

Assessment of spawning sites and reproductive status of
striped bass, *Morone saxatilis*, in the Savannah River Estuary

Final Report for Project 10-21-RR251-144
1 January 2000 - 31 January 2001

Prepared for:
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February 1, 2001

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Executive Summary

Task 1: Gear detection thresholds, sampling efficiency, sampling for striped bass eggs and larvae, and total egg abundance in the SRE

Detection Threshold and Gear Calibration

In the spring of 1999, results from bead-release trials suggested that sampling efficiency primarily depends on channel morphology and egg distribution pathways. Specifically, the channel morphology of the Back River is narrow and shallow compared to that of the Front River. Therefore, if equal numbers of eggs were in the Front and Back River, we would collect and report more eggs from the Back River than from the Front River. Further, beads released in the upper Savannah River Estuary (SRE) disperse into the Front, Middle, and Back rivers which suggests that the SRE should be treated as a whole system, not individual channels.

The release and subsequent recapture of striped bass egg surrogates in 2000 allowed stronger inferences about the adequacy of our standardized methods for collecting striped bass eggs during a spawning season. Our ability to detect eggs ranged from one egg per 140,000 at large (~0.0007%) to about one egg per million eggs at large (0.0001%). One large (about 900 mm TL) female striped bass can release about one million eggs. Therefore, our standardized sampling methods are sufficient to detect 1-2 female striped bass spawning in the SRE.

Spatial and Temporal Striped Bass Egg Abundances

The recovery of the Savannah River striped bass population may have begun already, but is still in the early stages. Although, egg densities in 2000 were not significantly higher than previous years, the upward trend in egg abundance is promising. A total of 943 eggs were collected during spring 2000, and mean egg density for all sampling stations was 0.95 eggs/100m³ (SD=4.28) as compared 0.21 eggs/100m³ (SD=1.96) in 1999. The majority (91%) of eggs captured were from the upper river stations at river mile 24, 26, and 31. Mean egg density at SR24 was 1.45 eggs/100m³ (SD=3.27), which was higher than the densities for the past eight reporting years (data were not collected in 1992 and 1993). Mean egg density at BR10 (0.42 eggs/100m³; SD=1.25) was higher than the densities for the past nine reporting years. Egg density (5.62 eggs/100m³; SD=11.84) at SR26, where most striped bass eggs were collected was the highest density recorded since 1986. Also, egg density at SR31 (1.15 eggs/100m³ ; SD=2.38) was the highest density reported since 1988. Temporally, eggs were caught from early-March through early-May; the majority were caught in April. Two striped bass larvae were collected: one at SR26 and one at SR19, and larvae of other fishes were common. Overall, if egg densities continue to increase in ensuing years, establishment of a self-sustaining striped bass population may only be a few years away. The viability of this self-sustaining striped bass population probably will depend on the availability of suitable nursery habitat for the developing larvae and juveniles.

Total Egg Abundance in the SRE

Total egg abundance in the SRE for 2000 was estimated at 142 million eggs (range: 122 million-856 million). Based on gear efficiencies calculated for 1999 and the number of eggs captured (Will et al. 2000a), an estimated 37 million eggs were produced in the SRE during 1999. Egg production in 2000 may represent a 4-fold increase over the previous year (but may be as high as 23 times higher). Although encouraging, this result is tempered by the apparent lack of spawning activity in the historically productive Back River. Additionally, 142 million eggs may represent less than 150 mature females in the SRE.

Task 2

Maturity scheduling and ultrasonic imaging of adult striped bass

Sampling efforts from Spring 1999 helped validate a non-invasive technique to assess the maturational status and fecundity of female striped bass in the SRE (Will et al. 2000b). This technique was used to estimate maturation and fecundity of striped bass during the spring of 2000, and these data were used to improve an existing model to predict fecundity. This model was then used to compare the 1999 fecundity and maturation estimates to the 2000 estimates and to evaluate the egg production data.

Twenty-eight female striped bass (>600 mm TL) were used for ultrasonic imaging. Ovary measurements in 1999 were restricted by the inability of the 6.0/8.0

MHz linear array probe to capture the entire cross-sectional ovary areas in larger striped bass (>900 mm, TL). Therefore, a 3.5/5.0 MHz curved array probe was used during Spring 2000 to improve image clarity. One 1-ml samples of ovarian tissue also were taken from each striped bass and used to estimate the number of eggs in each ovary and to assess the fish's maturational status. Analysis of the ultrasound data confirmed the utility of this model [Ovary volume = $0.7226 + 1.4818$ (log of mean ovary area)] for predicting ovary volume (adj. $r^2 = 0.97$). A similar model (adj. $r^2 = 0.95$) was reported by Will et al. 2000b.

