Maturity, spawning, and seasonal movement of arrowtooth flounder, *Atheresthes stomias*, off Washington

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Abstract.—Arrowtooth flounder, *Atheresthes stomias*, were sampled for macroscopic maturity stage, and females were subsampled for gonosomatic index (GSI) from commercial trawl landings from July 1991 to July 1992 and during the NMFS triennnial bottom trawl survey from September to November 1992. Arrowtooth flounder are batch spawners and spawn from fall to winter off Washington at depths of at least 366 m (200 fm). Hydrated oocytes were first seen in September 1991 when mean GSI for yolked oocyte-bearing females approximately doubled. Postovulatory follicles were present in all macroscopic stages of mature ovaries sampled for histology in late December 1991. By March 1992 all mature females were spent; females with hydrated oocytes were again seen in November 1992. Arrowtooth flounder show a group-synchronous pattern of oocyte development. Catch rates from trawl logbook data suggest that the mature population migrates seasonally, from depths of about 183 m (100 fm) in summer to depths exceeding 475 m (260 fm) in winter. Fork length at which 50% of fish were sexually mature ($L_{50\%}$) calculated from survey data was 28.0 cm for males and 36.8 cm for females, similar to estimates from Washington commercial trawl data but less than estimates from Oregon in the 1970's. Female $L_{50\%}$ varied seasonally. Problems of bias associated with sampling commercial trawl landings for size at maturity are discussed.

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Arrowtooth flounder, *Atheresthes stomias*, is a large, predatory flatfish ranging from the Bering Sea to central California (Hart, 1973). It is estimated to be the single most abundant species in the Gulf of Alaska and has shown significant increases there in both population numbers and biomass.[1] Arrowtooth flounder is typically not considered a high-value species in the Washington trawl fishery, but recent landings have been substantial. In 1990–92 more arrowtooth flounder were landed from areas off Washington than any other groundfish species except Pacific whiting,[2] and management interest in arrowtooth flounder has intensified. Little detailed information is available on arrowtooth flounder in the eastern Pacific Ocean. Kabata and Forrester (1974) studied parasitic infection of arrowtooth flounder off British Columbia and noted the population length and age structure as well as diet, but did not examine maturity. Pertseva-Ostroumova (1960) examined *Atheresthes* reproduction and larval development in the Bering Sea, but spawning data on *A. stomias* was limited and conclusions regarding time and depth of spawning were based primarily on the closely related Kamchatka flounder, *A. evermanni*. More recent genetic and food-habit studies have documented differences between arrowtooth flounder and Kamchatka flounder in the Bering Sea (e.g. Ranck et al., 1986; Yang and Livingston, 1986; Yang, 1988), but none have examined their reproduction. Unpublished arrowtooth flounder size-at-maturity estimates have been made from data collected off Oregon.[3] This study was designed to provide new estimates of size at maturity and a time series of reproductive development and spawning of arrowtooth flounder off Washington.

Methods

Maturity data were collected from three sources: 1) Washington commercial trawl landings ("market"-sized fish) sampled biweekly from July 1991 to July 1992 at shoreside processing plants; 2) fish normally discarded at sea because of their small size, brought in by fishermen

[1] Wilderbuer, T. K., and E. S. Brown. 1992. Flatfish. *In* Stock assessment and fishery evaluation report for the 1993 Gulf of Alaska groundfish fishery, Section 3. N. Pac. Fish. Manage. Counc., Anchorage, AK, 25 p.

[2] Pacific Fishery Management Council. 1993. Status of the Pacific coast groundfish fishery through 1993 and recommended biological catches for 1994: stock assessment and fishery evaluation. (Document prepared for the Council and its advisory entities.) Pac. Fish. Manage. Counc., 2000 SW First Ave., Ste. 420, Portland, OR 97201.

[3] Hosie, M. J., and W. H. Barss. 1977. Age and length at maturity of arrowtooth flounder, *Atheresthes stomias*, in Oregon waters. Oregon Dep. Fish Wildl. unpubl. manuscr., 13 p.

upon request (discards); and 3) survey samples collected at sea from September to November 1992 on the National Marine Fisheries Service (NMFS) triennial bottom trawl and slope surveys off Washington State and Vancouver Island, British Columbia (Table 1). All of the commercial trawlers sampled used larger codend mesh than did the trawl survey (11.4 cm and 8.9 cm, respectively) and reported arrowtooth flounder catch from grounds off northwest Washington (Fig. 1). Commercial trawlers combine catches from different tows so trawl landings and landed discards were sampled on a per trip basis. No samples were obtained in January or February 1992. Up to 100 fish were selected at random for each sample. If fewer than 100 fish were present, all fish were sampled. Each fish was measured to the nearest centimeter fork length (FL), sexed, and assigned a maturity stage based on the macroscopic appearance of the gonads (Table 2). A gonosomatic index (GSI), calculated as ovary weight divided by somatic weight (body weight with ovaries removed and stomach empty), was used to track seasonal changes in ovarian condition. In each sample, the first 10 females encountered at each macroscopic maturity stage were sampled for GSI. Whole ovaries were removed and weighed to the nearest gram, and somatic weight was recorded to the nearest gram. Average monthly GSI's were calculated by maturity stage.

