Chapter 7

Assessment of the Kamchatka Flounder stock in the Bering Sea and Aleutian Islands

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Executive Summary

This document is the third analysis of stock status and harvest recommendation for Kamchatka flounder as a single species. Kamchatka flounder had previously been a constituent of the *Atheresthes* species complex of which arrowtooth flounder had the dominant biomass and the complex ABC's were based upon arrowtooth flounder productivity and stock status. Due to the emergence of a targeted fishery on Kamchatka flounder it is now managed as a single species in the BSAI.

Summary of Changes in Assessment Inputs

Trawl survey biomass estimates from the 2012 Bering Sea shelf and slope surveys and the Aleutian Islands survey were used to update the assessment.

Summary of Changes in the Assessment Methodology

The natural mortality rate of Kamchatka flounder was evaluated from 4 separate methods for this assessment and was re-estimated at a lower value (0.13) than in 2011 (0.2).

Quantity	As estimated or *specified last* year for: 2012	2013	As estimated or *recommended this* year for: 2013	2014
M (natural mortality rate)	0.2	0.2	0.13	0.13
Tier	5	5	5	5
Biomass (t)	125,200	125,200	108,800	108,800
F_{OFL}	0.2	0.2	0.13	0.13
$maxF_{ABC}$	0.15	0.15	0.098	0.098
F_{ABC}	0.15	0.15	0.098	0.098
OFL (t)	24,800	24,800	16,300	16,300
maxABC (t)	18,600	18,600	12,200	12,200
ABC (t)	18,600	18,600	12,200	12,200
Status	As determined *last* year for: 2012	2013	As determined *this* year for: 2013	2014
Overfishing	n/a	n/a	n/a	n/a

The estimate of biomass from the three surveys conducted in 2012 is 13% less than in 2011. The lower 2012 biomass combined with the revised natural mortality value, gives a recommended ABC and OFL that is 31% less than the 2011 value.

Responses to SSC and Plan Team Comments on Assessments in General

Total catch accounting

From the September 2012 Plan Team minutes: The Teams recommend that the authors continue to include other removals in an appendix for 2012. Authors may apply those removals in estimating ABC and OFL; however, if this is done, results based on the approach used in the previous assessment much also be presented.

Other catch removals for Kamchatka flounder are minimal and were not applied in the estimation of 2013 and 2014 ABC and OFL. A compilation of these catch will be presented in the next assessment.

Methods for averaging surveys for apportionments and Tier 5 biomass
In September 2012 the Plan Teams recommended that assessment authors retain status quo assessment approaches for the November 2012 SAFE report but also apply the Kalman filter or random effects survey averaging for Tier 5 stocks and summarize the analytical results for comparison purposes only.

The current assessment uses a range of running averages of survey biomass to calculate ABC and OFL as previously recommended by the BSAI Plan Team. Time constraints prevented an analysis of the Kalman filter and random effects survey averaging methods. These methods will be explored in the 2013 assessment.

Responses to SSC and Plan Team Comments Specific to this Assessment

The Plan Team recommended additional sensitivity analyses of alternative values of M, further development of the age-structured model to be reported in September 2013, and inclusion of an alternative Tier 5 analysis using M=0.13. The SSC appreciates the efforts of the analysts to develop this initial assessment for this species and supports the Plan Team's requests of the analysts. In addition to those, the SSC adds the following requests:

1. **Report on what is known (or assumed) about stock structure. The assumption seems to be that Kamchatka flounder from the EBS and Aleutian Islands represent one stock. Are there any data at all that can be brought to bear on stock structure? For instance, do length/age frequency distributions from the Aleutians and EBS suggest synchrony in year classes?**
2. **Evaluate the sensitivity of the assessment to the assumption that Kamchatka flounder of a fixed sex ratio constituted 10% of the catch of arrowtooth flounder and Greenland turbot over 1991-2006. Also, the assessment reports that Kamchatka flounder have been consistently identified in trawl surveys starting in 1991 (executive summary) or 1992 (introduction). Does the start year of the time series affect the resulting assessment?**
3. **Report on the sex ratio of the commercial and survey catches, as well as the estimated population.**
4. **The weight-length relationships shown in the upper and lower panels of Fig. 7-6 appear to be identical. One of the two must be in error.**

5. **Consider whether any other methods (e.g., Alverson and Carney, Jensen) are available to generate alternative estimates of M. Also, consider whether there is evidence for different estimates of M for males and females. Is there evidence of sex-specific M's for closely related species?**
6. **Report whether data are available to examine potential changes in growth over time. Given the similarity in diets among Kamchatka and arrowtooth flounder and the increase in arrowtooth flounder biomass, there may be potential for changes in growth of Kamchatka flounder over time. If the reported size at age data for the Aleutian Islands in 2010 represents the only such data available, then such an analysis is not possible at this time.**
7. **In Fig. 7-5, consider truncating the x-axes so that the length-frequency histograms are spread out and easier to examine for year-to-year modal progressions.**
8. **The analysis assumes dome-shaped selectivity for the shelf survey and asymptotic selectivity for the slope and Aleutian Islands survey. Some justification is provided. Consider evaluating the sensitivity of the assessment to these assumptions.**
9. **Report what weightings were used for the three surveys. Confidence intervals appear to be tighter for the shelf survey compared to the slope and Aleutian Islands survey. Consider evaluating the sensitivity of the assessment to alternative weighting of the three survey time series. Also, the model appears to overestimate periods of low shelf survey biomass and underestimate periods of high shelf survey biomass (Fig. 7-16). Why? Are there potential model mis-specifications? Would this residual pattern be addressed with higher M estimates?**
10. **What is the justification for the sharp drop in full-selection F from 2009 to 2011? This appears to be counterintuitive, given that this is the time period corresponding to development of the targeted Kamchatka flounder fishery.**
11. **Explain the years that are represented in the averages shown in Fig. 7-18 in the associated figure caption.**
12. **Consider including tables of resultant population estimates (numbers or biomass) at age and time series of estimated recruitment.**
13. **Present and discuss model fit diagnostics (e.g., residuals) and discuss the model's ability to replicate the various input data series.**

To the extent possible, the SSC recommends that the author address some of the more minor issues above in time for the November/December 2012 assessment cycle. Otherwise, the SSC looks forward to further model development to address the other more substantial issues in the next assessment cycle.

This is an excellent review of the Kamchatka flounder Tier 3 provisional assessment. The authors plan to respond to each point for the 2013 assessment and therefore retain the Tier 5 analysis for this assessment cycle given the constraint of the shortness of time after receiving the SSC comments. The provisional Tier 3 assessment is appended to the document as an appendix.

Introduction

The Kamchatka flounder (*Atheresthes evermanni*) is a relatively large flatfish which is distributed from Northern Japan through the Sea of Okhotsk to the Western Bering Sea north to Anadyr Gulf (Wilimovsky et al. 1967) and east to the eastern Bering Sea shelf and south of the Alaska Peninsula (there is also a catch record from California). In U.S. waters they are found in commercial concentrations in the Aleutian Islands where they generally decrease in abundance from west to east (Zimmerman and Goddard 1996). They are also present in Bering Sea slope waters but are absent in survey catches east of Chirikof Island.

In the eastern part of their range, Kamchatka flounder overlap with arrowtooth flounder (*Atheresthes stomias*) which are very similar in appearance and were not routinely distinguished in the commercial catches until 2007. Until about 1992, these species were also not consistently separated in trawl survey catches (Fig. 7-1) and were combined in the arrowtooth flounder stock assessment (Wilderbuer et al. 2009). However, managing the two species as a complex became undesirable in 2010 due to the emergence of a directed fishery for Kamchatka flounder in the BSAI management area. Since the ABC was determined by the large amount of arrowtooth flounder relative to Kamchatka flounder (complex is about 93% arrowtooth flounder) the possibility arose of an overharvest of Kamchatka flounder as the *Atheresthes sp.* ABC exceeded the Kamchatka flounder biomass. Beginning with the 2011 fishing season, arrowtooth flounder and Kamchatka flounder are managed separately.

Catch History

Historical Kamchatka flounder catch is combined in catch records of arrowtooth flounder and Greenland turbot from the 1960s. The fisheries for Greenland turbot intensified during the 1970s and the bycatch of arrowtooth flounder and Kamchatka flounder is assumed to have also increased. Catches of these species decreased after implementation of the MFCMA and the Kamchatka flounder resource has remained lightly exploited with the combined catches with arrowtooth flounder averaging 12,831 t from 1977-2008 (Table 7-1). It is estimated that only a small fraction (<10%) of this catch was Kamchatka flounder. This decline resulted from catch restrictions placed on the fishery for Greenland turbot and phasing out of the foreign fishery in the U.S. EEZ. Catches in Table 7-1 through 2006 are for arrowtooth flounder and Kamchatka flounder combined, catches thereafter are those estimated for Kamchatka flounder only. The total catch estimated for arrowtooth and Kamchatka flounder by the Alaska Regional Office is a blend of vessel reported catch and observer at-sea sampling of the catch which was not differentiated by species through 2010. However, observers have separately identified the two species from catches aboard trawl vessels since 2007 and their sampling has indicated that the proportion of Kamchatka flounder in the combined catch has steadily increased from 10% in 2007 to 55% in 2010.

year	Percent of combined catch
2007	10
2008	31
2009	45
2010	55

The increased harvest was the result of a recently developed market for Kamchatka flounder which has now become a fishery target. The 2010 estimated catch of Kamchatka flounder was 21,153 t, taken primarily in area 514 and to a lesser extent in area 518. The 2011 and 2012 catch are similar at 9,935 and 9,466 t, respectively (through October 20,2012) The 2012 catch is 51% of the ABC and 38% of the OFL and was split evenly between the Aleutian Islands (55%) and the Bering Sea slope (45%). The catch by week in 2012 (Fig. 7-2) indicates that targeting for Kamchatka flounder began May 1 and most of the catch occurred in two periods; between May and mid-June and from mid-July to mid-August. It has continued in lesser amounts through mid-October.

Data

The data used in this assessment includes estimates of total catch and bottom trawl survey biomass estimates from the Bering Sea shelf, slope and Aleutian Islands surveys.

Absolute Abundance from Trawl Surveys

Biomass estimates (t) for Kamchatka flounder from the standard shelf survey area in the eastern Bering Sea, slope surveys and the Aleutian Islands region are shown in Table 7-2. Reliable estimates of Kamchatka flounder became available in 1991 and average 1991-1994 biomass was estimated at,45,500 t on the Bering Sea shelf (Fig. 7-1). During the following 11 years the biomass was estimated at a lower level (26,800 t average) before increasing to high and stable levels the past 7 years (53,200 t average). On the continental shelf they are usually found in highest concentrations at depths greater than 200 meters around the Pribilof Islands and also in the large shelf area west of St. Matthew Island. Trends of abundance from the slope and Aleutian Islands surveys also indicate the resource increased. They are common in the deeper waters of the slope area (500 to 800 meters, Zimmerman and Goddard 1996) in both the Aleutian Islands and the eastern Bering Sea slope (Figs. 7-3 and 7-4). The 2012 estimate includes survey estimates of biomass from all three sea areas and totals 108,838 t, a decrease of 13% from 2011 estimates, but still at a level higher than during the 1990s and early 2000s.

Estimates of total BSAI biomass for the years in which Aleutian Islands and slope surveys were not conducted was calculated by averaging the years in closest temporal (before and after) proximity.

Length-weight, maximum age and natural mortality

Length-weight measurements collected in 1999 from 193 fish indicate that males and females grow by accumulating the same weight for a given size (Fig. 7-5). Age at length calculations from a small sample collected in 1991 indicate that males and females exhibit divergent growth after about age 5-6 with females growing larger than males (Zimmerman and Goddard 1996). Both sexes have been found in relatively equal numbers and the oldest fish have been aged at 33 years indicating that Kamchatka flounder are similar in life history to other Bering Sea flatfish.

For this assessment, the natural mortality rate of Kamchatka flounder was analyzed using 3 methods from the literature based on the life history characteristics of maximum life span (Hoenig 1983), average age (Chapman and Robson 1960) and the relationship between growth and maximum length (Gislason et al. 2008). We then ran the stock assessment model (described in the appendix) for different combinations of male and female M to discern what value provides the best fit to the data components in terms of –log(likelihood). The best fit to the observable population characteristics occurred at M = 0.13 for both sexes (appendix Figure 7.11).

The results are summarized below and suggest a range of natural mortality values from 0.08 to 0.13 for males and 0.08 to 0.29 for females.

method	males	Females
Hoenig (1983)	0.094	0.086
Chapman and Robson (1960)	0.08	0.07

Gislason et al. 2008	0.235	0.228
Model profiling	0.13	0.13

The value of natural mortality from model profiling is in between values estimated from the other three methods and is also consistent with the natural mortality used in other assessments of Bering Sea shelf flatfish which have similar life histories, growth and maximum ages. The Gislason et al (2008). values are higher but similar to those estimated for arrowtooth flounder females, a congenetic species. A value of M = 0.13 was chosen to model natural mortality for both males and females in this assessment as it is bracketed by the values from the other methods.

Acceptable Biological Catch and exploitation rate

Kamchatka flounder have a wide-spread distribution along the deeper waters of the Bering Sea/Aleutian Islands region and are believed to be at a fairly high level as discerned from the increases in survey estimates from the time-series of Bering Sea shelf, slope and Aleutian Islands surveys. The 2012 combined estimate of total biomass from the three areas is 108,800 figure 7-1). Exploitation rates estimated for 2008-2010 steadily increased from 5% in 2008, 10% in 2009 to 16% in 2010 but has since declined to 9% in 2012.

Given the limited amount of biological information available for Kamchatka flounder, they are qualified to be managed under Tier 5 of Amendment 56 to the BSAI groundfish management plan, and thus have harvest recommendations which are directly calculated from estimates of biomass and natural mortality. The Tier 5 formula for calculating ABC is: ABC = 0.75 x M x average biomass.

ABC calculated from this formula is sensitive to the fluctuations in annual biomass estimated from bottom trawl surveys (shelf survey CV is 10%, Aleutians CV = 30%). In order to lessen this effect, annual estimates of Kamchatka flounder abundance (using trawl survey estimates when they are available and filling in missing years from the average of the closest previous and future year which bracket the missing year) from the three surveys were summed and then ABC was calculated using running averages which ranged from 3 to the 7 most recent years (all with M = 0.13). ABC estimates from these five methods indicate that the effect of annual variability on the estimate of ABC and OFL can be dampened by including more years in the estimation calculation which was particularly evident in the years of biomass increase from the past five years (Fig. 7-6 and Table 7-3). The seven year moving average for biomass is chosen for the ABC and OFL calculations for 2013 since it has the most resilience to the trawl survey variability and gives estimates which are close to the other moving averages.

The potential yield of Kamchatka flounder in 2013 and 2014, based on a combined biomass of **108,800 t** from the combined trawl survey estimates is summarized as follows:

F_{ABC}	F_{OFL}	ABC	OFL
0.098	0.13	12,200	16,300

The Tier 5 estimates of F_{abc} and F_{ofl} are 0.75 x M and M, respectively, and the ABC and OFL levels are the product of the fishing mortality rate and the 7 year running average of estimated biomass.

Ecosystem Considerations

Predators of Kamchatka flounder

Kamchatka flounder have rarely been found in the stomachs of other groundfish species in samples collected by the Alaska Fisheries Science Center. Their presence has only been documented in 17 stomach samples from the BSAI where the predators included Pacific cod, pollock, Pacific halibut, arrowtooth flounder and two sculpin species.

Kamchatka flounder predation

The prey of Kamchatka flounder can be discerned from 152 stomachs collected in 1983 (Yang and Livingston 1986). The principle diet was composed of walleye pollock, shrimp (most Crangonidae) and euphausids. Pollock was the most important prey item for all sizes of fish, ranging from 56 to 86% of the total stomach content weight. An examination of diet overlap with arrowtooth flounder indicated that these two congeneric species basically consume the same resources.

Ecosystem Effects on the stock

1) Prey availability/abundance trends

Kamchatka flounder diet varies by life stage as indicated in the previous section. Regarding juvenile prey and its associated habitat, information is not available to assess the abundance trends of the benthic infauna of the Bering Sea shelf. The original description of infaunal distribution and abundance by Haflinger (1981) resulted from sampling conducted in 1975 and 1976 and has not be re-sampled since. Information on pollock abundance is available in Chapter 1 of this SAFE report. It has been hypothesized that predators on pollock, such as adult Kamchatka and arrowtooth flounder, may be important species which control (with other factors) the variation in year-class strength of juvenile pollock (Hunt et al. 2002). The populations of arrowtooth flounder which have occupied the outer shelf and slope areas of the Bering Sea over the past twenty years for summertime feeding do not appear food-limited. These populations have fluctuated due to the variability in recruitment success which suggests that the primary infaunal food source has been at an adequate level to sustain the arrowtooth flounder resource.

2) Predator population trends

As juveniles, it is well-documented from studies in other parts of the world that flatfish are prey for shrimp species in near shore areas. This has not been reported for Bering Sea arrowtooth flounder due to a lack of juvenile sampling and collections in near shore areas, but is thought to occur. As late juveniles they are found in stomachs of pollock and Pacific cod, mostly on small arrowtooth flounder ranging from 5 to 15 cm standard length..

Past, present and projected future population trends of these predator species can be found in their respective SAFE chapters in this volume. Encounters between arrowtooth flounder and their predators may be limited as their distributions do not completely overlap in space and time.

