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Article

Age and growth of Southern Flounder in Texas reveal evidence of changing stock demographics

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ABSTRACT

Objective: The Southern Flounder *Paralichthys lethostigma* is an important sport fish found throughout the Gulf of Mexico and along the southeastern Atlantic coast. Despite increasingly stringent fishing regulations, Southern Flounder populations have been declining for decades. Texas Southern Flounder age and growth data are outdated, but new data may provide insight into factors contributing to the decline. Therefore, this study aimed to update age and growth knowledge for Southern Flounder sampled near two Texas inlets by examining age structure, length at age, and growth models.

Methods: Southern Flounder were collected via fishery-independent and fishery-dependent methods. Biological measurements (e.g., total length, standard length, and total weight) and sex were recorded, and all Southern Flounder were aged from sagittal otolith sections following standard methods. Four growth models were fitted to all length-at-age data.

Results: In total, 734 Southern Flounder were aged, and the female : male sex ratio from fishery-independent samples was 4.8:1.0. Ages ranged from 0 to 3 years, with age 1 comprising more than 50% of all sampled fish. Mean length at age was greater for females than for males, with females consistently reaching older ages. The von Bertalanffy model was selected as the best fit for both sexes combined and individually. The von Bertalanffy equations were $L_t = 495.6(1 - e^{-0.91[t-\{-0.19\}]})$ for females and $L_t = 464.0(1 - e^{-0.35[t-\{-1.67\}]})$ for males. Mean length at age for older fish was less than the values reported in previous Texas studies.

Conclusions: These findings suggest that age structure, sex ratio, length at age, and growth rates for Southern Flounder have changed since previous Texas studies in the late 1990s, potentially due to increased fishing effort and climate change impacts on population structure. Therefore, updating Southern Flounder age and growth data is necessary to provide relevant information to fishery managers with the goal of maintaining population sustainability.

KEYWORDS: ages, growth, *Paralichthys lethostigma*, Southern Flounder, Texas

LAY SUMMARY

Climate change and fishing pressures are impacting the age, growth, and sex ratio of Southern Flounder. Monitoring these changes is crucial for effectively managing sustainable Southern Flounder fisheries.

INTRODUCTION

The Southern Flounder *Paralichthys lethostigma* is a popular sport fish species found along the northern Gulf of Mexico (GOM) and in the western Atlantic from Florida to North Carolina (Gulf States Marine Fisheries Commission, 2015; VanderKooy & Flounder Technical Task Force, 2000). The Southern Flounder is the predominant flatfish species along the Texas coast and is both ecologically and economically important, particularly for coastal ecosystems and communities. In addition to supporting commercial fisheries, Southern Flounder have become an increasingly popular sport fish since the mid-1900s and continue to be a major target for recreational anglers in Texas and throughout the GOM (Riechers, 2008; Spiller, 1982).

Fishing effort and historic landings of Southern Flounder increased rapidly and peaked in the 1960s, but since then, the population, along with commercial and recreational harvest rates, has been dramatically declining throughout the GOM (Froeschke & Froeschke, 2016; Texas Parks and Wildlife Department [TPWD], 2019). Specifically, annual recreational harvests have declined from nearly 183,000 Southern Flounder in 1987 to less than 40,000 in 2018, and annual commercial

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harvests have declined from 551,000 Southern Flounder to less than 20,000 during that same period (TPWD, 2019). The TPWD's long-term fishery-independent monitoring surveys have also documented a steady decline in Texas Southern Flounder populations and CPUE since the 1980s. In response to this decline, numerous fishing regulations have been implemented to prevent the Texas fishery from becoming overfished. These regulations have included increased minimum size restrictions, reduced bag limits for commercial and recreational anglers, and season closures to protect Southern Flounder during their annual fall migration offshore to spawn. Despite these regulatory measures, abundance trends show little sign of recovery and continued decline (TPWD, 2019, 2020).

One popular method of targeting Southern Flounder is by gigging, which is the harvest of fish at night with the aid of lights by using a multi-pronged spear. This specialized method can be extremely effective at harvesting fish. High fishing mortality has the potential to impact growth rates and length at age of fish species (Conover et al., 2009; Walsh et al., 2006). The selective removal of larger, healthier fish from the spawning stock through harvest often drives younger sexual maturity and faster growth rates to maximize fecundity. The result of this selective removal is often reduced recruitment and overall smaller fish (Trippel, 1995; Walsh et al., 2006). Recent studies have determined that sexual maturity of Southern Flounder may be reached in as early as 1 year (Blanchet, 2010; Corey et al., 2017). However, prior studies observed sexual maturity to be reached after age 2 (Stokes, 1977). Southern Flounder also exhibit sexual dimorphism in which adult females are larger than adult males, resulting in a fishery that heavily favors females (VanderKooy & Flounder Technical Task Force, 2000). This may be particularly impactful during the fall spawning migration, when Southern Flounder are concentrated near inlets, thus increasing their vulnerability to fishing pressure (TPWD, 2020). While current populations exhibit a greater abundance of females compared to males (female : male ratio of at least 7:1; Fischer & Thompson, 2004; Stunz et al., 2000), the favored harvest of females due to their larger size and the current minimum legal size limit (381 mm [15 inches]) has the potential to skew the sex ratio by disproportionately reducing female abundance, altering natural sex ratios, and therefore potentially reducing successful spawning offshore.