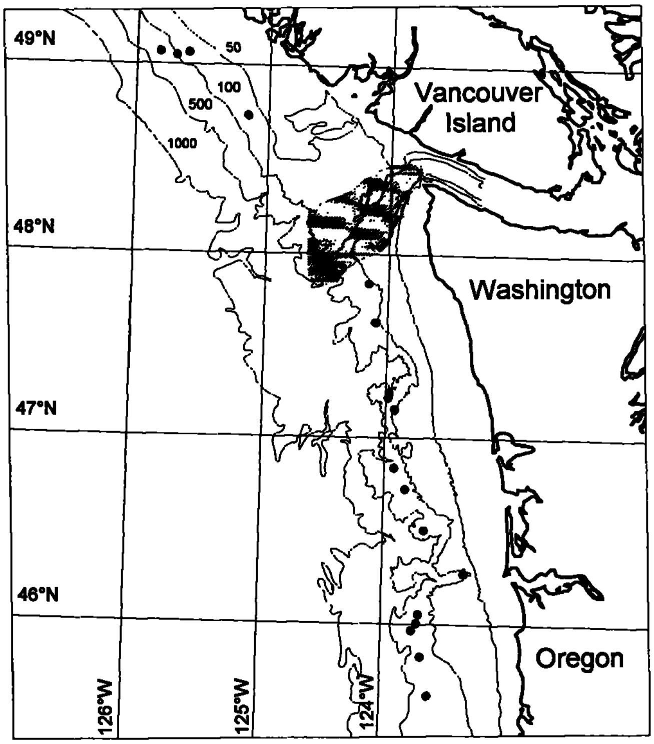

Figure 1
Reported arrowtooth flounder, *Atheresthes stomias*, catch area for sampled commercial bottom trawl trips, and locations of survey tows sampled for maturity, with fathom contours (1 fm=1.83 m).

Fish at any maturity stage other than "immature" were defined as mature. Length at maturity was estimated for each sex by calculating the fraction mature in each 1-cm interval and by fitting a logistic model

$$P_L = \frac{1}{1+e^{(a+bL)}},$$

where P_L = fraction mature at length L, and a and b are constants (Gunderson et al., 1980). The predicted size at which 50% of the fish are mature is

$$L_{50\%} = \frac{-a}{b}.$$

Confidence intervals for $L_{50\%}$ were calculated by using the delta method (Seber, 1982). To see if time of collection affected estimates of $L_{50\%}$, logistic equations were fit to the female length-maturity data that were grouped into the following periods for 1991 and 1992 separately: September–December, January–April, and May–August, corresponding to the prespawning, spawning, and postspawning seasons as determined below.

Ovarian tissue samples were collected from five tows on board the commercial trawler FV *Larkin* in late December 1991, during normal trawl operations off northwest Washington, to compare microscopic and macroscopic staging and provide additional information on arrowtooth flounder reproduction. Immediately after the net was retrieved, arrowtooth flounder were sorted by the crew into discard and market categories and were held alive until they could be sampled. Discard and market categories were maintained for maturity sampling but combined for histology. Length, sex, and maturity stage were recorded, and for the first 10 females encountered at each maturity stage an approximately 3-mm section of ovarian tissue was cut from the anterior third of the blind-side (left) ovary, placed in a tissue cassette, and fixed in Davidson's fixative (Mahoney, 1973). Tissue samples cut from the anterior third of the ovary were assumed to be representative of the arrowtooth flounder ovary as a whole. Weights for GSI were not taken owing to rough weather.

After fixation, tissues were embedded in paraffin, sectioned at 6 μm, and stained with hematoxylin and eosin. Tissue slides were examined under a compound microscope and measurements were taken with a calibrated ocular micrometer. A classification scheme of five stages of oocyte development, two stages of atresia, and a final stage of postovulatory follicles was adopted (Table 3), with terminology proposed by

Table 1

Sources of reproductive data on arrowtooth flounder, *Atheresthes stomias*, with numbers of fish sampled for maturity, and numbers of females sampled for GSI and histology. Samples were collected per trip obtained shoreside or collected per tow obtained at sea; average minimum depth[1] is the average of the minimum depths for tows with arrowtooth flounder from sampled trips and the minimum depth fished for sampled tows. Sampling includes mean fork length (cm) and standard deviation (SD) of fish sampled for maturity with probability *P* for test of difference between means (1-tailed Student's *t*-test, α = 0.05).

Sample category	Year	Month	Number of samples: Trips	Number of samples: Tows	Average minimum depth (m)	Number of fish: Maturity: Males	Number of fish: Maturity: Females	Number of fish: GSI	Number of fish: Histology[2]	Males: Mean length	Males: SD	Females: Mean length (cm)	Females: SD	*P*
Market	1991	July	2		140	1	199	43		53.0	—	62.1	4.8	—
		August	1		141	1	99	15		45.0	—	60.8	6.0	—
		September	3		196	25	275	70		44.8	2.1	62.1	9.2	0.001
		October	2		240	27	173	56		43.3	4.2	57.8	9.4	0.001
		November	1		265	17	83	25		39.7	1.9	54.2	10.1	0.001
		December	2	4	431	37	330	59	105	35.4	3.9	45.4	8.6	0.001
	1992	March	1		283	15	85	20		37.9	4.9	45.7	9.2	0.001
		April	2		304	46	154	26		43.6	3.1	56.1	10.1	0.001
		May	2		279	32	168	25		44.6	2.8	63.9	9.1	0.001
		June	2		242	24	176	44		45.6	2.2	62.8	8.1	0.001
		July	2		148	91	109	40		44.5	3.0	57.3	7.4	0.001
Discard	1991	December		2	393	74	26		6	29.6	2.4	28.8	1.3	0.050
	1992	May	1		214	10	6	6		37.6	6.9	32.5	6.5	0.083
		June	1		232	24	45			33.2	2.8	31.0	3.5	0.004
Survey[3]	1992	September		4	163	58	63	46		38.9	7.6	46.5	14.6	0.001
		October		7	335	49	85	20		33.6	7.1	40.8	12.5	0.001
		November		7	403	37	59	22		31.0	4.7	41.5	13.9	0.001

[1] Minimum depth is defined as the shallowest depth recorded for either start or end position of a tow.
[2] Histology samples collected at sea.
[3] GSI samples collected at sea, from 4 tows in September, 1 tow in October, and 1 tow in November.