Fecundity estimates for SRE striped bass differed ($p < 0.05$) among four specified size classes, which ranged from <800mm TL ($O = 404,590$; $SD = 167,133$) to >1000 mm TL ($O = 1,731,617$; $SD = 626,394$). Generally, fecundity estimates for striped bass in the SRE were similar to estimates reported for striped bass in the SRE in 1999. However, striped bass collection efforts in 1999 only yielded four striped bass > 900 mm TL as compared 10 fish > 900 mm TL collected in spring 2000. The additional data from the larger fish strengthened fecundity estimates for female striped bass in the SRE. Also, our ability to collect and produce fecundity estimates from a wide size range (640 mm to 1055 mm, TL) of female striped bass facilitated the development of a fecundity model based on general field measurements [Fecundity = $-410.31 + 124.95$ (weight, kg); adj. $r^2 = 0.77$].

Maturational status of Savannah River striped bass seems to be progressing normally. All maturational stages (primary oocytes, secondary oocytes,

vitellogen oocytes, post-vitellogenic oocytes, final oocyte maturity, and atretic oocytes) were identified. Based on the 20 most advanced oocytes staged, female striped bass development appeared to differ from Spring 1999 to Spring 2000. In 2000, none of the oocytes were vitellogenic, as most (72%) had progressed to post-vitellogenic, compared to 1999 when 43% were vitellogenic and 41% were post-vitellogenic (Will et al. 2000b). Whether this difference was related to environmental cues needed to progress oocyte development or some relationship in the condition of the female striped bass is unknown. However, the maturity of striped bass <800 mm TL was questionable (i.e., some vitellogenic oocytes were observed but most were primary and secondary oocytes). Oocytes developing to final stages of maturity were found mainly in larger fish (>800 mm TL) and coincided temporally with maximum egg densities in the SRE. There were more larger (>900 mm TL) fish in 2000, and their presence may account for the increase in the number of vitellogenic and post-vitellogenic eggs observed during 2000. Therefore, environmental cues needed for spawning seem to be sufficient to allow the development and the release of striped bass oocytes into the SRE.

Introduction

History

Striped bass *Morone saxatilis* and striped bass hybrids (i.e., cross with the white bass, *M. chrysops*) are highly popular fisheries in inland reservoirs across Georgia and account for a significant portion of the \$448 million in annual angler

expenditures [Carl Hall, Georgia Department of Natural Resources (GA-DNR), personal communication]. Historically, the Savannah River hosted Georgia's most important striped bass fishery and was the source of brood fish for the GA-DNR *Morone* stocking program. The population suffered a severe decline in the 1980's coincident with a conversion of tidal freshwater marsh to brackish marsh. The results of a U.S. Fish and Wildlife Service-funded project implicated the operation of a tide gate and diversion canal in the Back River as being responsible for the population decline and loss of freshwater marsh (Van Den Avyle et al. 1990).

Striped bass in the South Atlantic Region are predominantly riverine and spend their entire life cycle in the same river (Hill et al. 1989). In the Savannah River, the Back River area was vital to all life history stages of the endemic striped bass population. The majority of striped bass spawning occurred in the Back River (Dudley and Black 1979) and young-of-year stripers have used the Back and Middle rivers as nursery grounds (Wallin et al. 1995). Adult striped bass use the Back and Middle rivers to over-winter and spawn, and smaller fish remain there year-round (Mooneyhan and Van Den Avyle 1995). The decline in the striped bass population was attributed to increased salinity in spawning and nursery grounds and accelerated transport of eggs and larvae to areas of toxic salinity (Van Den Avyle and Maynard 1994). In hopes of restoring the freshwater marsh and suitable spawning habitat, mitigative efforts began in 1991 with the removal of the tide gate from operation and filling of the diversion canal in 1992. Recent studies indicate that salinity levels in the historic spawning grounds (Back River) are suitable, as

evidenced by lower interstitial salinities and the gradual increase in freshwater plant abundance and diversity (Latham and Kitchens 1996). However, egg abundance in the historic spawning locations of the Back River remains less than 1% of the levels documented in the late 1970's.

