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ABSTRACT: Growth rates, morphometric conversions, and otolith surface-pattern formation are reported and discussed for age 0–2 arrowtooth flounders *Atheresthes stomias* from Kachemak Bay, Alaska. Absolute growth rates averaged 0.20–0.24 mm/d or 0.17 g/d. Instantaneous growth rates averaged 0.17%/d in length and 0.49%/d in weight. The mean standard lengths for age-0, -1, and -2 flounders were 67, 108, and 211 mm. Annuli form sometime between February and May; the first annulus on the otolith was often indistinct.

INTRODUCTION

Arrowtooth flounders *Atheresthes stomias* (Family: Pleuronectidae) are right-eyed flatfishes common in the northern Pacific Ocean. The females can produce 250,000–2,400,000 eggs per spawning season. Arrowtooth flounders exhibit sexual dimorphism; females reach lengths at 50% maturity of 44–47 cm and males 29–42 cm, depending on location and method of maturity assessment (Fargo et al. 1981; Rickey 1995; Zimmermann 1997). Most North Pacific pleuronectids have similar life histories. Usually during the winter or spring months, the females extrude many small, planktonic eggs that are externally fertilized. The embryos and larvae are planktonic. The larvae begin metamorphosis and eye migration in the pelagic environment. By the time the young recruit to the benthos in nearshore nursery areas, metamorphosis is typically complete. As the juveniles develop, they tend to select deeper waters (Moyle and Cech 1988).

The arrowtooth flounder is abundant in the northern Pacific Ocean and potentially important in marine food webs. Only recently has it been exploited as a food-fish species. Because the arrowtooth flounder has not been an economically important species, little is known about its early life history. To properly manage this species, more information about its life history and biology is needed.

An understanding of the growth rates of the juvenile life stage will provide information to those interested in community energetics and to those studying inter- and intraspecific competition. Natural growth rate information can calibrate laboratory feeding experiments predicting consumption rates.

Mark and recapture is one of the best tools for studying growth rates. These experiments are expensive because they require large numbers of recaptures to provide meaningful data. Alternatively, an estimate of growth rates can be obtained by age estimation through examination of sagittal otoliths. It is important to use established, reproducible criteria for interpreting otolith patterns.

The objectives of our investigation were to: (1) describe criteria for age estimation of juvenile arrowtooth flounders; (2) estimate the growth rate of juvenile arrowtooth flounders; and (3) describe relationships of body length to age, weight, and otolith length.

METHODS

Arrowtooth flounders were captured from Kachemak Bay, Alaska, in lower Cook Inlet, incidental to other projects. Sampling dates and numbers of fish captured are listed in Table 1. Fish were collected from 2 different vessels. The 20-m Alaska Department of Fish and

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Table 1. Dates of capture of arrowtooth flounders and number of fish captured (*n*) from Kachemak Bay, Alaska.

Dates	Vessel	*n*
1994:		
Sep	UAF	33
1995:		
May	UAF	18
Aug	UAF	21
1996:		
Feb	UAF	10
May	UAF	9
Aug	*Pandalus*	16
Aug	UAF	14

Game research vessel, the R/V *Pandalus*, was used to drag a 400-mesh eastern trawl with 364-kg, Nor'Eastern Astoria V trawl doors (152×213 cm). The stretch mesh was 3.2 cm in the cod end, 8.9 cm in the intermediate, and 10.2 cm in the body and wings. Samples were taken at locations described in Bechtol and Yuen (1995). A University of Alaska (UAF), 8.5-m welded aluminum boat towed a 3-m plumbstaff beam trawl with a double tickler chain in nearshore flatfish nursery areas. The stretch mesh was 7 mm in the body and 4 mm in the cod end (Abookire 1997). More complete sampling methods are reported in Bouwens et al. (1999). Samples were frozen whole and transported to Fairbanks.

All fish were partially thawed and were measured in millimeters for total length (TL) and standard length (SL), and in grams wet weight (WW). Both sagittal otoliths were collected when possible. Sex was not determined. All available arrowtooth flounders < 300 mm SL were included in subsequent calculations. Regressions were calculated between TL and SL, TL and WW, and SL and WW.

Sagittal otoliths were cleared in a 50% solution of glycerin and thymol for at least 2 months. Otoliths were placed in a black dish and then examined with a dissecting microscope equipped with an ocular micrometer under reflected fiberoptic light. Only surface-pattern analysis was performed. Of the samples examined, annuli were readable in otoliths representing 101 individuals. The number of annuli and otolith lengths were determined from these fish. Linear regressions were calculated SL, TL, and otolith length (OL).

