		
32	0.01		
33	0.02		
34	0.05		
35	0.09		
36	0.17		
37	0.29		
38	0.46		
39	0.63		
40	0.78		
41	0.88		
42	0.93		
43	0.97		
44	0.98		
45	0.99		
46	1		
47	1		
48	1		
49	1		
50	1		

Table 16.5. Ecosystem Considerations.

Ecosystem effects on GOA Atka mackerel

Indicator	*Observation*	*Interpretation*	*Evaluation*
Prey availability or abundance trends			
Zooplankton	Data limited, indication of higher euphausiid abundance 2002-2003	Trends could possibly affect survival	Unknown
Forage fish	Data limited, indication of recent increases in some forage species	Trends could possibly affect survival	Unknown
Predator population trends			
Groundfish predators	Increased biomass groundfish predators since late 1970s	Possibly higher mortality on Atka mackerel	Possible concern
Marine mammals	Decreased or stable	Very minor decrease on Atka mackerel	No concern
Seabirds	Mixed trends	Mixed effects	Unknown
Changes in habitat quality			
Climate	Shifts in 1977, 1989, 1999	May provide temporary release from competition and predation	Unknown
Bottom temperature	Warming at depths <50 m		Unknown
Fishing gear effects on habitat	Mixed trends in effort	May affect spawning and nesting habitat	Possible concern

GOA Atka mackerel fishery effects on ecosystem

Indicator	*Observation*	*Interpretation*	*Evaluation*
Fishery contribution to bycatch	No directed fishery	No effect on ecosystem	No concern
Fishery concentration in space and time	No directed fishery	No effect on ecosystem	No concern
Fishery effects on amount of large size target fish	No directed fishery	No effect on ecosystem	No concern
Fishery contribution to discards and offal production	No directed fishery	No effect on ecosystem	No concern
Fishery effects on age-at maturity and fecundity	No directed fishery	No effect on ecosystem	No concern

