The Age and Growth of Southern Flounder, *Paralichthys lethostigma*, in Louisiana Waters

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ABSTRACT

Morphometric measurements and otoliths were collected from southern flounder *Paralichthys lethostigma* from a variety of sample sources from Louisiana waters. Transverse sections of otoliths (n = 1286) were examined and opaque zones validated to form once a year in the winter months. Maximum observed age for males was 4 years while that among females was 8 years. Growth was expressed by Vonbertalanffy's growth model as $L_t = 325.65\{1 - e^{[-1.33(t + 0.01)]}\}$ for males and $L_t = 520.14\{1 - e^{[-0.74(t + 0.14)]}\}$ for females where t is age in years and L_t is total length at age t. Growth was shown to be significantly different between males and females with males displaying a faster growth rate than females but a much smaller L_∞.

KEY WORDS: Otolith, growth model, southern flounder

INTRODUCTION

The southern flounder, *Paralichthys lethostigma*, is the largest member of the family Paralichthyidae (Hensley et al. 1984) in the Gulf of Mexico

coast of Florida. They are absent on the southern peninsular tip of Florida, but occur in the Caloosahatchee River and up the western coast of Florida and around the Gulf of Mexico to northern Mexico (Hoese and Moore 1998, Manooch 1984).

Southern flounder is an important species throughout Gulf coast region. Commercial and recreational landings of *Paralichthys* along Louisiana coasts for 1997 were estimated to be 94,898 lbs. and 319,607 lbs. (personal communication from the National Marine Fisheries Service, Fisheries Statistics and Economics Division). It is the dominant targeted flatfish in the region and is fished mainly using hook and line, gigging, and by trawl. Commercial landings for southern flounder in Louisiana have fluctuated since the 1950s with the highest landings in the mid-1990s at 0.97 million pounds (Louisiana Department of Wildlife and Fisheries 1998). Substantial restrictions have been put on the southern flounder fishery in recent years leading to a decrease in those landings.

The age structure and longevity of a species is important in formulating a proper fisheries management strategy. It is essential to obtain the age structure of fish populations being harvested to effectively monitor the status of those stocks (Williams and Bedford 1974). Age estimation can be accomplished through the use of otoliths. The sagitta, the largest of the three pairs of teleost otoliths is arrowhead shaped in the flounder. Although growth of the otolith is not uniform along all axes, it grows in a radial fashion forming layers of opaque and translucent zones. These zones, or annuli, are often utilized for age estimation; but in order to do so, the periodicity of the annuli must be validated. Validation of this periodicity of annuli formation is as important in fisheries biology as standardizing solutions or calibrating instruments are in other sciences (Beamish and McFarlane 1983).

The few studies conducted on the age and growth of southern flounder suggest that they are a short-lived species. Nall (1979) reported a maximum age of 10 years using whole otoliths, but did not validate his methods. Stokes (1977) used whole otoliths and reported a maximum age of five years for southern flounder. Wenner et al. (1990) used whole otoliths and reported a maximum age of seven years using length frequency data and marginal increment analysis to validate the use of whole otoliths. Interpretation of length frequency data for validation may be suspect, however, because overlapping size classes of cohorts beyond two years (Ross 1988) can complicate age-class designations. Music and Pafford (1984) assigned a maximum age of six years using scales. They attempted to use otolith counts to document the validity of increment counts on scales, although it is unclear whether they used whole or sectioned otoliths.

It appears that a number of flatfish exhibit sexual dimorphism in age and growth rates. Solomon et al. (1987) found that the growth of male and female *Limanda yokohamae* differed; females exhibited a higher growth rate than males of the same age. The same observation was reported for stone flounder, *Kareius bicoloratus* (Uehara and Shimizu 1996) with females reaching a greater size and living longer. Lux (1973) reported that female winter flounder, *Pleuronectes americanus*, grew faster then males after the second year. Lux and Nichy (1969) also stated a similar pattern of growth in the New England yellowtail flounder, *Limanda ferruginea*. Gilbert (1986) reported that there is evidence that *Paralichthys* females reach a larger size then males. Stokes (1977) stated that male southern flounder grew slower than females and did not exceed 320 mm total length where Miller et al. (1991) reported a difference in maximum size between male and female southern flounder with male maximum size at only 68% of females at the same age. Therefore, it may be necessary to generate separate growth curves by sex to properly manage the fishery.