Table 2

Maturity code definitions for arrowtooth flounder, *Atheresthes stomias*, based on the macroscopic appearance of the gonads.

Sex	Stage	Description
Female	Immature	Ovaries are small, pink to red in color, and gelatinous. Little or no visible internal ovarian tissue structure and no oocytes are visible.
	Mature	
	Developing	Ovaries are enlarging. Visible oocytes are white, opaque, and granular.
	Gravid	Ovaries are yellowish and mottled; some oocytes are translucent.
	Ripe/Running	Ripe and running. All oocytes are translucent and may be extruded with light pressure.
	Spent/Resting	Spent ovaries are flaccid, bloodshot, and red to purple. Resting ovary wall looks toughened, pink to beige.
Male	Immature	Testes small and thread-like, brown to pink. No folding or mottled coloration.
	Mature	Testes enlarged, folded, brown to white. Sperm may be visible in cross section or flows with external pressure.

Yamamoto (1956) and stage definitions used by Yamamoto (1956), Wallace and Selman (1981), Hunter and Macewicz (1985), and West (1990). The presence of α and β atretic oocytes was noted, although no attempt was made to differentiate α atretic oocytes by developmental stage. Postovulatory fol-

Table 3
Oocyte developmental stages based on histological criteria.

Stage	Description
Chromatin nucleolar	The oocyte is surrounded by a few squamous follicle cells, and scant cytoplasm surrounds a large nucleus containing a single, large basophilic nucleolus.
Perinucleolar	The oocyte grows, the nucleus increases in size and multiple basophilic nucleoli appear. These arrange themselves towards the periphery of the nucleus; a single dark dot or "Balbiani body" may be visible in the outer surface of the cytoplasm.
Cortical alveoli formation	Spherical vesicles appear in the cytoplasm. Zona radiata present.
Vitellogenic (yolk)	Oocytes are greatly increased in size and ooplasm is filled with yolk globules. Nucleus may be toward the periphery; there is a rapid thickening of the zona radiata.
Hydrated	Yolk globules fuse to form a continuous mass of fluid and the nucleus is not apparent. Postovulatory follicle may be visible.
α atresia	Oocyte is resorbed. Oocyte characterized by an irregular shape and granular, dark basophilic staining. When resorption is complete all that remains is the follicle.
β atresia	Follicle degenerates and is resorbed. Follicle compact, composed of several granulosa cells surounded by a thecal and blood vessel layer. Yellow-brown pigment may be present.
Postovulatory follicle	Collapsing follicle is irregularly shaped; cell layers form loose folds or loops. Degenerating follicle shows fewer loops and is reduced in size.

licles (POF) were identified except in later stages of degeneration when they could not be differentiated from β atresia (Hunter and Macewicz, 1985). Ovaries were staged on the basis of the most developmentally advanced oocyte observed. Proportions of oocyte stages, atretic structures, and POF's were calculated from counts of structures passing under a line horizontally bisecting the tissue slide. Because oocytes at different stages of development differ greatly in size, counts may be biased against smaller, less-developed stages. Average oocyte diameter was determined from the first 10 oocytes encountered at the most advanced developmental stage and sectioned through the nucleus, except hydrated oocytes which were measured as encountered.

Washington commercial bottom trawl logbook data from July 1991 to July 1992 were examined for trends in fishing depth and arrowtooth flounder catch rates. Information on the target fish and estimates of the amount of fish discarded at sea were unavailable. Catch rates were calculated from the set of 14,559 bottom trawl tows in which reported hours fished were greater than 0. Depth of each tow was defined as the shallowest (minimum) depth recorded for either start or end position. Catch rate or catch per unit of effort (CPUE) was computed as the average of the tow-by-tow arrowtooth flounder catch divided by hours fished; catch data were not adjusted to reflect actual fish ticket landings.

Results

Arrowtooth flounder larger than 53 cm FL were all female and the size ranges in each of the sample categories differed (Fig. 2). Females accounted for 85% (by number) of market, 42% of discard, and 67% of survey samples. Males were not well represented and did not show grossly apparent developmental changes over time; therefore, males were categorized only as mature or immature and were not considered further. However, males appeared most developed in July when the testes were largest, brown to whitish and folded. No spawning males were seen.

The average length of males was less than that of females in every month that market and survey samples were taken (Table 1; 1-tailed Student's t-test, α=0.05). Fish size (Table 1) and catch rates (Table 4) were highest in spring and summer. In winter, average length of market-sample fish decreased by approximately 9.0 cm for males and 16.0 cm for females. CPUE peaked (>200 kg/hr) in spring and fall at depths of 183–365 m and decreased in winter, while above 183 m CPUE was highest (about 50–150 kg/hr) in July–August but dropped to at or near 0.0 kg/hr in November–March. There was no apparent seasonal trend in CPUE at depths >366 m.

The proportion of mature females at each macroscopic maturity stage varied seasonally (Fig. 3). Because spring discards included fish that were the

