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Evaluating Management Regimes using Per-Recruit Models and Relative Stock Density for Mississippi’s Spotted Seatrout

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Abstract

The Spotted Seatrout Cynoscion nebulosus is the most popular target of recreational inshore fisheries in Mississippi coastal waters. The Gulf of Mexico (GOM) stock of Spotted Seatrout is composed of spatially distinct substocks, and each state imposes unique bag and size limits. In Mississippi, the stock is managed using minimum length limits and daily bag limits. We used two methods to evaluate the efficacy of length restrictions and fishing mortality (F) levels: (1) a per-recruit model simulation to evaluate the effects of proposed management actions on reproductive output and yield, and (2) an evaluation of how management regimes impact relative stock density (RSD). Relative stock density has been widely used as a management tool in recreational and generally freshwater fisheries but has not been widely employed in informing management of marine stocks. We used demographic information from fisheries-independent sampling and length-specific natural mortality estimates to construct both models. Our analysis suggested that decreased F, increased minimum length limits, and slot limits that include intermediate upper length limits could increase RSD measures for GOM Spotted Seatrout. We found that for all management regimes examined, local demographic properties of Spotted Seatrout may preclude large proportions of trophy-length (≥686 mm TL) individuals. Per-recruit modeling and RSD analysis are complementary approaches to inform management, as they consider spawning stock biomass, yield, and the maximization of angler satisfaction.

The Spotted Seatrout Cynoscion nebulosus is a coastal and estuarine species found throughout the Gulf of Mexico (GOM) and along the Atlantic coast (Hoese and Moore 1977) and is a prized recreational game fish. In Mississippi, the Spotted Seatrout is the most recreationally targeted inshore species (Deegen 1990). Evidence from tagging and genetics studies indicates that the GOM Spotted Seatrout stock is composed of spatially distinct substocks (Gold and Richardson 1998; Hendon et al. 2002). The management of the substocks is state specific, with each state imposing its own statewide or region-specific length restrictions and daily bag limits (Table 1). In Mississippi, the current minimum size limit is 330 mm TL (13 in TL), and the daily bag limit is 15 fish. The most recent assessment of Mississippi’s stock indicated that recreational landings have increased and that the estimated instantaneous annual fishing mortality rate (F; year⁻¹) is at or near the F at maximum sustainable yield (Fulford and Hendon 2010). Because minimum length limits influence stock sustainability and angler satisfaction, we evaluated how alternative length restrictions can affect the yield, reproductive output, and size structure of the Mississippi Spotted Seatrout stock.

The effects of different management regimes on yield and reproductive output can be explored by using per-recruit models (Prager et al. 1987; Newman et al. 2000; Sweka et al. 2014). Here, we follow Prager et al. (1987) and define a management regime as a minimum size limit or slot limit and a specific level of F. Yield-per-recruit (YPR) models allow estimates of the expected lifetime yield for each individual in the cohort. Eggs-per-recruit (EPR) models allow estimation of the expected lifetime egg production for each individual in the cohort. Egg production is maximized when there is no fishing mortality, whereas yield is maximized at an intermediate level of F; therefore, evaluating the output of both models simultaneously allows fisheries managers to compare and assess the potential trade-offs between yield and reproductive output. Previous uses of per-recruit models include an analysis of
TABLE 1. State-specific management regulations for Spotted Seatrout fisheries in the Gulf of Mexico. Spotted Seatrout are managed using minimum length limits (MLLs), slot limits (slot), and daily bag limits.

<table>
<thead>
<tr>
<th>State</th>
<th>MLL or slot (mm TL)</th>
<th>MLL or slot (in TL)</th>
<th>Daily bag limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Florida</td>
<td>381–508&lt;sup&gt;a&lt;/sup&gt;</td>
<td>15–20&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5</td>
</tr>
<tr>
<td>Alabama</td>
<td>356</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>Louisiana</td>
<td>305</td>
<td>12</td>
<td>25</td>
</tr>
<tr>
<td>Texas</td>
<td>381–635&lt;sup&gt;a&lt;/sup&gt;</td>
<td>15–25&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10</td>
</tr>
<tr>
<td>Mississippi</td>
<td>330</td>
<td>13</td>
<td>15</td>
</tr>
</tbody>
</table>

<sup>a</sup>Allow the harvest of one fish larger than the upper slot limit.