Figures

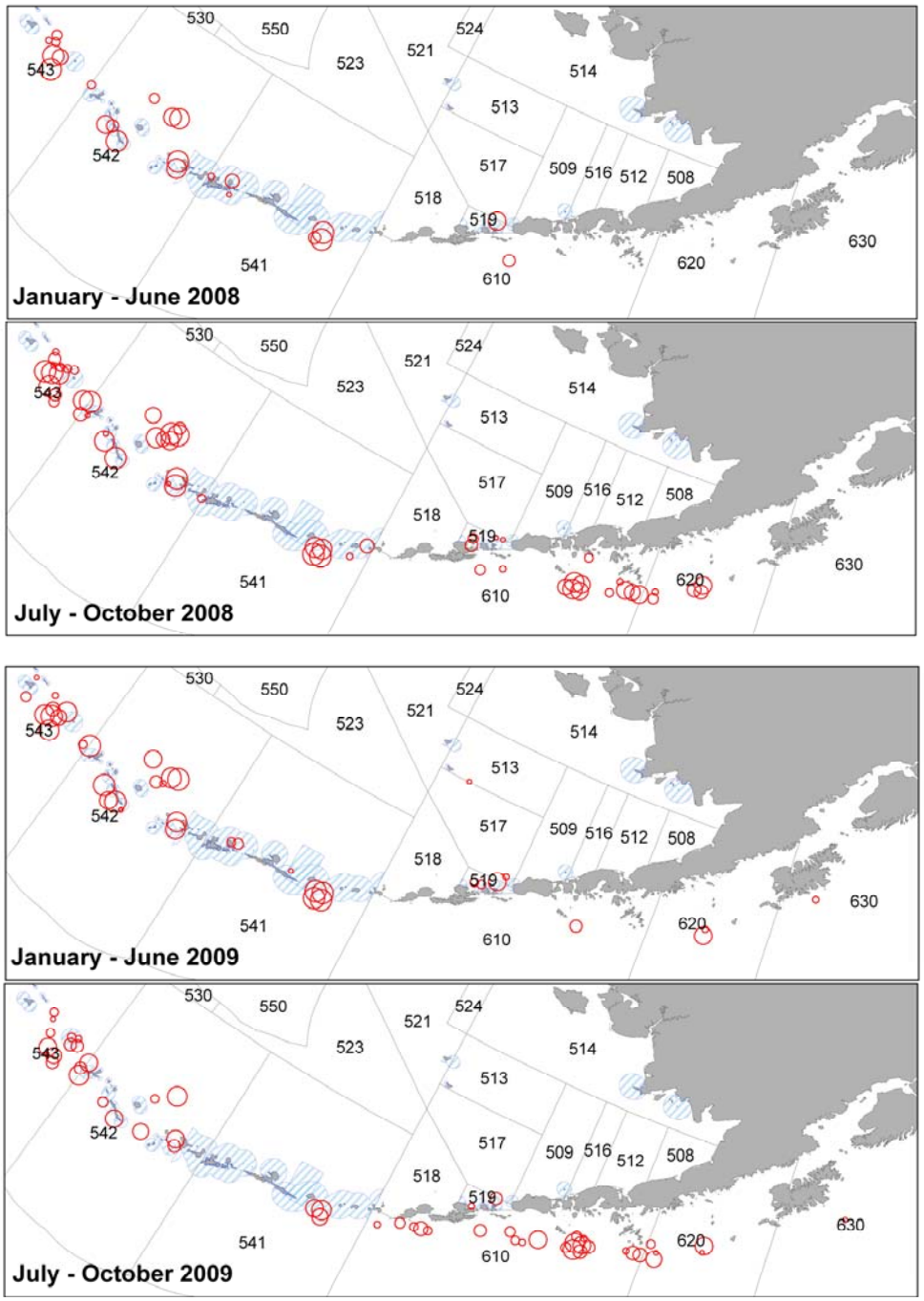

Figure 16.1. Observed catches of Atka mackerel in the 2008 and 2009 fisheries, summed by 20 km^2 cells. Open circles represent catches greater than 1 t; closed circles represent catches less than 1 t. Hashed circular areas represent no trawl zones.

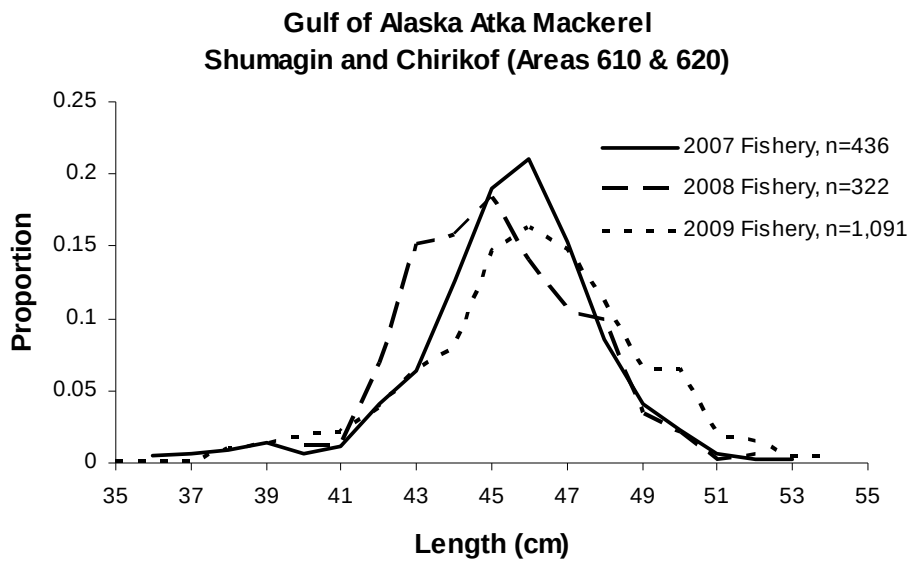

Figure 16.2. Fishery length frequency distributions of Atka mackerel from the Shumagin (610) and Chirikof (620) areas from 2007, 2008, and preliminary 2009 data.

