SPOTTED SEATROUT (FAMILY SCIAENIDAE) GROWTH AS AN INDICATOR OF ESTUARINE CONDITIONS IN SAN CARLOS BAY, FLORIDA

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Abstract: *Life history characters of the spotted seatrout (*Cynoscion nebulosus*) have tremendous potential to discern trends in environmental conditions within and among estuaries. The species is widely distributed (i.e., from North Carolina to Mexico), is both commercially and recreationally important, and rarely leaves its home estuary. Thus, the estuarine conditions to which a population was subjected while growing could affect changes in its life history features such as growth. About 400 spotted seatrout were collected from April through July 2003 from the San Carlos Bay area of the southern portion of Charlotte Harbor in southwest Florida. Otolith sections were examined with enhanced imagery to facilitate recording age and annulus increments from the otolith. There was a significant relationship between otolith radius and fork length that differed between sexes. A comparison of back-calculated size at Age 1 for four year classes (1999–2002) indicated that there were significant differences in growth between year classes. Initial time-series analysis indicated the potential effects of seagrass density and salinity on fish growth. Salinity conditions are artificially manipulated in this estuary and this action may be responsible for the differences in growth rates observed for both males and females among year classes.*

Key Words: Growth, estuaries, otolith, seagrass, salinity, time-series, spotted seatrout

The spotted seatrout (*Cynoscion nebulosus* (Cuvier) – a fish species in the croaker and drum family Sciaenidae) is one of the preferred food and game fishes within its native distribution that includes estuarine conditions along coastal areas of the southeastern portion of the USA, including the Gulf of Mexico. It is found chiefly within estuaries and has a strong affinity for seagrasses where it feeds on fishes and small crustaceans (see Bortone, 2003a for a complete compilation of its life history).

Northern American estuaries, including Charlotte Harbor, have become areas of rapid human population growth and development. Development along estuarine shorelines has resulted in stress through hydrologic alterations, water-quality degradation, and habitat loss (Kennish, 1991). Environmental managers must be vigilant to ensure that estuarine and coastal waters do not become so degraded that the normal biological function of these estuarine ecosystems becomes impaired. Similarly, estuarine-restoration efforts should have target goals that seek to re-establish the biological function of disturbed systems to approach or, hopefully, regain normal, undisturbed levels of biological integrity (Bortone, 2003b; Bortone et al., 2005).

After careful evaluation of several indigenous species, it became apparent that the spotted seatrout is particularly suited as a sentinel in detecting environmental stress to estuarine ecosystems along the warm temperate coast of North America (Bortone and Wilzbach, 1997a; Bortone, 2003b). The spotted seatrout is an exceptional fish among estuarine sport fish in that it generally spends its life within the confines of a single estuary. In addition, the spotted seatrout is a relatively long-lived species (often up to 10 years); thus, it is subjected to the conditions of a single estuary for an extended period and, therefore, can serve as a time-series monitor of estuarine conditions. It feeds on fishes and crustaceans found among seagrasses and thus serves as an important trophic link with the estuary (Bortone, 2000). It attracts considerable public attention as an important sport and food fish with significant landings throughout its range but especially in Lee County, Florida (Bortone and Wilzbach, 1997b). Lastly, the spotted seatrout has the attention of the scientific community as evidenced by the substantial database of life history information on the species (Johnson and Seaman, 1986; Bortone et al., 1997).

This project was initiated to develop an estuarine bio-indicator capable of discerning the environmental stressors and their degree of impact on the overall environmental conditions in the southern portions of the Charlotte Harbor estuarine ecosystem. Establishing a fully documented biological indicator would allow those concerned with the biological integrity of these estuarine waters to evaluate trends and determine the stressors that affect the functional attributes of the ecosystem.

The basic biology of the spotted seatrout (they are also known as specks, trout, and speckled trout) was recently summarized in a volume dedicated to establishing its life history parameters as potential metrics to assess the environmental conditions within an estuary (Bortone, 2003c). A host of biological characters are potentially available to serve this purpose. For example, reproductive condition (Brown-Peterson, 2003), genetic differentiation (Gold et al., 2003), and parasite infestation (Blaylock and Overstreet, 2003), among others, are biological features that could prove useful in providing characters that would allow an assessment of environmental stressors. However, growth is reflective of a metabolic component of this species that is intimately interwoven with its environment that includes water quality, habitat conditions, salinity regimes and the abundance of predators, prey, and conspecifics (Murphy and McMichael, 2003).