Striped Bass *Morone saxatilis* in the Atlantic by Prager et al. (1987), who reported that alternative management regimes can be used to achieve similar management goals. Other recent examples of per-recruit models include evaluation of minimum size limits and the effects of harvest refugia for red abalone *Haliothis rufescens* (Leaf et al. 2008), estimation of biological reference points for American lobster *Homarus americanus* by using an individual-based per-recruit model (Zhang et al. 2011), and comparison of regional differences in reproduction by Hogfish *Lachnolaimus maximus* (McBride et al. 2008). More recent per-recruit modeling approaches have been used to predict roe yields in Paddlefish *Polyodon spathula* (Colvin et al. 2013) and to address spatial differences in individual growth and fishing effort for sea scallops *Placopecten magellanicus* (Truesdell et al. 2016). Per-recruit simulations can be useful when data on a stock’s relative abundance and harvest magnitude are not of sufficient quality or quantity to permit statistical stock assessment approaches.

In addition to using per-recruit models in evaluating the Spotted Seatrout stock, we also evaluated the expected size distribution of the stock by using relative stock density (RSD) metrics. Relative stock density is a length categorization tool that is used to quantify the size structure of a stock (Gabelhouse 1984) relative to the world-record-sized fish. The RSD system includes multiple categories that are defined as the number of individuals greater than the minimum size limit that are also longer than the minimum length of a designated category. The RSD metrics have been extensively applied to freshwater systems, and the length categories are typically based on angler preferences and the length of the all-tackle world-record individual (Gabelhouse 1984; Shuman et al. 2006). Examples of fish stocks that are routinely assessed with RSD include the Largemouth Bass *Micropterus salmoides* (Johnson and Anderson 1974), sunfishes *Lepomis* spp., Walleyes *Sander vitreus*, and Yellow Perch *Perca flavescens* (Gabelhouse 1984). The five length categories that are typically used in the RSD system are stock (S), quality (Q), preferred (P), memorable (M), and trophy (T). Each category has a different defined minimum length. The category names refer to the perceived fish quality as a function of length (described by Weithman 1978).

Simulations investigating how yield and RSD change under different management regimes have been used to evaluate the utility of alternative minimum length limits in several freshwater fisheries (Allen and Miranda 1995; Maceina et al. 1998; Paukert et al. 2002; Isermann et al. 2007). Paukert et al. (2002) investigated whether increasing length limits would promote the production of large Bluegills *Lepomis macrochirus* in Nebraska lakes. Their simulations suggested that size structure would increase at low levels of exploitation and low levels of natural mortality (M). Additionally, a creel survey indicated that 100% of the surveyed anglers favored a 200-mm minimum length limit if it would improve the Bluegill size structure. Isermann et al. (2007) used the Fisheries Analysis and Simulation Tools (FAST) program (version 2.0; Slipke and Maceina 2002) to evaluate how two length limits for Yellow Perch would affect the yield, the number harvested, and the proportional stock structure of preferred-sized fish.

The results of their modeling effort suggested that Yellow Perch size structure improved (greater proportion of longer individuals) under both length limits but that the yield increased only marginally. Thus, investigating how both the yield and the size structure of a stock change under different management regimes is useful for meeting multiple management objectives.

Recreational fisheries are often managed to maintain a stock’s sustainability and to promote the participation of recreational anglers. These potentially conflicting management goals result in trade-offs among increasing yield, maintaining spawning stock biomass, and promoting the presence of trophy-sized fish (Luecke et al. 1994). Managers are tasked with evaluating angler motivations, stock dynamics, and the ecological effects of fishing (Johnson and Martinez 1995; Johnston et al. 2013). Achieving these management goals requires managers to consider (1) the status of the stock by using biological reference points, and (2) metrics that accurately reflect the goals and motivations of recreational fishers. An understanding of the human dimension of recreational fisheries is critical to their management; however, the goals of anglers are complex and can be difficult to quantify (Post et al. 2002).