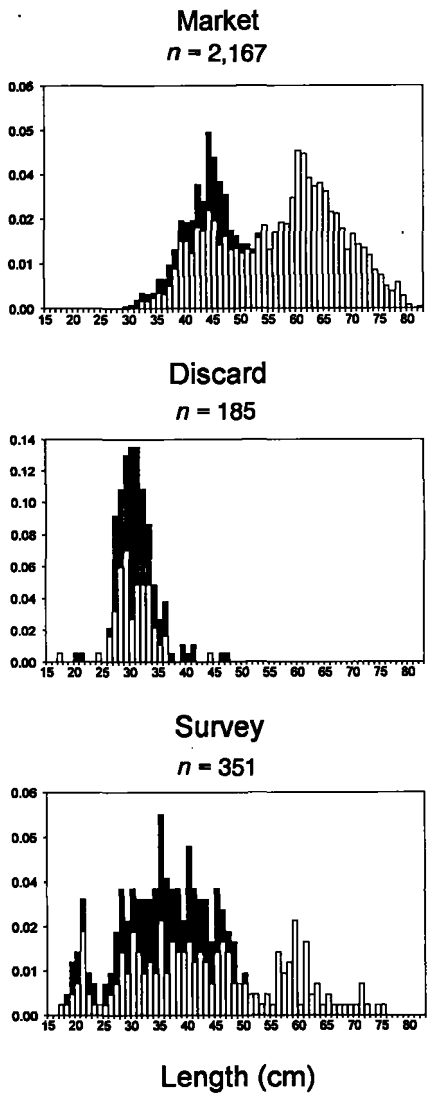

Figure 2
Length-frequency distributions of arrowtooth flounder by sample category. Dark bars = males; clear bars = females.

same size as fish in winter market samples, discard and market samples were pooled by common month and by keeping years separate. Throughout the year, samples almost always included large spent/resting females that did not show signs of ovarian recrudescence. Gravid females first appeared consistently in September 1991. The proportion of developing, gravid, and spent females stayed relatively constant through November. In December the first ripe/running fish and a substantial increase in the proportion of spent females were seen. The next available sample was March 1992 when all the mature females were in the spent/resting stage. Developing females reappeared the following May, and their proportion increased into the fall. In 1992, the first gravid and ripe/running fish were seen in November.

Length at 50% maturity calculated from survey data was 28.0 cm for males and 36.8 cm for females (Table 5). Estimates of $L_{50\%}$ from pooled market and discard ("commercial") data were lower for males and higher for females than estimates from survey data, although confidence intervals for $L_{50\%}$ overlapped. For females, seasonal estimates of $L_{50\%}$ varied widely. The greatest $L_{50\%}$ (>41 cm) was seen before spawning (May–August) and the lowest (<37 cm) during spawning (September–December). Parameters for the logistic function were compared with a likelihood-ratio test (Kimura, 1980). Estimates from commercial data were significantly different from survey estimates for both females (χ^2=145.490, P<<0.001; Fig. 4) and males (χ^2=79.383, P<<0.001). In a comparison of years, logistic curves fit to September–December 1991 (commercial) and September–November 1992 (survey) data were significantly different (likelihood-ratio test, χ^2=143.257, P<<0.001) although again confidence intervals for $L_{50\%}$ overlapped.

Ovarian tissue samples were analyzed histologically from 111 female arrowtooth flounder collected late December 1991 during spawning. Each of the five macroscopic maturity stages was represented and no two macroscopic stages showed the same frequency distribution of oocyte types (Fig. 5). Chromatin nucleolar, perinucleolar, and atretic oocytes were present in all the sampled ovaries. In ovaries of immature fish, none of the oocytes had progressed beyond the perinucleolar stage. Vitellogenic or yolked oocytes were prevalent in developing and gravid stage ovaries, and hydrated oocytes were seen frequently in gravid and ripe/running stage ovaries. Oocytes with cortical alveoli were most frequently seen in spent/resting ovaries.

Atresia was more prevalent in all the ovarian stages of spent/resting fish than in immature fish (Table 6). The percent occurrence of α atretic oocytes was lowest in ovaries from developing fish and highest in ovaries from spent/resting fish. Beta atresia was most common in spent/resting ovaries but also occurred in developing, gravid, and immature ovaries. All the immature and 43.8% of the spent/resting females had perinucleolar stage ovaries. Postovulatory follicles (POF) were present in ovaries from all macroscopic stages except immature. POF were most frequently seen in ripe/running ovaries and were common in gravid and spent/resting ovaries; whereas 7 of 29 developing females examined for histology had ovaries with POF. Postovulatory follicles were also present in 7 of 21 spent/resting

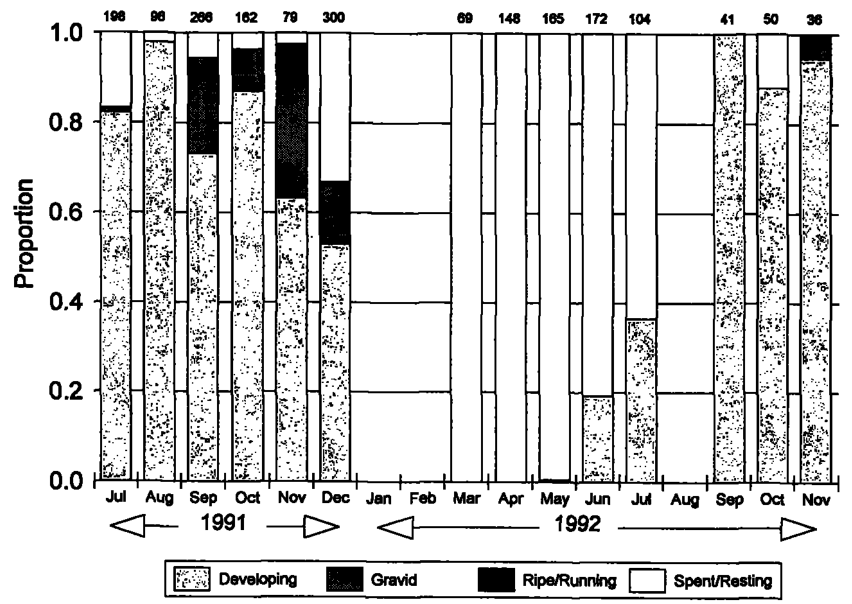

Figure 3

Proportions of mature female arrowtooth flounder at each macroscopic maturity stage by month. Number of females listed at top.