Growth discontinuities associated with hatching and settlement (Bouwens et al. 1999) were located on each otolith read. Under reflected light, these checks (areas of slow growth) appeared as hyaline bands on an opaque background. Any hyaline banding structure larger than the diameter of the settlement check was considered to be an annular mark. In some otoliths, an annulus consisted of several hyaline bands separated by very narrow opaque bands. These opaque (rapid growth) bands within an annulus were narrower than adjacent hyaline bands and were considered to be a growth anomaly. Arrowtooth flounders captured in February were assigned an age of 0 years if no annuli could be identified on their otoliths. These fish were clearly >1 month in age.

Because mean dates for arrowtooth flounder hatching and settlement have been identified (Bouwens et al. 1999), we also estimated age in days from actual mean hatch date of April 15 instead of using the conventional January 1 hatch date for north temperate fishes (DeVries and Frie 1986). Age in days for each arrowtooth flounder in our study was estimated by

Table 2. Morphometric conversions of juvenile arrowtooth flounders captured from Kachemak Bay, Alaska, 1994–1996; TL = total length (mm), SL = standard length (mm), WW = wet weight (g), and OL = otolith length (mm).

Conversion	Equation	r^2	F	*P*	*n*
TL to SL	SL = 0.8826 TL - 0.9085	> 0.99	54197	< 0.001	121
SL to TL	TL = 1.1306 SL + 1.5896	> 0.99	54197	< 0.001	121
TL to WW	$WW = 0.000004\ TL^{3.1124}$	> 0.99			121
SL to WW	$WW = 0.000007\ SL^{3.0986}$	> 0.99			121
SL to OL	OL = 0.0135 SL + 0.2202	0.98	4138	< 0.001	101
TL to OL	OL = 0.0117 TL + 0.228	0.98	4380	< 0.001	101
OL to SL	SL = 72.225 OL - 13.465	0.98	4138	< 0.001	101
OL to TL	TL = 83.37 OL -16.363	0.98	4380	< 0.001	101

Table 3. Age class data of juvenile arrowtooth flounders captured from Kachemak Bay, Alaska, 1994–1996; TL = total length (mm), SL = standard length (mm), WW = wet weight (g).

Age Class	Measurement	Mean	SD	Range	Min	Max	*n*
0	SL	66.7	16.78	59	40	99	23
0	TL	75.8	18.33	57	47	104	23
0	WW	3.57	2.51	7.51	0.68	8.19	23
1	SL	108	24.69	85	61	146	10
1	TL	123	28.06	95	73	168	10
1	WW	19.0	13.8	43.5	2.18	45.7	10
2	SL	211	26.76	104	152	256	17
2	TL	242	30.75	118	176	294	17
2	WW	127	53.08	221	40.1	261	17

$$\text{age} = (365a) \times b + c,$$

where a = the number of times the individual fish is known to have passed January 1, b = estimated hatch date (in days of the year or 105; Bouwens et al. 1999), and c = capture date (in days of the year).

All arrowtooth flounders with 3 or more annuli ($n = 5$ fish) were excluded from the growth rate calculations. Least-squares regression lines were empirically fitted to length-at-age (both days and years) relationships. Instantaneous growth rates were calculated using

$$G_x = [(\log_e Y_2 \times \log_e Y_1) / (t_2 \times t_1)]\, 100,$$

where G_x = specific growth rate; Y_1 is size at t_1, and Y_2 is size at t_2; and t_1 and t_2 are times 1 and 2 (days or years; Busacker et al. 1990). Absolute growth rates (mm/d or g/d), $[(Y_2 \times Y_1) / (t_2 \times t_1)]$, were calculated as described in Busacker et al. (1990).

Noticeably dehydrated fish were not included for calculation of growth rates in WW due to obvious desiccation of unknown magnitude among some fish in the freezer. These fish were retained for length–weight conversions because their removal did not change the regression equation.

RESULTS

Otolith Interpretation

Examination of otoliths from small (age 0) arrowtooth flounders captured February 28 showed no evidence of annulus (hyaline material) formation. Otoliths from fish captured in May showed evidence of formation of an annulus on the edge of the otolith with little or no opaque growth peripheral to the hyaline material. Fish captured in August showed substantial otolith growth peripheral to the latest annulus. The first annulus was often diffuse and difficult to identify.