We present an analysis using age-based per-recruit models and an evaluation of the expected length structure of the Mississippi Spotted Seatrout stock by using RSD metrics. The Mississippi stock of Spotted Seatrout is an ideal marine fish with which to explore the use of RSD as an assessment tool because the fishery is primarily recreational and because Spotted Seatrout exist in geographically discrete subpopulations (Somerset and Saillant 2014). Spotted Seatrout in Mississippi are primarily targeted by the recreational fishery, so the length of fish caught is a critical aspect of angler satisfaction (Deegen 1990). Specifically, we evaluated different management regimes using age-structured EPR and YPR models. We also conducted a simulation study to explore the use of RSD as a management evaluation tool. The objectives of this study were to (1) simulate common management strategies used in the GOM and apply them to the Mississippi stock of Spotted Seatrout, (2) compare estimates of yield and egg production under different management regimes, (3) investigate how measures of RSD could change under the
different management regimes, and (4) evaluate how per-recruit models and RSD can be used collaboratively to achieve multiple management objectives.

**METHODS**

To evaluate EPR and YPR under different management regimes, we constructed age-based models by using biological information available from published sources and demographic information (individual length, weight, and age) from fishery-independent sampling performed by the Gulf Coast Research Laboratory (Center for Fisheries Research and Development, University of Southern Mississippi). The biological information used for simulating the length-specific biomass and reproductive output for the age-based per-recruit models included the weight-at-length relationship, age-specific instantaneous annual natural mortality (M), fishery retention, and age-specific egg production.

We characterized the length-at-age relationship of Spotted Seatrout by using a three-parameter logistic function that described TL as a function of age,

\[
L_t = \frac{L_\infty}{1 + a(e^{-b})},
\]

where \(L_t\) is the expected TL (mm) at age \(t\) (years), \(L_\infty\) is the average maximum TL, \(a\) is a scaling coefficient, and \(b\) (year\(^{-1}\)) is the growth rate coefficient. We selected this model to describe the length-at-age relationship of Spotted Seatrout because it had the greatest support among alternative candidate models (Dippold et al. 2016). The female-only length-at-age relationship was used in all modeling because egg production was used as a proxy for reproductive yield. The weight-at-length relationship was described using a power equation,

\[
W_L = aL^b,
\]

where \(W_L\) is the weight (g) at length (TL, mm). The length-at-age and weight-at-length relationships were used throughout the analyses to generate age-specific life history characteristics.

Age-specific \(M\) (year\(^{-1}\)) was estimated by using the length-at-age relationship and length-specific Lorenzen mortality (Lorenzen 2005). The equation for Lorenzen mortality is

\[
M_L = M_1 \left(\frac{1}{L}\right),
\]

where \(M_L\) is the length-specific \(M\), \(L\) is the TL, and \(M_1\) is the \(M\)-at-length constant. Fish length is inversely related to \(M\).

Age-specific retention for a specified length limit was estimated by using the length-at-age relationship and a truncated normal probability function,

\[
P_L = e^{-\frac{(L - L_{SL})^2}{2SD^2}}
\]

where \(P_L\) is the probability of capture at length \(L\), \(L_{SL}\) is the length of the specified size limit; and \(SD\) is the standard deviation of \(L_{SL}\). In all simulations, the estimated SD was 15 mm (0.6 in). Both minimum length limits and slot limits were modeled using the normal probability density function. In analyses of different slot limits, \(P_L\) was equal to 1.0 for lengths within the specified slot limit. Estimates of retention at age were incorporated into the per-recruit models by correcting \(F\) for the age-specific retention value. We did not explicitly model the age-specific susceptibility of individuals to recreational hook-and-line gear. Little information exists on gear-specific selectivity for Spotted Seatrout, and this species is caught by using a variety of natural and artificial baits, which may have different selectivity curves.

Mean age-specific egg production was determined from the linear function reported by Brown-Peterson and Warren (2001). Length-specific batch fecundity (BF) was reported as

\[
BF = 554.2 \cdot SL - 88,398,
\]

where SL is the standard length (mm). We converted SL to TL (SL = 0.88·TL – 11.23) to determine age-specific mean BF. Spotted Seatrout are batch spawners (Brown-Peterson and Warren 2001); therefore, the total annual age-specific egg production (\(E_t\)) was estimated by dividing the length of the spawning season by the spawning frequency and multiplying by the mean BF at age. For Spotted Seatrout in Mississippi, the spawning season length is 5 months, and the average spawning frequency is 4–5 d (Brown-Peterson and Warren 2001). We used a spawning frequency of 4.5 d. Mean \(E_t\) estimates were corrected for percent maturity at age by using percent maturity estimates from Brown-Peterson and Warren (2001).

