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Age and Growth of Southern Flounder in Texas Waters, with Emphasis on Matagorda Bay

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Abstract.—Estimates of age and growth of southern flounder *Paralichthys lethostigma* from Matagorda Bay, Texas, were made by analyzing thin sections of sagittal otoliths from 892 specimens collected along the Texas coast from May 1992 to January 1995. Marginal increment analysis showed that a single annulus completed formation between January and March. The maximum age differed by bay systems, but it ranged from 0 to 4 years for both males and females. Males were generally smaller than females and exhibited asymptotic growth at an earlier age. The von Bertalanffy growth model equations for both females and males coastwide were $L_t = 660.45[1 - e^{-0.208\,(t+1.317)}]$ and $L_t = 308.67[1 - e^{-0.701\,(t+0.421)}]$, respectively.

The southern flounder *Paralichthys lethostigma* is one of the largest members of the family Bothidae occurring in Gulf of Mexico waters, and this species is distributed from North Carolina to Florida on the Atlantic coast and from Florida to Texas and into Mexico on the Gulf coast (Reagan and Wingo 1985). Over 25 bothid species occur along the Texas coast; nevertheless, *P. lethostigma* is the most sought after by commercial and recreational fishers (Stokes 1977).

In Texas between the years of 1972 and 1993, up to 500,000 kg of southern flounder, with an exvessel value of US$1,000,000, were landed annually by commercial fishers (Robinson et al. 1994). Approximately 100,000 sport-boat anglers target southern flounder as their primary species of interest; an estimated recreational fishery of 250,000 fish is landed annually (Weixelman et al. 1992; Warren et al. 1994).

During the 1980s, the inshore Texas fisheries for red drum *Sciaenops ocellatus*, spotted seatrout *Cynoscion nebulosus*, and southern flounder began showing signs of depletion. In 1988, the Texas Parks and Wildlife Department banned the use of nets to capture fish in salt water and instituted a recreational bag limit (Texas Parks and Wildlife Department 1994). Despite these regulations, the southern flounder fishery in Texas is presently experiencing a decrease in recreational and commercial landings, catch per unit effort and availability (number captured per hour in gill-net sampling), and recruitment (Texas Parks and Wildlife Department 1997).

Despite the prominence of the southern flounder in the northern Gulf of Mexico and Texas's inshore fisheries, few in-depth studies have been conducted concerning the age and growth of southern flounder. Most studies within the past 25 years have relied on whole sagittal otoliths (sagittae). Wenner et al. (1990) performed a detailed age and growth study in South Carolina using whole otoliths. However, this study may be of limited use in comparing specimens from Texas or the Gulf coast areas because of evidence indicating that southern flounder from different areas have different growth rates (Enge and Mulholland 1985). In Georgia waters, Music and Pafford (1984) contributed some information on age and growth, but they were limited to a small sample size and to the use of scale circuli. Nall (1979) conducted age and growth studies of southern flounder in western Florida, where estimates appear to be somewhat unrealistic, and no attempt was made to validate the aging method. In addition, both Nall (1979) and Music and Pafford (1984) failed to examine

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sexual dimorphism in relation to age and growth. Stokes (1977) carried out the only age and growth study in Texas waters. His findings were limited by his small sample size, and the whole otolith aging technique was not validated independently. The objective of our study was to describe the age and growth patterns of southern flounder in Texas's inshore waters, given the importance of this fishery in the Gulf of Mexico and the lack of detailed knowledge of age and growth parameters.

Methods

Southern flounder were collected from May 1992 through January 1995 from most major bay systems in Texas, although a majority of the sampling was conducted in Matagorda Bay. Additional samples were obtained from Sabine Lake, Galveston Bay, San Antonio Bay, Aransas Bay, Lower Laguna Madre, East Matagorda Bay, and from nearshore waters off Port O'Conner, Texas. Given the possibility that distinct subpopulations might exhibit varying growth rates, this age and growth study focused primarily on Matagorda Bay. Nonetheless, bay and coastwide data were generated for comparative purposes. Collections were made using hook and line, gill and trammel nets, and gigs. The fish were measured for total length (to the nearest millimeter) and were weighed (to the nearest gram). Both sagittal otoliths were removed and stored in a coin envelope for later age determination. Linear regression was used to determine a total length–weight relationship. Analysis of covariance was used to test for differences in sex-specific length–weight relations.