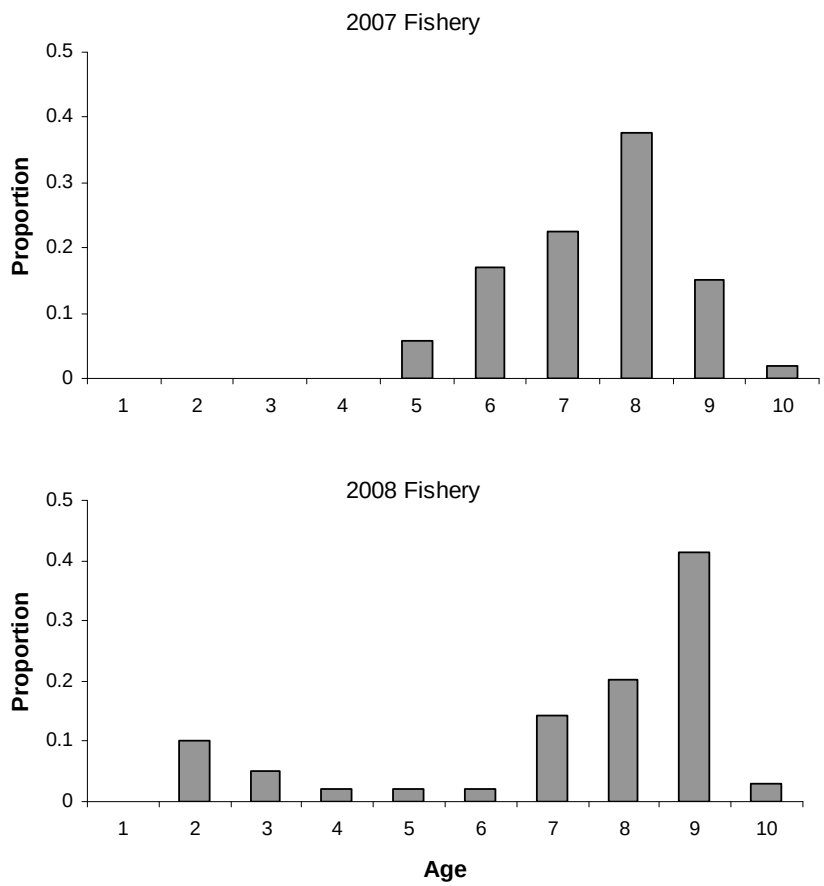

Figure 16.3. Atka mackerel age distributions from the 2007 and 2008 fisheries in the Shumagin (610) and Chirikof (620) Gulf of Alaska (GOA) management areas.

