Population Changes and Location-Specific Differences for Otolith-Derived Age and Growth of Recreationally Harvested Spotted Seatrout (*Cynoscion nebulosus*) From Alabama in 2007

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Population Changes and Location-Specific Differences for Otolith-Derived Age and Growth of Recreationally Harvested Spotted Seatrout (Cynoscion nebulosus) From Alabama in 2007

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Spotted seatrout (Cynoscion nebulosus), is a nonmigratory game fish common in the Gulf of Mexico that is important in estuarine ecosystems. Population dynamics of spotted seatrout were examined using otolith-based age-and-growth models derived from observed and back-calculated length-at-age values. These data were used to identify sex-based differences and annular variation. Recent growth was quantified, using marginal increment analysis for comparisons between sexes and the two major bays in Alabama (Mobile Bay and Mississippi Sound). Sex ratios were also compared for these locations. Our results show that females were larger than males and that fish collected in Mobile Bay were larger than those from Mississippi Sound. Combined data from both bays resulted in a sex ratio that approached 1:1; however, examination of each bay individually showed that the Mississippi Sound had a female-biased population and that Mobile Bay had a male-biased population. Differences in observed length-at-age measurements became evident between males and females by age 2 with females typically larger than males, whereas the maximum age for males was greater. The oldest females were age 5 and the oldest males were age 8. Compared to previous estimates of trout growth in Alabama, results showed an increase in the modal length of fish and increased growth rates. Results suggest faster growth of the fish in the current population and decreased harvest of larger fish compared to historic estimates. This may be indicative of ecosystem-wide changes in spotted seatrout populations and highlights the need to closely monitor this population.

S potted seatrout (Cynoscion nebulosus), is one of the most sought after species of inshore game fish along the southeastern United States (Schmidt et al., 2001; Hendon and Warren, 2003). They are a nonmigratory species found in most bay systems in the Gulf of Mexico and along the Atlantic coast (VanderKooy and Muller, 2002). Spotted seatrout have limited home ranges but are known to make intrabay migrations (Locascio and Mann, 2005; Walters, 2005; Bivins, 2011) and are an important trophic link in the estuarine food web (Hettler, 1989; Baker et al., 1993). Differences in demographics, growth characteristics, and genetics of spotted seatrout can be evident across small spatial scales (Gold et al., 1999; Bedee et al., 2002). For example, population-level differences were evident among bays in north Florida with spatial separations of tens of kilometers (Bedee et al., 2002). This combination of life history traits allows for the spotted seatrout to be managed effectively at the local level (Blanchet et al., 2001).

Growth information can be used to assess population-level responses to environmental conditions and also provide insight into population demographics and responses to harvest. Because metabolism has a significant role in otolith growth (Johnson et al., 2002; Hussy and Mosegaard, 2004), environmental variations that impact metabolic processes can also be quantified through changes in otolith morphometrics (Sinclair et al., 2002; Bortone et al., 2006). Otolith-based data of age and growth can identify changes within populations by quantifying cohort strength (Wilson et al., 2001), age related bottlenecks (Sinclair et al., 2002), and the impacts of habitat on growth (Rooker et al., 1999; Allman, 2007). Otolith-based age and growth measurements for spotted seatrout (Cynoscion nebulosus) have been positively correlated with seagrass abundance and salinity levels (Bortone et al., 2006). The sensitivity of otolith growth, combined with the limited variability in migration patterns, suggest that spotted seatrout age and growth has the potential to provide a predictive aspect toward the management of this species, and that the spotted seatrout may serve as an indicator species for detecting environmental variability at multiple scales (Bortone, 2003).

The spotted seatrout fishery in Alabama is the most popular inshore species targeted by recreational fishermen (ADCNR, 2007). Management of this species falls under the jurisdiction of the Alabama Department of Conservation and Natural Resources’ Marine Resources Division.
(ADCNR). Historically, there has been limited monitoring of the age and growth of spotted seatrout, with collections occurring in 1987, 1995–96, and 2002–06. Prior to the 2002–06 data set, fish were only collected from fishery-dependent sources (ADCNR, 2007). The mean (±SE) recreational harvest in Alabama between 2002 and 2006 was 290.4 ± 28.2 metric tons annually and the number of trips targeting spotted seatrout increased approximately 20% over that same time period. Excluding 2005, catch per unit effort (CPUE) has remained steady at approximately 0.6 fish hr⁻¹; however, harvest per unit effort has declined from 0.37 fish hr⁻¹ in 2002 to 0.2 fish hr⁻¹ in 2006. During 2005, CPUE increased to ~1.1 fish hr⁻¹ and harvest increased to ~0.4 fish hr⁻¹ (ADCNR, 2007). Because this is not a catch-and-release fishery, this may suggest that the population structure of spotted seatrout is shifting toward a population dominated by smaller fish. This type of shift in population structure can be harvest-related (Jennings et al., 2001).