Table 4

Washington commercial bottom trawl catch rates (kg/hr) of arrowtooth flounder, *Atheresthes stomias*, by depth interval based on the minimum depth recorded for each tow. *n* = number of tows.

		1–182 m		183–365 m		366–547 m		547+ m	
Year	Month	*n*	kg/hr	*n*	kg/hr	*n*	kg/hr	*n*	kg/hr
1991	July	1,644	155.7	176	184.0	31	44.6	9	134.5
	August	1,391	54.5	179	130.6	21	3.0	5	0.0
	September	1,362	14.5	187	157.6	54	27.7	7	0.0
	October	860	11.8	274	231.7	56	64.3	4	0.0
	November	210	0.0	95	20.3	37	22.7	3	0.0
	December	187	0.0	126	8.9	82	35.8	7	0.0
1992	January	221	0.1	120	14.9	82	8.9	18	11.0
	February	596	0.0	240	10.7	61	12.2	37	0.4
	March	883	0.3	201	19.5	178	39.8	85	8.9
	April	462	7.4	155	53.9	110	68.5	31	1.7
	May	829	16.3	232	228.2	63	71.0	40	0.0
	June	1,131	19.0	174	344.1	38	16.4	90	0.5
	July	1,246	53.4	134	50.8	13	1.7	82	1.5

females with perinucleolar-stage ovaries. One 41.0-cm gravid female had no POF and 6.3% of its oocytes were hydrated. All other gravid females had POF.

Overall mean oocyte diameters (μm) and standard deviations were as follows: perinucleolar 79.6 ± 34.9 (n=420); cortical alveoli 185.4 ± 23.4 (n=220); vitellogenic 722.9 ± 73.9 (n=290); and hydrated 940.6 ± 206.8 (n=170) (Fig. 6). Chromatin nucleolar stage oocytes were not measured because they never represented the most advanced stage present in an ovary. Mean diameter of perinucleolar oocytes in spent/resting females was about 10 μm greater than that in the immature females (Student's t-test, P<0.003). Some of the variance in hydrated oocyte size

Table 5

Parameter estimates for the logistic model[1] of proportion mature at length (cm), length at 50% mature, and 95% confidence intervals, for arrowtooth flounder, *Atheresthes stomias* from 1991–92 Washington commercial (pooled market and discard), 1992 Washington survey, and 1972–75 Oregon data (See Footnote 3 in the text). For females, results are also given for Washington commercial data grouped by months in relation to the spawning season.

Sex and stratum	a	b	R^2	$L_{50\%}$ (cm)	95% CI for $L_{50\%}$	n
Males						
Washington-survey	24.990	–0.893	0.968	28.0	27.6–28.4	144
Washington-commercial	33.264	–1.197	0.968	27.8	27.5–28.1	424
Oregon	17.397	–0.615	0.971	28.3	27.8–28.8	218
Females						
Washington-survey	19.891	–0.540	0.971	36.8	36.3–37.3	207
Washington-commercial	20.874	–0.559	0.984	37.4	37.0–37.7	1,928
Oregon	15.056	–0.352	0.989	42.8	42.4–43.2	1,628
Females[2]						
Jul–Aug 1991 (before)	13.050	–0.281	0.390	46.5	43.2–49.7	298
Sep–Dec 1991 (during)	14.800	–0.410	0.945	36.1	35.5–36.7	887
Mar–Apr 1992 (after)	61.111	–1.568	0.991	39.0	38.8–39.1	239
May–Jul 1992 (before)	18.194	–0.438	0.928	41.6	40.6–42.6	504

[1] $P_L = 1/(1+e^{(a+bL)})$.
[2] No samples obtained in January–February 1992.

can be attributed to distortion of hydrated oocytes that occurs during histological processing.

Gonosomatic indices (GSI) for immature and spent/resting fish remained fairly constant across seasons, whereas GSI for developing or gravid fish varied considerably over time, reflecting ovarian recrudescence (Table 7). Individual GSI for immature fish ranged from 0.0017 to 0.0154 (average 0.0055), and individual spent/resting GSI ranged from 0.0037 to 0.0259 (average 0.0135). GSI for ripe/running fish (n=4; $\bar{L}$=47.8) was not calculated because loss of eggs in handling precluded accurate gonad weights. From histological analysis, hydrated oocytes and POF were found in "developing" females, indicating some misclassification of spawning females. Because of suspected misclassification, developing and gravid GSI data were pooled by month. GSI for developing or gravid fish showed a rapid increase from about 0.03 in August 1991 and 0.02 in July 1992 to 0.06 in September of both years; the highest annual mean GSI occurred in December 1991 and November 1992. The highest individual GSI was 0.2201 in November 1992 for a 38-cm gravid female.

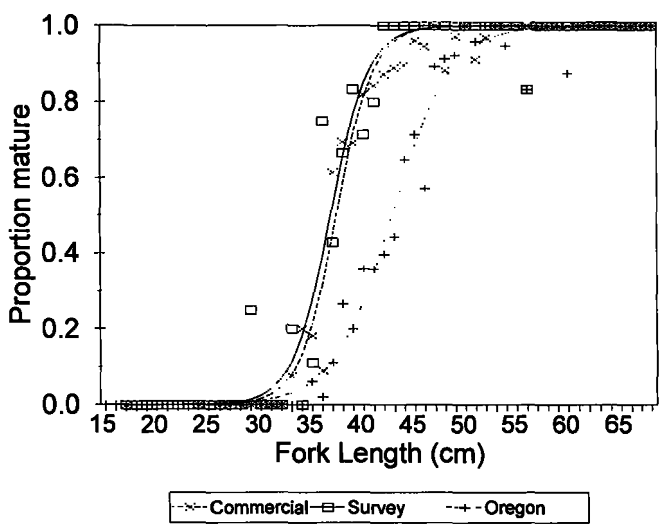

Figure 4

Maturity distributions and logistic curves for female arrowtooth flounder calculated from pooled 1991–92 market and discard (commercial) data, 1992 survey data, and 1973–75 data from Oregon (see Footnote 3 in the text).