3) Changes in habitat quality

Changes in the physical environment which may affect Kamchatka flounder distribution patterns, recruitment success, migration timing and patterns are discussed in the Ecosystem Considerations Appendix of this SAFE report. Habitat quality may be enhanced during years and warmer bottom water temperatures with reduced ice cover (higher metabolism with more active feeding). Environmental factors important to juvenile survival are presently not well known.

Ecosystem effects on Kamchatka flounder

Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Benthic infauna	Stomach contents	Stable, data limited	Unknown
Predator population trends			
Fish (Pollock, Pacific cod)	Stable	Possible increases to Kamchatka mortality	
Changes in habitat quality			
Temperature regime	Cold years Kamchatka catchability and herding may decrease	Deeper water species so less likely to affect surveyed stock	No concern (dealt with in model)
Winter-spring environmental conditions	Affects pre-recruit survival	Probably a number of factors	Causes natural variability

***Arrowtooth flounder* effects on ecosystem**

Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	Stable, heavily monitored	Minor contribution to mortality	No concern
Forage (including Pollock, shrimp and euphausids)	Stable, heavily monitored	Bycatch levels small relative to forage biomass	No concern
HAPC biota	Low bycatch levels of (spp)	Bycatch levels small relative to HAPC biota	No concern
Marine mammals and birds	Very minor direct-take	Safe	No concern
Sensitive non-target species	Likely minor impact	Data limited, likely to be safe	No concern
Fishery concentration in space and time	Recent high exploitation rate	Little detrimental effect	No concern
Fishery effects on amount of large size target fish	Recent high exploitation rate, but unknown effect	Natural fluctuation	No concern
Fishery contribution to discards and offal production	Stable trend	Improving, but data limited	Possible concern
Fishery effects on age-at-maturity and fecundity	Unknown	NA	Possible concern

References

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Gislason, H., Pope, J. G., Rice, J. C., and Daan, N. 2008. Coexistence in North Sea fish communities: implications for growth and natural mortality. – ICES Journal of Marine Science, 65: 514–530.

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Wilimovsky, N. J., A. Peden, and J. Peppar. 1967. Systematics of six demersal fishes of the north Pacific Ocean. Fish. Res. Board Can., Tech. Rep. 34, 52 p.

Yang, M. S. and P. A. Livingston. 1986. Food habits and diet overlap of two congeneric species, Atheresthes stomias and Atheresthes evermanni, in the eastern Bering Sea. Fish. Bull. Vol. 82 (8)615-623.

Zimmermann, Mark, and Pamela Goddard 1996. Biology and distribution of arrowtooth (Atheresthes stomias) and Kamachatka (A. evermanni) flounders in Alaskan waters. Fish. Bull 94:358-370.

Table 7-1. Total combined catch (t) of arrowtooth and Kamchatka flounder in the eastern Bering Sea and Aleutian Islands region, 1991-2006. Catches since 2007, when the two species were differentiated in commercial catches, is reported for Kamchatka flounder only in this table.

year	catch
1991	22,052
1992	10,382
1993	9,338
1994	14,366
1995	9,280
1996	14,652
1997	10,054
1998	15,241
1999	10,573
2000	12,929
2001	13,908
2002	11,540
2003	12,834
2004	17,809
2005	13,685
2006	13,309
2007	1,183
2008	6,819
2009	12,802
2010	21,153
2011	9,935
2012	9,466

Table 7-2 Estimated biomass from the three BSAI bottom trawl surveys.

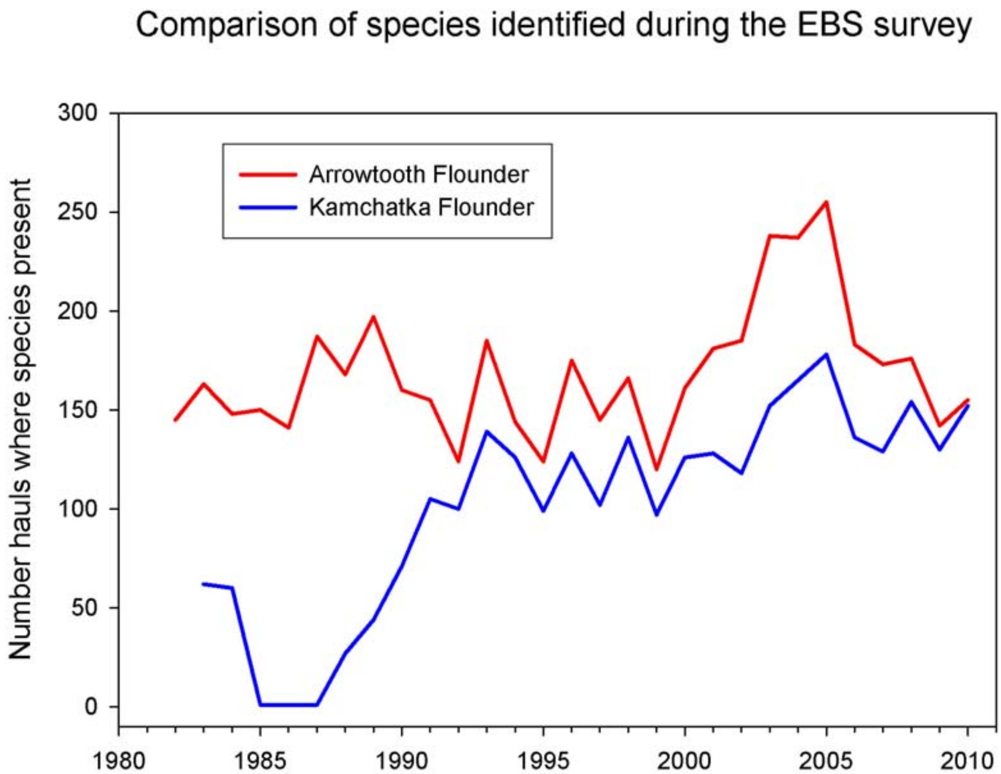
Reliable estimates of Kamchatka flounder biomass are only available after 1991.

	shelf	slope	Aleutian islands
1982	0		
1983	17,299		1,034
1984	20,695		
1985	31		
1986	0		565
1987	40		
1988	13,723		
1989	17,108		
1990	32,799		
1991	37,152		16,255
1992	50,081		
1993	38,376		
1994	56,268		49,156
1995	28,393		
1996	24,196		
1997	18,282		37,664
1998	23,474		
1999	18,974		
2000	21,551		28,535
2001	31,120		
2002	25,213	18,645	49,035
2003	27,531		
2004	29,663	14,740	39,219
2005	46,084		
2006	61,644		45,369
2007	65,191		
2008	53,967	24,822	
2009	47,252		
2010	51,927	27,875	49,069
2011	46,094		
2012	40,951	32,787	35,100

Table 7-3. Total biomass, ABC and OFL values calculated from 5 methods using running averages of biomass from 3 to 7 years.

running averages for total biomass						running averages for ABC calculation					
	7 yr	6 yr	5 yr	4 yr	3 yr		7 yr	6 yr	5 yr	4 yr	3 yr
1991						**1991**					
1992						**1992**					
1993					87,774	**1993**					8,558
1994				104,945	104,945	**1994**				10,232	10,232
1995			99,462	99,462	99,462	**1995**			9,698	9,698	9,698
1996		95,671	95,671	95,671	98,303	**1996**		9,328	9,328	9,328	9,585
1997	91,064	91,064	91,064	91,887	81,811	**1997**	8,879	8,879	8,879	8,959	7,977
1998	88,098	88,098	88,163	79,674	76,734	**1998**	8,590	8,590	8,596	7,768	7,482
1999	85,336	84,930	77,493	74,742	71,557	**1999**	8,320	8,281	7,556	7,287	6,977
2000	82,337	75,707	73,149	70,362	69,603	**2000**	8,028	7,381	7,132	6,860	6,786
2001	77,263	75,391	73,609	73,852	74,047	**2001**	7,533	7,351	7,177	7,201	7,220
2002	77,891	76,823	77,660	78,759	82,090	**2002**	7,594	7,490	7,572	7,679	8,004
2003	78,470	79,442	80,677	83,655	89,280	**2003**	7,651	7,746	7,866	8,156	8,705
2004	80,039	81,168	83,648	87,866	88,289	**2004**	7,804	7,914	8,156	8,567	8,608
2005	85,024	87,733	91,924	93,256	93,377	**2005**	8,290	8,554	8,963	9,092	9,104
2006	93,314	97,736	99,964	101,732	106,192	**2006**	9,098	9,529	9,746	9,919	10,354
2007	103,008	105,743	108,313	113,303	123,197	**2007**	10,043	10,310	10,560	11,047	12,012
2008	108,638	111,262	115,844	123,900	129,147	**2008**	10,592	10,848	11,295	12,080	12,592
2009	112,627	116,673	123,284	127,065	127,155	**2009**	10,981	11,376	12,020	12,389	12,398
2010	119,115	125,030	128,404	128,807	126,864	**2010**	11,614	12,190	12,519	12,559	12,369
2011	125,052	127,867	128,082	126,443	126,588	**2011**	12,193	12,467	12,488	12,328	12,342
2012	125,149	124,875	122,922	122,151	122,594	**2012**	12,202	12,175	11,985	11,910	11,953

running averages for OFL					
	7 yr	6 yr	5 yr	4 yr	3 yr
1991					
1992					
1993					11,411
1994				13,643	13,643
1995			12,930	12,930	12,930
1996		12,437	12,437	12,437	12,779
1997	11,838	11,838	11,838	11,945	10,635
1998	11,453	11,453	11,461	10,358	9,975
1999	11,094	11,041	10,074	9,716	9,302
2000	10,704	9,842	9,509	9,147	9,048
2001	10,044	9,801	9,569	9,601	9,626
2002	10,126	9,987	10,096	10,239	10,672
2003	10,201	10,327	10,488	10,875	11,606
2004	10,405	10,552	10,874	11,423	11,478
2005	11,053	11,405	11,950	12,123	12,139
2006	12,131	12,706	12,995	13,225	13,805
2007	13,391	13,747	14,081	14,729	16,016
2008	14,123	14,464	15,060	16,107	16,789
2009	14,642	15,168	16,027	16,518	16,530
2010	15,485	16,254	16,693	16,745	16,492
2011	16,257	16,623	16,651	16,438	16,456
2012	16,269	16,234	15,980	15,880	15,937



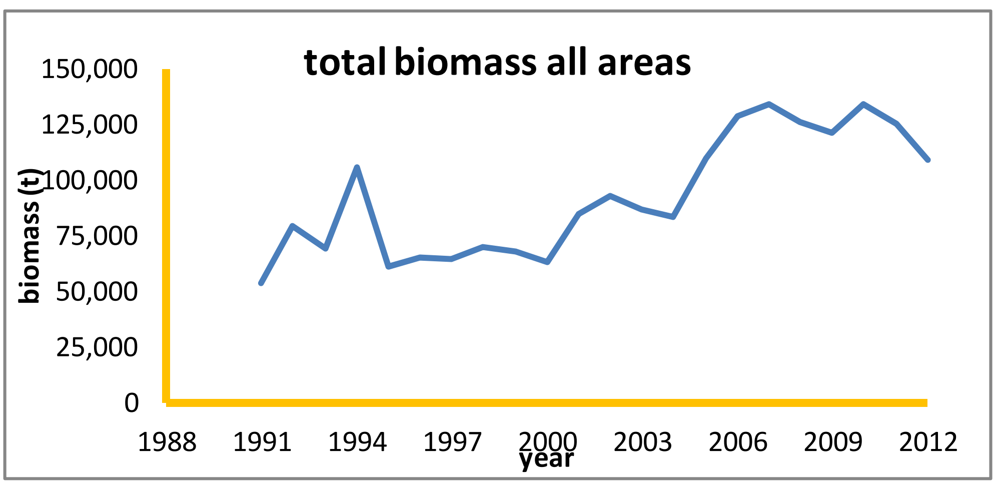


Figure 7.1—Number of hauls where arrowtooth flounder and Kamchatka flounder were identified during the annual Bering Sea shelf surveys, 1982-2010 (top panel), and the time-series of combined survey biomass estimates (bottom panel).

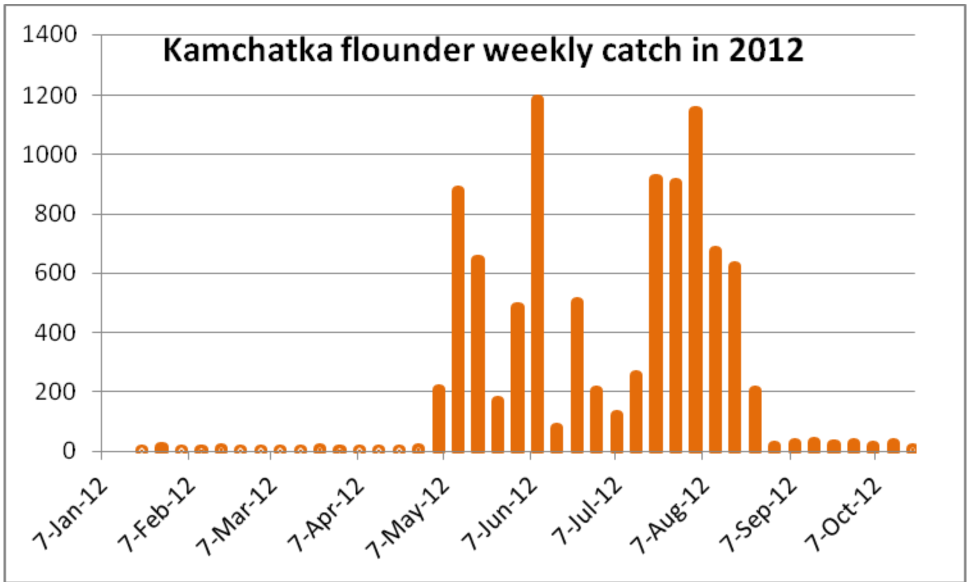


Figure 7-2 Arrowtooth and Kamchatka flounder catch (t) by week from Alaska Regional Office catch reports.

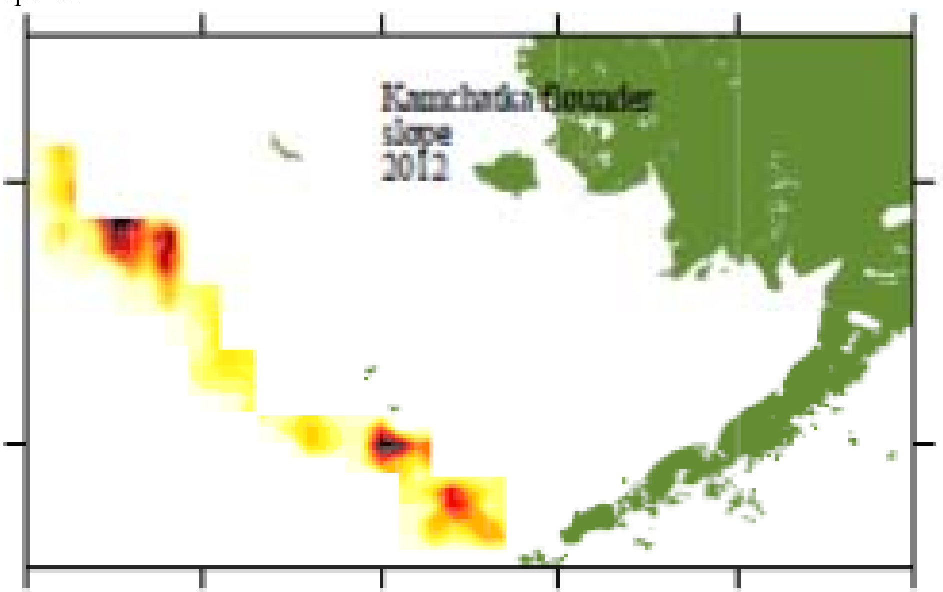


Figure 7-3. Distribution and relative of abundance of Kamchatka flounder from the 2012 slope survey.

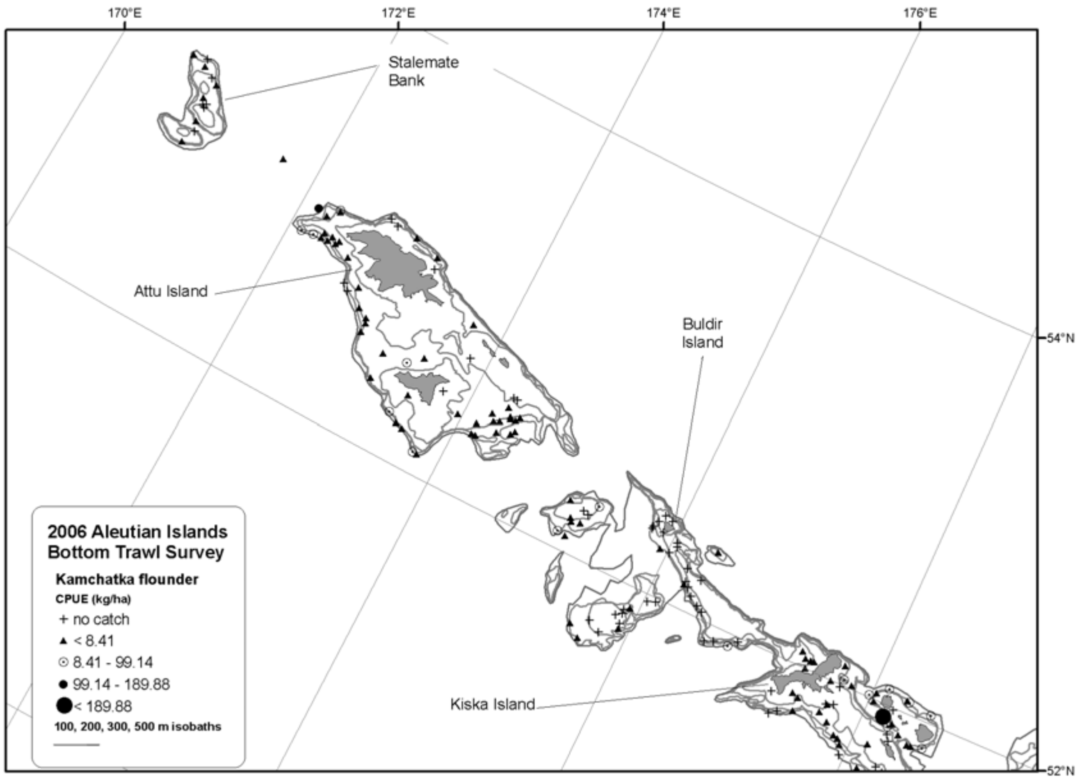


Figure 7-4. Distribution and relative abundance of Kamchatka flounder from the 2006 Aleutain Islands survey.