The objectives of this study are to describe the age and growth of southern flounder in Louisiana waters through examination of sagittal otoliths. Growth will be modeled using the VonBertalanffy growth model. Males and females will be compared to determine if southern flounder displays sexual dimorphism in age and growth and if separate models are required.

METHODS AND MATERIALS

Southern flounder used in this study came from a variety of sample sources from Louisiana waters or the Gulf of Mexico off the coast of Louisiana. Multiple sources provided the most reasonable cross section of the estuaries near shore population. Samples were collected at commercial docks in Grand Isle and Leeville, LA from October 1997 to January 1998 (n = 146). The Louisiana Department of Wildlife and Fisheries at the St. Amant Marine Laboratory also collected samples from Grand Terre with the use of a pound net during November and December 1997 (n = 125). An existing flounder data set compiled by Dr. Bruce Thompson of the Coastal Fisheries Institute of Louisiana State University was also used in the analysis (n = 1,134). This data set contains samples from 1987 to 1998 from a variety of sources with the large majority from commercial fish docks (n = 565) and hook and line fishing rodeo tournaments (n = 421).

Fish were weighed (mg), measured (total and standard lengths in mm), sex determined, and otoliths removed. Otoliths were stored in ethyl alcohol to preserve until they were returned to the laboratory for analysis. Otoliths were cleaned of any extraneous tissue and air dried for at least twenty-four hours. Right and left otoliths were then weighed (± 0.01 mg).

A length – weight regression was calculated on $\log_{10}$ transformed data using the model $\log_{10}$ (weight, g) = slope $\log_{10}$ (TL, mm) + intercept. Linear regressions were also calculated for otolith weight (mg) – age using the model otolith weight = age (slope) + intercept. Analysis of Covariance was used to compare sexes for both regressions.

Fish were aged through processing and analysis of 1,286 sagittal otoliths. A number of fish in the data set were not aged due to missing or broken sagittae. Due to the morphological differences between right and left saggitae, The left was chosen for embedding. Otoliths were embedded in a mixture of five parts araldite 8702 epoxy resin to one part hardener 8,700 and left to harden for twenty-four hours. Two transverse sections near the core of the otolith were taken and glued on to glass slides. The better of two sections was polished and inscribed with an identification number, and aged. Sections were read along the medial side of the section along the ventral side of the sulcus groove (Figure 1).

Reader variability was also evaluated; otoliths were viewed and aged by of two independent readers without the knowledge of the date of capture or sample source. Ages were assigned based on annulus count and edge condition.

Edge condition was recorded as opaque or translucent using the criteria of Beckman et al. (1991). Ages were assigned based on a January 1 birth date from Wenner et al. (1990) and data from this study.

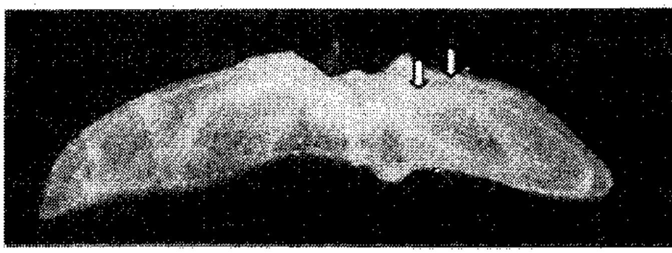

Figure 1. Photomicrograph of a transverse section near the core of a southern flounder otolith. Arrows point to opaque zones or "annuli" counted for age estimation.

Marginal increment analysis and a plot of edge condition by month were used to determine the periodicity of annulus formation in southern flounder otoliths. In addition, length-frequency distributions were plotted by month for young of the year (YOY) and yearlings with and without opaque zones on their otoliths to determine age of first annulus formation.

Length frequency distributions were examined for males and females. Distributions were plotted in 20mm intervals. A Komolgorov-Smirnov two-sample test (Tate and Clelland 1957) was used to test for differences between sexes.

Sex specific VonBertalanffy growth equations were derived from total lengths using nonlinear regression (SAS Institute Inc., 1985) based on the formula:

$$L_t = L_\infty\{1 - e^{[-k(t - t_0)]}\}$$

where t is age in years, and L_t is total length at age t, L_∞ is the theoretical maximum length, k is the growth coefficient, and t_0 is age at which length is zero. Individual fish were not included in the analysis if age or length data was not available. Each model also included 22 unsexed juveniles to provide points at the lower end of the curve. These juveniles ranged in size from 68 mm to 214 mm total length.