Bedee and co-workers (2003) and DeVries and co-workers (2003) clearly demonstrated the utility of using growth features of spotted seatrout to compare different estuaries. This study takes their concept further and makes use of comparative growth rates among spotted seatrout to monitor potential environmental stressors through time in the southern portions of the Charlotte Harbor estuarine ecosystem.

MATERIALS AND METHODS—About 400 spotted seatrout were captured using hook-and-line in an area limited to San Carlos Bay and portions of lower Pine Island Sound (FIG. 1) in the southern portions of Charlotte Harbor from April through July 2003. Upon capture, fish were placed on ice and returned to the laboratory where they were labeled by date and field-collection number, and frozen. Later, fish were thawed, the sex was determined, and each fish was measured for fork length (FL) to the nearest mm.

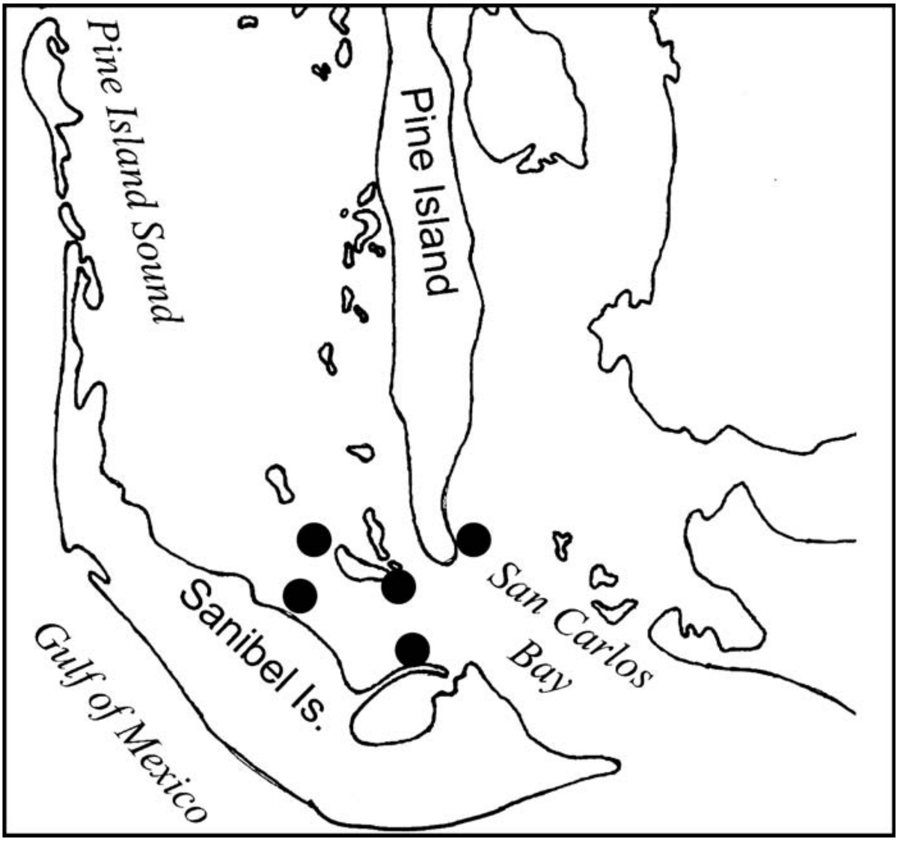

FIG. 1. Map of the study area. Filled circles indicate the specific sampling locations for spotted seatrout.

Otoliths were removed from thawed fish and prepared for analysis following the methods of Bedee and co-workers (2003) with the following two exceptions: 1) Crystal Bond® was used to affix otoliths to microscope slides for sectioning; and 2) Flo-Texx® (Lerner Laboratories) mounting media was used to affix the otolith sections to the microscope slides. The Image-Pro® Express image analysis system (Version 4.5.1.3) was used to record measurements from the otolith image. Each otolith was sectioned in cross section at its mid-point.

Since only one fish was recorded at Age 5 or older, only fish aged 1–4 were used in this study. The size at capture, otolith radius, and annular radii for each fish were used to back-calculate the size at annulus formation. The equation used was:

$$L_i = a + (L_c - a) \times (O_i/O_c) \tag{1}$$

where L_i = the fork length (FL in mm) of the fish when it became age i, a = the y-axis (fork length) intercept of the relationship between otolith radius (abscissa) and fork length (ordinate), L_c = size of fish (FL in mm) at capture, O_i = distance in mm from central core of otolith to the distal edge of the annulus at age i, and O_c = otolith radius in mm.