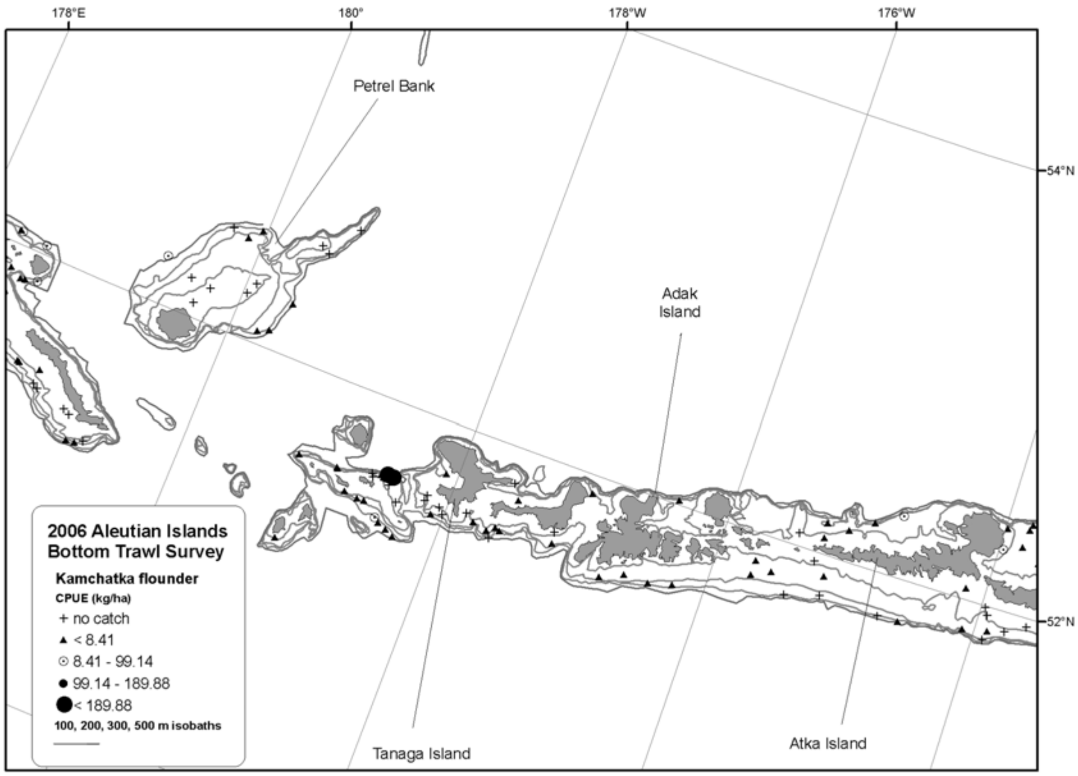


Figure 7-4 (continued).

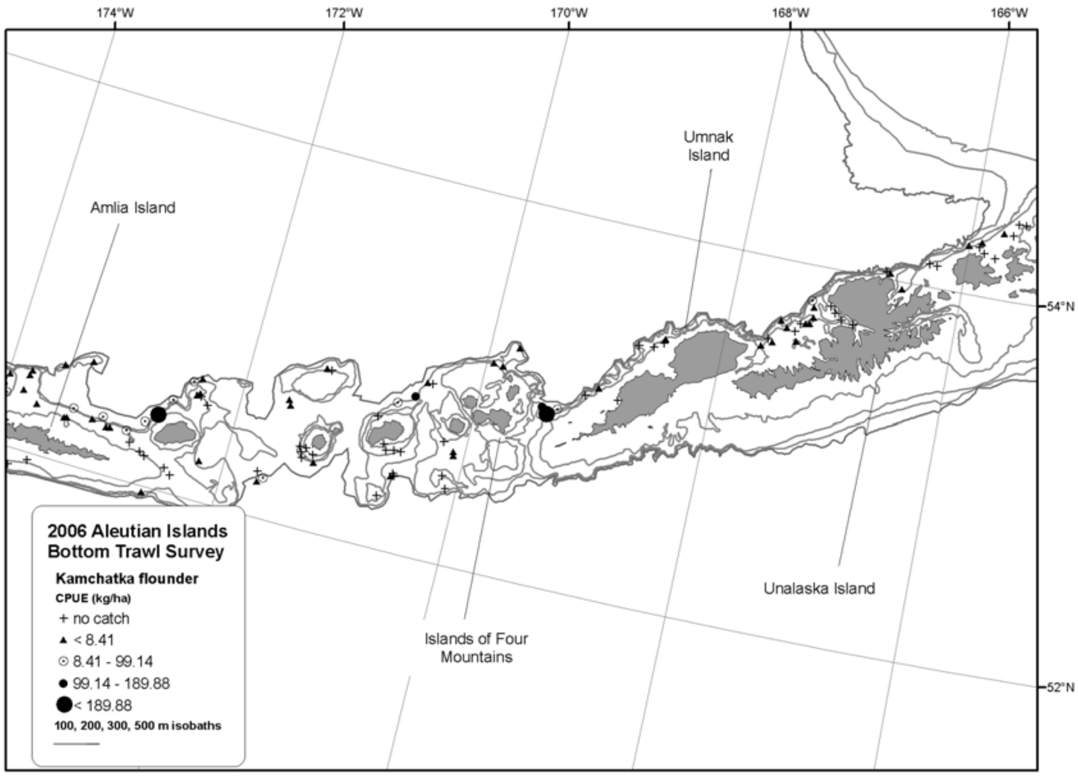


Figure 7-4 (continued).

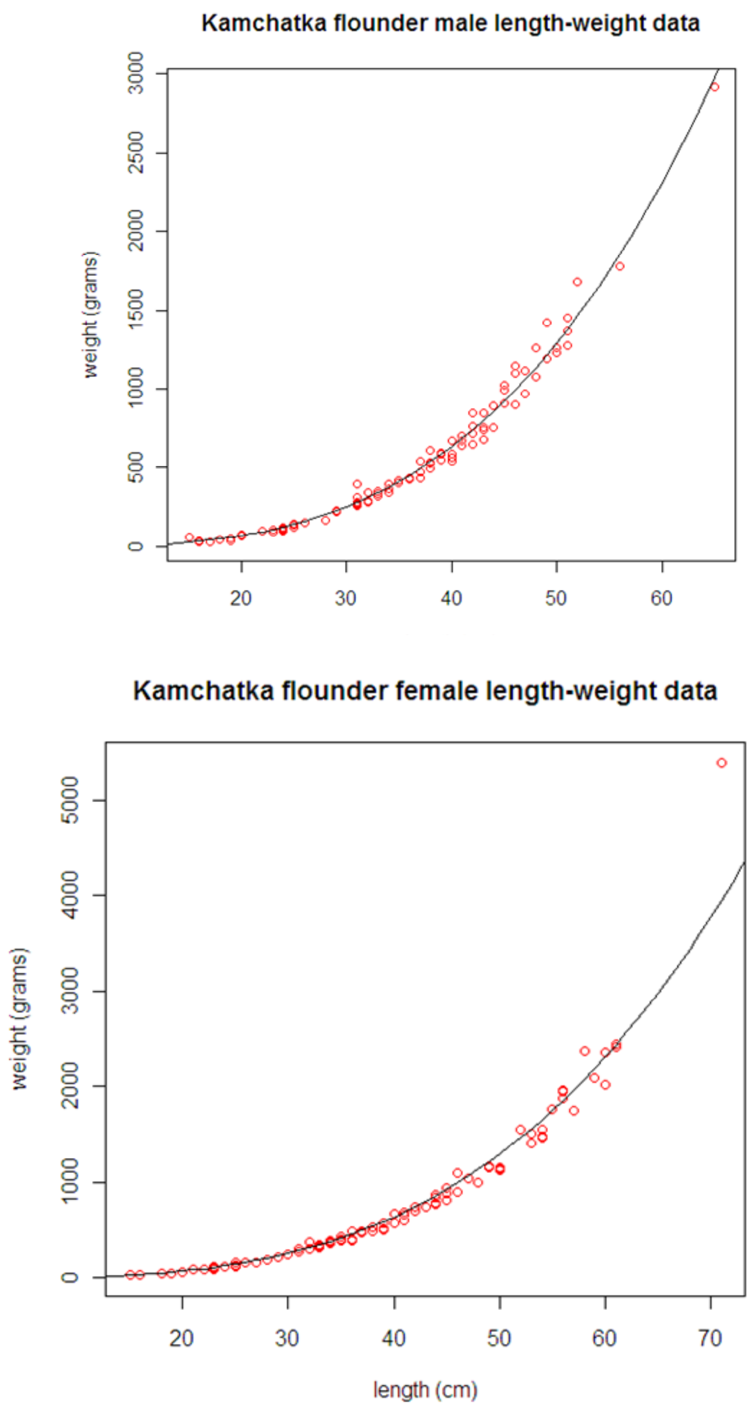


Figure 7-5 Kamchatka flounder length-weight plots for male and females.

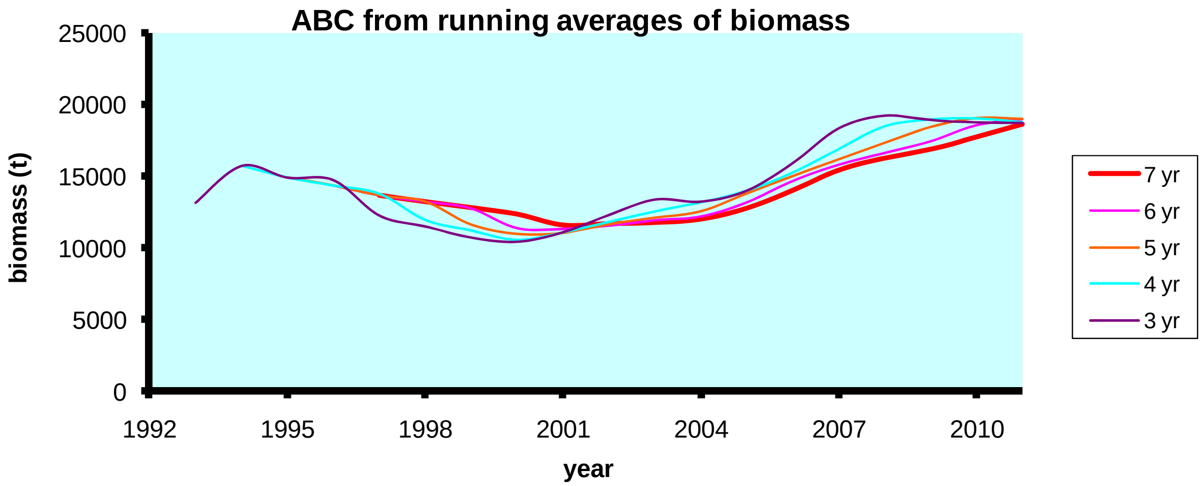


Figure 7-6 Estimated ABC (t), by year, from five methods each using a different number of years to calculate a moving average from shelf, slope and Aleutian Islands biomass estimates.

Appendix

Provisional analysis to assess the Kamchatka Flounder stock in the Bering Sea and Aleutian Islands using Tier 3 methodology

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Executive Summary

This document is the initial analysis to describe the stock status of Kamchatka flounder using Tier 3 age and length structured modeling. The assessment is presently a Tier 5 assessment reliant upon trawl survey biomass from the Bering Sea shelf, slope and the Aleutian Islands and an estimate of natural mortality. Kamchatka flounder have been distinguished from arrowtooth flounder in survey catches since 1991 and in the fishery since 2007 allowing that information to be utilized with recent age determinations and a maturity study to develop an age-structured model. Initial model runs apportioned biomass to the shelf, slope and Aleutian Islands based on the proportions from their relative survey estimates. Model evaluations resulted in reasonable fits to biomass estimates and size composition from the three surveys and a stable estimate of slope survey selectivity. A natural mortality value of 0.13 was obtained from direct estimation as a free parameter in the model and from profiling.

Introduction

This document is the initial analysis to describe the stock status of Kamchatka flounder using Tier 3 age and length structured modeling. The assessment is presently a Tier 5 assessment reliant upon trawl survey biomass from the Bering Sea shelf, slope and the Aleutian Islands and an estimate of natural mortality. ABC and OFL are determined from a 7-year averaging technique of survey biomass.

The Kamchatka flounder (*Atheresthes evermanni*) is a relatively large flatfish which is distributed from Northern Japan through the Sea of Okhotsk to the Western Bering Sea north to Anadyr Gulf (Wilimovsky et al. 1967) and east to the eastern Bering Sea shelf and south of the Alaska Peninsula (there is also a catch record from California). In U.S. waters they are found in commercial concentrations in the Aleutian Islands where they generally decrease in abundance from west to east (Zimmerman and Goddard 1996). They are also present in Bering Sea slope waters but are absent in survey catches east of Chirikof Island.

In the eastern part of their range, Kamchatka flounder overlap with arrowtooth flounder (*Atheresthes stomias*) which are very similar in appearance and were not routinely distinguished in the commercial catches until 2007. Until about 1992, these species were also not consistently separated in trawl survey catches (Fig. 7A-1) and were combined in the arrowtooth flounder stock assessment (Wilderbuer et al. 2009). However, managing the two species as a complex became undesirable in 2010 due to the emergence of a directed fishery for Kamchatka flounder in the BSAI management area. Since the ABC was determined by the large amount of arrowtooth flounder relative to Kamchatka flounder (complex is about 93% arrowtooth flounder) the possibility arose of an overharvest of Kamchatka flounder as the *Atheresthes sp*. ABC exceeded the Kamchatka flounder biomass. Arrowtooth and Kamchatka flounder have been managed separately since 2011.

Catch History

Historical Kamchatka flounder catch is combined in catch records of arrowtooth flounder and Greenland turbot from the 1960s. The fisheries for Greenland turbot intensified during the 1970s and the bycatch of arrowtooth flounder and Kamchatka flounder is assumed to have also increased. Catches of these species decreased after implementation of the MFCMA and the Kamchatka flounder resource has remained lightly exploited with the combined catches with arrowtooth flounder averaging 12,831 t from 1977-2008 (Table 7A-1). It is estimated that only a small fraction (<10%) of this catch was Kamchatka flounder. This decline resulted from catch restrictions placed on the fishery for Greenland turbot and phasing out of the foreign fishery in the U.S. EEZ. Catches in Table 7A-1 through 2006 are for arrowtooth flounder and Kamchatka flounder combined, catches thereafter are those estimated for Kamchatka flounder only. The total combined catch estimated for arrowtooth and Kamchatka flounder reported by the Alaska Regional Office (catches were not differentiated by species until 2011), is a blend of vessel reported catch and observer at-sea sampling of the catch. However, observers have separately identified the two species from catches aboard trawl vessels since 2007 and their sampling has indicated that the proportion of Kamchatka flounder in the combined catch has steadily increased from 10% in 2007 to 55% in 2010.

year	Percent of combined catch
2007	10%
2008	31%
2009	45%
2010	55%

The increased harvest was the result of a recently developed foreign market for Kamchatka flounder which has now become a fishery target. Based on the above observer derived percentages, the 2010 estimated catch of Kamchatka flounder was 21,153 t, taken primarily in area 514 and to a lesser extent in area 518. The 2011 catch of 9,935 is less than half of the 2010 combined total (TAC and ABC = 17,700, OFL = 23,600) and was evenly split between area 541 in the central Aleutian Islands (51%) and area 524 in the northern Bering Sea (34%). Based on this result in 2011, area apportionment has not been pursued in the assessment. The Kamchatka catch by week in 2011 (Fig. 7A-2) shows that targeting for Kamchatka flounder began May 1 when about one third of the annual total was taken in one week, and then continued in lesser amounts through mid-October.

Data

The data used in this assessment includes estimates of total fishery catch, bottom trawl survey biomass estimates and length composition from the Bering Sea shelf, slope and Aleutian Islands surveys. Age data are available from the 2010 Aleutian Islands survey and all survey length-weight observations were included.

Fishery catch

Fishery catch from 2007-2011 were included in the model as listed above. Catches from 1991-2006, years when Kamchatka and arrowtooth flounder were not identified to species were calculated by assuming that Kamchatka flounder comprised 10% of the catch during that time period.

