Abstract.–The biology and distribution of arrowtooth, *Atheresthes stomias*, and Kamchatka, *A. evermanni*, flounder were examined in Alaskan waters to determine whether there were sufficient differences to justify treating them as separate species in resource assessment surveys conducted by the National Marine Fisheries Service. Geographic ranges of the two flounder species overlap in Alaska waters; both occur in the eastern Bering Sea and western Aleutian Islands region. However, only arrowtooth flounder occur throughout the eastern Aleutian Islands region and the Gulf of Alaska. Arrowtooth flounder were abundant over a wide range of depths (76–450 m) and were more abundant than Kamchatka flounder in catches shallower than 325 m. Kamchatka flounder were abundant only in deep trawl hauls (226–500 m) and were more abundant than arrowtooth flounder in catches at depths greater than 375 m. Arrowtooth flounder were also abundant over a wide range of bottom-water temperatures (2.1°–4.6°C), whereas Kamchatka flounder were abundant in a much narrower range of bottom temperatures (3.8°–4.2°C). By percentage, females dominated the arrowtooth flounder population in the eastern Bering Sea (68.6%) and Aleutian Islands region (59.6%), whereas the Kamchatka flounder population was 55.9% and 47.5% female, respectively. The females of both species attained greater length at age than did the males. The difference in growth between the sexes was greater among arrowtooth flounder and may account for the preponderance of females in the arrowtooth flounder population.

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Biology and distribution of arrowtooth, *Atheresthes stomias*, and Kamchatka, *A. evermanni*, flounders in Alaskan waters

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Arrowtooth flounder, *Atheresthes stomias*, and Kamchatka flounder, *A. evermanni*, were not always treated as separate species in resource assessment bottom trawl surveys of the Alaska Fisheries Science Center (AFSC) prior to 1991 because of their similarity in appearance, lack of commercial importance, and the limited abundance of Kamchatka flounder in comparison with arrowtooth flounder. They were both grouped as arrowtooth flounder and possible differences between them were not thoroughly documented. Most of the previous research conducted on *Atheresthes* spp. has treated them as a species complex. The few comparative studies of *Atheresthes* spp., based on morphometrics (Norman, 1934; Wilimovsky et al., 1967; Yang, 1988), genetics (Ranck et al., 1986), diet (Yang and Livingston, 1986), and geographic distribution (Shuntov, 1965; Wilimovsky et al., 1967; Allen and Smith, 1988), have documented few differences between the two species.

Arrowtooth flounder accounts for 55% of the flatfish biomass in the western Gulf of Alaska (Brown[1]); it is the dominant flatfish of that area, and yet it has not supported a large fishery. Arrowtooth flounder have been caught commercially in small fisheries off the Pacific coast of Canada and off the Washington and Oregon coasts for use in animal feeds as well as for human consumption (Kabata and Forrester, 1974). Softening of the flesh, probably caused by an enzyme released from a myxosporean parasite (Greene and Babbitt, 1990), has limited the marketability of arrowtooth flounder as food. Recent work, however, has shown promise in producing marketable flounder products, such as arrowtooth flounder fillets (Greene and Babbitt, 1990), arrowtooth flounder surimi (Wasson et al., 1992; Porter et al., 1993; Reppond et al., 1993), and Kamchatka flounder surimi (Haga et al.[2]). Potentially, a fishery targeting arrowtooth flounder in Alaskan waters could have an effect on the Alaskan population of Kamchatka flounder. Knowledge of the biology of the two species may provide crucial information needed for their proper management and conservation. Therefore, since 1991, these species have been considered as two separate

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[1] Brown, E. S. 1994. Alaska Fisheries Science Center, Resource Assessment and Conservation Engineering Division, 7600 Sand Point Way NE, Seattle, WA 98115. Personal commun.

[2] Haga, H., R. Shigeoka, and T. Yamauchi. 1980. Method for processing fish contaminated with sporozoa. U.S. Patent 4,207,354, Jun. 10.

species during resource assessment surveys conducted by the AFSC.

The purpose of the present work was to document the geographical overlap of the two flounder species in Alaskan waters and to describe the ecological differences, such as length at age, sex-ratios, and depth and temperature preferences that allow such externally similar species to coexist. Incorporation of this information into future AFSC surveys may prove essential for the management of the two species.

Materials and methods

Data were obtained from bottom trawl surveys conducted from research vessels over the continental shelf (<200 m) and slope (200–800 m) of the eastern Bering Sea and off the Aleutian Islands (<500 m). The surveys were conducted from June through September 1991. Sample design, fishing gear and methods, catch sampling procedures, and data analyses are described by Goddard and Zimmermann[3] for the eastern Bering Sea shelf and slope and by Harrison (1993) for the Aleutian Islands. The bottom trawl used in the Bering Sea shelf survey was different from that used in the Bering Sea slope and Aleutian Islands region. The bottom trawl used on the Bering Sea shelf had smaller meshes in the net wings and body and was used without roller gear; therefore it fished heavily on the bottom. The bottom trawl used on the Bering Sea slope and in Aleutian Islands region was used with bobbin roller gear and had larger meshes in the net wings and body. Additional data were incorporated from the western Gulf of Alaska bottom trawl survey (<500 m) conducted in 1993 but were used only for defining geographic ranges. Nets were towed at approximately 5.5 km/hr (3 knots) for 30 minutes, covering a distance of 2.8 km (1.5 nmi). Mean net width, as measured with SCANMAR net mensuration gear, was multiplied by the distance traveled to calculate the area swept by the net. Catch per unit of effort (CPUE) was calculated for each species for each tow in kilograms per hectare (kg/ha). Either micro-bathythermograph probes fixed to the net or expendable bathythermograph probes dropped at the haul sites recorded bottom temperatures (±0.1°C).

Arrowtooth and Kamchatka flounders were distinguished by the position of their upper eyes. The upper eye of arrowtooth flounder interrupts the profile of the head and can be seen from the blind side. The upper eye of the Kamchatka flounder does not interrupt the head profile. Fish whose upper eye was not located with any certainty or which had a damaged upper eye were distinguished by number of gill rakers (Yang, 1988). After sorting, each species was weighed separately. Fish size was recorded as fork length, and the sex of each fish was determined by making an incision posterior to the abdomen on the blind side and by visually inspecting the gonadal tissue.