Current Status

In response to the decreasing striped bass population, the states of Georgia and South Carolina adopted a fishing moratorium (in 1988 and 1991, respectively) to protect the remaining adult fish, and the GA-DNR adopted a management objective of re-establishing a self-sustaining striped bass population in the river system through stock enhancement. The surviving females from these stocking efforts are assumed to have begun maturing in 1995, and spawning activity in the estuary was expected to increase if suitable salinity was present on the spawning grounds. The estimated annual survival of striped bass stocked in the Savannah River since 1990 is 35-45%. This survival rate has substantially increased the numbers of striped bass in the river. These stocked fish constitute a majority (>75%) of the current population. Annual electrofishing surveys also have shown increased abundance of fish greater than 9.0 kg (from 0.0 fish/hour in 1990 to 0.2 fish/hour in 1997 and 0.67 fish/hour in 2000). Currently, population catch-per-unit-effort (for ages 2+) is near levels seen prior to the decline.

Egg abundance and spatial distribution data indicate that the majority (>80%) of eggs captured are found in the upper reaches of the Front River.

Apparently, spawning has not shifted to the Front River, as eggs have always been captured there, but spawning activity is greatly reduced in the historically-productive Back River (Reinert et al. 1996, 1998). A positive trend in 1999 indicated egg abundances in the Back River were higher than they have been over the last nine years, and egg abundances in the Front River were higher than the last three years. Furthermore, egg abundances for all sampling stations were comparable to 1991, 1994, and 1995. If egg abundances continue to increase, then successful restoration of the striped bass population may only be a few years away.

Potential Threats of Harbor Deepening

Since the decline of the striped bass population, all study efforts have been directed towards Back River restoration. However, recent studies indicate that focusing on the Front River spawning sites and nursery habitats may be more appropriate (Will et al. 2000a). The importance of the Front River in sustaining the striped bass population has been overshadowed by the focus on Back River restoration. The Front River spawning and nursery habitats were virtually ignored for two reasons. First, egg densities in the Front River in the late 1970's and early 1980's were lower than egg densities in the Back River, implying that the Back River encompassed the primary spawning and nursery grounds for striped bass. Secondly, since the 1970's, dramatic decreases in egg densities were less apparent in the Front River when compared to the Back River. If the Front and Back rivers were morphologically and hydrologically similar, focusing on the Back River

instead of the Front River may be acceptable for restoration efforts. However, given the notable morphometric and hydrologic differences between the two and the frequent, long-term, and continuing anthropogenic modifications to the Front River, the proposed channel deepening increases the prospects for additional habitat degradation (e.g., changing hydrologic conditions, increasing salinity, decreasing dissolved oxygen, etc.). Accordingly, striped bass spawning activity and potential egg survival in the Front River could be affected again and needs to be assessed. Restoration of Back River habitats is still important, but the majority striped bass reproduction is taking place in the Front River; therefore, understanding the contribution of the Front River as spawning and nursery habitat for striped bass is vital to the goal of re-establishing a self-sustaining population.

Egg Monitoring Studies

Egg monitoring studies in the SRE began in the late 1970's and have continued through 1999. Typically, these studies of egg abundance were limited to comparing relative changes in the spatial and temporal densities of eggs. Until Spring 1999, data on gear detection thresholds and efficiency of egg collection methods were non-existent, and estimates of the actual number of eggs at large were unobtainable. In addition to normal egg sampling efforts, Will et al. (2000a) used known amounts of striped bass egg surrogates (beads) to determine the detection threshold and efficiency of egg sampling gear. They found that for the same number of beads released in the Front and Back Rivers, substantially more

beads were collected in the Back River than in the Front River. Furthermore, some gelatin gum beads released in the Front River were collected in the Back River, which indicates that eggs collected in the historically productive Back River may be indicative of spawning events in the Front River. Overall, the implications from their pilot study are that the Front River was more important in sustaining the striped bass population than previously considered, and stronger inferences about the adequacy of striped bass egg abundance during a spawning season are now possible.