Because Southern Flounder exhibit environmental sex determination during their juvenile stage, climate change may also be contributing to declines in Southern Flounder populations. The sex of juvenile Southern Flounder is influenced by water temperature, meaning that exposure to water temperatures 2°C above or below 18°C can cause genetically female Southern Flounder to become phenotypic males (Honeycutt et al., 2019). Even at the optimum temperature of 18°C, approximately 50% of juveniles remain females, with greater deviation from the optimum temperature resulting in a greater percentage of males (Luckenbach et al., 2009; Montalvo et al., 2012). This suggests that warming water temperature trends have the potential to masculinize Southern Flounder populations, further skewing the sex ratio (Erickson et al., 2021; Honeycutt et al., 2019). Other recently published studies have also described major changes in Southern Flounder life history corresponding to climate change, including the delay of major life history events, such as juvenile metamorphosis, the fall spawning migration, and the spawning season (Anderson et al., 2023; Beeken et al., 2023; Erickson et al., 2021; Honeycutt et al., 2019; Midway et al., 2024; Steffen et al., 2023).

Documenting fishing pressure and harvest impacts as well as climate-driven effects on Southern Flounder population dynamics is critical for effective management of sustainable fisheries. Some important methods used by management agencies to determine the health of exploited fish populations include validation of age structure and growth models. Specifically, management studies often use age structure and growth models to evaluate changes over time or to compare different species (Katsanevakis, 2006; von Bertalanffy, 1938). Age in teleost fish is typically determined by counting the rings (annuli) formed within otoliths (Katayama et al., 2010; Rodriguez-Mendoza, 2006; VanderKooy et al., 2020).

There are few recent published age and growth studies for Southern Flounder (Corey et al., 2017; Fischer & Thompson, 2004; Stanfill, 2017; Takade-Heumacher & Batsavage, 2009) and even fewer such studies on Southern Flounder in Texas (Matlock, 1991; Midway et al., 2015; Stokes, 1977; Stunz et al., 2000). In the 1970s, extensive data on the life history of Southern Flounder in Texas bays were published, including age and growth data (Stokes, 1977). Since then, few studies have focused on Southern Flounder age and growth, and the most recent age and growth study in Texas evaluated fish that were sampled in the 1990s (Stunz et al., 2000). A reduced number of age-classes was observed in the 1990s for males, but length at age was similar to previous findings (Stokes, 1977; Stunz et al., 2000). However, regulation changes and increasingly warm water temperatures likely have resulted in greater changes in Southern Flounder populations over the past few decades (National Oceanic and Atmospheric Administration, 2025; TPWD, 2019). Because of large gaps in time between age and growth studies and the changing climate in Texas, this study aimed to update the age and growth of Southern Flounder in Texas bay systems. The specific objectives of this study were as follows: (1) to determine the age structure and sex ratio of Southern Flounder sampled from two Texas tidal inlets, (2) to update length-at-age ranges for specific Texas bays to inform future management decisions, and (3) to estimate current growth curves for male and female Southern Flounder within Texas bays.

METHODS

Sample collection

Southern Flounder were collected from both fishery-independent and fishery-dependent sources. For fishery-independent data, Southern Flounder were collected from September through December in 2022 and 2023 during standardized gigging surveys near two tidal inlets along the mid-Texas coast (Aransas Pass and Packery Channel; Figure 1). To minimize bias in growth models, all Southern Flounder, including those beneath the legal minimum size limit (381 mm [15 inches]), were collected during these surveys. To estimate length at age and the average maximum length (L_∞) more accurately, larger and older Southern Flounder were opportunistically collected from charter guides during fishery-dependent surveys in May–October 2023. Southern Flounder collected

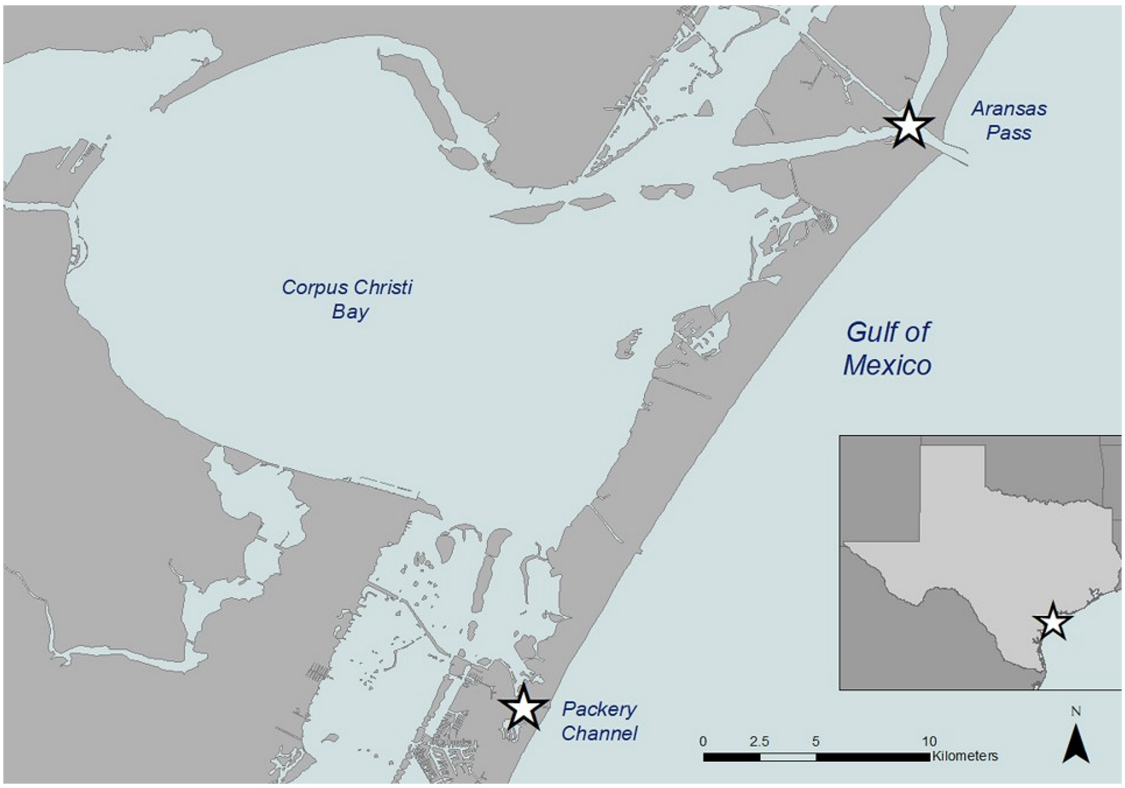

Figure 1. Map of the sampling area along the south Texas coast. Southern Flounder sampling sites were within 10 km of the two tidal inlets (stars).