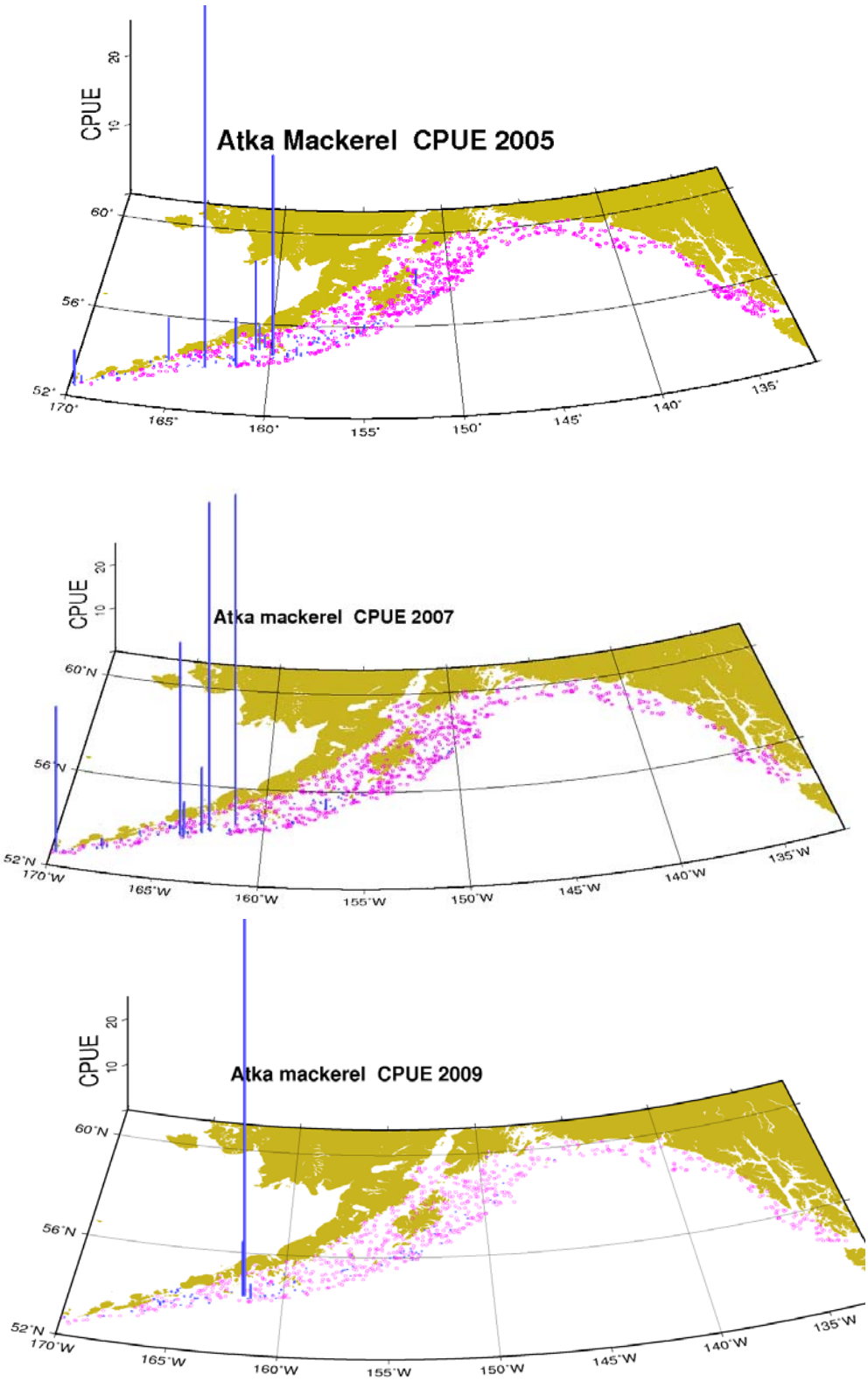

Figure 16.4. Atka mackerel bottom trawl survey CPUE by station, 2005, 2007, and 2009. Circles represent tows where Atka mackerel were absent, height of bars is proportional to CPUE by weight.