Maturation studies

The primary cause of the striped bass population decline has been removed, and environmental conditions seem suitable for striped bass spawning; however, the current maturational status and fecundity of this population are unknown. Whether low egg densities are related to the maturational status of the population or to a lack of suitable spawning conditions is unknown. Assessing striped bass maturity requires a sample of ovarian tissue, but fecundity estimates require examination of the entire ovary. The uncertainty about the number of adult female spawners makes sacrificing fish to obtain fecundity estimates undesirable. During Spring 1999, striped bass were collected and a sample of ovarian tissue was withdrawn from each female captured; also ultrasonic imaging, a simple and non-lethal technique, was used to examine and measure the individual ovaries (Will et al. 2000b). The tissue samples were used to enumerate eggs and estimate

maturational status. The ultrasound images were used to develop a model that predicts ovary volume, which combined with the ovarian tissue sample, was used to predict striped bass total fecundity and maturational status. Though successful, use of this technique was preliminary, and continued ultrasound imaging could provide a three-fold advantage. First, additional data could be used to strengthen the current fecundity model. Secondly, maturation and fecundity estimates from years 1999 and 2000 can be compared to provide insights into temporal trends in the maturational status and fecundity estimates of the adult female striped bass population. Thirdly, the maturity and fecundity estimates can be used to decipher the egg abundance estimates from the egg monitoring studies. Data from the egg monitoring study can be used to estimate the total number of eggs released in the estuary, but the maturational status and fecundity estimates can help determine the number of eggs released by female striped bass of a given length and weight.

Study Goals

The overall goals of this study were to evaluate our egg sampling protocol for efficiency and to use those data to make stronger inferences about whether the observed egg abundances reflect poor environmental quality or the maturational status of the population. The specific objectives of this study include: 1) validating egg detection thresholds for our standardized egg collection methods and determining sampling efficiency by sampling known abundances of striped bass egg surrogates, 2) quantify spatial and temporal egg abundances in the SRE, 3)

estimate total egg abundance in the SRE, 4) evaluating an existing fecundity model for female striped bass, and 5) assess temporal changes in maturation and fecundity from 1999 to 2000.

Methods

Task 1: Gear detection thresholds, sampling efficiency, sampling for striped bass eggs and larvae, and total egg abundance in the SRE

Detection Threshold and Gear Calibration

Thirteen 50-gal barrels of Gellan® Gum Beads (hereafter referred to as beads) were released and subsequently recaptured to evaluate standardized egg collection methods. These beads, which have a unique color and flavor (yellow/lemon, red/strawberry, and white/coconut), were used as surrogates for striped bass eggs because they are about the same size and specific gravity as striped bass eggs; the beads also drift like striped bass eggs floating in river currents (Davin et al. 1999). The beads behave similarly to striped bass eggs when exposed to different concentrations of salt water; and depending on substrate type, beads start disintegrating 48 hours after being released. Specifically, the persistence of the beads in a river system depends on the abrasiveness of the substrate they contact while drifting in the river currents (Davin et al. 1999).

Total number of beads contained in a 50-gal barrel was estimated by multiplying the mean number of beads from three small (25-65 grams) samples taken from each barrel and extrapolating (mean number beads/gram) to the total weight (g) of beads in the barrel. A known quantity of beads was then released across known historic and current spawning areas. Bead collection procedures followed our standardized striped bass egg collections, except an additional egg sampling boat was included to assist in simultaneously sampling Front and Back River sites.

Bead release times were dependent on water temperature and flow conditions and generally coincided with times and conditions when the majority of striped bass eggs were collected. In the spring of 1999, a pilot net-calibration study investigated gear detection threshold and sampling efficiency, but those data needed to be verified and validated. To address those needs, the beads were released in numbers that helped decipher gear sensitivity relationships (e.g., is the relationship linear to the number of beads released), replicated our methods across different flows and tides, and released and sampled beads in areas that will help determine spatial spawning activity.

In Spring 1999, beads were released on low flood tides; in Spring 2000, beads were released under similar tides and locations. About 3.6 and 6.8 million yellow beads were released at SR29 on March 27 and 31, respectively. Also, about 0.9 and 2.8 million red beads were released at BR15 on March 29 and 31, respectively. These releases provided data needed to address density dependent

relationships between the total number of eggs at large in the estuary compared to number of eggs collected.

Sampling gear sensitivity also was tested based on different release locations and tides. Toward that end, 2.0 million yellow beads were released at SR26 and about 1.8 million white beads released above the mouth of Union Creek, both on May 10. An additional 2.3 million yellow beads were released again at SR26 on May 15. All releases were made on high tides. Release sites were selected based on potential spawning habitat and location within the SRE. Specifically, a large number fish were collected while electrofishing just above SR26 and in the mouth of Union Creek, which suggested that striped bass may have been using these areas for spawning. Also, SR26 is located just below the division of the Savannah River into Front, Middle, and Back channels, and the release of beads at SR26 at high tide was an attempt to isolate the Front River for gear sensitivity. Multiple releases at SR26 provide an estimate of variation in bead recaptures based on daily sampling times for our standardized egg collection procedures.