We used the left sagitta of each specimen for age determination, because otoliths are less subject to calcium resorption than are scales (Murphy and Taylor 1994). Each otolith was embedded in a mold of epoxy resin, cured for 2 h at 47°C, and placed on a Buehler Isomet 2000 high-speed precision saw with a diamond wafering blade. Thin transverse sections were obtained by cutting along the dorsoventral plane, in 1-mm sections, close to the focus. Several sections were cut, viewed under a microscope for clarity and proximity to the focus, and mounted on a microscope slide for further age analysis.

The sections were viewed using Optimas 4.02 (Optimas 1992), an image-enhancing system. The image was digitized by transferring the field of view from a compound microscope, using a black-and-white video camera, to a color video medical monitor that was interfaced to a computer. Age was determined to the nearest year by enumerating each opaque ring, beginning at the focus and extending outward to the margin. As spawning occurred from fall to early winter, ages were assigned from these annular counts using January 1 as an arbitrary birth date (Jearld 1983). Opaque ring counts were performed by two readers. Readings that differed were read a third time. Otoliths on which the two readers could not agree were discarded from the analysis. The three following measurements were made on the otolith radius for a random sample of fish ($n = 100$): from the focus to the dorsolateral edge, from the focus to the dorsal edge of the sacculus acusticus, and from the focus to the ventral edge. The best fit for a regression analysis of the total length–otolith relationship for the three measurements was from the focus to the dorsolateral edge, and this fit was used for all experimental measurements along this plane. The radius of the otolith section was defined as the distance from the focus along this plane to the margin of the otolith along the dorsolateral plane. All measurements of the distance from the focus to the distal edge of each opaque band were made along this line by computer-calculated measurements. The marginal increment method, used to validate the annual increment formation of the rings, consisted of measuring the distance from the dorsal side of the last annuli to the edge of the otolith and then comparing these distances seasonally for southern flounder from Matagorda Bay (Bagenal and Tesch 1978).

Average observed, back-calculated, and model-predicted sizes were used in examining the growth of southern flounder. Back-calculations were performed using a modified direct-proportionality method. The formula is $l_n - c = S_n / S\ (l - c)$, where l_n = length of fish when annulus 'n' was formed, c = the intercept on the length axis, l = length of fish at capture, S_n = radius of annulus 'n', and S = total otolith radius (Bagenal and Tesch 1978). In order to evaluate growth using model-predicted sizes, a von Bertalanffy growth equation was determined by using nonlinear regression (Ricker 1975). The growth equation is $L_t = L_\infty\ [1 - e^{-K(t-t_0)}]$, where L_t = total length at time t (years), L_∞ = maximum theoretical attainable total length (mm), K = growth coefficient per year, and t_0 = time (years) when length theoretically would be zero (von Bertalanffy 1957). These models were developed using length at capture and the estimated age at capture. Nonlinear regression was performed using the Statistical Analysis System (SAS Institute 1990). Growth curves derived for male and female southern flounder were com-

TABLE 1.—Summary of mean total length (mm) for southern flounder along the Texas coast.

Location and sex	*N*	Range (mm)	Length ± SE
Matagorda			
Sexes combined	651	153–633	333 ± 2.9
Females	541	197–633	341 ± 3.2
Males	74	153–381	276 ± 4.8
Coastwide			
Sexes combined	892	102–633	340 ± 2.4
Females	718	197–633	350 ± 2.8
Males	144	153–479	295 ± 3.7

pared by using the maximum-likelihood test (Kimura 1980). All statistical tests were considered significant at P is less than 0.05.

Results

Southern flounder were captured in Matagorda Bay ($N = 651$), Galveston Bay ($N = 158$), Lower Laguna Madre ($N = 118$), Sabine Lake ($N = 26$), San Antonio Bay ($N = 6$), East Matagorda Bay ($N = 5$), Aransas Bay ($N = 1$), and offshore (Port O'Conner) ($N = 16$). Eighty percent of the fish collected were females, 13% were males, and the remaining 7% were of undifferentiated or undetermined sex. The ratio of females to males was 7:1 in Matagorda Bay and 6:1 coastwide.

Student's t tests indicated a significant difference ($P < 0.05$) between mean lengths for male and female southern flounder in Matagorda Bay and coastwide (Table 1). Weights determined for 222 southern flounder from Matagorda Bay ranged from 99 to 1,840 g. A significant difference occurred between the mean weight for males and females ($P < 0.05$). The weight ranges for males and females were 110 to 570 g and 99 to 1,840 g, respectively (Figure 1). Analysis of covariance indicated significant differences ($P < 0.05$) in sex-specific length–weight relations (Figure 1).