Discussion

The progression of gonad maturity stages, increase in GSI, and the appearance of gravid females show that arrowtooth flounder spawn during fall–winter off Washington. Spawning begins as early as September, extends at least through December, and is completed by March. This coincides with the spawning season for *Atheresthes evermanni* in the western

Table 6

Percent occurrence of oocytes in each oocyte developmental stage in arrowtooth flounder, *Atheresthes stomias*, by macroscopic and microscopic maturity stages. Percent occurrences of atresia and postovulatory follicles (POF) among all oocyte structures also included. Microscopic stage reflects the most advanced oocyte type present. n = number of females, $\bar{L}$ = mean FL in cm; oocyte-stage 1 = chromatin nucleolar; stage 2 = perinucleolar; stage 3 = cortical alveoli; stage 4 = vitellogenic; stage 5 = hydrated; and POF = postovulatory follicle. Samples were collected late December 1991.

Macroscopic stage	Microscopic stage	n	$\bar{L}$ (cm)	Oocyte developmental stage 1	2	3	4	5	Atresia α	β	POF
Immature	Perinucleolar	17	35.7	19.0	81.0	0.0	0.0	0.0	11.5	1.3	0.0
Developing	Vitellogenic	26	43.0	2.4	20.7	0.1	76.8	0.0	3.6	0.9	0.5
Developing	Hydrated	3	39.7	1.0	20.6	0.0	77.0	1.4	6.6	0.9	0.9
Gravid	Hydrated	15	40.4	3.1	25.5	0.2	47.0	24.1	7.2	0.9	7.1
Ripe/Running	Hydrated	2	59.0	3.3	39.6	0.0	1.1	56.0	7.2	0.0	26.8
Spent/Resting	Perinucleolar	21	48.2	15.8	84.2	0.0	0.0	0.0	21.7	7.3	5.4
Spent/Resting	Cortical alveoli	26	61.8	14.5	76.1	9.4	0.0	0.0	20.1	10.2	2.9
Spent/Resting	Hydrated	1	42.0	6.3	34.4	0.0	34.4	25.0	16.7	0.0	7.1

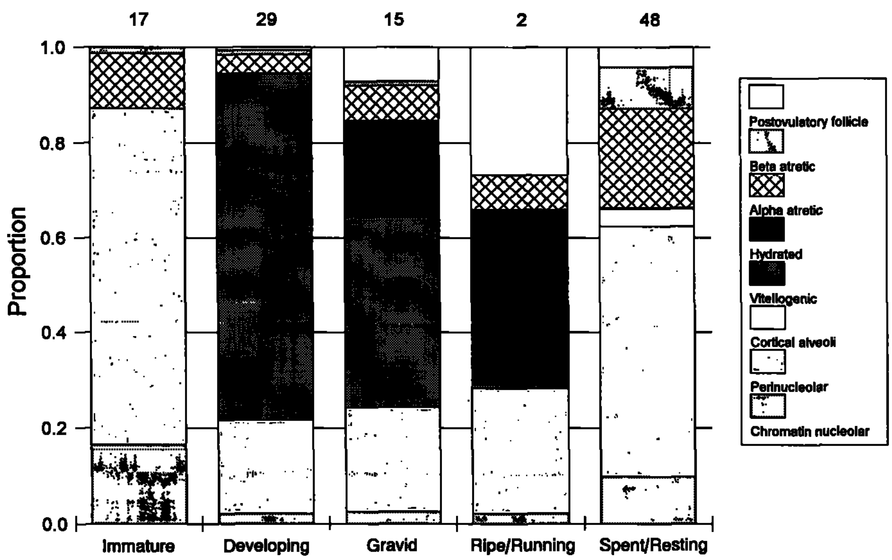

Figure 5

Proportion of arrowtooth flounder oocytes assigned by histological criteria to ovarian developmental stages according to macroscopic maturity stage of the whole ovary. Samples were collected late December 1991. Number of females is listed at top.

Bering Sea reported by Pertseva-Ostroumova (1960). Hirschberger and Smith (1983) found some spawning arrowtooth flounder during spring and summer months in the Gulf of Alaska, but their survey data were insufficient to define the spawning season with any certainty. The appearance of translucent oocytes is usually taken as an indication that spawning is imminent (hours or days) (West, 1990), although there are no laboratory data to indicate the speed at which arrowtooth flounder oocytes ripen and are ovulated. Gravid females were first seen in September 1991 coincident with an increase in GSI. A similar increase in September GSI was seen in 1992, but the first gravid females were observed in November, suggesting that the start of arrowtooth flounder spawning may vary from year to year.

Histological results show arrowtooth flounder are batch spawners, where one female spawns repeat-

Table 7

Arrowtooth flounder, *Atheresthes stomias*, monthly mean fork length ($\bar{L}$, in cm) and mean gonosomatic index (GSI) and standard deviation (SD) for females selectively sampled for GSI by macroscopic maturity stage. July 1991–July 1992 samples were collected shoreside; September–November 1992 samples were collected at sea.