Comparisons were made between the abundance of the two species in CPUE (kg/ha) by depth interval and water temperature interval. When there were a sufficient number of hauls, depth was divided into 25-m intervals and temperature into 0.1°C intervals. When there were few hauls, catches were grouped into 100-m depth intervals and 1.0°C intervals. For trawl hauls in which both species were caught, a logistic model was developed to show the relationship between the proportion of arrowtooth flounder in the total *Atheresthes* catch and depth;

$$(\ln(p/1-p)=\alpha+\beta x),$$

where p is the proportion of arrowtooth flounder in the total *Atheresthes* catch rate, $1-p$ is the proportion of Kamchatka flounder in the total *Atheresthes* catch rate, α and β are constants, and x is the depth in meters.

The geographic distributions of both species were described from our thorough but depth-limited bottom trawl survey data, supplemented by data supplied by the Fishery Observer Program of the AFSC, which also supplied species composition data on catches from deep waters in the Gulf of Alaska. Nonlinear regressions related mean length of arrowtooth and Kamchatka flounder by haul to depth;

$$L=L_{\infty}-Ae^{BM},$$

where L is estimated length, L_{∞} is theoretical maximum length, M is depth in meters, and A and B are constants.

Initial observations indicated an unusually high percentage of females in the arrowtooth flounder population. Juvenile fish from which the sex could not be determined, generally less than 20 cm in length, were not included in the analysis. The percentage of females in the arrowtooth flounder population was compared against the percentage of females in the Kamchatka flounder population for both the Aleutian Islands and the eastern Bering Sea. Comparisons were also made against the other major flatfish species in the eastern Bering Sea to de-

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[3] Goddard, P., and M. Zimmermann. 1993. Distribution, abundance, and biological characteristics of groundfish in the eastern Bering Sea based on results of the U.S. bottom trawl survey during June–September 1991. AFSC Processed Rep. 93-15, 342 p. Alaska Fisheries Science Center, Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way NE, Seattle, WA 98115-0070.

termine whether the unusually high percentage of females in the arrowtooth flounder population, seemingly an odd occurrence, was also typical of the other species from the same area caught in the same survey. Additional comparisons could not be made from data gathered in the Aleutian Islands because of the limited number of sex determinations of other flatfish species.

The unusually high percentage of females in the arrowtooth flounder population prompted us to analyze the data in different ways to look for trends in percentages of females. The percentage of females was calculated from individual trawl hauls in which the sex was determined from a minimum of 10 fish. Percent-female values for arrowtooth flounder were examined geographically to determine whether there were regions where male arrowtooth flounder were abundant. Percent-female values were also regressed against bottom temperature and depth. By searching for trends in percent-female values, we hoped to identify areas where high proportions of arrowtooth flounder males may have occurred but were not sampled or were underrepresented in our survey.

For fish from the eastern Bering Sea slope, sagittal otoliths were collected from up to three fish per sex per centimeter interval for ageing and were stored in a glycerol-thymol solution. Because previous methods for preparing the otoliths for ageing did not clearly reveal the annular rings, researchers at the AFSC developed a new technique (Scott[4]). Otoliths were cut along their dorsal-ventral axis through the nucleus and evenly heated in a muffle furnace at 270°C for 5 to 10 min. If the annular rings were not sufficiently darkened, the otoliths were burned in an alcohol flame. When cool, oil was applied to the otolith surface and the cut surface read with a binocular dissecting scope.

Von Bertalanffy growth curves were calculated for the age and length data by using nonlinear regression to provide estimates of L_∞, K, and t_0. To determine whether growth differed significantly between sexes or between species, the residual sum of squares (RSS) from a combined model was compared by using an approximate F-test (Draper and Smith, 1981):

$$F = \frac{(RSS_{TOTAL} - (RSS_1 + RSS_2))/3}{(RSS_1 + RSS_2)/N - 6},$$

where N is equal to the number of otoliths aged, and 1 and 2 are either male and female arrowtooth or male and female Kamchatka flounder. Kimura (1990) showed that this approximation of the test statistic, which tests for differences between all growth curve parameters simultaneously, can be useful for testing von Bertalanffy growth parameters. The test statistic was compared against values from the F-distribution at the α=0.05 level of significance. The von Bertalanffy parameters were then used to provide estimates of length at age for the range of ages found for each species and sex group.

Results

Atheresthes spp. were caught in 492 of the 779 trawl hauls. Neither species was caught in the shallowest trawl hauls (<25 m), whereas catch rates for both species were low in the deepest trawl hauls (700 m to 800 m). Arrowtooth flounder were abundant from 76 m to 450 m, with mean CPUE ranging from 3.3 to 13.6 kg/ha (Fig. 1). Kamchatka flounder were abundant from 226 m through 500 m, with mean CPUE ranging from 3.8 to 12.8 kg/ha. Arrowtooth flounder catch rates showed a bimodal distribution in relation to depth, with high catch rates in both shallow (76 m to 225 m) and deep (226 m to 450 m) trawl hauls. Kamchatka flounder catch rates were weakly bimodal, with only low catch rates in shallow waters and all the highest catch rates in deeper waters.

A comparison of the percent of the total *Atheresthes* CPUE by species for each depth interval shows that arrowtooth flounder were more abundant in the shallower depth intervals (≤250 m) (Fig. 2). There was a zone of transition between the two species from 251 m to 425 m. Finally, Kamchatka flounder were more abundant than arrowtooth flounder from 426 m to 800 m. For trawl hauls in which both species were caught, a logistic regression relating percentage of arrowtooth flounder of the total *Atheresthes* CPUE against depth (Fig. 3) showed a significant, negative relationship (df=277, F=98.8, P<0.001, R^2=0.26). The model was

$$3.47 - 0.009(Depth) = \ln(p/1 - p),$$

where p = Arrowtooth flounder CPUE/*Atheresthes* CPUE.

Data on the water temperature distribution of *Atheresthes* spp. were recorded from 252 of the 492 trawl hauls in which *Atheresthes* spp. were caught. *Atheresthes* spp. were caught only in temperatures between 0.3° and 5.9°C (Fig. 4), whereas the survey temperatures ranged from –1.5° to 11.7°C. Arrowtooth flounder were abundant at a wide range of bottom temperatures, but they were most abundant at temperatures of 2.1° to 4.6°C. While the total range

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[4] Scott, K. 1994. Alaska Fisheries Science Center, Resource Ecology and Fisheries Management Division, 7600 Sand Point Way NE, Seattle, WA 98115. Personal commun.