from the fishery-dependent surveys were filleted carcasses and were taken with permission from the anglers. Gear selection may bias growth parameters, whereas using multiple methods of collection increases growth parameter accuracy (Gwinn et al., 2010; Thorson & Simpfendorfer, 2009; Wilson et al., 2015). Therefore, supplementing the fishery-independent surveys with fishery-dependent surveys was beneficial to reduce the impact of potential sampling bias by incorporating multiple methods. All sampling occurred under TPWD Scientific Permit SPR-0303-279.

Biological measurements (e.g., standard length, total length, and total weight) were taken from all sampled Southern Flounder, with the exception that total weight was not obtained from the filleted carcasses in the fishery-dependent surveys. When possible, each fish was sexed via macroscopic examination of the gonads. For some of the fish received from charter guides, the gonads were damaged or lost from filleting, and those individuals could not be sexed. For all Southern Flounder, sagittal otoliths were extracted, rinsed, and dried before storage in individual envelopes.

Age determination

Annuli (opaque zones) from thin sections of the left sagittal otolith were counted to determine the age-class of each fish. When the left otolith was unavailable, the right otolith was used ($n = 11$). Asymmetry between the left and right otoliths has been reported for Southern Flounder (Fischer & Thompson, 2004; VanderKooy et al., 2020); thus, analyses were conducted with and without the right (blind-side) otoliths to ensure that the inclusion of right-side otoliths did not alter the results. There was no change in the results when the right-side otoliths were included, so both left and right otoliths were kept in the final analyses. All otoliths were encased in epoxy and sectioned to expose the core by using a low-speed Buehler wafering saw. Sections were 0.5 mm in width and were adhered to microscope slides following the methods described by VanderKooy et al. (2020). Reading required the use of immersion oil on the slides and magnification between 12× and 16×. Two readers observed each otolith independently to determine the number of annuli. When counts differed between readers, both readers viewed the otolith independently a second time to reach a consensus. If a consensus was not reached, the otolith was removed from the analysis. Precision of the two readers was evaluated based on average percent error (Beamish & Fournier, 1981) and the estimated average coefficient of variation (Campana, 2001; Chang, 1982), and overall reader bias was evaluated with age-bias plots (Campana et al., 1995).

Southern Flounder age was assigned by adjusting the number of counted annuli to fractional ages determined by the month before the capture date (Midway et al., 2015). For example, a fish with two annuli collected in October was assigned the age 2.75 (2 + [month 9/12]). Consistent with all prior literature, January 1 was used as the Southern Flounder birth date (Corey et al., 2017; Midway et al., 2015; Stunz et al., 2000; VanderKooy et al., 2020).

Length and age structure

Welch's *t*-test (Welch, 1938) was used to observe potential differences in mean length and age between sexes, and ANOVA was used to evaluate potential differences in length and age

between Southern Flounder collected through fishery-dependent and fishery-independent sources. Length and age were used as dependent variables, with sex and sampling source as independent variables. Undersized Southern Flounder (i.e., beneath the legal minimum size of 381 mm) collected during the fishery-independent surveys were omitted from this analysis to prevent bias because all Southern Flounder kept by anglers were of legal size. All tests were conducted in R version 4.3.0 ($\alpha = 0.05$). Fishery-independent length-at-age ranges were compared qualitatively with previously published Texas length-at-age ranges to evaluate potential changes in growth over time.

Growth models

Following the recommendations for multi-model inference (Burnham & Anderson, 2002; Katsanevakis & Maravelias, 2008), four growth models were fitted to the length-at-age data for all Southern Flounder. The four models evaluated were the three-parameter von Bertalanffy growth model, the logistic growth model, the Gompertz growth function, and a power curve regression model. All growth models were calculated in R using the packages nls (R Core Team, 2024) and FSA (Ogle et al., 2023) and were fitted to the length-age data using nonlinear least-squares regressions.

The first model fitted to the data was the three-parameter von Bertalanffy model, as first described by von Bertalanffy (1938):

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

in which L_t is the expected length at time t, L_∞ is the average maximum total length (mm), k is the growth coefficient (i.e., the growth rate approaching L_∞), and t_0 is the hypothetical age at which length is zero. The second model was the logistic growth model (Katsanevakis, 2006; Ricker, 1979):

$$L_t = L_\infty / \left[1 + e^{-g(t-t_0)}\right],$$

in which g is the relative growth rate parameter and t_0 represents the time at which the growth rate is maximized. The third model was the Gompertz model:

$$L_t = L_\infty \left[e^{-k\exp(-gt)}\right],$$

where g is the instantaneous growth rate and k is the initial relative growth rate at age 0 (Ricker, 1979). The final model was the power regression growth model (Katsanevakis & Maravelias, 2008):

$$L_t = a \times t^b,$$

with a representing the value of L_t when age is 1 and b representing the shape of the relationship between a and age.

Once each model was fitted, the best fit was determined by the lowest value of Akaike's information criterion corrected for small-sample bias (AIC_c; Akaike, 1973; Hurvich & Tsai, 1989). The fit of other models was compared to the lowest AIC_c model, and models with an AIC_c difference less than or equal to 2 were considered strongly supported by the data (Banks et al., 2024; Burnham & Anderson, 2002). Akaike weights were also calculated to determine the best fit. Greater Akaike weights correspond to models with a better fit to the data (Burnham & Anderson, 2002). Thus, the best-fitting model was determined based on a combination of the lowest AIC_c value and the highest Akaike weight (Burnham & Anderson, 2002). Using the best-fitting model, separate growth models were examined for each sex due to different lengths at age attributed to their sexual dimorphism (Stokes, 1977).