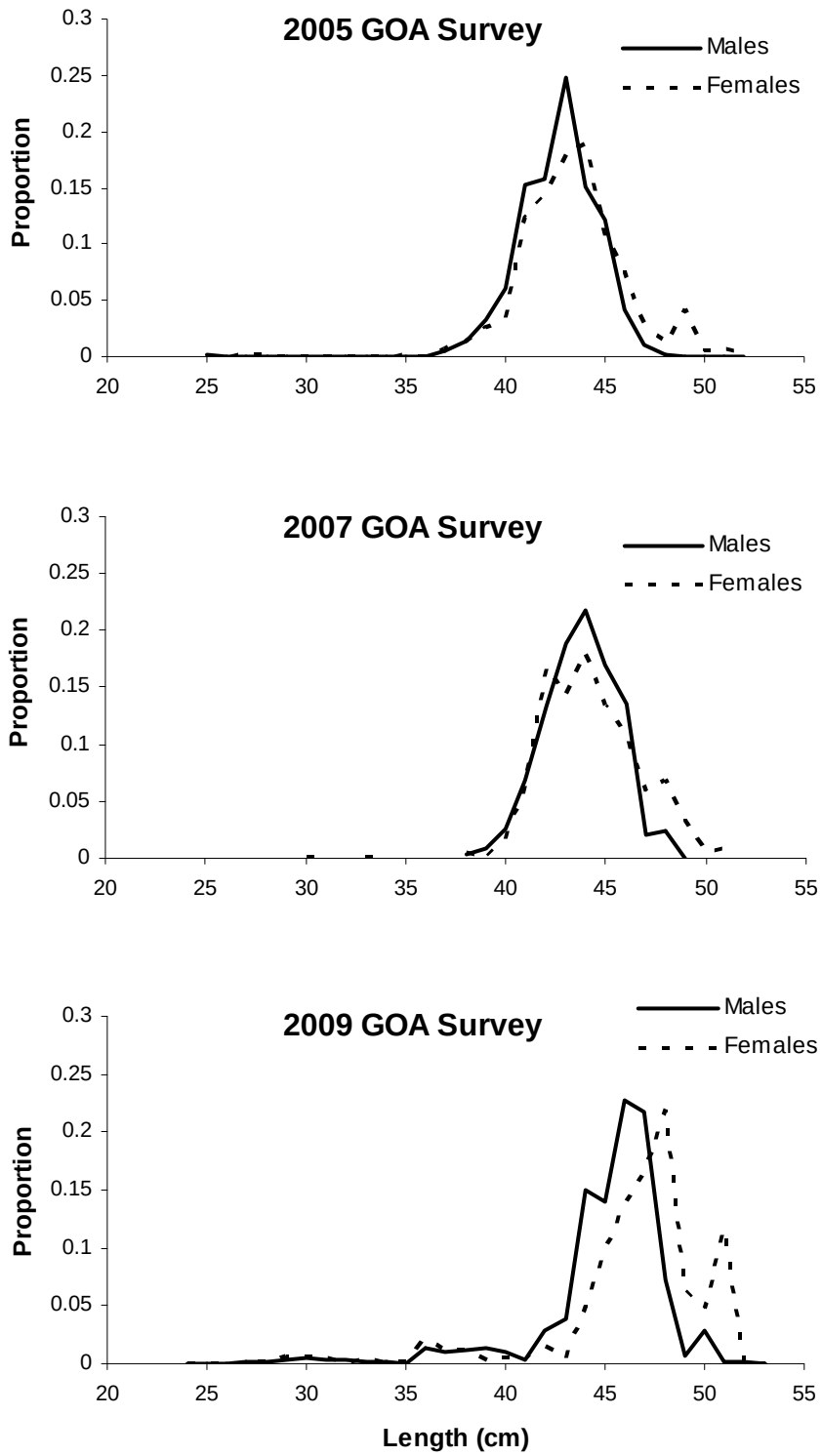

Figure 16.5. Atka mackerel length frequency distributions from the 2005, 2007, and 2009 Gulf of Alaska bottom trawl surveys.