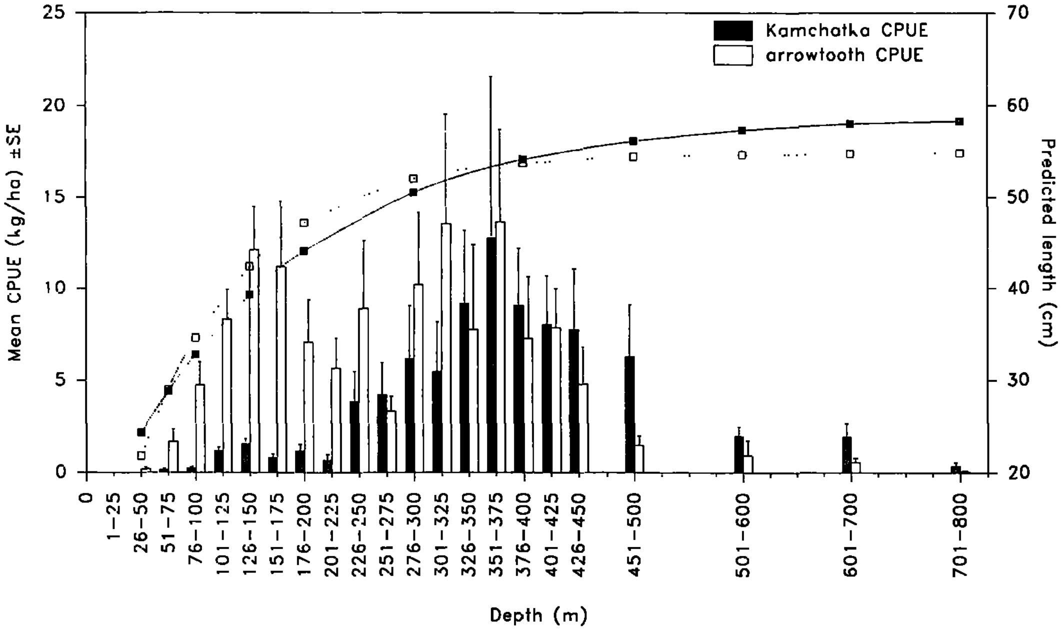

Figure 1

Mean catch per unit of effort (CPUE) in kg/ha (±1 SE) in relation to depth interval for the *Atheresthes* species. Length-at-depth curves are superimposed over the bar graph.

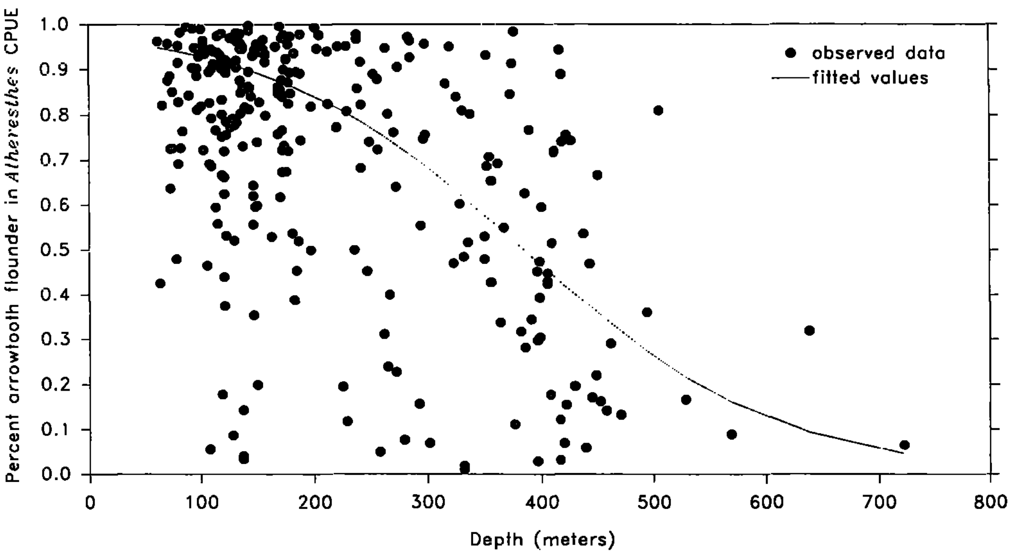

Figure 2

Percent by species of the total *Atheresthes* catch per unit of effort (CPUE) in relation to depth interval.

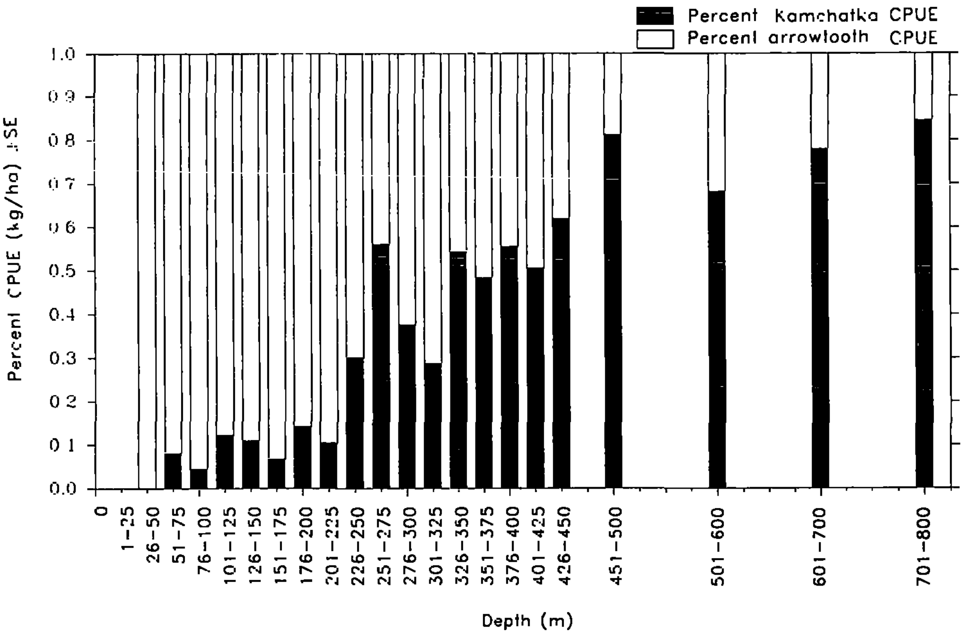

Figure 3

Logistic model relating percentage of arrowtooth flounder of the total *Atheresthes* catch rate to depth.