RESULTS

Sample collection

In total, 734 Southern Flounder were aged and consisted of 567 females, 115 males, and 52 individuals of undetermined sex. Of those, 618 Southern Flounder were collected from the fishery-independent surveys, consisting of 492 females, 110 males, and 16 fish of undetermined sex. The female : male ratio was 4.8:1.0. Females ranged in total length from 221 to 585 mm, and males ranged from 220 to 398 mm. Fish with undetermined sex ranged from 160 to 340 mm total length. The remaining 116 Southern Flounder carcasses were collected by fishery-dependent means. Of these, 75 were females, 5 were males, and 36 individuals were of undetermined sex due to gonad loss. The sex ratio was 15:1 favoring females because males seldom reach harvestable size (≥381 mm in Texas). Females ranged between 385 and 560 mm, and males ranged from 383 to 484 mm. Fish of undetermined sex ranged from 384 to 555 mm.

Age determination

Of the 618 Southern Flounder collected from the fishery-independent surveys, 602 were successfully aged (479 females, 107 males, and 16 fish of undetermined sex). Of the 116 fish that were collected from the fishery-dependent surveys, 47 females, 4 males, and 27 fish of undetermined sex were successfully aged. A total of 682 Southern Flounder were aged between both years of the study, with 527 (including 78 from the fishery-dependent surveys) collected during year 2 (2023).

Annuli were typically distinct except for the first annulus, which was occasionally faint and difficult to discern. Despite this, only 3.6% of otoliths were disagreed upon between readers after the first read. The average percent error was 1.2% and the average coefficient of variation was 1.7% for the first read. All disagreements were resolved during the second read, with most disagreements arising due to difficulty in discerning the first annulus. There was no significant systematic bias between readers, and an age consensus was made for all otoliths; thus, no otoliths were discarded from the data.

Overall, Southern Flounder age structure favored younger age-classes, with a mean age of 1.9 years (SD = 0.7). Ages of Southern Flounder ranged from 0 to 3 years, with the only age-3 fish collected from a fishery-dependent survey, and 52% of all combined Southern Flounder were age 1. Females were typically older than males, with a mean age of 2.0 years (SD = 0.7), whereas males had a mean age of 1.5 years (SD = 0.6). After age 1 (52%), the most predominant age-classes for all collected flounder were age 2 (27.4%), followed by age 0 (20.5%) and age 3 (0.1%). Mean age from the fishery-independent surveys was 1.8 years (SD = 0.7). The mean age from the fishery-dependent surveys was 2.3 years (SD = 0.5), with most Southern Flounder being age 1 (57%).

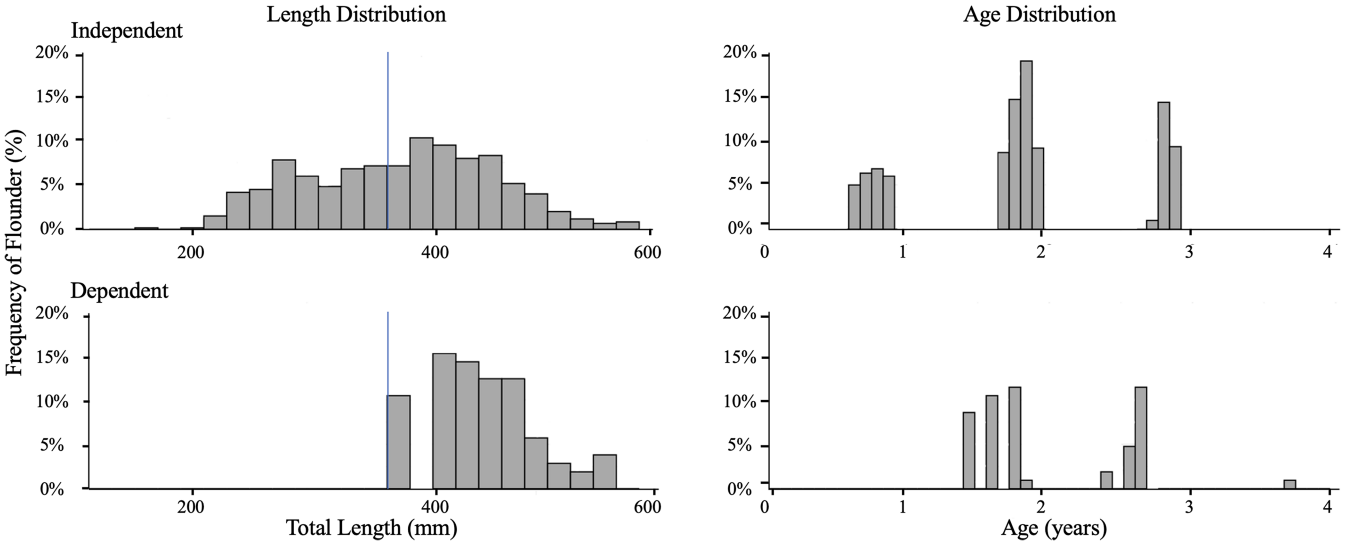

Figure 2. Frequency of total length (mm; left) and fractional age (years; right) for Southern Flounder that were collected from fishery-independent (top panels) and fishery-dependent (bottom panels) surveys in Texas, 2022–2023. The vertical blue line at 381 mm represents the minimum legal size in Texas.

Table 1. Summary of mean total length (mm) and the length range for male and female Southern Flounder obtained from fishery-independent (FI) and fishery-dependent (FD) sampling sources in Texas between September 2022 and December 2023.