The resultant models fitting parameters for both males and females were then combined into one full six-parameter model and compared to a reduced model on the pooled data in which sex was not considered. A likelihood ratio test of the six-parameter and the pooled data models was used to test for differences in the models. Plots of residuals were used to test for normality of the data.

RESULTS

Fourteen hundred and five southern flounders (139 males, 1,201 females, 22 juveniles, and 43 unsexed) were sampled from August 1987 through January 1998. Fish came from numerous sources including commercial and recreational catches from the northern Gulf of Mexico, Louisiana Offshore Oil Port (LOOP) trawls, and the Louisiana Department of Wildlife and Fisheries which provided samples of flounder taken from Barataria Bay. Because not all parameters could be measured for each fish, the numbers of fish included in the different analyses vary.

Total length (TL) frequency distributions plotted by sex were significantly different ($p < 0.05$) (Figure 2). Males ranged in size from 68 mm to 414 mm TL. Males were most abundant at the 280 mm interval with fifty-three percent of all males ranging from 260 mm to 300 mm TL. Females were more abundant at much larger sizes ranging from 189 mm to 764mm TL and were most abundant at the 390 mm interval. Fifty-three percent of all females ranged from 380 mm to 440 mm TL. As expected, males also had a much lower range in body weight then females ranging from 19 g to 936 g. Females ranged in weight from 61 g to 5,953 g.

Regression equations of $\log_{10}$ transformed data were calculated to predict total weight at total length for males and females. Analysis of covariance (ANCOVA) showed no statistical difference between sexes ($p > 0.05$) for slopes; $p > 0.05$ for intercepts). Therefore, a combined length–weight regression was fit for males and females:

$$\log_{10} \text{weight (g)} = 3.21\log_{10}(\text{TL, mm}) - 5.46 \quad (r^2 = 0.98;\ n = 1236)$$

The slope of 3.21 was significantly different then 3 ($p < 0.0001$).

Opaque rings are easily distinguishable on both the ventral and dorsal sides of the sulcus groove in cross section of southern flounder otoliths. Marginal increment analysis and a plot of otolith edge condition were used to determine the seasonal periodicity of annulus formation. Opaque margins were found in fish caught from the months of January and May and the margins of nearly all samples taken from August through December were translucent. The plot of edge condition corresponded with marginal increment analysis showing the progression of opaque zones from January through May and translucent zones from March through December. Length-frequency distributions for young of the year (YOY) and yearlings indicated first annulus formation as early as 200 mm in length and up to 330 mm. The first annulus appeared on YOY otoliths between the months of January and March.

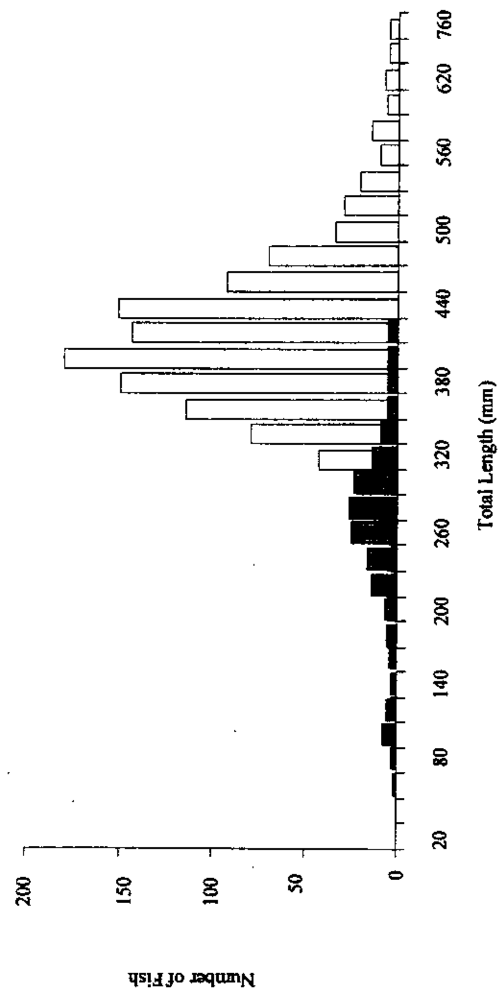

Figure 2. Length frequency distribution of male, female and juvenile southern flounder caught from 1987 to 1998. Males range in size from 68mm to 414mm and are most abundant at 280mm interval. Females range in size from 189mm to 764mm and are most abundant at 390mm interval. Juveniles range from 68 to 309mm and are most abundant at 100mm interval. Males are shown in shaded pattern, females are shown in white, and juveniles are shown in solid black.