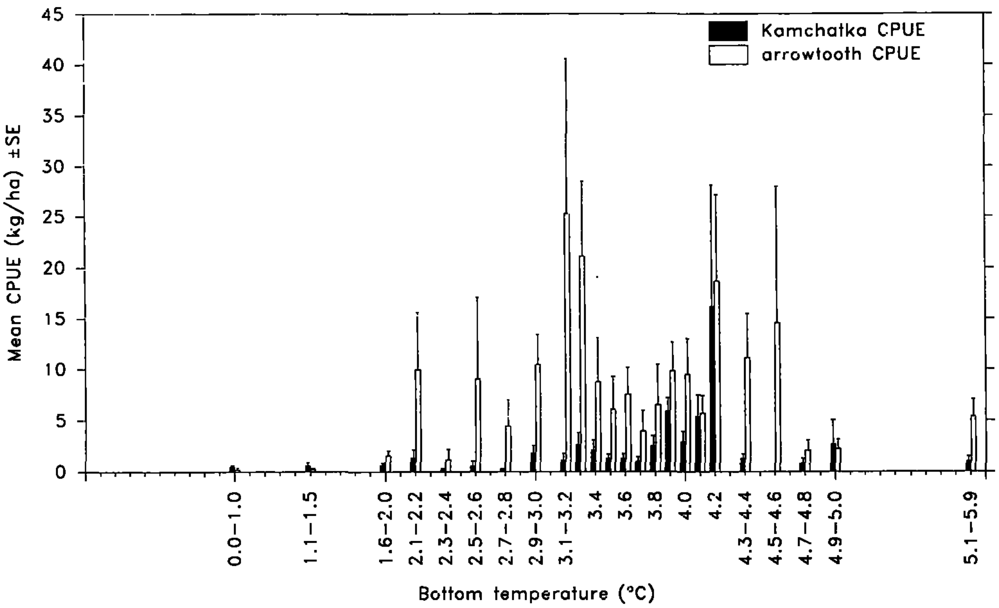

Figure 4

Mean catch per unit of effort (CPUE) in kg/ha for the *Atheresthes* species in relation to bottom temperature.

of water temperatures for Kamchatka flounder (0.7° to 5.9°C) was similar to the range for arrowtooth flounder (0.3° to 5.9°C), the highest catch rates of Kamchatka flounder were distributed over a narrower temperature range (3.8° to 4.2°C).

Arrowtooth flounder catch rates were high on the eastern Bering Sea continental shelf (7.3 kg/ha), especially in waters between 100 m and 200 m (17.7 kg/ha), on the eastern Bering Sea continental slope (8.8 kg/ha), and the fish occurred throughout the Aleutian Islands (Fig. 5). The Kamchatka flounder geographic distribution was similar to that of arrowtooth flounder (Fig. 6), except that Kamchatka flounder were not caught along the Alaska Peninsula, nor in the Gulf of Alaska. Kamchatka flounder were much less abundant than arrowtooth flounder in the eastern Bering Sea, especially on the shelf (1.2 kg/ha), and about half as abundant as arrowtooth flounder on the slope area (4.6 kg/ha). However, in the deepest half of the slope area (500 m to 800 m), the catch rate of Kamchatka flounder (1.5 kg/ha) was about twice that of arrowtooth flounder (0.7 kg/ha). Kamchatka flounder occurred on the northwest tip of the eastern Bering Sea shelf, whereas arrowtooth flounder were absent from that area. Arrowtooth flounder catch rate was high along the north side of the easternmost Aleutian Islands bordering the southern Bering Sea (16.4 kg/ha), where more than half of the total biomass for the entire Aleutian Islands occurred (Harrison, 1993). Kamchatka flounder generally decreased in abundance from west to east along the Aleutian Islands (Harrison, 1993). The easternmost Aleutian Islands were the southeastern border of their distribution, where the catch rate was low (0.7 kg/ha). In the rest of the Aleutian Islands area, Kamchatka flounder had a slightly higher catch rate (3.1 kg/ha) than arrowtooth flounder (2.9 kg/ha), particularly in the 300 m to 500 m depth interval (10.8 vs. 2.0 kg/ha, Harrison, 1993).

Data provided from the Fishery Observer Program of the AFSC indicated the presence of Kamchatka flounder in the Gulf of Alaska as far east as 154°26'W, but in limited numbers and at great depths (Conrad[5]). The identification of Kamchatka flounder oc-

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[5] Conrad, M. 1994. Alaska Fisheries Science Center, Fishery Observer Program, 7600 Sand Point Way NE, Seattle, WA 98115. Personal commun.