Time-series analyses were conducted to relate environmental conditions in the estuary with fish growth, by determining time-lagged measures of association (i.e., correlation coefficients) in annual fish growth to environmental features in the estuary. Time-series analyses (i.e., ARIMA – AutoRegressive, Integrated Moving Average) were conducted using the back-calculated size at age one for each year class (dependent variable) versus several environmental variables (independent variables) using the SPSS® statistical program package (Version 8.0). In the lower Charlotte Harbor area, few environmental data were available as annual parameters collected corresponding to the year classes examined here (i.e., 1999–2002) Environmental variables that were available for inclusion in the time-series analyses, however, were salinity and species-specific, seagrass density.

Annual conductivity parameters (overall average, average daily minimum, average daily maximum and overall standard deviation) as a surrogate for salinity were used as relative indicators of water quality. Conductivity data were obtained from the South Florida Water Management District's water-quality monitoring probe near the Sanibel Causeway at the entrance of San Carlos Bay. Species-specific seagrass densities were obtained chiefly from the Florida Department of Environmental Protection Agency's Burnt Store Road facility in Punta Gorda, Florida. The seagrass density estimates were based on Braun-Blanquet measures of percent cover averaged from five transects in lower Charlotte Harbor surveyed annually each fall.

RESULTS—*Age and growth*—Although more than 400 fish were captured during this study, only 295 (161 males and 134 females; FIG. 2) were used for age determination. Nearly 100 fish could not be reliably aged for a variety of reasons. Sometimes both otoliths from some individuals were damaged during extraction, sectioning, or mounting and, therefore, no age or growth could reliably be determined. Each otolith was read at least twice by two investigators. Otoliths that were problematic were read a third time by a third investigator. If agreement was not attained then that fish was excluded from ageing. It was assumed that exclusion or inclusion of data from an otolith was not biased with regard to age or growth of a particular fish.

The mean (±SD, min-max, number) size of males was 293.75 (±36.37, 217–420, 161) mm FL and females was 321.36 (±51.08, 228–557, 134) mm FL. The relationship between the otolith radius and length was determined separately for each sex using regression analysis (FIG. 3). While both regression lines showed a positive correlation, the lines were significantly different ($p \leq 0.05$) from each other with regard to both slope and y-axis intercept. Consequently, all analyses were conducted separately for each sex, using the respective slope and y-intercept information.

All fish used in the analyses were captured after March 2003. The literature indicates that spotted seatrout generally deposit the annulus in the early spring of each year (Murphy and McMichael, 2003). The bar chart (FIG. 4) indicates that the marginal increment increased after March. All fish used for aging here were captured beginning in April.

Annual growth and overall total mortality can be determined by examination of the actual and back-calculated size data presented in Table 1. Size at annulus formation was determined separately for each sex: males – 251, 294, 331, and 373 mm FL; and females – 260, 324, 354, and 443 mm FL for ages 1–4, respectively. Generally, females were larger and grew faster than males at each age at annulus formation. The decline in the number of fish at each subsequent age is indicative of total mortality and is presented here as supplemental population information. Males displayed a classic and typical decline where the most abundant year class was