		Females			Males			Both sexes		
Source	Age	*n*	Range (mm)	Mean (mm)	*n*	Range (mm)	Mean (mm)	*n*	Range (mm)	Mean (mm)
FI	0	92	221–385	297	41	220–390	267	133	220–390	284
	1	245	259–558	411	60	240–388	317	305	240–558	391
	2	141	361–585	460	7	337–398	396	148	337–585	457
FD	1	31	385–520	428	4	383–484	432	35	383–520	422
	2	42	387–560	469	0	0	0	42	387–560	470
	3	1	558	558	0	0	0	1	558	558

Length and age structure

Significant differences were found in mean age and length between females and males (age: $t = 8.26$, df = 180.78, $P < 0.001$; length: $t = 18.41$, df = 212.96, $P < 0.001$). Female Southern Flounder were larger, with a mean total length of 402 mm (SD = 75.4), compared to males, which had a mean total length of 309 mm (SD = 49.1). Significant differences in mean total length at each age between sexes were detected for all ages collected (age 0: $t = -4.53$, df = 83.50, $P < 0.001$; age 1: $t = -14.29$, df = 102.62, $P < 0.001$; age 2: $t = -8.84$, df = 6.46, $P < 0.001$). Mean age and mean length of Southern Flounder collected from fishery-dependent surveys did not significantly differ from those of fish collected from the fishery-independent surveys when undersized Southern Flounder were removed (ANOVA; age: $F = 0.036$, $P = 0.85$; length: $F = 0.27$, $P = 0.72$). Because there was no significant difference and the total sample size was limited for fish collected from fishery-dependent surveys, Southern Flounder were analyzed collectively.

When undersized Southern Flounder (<381 mm) were included, length and age composition differed between the fishery-independent surveys and the fishery-dependent surveys (Figure 2). The fishery-independent surveys observed an age range of 0–2 years for both males and females, while the fishery-dependent surveys observed a range from 1 to 3 years for females and only age-1 males (Table 1). Length at age for the fishery-dependent surveys was similar to that for the fishery-independent surveys with sexes combined for all ages (Figure 3). Mean length at age for age-1 males differed between sources by 116 mm total length, whereas female length at age was similar between sources for all ages. Other ages could not be compared since certain age-classes were not collected from fishery-dependent methods. Minimum size limits drive anglers to harvest selectively based on the size of fish, while every Southern Flounder was equally targeted during the fishery-independent surveys; thus, differences in length at age were expected. Males in the fishery-independent surveys did not typically reach harvestable size until age 2, if at all. Because of this, less than 4% ($n = 4$) of Southern Flounder collected from fishery-dependent sources were males.

Growth models

Of the four models explored, the three-parameter von Bertalanffy growth model provided the best fit (Figure 4). Visually, the other growth models were very similar to the plotted data. The AIC_c values and weights were similar among all models, which suggests that all models were useful for modeling

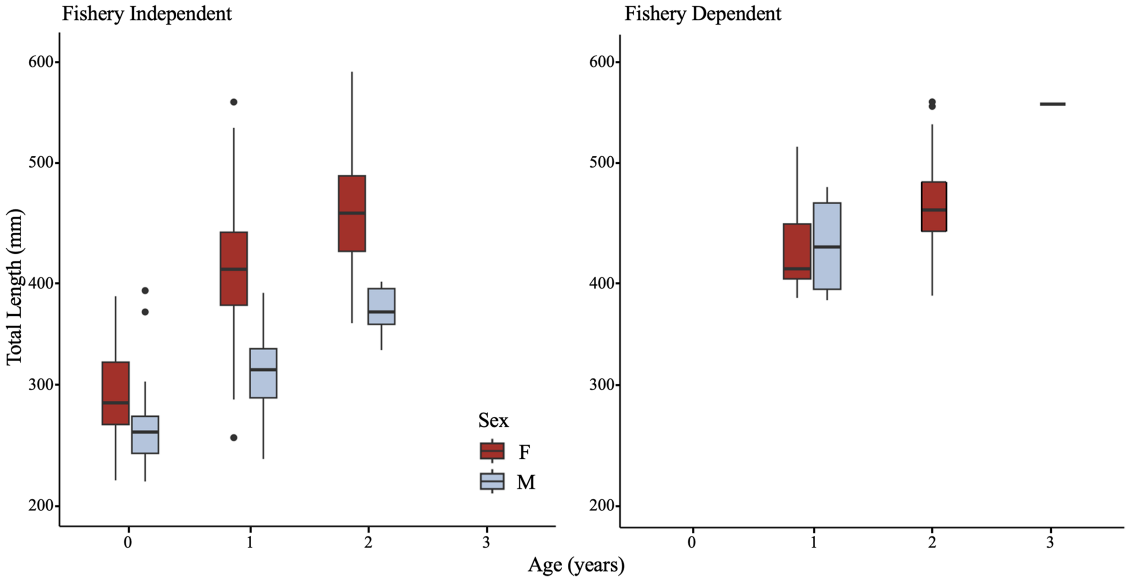

Figure 3. Mean total length at age for female (red) and male (blue) Southern Flounder collected from fishery-independent (left panel) and fishery-dependent (right panel) surveys in Texas bay systems, 2022–2023. The mean bar is located at the center of each box, dots represent outliers of the data, and the lines represent the total length range excluding the outliers.