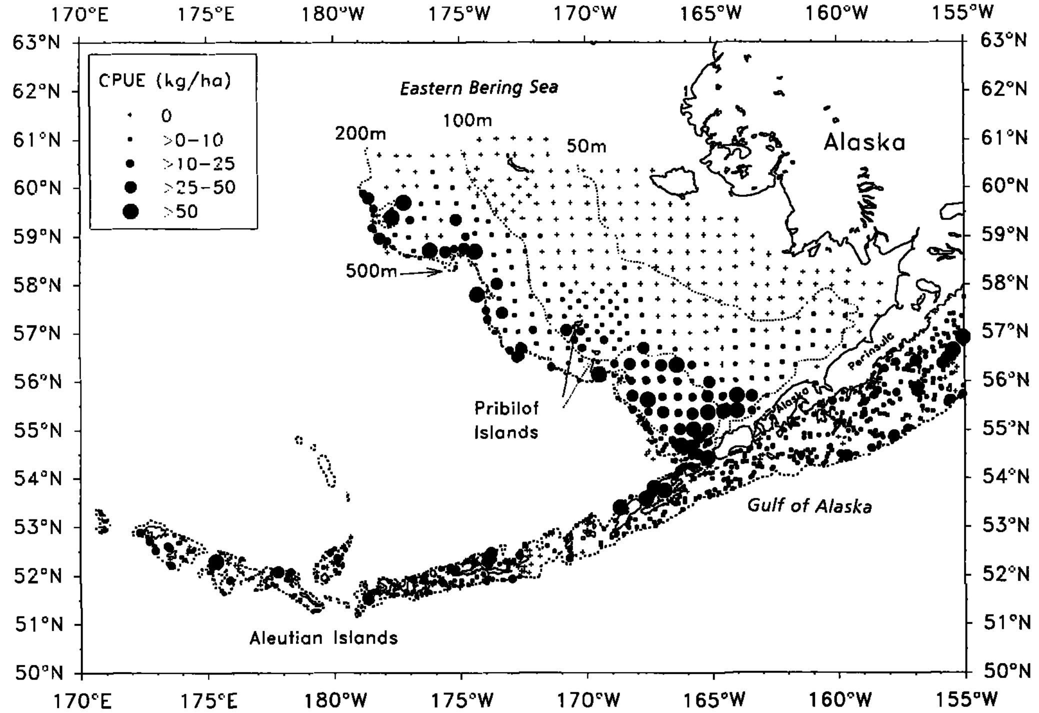

Figure 5

Map of arrowtooth flounder, *Atheresthes stomias*, CPUE (kg/ha) over the eastern Bering Sea shelf and slope, in waters off the Aleutian Islands, and in Gulf of Alaska areas. The 50-, 100-, and 200-m bathymetric contours are not included in the Aleutian Islands and Gulf of Alaska areas owing to complicated bottom topography.

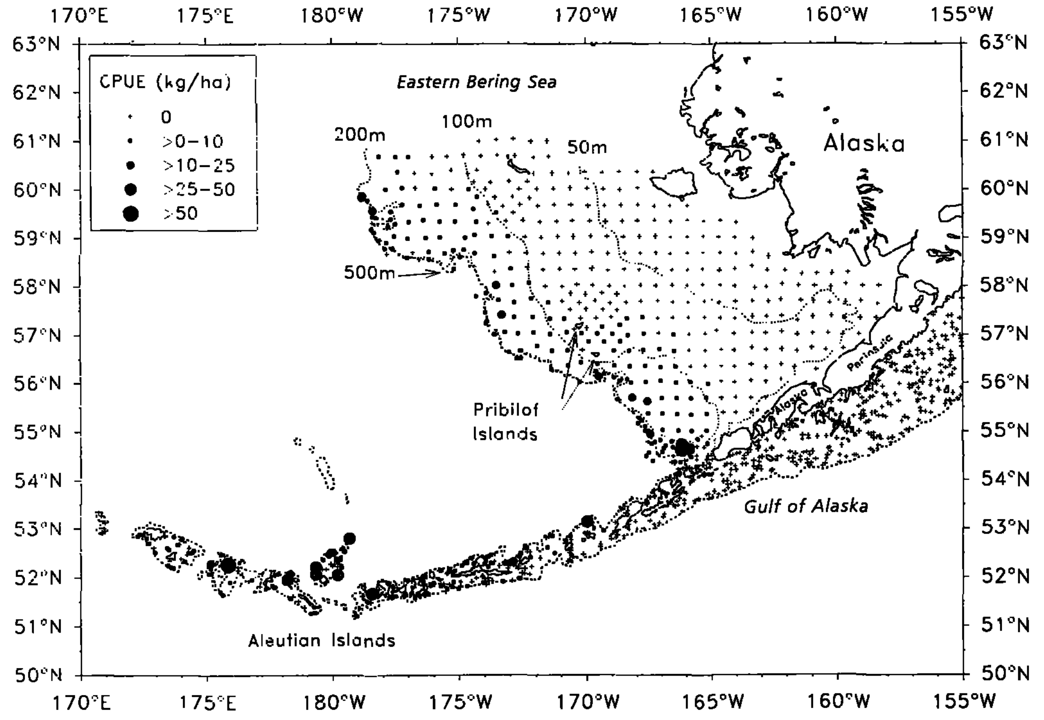

Figure 6

Map of Kamchatka flounder, *Atheresthes evermanni*, CPUE (kg/ha) over the eastern Bering Sea shelf and slope, in waters off the Aleutian Islands, and in Gulf of Alaska areas. The 50-, 100-, and 200-m bathymetric contours are not included in the Aleutian Islands and Gulf of Alaska areas owing to complicated bottom topography.

curring in the Gulf of Alaska was confirmed by meristic data recorded from three specimens. These rare occurrences of Kamchatka flounder in the Gulf of Alaska (length range 56–65 cm) were in depths (549–686 m) outside the depth range covered during the Gulf of Alaska bottom trawl survey.

The mean length of both *Atheresthes* flounders increased with depth, and asymptotic, curvilinear models were fitted to the data

$$\textit{arrowtooth flounder length} = 54.8 - 53.8e^{-0.0098 depth},$$

$$(df=131, F=3618.8, P<0.001, R^2=0.80);$$

$$\textit{Kamchatka flounder length} = 58.8 - 45.9e^{-0.0057 depth},$$

$$(df=64, F=2123.3, P<0.001, R^2=0.75).$$

The models show that for much of the size range (~30 cm to ~50 cm) for both species, Kamchatka flounder of the same length as arrowtooth flounder occur at a greater depth (superimposed on Fig. 1). Kamchatka flounder attain a greater length at depth than do arrowtooth flounder in depths greater than 400 m.

The relationship between length and water temperature was more complex and could be adequately described only in combination with geographic and depth relationships. The combined results from the eastern Bering Sea and Aleutian Island regions are presented in Table 1. A comparison of the depth and temperature differences between size groups and between species by statistical analyses was difficult because of lack of independence of the samples (both species were often taken together). Although the differences could not be tested, different size groups appeared to be associated with different depth zones and temperatures.

Catches of small arrowtooth flounder (<30 cm FL) were associated with shallow areas near the Pribilof Islands, the Alaska Peninsula, and the region north of the eastern Aleutian Islands. Medium-size arrowtooth flounder (from ≤30 to <40 cm FL) were grouped mostly between the 100 m and 200 m isobaths on the eastern Bering Sea shelf and around the central Aleutian Islands. The largest arrowtooth flounder

Table 1

Mean depth and mean temperature of trawl hauls from the eastern Bering Sea and Aleutian Islands region for small (<30 cm), medium (≥30 to <40 cm), and large (≥40 cm) arrowtooth, *Atheresthes stomias*, and Kamchatka, *A. evermanni*, flounder. Standard errors (±1) are in parentheses.