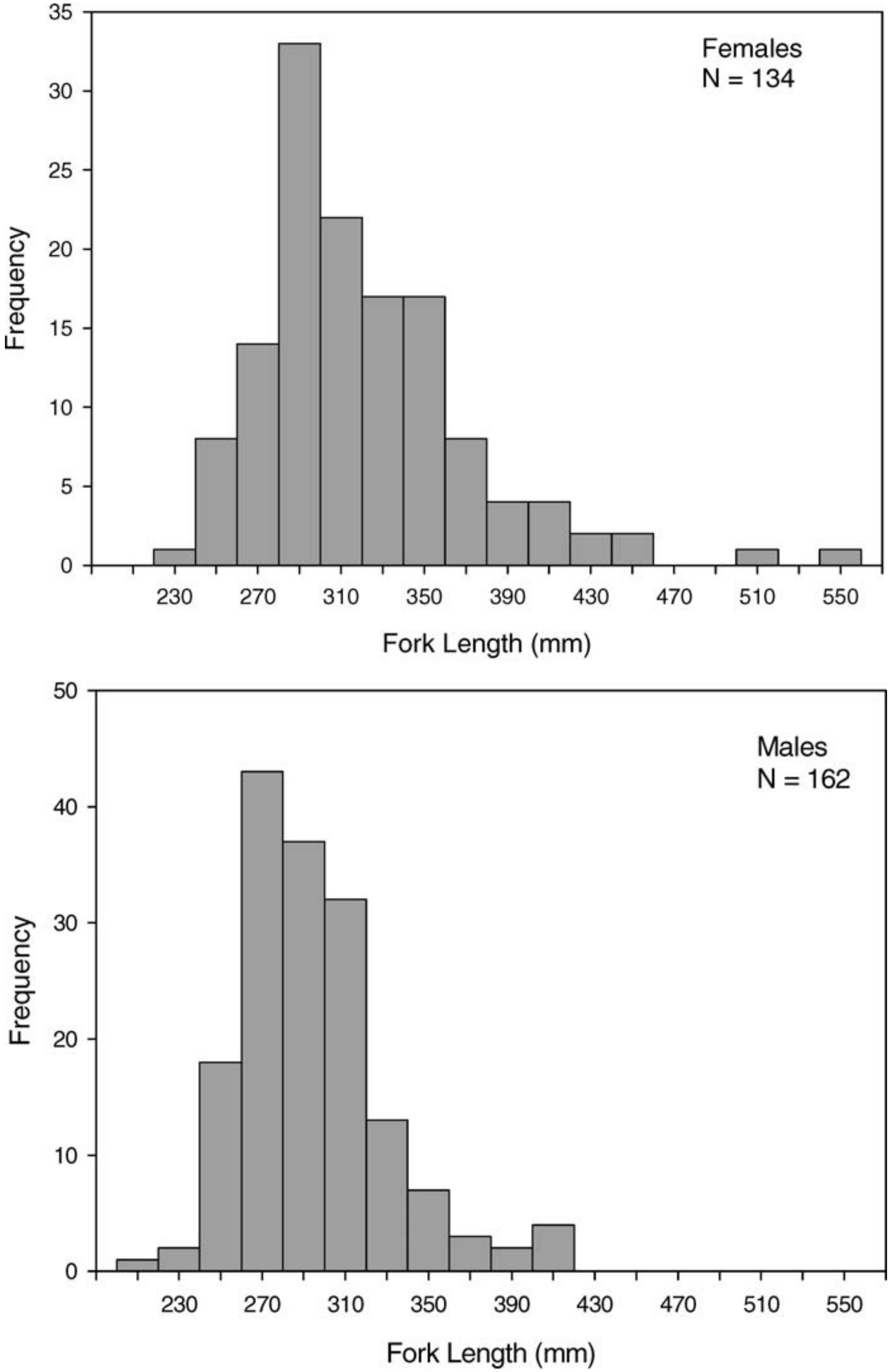

FIG. 2. Length-frequency histogram of all females (above) and males (below) examined during this study.

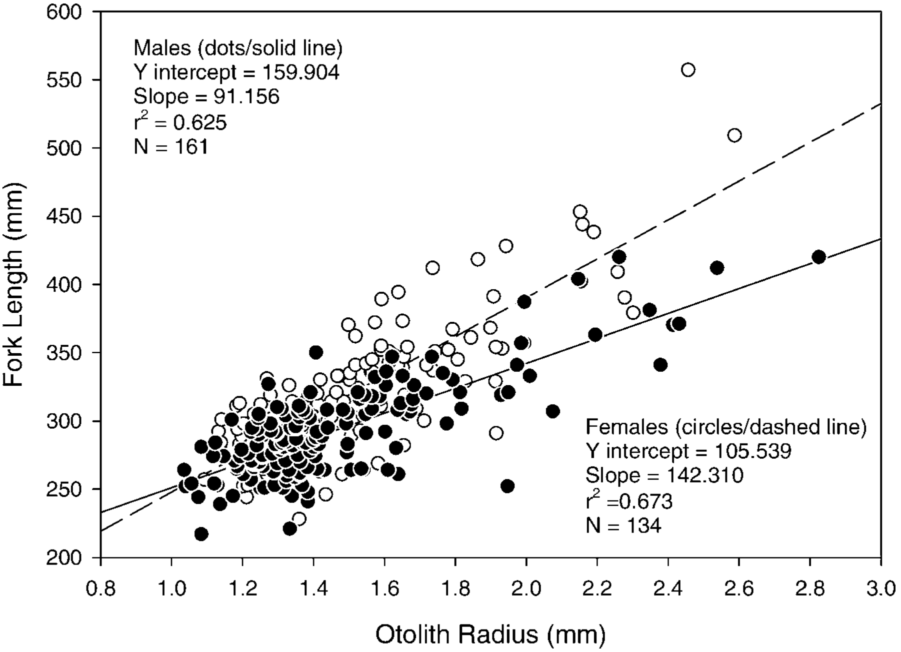

FIG. 3. Scatter diagram of otolith radii and fork lengths (both in mm) for male (dots/solid line) and females (circles/dashed line).

age-group 1 and the decline asymptotically approached the abscissa. A slightly different profile was observed among females. Age-group 2 was proportionately more abundant, or concomitantly, age-group 1 was slightly underrepresented among the data. An age-length key to fish-size classes (Table 2) indicates considerable size overlap with regard to size within an age-group for each sex.

