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Estimation of the Length-at-Age Relationship of Mississippi’s Spotted Seatrout

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Abstract

Spotted Seatrout Cynoscion nebulosus are a highly valued recreational inshore species in Mississippi coastal waters. The accurate description of the length-at-age relationship is critical for assessment efforts of the stock. Because Spotted Seatrout exhibit small-scale movements, the stocks in the Gulf of Mexico are managed as state-specific units. Therefore, local demographic estimates of length at age are needed for assessment. We estimated the length-at-age relationship of Spotted Seatrout in Mississippi by using tag recapture records and otolith-derived age estimates. Three nonlinear length-at-age models were fit to sex-aggregated, tag recapture data and four nonlinear length-at-age models were fit to sex-specific, otolith-derived age data. For each suite of models, model support was determined using Akaike information criteria. The Francis (1988a) GROTAG method had the greatest support of the three models fit to the tag recapture data, and the resulting parameter estimates from the model were $L_{\infty} = 550.8$ mm and $k = 0.45$/year. The three-parameter logistic model had the greatest support of the four models fit to the otolith-derived age data for both males and females and the resulting parameter estimates of $L_{\infty}$ were $605.3$ mm TL for females and $574.9$ mm TL for males. The results of this study indicate that (1) the Francis (1988a) GROTAG method was the best-supported method for the determination of the von Bertalanffy growth function parameters from tag recapture information, and (2) the von Bertalanffy growth function may not be the best model to describe the length-at-age relationship of Mississippi’s Spotted Seatrout. This work highlights the utility of using multiple sources of length-at-age information and fitting multiple models to enhance both the description of the length-at-age relationship and to determine biases that occur in both.

Spotted Seatrout Cynoscion nebulosus are found in estuarine and nearshore environments throughout the Gulf of Mexico and Atlantic coast (Hoese and Moore 1977). Because of its popularity as a recreational game fish, especially in the Gulf of Mexico, a significant amount of research has been conducted regarding the biology, life history, and management of the species (Brown-Peterson et al. 1988; Helser et al. 1993; Bumgardner et al. 1998; Brown-Peterson and Warren 2001; Fulford and Hendon 2010). In Mississippi coastal waters, Spotted Seatrout are the most sought after recreational inshore fish species (Deegen 1990). The Gulf of Mexico stock complex is managed separately by each Gulf state and each state has state-specific or region-specific regulations (GSMFC 2001). These stock boundaries are supported by the results of genetic (Gold and Richardson 1998) and tagging (Hendon et al. 2002) studies that indicate that the Gulf of Mexico metapopulation is composed of distinct sub-stocks. Currently, the Mississippi fishery is regulated using minimum size limits and

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daily bag limits. The assessment of the stock was most recently performed using an age-structured model (Fulford and Hendon 2010). Age-structured models require length-at-age information because the age structure of both the catch and the population in Mississippi are derived from length-frequency data. Without precise and accurate information about the dynamics of individual growth, there is a risk of having poorly defined and potentially biased fishery reference points (Reeves 2003). Previous analysis of the Spotted Seatrout length-at-age relationship indicated that the relationship is highly variable (Murphy and Taylor 1994).

The length-at-age relationship of fish is described using a variety of nonlinear models (Gompertz 1825; von Bertalanffy 1938). The von Bertalanffy growth function (VBGF), first introduced to fisheries by Beverton and Holt (1957), is commonly used because it has biologically relevant parameters that are useful for creating fishery management reference points and estimating other life history characteristics like mortality (Pauly 1980; Chen et al. 1992; Clark 1999; Williams and Shertzer 2003).

Despite the widespread use of the VBGF, it is not always the most accurate model to describe length at age. Model misspecification or choosing an inaccurate model to describe data can result in biased parameter estimates (Katsanevakis 2006; Katsanevakis and Maravelias 2008). Because choosing a priori to model the length-at-age relationship using a single model does not allow an understanding of the magnitude of model selection uncertainty, multimodel inference has been developed as a method allowing multiple models to be fit to data, including length-at-age age data (Burnham and Anderson 2002). Using multimodel inference in assessing growth dynamics involves fitting several different length-at-age models to determine which candidate model has the greatest support among the models considered (Burnham and Anderson 2002). The process of fitting several models and using Akaike weights (Akaike information criteria) to objectively evaluate the relative fit of alternative candidate models can mitigate model selection uncertainty and provide robust parameter estimates (Katsanevakis 2006). Using the multimodel inference approach helps identify which model is best supported from a suite of candidate models, rather than assuming that a single model, such as the VBGF, is the best model to describe the length-at-age relationship (Katsanevakis and Maravelias 2008).