Otoliths from 892 southern flounder were sectioned and examined. Annular marks on transverse sections were easy to discern. Paired independent counts agreed for all but three otoliths. Reexamination of discrepancies resulted in 99% agreement. The fish length–otolith radius (OR) relationship was total length = 23.67 + 146.24OR ($r^2 = 0.85$, $N = 827$, $P < 0.001$).

Marginal increment analysis indicated that a single opaque band completed its formation on the otolith section once each year from January to April (Figure 2), and no apparent differences were observed in timing or duration of the deposition of the annular mark between sexes or among age classes.

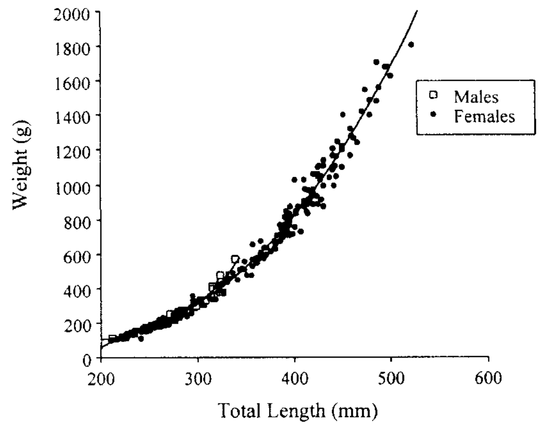

FIGURE 1.—Total length–weight relationships for females (range = 210–521 mm TL; $N = 206$; $a = -5.6644$; $b = 3.2953$; $r^2 = 0.991$), males (range = 211–339 mm TL; $N = 33$; $a = -5.6853$; $b = 3.3087$; $r^2 = 0.975$), and both sexes combined (range = 210–521 mm TL; $N = 239$; $a = -5.6067$; $b = 3.2734$; $r^2 = 0.990$) for southern flounder in Matagorda Bay, Texas.

Male and female southern flounder ranged from age 0 to age 4 in both males and females (Table 2). Average observed lengths at age indicated that male and female flounder had different growth patterns in Matagorda Bay and coastwide. While overall longevity may be the same coastwide, a significant difference between sexes exists for mean length at each age and for overall mean age–length (Table 2).

Because of the small number of older fish obtained from Matagorda Bay, back-calculation was done only for southern flounder coastwide. Mean

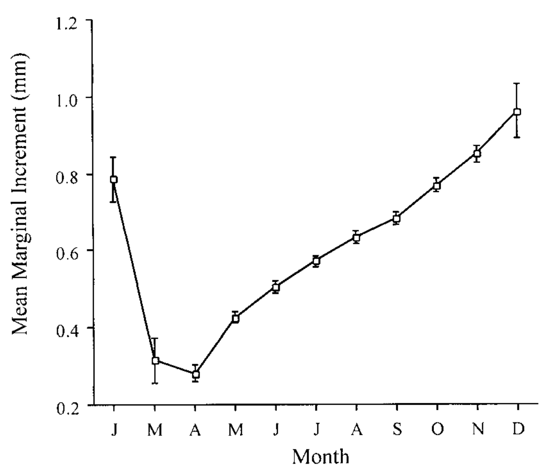

FIGURE 2.—Mean marginal increment distances by month (±SE) for all ages of male and female southern flounder.

TABLE 2.—Summary of age–length data for southern flounder in Matagorda Bay and coastwide for different age categories.

Annulus group	N	Total length (mm) Range	Mean ± SE
Matagorda Bay			
Sexes combined			
0	198	197–390	251 ± 2.27
1	420	153–500	362 ± 2.54
2	30	335–624	432 ± 10.41
3	2	573–633	603 ± 29.70
4	1	585	585 ± 0.00
Females			
0	165	197–390	253 ± 2.49
1	347	242–500	374 ± 2.36
2	26	335–624	434 ± 11.18
3	2	573–633	603 ± 29.70
4	1	585	585 ± 0.00
Males			
0	22	201–331	243 ± 6.61
1	52	153–381	291 ± 5.13
Coastwide			
Sexes combined			
0	238	197–390	254 ± 2.14
1	554	102–500	360 ± 2.21
2	116	276–624	400 ± 5.49
3	13	361–633	477 ± 26.90
4	6	349–585	450 ± 37.97
Females			
0	186	197–390	256 ± 2.49
1	438	242–500	373 ± 2.05
2	81	333–624	419 ± 5.89
3	9	369–633	491 ± 23.00
4	4	431–585	500 ± 47.50
Males			
0	32	201–331	251 ± 5.30
1	87	153–381	300 ± 3.86
2	21	276–479	336 ± 8.73
3	2	361–366	363 ± 2.83
4	2	349–354	351 ± 2.83

back-calculated lengths at age for males and females were smaller for each age than was average observed length at each age. In addition, back-calculated length at each annulus formation was consistently larger for females than for males (Table 3).