Ages were assigned through analysis of 1,286 otoliths. Seven otoliths were excluded from the analysis due to lack of agreement between the two readers. Each of the seven age estimates differed by one year. The two readers agreed on all other otolith annulus counts (N = 1279) or 99.5% of age estimates. The mean coefficient of variation (V) was 0.0011. The mean index of precision (D) was 0.00081 indicating an average error of 0.08 annuli per one hundred counts (Beckman 1989).

A large number of the fish collected were estimated to be two years of age (Figure 3). Forty-six percent of females and thirty-six percent of males fell into this age class. The oldest female was 8.5 years in age and the oldest male was found to be 4.13 years.

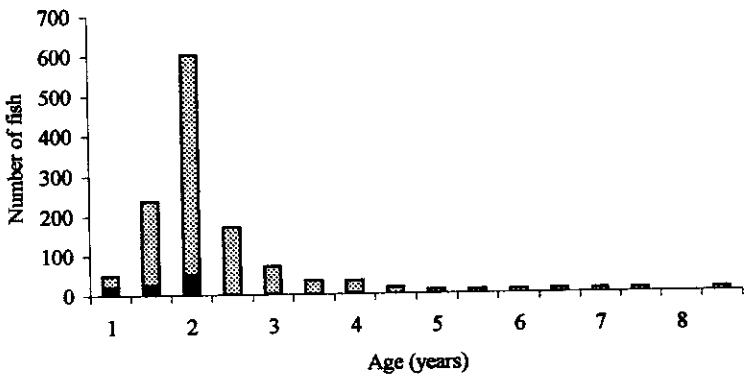

Figure 3. Age frequency distribution for male and female southern flounder sampled from 1987 through 1998. Males reached a maximum age of 4 years and females reached a maximum age of 8.5 years.

Data were fit to a Von Bertalanffy growth model and compared. A likelihood ratio test indicated that there was a significant difference between a full six-parameter Von Bertalanffy growth model and the pooled data growth model ($p < 0.0001$). Therefore, separate growth models were fit for each sex (Figure 4). The Von Bertalanffy growth models derived from total lengths are:

$$\text{Male: } L_t = 325.65\{1 - e^{[-1.33(t + 0.01)]}\} \quad (r^2 = 0.68)$$
$$\text{Female } L_t = 520.14\{1 - e^{[-0.74(t + 0.14)]}\} \quad (r^2 = 0.52)$$

Plots of residuals indicated normal distribution of the data.

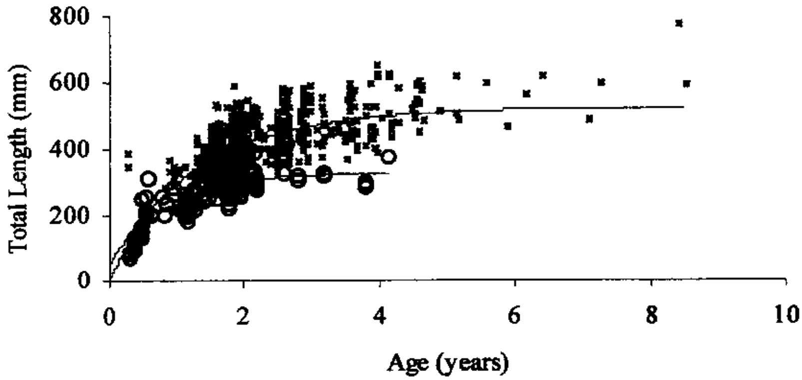

Figure 4. Von Bertalanffy growth models fit for male and female southern flounder sampled from 1987 through 1998. Each model includes 22 unsexed individuals ranging from 68 mm to 214 mm. Gray crosses represent females and hollow circles represent males.