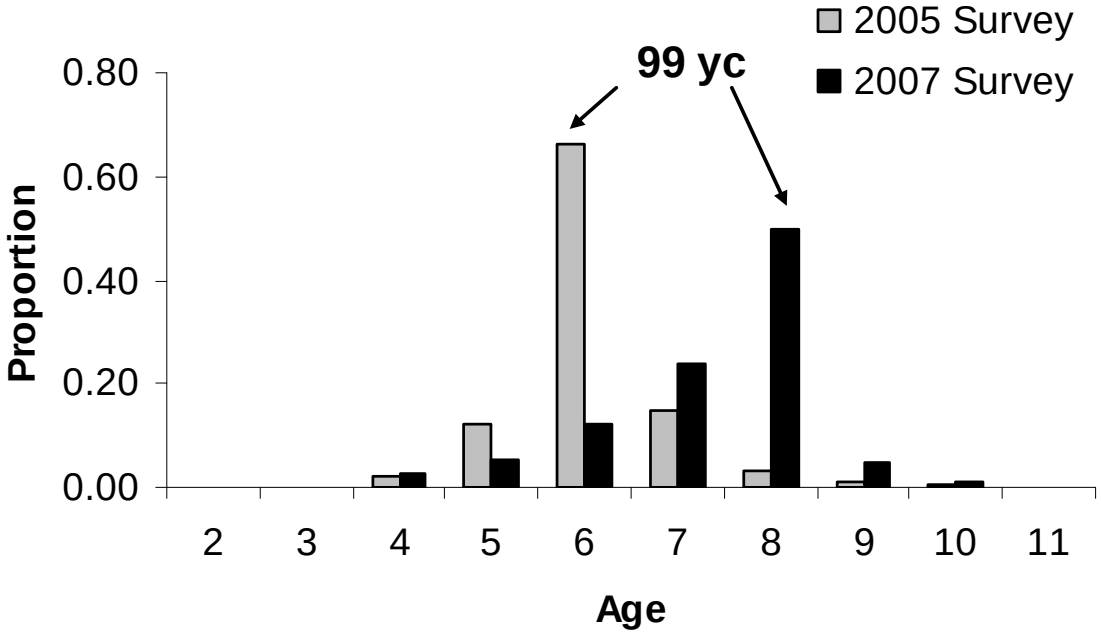

Figure 16.6 Atka mackerel age distributions from the 2005 and 2007 Gulf of Alaska bottom trawl surveys (315 and 143 fish were aged respectively, from the 2005 and 2007 surveys).

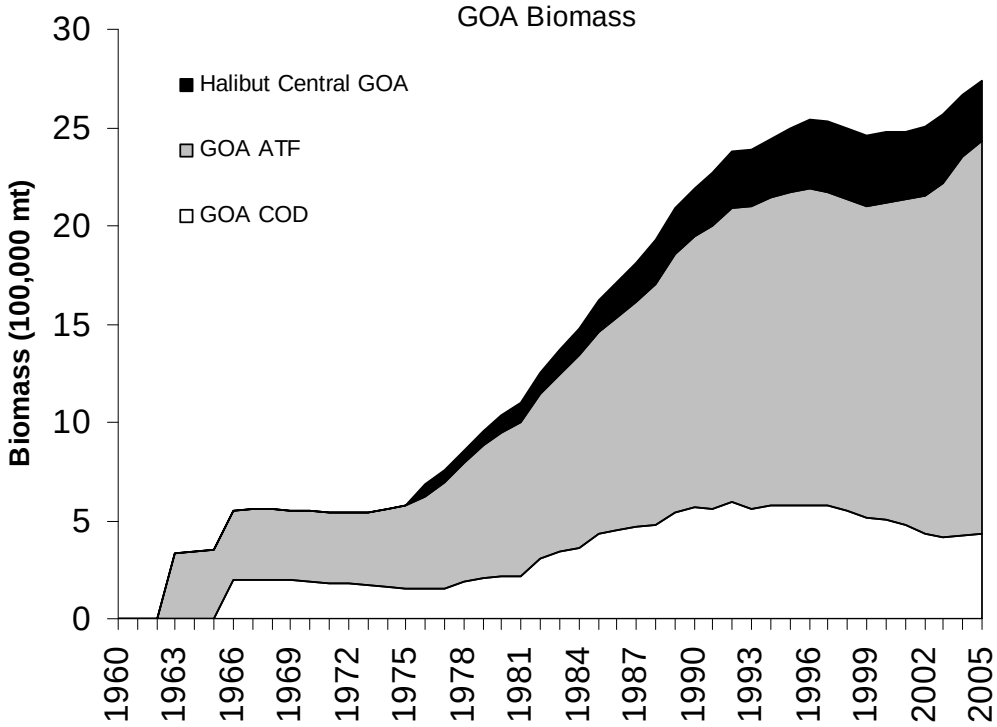

Figure 16.7 Biomass of predominant Gulf of Alaska (GOA) Atka mackerel predators: Pacific cod arrowtooth flounder (ATF), and halibut in the central GOA.

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