A von Bertalanffy growth equation was calculated for southern flounder coastwide and in Matagorda Bay using both observed lengths and back-calculated lengths. The equations calculated for these growth models are summarized in Table 4. Overall growth models were significantly different (back-calculated model: $\chi^2 = 3.384$, df = 3, $P < 0.05$; coastwide model: $\chi^2 = 128.37$, df = 3, $P < 0.05$; Matagorda model: $\chi^2 = 117.71$, df = 3, $P < 0.05$). The theoretical maximum attainable length (L_∞) predicted from back-calculated and observed length models was close to the maximum size collected for male and female southern flounder. Since L_∞ represents an average maximum attainable size, L_∞ should be less than the actual maximum size recorded for any given population (Matlock 1991).

Discussion

Female southern flounder are more numerous and larger than males both in Matagorda Bay and coastwide. Similar sex ratios and size differences were observed by Stokes (1977) in Aransas Bay, Texas, and by Music and Pafford (1984) in Georgia. Stokes (1977) suggested that a high percentage of males die before reaching larger sizes. While a tagging study indicated that some larger males spend the latter portion of their lives in the Gulf (Stokes 1977), surveys in the Atlantic (off the southeastern United States) found no large concentrations of male or female southern flounder during summer (Barans and Burrell 1976). Adult

TABLE 3.—Average back-calculated total lengths (mm), SD, range, N, and length at capture at age for male and female southern flounder from the Texas Gulf Coast at the time of annulus formation.

Sex and statistic	Annulus 1	2	3	4
Males				
Mean	194	252	284	292
SD	26	31	20	2
Range	130–257	207–335	268–306	291–293
N	83	14	3	2
Average observed	300	336	363	351
Females				
Mean	253	328	402	429
SD	41	47	87	63
Range	129–379	221–452	307–574	372–511
N	524	92	13	4
Average observed	373	419	491	500

TABLE 4.—Summary of the von Bertalanffy growth equation parameters for southern flounder in Matagorda Bay and coastwide using both average observed and back-calculated lengths.

Sex and parameter[a]	Parameter estimate	Asymptotic standard error	Asymptotic 95% confidence interval Upper	Lower	r^2
Back-calculated models Coastwide					
Females					
L_∞	660.439	232.091	204.666	1116.212	0.694
K	0.209	0.140	0.000	0.484	
t_0	−1.317	0.528	−2.354	−0.280	
Males					
L_∞	308.666	34.971	239.275	378.058	0.680
K	0.701	0.382	−0.056	1.459	
t_0	−0.421	0.522	−1.456	0.615	
Observed length models Coastwide					
Females					
L_∞	482.834	13.163	456.991	508.677	0.662
K	0.751	0.077	0.060	0.901	
t_0	−0.308	0.074	−0.455	−0.162	
Males					
L_∞	383.987	28.601	327.410	440.563	0.528
K	0.496	0.168	0.164	0.829	
t_0	−1.381	0.495	−2.360	−0.402	
Matagorda Bay					
Females					
L_∞	565.609	33.906	499.005	632.214	0.721
K	0.527	0.081	0.367	0.686	
t_0	−0.406	0.093	−0.589	−0.222	
Males					
L_∞	300.614	5.171	290.294	310.935	0.582
K	3.167	1.203	0.766	5.568	
t_0	0.225	0.171	−0.117	0.567	

[a] L_∞ = maximum theoretical attainable total length; K = growth coefficient per year; t_0 = time (years) when length theoretically would be zero.

male southern flounder averaged 295 mm, and the largest male collected was 479 mm. Wenner et al. (1990) reported a male of 476 mm, but most male southern flounder were less than 300 mm. The largest southern flounder captured during this study was 633 mm, although exceptionally large specimens of greater than 700 mm do occur, as several researchers have reported (Music and Pafford 1984; Wenner et al. 1990). The largest southern flounder reported in Texas measured 711 mm and weighed 5.9 kg (Texas Parks and Wildlife Department 1989). The largest southern flounder reported in the literature measured 762 mm, but it weighed only 5 kg (Ginsburg 1952).