Absolute Abundance from Trawl Surveys

Biomass estimates (t) for Kamchatka flounder from the standard shelf survey area in the eastern Bering Sea, slope surveys and the Aleutian Islands region are shown in Table 7A-2. Reliable estimates of Kamchatka flounder became available in 1991 and they were estimated at an average biomass of 45,500 t through 1994 on the Bering Sea shelf (Fig. 7A-1). During the following 11 years the biomass was estimated at a lower level (26,800 t average) before increasing to high and stable levels the past 7 years (53,200 t average). On the continental shelf they are usually found in highest concentrations at depths greater than 200 meters around the Pribilof Islands and also in the large shelf area west of St. Matthew Island. Trends of abundance from the slope and Aleutian Islands surveys also indicate an increasing resource. They are common in the deeper waters of the slope area (500 to 800 meters, Zimmerman and Goddard 1996) in both the Aleutian Islands and the eastern Bering Sea slope (Figs. 7A3 and 7A4).

An estimate of total BSAI biomass for the years in which Aleutian Islands and slope surveys were not conducted was calculated by averaging the years in closest temporal (before and after) proximity. Population length composition estimates for the three trawl surveys are shown by year and sex in Fig. 7A-5.

Length-weight, length and weight at age, maturity and natural mortality

All length-weight measurements collected during RACE surveys (1,074 total, 483 males and 591 females) were used to describe the Kamchatka flounder length (cm)-weight (g) relationship (Fig 7A.6) by the equation:

Males: $W = 4.73 \times 10^{-6} L^{3.757}$

Females $W = 2.08 \times 10^{-3} L^{3.393}$

Length at age calculations from the ageing of 450 otoliths from the 2010 Aleutian Islands survey were fit to a von Bertalanffy growth model to obtain male and female length at age. These data were then multiplied by the sex-specific length-weight data to obtain estimates of weight-at-age for the assessment model. Weight-at-age data indicate that females and males grow at a similar rate until about the age of maturation after which females continue to grow to a larger size (Fig 7A.7). Maturity was determined in a study by Stark (in press) from a histological examination of ovary samples collected in the Bering Sea.

Both sexes have been found in relatively equal numbers and the oldest fish have been aged at 35 years indicating that Kamchatka flounder are similar in life history to other Bering Sea flatfish. The assessment model was used to explore estimates of natural mortality.

Analytic Approach

Model Structure

This stock assessment utilizes the AD Model Builder software to model the population dynamics of Bering Sea and Aleutian Islands Kamchatka flounder since 1991. The model is a sex-specific length-based approach where survey and fishery length composition observations are used to calculate estimates of population numbers-at-age by the use of a length-age (growth) matrix. The model simulates the dynamics of the population and compares the expected values of the population characteristics to those observed from surveys and fishery sampling programs. This is accomplished by the simultaneous estimation of the parameters in the model using the maximum likelihood estimation procedure. The fit of the simulation values to the observed characteristics is optimized by maximizing the log(likelihood) function given the following distributional assumptions about the observed data (see Tables 7A-3 and 7A-4).

The suite of parameters estimated by the base model are classified by the following likelihood components:

Data Component	Distribution assumption
Trawl fishery size composition	Multinomial
Shelf survey population size composition	Multinomial
Slope survey population size composition	Multinomial
Shelf survey age composition (2010)	Multinomial
Aleutian Islands survey size composition	Multinomial
Trawl survey biomass estimates and S.E.	Log normal

The total log likelihood is the sum of the likelihoods for each data component. The model allows for the individual likelihood components to be weighted by an emphasis factor. Equal emphasis was placed on fitting all data components for this assessment and the relationship between annual bottom water temperature (Temp) and shelf survey catchability (q) was modeled to improve the fit to the shelf survey biomass estimates. The number of parameters estimated in the base configuration of the model are presented below:

Fishing mortality	Selectivity	Temp-q	Year class strength	Total
22	16	2	45	85

The recruitment parameters are comprised of the 24 initial ages in 1991 (ages 2-25), the 20 subsequent recruitment deviation estimates from 1976-2007 and the mean log of all recruitment. Fishing mortality (F) parameters include the log of average F and the 21 annual fishing mortality deviations. Selectivity parameters are from the logistic model for 3 surveys and a single fishery, for each sex. In addition, two more parameters are estimated in a later stage to estimate the annual relationship between bottom water temperature and shelf survey catchability and bottom water temperature and the overall value of catchability which relates to the capture process and availability of the stock (discussed in the next section).

It was assumed that the shelf, slope and Aleutian Islands surveys measure non-overlapping segments of the Kamchatka flounder stock. Biomass was apportioned between the three areas by calculating the average of the annual proportions estimated from the trawl surveys (Fig 7A-8). The resulting proportions are 37% shelf, 18% slope and 45% in the Aleutian Islands. The length-age conversion matrices (sex-specific) were constructed using fitted von Bertalanffy growth curves to the available age data. The variability in length at age was estimated to reflect a CV of about 8% (in cm). This provided the variance in growth for the length-age conversions.

Parameters Estimated Independently

Catchability

Examination of Bering Sea shelf survey biomass estimates indicate that some of the annual variability seemed to positively co-vary with bottom water temperature. Variations in shelf survey biomass were particularly evident during the coldest year (1999) and the warm trend that occurred from 2001-2005. The relationship between average annual bottom water temperature collected during the survey and annual survey biomass estimates can be better understood by modeling survey catchability as:

$$q = e^{-\alpha + \beta T}$$

where q is catchability, α and β are a parameters estimated by the model, and T_t is the average annual bottom water temperature. The catchability equation has two parts. The e^{α} term is a constant or time-independent estimate of q. The second term, $e^{\beta T}$ is a time-varying (annual) q which relates to the metabolic aspect of herding or distribution (availability) which can vary annually with bottom water temperature.

Year class strengths

The population simulation specifies the number-at-age in the beginning year of the simulation, the number of recruits in subsequent years as deviations from overall mean log recruitment, and the survival rate for each cohort as it moves through the population calculated from the population dynamics equations (see Table 7A-3 and Table 7A-4).

Fishing Mortality

The fishing mortality rates for each age and year are calculated to approximate the catch weight by solving for F while still allowing for observation error in catch measurement. A large emphasis (300) was placed on the catch likelihood component.

Selectivity

Survey results indicate that fish less than about 4 years old (< 30 cm) are found mostly on the Bering Sea shelf and to a lesser extent in the Aleutian Islands. Males and females from 30-50 cm are found on the shelf and in deeper waters of the Aleutian Islands and Bering Sea slope waters, and males and females > 50 cm are mainly found at depths below 200 meters. Sex specific "domed-shaped" selectivity was freely estimated for males and females in the shelf survey due to the lack of larger fish there. We assumed an asymptotic selectivity pattern for both sexes in the slope surveys and the Aleutian Islands surveys. Selectivity was assumed constant over all survey years.

Up to the present, the low level of length measurements collected from the fishery may not provide sufficient information for the model to reliably estimate fishery selectivity. The input sample size for fitting this data was set at a low level (25) and may be overemphasized. This results in sample size problems which make estimates of fishery selectivity unreliable. The shape of the selectivity curve was fixed asymptotic for older fish in the fishery since the directed fishery for Kamchatka flounder presumably targets the larger fish.

Model Evaluation

1) Started with q's (catchability) apportioned by their relative survey biomass estimates for the three survey areas.
2) Examination of the results from the initial model run indicated that fishery selectivity is poorly determined (presumably due to the low sample sizes) and that there are males present in the length records that are larger than those observed in any survey data. It is suspected that this is the result of some mis-sexing of Kamchatka flounder in the commercial fishery sampling. This was resolved by fixing the slope of the logistic curve (age at 50% selection is still estimated for each sex) which produced more sensible results (Fig. 7A-9) and estimated reference F values similar to other Bering Sea flatfish species.
3) Based on selectivity patterns, the shelf survey showed big differences in the ages of fish available to these different surveys (Fig. 7A-10). The slope survey selectivity estimates seemed most stable hence: Alternative values of q were fixed for the slope survey and freely estimated the q values for the shelf and Aleutian Islands surveys.

4) Since q is confounded with natural mortality, M was estimated as a free parameter and returned estimates similar to that obtained from profiling over M with catchability fixed for the three surveys (~.13, Fig 7A-11). M was fixed at 0.13 for subsequent model runs.

Estimates of q from the slope survey profile and the associated likelihood indicated that slope q is less than 0.3, but flat from about 0.2-0.05. Estimates of female spawning biomass derived from slope q = 0.1 and q = 0.18 are shown in figure 7A-12. The difference in total likelihood between these models was only 1.95, with the q=0.1 model being favored (in terms of total log likelihood) since the best fit to the overall likelihood is a low slope q (Fig. 7A13). Since the likelihood surface was so flat between q=0.1 and 0.18, the fixed value of 0.18 was retained for slope q. With the model configured in this way (slope survey q=0.18, M = 0.13 and fishery selectivity logistic slope fixed) the model was run to estimate the status and the population dynamics of the Kamchatka flounder stock over the period 1991-2011.

Model results

Model results estimate that the total biomass of Kamchatka flounder steadily increased from 1991 to 2009 to over 160,000 t and has since declined by nearly 20,000 t (Fig. 7A14). The female spawning biomass trend mirrors the total biomass with a parallel trend that peaks at 54,000 t in 2009 and has declined by 2,000 t to the 2011 estimate (Fig. 7A-15). The model estimates of shelf, slope and Aleutian Islands surveys fit the trends estimated by those data sources reasonably well (Fig. 7A-16). Selectivities, as previously discussed, were constrained for the fishery and were freely estimated for the surveys. It is clear that the shelf survey samples a younger portion of the population than those surveys conducted on the Bering Sea slope and in the Aleutian Islands (Fig. 7A-10).

Model estimates of fishing mortality indicate that the stock was lightly harvested from 1991 to 2008 with an average annual full selection F of 0.015 (Fig 7A-17). As the fishery developed for Kamchatka flounder in 2008 the fishing mortality was much higher in 2009-2011 with the 2010 F estimated at 0.17.

Examination of the model fit to the survey length composition data was made by comparing the average observed proportion at length from the time-series to the average predicted proportion at length from the model (Fig. 7A-18). Overall the model fits the general shape of the length compositions but has some residual trends for large fish on the slope and the Aleutian Islands. Fits to the individual annual length compositions, by sex, are shown in figure 7A-19. last.

Ecosystem Considerations

Predators of Kamchatka flounder

Kamchatka flounder have rarely been found in the stomachs of other groundfish species in samples collected by the Alaska Fisheries Science Center. Their presence has only been documented in 17 stomach samples from the BSAI where the predators included Pacific cod, pollock, Pacific halibut, arrowtooth flounder and two sculpin species.

Kamchatka flounder predation

The prey of Kamchatka flounder can be discerned from 152 stomachs collected in 1983 (Yang and Livingston 1986). The principle diet was composed of walleye pollock, shrimp (mostly Crangonidae) and euphausids. Pollock was the most important prey item for all sizes of fish, ranging from 56 to 86% of the total stomach content weight. An examination of diet overlap with arrowtooth flounder indicated that these two congeneric species basically consume the same resources. Therefore the following sections are from the arrowtooth flounder assessment but pertain to Kamchatka flounder.

Ecosystem Effects on the stock

1) Prey availability/abundance trends

Arrowtooth flounder diet varies by life stage as indicated in the previous section. Regarding juvenile prey and its associated habitat, information is not available to assess the abundance trends of the benthic infauna of the Bering Sea shelf. The original description of infaunal distribution and abundance by Haflinger (1981) resulted from sampling conducted in 1975 and 1976 and has not be re-sampled since. Information on pollock abundance is available in Chapter 1 of this SAFE report. It has been hypothesized that predators on pollock, such as adult arrowtooth flounder, may be important species which control (with other factors) the variation in year-class strength of juvenile pollock (Hunt et al. 2002). The populations of arrowtooth flounder which have occupied the outer shelf and slope areas of the Bering Sea over the past twenty years for summertime feeding do not appear food-limited. These populations have fluctuated due to the variability in recruitment success which suggests that the primary infaunal food source has been at an adequate level to sustain the arrowtooth flounder resource.

2) Predator population trends

As juveniles, it is well-documented from studies in other parts of the world that flatfish are prey for shrimp species in near shore areas. This has not been reported for Bering Sea arrowtooth flounder due to a lack of juvenile sampling and collections in near shore areas, but is thought to occur. As late juveniles they are found in stomachs of pollock and Pacific cod, mostly on small arrowtooth flounder ranging from 5 to 15 cm standard length..

Past, present and projected future population trends of these predator species can be found in their respective SAFE chapters in this volume. Encounters between arrowtooth flounder and their predators may be limited as their distributions do not completely overlap in space and time.

3) Changes in habitat quality

Changes in the physical environment which may affect Kamchatka flounder distribution patterns, recruitment success, migration timing and patterns are catalogued in the Ecosystem Considerations Appendix of this SAFE report. Habitat quality may be enhanced during years and warmer bottom water temperatures with reduced ice cover (higher metabolism with more active feeding). Environmental factors important to juvenile survival are presently not well known.

Ecosystem effects on Kamchatka flounder			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Benthic infauna	Stomach contents	Stable, data limited	Unknown
Predator population trends			
Fish (Pollock, Pacific cod)	Stable	Possible increases to Kamchatka mortality	
Changes in habitat quality			
Temperature regime	Cold years Kamchatka catchability and herding may decrease	Deeper water species so less likely to affect surveyed stock	No concern (dealt with in model)
Winter-spring environmental conditions	Affects pre-recruit survival	Probably a number of factors	Causes natural variability

Arrowtooth flounder **effects on ecosystem**			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	Stable, heavily monitored	Minor contribution to mortality	No concern
Forage (including Pollock, shrimp and euphausids)	Stable, heavily monitored	Bycatch levels small relative to forage biomass	No concern
HAPC biota	Low bycatch levels of (spp)	Bycatch levels small relative to HAPC biota	No concern
Marine mammals and birds	Very minor direct-take	Safe	No concern
Sensitive non-target species	Likely minor impact	Data limited, likely to be safe	No concern
Fishery concentration in space and time	Recent high exploitation rate	Little detrimental effect	No concern
Fishery effects on amount of large size target fish	Recent high exploitation rate, but unknown effect	Natural fluctuation	No concern
Fishery contribution to discards and offal production	Stable trend	Improving, but data limited	Possible concern
Fishery effects on age-at-maturity and fecundity	Unknown	NA	Possible concern

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Zimmermann, Mark, and Pamela Goddard 1996. Biology and distribution of arrowtooth (Atheresthes stomias) and Kamachatka (A. evermanni) flounders in Alaskan waters. Fish. Bull 94:358-370.

Table 7A1. Total combined catch (t) of arrowtooth and Kamchatka flounder in the eastern Bering Sea and Aleutian Islands region[a], 2001-2006. Catches from 2007 to present, when the two species were differentiated in commercial catches, is reported for Kamchatka flounder only in this table

year	catch
1991	22,052
1992	10,382
1993	9,338
1994	14,366
1995	9,280
1996	14,652
1997	10,054
1998	15,241
1999	10,573
2000	12,929
2001	13,908
2002	11,540
2003	12,834
2004	17,809
2005	13,685
2006	13,309
2007	1,183
2008	6,819
2009	12,802
2010	21,153
2011	9,160

Table 7A2. Estimated Kamchatka flounder? biomass from the three BSAI bottom trawl surveys. Reliable estimates of Kamchatka flounder biomass are only available after 1991 when Kamchatka and arrowtooth flounder were differentiated.

	shelf	slope	Aleutian islands
1982	0		
1983	17,299		1,034
1984	20,695		
1985	31		
1986	0		565
1987	40		
1988	13,723		
1989	17,108		
1990	32,799		
1991	37,152		16,255
1992	50,081		
1993	38,376		
1994	56,268		49,156
1995	28,393		
1996	24,196		
1997	18,282		37,664
1998	23,474		
1999	18,974		
2000	21,551		28,535
2001	31,120		
2002	25,213	18,645	49,035
2003	27,531		
2004	29,663	14,740	39,219
2005	46,084		
2006	61,644		45,369
2007	65,191		
2008	53,967	24,822	
2009	47,252		
2010	51,927	27,875	49,069
2011	46,094		
2012	40,951	32,787	35,100

Table 7A-3. Key equations used in the population dynamics model.

$N_{t,1} = R_t = R_0 e^{\tau},\ \tau_t \sim N\left(0, \delta_R^2\right)$	Recruitment t=1969-1990
$N_{t,1} = R_t = R_y e^{\tau},\ \tau_t \sim N\left(0, \delta_R^2\right)$	Recruitment t=1991-2012
$C_{t,a} = \frac{F_{t,a}}{Z_{t,a}}\left(1 - e^{-Z_{t,a}}\right) N_{t,a}$	Catch in year t for age a fish
$N_{t+1,a+1} = N_{t,a} e^{-Z_{t,a}}$	Numbers of fish in year $t+1$ at age a
$N_{t+1,A} = N_{t,A-1} e^{-Z_{t,A-1}} + N_{t,A} e^{-Z_{t,A}}$	Numbers of fish in the "plus group"
$S_t = \sum N_{t,a} W_{t,a} \phi_a$	Spawning biomass
$Z_{t,a} = F_{t,a} + M$	Total mortality in year t at age a
$F_{t,a} = s_a \mu^F \exp^{\varepsilon^F{}_t},\ \ \varepsilon^F{}_t \sim N(o, \sigma^{2_F})$	Fishing mortality
$s_a = \frac{1}{1 + \left(e^{-\alpha + \beta a}\right)}$	Age-specific fishing selectivity
$C_t = \sum C_{t,a}$	Total catch in numbers
$P_{t,a} = {}^{C_{t,a}}\!/_{C_t}$	Proportion at age in catch
$SurB_t = q \sum N_{t,a} W_{t,a} v_a$	Survey biomass
$reclike = \lambda\left(\sum_{i=1965}^{endyear} \bar{R} - R_i\right)^2 + \sum_{a=1}^{20} (\bar{R}_{init} - R_{init,a})^2$	Recruitment likelihood
$catchlike = \lambda \sum_{i=startyear}^{endyear} (\ln C_{obs,i} - \ln C_{est,i})^2$	catch likelihood
$surveylike = \lambda \frac{(\ln B - \ln \hat{B})^2}{2\sigma^2}$	survey biomass likelihood
$SurvAgelike = \sum_{t,a} n_t P_{t,a} (\ln \hat{P}_{t,a} + 0.001) - \sum_{t,a} n_t P_{t,a} (\ln P_{t,a} + 0.001)$	survey age comp likelihood
$SurvLengthlike = \sum_{t,a} n_t P_{t,a} (\ln \hat{P}_{t,a} + 0.001) - \sum_{t,a} n_t P_{t,a} (\ln P_{t,a} + 0.001)$	survey length comp likelihood

Table 7A4. Variables used in the population dynamics model.