	Length group					
	Small	*n*	Medium	*n*	Large	*n*
Arrowtooth flounder						
Mean depth (m)	74.1 (3.11)	26	121.4 (2.64)	109	255.0 (10.41)	110
Mean temperature (°C)	4.5 (0.30)	16	3.4 (0.12)	48	3.7 (0.09)	70
Kamchatka flounder						
Mean depth (m)	—		135.1 (3.96)	37	351.4 (13.36)	66
Mean temperature (°C)	—		3.7 (0.19)	15	3.8 (0.09)	50

(≥40 cm FL) were caught near the edge of the Bering Sea shelf, in the Bering Sea slope area, and throughout the Aleutian Islands regions.

There was a difference in the temperature regimes of the Aleutian Islands and eastern Bering Sea regions. In waters off the Aleutian Islands, where collection of length data combined with bottom temperature data was scant (n=18), there was a significant, negative relationship between length and bottom temperature (df=16, F=13.5, P=0.002, R^2=0.46): smaller fish were present in the shallowest and warmest water (~5° to 6°C) whereas larger fish were found in deeper, cooler water, approaching 4°C. On the Bering Sea shelf and slope, there was a more complex relationship between fish size and bottom temperature, described by a large number (n=116) of observations. As fish size increased with depth, the bottom temperature dropped from 4.1°C (<30 cm FL, n=10) to 3.3°C (from ≤30 to <40 cm FL, n=43), and to 2.4°C (≥40 cm FL, n=12) near the shelf edge, though the largest fish were located where the bottom temperature increased (3.9°C, n=51) in the slope area.

For Kamchatka flounder, the group of smaller size fish was eliminated from analysis because it was represented by only five hauls, and for only two of those hauls had bottom temperatures been recorded. The groups of medium- and large-size Kamchatka flounder had geographic distributions similar to groups of comparable-size arrowtooth flounder. The medium-size (from ≤30 to <40 cm FL) Kamchatka flounder were found on the Bering Sea shelf generally between the 100 m and 200 m isobaths; however, they did not extend along the Alaska Peninsula nor near the eastern Aleutian Islands as did arrowtooth flounder. The group of large-size Kamchatka flounder (≥40 cm FL) was found along the edge of the Bering Sea shelf, the Bering Sea slope, and throughout waters off the Aleutian Island chain, similar in geographic range to arrowtooth flounder. However, they were absent from the eastern islands. The bottom temperature data for the Kamchatka flounder was similar to that of the arrowtooth flounder, except that there were fewer data.

Arrowtooth flounder catches typically had a high percentage of females, whereas the Kamchatka flounder catches taken from the same trawl hauls generally had an equal sex ratio (our observations). In the eastern Bering Sea, the arrowtooth flounder population had a greater percentage of females (68.6%) than did the Kamchatka flounder population (55.9% female) (Table 2). Arrowtooth flounder also had a greater percentage of females than did *Hippoglossoides* spp. (51.7% female), Alaska plaice (*Pleuronectes quadrituberculatus*, 42.3% female), rock sole (*P. bilineatus*, 48.9% female) and yellowfin sole (*P. asper*, 54.2% female).

In the Aleutian Islands, arrowtooth flounder also had a higher percentage of females (59.6% female) than did Kamchatka flounder (47.5% female) and rock sole (52.6% female), the only species encountered in sufficient numbers in trawl hauls for comparison.

Plotting female percentage values of arrowtooth flounder geographically did not indicate any large areas where the percentage of females was low. Nor did it indicate areas where the population had a low percentage of females but was either undersampled or outside of the sampled area. The percentage of females was not significantly related to depth

($P>0.05$). The percentage of females was, however, significantly related to mean bottom-water temperature (df=121, $F=9.3$, $P=0.003$), but the relationship was very poor ($R^2=0.07$).

Otoliths were read from 187 arrowtooth and 120 Kamchatka flounder (Table 3). Computer generated estimates of L_∞, K, and t_0 were accepted except for the L_∞ estimates for arrowtooth flounder females. Our length measurement data indicated that the computer estimate was about 40 cm too long, therefore the relationship was forced, with L_∞ set to 85 cm. The von Bertalanffy growth curve was significantly different ($F=42.8$, $P<0.001$) between arrowtooth flounder males ($n=53$, range 3 to 9 years old) and females ($n=134$, range 4 to 12 years old, Fig. 7A). The growth curve was also significantly different ($F=10.6$, $P<0.001$) between Kamchatka flounder males ($n=57$, range 3 to 10 years old) and females ($n=63$, range 4 to 33 years old, Fig. 7B). Most of the Kamchatka flounder females were between the ages of 4 and 13 years, and just two fish were aged as 30 and 33 years old (not shown in Fig. 7B). All analyses were performed with and without the 30- and 33-year-old Kamchatka flounder females, with no change in results. The females of both species attained a longer length at age than did the males. For example, at age 9, female Kamchatka flounder were estimated to be 5 cm longer than male Kamchatka flounder and at age 9, female arrowtooth flounder were estimated to be 13 cm longer than the males.

The growth curves of arrowtooth flounder females and Kamchatka flounder females were significantly different ($F=25.0$, $P<0.001$), indicating that female arrowtooth flounder attain a greater length at age than Kamchatka flounder females (Fig. 7). For example, at age 9, female arrowtooth flounder were 7 cm longer than female Kamchatka flounder. The growth curve parameters of arrowtooth flounder males and Kamchatka flounder males were not significantly different ($P>0.05$).

Table 2

Percentage of females in the populations of the major flatfish species surveyed in the eastern Bering Sea in 1991.

Species	Percent female	Fish sampled	Trawl hauls
Arrowtooth flounder (*Atheresthes stomias*)	68.6	14,437	142
Kamchatka flounder (*A. evermanni*)	55.9	3,443	71
Yellowfin sole (*Pleuronectes asper*)	54.2	33,387	289
Flathead sole and Bering flounder (*Hippoglossoides* spp.)	51.7	25,872	342
Rock sole (*P. bilineatus*)	48.9	29,677	281
Alaska plaice (*P. quadrituberculatus*)	42.3	10,283	205

Discussion

In areas where the two species are found together, Kamchatka flounder occupy deeper water than arrowtooth flounder. The percent of arrowtooth flounder in the total *Atheresthes* catch was negatively related to depth. Even though the biomass of Kamchatka flounder was much smaller than that of arrowtooth flounder in the study area, their catch rates were actually higher than those for arrowtooth flounder in deep waters. For fish of similar size, Kamchatka flounder occurred at greater depths than arrowtooth flounder. The rare catches of small-size

Table 3

Parameters of the von Bertalanffy growth curves for arrowtooth, *Atheresthes stomias*, and Kamchatka, *A. evermanni*, flounder by sex, based on age readings from otoliths and length data from the 1991 AFSC bottom trawl survey of the eastern Bering Sea slope.