Length–Age Analysis

Morphometric regression conversions between TL, SL, WW, and OL are listed in Table 2. All these are significant relationships with $r^2 \geq 0.98$ and $P < 0.001$. Actual mean SL (mm ± standard deviation) for ages 0, 1, and 2 were approximately 67 (± 17), 108 (± 25), and 211 (± 27). Mean TLs were approximately 76 (± 18), 123 (± 28) and 242 (± 31). Mean WWs for the same 3 age classes were approximately 3.57 (± 2.51), 19.0 (± 13.8), and 127 (± 53.1) (Table 3).

Exponential line fits of TL and SL with age had higher r^2 values when age was reported in days than in years (Figures 1, 2). Table 4 lists absolute and instantaneous growth rates in TL, SL, and WW. Arrowtooth flounders grew relatively slowly in their first year, both absolutely and as a percentage of their body length, and then increased growth in their second year.

DISCUSSION

Otolith Interpretation

Otoliths provide a record of individual fish growth that requires interpretation. The first annulus was often difficult to identify. The hyaline band immediately surrounding the inner portion of the otolith was defined as a settlement check (Bouwens et al. 1999). The metabolic drain of body reorganization and changing lifestyle may have temporarily reduced growth rate. Because age-0 arrowtooth flounders may recruit to the benthos as late as October (Bouwens et al. 1999), the settlement check and the first annulus may not always be separated by a significant area of opaque growth. The settlement check may be confused with the first annulus in these situations. It is important to incorporate information on individual fish body length and capture date when making age determinations from otolith surface patterns.

The first annulus of arrowtooth flounder otoliths is often weak in comparison to subsequent annuli. The strength of the check or annulus may be due to different diets, growth characteristics, or other differences between very young fish and older fish. The first annulus was most apparent in age-1 fish because in fish older than age 2, it became covered by additional material as the otolith grew.

In some of our specimens the first annulus was especially ill-defined. These fish were long for their age and may have taken up a benthic existence early in comparison to others in their cohort. The annulus