To determine EPR and VPR values for different management regimes, the number of individuals at age \(N_{t+1}\) was calculated using the exponential decay equation

\[
N_{t+1} = N_t e^{-Z_t},
\]

where \(N_t\) is the number of individuals at age \(t\), and \(Z_t\) is the instantaneous total mortality rate (year\(^{-1}\)) at age \(t\). We calculated \(Z_t\) as

\[
Z_t = F_t + M_t,
\]

where \(F_t\) is the age-specific instantaneous annual fishing mortality rate, and \(M_t\) is the age-specific instantaneous annual natural mortality rate. For ages where the mean length at age was lower than a given minimum length limit, lower than the lower slot limit, or greater than the upper slot limit, release mortality was calculated as \(F_t \times (1 - P_{S})\), where \(P_{S}\) is the fish’s probability of survival if captured and released (Waters...
and Huntsman 1986). In all simulations, \( P_f \) was assumed to be 90%. This value is based on the work of Stunz and McKee (2006), who found that postrelease mortality for Spotted Seatrout was low and did not vary with length.

The number of individuals that died from fishing \( (N_d) \) was calculated from the total number of individuals that died \( (N_d) \),

\[
N_d = N_i \left(1 - e^{-Z_i^t}\right) \quad (8)
\]

and

\[
N_c = N_d \left(\frac{F_i}{Z_i^t}\right). \quad (9)
\]

The YPR value at a specific \( F \) and length restriction was calculated as the summed products of the number harvested at age \( (N_c) \) and the mean weight at age for all ages used in the analyses,

\[
YPR = \sum_{t=0}^{t_{max}} N_c W_t. \quad (10)
\]

The EPR value was calculated as the summed products of the number of individuals at age \( (N_i) \) multiplied by the total egg production at age \( (E_i) \),

\[
EPR = \sum_{t=0}^{t_{max}} N_i E_t. \quad (11)
\]

We calculated EPR and YPR over a range of \( F \)-values from 0 to 2 year \(^{-1} \) using four different minimum length limits (305, 356, 406, and 457 mm TL [12, 14, 16, and 18 in TL]) and four different slot limits (305–457, 305–508, 381–508, and 381–635 mm TL [12–18, 12–20, 15–20, and 15–25 in TL]). The age range evaluated was age 1 to age 8 and older.

To investigate how measures of RSD could change under different management regimes, five length categories were assigned based on percentages of the International Game Fish Association’s all-tackle world-record length (1,003.3 mm TL [39.5 in TL]) for Spotted Seatrout (Table 2). The percentage values used were based on recommended values from Gabelhouse (1984). These length categories were used in the simulation to calculate the RSD values under each management regime. The RSD value for each category was calculated as

\[
RSD = \frac{\text{number of fish} \geq \text{length category}}{\text{number of fish} \geq \text{stock length}} \times 100. \quad (12)
\]

We calculated RSD values for the quality (RSD-Q), preferred (RSD-P), memorable (RSD-M), and trophy (RSD-T) categories.

After the length categories were assigned, frequency distributions for the parameters of the logistic growth model (equation 1) were generated for use in the simulation analysis. The residuals derived from the mean predicted estimates were used to perform a bootstrap resampling analysis. We resampled the set of residuals 1,000 times to generate new length-at-age data. The logistic model was then fitted to each new data set to determine the length-at-age parameters. The 1,000 sets of parameters \( (L_\infty, a_n, b_n) \) were included in the simulation to propagate uncertainty in the calculation of RSD under the different management regimes.

To investigate how measures of RSD could change under different management regimes, we conducted a simulation wherein RSD-Q, RSD-P, RSD-M, and RSD-T were calculated for simulated fish stocks that were subjected to different management regimes. The fish populations were simulated using the exponential decay function to determine the number of individuals at age for ages 0–8. Age frequencies were converted to length frequencies based on the length-at-age relationship, and RSD values were then calculated. For each management regime, RSD values based on the simulated population were determined \( (n = 1,000 \text{ times}) \) by using each set of length-at-age parameters generated in the resampling analysis. In each run of the simulation, retention at age and age-specific mortality were calculated based on the specific lengths at age. Values for the RSD categories were calculated for each of the 1,000 model runs that were conducted for each management regime; based on the 1,000 RSD values, the mean and SD for each RSD category were calculated for each management regime.