Length–weight relationships were significantly different for male and female southern flounder. The length–weight relationships determined in this study had slopes and intercepts that were similar to those found in previous studies (Matlock 1979; Music and Pafford 1984), although these earlier studies did not separate male and female southern flounder. The male, female, and coastwide total length–weight relationships for log-transformed data were characterized by high coefficients of determination; therefore, length was a good indicator of overall weight.

Transversely sectioned southern flounder sagittas contain easily discernible annular marks. A high degree of precision (99%) was obtained by two independent readers. A high degree of precision (95.1%) was also observed by Wenner et al. (1990), who used thin sectioned sagittal otoliths.

Marginal increment analysis for southern flounder suggests that annular marks are completed during the period extending from January to April. This period of annulus formation seems to be reasonable, because factors affecting the deposition of annuli, such as spawning, migration, and reduced winter growth, all occur during this time. Wenner et al. (1990) reported that annular formation in southern flounder from South Carolina waters occurred during this time period. Music and

Pafford (1984) found that southern flounder in Georgia waters formed a single annulus during the period extending from February to March. Stokes (1977) reported, but did not verify, that the southern flounder in Aransas Bay, Texas, appeared to lay down one ring on its otolith at the completion of a year's growth. Stokes (1977) also reported that the gulf flounder *Paralichthys albigutta* in Aransas Bay exhibited the same pattern of otolith deposition.

The mean lengths at the age reported here are similar to those values reported in Aransas Bay, Texas, by Stokes (1977) and in South Carolina by Wenner et al. (1990). Other researchers reported differences in maximum observed age. In Stokes (1977) and the present study, southern flounder reached age 4, and the maximum specimen length was about 600 mm. However, Wenner et al. (1990) and Music and Pafford (1984) collected southern flounder of greater than 700 mm, and they reported a few age-6 fish based on scale circuli. The oldest male reported in any of the above studies was age 3. Since southern flounder may exceed 700 mm in Texas waters, it is possible that older fish exist.

Southern flounder may exhibit intermediate longevity relative to a few congeners. Smith and Daiber (1977) reported a maximum age 9 for summer flounder on the mid-Atlantic coast. Stokes (1977), however, reported the maximum for gulf flounder to be age 3. All of the above studies reported a maximum size that was greater for females than for males.

During the first year (no annuli present), southern flounder attain an average size of 251 mm in Matagorda Bay (age-0 males and females have reached 243 and 253 mm, respectively). However, during their second year, male and female southern flounder exhibit very different growth characteristics. Whereas the mean total length for males coastwide remained below 370 mm for ages 0 to 4, the mean lengths for females were 419, 491, and 500 mm for ages 2, 3, and 4, respectively. Wenner et al. (1990) and Stokes (1977) observed this same sex-related growth difference.

At each annulus, the back-calculated total length was significantly smaller than the average observed total length for both males and females. Music and Pafford (1984) reported similar results for back-calculated lengths based on scale measurement for combined male and female southern flounder back-calculations. Back-calculated lengths for a given age group are frequently smaller than the observed sized of fish in that age group. This effect, termed Rosa Lee's phenomenon, has been attributed to four possible causes: incorrect calculation procedure, nonrandom sampling, selective natural mortality, and selective fishing mortality (Bagenal and Tesch 1978). Several of these reasons might be plausible explanations for the size discrepancies in this study. The first possibility might be that there was an inadequate number of older fish in the sample. There were very few 3- and 4-year-old fish. Second, both fishing and natural mortality probably favor the smaller fish of a given age group. In addition, some of the differences can be attributed to the average age of the fish used in each calculation. Therefore, the use of back-calculated length of southern flounder in this study may be of limited use, and the inclusion of back-calculated data may mask the actual growth pattern of southern flounder.

Estimates of the growth of southern flounder appear to agree with other studies. Matlock (1992) found a similar von Bertalanffy growth equation when looking at the growth of southern flounder in Texas bays. Using combined males and females, he estimated an L_∞ of 836 mm and a K of $0.230 \cdot \text{year}^{-1}$. In another study examining the growth and mortality of southern flounder (Matlock 1991), L_∞ was estimated to be 631 mm, but K was $0.350 \cdot \text{year}^{-1}$. In South Carolina waters, Wenner et al. (1990) found von Bertalanffy growth equation–predicted growth rates for southern flounder that were similar. When separated, males approached a smaller theoretical asymptotic size at an earlier age than did females. The K values were 0.258 and $0.235 \cdot \text{year}^{-1}$ for South Carolina males and females, respectively. The estimates for L_∞ were 518 and 759 mm for males and females, respectively, and these values closely approximated the observed maximum size for females. This more rapid approach to asymptotic size for males was also observed in the current study.

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