Currently, spotted seatrout stocks are not considered to be overfished, with estimates of F being 0.72 and 0.82 for fishery dependent and fishery independent samples, respectively. However, recent increases in fishing pressure suggest that modifications may be needed for current management practices to better manage the species and prevent overfishing (ADCNR, 2007). As such, there is a need for continued monitoring of spotted seatrout population dynamics in Alabama. The objectives of this study were to model age and growth of spotted seatrout and identify area specific differences in demographics (length, age, and sex structure) between the two major bay systems within Alabama. Additionally, historic age, growth, and population structure were examined using otolith-based back-calculation techniques to assess the applicability of this technique to management of spotted seatrout.

**METHODS**

From May to July 2007, we sampled 400 spotted seatrout from Alabama through a cooperative program with local fishing guides and clients, a fisherman-intercept program conducted during local fishing tournaments, and research-related gill net monitoring conducted by the Dauphin Island Sea Lab, Dauphin Island, AL. Alabama state waters comprise two central areas, Mobile Bay and the eastern Mississippi Sound (Fig. 1). Separation of the two bays at this location was due to the presence of a naturally occurring “choke” point between the deeper, open waters of Mobile Bay proper and the shallower waters and intertidal oyster reefs of the Mississippi Sound. The area south of Dauphin Island in the Gulf of Mexico was considered part of the Mississippi Sound area because of the shallow depths and packed-sand bottom, similar to non-oyster-covered bottoms in the Mississippi Sound. Gill netting was conducted at five fixed locations (two in Mississippi Sound, three in Mobile Bay) using 30-m nets with two 15-m panels of either 5.1- and 10.1-cm mesh or 10.1- and 15.2-cm mesh. Because of the small number of fishery-independent fish collected, all the fish collected were pooled to provide for a more robust sampling of spotted seatrout. Although it is preferable to separate fishery-independent and dependent samples, low sample sizes precluded that reliable estimates would not be possible for the fishery-independent data alone. Any fish below the state size limit of 35.5 cm were collected under the appropriate scientific collection permits. For each fish, total length (TL) was measured, sex was determined macroscopically, area of capture was identified, and sagittal otoliths were removed for ageing.

Unless missing, damaged, or broken, the left otolith was used to determine age. Otoliths were sectioned transversely with a low-speed wafering saw following VanderKooy and Guindon-Tisdel (2003) and examined at ×12 with a stereomicroscope fitted to a high-resolution camera. Ages were estimated by counting the number of opaque and clear annulus pairs present in the section using methods identical to those described in Bortone et al. (2006). Because all the fish were collected over a 2-mo period near the theoretical hatch date (1 July), ring counts were considered to be actual age (Brown-Peterson et al., 1988; Brown-Peterson and Warren, 2001; Nieland et al., 2002). Otolith images were saved with PictureFrame® software and analyzed with ImagePro Express® image-analysis software. Otolith radius and annular radii were measured along the short axis parallel to the sulcus.

Back-calculated size at annulus formation was determined from fish size at capture, otolith radius, and annular radii using the Frasier–Lee method (see Morita and Matsuishi, 2001):

\[
Li = a + (Lc - a) \times (Oi/Oc)
\]

where \(Li\) = the TL (mm) of the fish when it became age \(i\), \(a\) = the \(y\)-axis (TL) intercept of the relationship between otolith radius (abscissa) and TL (ordinate), \(Lc\) = TL (mm) at capture, \(Oi\) = distance (mm) from otolith core to distal edge of annulus at age \(i\), and \(Oc\) = otolith radius
Back-calculation methods have been used for many species and rely on the assumption that there is a proportional relationship between somatic growth and otolith growth (Vigliola et al., 2000; Araya and Cubillos, 2002). Although this assumption is often violated (Araya and Cubillos, 2002), this technique has been successfully demonstrated for spotted seatrout by Bortone et al. (2006).

Growth comparisons between Mobile Bay and Mississippi Sound for fish collected were made using an estimate of recent growth along the margin of the otolith (clear otolith growth beyond the last opaque zone formed). To obtain this value, we divided the marginal increment by the month of capture to standardize growth to age (mm month$^{-1}$). Because spotted seatrout make predictable intrabay migrations but minimal interbay migrations (Clark et al., 2002), and sampling was limited to a single season, specific growth responses should have been accurately attributed to specific areas (bays).