A sensitivity analysis was performed to address how variation in \( M \)-estimates would affect the measures of yield and reproductive output. Age-specific estimates of \( M \) were scaled by 25% in both directions to conduct high-\( M \) and low-\( M \) sensitivity runs. Both the YPR and EPR analyses were then rerun with the adjusted estimates of age-specific \( M \).

### RESULTS

The logistic length-at-age model and the weight-at-length relationship were fitted for use in the simulation model. The parameters for the logistic growth model were as follows: \( L_\infty \) was 675.4 mm TL (95% confidence

<table>
<thead>
<tr>
<th>Length category</th>
<th>Minimum TL (mm)</th>
<th>Minimum TL (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stock</td>
<td>261</td>
<td>10.3</td>
</tr>
<tr>
<td>Quality</td>
<td>361</td>
<td>14.2</td>
</tr>
<tr>
<td>Preferred</td>
<td>451</td>
<td>17.8</td>
</tr>
<tr>
<td>Memorable</td>
<td>592</td>
<td>23.3</td>
</tr>
<tr>
<td>Trophy</td>
<td>686</td>
<td>27.0</td>
</tr>
</tbody>
</table>

**Table 2.** Assigned minimum lengths for Spotted Seatrout in each relative stock density category. Lengths were assigned based on the International Game Fish Association’s all-tackle world-record length (1,003.3 mm TL [39.5 in TL]) for Spotted Seatrout.
interval (CI) = 629.92–738.13 mm), \(a\) was 2.31 (95% CI = 2.15–2.53), and \(b\) was 0.57 year\(^{-1}\) (95% CI = 0.59–0.63 year\(^{-1}\)). The weight-at-length parameters \(a\) and \(b\) were estimated from fitting the power model to Spotted Seatrout weight-at-length information; the parameter values were \(5.36 \times 10^{-6}\) (95% CI = \(4.67 \times 10^{-6}\) to \(6.16 \times 10^{-6}\)) for \(a\) and 3.098 (95% CI = 3.08–3.12) for \(b\). Natural mortality decreased with age (Figure 1A), and retention differed depending on the management regime (Figure 1B, C).

Lifetime yield estimates varied at different levels of simulated \(F\) and different length-at-entry restrictions. Among the four minimum length limits, the 457-mm and 406-mm limits resulted in the greatest estimates of YPR (YPR\(_{\text{MAX}}\)). Among the four different slot limits, the 381–635-mm slot limit resulted in the greatest estimate of YPR\(_{\text{MAX}}\) (Figure 2). The 381–508-mm slot limit had the second-greatest YPR\(_{\text{MAX}}\), but it was only 57.4% of the YPR\(_{\text{MAX}}\) generated by the 381–635-mm slot limit. The \(F\) at YPR\(_{\text{MAX}}\) (\(F_{\text{MAX}}\)) varied among length restrictions. For the minimum length limits, \(F_{\text{MAX}}\) values ranged from 0.28 to 0.33 year\(^{-1}\); the 305-mm minimum length limit resulted in the smallest \(F_{\text{MAX}}\) value (Figure 2). The 406- and 457-mm minimum length limits produced the same value for \(F_{\text{MAX}}\). For the four simulated slot limits, \(F_{\text{MAX}}\) values ranged from 0.32 to 0.77 year\(^{-1}\). At greater levels of \(F\), the minimum length limit with the greatest estimate of YPR changed from 457 to 406 mm (Figure 2).

The proportion of lifetime egg production relative to that of an unfished stock decreased with increasing \(F\) and decreasing minimum length limits (Figure 3). For all \(F\)-values examined, the 457-mm minimum length limit had the greatest EPR values. Among the simulated slot limits, the 305–457-mm slot limit had the greatest EPR across all values of \(F\) (Figure 3). The percentage of EPR values at \(F_{\text{MAX}}\) ranged from 46.3% to 55.8% for the minimum length limits and from 41.6% to 46.3% for the slot limits.

To execute the simulation procedure, the logistic length-at-age curve (Figure 4A) was fitted, and the residuals appeared uniformly distributed around the expected mean length at age (Figures 4B, 5). The 1,000 sets of model parameters were used in the simulation to incorporate uncertainty around the mean RSD value for each management regime.