Information on the length-at-age relationship of fish can be obtained from both otolith-derived age estimates and tag recapture studies (Natanson et al. 1999; Johnson et al. 2011). The most widely used method of age determination in fish is to count growth increments on calcified structures, such as otoliths (Secor 1995). Despite the widespread use of this aging method, biases may occur when determining age via otoliths (Campana 2001). Variation in an individual’s formation of annuli and difficulties in observing and counting annuli are two potential sources of otolith aging error (Kimura et al. 1979; Boehlert 1985). Because of the potential error, several methods of age validation and corroboration exist. Age validation is the verification of the periodicity of annuli formation and age corroboration is the use of an alternative method of estimating and comparing growth parameter estimates (Campana 2001). Age validation methods include release of a known age and marked fish, bomb radiocarbon chemistry, and marginal increment analysis. Age corroboration methods include tag recapture analysis and length-frequency analysis (Kalish 1993; Fitzgerald et al. 1997; Fowler and Short 1998; Natanson et al. 1999).

Tag recapture has been employed as a method of corroboration for several species (Thorson and Lacy 1982; Natanson et al. 1999), and there are several nonlinear models that have been derived to describe the length-at-age relationship using tag recapture information (Fabens 1965; Francis 1988a; Tropykiv et al. 1998). Tag recapture data consists of the measurements of the length of marked individuals at known capture and recapture dates. By using the change in length between capture events and the time at liberty, annual growth rate estimates can be used to calculate the von Bertalanffy growth parameters (Gulland and Holt 1959). There are several nonlinear, reparameterized versions of length-at-age models that can be fit to tag recapture data (Fabens 1965; Francis 1988a; Tropykiv et al. 1998). Although many length-at-age models can be reparameterized to fit tag recapture data, the interpretation of the parameters of the tag recapture, length-at-age models may not be comparable to the parameters of the models fit to otolith-derived, length-at-age information (Francis 1988b). This difference in parameter meaning is due to differences in length being an expected value in models fit to otolith-derived length-at-age information and an observed value in models fit to tagging information (Francis 1988b). However, there are methods of estimating growth parameters from tagging information that address these issues (Francis 1988a), and caution should be used when attempting to validate one method with another.

The VBGF has been used to model the length-at-age relationship of the Spotted Seatrout stock in Mississippi (Fulford and Hendon 2010). However, the otolith-derived parameter estimates of the VBGF have not been compared with parameter estimates derived from alternative methods, nor have alternative models been used. In this study we used three nonlinear models of tag recapture data from an extensive tag recapture study and four nonlinear models of otolith-derived age data to describe the length-at-age relationship of Spotted Seatrout. We investigated the utility of fitting multiple growth functions to length-at-age information and assessed how alternative data sources and modeling approaches can be useful in obtaining robust growth parameter estimates while also reducing model misspecification errors.

METHODS
Tag recapture records analyzed in this study were obtained from the Mississippi Spotted Seatrout Tag and Release...
Program conducted by the University of Southern Mississippi’s Gulf Coast Research Lab. The objective of the tagging effort was to collect, tag, and release Spotted Seatrout in Mississippi coastal waters. Participating volunteer recreational anglers were given a tagging kit containing a tagging instruction booklet, a stainless steel tag applicator, and 10 high-visibility-yellow plastic-tipped dart tags. The tags had a streamer length of 7.6 cm and were manufactured by Hallprint, Holden Hills, Australia. Each tag contained the GCRL address, a unique numerical identifier, and a contact phone number. Attached to each tag was a corresponding data card the angler filled out that included tagging date, release location, total length (TL), an indication of whether length was estimated or measured, and the angler’s name and address. When an angler tagged a Spotted Seatrout, they completed and mailed the information card to GCRL, where the data were recorded and stored. The Mississippi Spotted Seatrout Tag and Release Program was advertised using posters placed along the Mississippi coast at boat launches and piers. The posters contained instructions on reporting procedures and other public information regarding the program. When anglers caught a tagged fish, they were asked to provide their name and address, the location of recapture, fish total length (in), tag number, whether the reported length was measured or estimated and if the fish was released. If the fish was released the angler was asked to report whether or not the tag was removed.