Group	Number of age readings	Age range (yr)	Length range (cm)	Parameters L_∞	Parameters K	Parameters t_0	Forced parameters
Arrowtooth flounder							
Male	53	3–9	33–51	57.932	0.172	–2.172	none
Female	134	4–12	36–75	85.000	0.161	0.812	L_∞
Kamchatka flounder							
Male	57	3–10	33–55	62.344	0.157	–1.411	none
Female	63	4–33	38–91	93.880	0.085	–1.519	none

and infrequent catches of medium-size Kamchatka flounder in the study area made it impossible to compare the catch rates of both species across the shallow end of the depth distribution. Whether this situation was a sampling artifact, year-class artifact, or an accurate representation of the Kamchatka flounder depth distribution, it increased the Kamchatka flounder's apparent preference for greater depths.

Comparison of the water temperature distribution of both species may also have been confounded by the limited catches of small- and medium-size Kamchatka flounder in the study area. For arrowtooth flounder, the more common catches on the Bering Sea shelf of small-size (warmest bottom temperature) and medium-size (coldest bottom temperature) arrowtooth flounder broadened the temperature range for the species. Thus the few trawl catches of small- and medium-size Kamchatka flounder on the Bering Sea shelf might have narrowed the temperature distribution of Kamchatka flounder.

The peculiar relationship of bottom-water temperature with mean fish size (i.e. medium-size fish at moderate depths but coldest water) may be explained by the unusual bottom-water temperature distribution of the eastern Bering Sea. The coldest bottom temperatures in the eastern Bering Sea in 1991 were on the mid-shelf area (Goddard and Zimmermann[3]), as is typically the case (Kinder and Schumacher, 1981). These mid-shelf waters are a cold-water remnant of the previous winter's ice cover (Takenouti and Ohtani, 1974). In contrast to the coastal waters, the mid-shelf waters do not increase in temperature with the spring and summer increase in solar radiation (Kinder and Schumacher, 1981). The depths of the mid-shelf waters are too great to permit wind- or tidal-driven mixing, and a thermocline develops that increases the stability of the water column. No strong currents bring warmer waters from the Gulf of Alaska into this area, and the relatively warm slope waters, which are not as affected by the winter ice cover, are fortified with warm waters from the deep (Schumacher[6]).

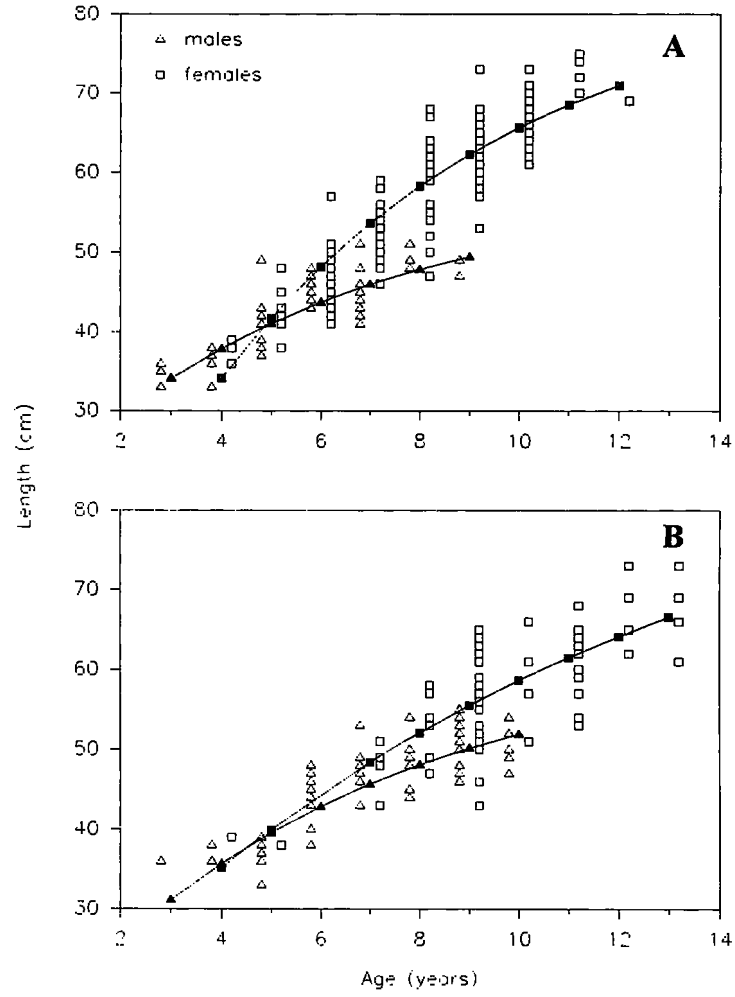

Figure 7

Individual length-at-age data (empty symbols) and von Bertalanffy estimates of mean length at age (filled symbols) for arrowtooth flounder, *Atheresthes stomias* (**A**), and Kamchatka flounder, *A. evermanni* (**B**).

The temperature data collected off the Aleutian Islands show a more typical relationship with depth; shallow bottom temperatures were warm and bottom temperature decreased, approaching 4°C, as depth increased. Most of the temperature data collected, however, came from the eastern Bering Sea shelf and slope.

Studies have shown that the geographic ranges of *Atheresthes* species do overlap in the north Pacific Ocean (Shuntov, 1965; Wilimovsky et al., 1967; Allen and Smith, 1988). The extent of the overlap and the southeastern boundary of the Kamchatka flounder distribution, however, had not been clearly defined. Kamchatka flounder has been reported to be the

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[6] Schumacher, J. D. 1994. Pacific Marine Environmental Laboratory, 7600 Sand Point Way NE, Seattle, WA 98115. Personal commun.

dominant species on the northwestern side of the Pacific Ocean, and arrowtooth flounder the dominant species on the northeastern side of the Pacific Ocean (Wilimovsky et al., 1967).