In our simulation, RSD values were sensitive to the length-at-entry restriction and the \(F\)-values examined. The RSD values for all length categories decreased with increasing \(F\), and greater length limits resulted in greater RSD values (Figure 6). The maximum RSD-Q value for the minimum length limits was 70% (\(F = 0\) year\(^{-1}\)) and decreased with increasing \(F\). The maximum \((F = 0\) year\(^{-1}\)) RSD-P value was 50%, the maximum RSD-M value was 21%, and the maximum RSD-T value was 0.66%. The mean RSD-M and RSD-T values did not differ greatly among the minimum length limits.

FIGURE 1. (A) Age-specific estimates of instantaneous annual natural mortality in Spotted Seatrout, calculated using Lorenzen’s (2005) length-specific mortality equation (\(y = \text{year}\)); and examples of retention curves representing (B) a minimum length limit and (C) a slot limit. Retention was described by using truncated normal probability functions.
FIGURE 2. Results of Spotted Seatrout yield-per-recruit (YPR) analyses for minimum length limits and slot limits. Each line represents a specific length restriction at varying levels of fishing mortality (y = year).

FIGURE 3. Results of Spotted Seatrout eggs-per-recruit (EPR) analyses for minimum length limits and slot limits. Each line represents a specific length restriction at varying levels of fishing mortality (y = year).

FIGURE 4. Mean predicted length at age ($L_t$) of Spotted Seatrout (left panel; $L_\infty$ = average maximum TL; $a$ = scaling coefficient; $b$ = growth rate coefficient); and plot of residuals from fitting the logistic growth model (right panel).
For the slot limit simulations, RSD-M and RSD-T values did not decrease as rapidly as those for the minimum length limit simulations at greater levels of $F$ (Figure 7). Maximum RSD values were the same as observed in the minimum length limit simulations, and the 305–457-mm slot limit resulted in greater RSD values across all levels of $F$. In contrast, the 381–635-mm slot limit had lower RSD values across all levels of $F$. The mean RSD values for the 305–508-mm and 381–508-mm slot limits did not differ greatly across all $F$-levels (Figure 7).

Under the high-$M$ and low-$M$ sensitivity runs, the $F_{\text{MAX}}$ values for each of the minimum length limits and slot limits did not change substantially; however, the magnitude of the yield at $F_{\text{MAX}}$ varied between the high-$M$ and low-$M$ scenarios. Specifically, under the low-$M$ run, the yield at $F_{\text{MAX}}$ for minimum length limits increased by 41–56% relative to the YPR$_{\text{MAX}}$ in the base model run. Conversely, in the high-$M$ sensitivity run, yield at $F_{\text{MAX}}$ for minimum length limits decreased to values that were 62–65% of the YPR$_{\text{MAX}}$ in the base model run. For the four slot limits, the yield at $F_{\text{MAX}}$ for the high-$M$ run was 29–69% of the base model YPR$_{\text{MAX}}$. Yield at $F_{\text{MAX}}$ increased for each of the slot limits in the low-$M$ run, with values ranging from 48% to 147% of the YPR$_{\text{MAX}}$ in the base model run.

Sensitivity of the EPR analysis to changes in age-specific $M$ was evaluated by comparing the $F$-values of each length restriction at 35% and 50% of the maximum EPR in the base model run. The high-$M$ run decreased the $F$ at the specified 35% and 50% EPR values, whereas the low-$M$ run increased the $F$ at the 35% and 50% EPR values (Table 3).

**DISCUSSION**

Fisheries managers are tasked with balancing the desires of stakeholders and the responsibility of maintaining long-term sustainability (Hampton and Lackey 1976; Beardmore et al. 2014). We present a method for evaluating a suite of alternative management regimes to assess the potential reproductive output and yield and the resulting length structure of the Mississippi Spotted Seatrout stock. Alternative management regimes that were consistent with regulations used in other GOM states resulted in changes to the expected yield and reproductive output of the stock. The regimes imposed in the simulations also generated variations in the length structure of the stock. These simulations are useful in evaluating potential management actions because the length of fish caught is a major aspect of angler satisfaction (Petering et al. 1995). Deegen (1990) reported that for Mississippi anglers, satisfaction was derived from the length of fish caught, the number of fish caught, eating the fish they caught, and catching larger fish. Our analysis highlights the unique growth characteristics of the Mississippi stock of Spotted Seatrout relative to the world-record-sized fish. We found that the growth patterns exhibited by this stock resulted in low proportions of trophy-length (>686 mm TL) individuals.