A pair-wise bar-chart for size of males and females for each year class at age one were derived from the back-calculated size at age one for each of the four year classes (FIG. 5). Again, females tended to attain a larger size at annulus formation than males for each year class. Interestingly, for both males and females, the longest fish were from the most recent year class (2002). The shortest fish were males from the 1999 and 2000 year classes and females from the 2000 year class. This may indicate Lee's Phenomenon (Gutreuter, 1987) where earlier back-calculated lengths tend to be shorter in older fish. However, it should be noted that length of females for year classes 1999 and 2002 were not statistically different ($p > 0.05$). The results of a One-Way Analysis of Variance and Tukey's post-hoc test) for size at age 1 for each year class (sexes analyzed separately) indicated that fish from year-class 2002 were significantly longer ($p < 0.05$) than fish from year-class 2001 and 2000 among females. Fish from year-class 2002 were significantly longer than fish from year-classes 2001 and 2000 among males as well. Fish of both genders from year-class 2000 were shorter at age-1 annulus formation than fish from all other year classes, but this difference was not statistically significant at $p < 0.05$) in all cases.

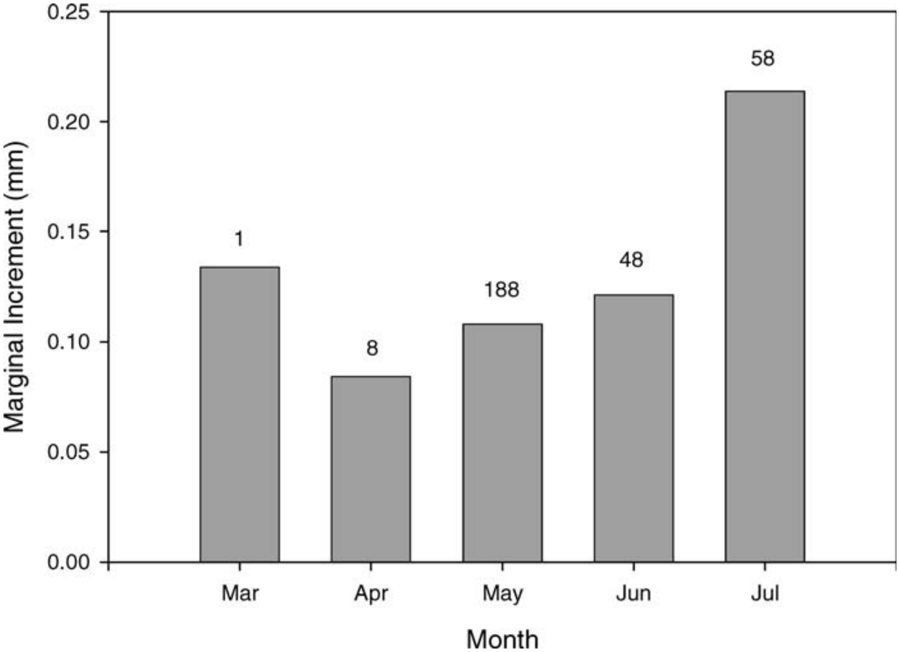

FIG. 4. Bar graph of marginal increment, by month, of all fish examined. Numbers above bars indicate number of fish examined.

Environmental associations—Densities (Braun-Blanquet percent cover) for each of three species of seagrass from the lower portion of Pine Island Sound and San Carlos Bay were used, along with evidence of salinity, as measures of habitat condition (Table 3). Results of the time-series analyses (summarized in Table 4) produced correlation coefficients that indicated the degree of association between the dependent (size at age 1) and independent (species-specific seagrass densities and conductivity parameters) variables between all possible years for which there were data. Because there were data for only four years, none of the associations were

TABLE 1. Summary of fork length (mm) statistics (actual and back-calculated) by age for male and female spotted seatrout captured during this study.