In addition to tag recapture records, otolith-derived length-at-age information was used to describe the length-at-age relationship of Spotted Seatrout. The Mississippi Department of Marine Resources and GCRL collected Spotted Seatrout from 2005 through 2013 using gill nets at fixed and random survey stations located throughout Mississippi coastal waters (Figure 1). Spotted Seatrout were returned to the laboratory for processing, fish were measured (TL, mm), weighed (g), and otoliths were removed. Otoliths were obtained from 2,637 females (170–794 mm TL) and 697 males (209–611 mm TL). Otoliths were processed and aged by counting the number of opaque rings present. Biological ages were assigned based on the number of opaque rings, the margin code, and the date of capture. A birth date of July 1 was assumed for all individuals, and the average date of annuli formation was assumed to be April 1, based on standard age determination techniques (VanderKooy and Guindon-Tisdel 2003).

To analyze the tag recapture information, three nonlinear length-at-age models were fit using maximum likelihood estimation (MLE). The first model fit to the tag recapture records was the Fabens (1965) VBGF, a two parameter model:

$$\Delta L = (L_{\infty} - L_t)(1 - e^{-k \Delta t}),$$

where $\Delta L$ is the expected change in total length (mm) of an individual during the time at large between initial tagging and recapture $\Delta t$. The two parameters are $L_{\infty}$, which is the average maximum total length (mm), and $k$ (y$^{-1}$) which is the growth rate coefficient.

The second model fit to the tag recapture data was the Francis (1988a) GROTAG model. The GROTAG model is considered an improvement to the Fabens (1965) method because it incorporates growth variability ($\sigma$) and measurement error ($m$ and $s$; mm) as model parameters (Francis 1988a). The model was fit using an Excel Solver version of the GROTAG analysis (Simpfendorfer 2000). The Francis (1988a) equation is

$$\Delta L = \left( \frac{\beta g_a - \alpha g_b}{g_a - g_b} - L_1 \right) \left( 1 - \left( 1 + \frac{g_a - g_b}{\alpha - \beta} \right)^{\Delta t} \right),$$

where $\beta$ and $\alpha$ are the growth parameters, $g_a$ and $g_b$ are the growth variability coefficients, $L_1$ is the length at age 1, and $\Delta t$ is the time at large between tagging and recapture.
where $\Delta L$ is the expected change in length (mm) over the change in time, $\Delta t$ (y) and $L_i$ is the initial length (mm) of an individual at tagging. The parameters $g_\alpha$ and $g_\beta$ are the mean annual growth rates (mm/year) of fish at user-selected total lengths (mm) of $\alpha$ and $\beta$. If lengths $\alpha$ and $\beta$ are assigned values within the range of lengths of tagged individuals, then $g_\alpha$ and $g_\beta$ can be considered descriptive of the individual growth rates encompassed by the tagging data (Francis 1988a). In this study $\alpha = 250$ mm and $\beta = 350$ mm. After fitting the model, $L_\infty$ (mm) can be estimated from $g_\alpha$ and $g_\beta$ using the equation

$$L_\infty = (\beta g_\alpha - \alpha g_\beta) / (g_\alpha - g_\beta).$$  

Similarly, $k$ (y$^{-1}$) can be calculated from the GROTAG model parameters using the equation

$$k = -\ln(1 + (g_\alpha - g_\beta) / (\alpha - \beta)).$$

The 95% confidence intervals (CI) of $L_\infty$ and $k$ were determined using bootstrap methods similar to those described in Simpfendorfer (2000).

The third model fit to the tag recapture data was the reparameterized Gompertz model introduced by Troynikov et al. (1998). The equation is:

$$\Delta L = L_\infty \left( \frac{L_i}{L_\infty} \right)^{\exp(-g \Delta t)} - L_i,$$

where, $\Delta L$ is the expected growth increment (mm) and $L_\infty$ is the average maximum body length (mm), $L_i$ is the length (mm) at initial tagging, $g$ (y$^{-1}$) is the exponential decrease in growth increment, and $\Delta t$ is the time at liberty (y).