Variables	
R_t	Age 1 recruitment in year *t*
R_0	Geometric mean value of age 1 recruitment, 1956-75
R_γ	Geometric mean value of age 1 recruitment, 1976-96
τ_t	Recruitment deviation in year *t*
$N_{t,a}$	Number of fish in year *t* at age *a*
$C_{t,a}$	Catch numbers of fish in year *t* at age *a*
$P_{t,a}$	Proportion of the numbers of fish age *a* in year *t*
C_t	Total catch numbers in year *t*
$W_{t,a}$	Mean body weight (kg) of fish age *a* in year *t*
ϕ_a	Proportion of mature females at age *a*
$F_{t,a}$	Instantaneous annual fishing mortality of age *a* fish in year *t*
M	Instantaneous natural mortality, assumed constant over all ages and years
$Z_{t,a}$	Instantaneous total mortality for age *a* fish in year *t*
s_a	Age-specific fishing gear selectivity
μ^F	Median year-effect of fishing mortality
ε_t^F	The residual year-effect of fishing mortality
v_a	Age-specific survey selectivity
α	Slope parameter in the logistic selectivity equation
β	Age at 50% selectivity parameter in the logistic selectivity equation
σ_t	Standard error of the survey biomass in year *t*

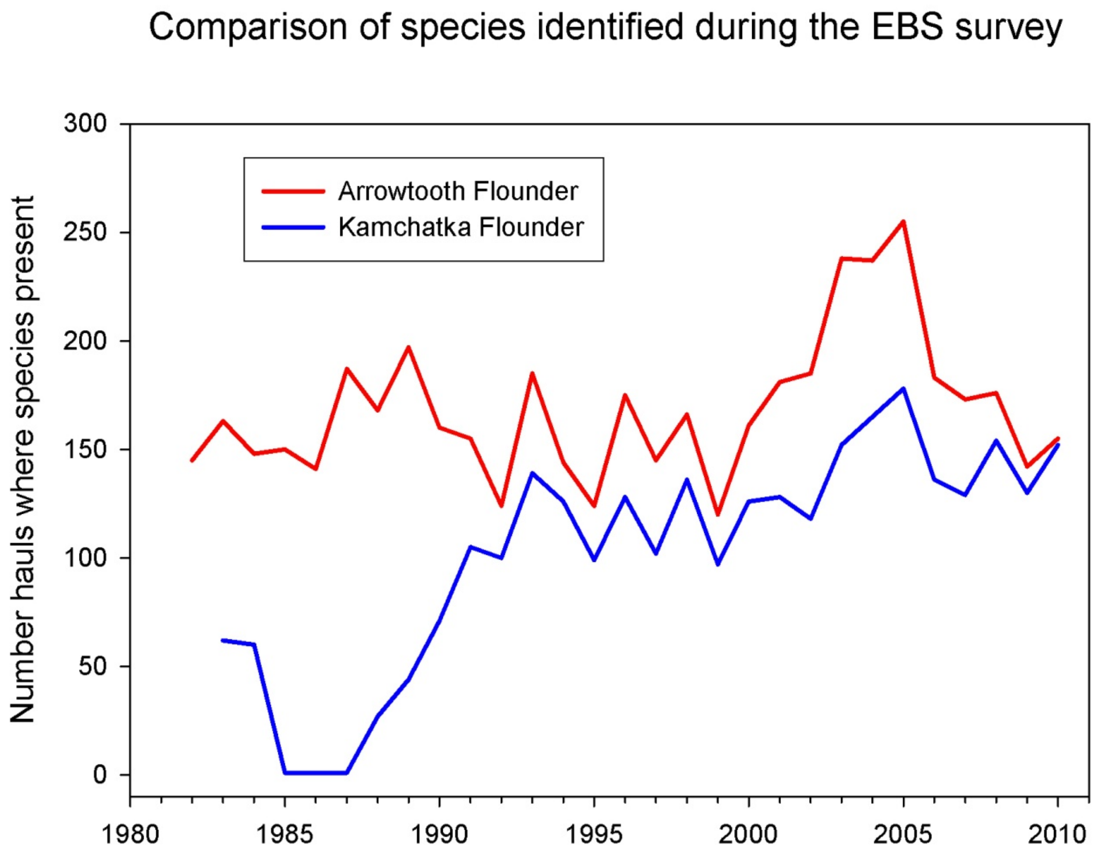


Figure 7A.1—Number of hauls where arrowtooth flounder and Kamchatka flounder were identified during the annual Bering Sea shelf surveys, 1982-2010.

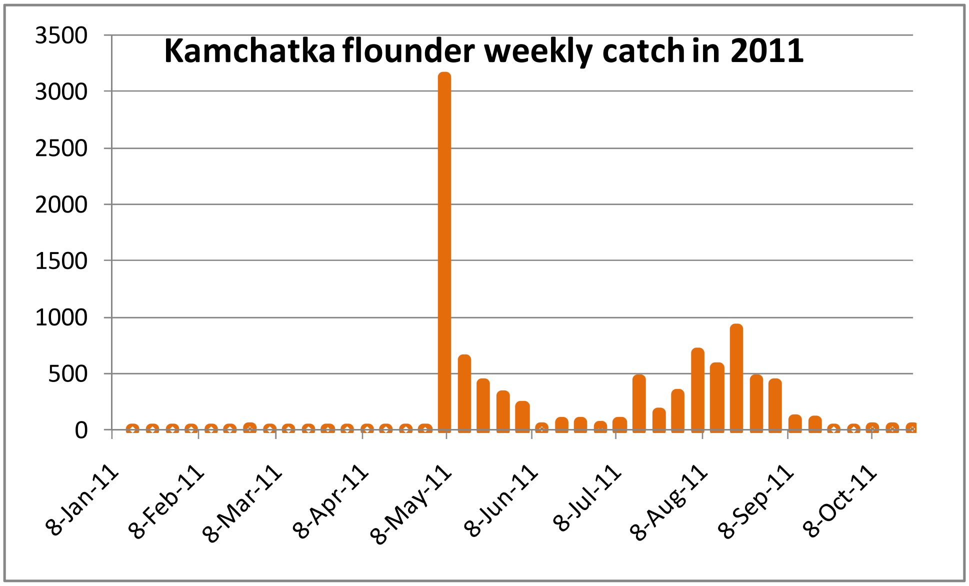


Figure 7A-2 2011 arrowtooth and Kamchatka flounder catch (t) by week from Alaska Regional Office catch reports.

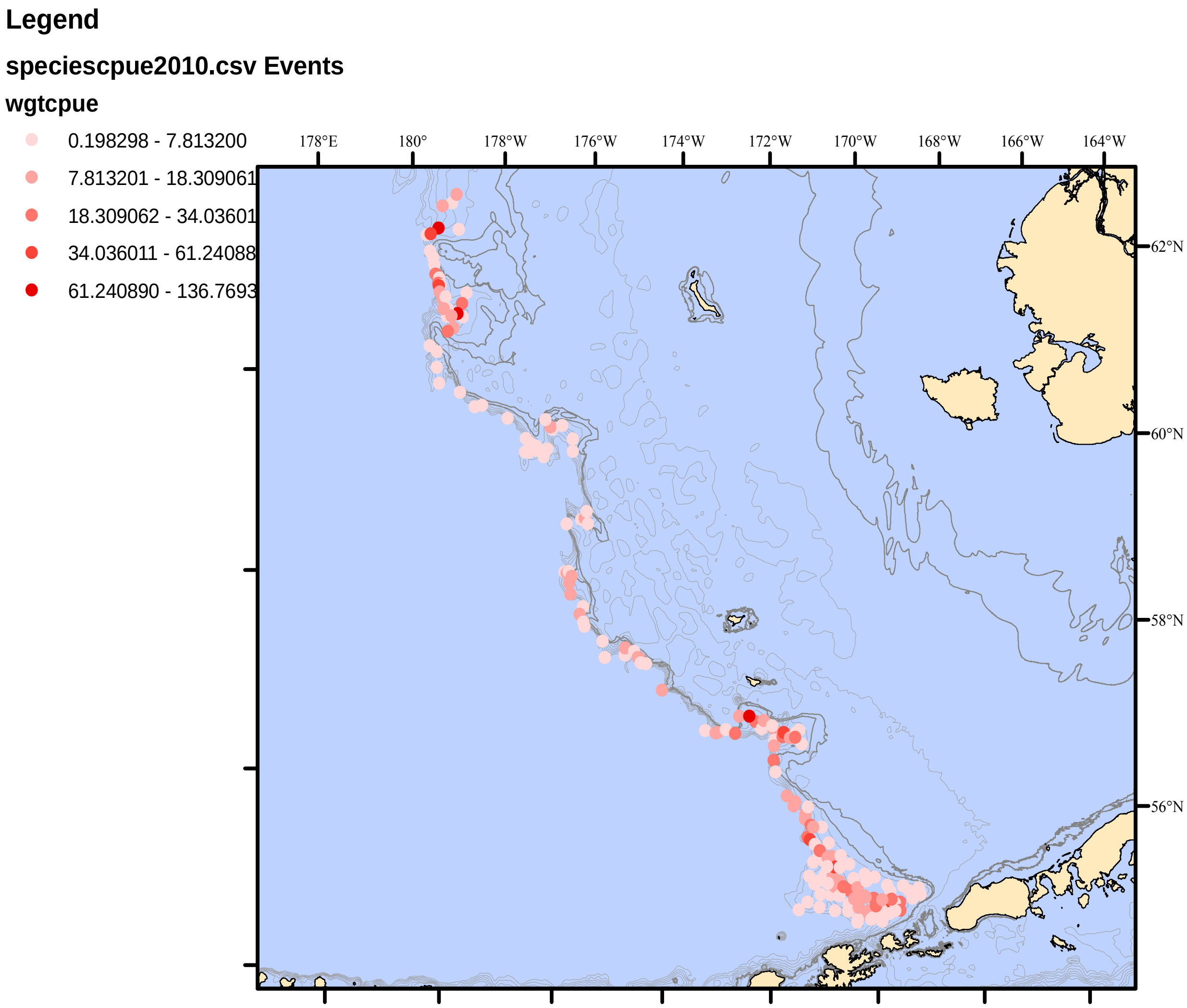


Figure 7A-3. Distribution and relative of abundance of Kamchatka flounder from the 2010 slope survey.

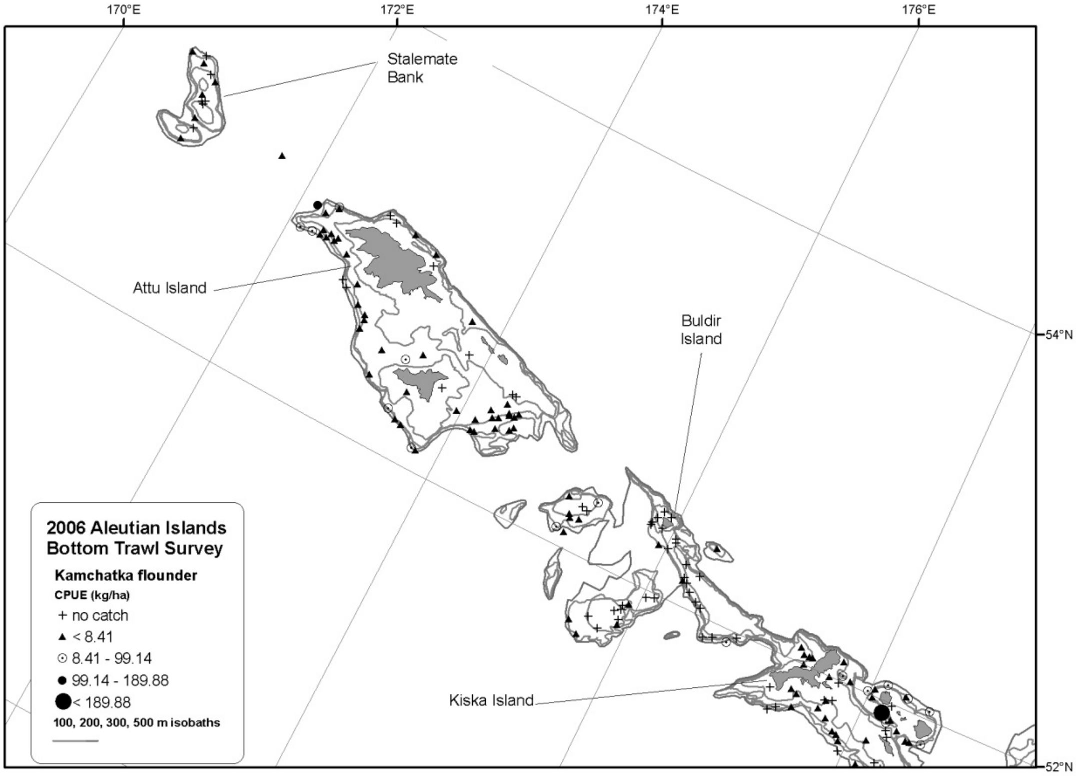


Figure 7A-4. Distribution and relative abundance of Kamchatka flounder from the 2006 Aleutian Islands survey.

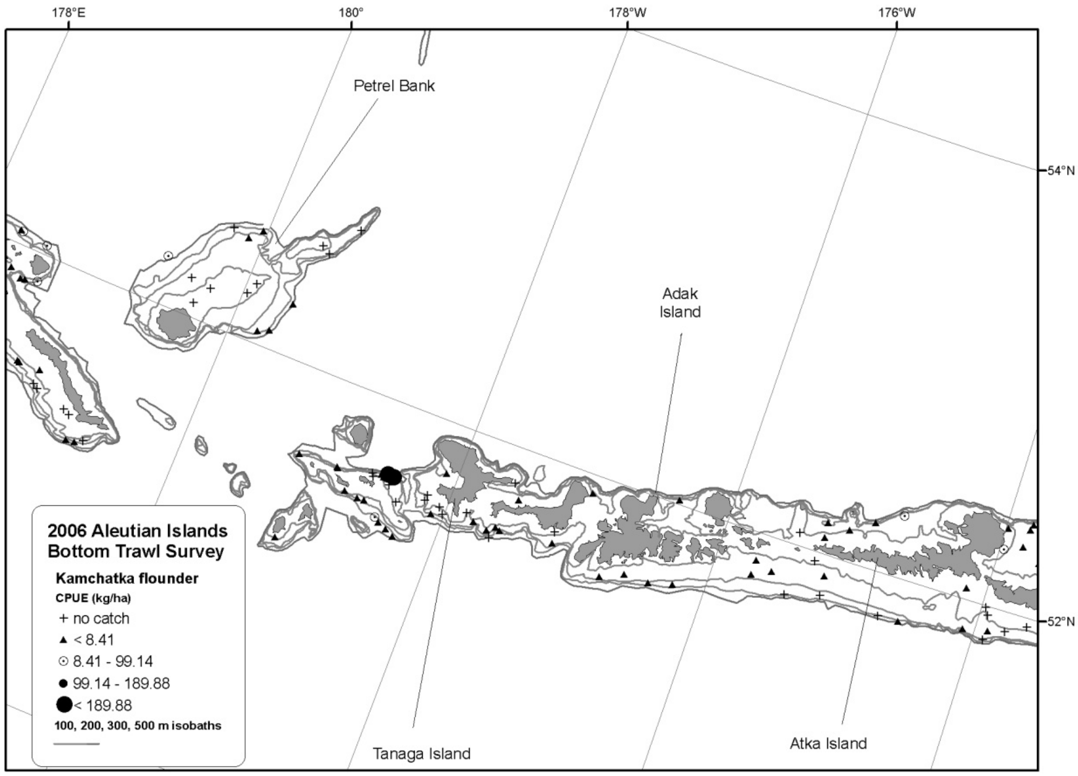


Figure 7A-4 (continued).