To examine differences in observed TL and observed age, a two-way analysis of variance (ANOVA) was performed for each dependent variable where sex and area were fixed, independent factors. To identify differences in recent growth from marginal increment analysis, a two-way analysis of covariance was used where area was the independent variable and age, fork length, and sex were the covariates. All values were transformed using a log transformation to meet the homogeneity of variance assumption (Sokal and Rohlf, 1981). Because previous studies indicate differences in size-at-age for spotted seatrout (Murphy and Taylor, 1990; Nieland et al., 2002), Student’s t-tests were used to examine observed size-at-age between sexes to identify the age when differences in size become evident. A nonparametric binomial response test (SPSS, v. 11) was used to examine sex ratios between Mobile Bay and Mississippi Sound. The expected response for this test was a 1 : 1 ratio, male to female.

Observed and back-calculated growth rates were modeled using the Regression Wizard subroutine in SigmaPlot®. The relationship between age and TL was best described for males and females separately using a two-parameter power regression. A von Bertalanffy growth equation (VBGE) was estimated for observed female fish for comparative purposes.
than previous estimates and a growth coefficient that was smaller than previous estimates. All parameter values were significantly different than the values estimated by ADCNR for fish collected in 1995–96 and 2000–06 (Table 1).

Back-calculated growth models resulted in adequate estimates of growth for spotted seatrout. Power regressions underestimated length-at-age values by 4.6% or less compared to observed TL for males and females (Fig. 5). Like the parameter estimates from the observed data, VBGE parameters estimated from back-calculated values resulted in maximum length values that were greater than previous estimates and a growth coefficient that was smaller than previous estimates. All parameter values were significantly different than values estimated by ADCNR for fish collected in 1995–96 and 2000–06 (Table 1).

Cohort analyses of the different-aged fish indicated significant differences for 2003 age 2 fish (males and females) compared to other years. Specifically, age 2 males in the 2003 cohort had a mean size that was greater than the age 2 fish belonging to the 2004 and 2005 cohorts (ANOVA: F3,191 = 3.95, P = 0.01; Bonferroni post hoc: 2003 vs 2004, mean difference = 9.6, P
Fig. 2. Total length–frequency histograms for female and male spotted seatrout (*Cynoscion nebulosus*) collected in Alabama during 2007 by collection method. Panel A represents fish collected from guides, panel B represents fish collected from gillnets, and panel C represents fish collected during tournaments.
For age 2 females in the 2003 cohort, mean size was greater than the age 2 fish belonging to the 2005 cohort (ANOVA: $F_{3,191} = 4.04, P = 0.01$; Bonferroni post hoc: 2003 vs 2005, mean difference $= 7.83, P = 0.03$) (Table 2).

**DISCUSSION**

Observed and back-calculated age and growth of seatrout in Alabama showed an increase in fish length compared to previous surveys suggesting that the average fish being harvested is larger than historical catches, but that there are fewer of these larger fish present in the population as suggested by the increase in CPUE and by the decline in yield per unit of effort (ADCNR, 2007). This could be the result of selective harvesting of older fish or an increase in the number of smaller fish within the population. This trend was evident in regression analysis, VBGEs, and length–frequency histograms. These results are not an artifact of use.
of fishery-dependent data, because prior to 2002, all age and growth analysis of fish collected by ADCNR were from creel surveys and tournament landings. Additionally, estimates from both data sets should converge in older fish, but they do not. ADCNR’s assessment of spotted seatrout caught in the recreational fishery between 2002 and 2006 had a length–frequency analysis with mode of approximately 381 mm (ADCNR, 2007), approximately 10% less than the current study. However, we found that the growth rate coefficient (K) in the VBGE remained within the range of historic values (0.35–0.53). By calculating size-at-age from ADCNR’s age-and-growth estimates then applying our power regression techniques to these values (ADCNR, 2007), our model resulted in growth that was approximately 9% higher than in previous ADCNR estimates. At the macro scale, observed age and growth during 2007 was comparable to estimates of seatrout growth along the western Gulf of Mexico. Prior to 2006, age and growth estimates from Alabama were, however, more similar to locations along the northern and eastern Gulf of Mexico (see

Fig. 4. Age–frequency histograms for female and male spotted seatrout (Cynoscion nebulosus) collected in Alabama during 2007. Panel A represents Mobile Bay and panel B represents Mississippi Sound.
review in GMFMC, 2001; Nieland et al., 2002; Murphy and McMichael, 2003). Changes at this scale may be indicative of changes at the ecosystem level rather than at the local level.

Shifts in fisheries production can result from environmental changes or catch-related demographic restructuring (Walters and Martell, 2004). In Alabama, there have been no changes in harvest regulations of spotted seatrout since 2000; however, there has been an increase in fishing pressure, a relatively constant CPUE, and a decline in yield per unit of effort (ADCNR, 2007). These data suggest that populations of younger fish are increasing, but that they are not entering the fishery. This shift in growth seems to be sudden, as it was not evident in the ADCNR’s 2002–06 survey (ADCNR, 2007). These data suggest that populations of spotted seatrout are known to have variable growth rates among estuaries, often related to environmental forcing, even when subjected to identical harvest restrictions (Bedee et al., 2002; Nieland et al., 2002; VanderKooy and Muller, 2002; Nieland and Wilson, 2005; Bortone et al., 2006).