After fitting each model to the tag recapture data, model support was determined using Akaike information criteria (AIC), which is an objective criteria used to compare model fit by evaluating and balancing the fit and parsimony of a candidate model (Burnham and Anderson 2002). The use of AIC is common in fisheries science and has been used to compare growth curves of other sciaenids (Porch et al. 2002). The model with the lowest AIC value is considered the model with the most support. Models with an AIC difference of 2 compared with the minimum AIC model are considered to have high support, differences of 4 to 7 are considered to have little support, and models with an AIC value $> 10$ are considered to have no model support. Model support was quantified by calculating Akaike weight, $w_i$, for each model:

$$w_i = e^{(-1/2)AIC_i}) / \sum e^{(-1/2)AIC_i},$$  

Four nonlinear length-at-age models were fit to the otolith-derived age data to determine the sex-specific length-at-age relationship of Spotted Seatrout. Each model was fit using maximum likelihood estimation. The first model fit to the length-at-age data was the three-parameter VBGF (von Bertalanffy 1938):

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

where $L_t$ is the expected length (mm) at age (years) $t$. The model has three parameters: $L_\infty$ is the average maximum total length (mm), $k$ (y$^{-1}$) is the growth rate coefficient, and $t_0$ (y) is the hypothetical age (years) when TL = 0 mm. The second model fit to the length-at-age data was a two-parameter VBGF:

$$L_t = L_\infty \left( 1 - e^{-kt} \right).$$

In this equation, $t_0$ is assumed to be zero, which serves to anchor the growth curve to the origin. The parameters in the two-parameter VBGF are identical to those of the three-parameter version.

The third model fit to the otolith determined length-at-age data was a three-parameter logistic model (Ricker 1975):

$$L_t = \frac{L_\infty}{1 + a(e^{-kt})},$$

where $L_t$ is the expected length (mm) at age (years) $t$ and $L_\infty$ is the average maximum total length (mm). The parameters $a$ (unitless) and $b$ (as years$^{-1}$) determine the shape of the curve. The last model fit to the otolith-derived data were a three-parameter Gompertz model (Gompertz 1825):

$$L_t = L_\infty a e^{-b t},$$

where $L_t$ is the expected length (mm) at age (years) $t$, $L_\infty$ is the average maximum total length (mm), and $a$ and $R$ are parameters that control the structure of the growth curve. After the four models were fit to the otolith-derived age information, AIC and Akaike weights were again used to evaluate model support. An analysis of residual sum of squares (ARSS; an $F$-ratio) was calculated to determine if there was a significant difference between the best-fitting male and female length-at-age curves (Chen et al. 1992):

$$RSS_p - \sum RSS_i \over DF_p - \sum DF_i \over \sum RSS_i \over \sum DF_i$$

(11)

The residual sum of squares (RSS) and degrees of freedom (DF) for the best-fitting model of each sex, $i$, was calculated and summed to get $\sum RSS_i$ and $\sum DF_i$. The sexes were then pooled and a new curve was fit to the sex-aggregated
otolith-derived age data. The $F$-statistic was then calculated (via equation 11) to test whether or not the curves were statistically different.

RESULTS

A total of 19,311 Spotted Seatrout were tagged from 1995 through 2013 in Mississippi’s coastal waters (Figure 1) and a total of 530 individuals (2.7%) were recaptured. We focused our analysis on only those individuals ($n = 191$) that were at liberty for at least 22 d and whose lengths were reported as measured not estimated by anglers at either tagging or recapture. The 22-d threshold was used to allow time for adequate, measurable growth to occur. Of those individuals, total length ranged from 197 to 648 mm (Figure 2A) and time at liberty ranged from 0 to 741 d (Figure 2B).

Of the three tag recapture models fit to the tag recapture data, the Francis (1988a) GROTAG model had 100% of the model support relative to the Fabens’ (1965) VBGF and Troy- nikov et al.’s (1998) Gompertz model (Table 1). The estimated values were $g_a = 109.90$ (95% CI, 85.34–129.33) and $g_b = 73.28$ (95% CI 56.33–87.10), and both $L_\infty$ and $k$ were estimated using equations (3) and (4). The Fabens (1965) VBGF resulted in a greater estimate of $L_\infty$ than did the Francis (1988a) GROTAG method (Figure 3). The change in length during the time at large growth vectors were plotted using back-calculated ages from the GROTAG derived VBGF parameters and a fixed $t_0$ parameter to qualitatively analyze the fit of the most supported candidate model (Figure 4).