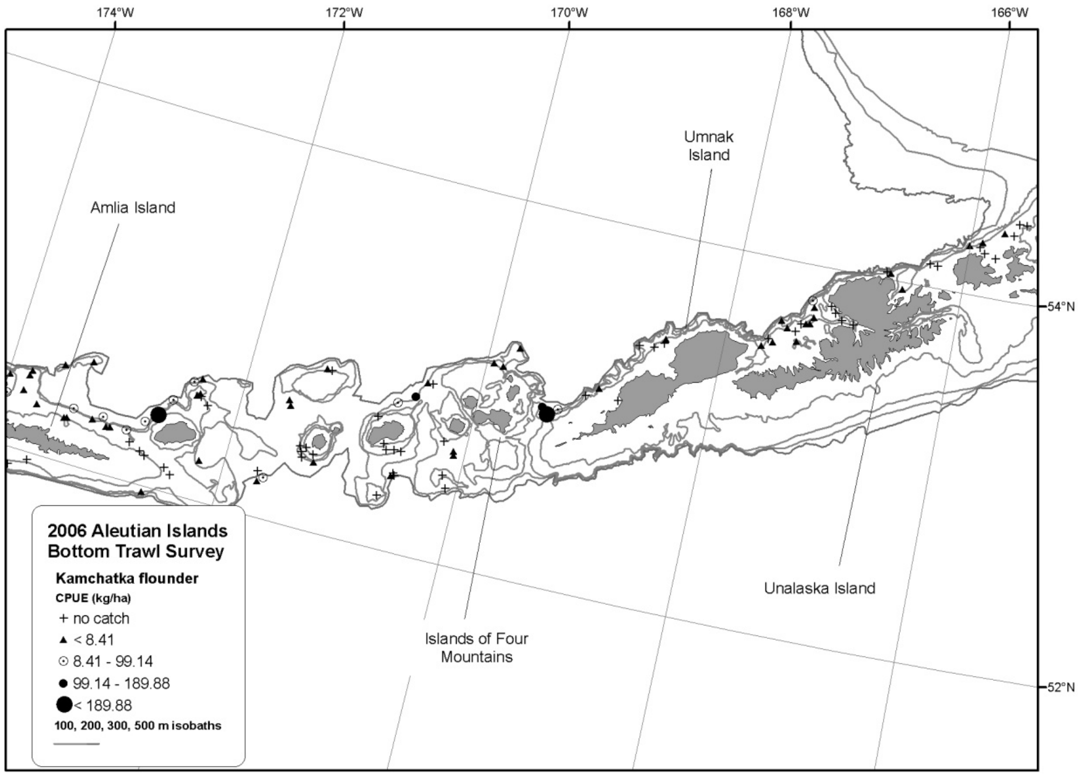


Figure 7A-4 (continued).

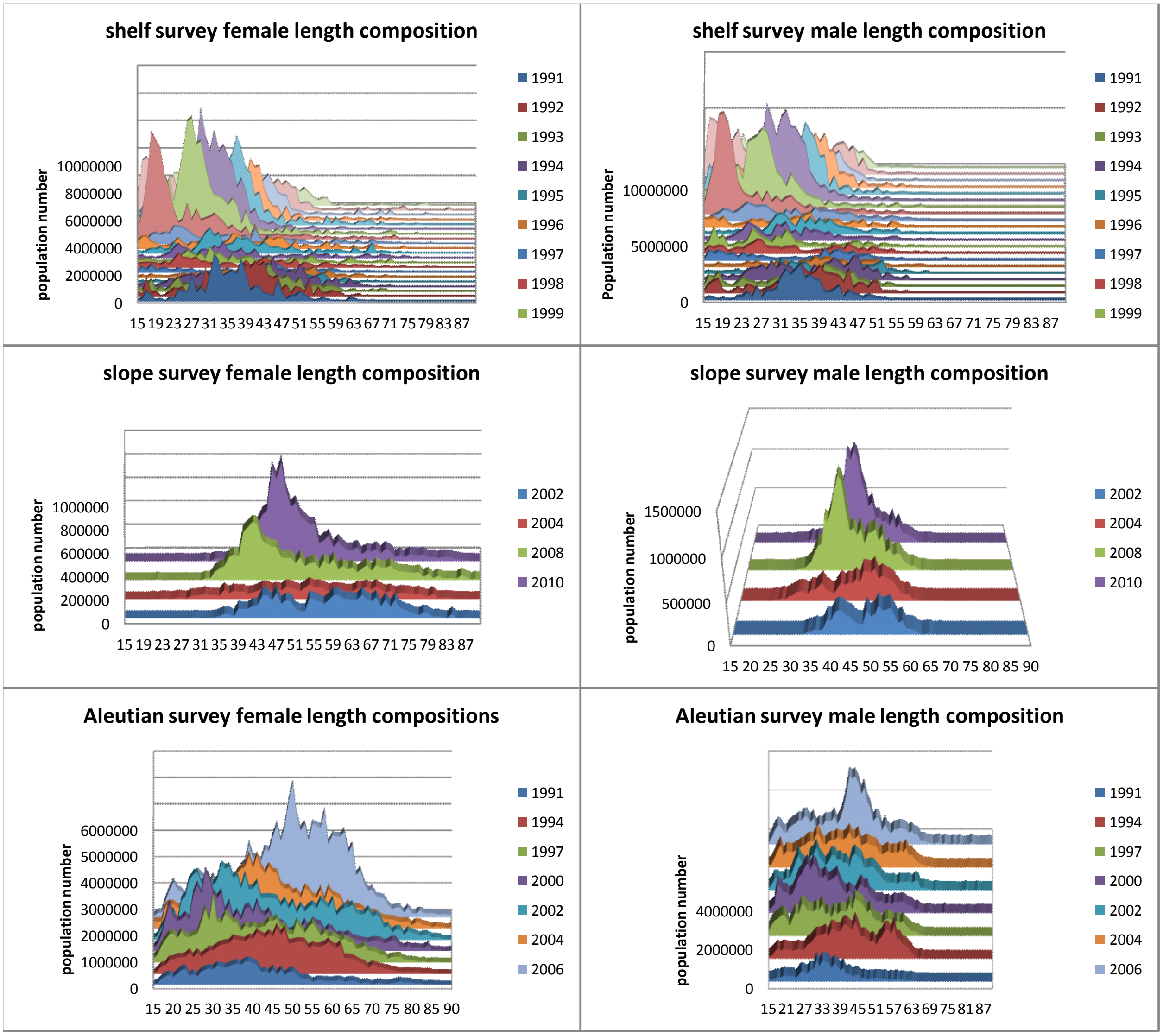
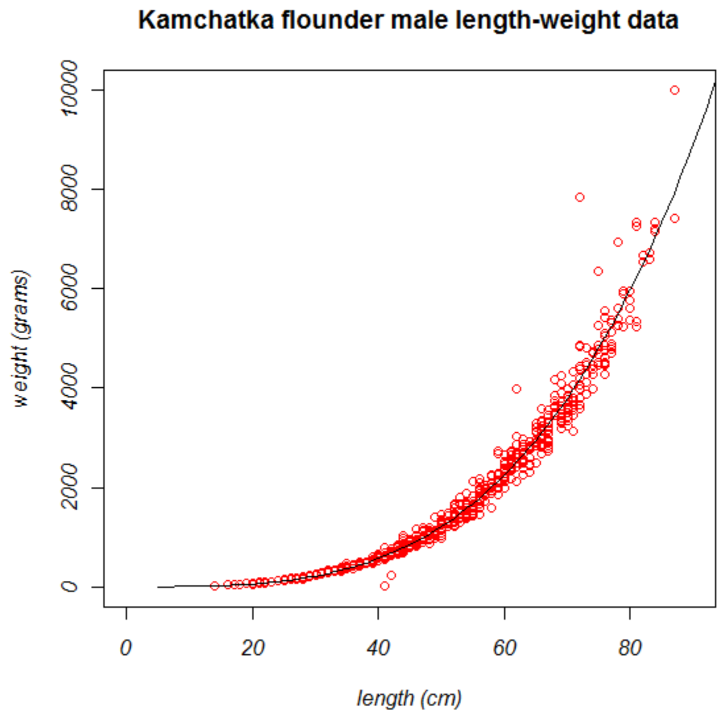


Figure 7A-5. Kamchatka flounder population length composition estimates from the shelf, slope and Aleutian Islands survey for males and females.



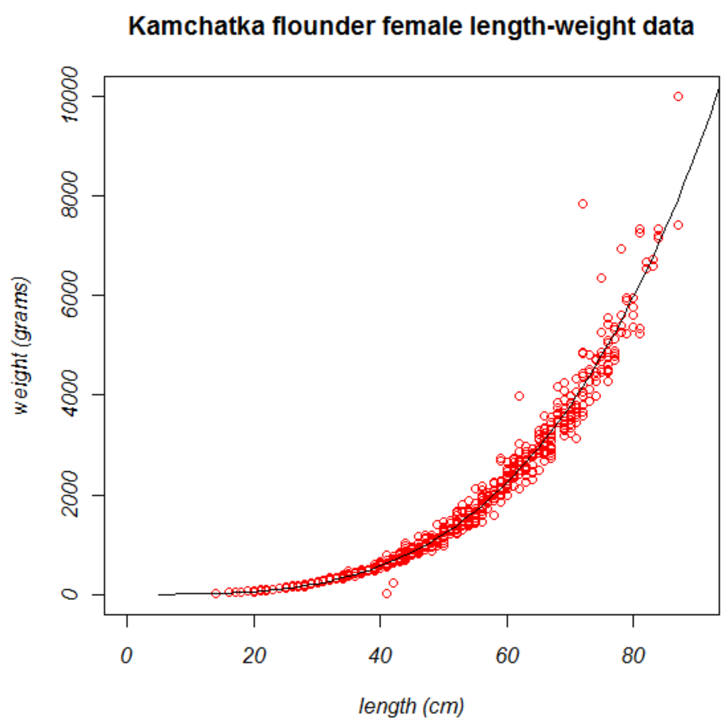


Figure 7A-6 Kamchatka flounder length-weight plots for male and females.

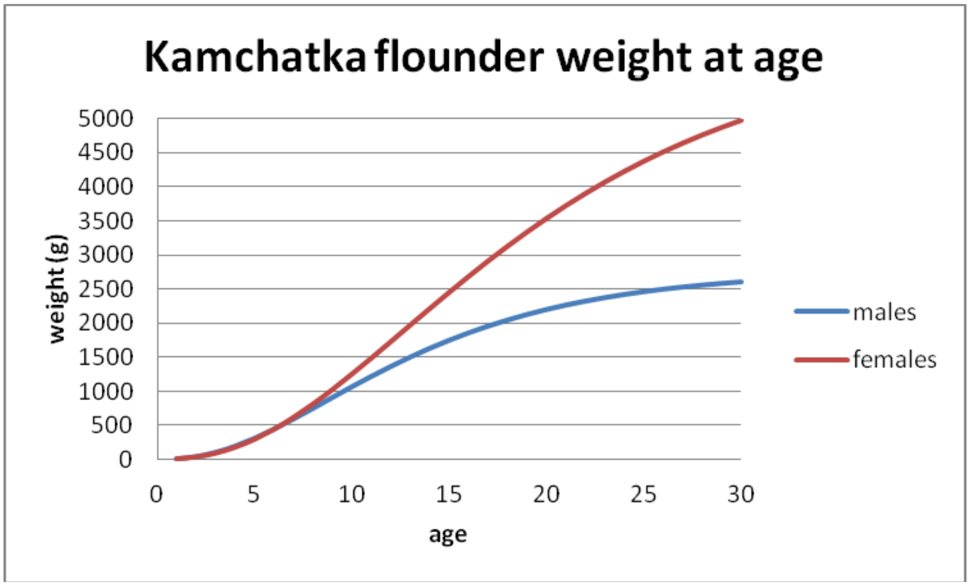


Figure 7A-7 Estimated weight-at-age for male and female Kamchatka flounder from a 2010 age sample from the Aleutian Islands.

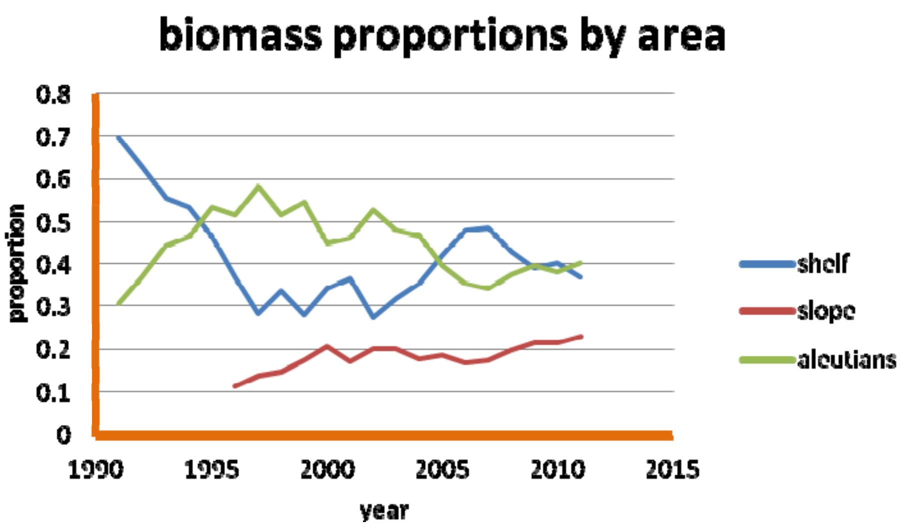


Figure 7A-8 Area-specific catchability was assigned in the assessment model according to the proportion of the average biomass from the time-series of each trawl survey (shelf, slope and Aleutian Islands).

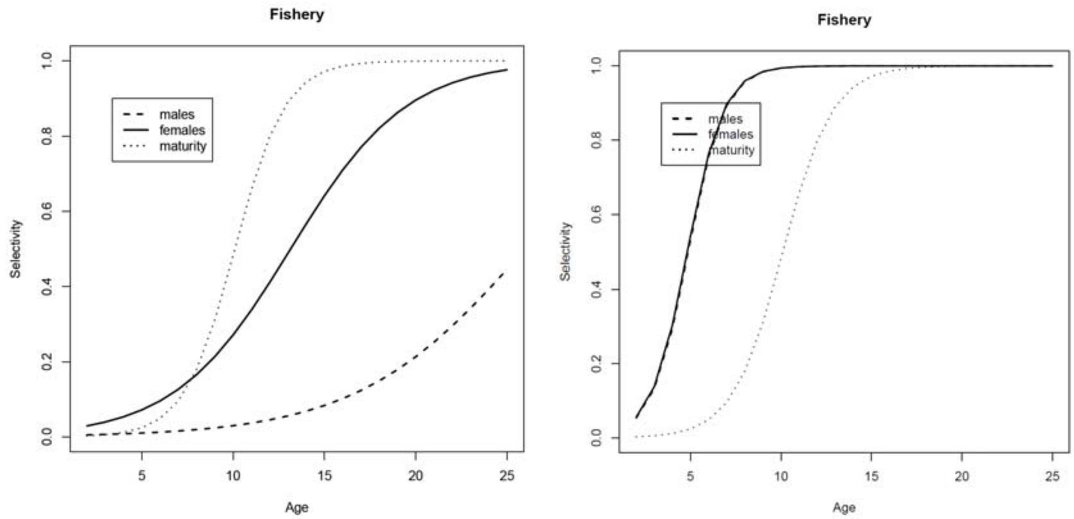


Figure 7A-9 Estimated fishery selectivity from two model runs, unconstrained (left panel) and estimated with slope parameter fixed (right panel). Maturity curve is also plotted.

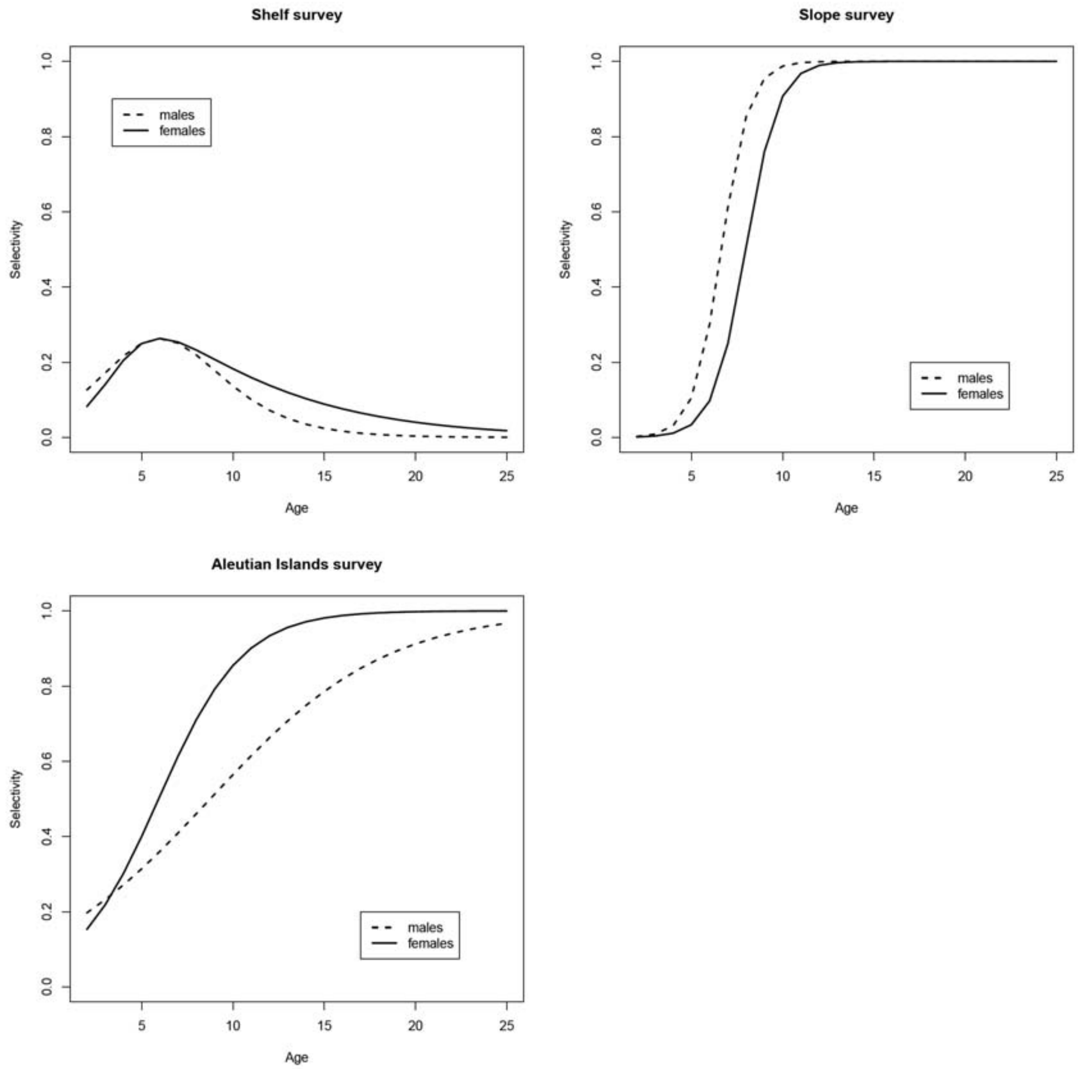


Figure 7A-10 Model estimates of survey selectivity, males and females, for the shelf, slope and Aleutian Islands.