Kamchatka flounder occurs along the eastern shores of Japan from as far south as 38°N (Moiseev, 1953), in the Sea of Japan (Allen and Smith, 1988), along the eastern and western shores of the Kamchatka Peninsula, and along the eastern coast of Siberia north to Cape Navarin (Shuntov, 1965). Shuntov (1965) also reported that Kamchatka flounder occurs in the eastern Bering Sea, Commander Islands region, throughout the Aleutian Islands, and into the Gulf of Alaska as far east as Shelikof Strait.

On the western side of the Pacific Ocean, arrowtooth flounder occurs along the eastern shore of the Kamchatka Peninsula north to Cape Navarin (Shuntov, 1965). It occurs in the Commander Islands region (Shuntov, 1965), the eastern Bering Sea, throughout waters off the Aleutian Islands chain, in the Gulf of Alaska, and down the West Coast of North America to San Simeon, California, 40°N (Allen and Smith, 1988).

The geographic distribution and overlap of *Atheresthes* species in Alaskan waters were more clearly defined than had been previously reported (Shuntov, 1965; Wilimovsky et al., 1967; Allen and Smith, 1988). The arrowtooth flounder population was less abundant in the Aleutian Islands than in the southern Bering Sea area. The absence of arrowtooth flounder from the northwest tip of the eastern Bering Sea shelf perhaps also indicates the decreasing abundance of arrowtooth flounder from east to west in the eastern Bering Sea. The waters around the easternmost Aleutian Islands marked the general southeastern border of the Kamchatka flounder population. Our bottom trawl survey data show a smaller geographic range for Kamchatka flounder than that reported by Shuntov (1965). Data collected by the Fishery Observer Program of the AFSC were supported by the findings of Shuntov (1965), indicating that the Kamchatka flounder distribution also extends into the Gulf of Alaska, but only in limited numbers and in deep water. Future bottom trawl hauls in deeper waters (>500 m) during AFSC Gulf of Alaska surveys may extend the Kamchatka flounder's known range farther east.

Although large-size Kamchatka flounder were reported from deep waters in the Gulf of Alaska (Conrad[5]), the lack of any Kamchatka flounder in our Gulf of Alaska survey may indicate that this is not a self-sustaining population. These large-size Kamchatka flounder may have ventured into the Gulf of Alaska from the Aleutian Islands or eastern Bering Sea areas. The westerly flowing currents in the Gulf of Alaska do not foster retention of larvae in this area (Schumacher[6]), which might make it more difficult for larval Kamchatka flounder spawned in the Gulf to remain there.

The observed high percentage of females in the arrowtooth flounder population clearly distinguishes this species from Kamchatka flounder. The overabundance of females in the arrowtooth flounder population is an unusual occurrence among the major flatfish species in the eastern Bering Sea. The possibility that the sampling gear undersampled males, either by not catching them or by not retaining them as well as it did females, remains a possible explanation that was not examined. Many other possible sources of error were explored to determine whether the number of arrowtooth flounder females was overestimated. There was no indication that areas high in percentages of males were excluded from the trawl surveys. The possibility that fishery biologists conducting the surveys might have consistently made incorrect sex determinations seems highly unlikely because females are determined by the presence of ovarian tissue, whereas males are often designated males simply because no gonadal tissues were found. Any error made because of improper sex determination should have overestimated the number of males in the population. An explanation for the overabundance of female arrowtooth flounder in our observations may come from the length-at-age results.

The difference in length at age between male and female arrowtooth flounders was significant and indicated that for fish over 5 years old, female arrowtooth flounder were larger than male arrowtooth flounder. Our results were supported by earlier AFSC surveys for the eastern Bering Sea (Smith and Bakkala, 1982; Bakkala et al., 1985; Sample et al., 1985; Walters et al., 1988) and Aleutian Islands (Ronholt et al., 1994). These studies show that growth curves for arrowtooth flounder males and females diverge as early as three to five years of age and that females are larger than males. It is doubtful, however, that in past surveys arrowtooth and Kamchatka flounder were regularly separated for otolith collections, because they were not consistently separated for other purposes. Our results differ from the length-at-age data collected from arrowtooth flounder in British Columbian waters, which showed no separation in growth curves between sexes until age 9 (Kabata and Forrester, 1974).

Our findings that female arrowtooth flounder attain a greater size at age than do male arrowtooth founder was supported by sexual maturity studies. Fifty-percent maturity occurs at a larger size in female arrowtooth flounder than in males off both the Washington (37 cm vs. 28 cm, respectively, Rickey, 1995) and Oregon coasts (44 cm vs. 29 cm, Hosie and

Barss[7]). Growth rates of males may decline as they become mature, whereas females, to support the greater reproductive burden of egg production, continue their rapid growth rate and become mature at a larger size (see Roff, 1982).

Difference in size gives arrowtooth flounder females a survival advantage over males because larger fish are better able to avoid predation. Larger fish are also better able to capture and consume larger items of prey, such as walleye pollock, *Theragra chalcogramma*, which are an important part of their diet (Yang and Livingston, 1986). Perhaps this size difference accounts for the high percentage of females in the arrowtooth flounder population.

Although the possibility of cannibalism influencing the sex ratio of arrowtooth flounder cannot be ignored, it is unlikely because cannibalism is uncommon in arrowtooth flounder (Kabata and Forrester, 1974; Yang and Livingston, 1986).

Although the von Bertalanffy growth curve parameters tested as significantly different between male and female Kamchatka flounder, the difference in length at age between the sexes was less than the difference for arrowtooth flounder and perhaps did not afford a significantly higher survival rate for the females. There were no length-at-age results for Kamchatka flounder previously reported in the literature.

The unusually high percentage of females in the arrowtooth flounder population, the greater length at age of female arrowtooth flounder over female Kamchatka flounder, the greater depth preference of Kamchatka flounder over arrowtooth flounder, and the geographic boundaries of the two species defined in the study area all indicate significant interspecies differences. We therefore recommend that arrowtooth and Kamchatka flounder be treated as separate species in resource assessment surveys and for management purposes. Additional information should be gathered on possible differences in mortality of the male and female arrowtooth flounder, the reason for the greater depth preference of Kamchatka flounder, and whether or not the Kamchatka flounder population in the study area is successfully reproducing, or whether it is migrating into the area from the west.

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