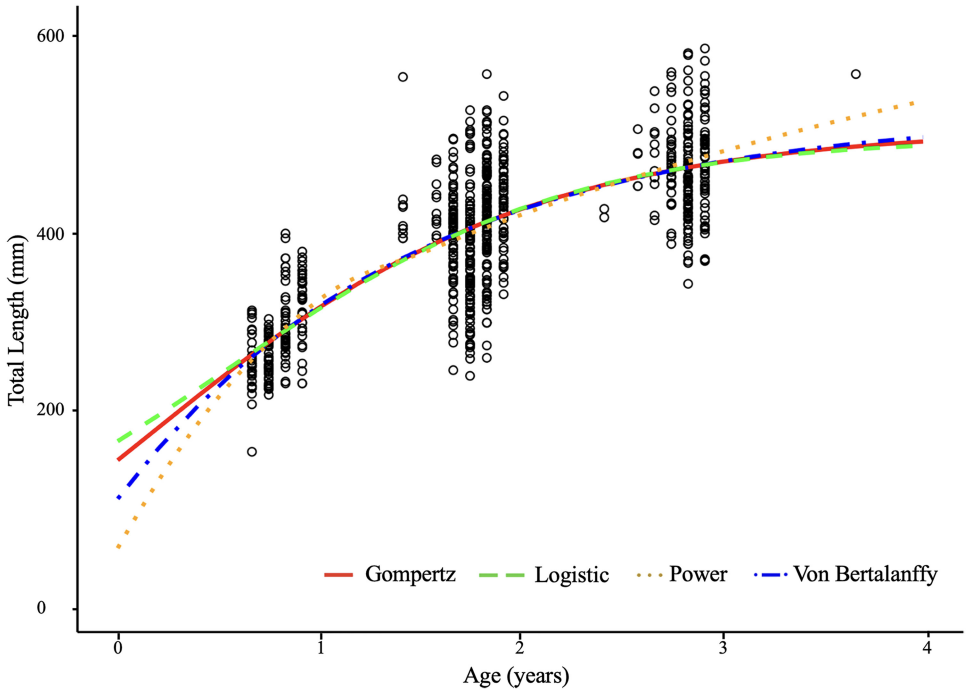

Figure 4. Model comparisons of Southern Flounder predicted total length at age estimated by the Gompertz (red, solid line), logistic (green, dashed line), power (orange, dotted line), and von Bertalanffy (blue, dot-and-dash line) models.

the data. However, the three-parameter von Bertalanffy model had the lowest AIC_c value and the highest AIC_c weight, indicating that this growth model was the best fit for the data (Table 2).

The von Bertalanffy parameters for the model with combined sexes were as follows: L_∞ was 517.1 mm, k was 0.69, and t_0 was −0.35. For sex-separated models, L_∞ was 495.6 mm, k was 0.91, and t_0 was −0.19 for females and L_∞ was 464 mm, k was 0.35, and t_0 was −1.67 for males. The L_∞ estimate for females was higher than that for males by 30.4 mm. Females also had larger k and t_0 values. Visual examination of the growth curves suggested differences in mean length at age for males and females (Figure 5). Starting at around age 1, females exhibited a larger length at age than males.

DISCUSSION

This study provides a much-needed update of age and growth parameters for Southern Flounder in Texas and highlights

Table 2. Comparison of parameter estimates among the four growth models fitted to Texas Southern Flounder length-at-age data, 2022–2023. Abbreviations are as follows: L_∞ = theoretical maximum total length (mm); k = growth coefficient (von Bertalanffy) or initial relative growth rate at age 0 (Gompertz); t_0 = hypothetical age at which length is zero (von Bertalanffy) or time at which the growth rate is maximized (logistic); g = instantaneous growth rate (Gompertz) or relative growth rate parameter (logistic); a = expected length (mm) when age is 1 (power); b = shape of the relationship between a and age (power); AIC_c = Akaike's information criterion corrected for small-sample bias; Δ_i = AIC_c difference; and w_i = Akaike weight.

Model	L_∞	k	t_0	g	a	b	Parameters	AIC_c	Δ_i	w_i
Von Bertalanffy	517.1	0.69	−0.35				4	7,602.5	0.00	0.56
Gompertz	501.5	1.20		0.93			4	7,603.8	1.37	0.28
Logistic	491.2		0.54	1.17			4	7,605.1	2.64	0.15
Power					316.09	0.37	3	7,610.4	7.96	0.01

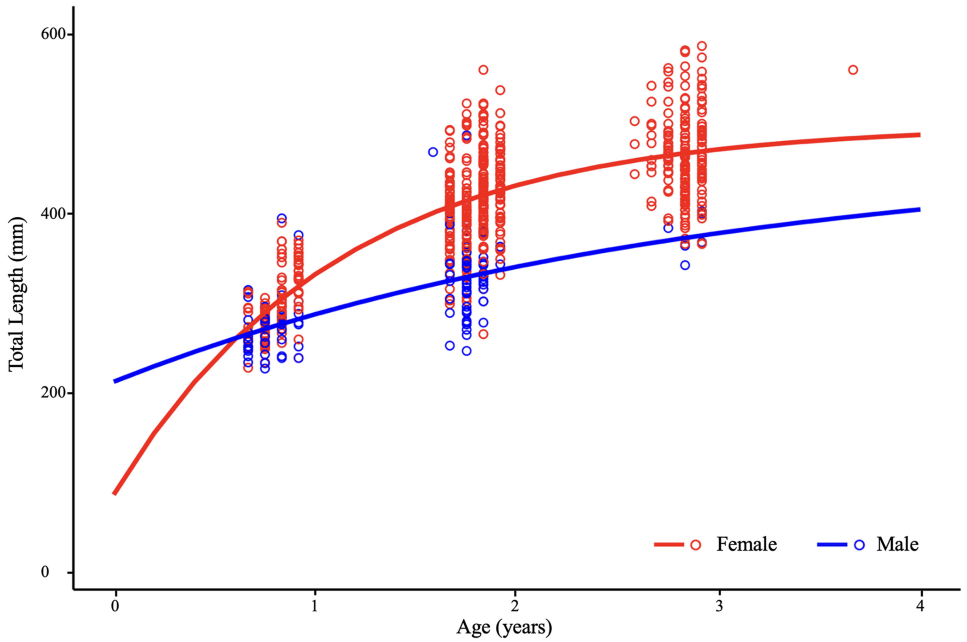

Figure 5. The von Bertalanffy growth models for female (red line) and male (blue line) Southern Flounder sampled in Texas bay systems, 2022–2023. Total length-at-age data for females (red points) and males (blue points) are also depicted.