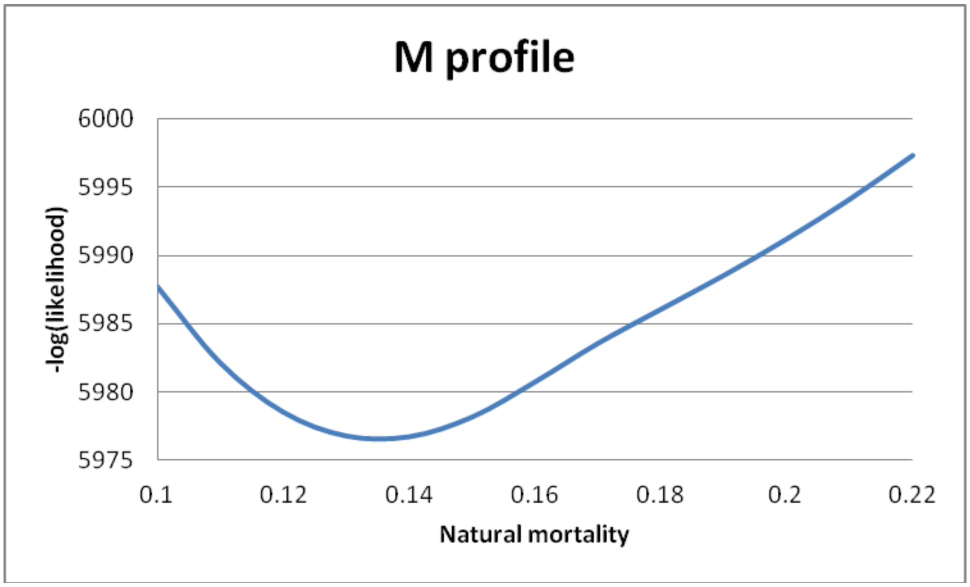


Fig 7A-11. Total –Log(likelihood) values for model runs where natural mortality values ranged from 0.1 to 0.22.

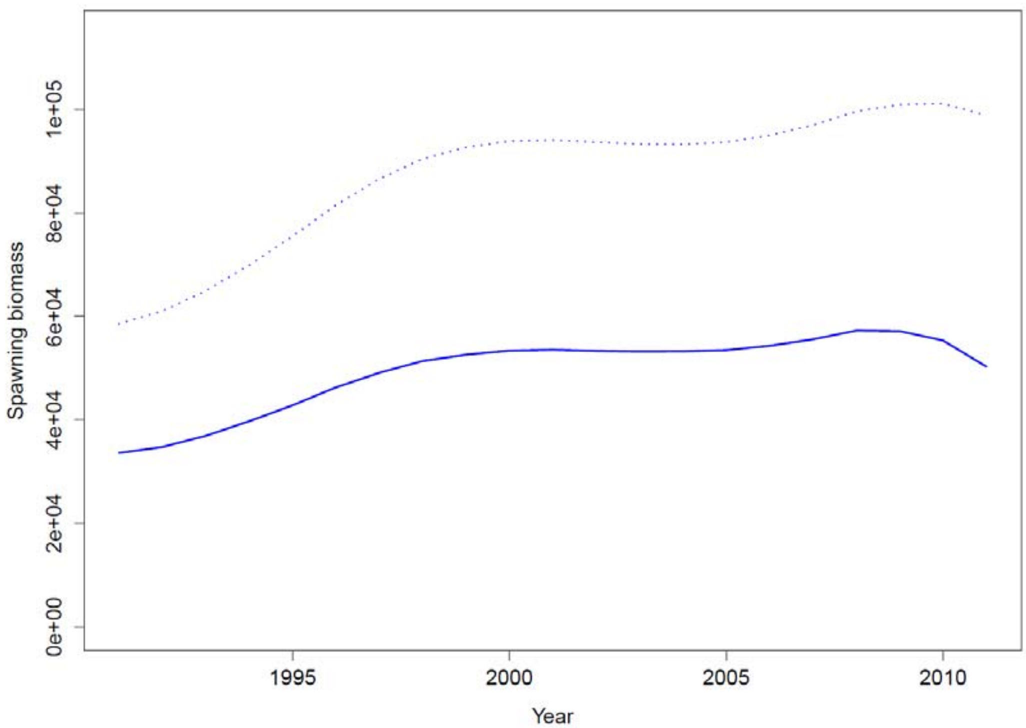


Figure 7A-12 Comparison of spawning biomass estimates with slope survey catchability fixed at 0.18 (solid line) and 0.1 (dotted line). The difference in total likelihood between these models was 1.95 (with the higher biomass model being favored).

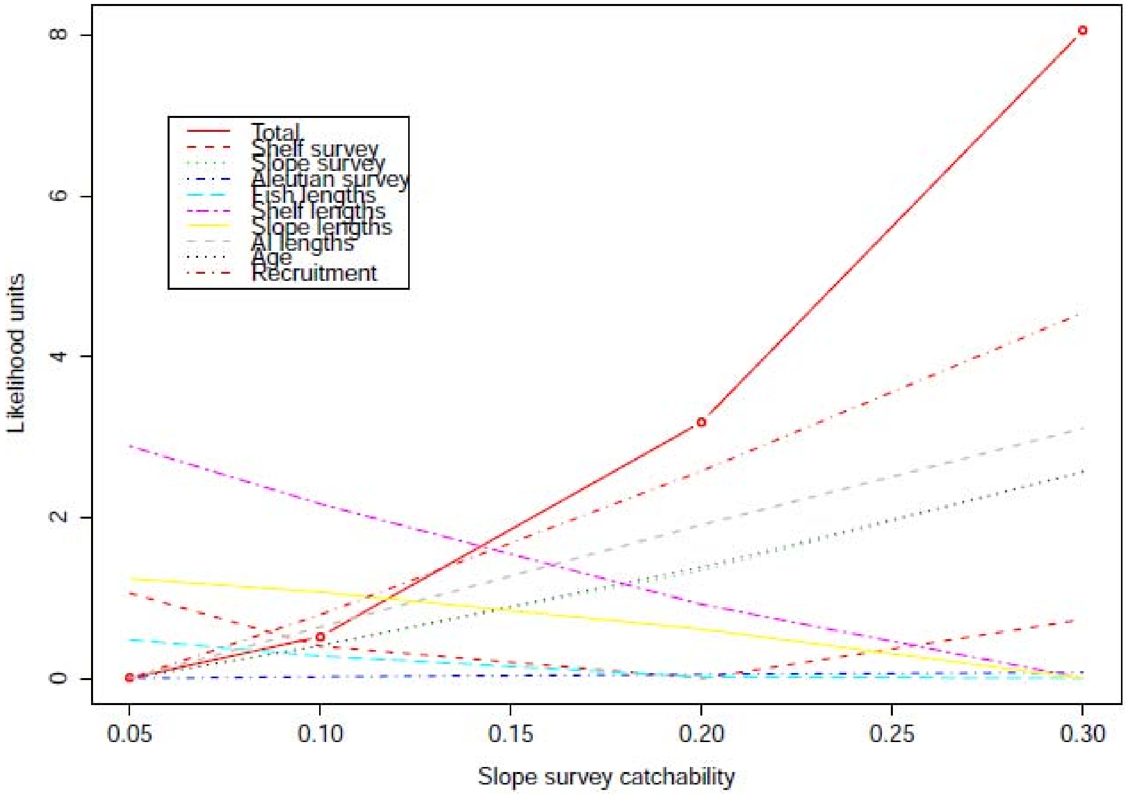


Figure 7A-13 Plot of –log(likelihood) values for model components when profiling over values of slope survey q ranging from 0.05 to 0.3.

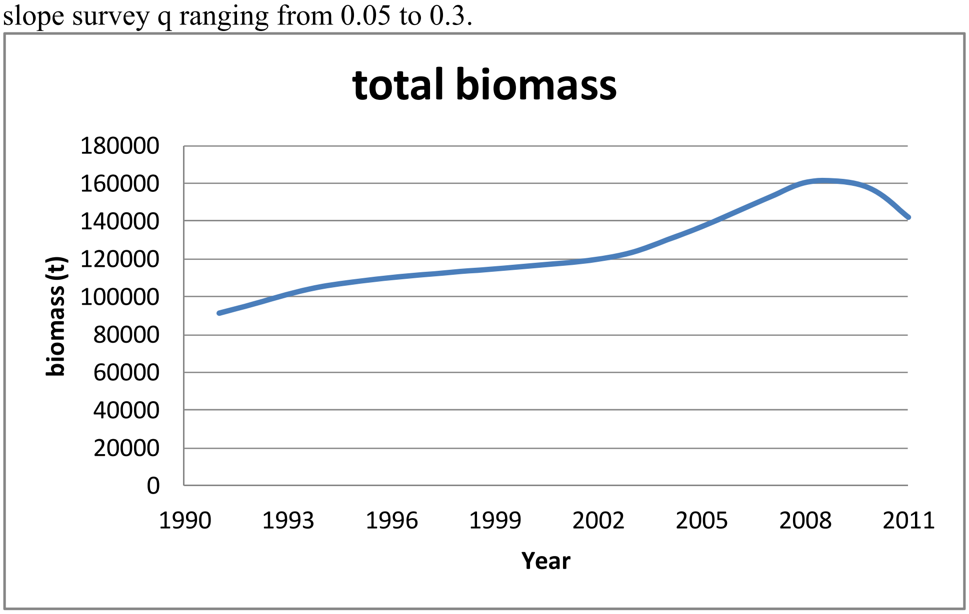


Figure 7A14 Assessment model estimate of total Kamchatka flounder biomass (t) from 1991-2011.

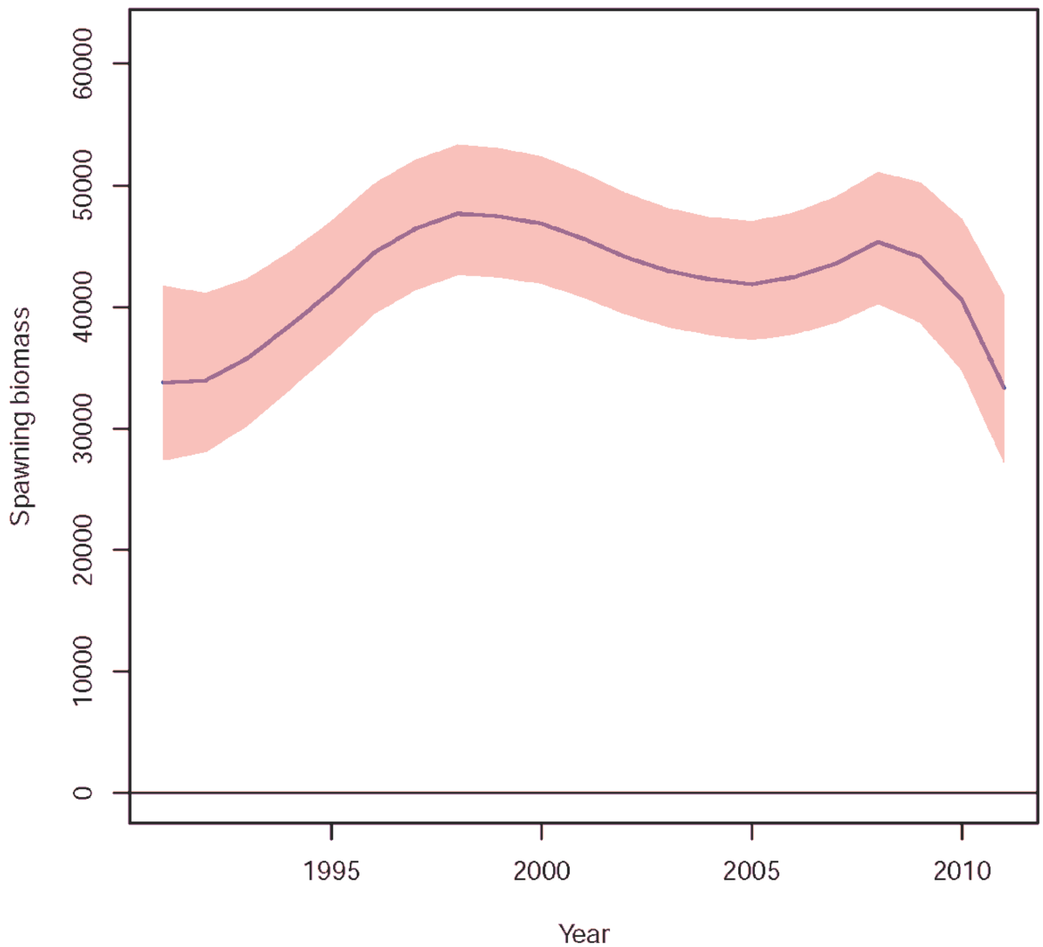


Figure 7A-15 Assessment model estimate of female spawning biomass (t).

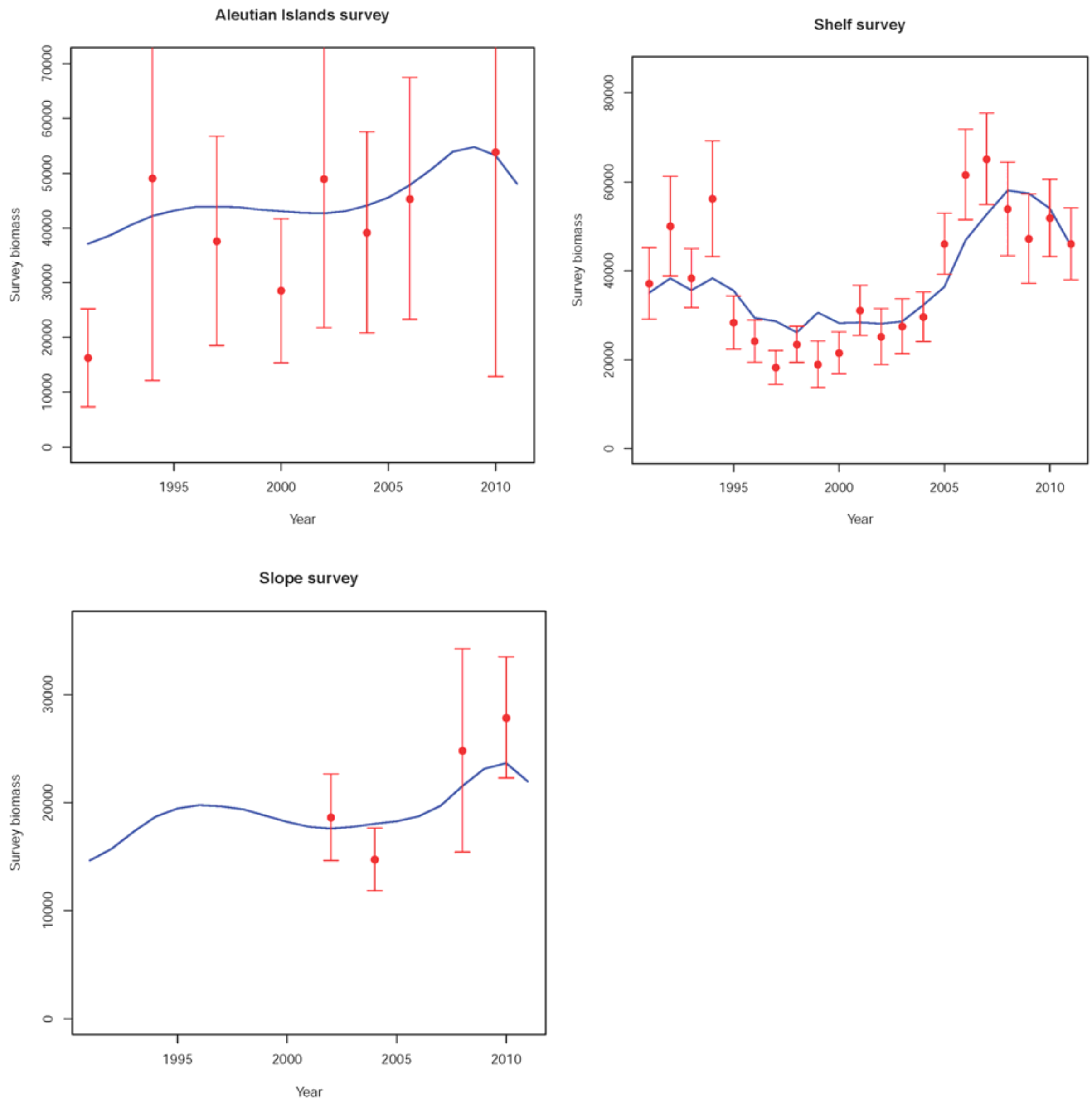


Figure 7A-16 Assessment model fit (blue line) to the shelf, slope and Aleutian Islands surveys (shown with 95% confidence intervals).