Support for the four candidate models used to examine the sex-specific, otolith-derived length-at-age information differed. Of the four models fit to the otolith-derived age data, the three-parameter logistic model had the greatest support for both sexes (Table 2). The three-parameter logistic model, three-parameter VBGF, and the three-parameter Gompertz model all had similar mean length-at-age estimates (Figure 5). For females, the Gompertz model had the second-most support, whereas both the three-parameter VBGF and the two-parameter VBGF had little or no model support (Table 2).

Asymptotic mean maximum length, $L_\infty$, of the best-fitting models was not significantly different for each of the sex-specific length-at-age relationships (Figure 6). The estimated mean $L_\infty$ value for females for the three-parameter logistic model was contained in the 95% confidence interval for males, but the estimated mean $L_\infty$ value for males fell outside the 95% confidence interval for females (Table 2). The mean estimate of $L_\infty$ from the GROTAG model was outside the predicted 95% confidence interval of the female three-parameter logistic length-at-age relationship and inside the 95% confidence interval of the male three-parameter logistic length-at-age relationship. The mean $L_\infty$ value estimated from the GROTAG model using tag recapture information was lower than both the male and female $L_\infty$ estimate from the three-parameter logistic models (Figure 6). Although the estimated mean value of $L_\infty$ was not significantly different between sexes, the ARSS analysis indicated that the growth curves of male and female Spotted Seatrout were significantly different ($F = 270.2, P < 0.0001$).

![FIGURE 2](image-url)

**FIGURE 2.** (A) Frequency distribution of total length of Spotted Seatrout at tagging in Mississippi coastal waters, and (B) the time at large. Total lengths at tagging ranged from 197 to 648 mm. Time-at-large ranged from 0 to 741 d for the 191 recovered.
DISCUSSION

In this study we described the length-at-age relationship of the Mississippi’s Spotted Seatrout stock using a suite of non-linear length-at-age models fit to tag recapture data and sex-specific otolith-derived length-at-age information. The results of the tag recapture analysis supports the continued use of the VBGF to describe the length-at-age relationship of this stock and the Francis (1988a) GROTAG method is the most supported model for determining the VBGF parameters. The observed change in length during the time individuals were at large was highly variable in the tag recapture records. The low precision can be attributed to measurement error (most length information was recorded with a precision of about 0.25 in by anglers), individual growth, and naturally occurring variability in growth (Francis 1988a). The advantage of using the GROTAG method is that measurement error and growth variability parameters are estimated. In addition to measurement error and growth variability being incorporated into the GROTAG model, we attempted to mitigate measurement error by only using those individuals whose lengths were reported as not estimated at tagging or recapture. Although removing individuals whose lengths were estimated does not eliminate all measurement error it can serve to increase the precision of the parameter estimates. Two other sources of bias exist that may influence the accuracy of the estimated parameters in the tag recapture analysis. The first is the gear selectivity associated with recreational angling and the second is the selectivity of anglers perhaps nonrandomly choosing which fish were

<table>
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<tr>
<th>Model</th>
<th>$L_\infty$ (mm)</th>
<th>$k$ (y$^{-1}$)</th>
<th>$g$ (y$^{-1}$)</th>
<th>$\Delta$AIC</th>
<th>$w_i$</th>
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</thead>
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<td>Fabens</td>
<td>621.1 (532.4–854.9)</td>
<td>0.41 (0.21–0.64)</td>
<td>34.6</td>
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<tr>
<td>Gompertz</td>
<td>577.3 (515.7–697.0)</td>
<td>0.64 (0.44–0.87)</td>
<td>38.1</td>
<td>0.00</td>
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</tbody>
</table>

FIGURE 3. Estimated mean and 95% confidence intervals of (A) $L_\infty$ (the average maximum total length), and (B) the growth rate coefficients from the three models fit to Spotted Seatrout tag recapture analysis. The growth rate coefficients, $k$ of the Fabens and GROTAG models and the growth rate coefficient, $g$, are analogous.