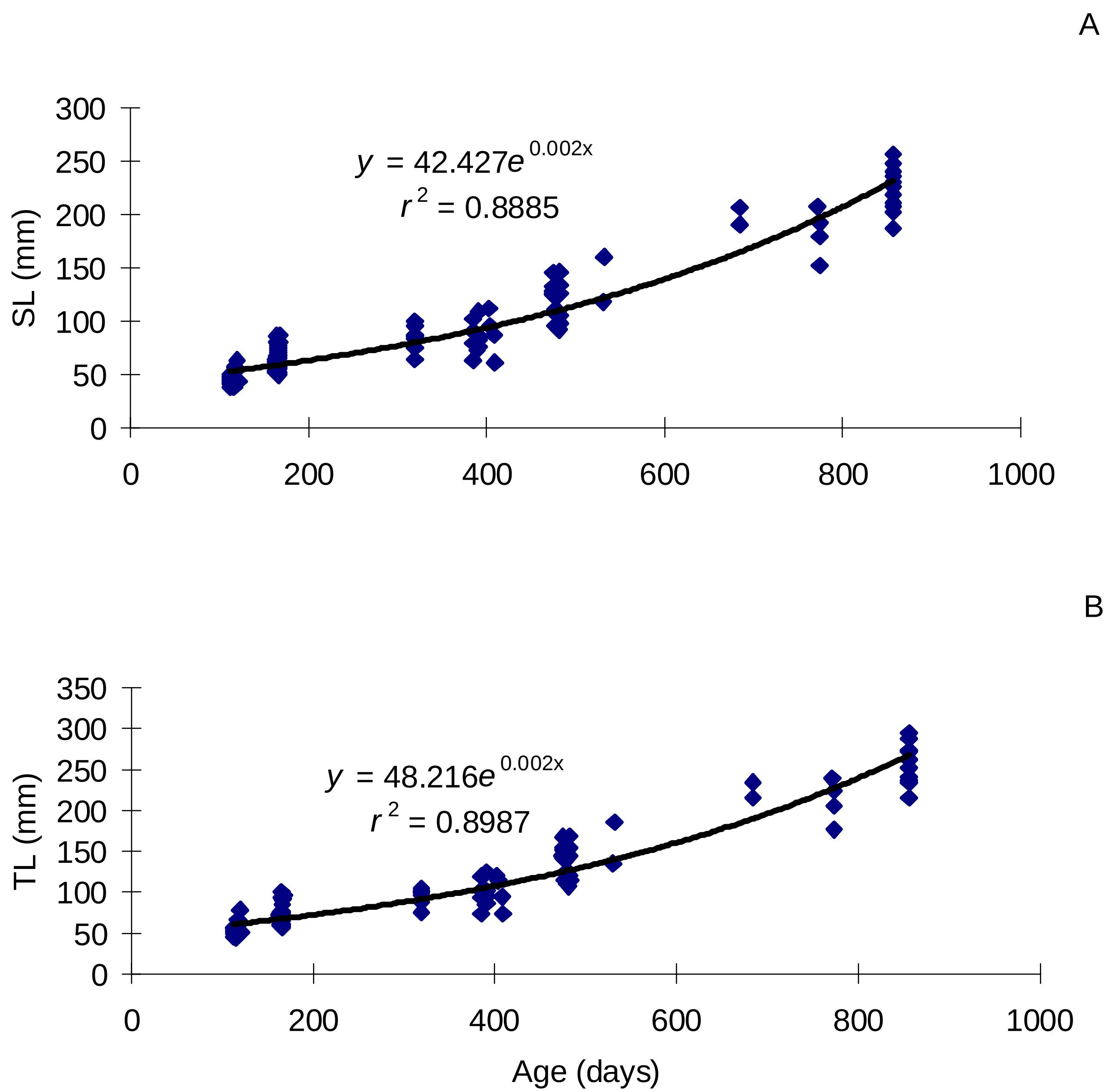

Figure 1. The relationship of age in days since hatch and standard length (A) and total length (B) of juvenile arrowtooth flounders captured in Kachemak Bay, Alaska, 1994–1996.

may be weak due to the headstart these fish had over others of their cohort. They may have entered the winter energetically more prepared than those settling later, and therefore did not experience the metabolic drain the later settling fish experienced, making their annuli less distinct.

Annuli are formed sometime between February and May, based on examination of otolith surface patterns. Bouwens et al. (1999) reported a mean settlement date of September 7±37 d. Arrowtooth flounders <50 mm captured in February in benthic trawls probably were late settlers from the previous fall that had not yet formed an annulus.

Length–Age Analysis

Our morphometric conversion equations, particularly OL to SL or TL, should be useful to investigators performing feeding studies on other species. Sometimes otoliths are all that remain in the stomachs of predators