DISCUSSION

The hypothesis that southern flounder display sexual dimorphism in age and growth is supported by length frequency distributions for males and females. Females had a distribution mode of 390 mm and reached up to 764 mm TL while males had a mode of only 280 mm and reached a maximum size of 414 mm. Shepard (1986) reported similar modal lengths with female mode at 358mm and a male mode of 247 mm. Wenner et al. (1990) did not report modal lengths by sex but stated that forty-four percent of aged females were greater than 300mm and few aged males were above 300 mm.

The length-weight regression of $\log_{10}$ transformed data indicated the slope was significantly different from 3.0 ($p = 0.0001$) indicating growth is allometric; weight of the fish increases in relation to its size as length increases. Length-weight regressions on southern flounder produced slopes of 3.14 in South Carolina, 3.09 in Georgia, 3.10 in Florida, and 3.13 in Texas. These slopes were not tested to see if they were significantly different then 3 so it is unclear if there is significant allometric growth in southern flounder from different regions. The higher slope suggests Louisiana southern flounder are more robust then those in previous studies.

Marginal increment analysis and plot of edge condition indicate that one opaque zone is deposited on the otolith between the months of January and May and that annuli on sectioned otoliths may be utilized for accurate age estimation (Barger

1985). A peak of fifty-six percent of individuals with an opaque zone at the growing edge of the otolith is consistent with that of Beckman and Wilson (1995). In a review of 49 studies on north latitude temperate populations using sectioned otoliths, Beckman and Wilson (1995) reported a mean percentage of 65% of individuals with an opaque zone at the growing edge of the otolith.

Analysis of sectioned otoliths of young of the year (YOY) and yearling southern flounder indicated they formed their first annulus as early as 200 mm and up to 330 mm TL. The first annulus began to form in January with all yearlings completing their first annulus by March. These findings are consistent with Powell (1982) who found first annulus formation in the summer flounder to take place between January and March. Stokes (1977) also reported lengths of up to 300 mm by first annulus formation in southern flounder. Wenner et al. (1990) detected no delayed or "lost" first annulus. Therefore this variability in size at first annulus formation is most likely due to differential growth among individuals, which Fitzhugh et al. (1996) found accounted for the broad dispersion of lengths occurring in the first year.

Females live longer than males. Females reached a maximum age of just over eight years while males reached only four years. These findings are close to Wenner et al. (1990) who reported a maximum age of seven years for females and three years for males. Although they employed the use of whole otoliths, their validation techniques of evaluating the edge condition of whole otoliths were similar to this study producing similar maximum age estimates for each sex. Music and Pafford's (1984) maximum age of six years for a female came from a data set of only 198 fish. It is not unexpected that they found a lower maximum age considering that only 11 out of 1,286 (0.009%) aged fish in our data set were five years or older. Nall (1977) reported a maximum female age of 10 years. However, this age estimate seems unlikely when taking into account his invalidated use of whole otoliths. Williams and Bedford (1974) stated that the main source of difficulty in using whole otoliths to age fish is the presence of secondary checks or rings that could be perceived as additional annuli and thus increase your age estimation. In all studies on southern flounder cited here, males have never been aged above three years.

Growth parameters from sex specific curves suggest rapid growth to age two for males and to age three for females. Maximum theoretical size was calculated at 326 mm for males and 520 mm for females. This study predicts more rapid growth and smaller maximum sizes for males and females then reported on southern flounder from South Carolina by Wenner et al. (1990). These parameters and the contrast of the Louisiana and world record suggest that Southern flounder occupying the cold temperate waters of the Atlantic appear to reach greater maximum sizes then those in the warm temperate waters of the Gulf of Mexico. These differences in sizes between the Atlantic and Gulf of

Mexico populations suggest zoogeographic variation in population dynamics of southern flounder. Such variation has been suggested for red drum (Matlock 1987) and Atlantic croaker (White and Chittenden 1977).

These sex specific growth models included 22 unsexed young of the year fish ranging from 68 mm to 214 mm total length. Music and Pafford (1984) stated that sex could not be determined before 130 mm for females or 232 mm for males. Stokes (1977), however, reported that sexual differentiation was not possible for either sex before 170 mm. Juvenile southern flounder have exhibited a capacity for high growth rate relative to other fishes (Fitzhugh 1993). The addition of unsexed juveniles into the growth models may account for the high growth coefficient (k).

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