FIGURE 4. Mean predicted Spotted Seatrout length at age (yr = years) from the Francis (1988a) GROTAG von Bertalanffy growth function. The line segments represent the change in length during the time at large. The segments are anchored to the curve with the length at tagging and a back-calculated age from the von Bertalanffy growth function. The other end of the line segment is the length at recapture and age estimated by adding the time at large to the back-calculated age at tagging.
tagged. Angling probably discriminated against tagging fish with lengths approaching and below the susceptibility of the angling gear. Thus, the resulting mean parameter estimates may be biased. Specifically, measurement error may have caused bias in the estimates of growth rate coefficients, and the lack of fish <200 mm TL (due to the susceptibility of gear) may bias the estimated mean lengths at age for younger (i.e., smaller fish). The lack of smaller fish may cause the models to poorly describe early growth.

Dimorphism between sexes in length at age of Spotted Seatrout has been observed here and elsewhere; i.e., females have greater mean lengths at age than males (Murphy and Taylor 1994; Johnson et al. 2011). The tag recapture data were not sex aggregated due to the lack of a feasible means of sex determination in the field by recreational anglers. The bias resulting from sex-aggregated tag recapture records for a fish species with a known sexual length dimorphism reinforces the need for sex determination when devising tag recapture studies. Sex-determination could be achieved in tag recapture studies by sacrificing the recaptured fish or estimating the sex-ratio based on sex-ratio-at-length keys. However, the use of tag recapture information in length-at-age analysis is a valuable tool for comparing length-at-age parameter estimates.

The tag recapture study supported the continued use of the VBGF, whereas the length-at-age analysis using otolith-derived age estimates did not. For both males and females, the two-parameter VBGF and the three-parameter VBGF had <1% of the model support. Although a two-parameter model is more parsimonious than any of the three-parameter models, the poor fit of the model resulted in very different predicted mean length-at-age estimates and no model support. The poor fit of the two-parameter VBGF may be an artifact of constraining the curve to pass through the origin. This constraint resulted in an increase estimate of k (year^{-1}) and because k (year^{-1}) and L_{\infty} are strongly negatively correlated, a greater estimate of k (year^{-1}) decreases the estimate of L_{\infty}. Although the different growth rate coefficients cannot be directly compared between each model, L_{\infty} has the same biological meaning and is comparable between models (Katsanevakis 2006). The L_{\infty} values varied between the models; the two-parameter VBGF had the smallest L_{\infty} estimate and the three-parameter VBGF had the greatest L_{\infty} estimate of the four length-at-age models fit to otolith-derived age estimates for both males and females.

Although the estimated mean L_{\infty} values from the otolith-derived length-at-age information did not differ between the sexes, the ARSS indicated that the overall male and female curves were statistically different. This could indicate differences in growth during ontogeny before mean maximum length is achieved. The use of ARSS, in addition to directly comparing model parameters, highlights the utility of using both approaches to gain a better understanding of growth dynamics, identify sex-specific differences in length at age, and accurately convert catch-at-length data to catch-at-age data.

Although the AIC values and Akaike weights indicate the three-parameter logistic model has overwhelming support for both the male and female otolith-derived length-at-age