		Actual Age					Back-calculated				
Sex	Age	Mean	Min.	Max.	SD	No.	Mean	Min.	Max.	SD	No.
Males	1	278.43	217	336	22.09	113	251.11	194	323	24.48	161
	2	310.25	265	350	21.15	28	293.72	251	338	19.97	48
	3	337.00	307	387	25.10	10	330.91	297	379	25.17	20
	4	368.60	252	420	51.73	10	373.30	328	413	34.10	10
Females	1	288.38	228	333	22.91	68	260.14	201	323	23.02	134
	2	338.43	269	428	29.34	48	324.06	245	418	29.54	66
	3	371.00	291	438	42.45	12	354.39	189	460	72.76	18
	4	457.33	379	557	66.33	6	443.23	364	539	67.41	6

TABLE 2. Age-Length (FL in mm) key for spotted seatrout captured in 2003 relative to sex.

Class Size	Age Group				Total	Age Group				Total
FL (mm)	1	2	3	4	Female	1	2	3	4	Male
200						1				1
220										
240	1				1	2				2
260	8				8	17				17
280	13	1			14	40	3			19
300	28	4	1		33	32	5			37
320	13	8	1		22	18	11	3		32
340	5	13			18	3	6	3	1	69
360		13	4		17		3	3	4	10
380		7		1	8			1	1	2
400		1	3	1	5					5
420			3		3				4	4
440		1			1					1
460				2	2					2
480										
500				1	1					1
520										
540										
560				1	1					1
Totals	68	48	12	6	134	113	28	10	10	161

statistically significant, nevertheless, several associations were high (i.e., $> |0.75|$) and these deserve comment.

During the first year, female growth was positively associated with the density of the seagrass *Halodule wrightii* (Ascherson) (shoal grass) from the preceding year and positively with *Syringodium filiforme* (Kützing) (manatee grass) density from the preceding year and negatively with the same year.

During the first year of growth for each year class, female growth was positively associated with salinity from the preceding year. There was little evidence that minimum salinity was related to female growth during their first year; however, maximum salinity was positively associated with growth of females during their first year for each year class. Variation in water conditions, as measured by the annual standard deviation in conductivity, was somewhat associated with female growth during the concurrent year for each year class.

Growth among males, during the first year of life for each year class showed similar patterns to those described for females. A positive association was determined for both *H. wrightii* and *S. filiforme* density from the preceding year, while a negative association of *Thalassia testudinum* (Banks ex König) (turtle grass) density occurred with male growth from the two years proceeding the first year of growth for males. The initial year of growth among males was positively associated with salinity the year before.

DISCUSSION—The observed monthly increase in marginal increment after April indicates that the annulus is generally deposited in early spring for this species in

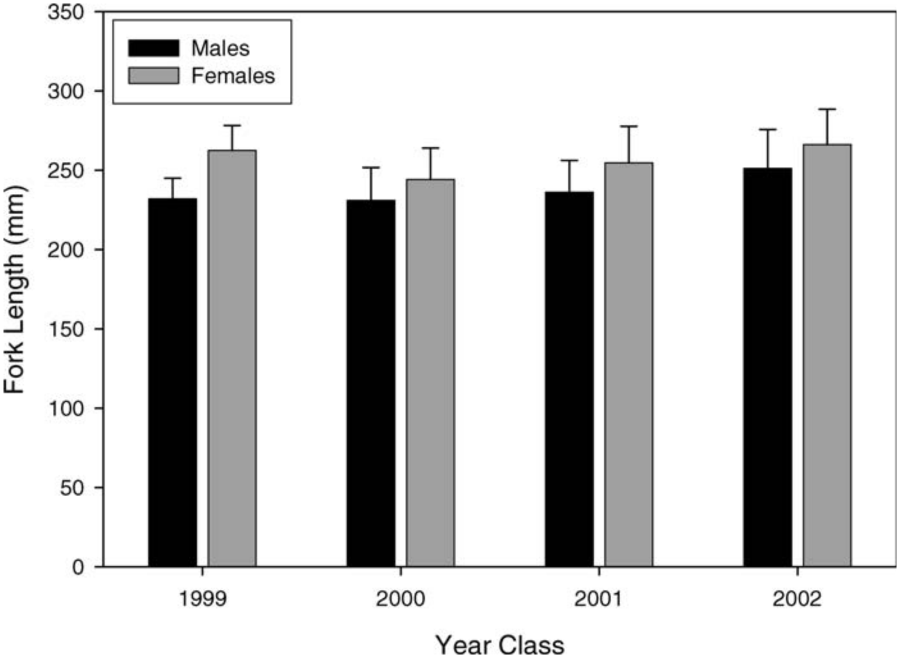

FIG. 5. Bar graph comparing back-calculated size (fork length in mm) at age 1 for the year classes 1999–2002. Males and females separately.