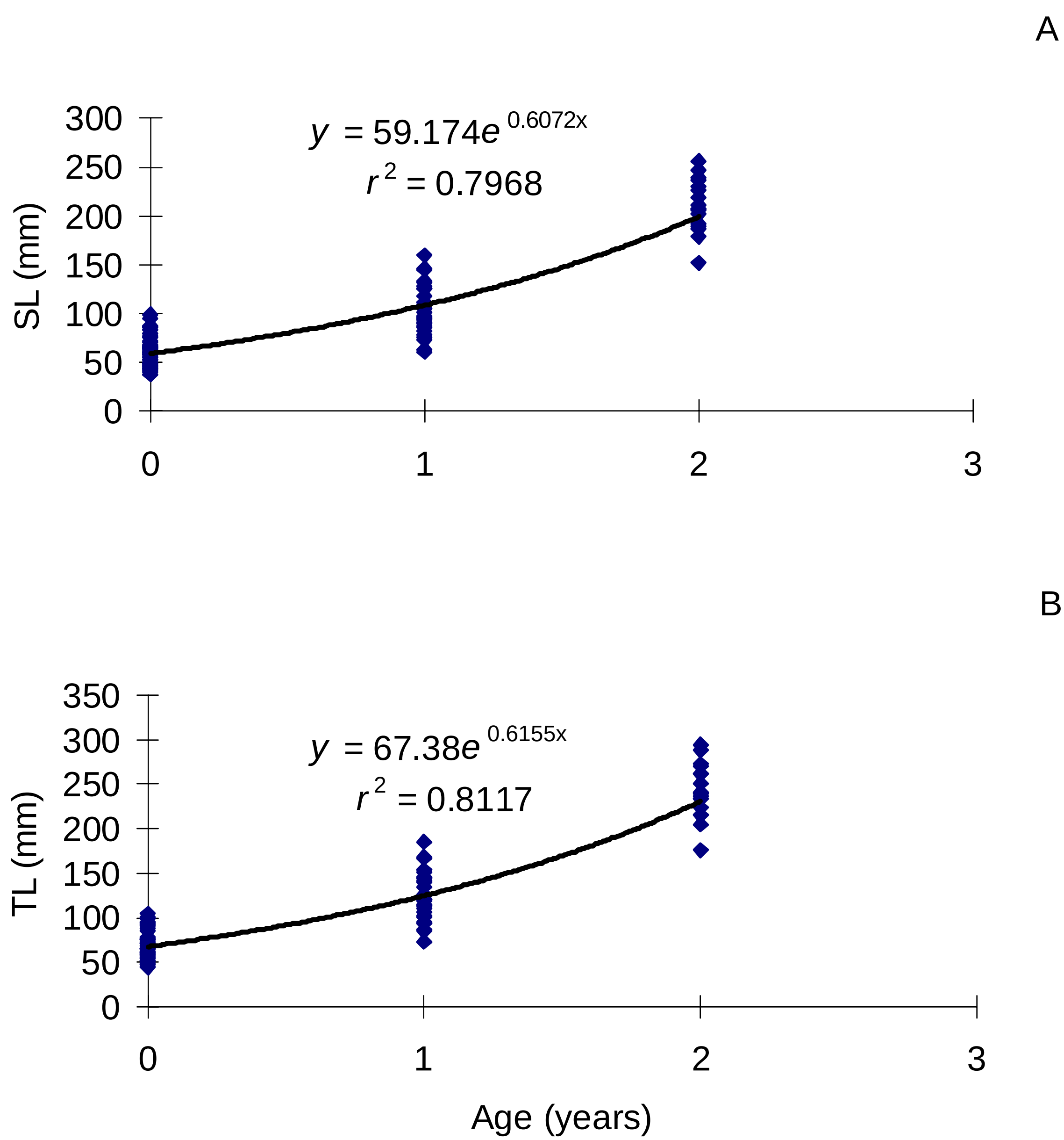

Figure 2. The relationship of age in years with standard length (A) and total length (B) of juvenile arrowtooth flounder from Kachemak Bay, Alaska, 1994–1996.

Table 4. Growth rates of juvenile arrowtooth flounders captured from Kachemak Bay, Alaska, 1994–1996.

Age	Total Length	Standard Length	Wet Weight
Absolute (lengths in mm/d; weight in g/d):			
0–1	0.14	0.12	0.04
1–2	0.33	0.29	0.30
0–2	0.24	0.20	0.17
Percent of Body Length (%/d) and Weight (%/d):			
0–1	0.15	0.15	0.46
1–2	0.19	0.19	0.52
0–2	0.17	0.17	0.49

being examined. There are keys to otolith identification, so one could measure OL to estimate the size of the fish consumed.

This study combined samples obtained from February through September, which meant fish could grow considerably between sampling events. This caused our size data to vary greatly (Figure 2). We were able to reduce this large variation in length-at-age by estimating age in days since hatching (Figure 1).

We excluded fish >300 mm, or age-3 and older fish from the growth rate calculations, which avoided potential length and weight-at-age bias due to sexual dimorphism (Zimmermann 1997). Some age-3 arrowtooth flounders are probably >300 mm, and mean size-at-age for this age class would have been underestimated from our data.

Our age-estimation methods result in different mean size-at-age values than those described by Bechtol and Yuen (1995). They reported mean TL at age 0 of 95 mm, 192 mm for age-1, and 276 mm for age-2 arrowtooth flounders. All these fish were captured in October 1989 from Kachemak Bay. We found smaller mean fish lengths at these ages (Table 3). Time of collection alone does not fully explain the difference in size-at-age between our values and those of Bechtol and Yuen (1995). Even our largest fish at these ages (captured in September) were smaller than their reported mean lengths-at-age. Arrowtooth flounders generally settle to the benthos at about 40 mm TL during September (Bouwens et al. 1999). Although settlement time is variable within and between years, a fish that settled as early as August 15 would need a growth rate of about 0.92 mm/day to grow to Bechtol and Yuen's (1995) reported mean length for age-0 fish. This growth rate is much greater than our calculated growth rate of 0.14 mm/d, as well as the growth rate of 0.26 mm/d we calculated from Bechtol and Yuen's figures. Even if one assumed all annual growth took place from May to October, summer growth rates would equal only 0.32 mm/d for our sample and 0.64 mm/d for Bechtol and Yuen's (1995).

Bechtol and Yuen's arrowtooth flounders collected in October and having a mean length of 95 mm were age 1, rather than age 0. Similarly, the mean length of their age-1 arrowtooth flounders was substantially larger than the mean age-1 length from our study. Settlement and hatch-date information (Bouwens et al. 1999) was unavailable at the time of Bechtol and Yuen's (1995) study. Use of this additional life history information would probably explain most of the difference in size-at-age estimates between the 2 studies.

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