Our per-recruit simulation analysis demonstrated how the length structure of the stock can be altered depending on the management regime imposed. For example, slot limits resulted in an increased proportion of memorable-sized (>592 mm TL) and trophy-sized (>686 mm TL) Spotted Seatrout. Slot limits are used in recreational and commercial fisheries to (1) protect larger individuals whose larvae have a greater survival

![FIGURE 5. Histograms of parameter values from the logistic length-at-age model for Spotted Seatrout: (A) average maximum TL ($L_{\infty}$); (B) scaling coefficient ($a$); and (C) growth rate coefficient ($b; y^{-1}$). The parameter values resulted from residual resampling.](image-url)
potential (Birkeland and Dayton 2005), (2) create trophy fisheries, and (3) ensure stock sustainability (Dotson et al. 2013; Gwinn et al. 2015). Currently, slot limits are used in the Florida and Texas fisheries for Spotted Seatrout (Table 1) and in the Mississippi fishery for another sciaenid, the Red Drum Sciaenops ocellatus. One criticism of using slot limits is that postrelease mortality may be high. However, the mortality associated with catch and release of Spotted Seatrout is thought to be low and is not size specific (Stunz and McKee 2006). Because Spotted Seatrout may exhibit low postrelease mortality, there is a benefit to using slot limits as a management tool for the Mississippi stock. Specifically, in our simulations, the 305–457-mm slot limit resulted in greater proportions of trophy- and memorable-length individuals, even when levels of $F$ increased. The implementation of a slot limit restriction allows multiple aspects of angler satisfaction to be achieved: catching fish to eat, catching larger fish, and catching trophy-length fish. The lower and upper limits of the simulated slot impacted the expected length structure of the stock. Among the slot limits, the 381–635-mm slot limit resulted in the greatest $YPR_{MAX}$, but this maximum yield occurred at a lower level of $F$ and resulted in lower RSD-M and RSD-T values. Information on how different length restrictions can alter the size structure of the stock can be used in collaboration with information on how yield and egg production change under the given management regime. Such approaches have been used in freshwater recreational fisheries to investigate how different length restrictions affect stock yield and size structure (Allen and Miranda 1995; Maceina et al. 1998; Paukert et al. 2002; Isermann et al. 2007). The results of these previous studies indicate how decreased rates of exploitation can increase yield (Allen and Miranda 1995) and improve the size structure of a stock (Isermann et al. 2007). Their findings are consistent with the results of our
modeling efforts and per-recruit simulation models: decreasing $F$ to an intermediate range increases yield, egg production, and the proportion of longer individuals across all length restrictions.

Although the magnitude of $F$ and the length-at-entry and slot limits can increase the proportion of longer individuals in a stock, the stock-specific individual growth characteristics and the length of the world-record individual also influence the expected length structure of the stock. The RSD categories were based on the length of the world-record Spotted Seatrout, which was caught along the east coast of Florida. The length of the world-record individual is normally used to define RSD categories so that (1) standardization among agencies can be achieved, and (2) ambiguities in reporting the size structure of the stock can be avoided (Gabelhouse 1984). Based on our analysis with stock-specific individual growth characteristics, individuals in the Mississippi Spotted Seatrout stock may not have the potential to reach trophy sizes. Even at the lowest levels of $F$, the percentage of trophy-length individuals in this stock did not exceed 1% under any of the simulated length-at-entry regimes. The Mississippi State-record Spotted Seatrout was 723.9 mm (28.5 in) in length (Mississippi Department of Marine Resources), approximately 279.4 mm (11 in) shorter than the world record for this species. The state records for Spotted Seatrout vary considerably among the GOM states. We note that the use of an extremely large individual to calibrate the length categories may be inappropriate, and the use of a GOM-specific or Mississippi-specific record-sized individual may be warranted due to the reduced lengths observed in the northern GOM. The mean estimate of $L_\infty$ we used for Mississippi Spotted Seatrout (675.3 mm TL) was lower than the mean $L_\infty$ estimates reported from Florida, which ranged from 698.3 to 839.2 mm TL for females (Murphy and Taylor 1994). However, the $L_\infty$ estimate for the