		Immature				Developing/Gravid				Spent/Resting			
Year	Month	*n*	$\bar{L}$	GSI	SD	*n*	$\bar{L}$	GSI	SD	*n*	$\bar{L}$	GSI	SD
1991	July	1	48.0	0.0056	—	22	63.3	0.0277	0.0096	20	61.1	0.0164	0.0021
	August	3	48.0	0.0080	0.0035	10	60.4	0.0290	0.0082	2	63.5	0.0120	0.0028
	September	9	42.8	0.0064	0.0020	46	65.1	0.0587	0.0249	15	53.9	0.0163	0.0047
	October	10	39.4	0.0051	0.0006	40	61.0	0.0738	0.0246	6	56.7	0.0120	0.0066
	November	3	41.7	0.0045	0.0003	20	55.7	0.0883	0.0223	2	54.5	0.0051	0.0003
	December	14	36.3	0.0048	0.0018	33	47.0	0.1160	0.0332	11	45.7	0.0070	0.0060
1992	March	10	35.9	0.0045	0.0017	0	—	—	—	10	49.5	0.0126	0.0015
	April	6	40.5	0.0051	0.0013	0	—	—	—	20	55.3	0.0114	0.0035
	May	9	36.6	0.0048	0.0030	1	67.0	0.0140	—	21	65.4	0.0135	0.0026
	June	4	44.5	0.0067	0.0009	20	61.9	0.0171	0.0042	20	64.4	0.0151	0.0030
	July	5	41.0	0.0071	0.0034	17	57.8	0.0215	0.0046	18	53.8	0.0145	0.0031
	September	18	29.2	0.0063	0.0042	28	55.6	0.0615	0.0292	0	—	—	—
	October	10	35.9	0.0049	0.0017	10	46.0	0.0567	0.0303	0	—	—	—
	November	10	30.0	0.0056	0.0041	11	46.4	0.1004	0.0487	0	—	—	—

edly over a protracted spawning season, as are Pacific halibut, *Hippoglossus stenolepis* (St-Pierre, 1984), and Dover sole, *Microstomus pacificus* (Hunter et al., 1992). Size frequencies of oocyte stages (Fig. 6) show distinct populations of oocytes that indicate a group-synchronous pattern of development. Postovulatory follicles were found in "developing" females, those with no visible translucent oocytes, evidence that these fish had recently spawned and that macroscopic examination of ovaries could not separate all spawning from nonspawning fish. In September 1991, early in the spawning season, gravid mean GSI was significantly greater than developing GSI (Student's *t*-test, $P<<0.001$), but by November and December there was essentially no difference between mean GSI for developing and gravid females (Student's *t*-test, November $P<0.105$, December $P<0.841$); the highest mean GSI was observed in December. Under the macroscopic maturity definitions used, females progress from immature to the developing stage, then cycle between "developing" and "gravid" as successive batches of oocytes ripen and are ovulated. The ripe/running stage corresponds then only to the last and perhaps largest batch of oocytes, suggesting that by December spawning was near completion for some females.

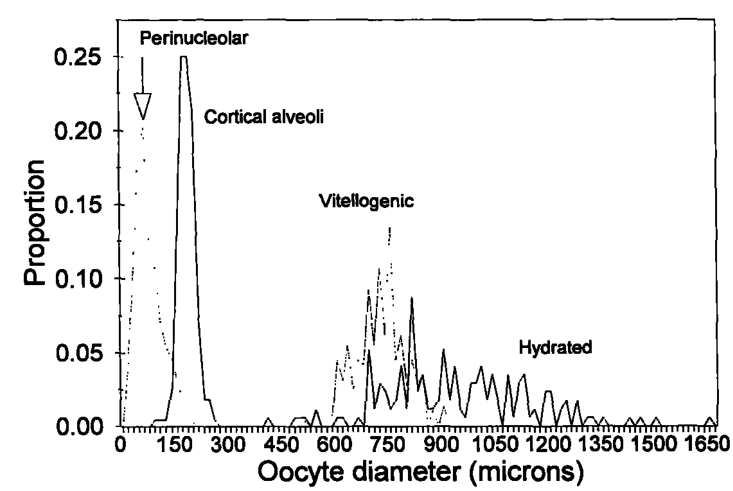

Figure 6

Size-frequency distributions of arrowtooth flounder oocyte developmental stages from ovaries collected late December 1991. Proportions were calculated separately for each oocyte type.

Spent/resting females were seen year-round, evidence that adult arrowtooth flounder may not spawn every year.

Of particular concern is whether small, resting mature fish were misclassified as immature, and vice versa, since errors will bias estimates of size at maturity. Immature male arrowtooth flounder were difficult to identify and errors undoubtedly occurred, but there was not enough auxiliary information to quantify them. Macroscopically immature females examined for histology did not show signs of recent spawning, and all were microscopically staged as perinucleolar. Out of 48 spent/resting females examined for histology, 43.8% also had perinucleolar ovaries. Seven of these had POF, direct evidence of prior spawning. Of the remaining 14, atretic structures were more than twice as common as in immature females. Hunter et al. (1992) used atresia to distinguish immature from uncertain maturity in Dover sole ovaries defined as inactive but concluded that microscopic examination of oocytes in histological sections may not identify all mature, postspawning females. Relatively high rates of atresia may indicate that fish have finished spawning (Wallace and Selman, 1981), but this alone is insufficient to separate mature from immature fish because atresia can be brought on by stresses not necessarily associated with spawning, such as starvation, pollution, or other environmental conditions (Wallace and Selman, 1981; Hunter and Macewicz, 1985; Hunter et al., 1992). Because histological criteria could not differentiate all mature from immature females and because other microscopic evidence of prior spawning such as ovarian wall thickness (Burton and Idler, 1984) was not available, the degree of misclassification of mature vs. immature females staged macroscopically could not be determined.

Histological processing is known to cause shrinkage of oocytes (West, 1990); therefore oocyte diameters determined from processed tissue sections should be considered an index rather than an absolute measurement of oocyte size. For arrowtooth flounder, Pertseva-Ostroumova (1960) reported whole egg diameters are about 2.5–3.5 mm. Matarese et al. (1989) lists *A. stomias* egg diameter as approximately 3 mm, three times the mean diameter of ripe oocytes determined in this study.