Florida waters (Murphy and Taylor, 1994) and helps validate the use of otoliths in determining age for the spotted seatrout in this area.

Males and females grew differently, with females generally growing faster and attaining a larger size at an equivalent age. Differences in growth between sexes (as observed in the relationship between otolith radius and length) indicated that each sex should be treated separately in all analyses. While outwardly cumbersome, analyzing sexes separately allows the advantage in offering a test by congruence

TABLE 3. Summary data for the variables used in the Time-Series analysis for each respective year class. Fish lengths are FL in mm, seagrass species are density estimates based on cover (Braun-Blanquet).

	Year Class			
Variable	1999	2000	2001	2002
Male FL (mm)	231.97	230.93	232.32	251.11
Female FL (mm)	262.53	244.28	254.72	266.39
H. wrightii	0.78	1.23	1.63	0.96
S. filiforme	1.47	2.75	3.65	1.43
T. testudinum	1.41	2.06	1.38	1.33
Average Conductivity	46751	48415	51228	48675
Minimum Conductivity	34315	37589	35846	38395
Maximum Conductivity	52699	54104	55680	53863
Cond. Stand. Dev.	3932	2996	4297	3722

TABLE 4. Summary of Time-Series analyses of size at age 1 in spotted seatrout relative to seagrass species density and salinity parameters recorded for years 1999–2002 in San Carlos Bay. Underlining indicates associations greater than |0.75|. Salinity average is measured as average annual salinity (generally measured daily), salinity minimum is the average monthly minimum, salinity maximum is average monthly maximum, and salinity standard deviation (SD) is based on all data.

Dependent Variable	Independent Variable	Lag Time (years)				
		−2	−1	0	+1	+2
Male Size	*H. wrightii*	0.15	0.86	−0.16	−0.33	−0.14
	S. filiforme	0.23	0.77	−0.39	−0.34	−0.05
	T. testudinum	0.74	−0.21	−0.56	−0.16	0.25
	Salinity Avg	−0.04	0.91	0.18	−0.28	−0.26
	Salinity Min	0.36	0.08	0.62	−0.07	−0.17
	Salinity Max	0.06	0.90	0.08	−0.30	−0.22
	Salinity SD	−0.67	0.47	0.19	0.03	−0.20
Female	*H. wrightii*	0.15	0.84	−0.55	−0.48	0.47
	S. filiforme	0.19	0.71	−0.69	−0.40	0.60
	T. testudinum	0.51	−0.10	−0.88	0.54	0.18
	Salinity Avg	0.02	0.92	−0.24	−0.61	0.27
	Salinity Min	0.28	0.36	−0.13	0.20	−0.51
	Salinity Max	0.09	0.91	−0.38	−0.55	0.33
	Salinity SD	−0.46	0.28	0.57	−0.70	0.21

of any observed trends detected for one sex. Previous studies on spotted seatrout have also found that females grow faster than males (Mercer, 1984) although the difference may not be significant during the first year of growth (Murphy and McMichael, 2003).

Murphy and McMichael (2003) summarized the growth of spotted seatrout throughout their range for which there are data. Comparisons with other studies should be done with caution as sometimes size-at-age data are reported as standard length as opposed to total length and fork length (these are equivalent in spotted seatrout) and authors do not always indicate which measure for length was used. With this caveat, an inspection of back-calculated lengths at age (Murphy and McMichael, 2003) indicates that male spotted seatrout from San Carlos Bay in the Charlotte Harbor system seem to grow faster than other male spotted seatrout in other areas of the eastern Gulf of Mexico. We found that the back-calculated size for the first four years of age (251, 293, 331, and 373) were similar to the sizes (237, 305, 345, and 384) reported for Charlotte Harbor by Murphy and Taylor (1994) while Moffett (1961) reported slower growth among males from Fort Myers, Florida (i.e., 156, 245, 302, and 364, ages 1–4 respectively).

Moffett (1961) reported females at age of annuli 1–4 as 160, 248, 313, and 377, respectively, for Fort Myers whereas Murphy and Taylor (1994) reported sizes as 242, 357, 434, and 495 mm TL in Charlotte Harbor. Here, female spotted seatrout were observed to be 288, 388, 371, and 457 mm TL for their back-calculated size at annulus formation. Our study results are more similar to the growth observed for both sexes by Murphy and Taylor (1994) but much faster than that observed by Moffett (1961) for Fort Myers. These differences could be due to methodological differences in aging fish, differences in back-calculation protocols, or real differences in growth rates taken over different time periods.