FIGURE 7. Mean values of each relative stock density (RSD) category resulting from the simulation models for Spotted Seatrout (Q = quality; P = preferred; M = memorable; T = trophy). Each line represents a different slot limit (y = year).
Mississippi stock is similar to those reported for the Alabama and Texas stocks (Maceina et al. 1987; Johnson et al. 2011). In our growth parameter estimates, we did not characterize the effects of gear selectivity, and this also could have biased our per-recruit and RSD calculations. Our analysis does indicate that it may not be reasonable for managers to promote Mississippi as hosting a trophy Spotted Seatrout fishery based on the current level of \( F \) and the current individual growth dynamics. Instead, managers should focus on other components of angler satisfaction; these can include both catch and noncatch outcomes, such as enjoying nature, having the ability to target many stocks simultaneously, and obtaining relatively high bag limits (Hampton and Lackey 1976; Deegen 1990; Fedler and Ditton 1994; Beadmore et al. 2014).

However, we note that a shift in the individual growth dynamics or a change in the level of \( F \) could result in greater proportions of larger Spotted Seatrout.

The per-recruit modeling approach employed here can be useful for understanding the potential yield and reproductive output of marine and freshwater recreational stocks. However, violations of the model assumptions will affect the estimates of yield and egg production (Prager et al. 1987). The assumption of a closed population for Mississippi Spotted Seatrout is supported by evidence that the GOM stock is composed of geographically distinct substocks. However, limited large-scale movements have been observed (Hendon et al. 2002). We used the arbitrary SD value of 15 mm instead of knife-edge retention in our model to incorporate uncertainty associated with measurement error from anglers determining whether their catch was of legal length. However, the rapid early ontogenetic growth of Spotted Seatrout makes it likely that differences in the SD value used in the retention function would not greatly affect the \( F \) at age. We did not explicitly model selectivity (gear susceptibility at length or at age) in our analysis. There is little information on the selectivity of recreational gear types for Spotted Seatrout in Mississippi. Furthermore, selectivity of recreational fisheries often varies with bait type and size (Arlinghaus et al. 2008); thus, determining one selectivity curve for Spotted Seatrout would be difficult. However, we note that violating the assumption of constant selectivity across all ages could have substantial effects on estimates of yield and egg production. Specifically, in a recreational fishery, selectivity at older ages (i.e., larger individuals) is likely attributable not only to gear susceptibility, but also to other factors, such as angler skill level and bait type and size. More research is needed on size- and age-specific selectivity of recreational fisheries to increase the accuracy and precision of future modeling efforts.

Based on the results of our sensitivity analysis, the calculations of Spotted Seatrout yield and egg production were very sensitive to the age-specific \( M \)-estimates. An increase in age-specific \( M \) led to decreases in yield and egg production across management regimes, while a decrease in age-specific \( M \) resulted in increased yield and egg production across management regimes. Due to the model’s sensitivity to \( M \), accurate estimates of age- or length-specific \( M \) for Spotted Seatrout in Mississippi are needed.

The current estimated level of \( F \) for Mississippi Spotted Seatrout is 0.65 year\(^{-1}\) (Fulford and Hendon 2010). At this \( F \)-value, our simulations suggested that slot limits resulted in greater percentages of memorable- and trophy-length individuals; however, the percentages of quality- and preferred-length individuals were similar across management regimes. Our simulation indicates that an advantage of slot limits relative to minimum length limits is that the slot limits allow for the harvest of smaller individuals. This knowledge is useful in achieving angler satisfaction goals because many anglers target Spotted Seatrout to harvest them for consumption (Deegen 1990). We note that per-recruit models do not predict levels of sustainable yield or \( F \). However, the models’ utility in evaluating how yield and egg production change under different

<table>
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<th>MLL or slot (mm TL)</th>
<th>Model run</th>
<th>( F ) at 35%</th>
<th>( F ) at 50%</th>
<th>Percentage of maximum yield in base model</th>
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management regimes make them valuable tools with which fisheries managers can make informed decisions. The results of our models suggest that decreasing $F$ can increase yield, reproductive output, and the size structure of the Mississippi Spotted Seatrout stock across all management regimes.

We recommend that per-recruit models be used together with measures of RSD as an initial approach to evaluate potential management regimes for recreational fish stocks like the Mississippi stock of Spotted Seatrout. Local estimates of biological parameters are needed to manage the stocks. The methods we have presented are useful for evaluating the quality of a recreational fishery in terms of the stock’s size structure. Although more complex age-structured approaches are used to assess stock status and fishery status, this relatively simple analysis provides a framework for investigating how different management regimes can change measures of yield, reproductive output, and size structure.

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