some striking differences with previous research efforts. The observed age range of 0–3 years in our study had fewer Southern Flounder age-classes represented than in previous studies (Stokes, 1977; Stunz et al., 2000), particularly with the lack of age-3 and age-4 females that were typically observed in Texas tidal inlets. In addition to different age structures, previously published length-at-age ranges for Southern Flounder in nearby Texas bays differed from the length-at-age ranges produced in this study (Table 3). Relative to the present study, previous studies observed smaller length-at-age ranges for female Southern Flounder at ages 0 and 1 (Stokes, 1977; Table 3) but larger length-at-age ranges for ages 2 and 3 (Stokes, 1977; Stunz et al., 2000; Table 3). Length-at-age ranges for males in previous Texas studies were consistently smaller (the maximum length-at-age difference was up to 110 mm; mean difference per age-class = 68.4 mm) than the ranges observed in our study, and male total lengths at all observed ages were mostly below the minimum size.

Recent studies have suggested that Southern Flounder are reaching sexual maturity at increasingly younger ages (Blanchet, 2010; Corey et al., 2017; Monaghan & Armstrong, 2000), with maturity attained closer to age 1 rather than at the previously observed ages of 2 and 3 (Manooch, 1984; Pattillo et al., 1997; Powell, 1974; Stokes, 1977). Because of this trend, Southern Flounder in younger age-classes may benefit from larger lengths at age, especially if this translates to increased

Table 3. Total length-at-age ranges (mm) for female and male Southern Flounder in Texas (present study) and the two most recent length-at-age studies in Texas bays (Stokes, 1977; Stunz et al., 2000).

		Range (mm)		
Sex	Age (years)	Stokes, 1977	Stunz et al., 2000	Present study
Female	0	161–320	197–390	221–385
	1	221–480	242–500	259–558
	2	341–560	335–624	361–585
	3	461–580	573–633	558
	4	581–620	585	
Male	0	161–280	201–331	220–390
	1	161–300	153–381	240–388
	2	261–320		337–398

Table 4. Comparison of von Bertalanffy growth model parameter estimates for Gulf of Mexico (GOM) Southern Flounder from the present study with parameter estimates from previous studies of the GOM and Atlantic coast. Abbreviations are as follows: L_∞ = average maximum total length, k = growth coefficient, t_0 = hypothetical age at which length is zero, M = male, and F = female.

Study	Location	Sex	$L\infty$ (mm)	k (year^{-1})	t_0	Parameters
Present study	Texas	F	495.6	0.91	−0.19	3
		M	464	0.35	−1.67	3
Matlock, 1991	Texas	Both	631	0.35		2
Stunz et al., 2000	Texas (Matagorda Bay)	F	565.6	0.53	−0.41	3
		M	300.6	3.17	0.23	3
Stunz et al., 2000	Texas (coastwide)	F	482.8	0.75	−3.08	3
		M	383.9	0.50	−1.38	3
Fischer, 1999	Louisiana	F	520.1	0.74	−0.14	3
		M	325.7	1.33	−0.01	3
Fischer and Thompson, 2004	Louisiana	F	556.5	0.51	−0.62	3
		M	332.5	1.03	−0.25	3
Erickson, 2020	Louisiana	F	477.3	0.60	−0.69	3
		M	365	0.80	−0.52	3
Corey et al., 2017	Northern GOM	F	513.7	0.67	−0.5	3
Stanfill, 2017	Northern GOM	F	483.2	0.97		2
		M	358.8	0.63		2
Wenner et al., 1990	South Carolina	F	759	0.24	−0.57	3
		M	518	0.25	−1.07	3
Takade-Heumacher and Batsavage, 2009	North Carolina	F	699	0.28	−0.76	3
		M	381	0.80	−0.01	3

fecundity and reproductive potential. Therefore, Southern Flounder populations may be driven toward faster growth and larger lengths at age in early years while shifting to slower growth and smaller lengths at age in older age-classes due to changes in fishing pressure over time. This is likely more apparent in females given that males do not typically reach harvestable sizes, which may contribute to the differences in length at age for females in this study compared to previous Texas studies, when male length at age did not differ.

Similar to length and age frequencies, mean lengths at age for fishery-independent and fishery-dependent surveys were overall the same. However, fishery-dependent sources only provided age-1 males, which were distinctly larger than the fishery-independent age-1 males. This may be explained by minimum size limits driving anglers to search for the largest fish available, whereas every Southern Flounder was equally targeted during the fishery-independent surveys. Lengths of age-1 females were significantly different between sources, although the actual mean total length difference was only 17 mm. Mean length at age 2 for females was not significantly different between sources, likely because most age-2 females had reached legal sizes and were therefore not restricted by regulations in the fishery-dependent surveys.

The von Bertalanffy model parameters fitted to data from females and males in our study were similar to previous studies' estimated parameters for Southern Flounder (Table 4). In this study, parameters for females were as follows: L_∞ was 495.58 mm, k was 0.91, and t_0 was −0.19. The L_∞ was remarkably similar to what was previously observed in Texas (Stunz et al., 2000) and in the northern GOM (Corey et al., 2017; Stanfill, 2017) but lower than the L_∞ values observed along the Atlantic coast, likely due to geographical differences in growth (Table 4; Fischer, 1999; Fischer & Thompson, 2004; Wenner et al., 1990). The growth coefficient for females (k = 0.91) was higher than most previously reported values, with older Texas studies having k-values as low as one-third the value observed in our study (Matlock, 1991). Although higher values of k typically suggest faster growth, the higher k in this study may be more attributable to the lack of representation of other bays or to seasonal and gear differences. Other Southern Flounder studies reported lower t_0 values, which are typically indicative of higher L_∞ values and are more commonly observed in coastwide studies than in studies of individual bay systems (Corey et al., 2017; Stanfill, 2017; Stunz et al., 2000).