**TABLE 2.** Sex-specific mean and 95% confidence interval (in parentheses) estimates of length-at-age model parameters from the four models fit to otolith-derived age estimates. L_{\infty} is the average maximum total length (mm); k, r, and b are growth rate coefficients (years^{-1}); t_0 is the hypothetical age at length 0; a is a scaling coefficient in the Logistic and Gompertz growth models; \Delta AIC is the difference in Akaike information criteria; and \textit{w}_{i} is the Akaike weight for each model.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
<th>\Delta AIC</th>
<th>\textit{w}_{i}</th>
<th>Values</th>
<th>\Delta AIC</th>
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<tr>
<td>L_{\infty}</td>
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<td>574.93 (528.90–643.32)</td>
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<td>a</td>
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<td>1.68 (1.50–1.93)</td>
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<tr>
<td>b</td>
<td>0.54 (0.49–0.61)</td>
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<td></td>
<td>0.36 (0.30–0.42)</td>
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<tr>
<td>L_{\infty}</td>
<td>663.68 (619.76–721.89)</td>
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<td>0.00</td>
<td>647.96 (572.74–780.17)</td>
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<td>0.33 (0.28–0.36)</td>
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<tr>
<td>r</td>
<td>0.70 (0.66–0.74)</td>
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<td></td>
<td>0.32 (0.25–0.37)</td>
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<tr>
<td>L_{\infty}</td>
<td>820.07 (722.82–982.02)</td>
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<td>1030.46 (698.6–NA)</td>
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<td>k</td>
<td>0.26 (0.12–0.21)</td>
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<td></td>
<td>0.16 (0.03–0.12)</td>
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</tr>
<tr>
<td>t_0</td>
<td>-1.78 (–2.09 to –1.52)</td>
<td></td>
<td></td>
<td>-3.78 (–4.91 to –2.88)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>\text{von Bertalanffy growth function model, 2 parameter}</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>L_{\infty}</td>
<td>467.78 (459.56–476.40)</td>
<td>811.62</td>
<td>0.00</td>
<td>391.5 (380.2–403.42)</td>
<td>494.77</td>
<td>0.00</td>
</tr>
<tr>
<td>k</td>
<td>0.96 (0.91–1.00)</td>
<td></td>
<td></td>
<td>0.94 (0.86–1.03)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\text{NA} = \text{not applicable}; convergence was not achieved.
A visual inspection of the observed lengths at age and predicted mean length at age for all models demonstrates how the observed lengths at age are highly variable, and the predicted mean lengths at age of some models is very similar across the range of observed values. Thus the overwhelming support of one model statistically may have less importance biologically. However, a comparison of models is still warranted especially since length-at-age parameters are sometimes used to estimate other vital rates, e.g., mortality. So, despite the similarities of model fit, differences in estimates of the $L_\infty$ parameter between models highlights the advantage of using AIC to evaluate model fit. Additionally, gear selectivity (Taylor et al. 2005) and potential errors in estimating age (Cope and Punt 2007) using otoliths are two sources of potential bias in the fitting length-at-age models to these data.

The 95% confidence intervals of the parameter estimates provide information into the variation around each estimate of $L_\infty$ and the potential similarity or dissimilarity among estimates in this study and between this study and other reported parameter estimates of the Spotted Seatrout length-at-age relationship. Using the parameter estimates of the most supported models in this study, the Spotted Seatrout length-at-age parameters can be compared with other reported values from the Gulf of Mexico. Specifically, we compared the parameter estimates of $L_\infty$ with other reported values. Johnson et al. (2011) reported an $L_\infty$ value of 659.2 mm TL (SD, 45) for Spotted Seatrout in Alabama. This parameter estimate is greater than the $L_\infty$ value estimated from the GROTAG analysis (550.8 mm TL, 95% CI $=$ 499.58–633.5) and from the $L_\infty$ value estimated from the three-parameter logistic model fit to the female otolith-derived age data (605.27 mm TL, 575.8–641.88). Murphy and Taylor (1994) described the length-at-age relationship of Spotted Seatrout in Florida waters and concluded that the female Spotted Seatrout length-at-age relationship was best modeled by a location-specific Gompertz growth equation rather than the VBGF. Estimates of $L_\infty$ differed between regions and ranged from 698.3 mm TL (SE, 23.09) to 839.2 mm TL (SE, 30.30). These estimates are all greater than those estimated from the tag recapture and otolith-derived analyses in this study. Murphy and Taylor (1994) suggested that spatial differences in the length-at-age relationship may be caused by environmental factors or differences in fishing effort. These are two possible explanations for the lower estimates of $L_\infty$ in Mississippi; however, we did not investigate any spatial differences in this study.
There are many more nonlinear models available to describe the length-at-age relationship of fish, but we employed some of the most widely used models to describe the length-at-age relationship. Although we did not completely eliminate model uncertainty or the potential for model misspecification, by fitting multiple models to multiple types of length-at-age data, we did generate more accurate and robust parameter estimates than those calculated from fitting a single length-at-age model. If the model support was not highly skewed to one model, an extension of this approach could be used to construct a composite model using model averaging. Our study provides an alternative to the conventional approach of choosing to model the length-at-age relationship using only one nonlinear model and supports the use of fitting multiple models to the available length-at-age relationship.

In conclusion, the GROTAG model was the preferred method of determining VBGF parameters from tag recapture information but the VBGF may not be the most accurate model to describe the length-at-age relationship of Mississippi’s Spotted Seatrout. Using multiple sources of length-at-age information and fitting multiple models to available information can result in more robust parameter estimates and help identify biases in both.

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REFERENCES