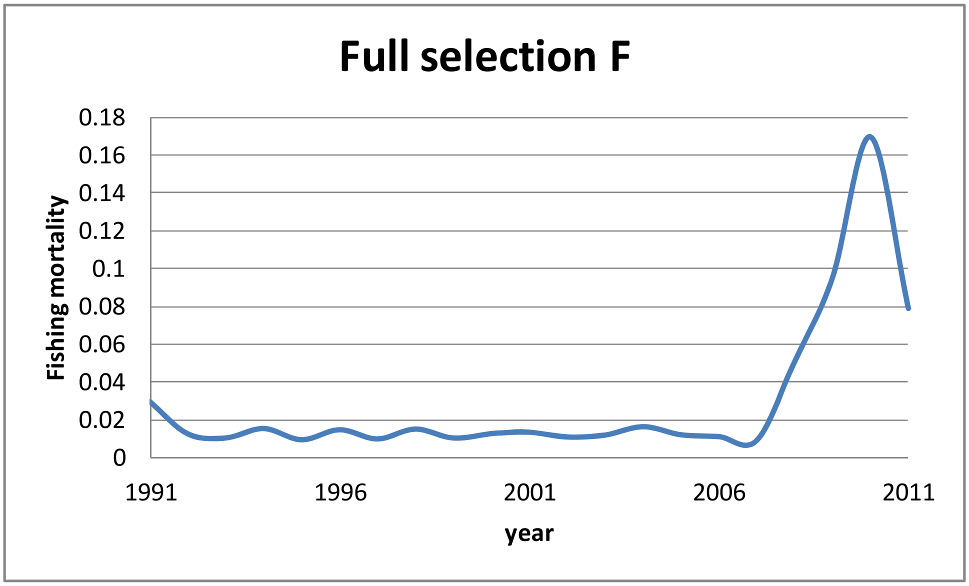


Figure 7A-17. Assessment model estimate of full selection F for 1991-2011.

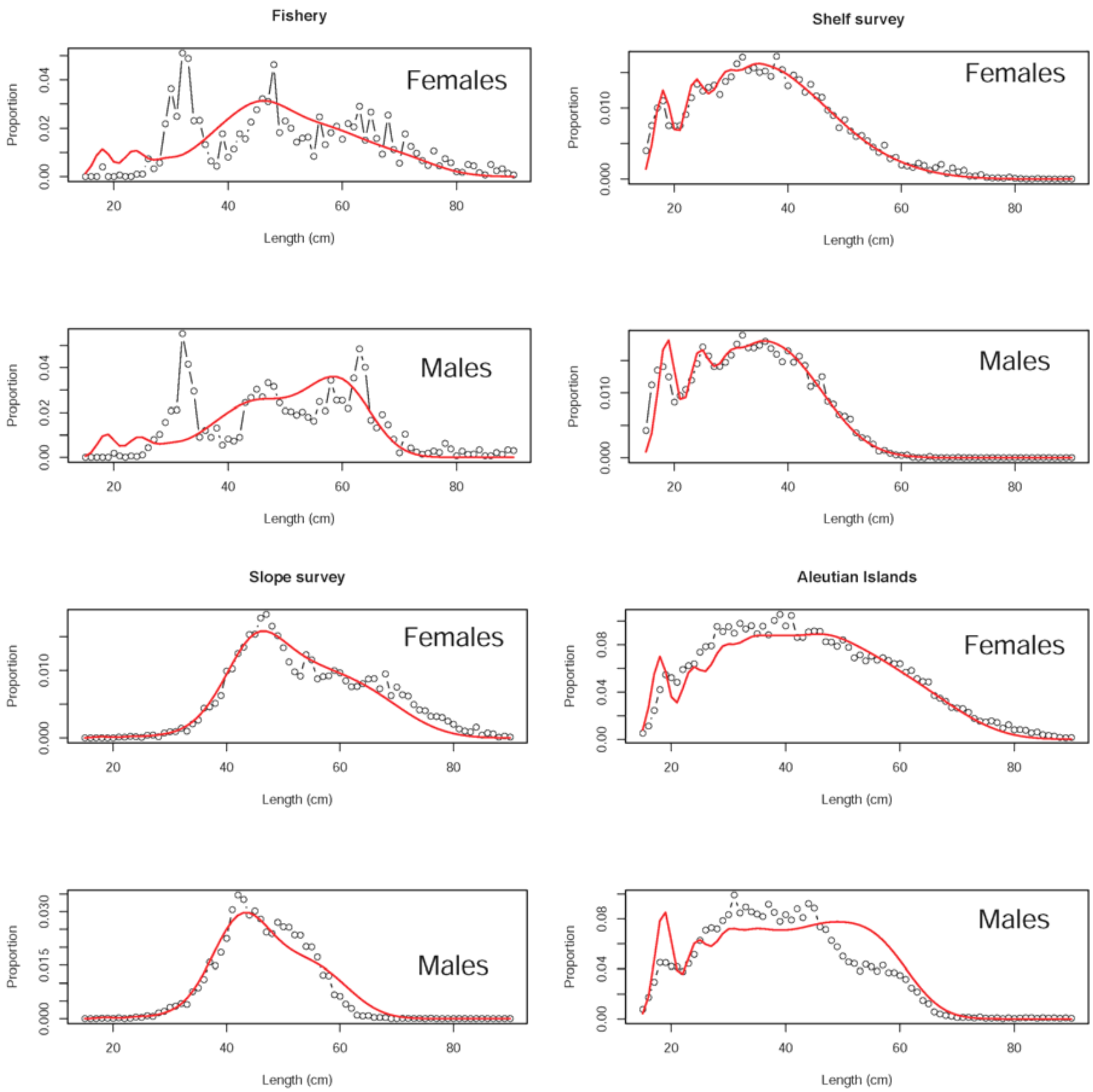


Fig. 7A-18 Comparison of the average observed proportion at length from the time-series to the average predicted proportion at length from the model for the fishery, and the three surveys on the Bering Sea shelf, slope and the Aleutian Islands.

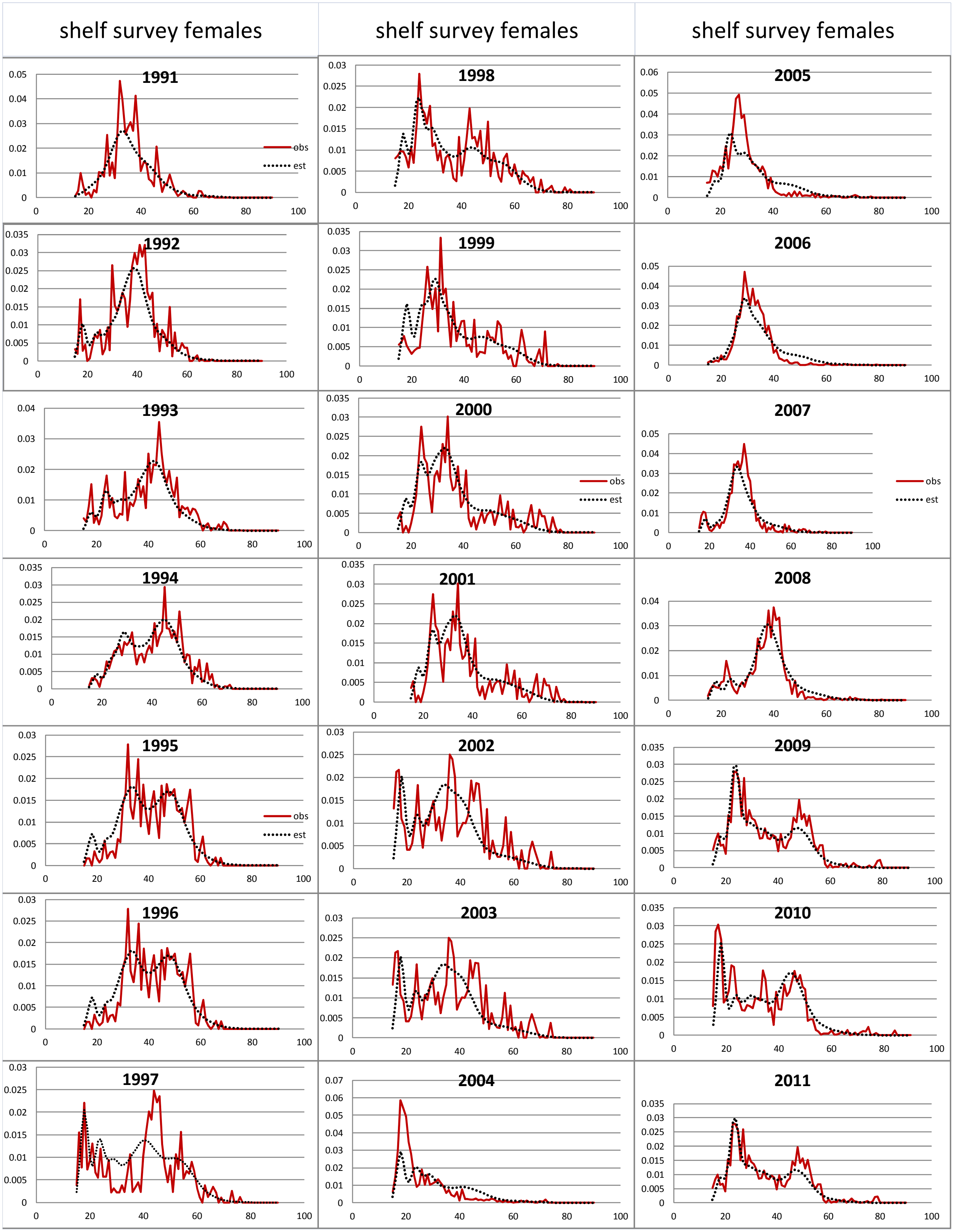


Figure 7A-19 Assessment model fit (black dotted line) to the shelf, slope and Aleutian Islands survey size compositions (red solid line).

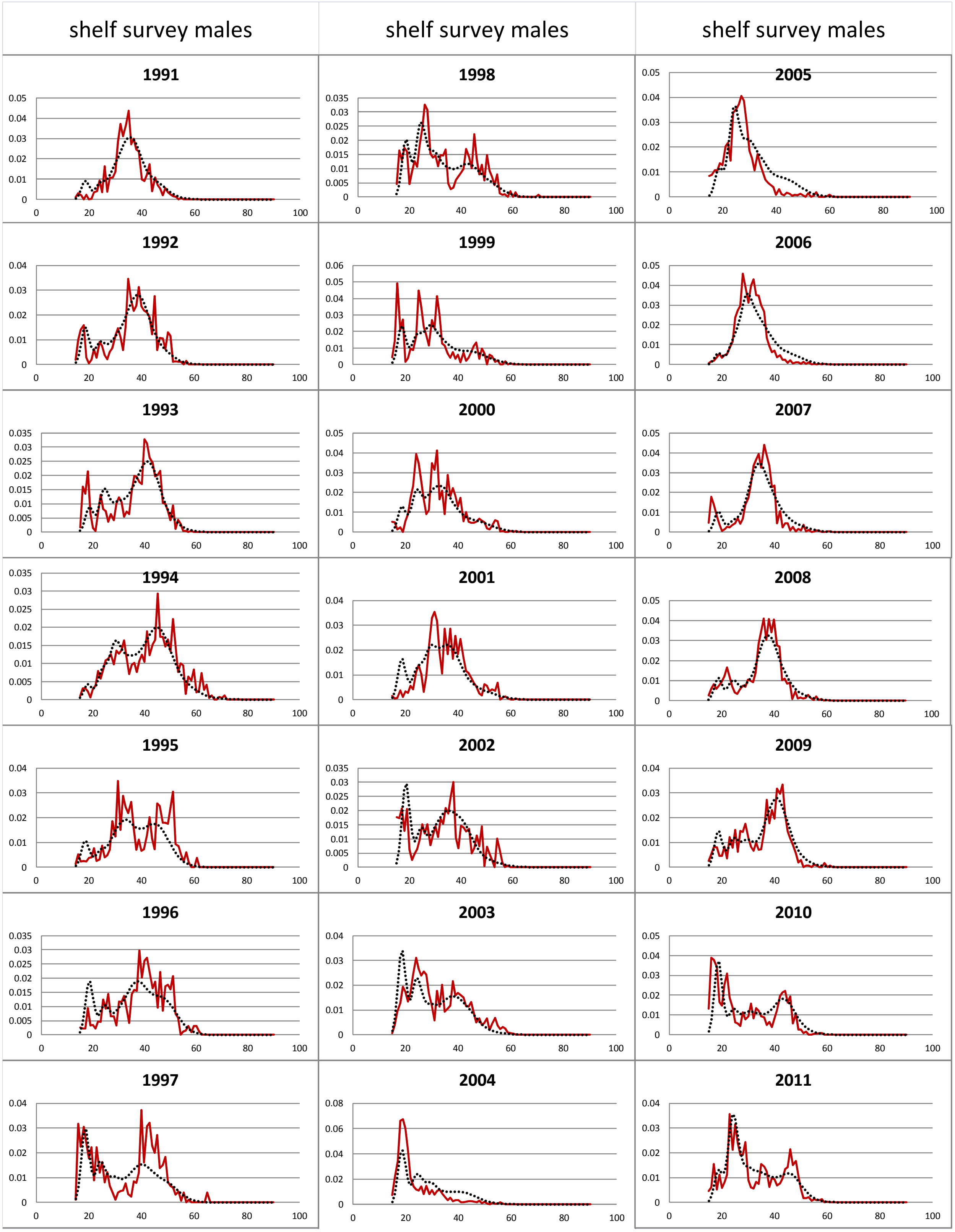


Figure 7A-19 continued.

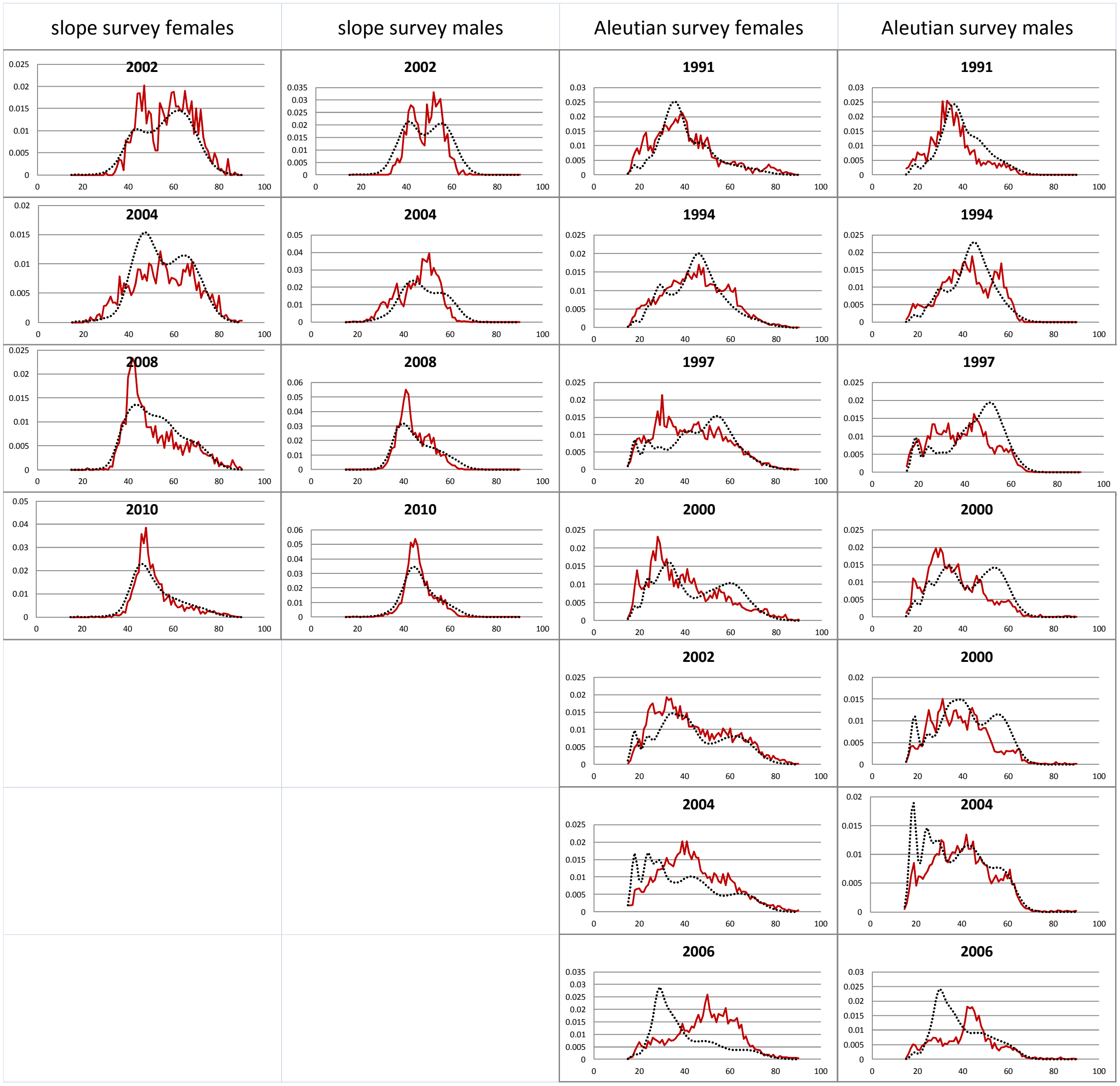


Figure 7A-19 continued.

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