Parameter estimates for male Southern Flounder in this study were as follows: L_∞ was 464 mm, k was 0.35, and t_0 was −1.67. The L_∞ and k for males were lower than the corresponding values for females, as expected from their sexual dimorphism. The L_∞ for males in this study was greater than values for males in previous studies except a study on the Atlantic coast (Wenner et al., 1990) in which an L_∞ of 518 mm for males was reported. The higher male L_∞ observed in this study may be skewed by the small number of exceptionally large males collected from the fishery-dependent surveys. A larger sample size of male Southern Flounder from the fishery-dependent surveys might have provided a better distribution of male total lengths and a more accurate L_∞ value with a smaller SE. However, removing the larger males from fishery-dependent surveys from the growth model prevented model convergence due to the decreased sample size. The k-values for males in this study were lower compared to values from most previous studies, which does not provide evidence for shifts towards larger length at age for males. However, the small adult male size typically eliminates the fishing pressure impacts that might otherwise drive males toward faster

growth before sexual maturity. Since males experience less fishing pressure than females, males would be less driven to reach larger sizes at younger ages. The t_0 value for males in this study was similar to values reported from GOM and Atlantic coast studies (Stunz et al., 2000; Wenner et al., 1990).

Comparing growth parameter estimates among studies coastwide is important for determining regional changes in population structure and changes over time. However, variations in the study design and the collected age-classes impact parameter estimates and must be considered. Other growth studies in Texas (Stokes, 1977; Stunz et al., 2000) were conducted within the same bay system as this project, but they used additional collection methods that were not used in the present work, which may in part contribute to the difference in age-classes observed. Additionally, the lack of older fish may have led to underestimation of L_∞, which may explain the poor fit of the model to the age-3 fish collected. Although multiple collection methods were used in our study, more extensive studies may be needed to further reduce potential sampling bias and confirm the truncated age structure in Texas bay systems.

Although age and growth were successfully estimated and potential otolith reader bias was minimal, sample collection for this project may not be reflective of the entire Texas Southern Flounder population. Most Southern Flounder in this study were collected near two tidal inlets in south Texas during the migration period (September–December). These data may not represent Southern Flounder that remain offshore after migration (Simmons, 1951; Stokes, 1977) or the recently observed Southern Flounder contingents that are thought to not migrate offshore (Steffen et al., 2023). However, growth model parameter estimates in this study were compared only with those of other studies that used data predominantly from Texas inlets. Therefore, the data are still useful in describing changes in age and growth over time and in this region. In addition, the presence of juvenile Southern Flounder that would not migrate through tidal inlets suggests that at least some nonmigratory Southern Flounder were included in the data set.

With the recent discovery of potentially nonmigratory contingents of Southern Flounder (Steffen et al., 2023), future studies should further explore potential life history differences between migratory and nonmigratory Southern Flounder, including age and growth. Since previous Texas age and growth studies have mostly been limited to individual bay systems, a statewide study of age and growth may provide more thorough insights into Southern Flounder age structure and growth rates. Age and growth data across a wider geographic range are crucial to avoid data gaps, particularly because age and growth data differ significantly throughout the GOM (Corey et al., 2017; Fischer & Thompson, 2004; Stunz et al., 2000).

Frequent determination of age and length composition is increasingly important as climate change trends affect Southern Flounder behaviors and life history, which may have contributed to the observed difference in the female : male ratio relative to the 1990s (7:1 from Stunz et al., 2000 versus 4.8:1.0 from this study). Although this difference in sex ratios may potentially be attributed to differences in time of year (males have been observed to migrate earlier in the year than females and occasionally remain offshore after migration; Stokes, 1977) or sampling design between studies, these findings allude to the importance of monitoring warming water impacts on sex ratios (Erickson et al., 2021). The lower proportion of females, compounding with reduced lengths at age for older fish, significantly reduces the number of Southern Flounder that reach large enough sizes to enter the fishery and could have population-level effects on reproductive potential. Future research should also incorporate a greater number of juvenile Southern Flounder to reduce sampling bias. The lack of juveniles smaller than 200 mm total length in the growth models may have impacted the final parameter estimates.

In conclusion, the age and length composition and growth trends of Southern Flounder in Aransas Bay and Corpus Christi Bay differ from those reported in previous Texas studies (Stokes, 1977; Stunz et al., 2000). Younger ages are more predominant compared to findings throughout the GOM. Female Southern Flounder typically reach older ages than males, but both sexes seem to disappear from the surveyed tidal inlets before age 3. Seemingly truncated age-classes and reduced lengths at age for age-2 and older Southern Flounder indicate fishing pressure impacts and may contribute to less successful spawning and the population decline. The larger lengths at age observed in younger fish may be attributed to a younger age of maturity and result in more age-1 Southern Flounder entering the fishery before spawning, which decreases the efficiency of current minimum size limits. Modifying current regulations, such as minimum size limits and fall season closures, may be critical for allowing Southern Flounder to spawn at least once before harvest. The von Bertalanffy growth curves also suggested larger lengths at age for younger Southern Flounder by depicting an increased rate of growth to maximum size for younger ages compared to previous Texas studies. Although high fishing mortality is the most apparent cause of the observed shift to truncated age-classes, other factors, such as climate change-driven effects on sex ratios, spawning season, and the length-at-age composition, may potentially have a compounding effect on the fishery. The changes in age structure, length at age, and sex ratio observed in this study may be representative of changes occurring throughout the entire Southern Flounder distribution due to globally warming waters. For this reason, regular monitoring of Southern Flounder age structure and growth is critical for management agencies to effectively maintain the Southern Flounder as a valuable resource and sport fish throughout the GOM.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon request.

ETHICS STATEMENT

All sampling was conducted under Institutional Animal Care and Use Committee-approved protocols 2021-06-017 and 2023-0007 as well as TPWD Scientific Permit SPR-0303-279.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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