Seasonal bathymetric migrations are a familiar pattern in flatfish. Dover sole, *Microstomus pacificus*, petrale sole, *Eopsetta jordani*, and English sole, *Pleuronectes vetulus*, migrate seasonally across depths (Alverson et al., 1964), and Dover sole tend to reside at deeper depths at older ages (Hunter et al., 1990). Kabata and Forrester (1974) sampled arrowtooth flounder off Vancouver Island in May–June 1968 and found increasing length with depth, and a drop in abundance below 420 m (230 fm) consistent with these results. Trends in arrowtooth flounder catch rates by depth and season (Table 4) indicate arrowtooth flounder move offshore in winter. Arrowtooth flounder were common in shallow water (<183 m) in summer, when the average size of landed fish was large. In winter, smaller numbers and sizes of arrowtooth flounder were caught in deeper water; whereas several hundred tows were reported in shallow water with virtually no arrowtooth flounder. Large, mature, presumably spawning arrowtooth flounder may have moved out of the range of the trawl fishery, possibly to deeper water or north into Canadian waters. However, targeted arrowtooth flounder trips are rare and independent estimates of the amounts of arrowtooth flounder discarded from trawl catches are high, from nearly 76% off Oregon and Washington (Barss and Demory, 1985) to over 80% in the Gulf of Alaska.[1] Large volumes of discards and catch unreported in logbooks may obscure trends in distribution; they certainly result in underestimates of arrowtooth flounder CPUE. Hosie (1976) states that arrowtooth flounder spawn off central Oregon from December through March at about 200 fm. Hirschberger and Smith (1983) reported spawning arrowtooth flounder at depths of over 350 m (191 fm) in the Gulf of Alaska. The full extent of the spawning depth range inhabited by arrowtooth flounder has not been determined, but in this study in 1991 gravid females were found in commercial tows out to 512 m (280 fm) and ripe/running females at 475 m (260 fm). In 1992 gravid and ripe/running females were found at 399 m (218 fm). Since these results also suggest that in winter the bulk of the population was in water as deep or deeper than 366 m, it is likely that the majority of arrowtooth flounder off Washington spawn at depths exceeding 366 m (200 fm).

To examine trends in length at maturity over time, I fitted logistic curves to Oregon trawl survey data from the 1970's[3] to compare with results from Washington (Table 5). The Oregon survey covered the area from Newport, Oregon, south to Cape Blanco and included FL and maturity for 218 male and 1,628 female arrowtooth flounder. Macroscopic criteria used to distinguish mature from immature fish were identical in both studies. Washington maturity samples were collected in all months except January and February. All months except July, August, and November were represented in the Oregon data. Arrowtooth flounder in the present study matured at a smaller size than those collected off Oregon, and likelihood-ratio tests (Kimura, 1980) showed sample nonlinear regressions for Oregon were significantly different when compared with both Washington survey data (male χ^2=74.555, P<<0.001; female χ^2=137.922, P<<0.001) and commercial data (male χ^2=80.539, P<<0.001; female χ^2=147.920, P<<0.001). Distribution of female maturities across lengths (Fig. 4) suggests that female arrowtooth flounder are maturing at a smaller size than they were off Oregon in the early 1970's, or that there are latitudinal differences in size at maturity. However, differences between results for Oregon and the present study could be explained by differences in sampling distributions across months, or by different interpretations of maturity codes by different observers; therfore they may not represent a biological change.

Size-selectivity and areal or bathymetric sampling biases are critical to estimates of $L_{50\%}$ (Welch and Foucher, 1988; Trippel and Harvey, 1991). Predicted length at maturity may be biased if fish are size-segregated by area or depth (e.g. if immature fish do not migrate to spawning depths while targeted commercial trawl fisheries typically operate where large fish are most likely to be found in quantity, i.e. the spawning grounds). Smaller arrowtooth flounder were not well represented in commercial landings. Size selectivity in commercial fisheries occurs either through net selection (a lesser problem in the trawl survey) or through size-selective targeting and discarding. Net avoidance by larger fish may also be a factor. In the extreme case of male arrowtooth flounder, estimated $L_{50\%}$ was below the size range of fish in market samples though well within the size range of fish in commercial discards and survey catches. Because the trawl survey sampled the widest size range of arrowtooth flounder over a fairly large area and depth range prior to peak spawning in 1992, size-at-maturity estimates from the trawl survey represent the best available.

Hunter et al. (1992) estimated size at maturity for female Dover sole and found samples taken during the spawning season yielded higher estimates of $L_{50\%}$ than did samples taken before spawning. They attributed this to the presence of postspawning females with "highly regressed" ovaries that were histologically indistinguishable from immature females, and they concluded that estimates of length or age at first maturity should always be conducted prior to the onset of spawning, when such females are rare. I found the opposite seasonal pattern in length at maturity for female arrowtooth flounder; lowest $L_{50\%}$ was estimated from commercial samples collected in the fall during spawning, and highest $L_{50\%}$ was estimated from months preceding spawning. Market samples collected in summer (before spawning) tended to underrepresent smaller arrowtooth flounder and yielded extremely high estimates of female length at maturity. In the case where sampling is limited to commercial trawl fisheries, it may be preferable to pool year-round sampling data to generate estimates of $L_{50\%}$ if fish are moving in and out of range of the trawl fleet, rather than to attempt to narrow the sampling window to just prior to spawning as suggested by Hunter et al. (1992). This involves the explicit trade-off of some assumed increase in the misclassification of small fish with the significant bias caused by a seasonal inability to obtain representative samples of the entire size or bathymetric range of a population. Perhaps coincidentally, female length-at-maturity curves generated from the year-round commercial data and the survey data were strikingly similar (Fig. 4), although statistically the curves were different.

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