Differences in demographics between Mississippi Sound and Mobile Bay seen in this study can be attributed to variability in habitat selection by male and female seatrout during summer spawning. This may be due to seasonal demographic segregation via intrabay migrations rather than the presence of two separate populations. Female spotted seatrout prefer to spawn in areas where there are deep channels with moving water such as in open bays, between barrier islands, or at the mouth of an embayment (Saucier et al., 1992; Saucier and Baltz, 1993). The Mississippi Sound has greater variability in depth and more islands, and is typically shallower than Mobile Bay. Mobile Bay, more specifically lower Mobile Bay, is a typical open water system with depth gradients that are sloping rather than steep drop-offs, and the primary structures are...
oil platforms and a subtidal, low-relief oyster reef (May and Bland, 1970; Chen et al., 2005). These characteristics may make Mississippi Sound more conducive for spawning activities, resulting in greater numbers of females in the Mississippi Sound compared to Mobile Bay.

Although there was little evidence of variation among cohorts, there was faster growth for the age 2 fish from the 2003 cohort, but it remains unknown why this was not evident for other age classes during the same year (i.e., age 3 from 2002 or age 1 fish from 2004). Faster growth in 2003 was interesting given the possibility of increased competition for resources resulting from the 2002 year class (age 2 fish in 2003) being 18% larger than the 2001 year class and 10% larger than the 2000 year class (ADCNR, 2007). Growth could be the result of record rainfalls during spring and early summer 2003 triggering a decade-high abundance of brown and white shrimp between 2003 and 2004 (NWS, 2003; Ware and Thomson, 2005; NMFS, 2006a, b). Shrimp is one of the primary prey items throughout the life history of spotted seatrout (Carr, 1973; Lassuy, 1983; Minello, 1984). Alternatively, decreased salinity levels in Mobile Bay over several months (MBNEP, 2003) could have resulted in increased vulnerability for typical prey items as they were forced from their home niche in search of more saline habitats. If these two events coincided with the ontogenetic prey preferences of this cohort, this could explain the increased growth for only a single age group.

The ability to retrospectively evaluate the long-term impact of environmental disturbances in coastal environments is important because resources and time are often limited for extensive monitoring programs. Since spotted seatrout move throughout the estuary in a predictable manner based on salinity and temperature (Baltz et al., 2003), changes in seatrout demographics may be a good proxy for system-wide disturbances. This may be even more important in systems without active monitoring programs. For example, Bortone et al. (2006) determined that the variations in salinity and the areal extent of seagrasses in a south Florida estuary were positively correlated with the back-calculated, otolith-derived growth for age 1 spotted seatrout.

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<th>Table 1. Estimated von Bertalanffy growth equation parameters (L∞ = asymptotic length, cm; K = von Bertalanffy growth coefficient; t₀ = theoretical age [yr] at a length of zero) from this study and those estimated by the Alabama Department of Conservation and Natural Resources (ADCNR, 2007) (section A) and results for likelihood ratio tests comparing results from this study to recent ADCNR estimates (section B). Coincident model terms from one group were set equal to terms in second group (see Haddon, 2000). Significant results are denoted by asterisks.</th>
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Although not necessarily causative, an increase in suitable habitat and salinity levels that remain above a critical level could provide favorable conditions that enable rapid growth of juvenile spotted seatrout.

Although our analysis was limited to a single year of collection, our results concur with the opinions expressed in the latest stock assessment that spotted seatrout stock in Alabama may be experiencing population changes (ADCNR, 2007). Typically, a shift toward larger fish is indicative of success in fisheries management (e.g., implementation of size-based harvest restrictions); however, yield per unit of effort should also increase (Quinn and Deriso, 1999). This has not happened in the Alabama fishery. Identifying the underlying reason for these population trends may be critical to expanding our understanding of seatrout populations in this region. Because our back-calculated regression estimates were 4% less than the regressions derived from the observed data and we limited our analysis to fish 5 yr old or younger, back-calculated lengths appearing smaller for older fish (Lee’s phenomenon) was not problematic in these data (Duncan, 1979; Murphy and McMichael, 2003). Difference in models may also be indicative of the recent changes in population structure toward smaller fish. Without the recent changes, we would have expected back-calculated growth to be closer to 10% less than our observed values, matching the change in mode and observed growth rates.

In conclusion, as long as spotted seatrout remains a highly desired recreational species in Alabama, caution should be expressed related to the health of the population. The unique characteristics of this fish make it a model for small-scale, local management; moreover, population-wide effects may be quicker to manifest than in larger populations. Monitoring efforts should be increased to identify basin-wide changes in population dynamics and preemptive corrective actions that can be taken to maximize the long-term health of fishery.

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