Comparisons of size at a similar age are facilitated by using back-calculated size at annulus formation data. Assuming some feature such as Lee's Phenomenon was not acting to invalidate comparisons, this technique allows ready comparison among previous year classes. One of the objectives of this study was to relate environmental conditions in the estuary to growth parameters. In this study, it was inviting to make the assumption that there may have been environmental factors affecting the slower growth (size at age) observed for both males and females for year-class 2000. This year was environmentally significant in the Caloosahatchee River/Estuary in that extreme conditions of salinity, caused by excessive releases of fresh water from Lake Okeechobee followed by a complete cessation of releases of water from the Lake. It is tempting to speculate that the observed differences in growth among spotted seatrout were caused by extremes in the salinity regime. Lowest salinities were recorded in 1999 and the greatest variance was recorded in 2001. The advantage of initiating such a database on spotted seatrout growth is that we now have a basis upon which to compare future responses of fish growth to extreme salinity conditions.

The time-series analysis indicated some interesting associations between environmental conditions, as measured by seagrass density and salinity, and growth during the first year of life for both males and females for each year class. Faster growth was preceded by higher densities of *H. wrightii* and *S. filiforme* and higher average salinities. One should interpret these findings with some caution as the apparent association found here does not necessarily indicate causation. Green (1979) indicated that strong correlations in Time-Series analysis could represent causative relationships but, oppositely, they could also result from similar responses to the same unmeasured, natural rhythms. As with any time-series analysis, there should be many replicates of natural cycles and concomitant fish growth responses to make statements regarding causation. Nevertheless, the model presented here indicates that it is possible to speculate on subsequent year-class growth based on seagrass density information or salinities.

There is an indication here that higher salinities favor faster growth among spotted seatrout preceding their first year of life (or conversely, lower salinities precede slower growth). The inevitable implication for management is that increasing the average salinity of the estuary through reductions in freshwater discharges may lead to higher growth rates among spotted seatrout. However, more evaluation is needed before this becomes an acceptable management action. Alternatively, it may be that seagrass density, as influenced by salinity, could be the factor controlling spotted seatrout growth. We have no way, at this time, to separate the potentially interactive or co-variant effects of these factors. Similarly, we are aware that many other factors can influence fish growth. Some of these factors include: food availability and condition, predation pressure, and fishing mortality. This study was unable to obtain sufficient year-specific data on these factors for our analysis here. It could be assumed, however, that since there were few changes in fishing regulations during the years examined, that fishing pressure was relatively constant during the period of interest. Similarly, the area was not subjected to major hurricanes or storms during this period. Obversely, red tide is known to occur in the area and could have affected fish growth.

From the final posed hypotheses we offer the question: Are differences in spotted seatrout growth reflective of differences in estuarine condition over time? This is the very premise of the current research effort. With only a few years of data (both with regard to fish growth and environmental data) with which to conduct the analyses, the hypothesis that environmental differences in the estuary can be observed in the growth rate among an estuarine-resident fish like the spotted seatrout is not rejected. Continued examination of the relationship between growth and the environment is warranted. If this hypothesis continues to stand after further examination, then growth rates of spotted seatrout can serve as a valuable indicator of estuary conditions. Furthermore, knowledge of this relationship could also provide environmental managers with a gauge to determine the effects of efforts to restore estuaries.

The data on age and growth offered in these study results are important. They help form a baseline for assessing future trends in age and growth in this ecologically and economically important species, both within and between estuaries. To be fully evaluated, consideration should also be given to other factors that may influence growth (such as food availability, genetic differences, etc.) The data presented here lend credence to the idea that some features or factors in the estuary are associated with seatrout growth. With a longer-term database, it may one day be possible to predict fish growth in the estuary through evaluation of a few pertinent environmental features. Eventually, it may even be possible to affect growth in some fish species through manipulation of controllable environmental features, such as salinity. Longer-term trends in age and growth may allow us to detect long-term, global-scale phenomena related to factors related to global climate change. One such rule is the Moran Effect (Hudson and Cattadori, 1999; Ripa, 2000; Koenig, 2002; Stenseth et al., 2002) that implies common biological trends may be detected across a wide spatial scale if subjected to a generally widespread stressor such as climate change. While such a feature was not detected here, the baseline information is accumulating through data gathered by studies such as this to be able to make such determinations.

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