Two releases of about 0.9 million red beads each were conducted at BR15 on May 10 and 16. Beads released and recaptured in the Back River also provided data necessary to determine variation in gear detection thresholds across various tides and sampling times for standardized egg collection procedures.

Spatial and Temporal Striped Bass Egg Abundances

Striped bass eggs and larvae have been sampled periodically in the SRE since the early 1970's and most intensively since 1977 (Dudley and Black 1979, Larson 1985, Wallin and Van Den Avyle 1995, Reinert et al. 1996, 1998). Egg sampling followed the protocols established over the past six seasons (as adapted from Dudley and Black 1979). Samples were collected at 10 stations (five stations per day) on outgoing tides throughout the striped bass egg spawning season. Stations included five on the Front River (river miles 12.0, 19.0, 24.0, 26.0 and 31.0), one Middle River station (Middle River mile 2.0), and four Back River stations (Back River miles 2.0, 6.0, 10.0 and 15.0; see Figure 1). At each station, three replicates were collected with a 50-cm diameter conical plankton net made of 500- μ m mesh netting. Nets were lowered to 1 m below the surface and pushed until about 100 m³ of water were sampled. A General Oceanics™ flow meter was placed in the mouth of each net to determine actual volume of water sampled. Samples were preserved in 7% unbuffered formalin and stained with Biebrich Scarlet and Eosin B to facilitate sorting. Sampling began on March 7 and ceased on May 12, 2000, when water temperature reached 23 °C for five consecutive days at river mile 26.0 of the Front River. Striped bass eggs were separated from debris, enumerated, and categorized according to developmental stage as described by Bayless (1972). Other larval fishes at predefined stations (BR6, BR10, SR19, and SR26) were identified to lowest taxon possible and enumerated (Appendix A). Historical ichthyoplankton data indicate that more numbers and

species were collected at these stations; also, there was a general overlap in species among the remaining stations.

Salinity, conductivity, temperature, pH, and dissolved oxygen were measured at 1-m deep intervals for each sample collected (Appendix B). Daily estimates of tidal amplitude in the estuary and measurements of river discharge at Clio, Georgia, (river mile 62; see Figure 2) were obtained from the United States Geological Survey (USGS). Water quality profiles (salinity, conductivity, temperature, dissolved oxygen, and pH) were measured at each egg sampling station (except SR31) four times per month during March and April. Profiles were measured at high- and low-slack tides during the neap and spring tidal phases. Measurements were taken over the 2-3 day period encompassing each tidal phase. Profiles were measured at 1-3 m intervals (depending on depth) from 1 m below the surface to 1 m above the substrate (Appendix C).

Water quality profiles were taken to define maximum and minimum salinity conditions and to assess patterns of saltwater intrusion into the estuary. Since eggs and larvae are passive drifters, transport to areas that are unsuitable for only a portion of the tidal cycle may still cause recruitment failure. The location of the saltwater-freshwater interface (defined here as the 0.5 ppt halocline) is not static in the estuary. It varies temporally and spatially and may also vary vertically and horizontally. The 9.0 ppt halocline is also noteworthy, as this level has been shown to be the upper bound of suitable habitat for Savannah River striped bass eggs and larvae (Winger and Lasier 1994).

Total Egg Abundance in the SRE

Total egg abundance was estimated by using the results from the gear calibration study with the data from the striped bass egg surrogate study and the total number of actual striped bass eggs collected during the sampling season.

Task 2: Maturity scheduling and ultrasonic imaging of adult striped bass

Striped bass collection

Striped bass collection efforts were accomplished through a partnership with GA-DNR personnel during their standardized electrofishing program, and the Georgia Cooperative Fish and Wildlife Research Unit electrofishing efforts on dates when GA-DNR personnel were not in the field. All sampling efforts occurred just before and during the striped bass spawning season. Striped bass length, weight, date of capture, and location of capture for each individual fish was recorded. An individually-numbered dart tag was applied to all sampled fish. If a sampled fish had a dart tag present, the number was recorded and the tag was left in the fish.

Ultrasonic Imaging

A portable ultrasound machine (LC100 Scanner with 3.5/5.0 MHZ curved array probe and 6.0/8.0 MHZ linear array probe) was used to sex striped bass from

the SRE and to produce cross-sectional ovary area images from females (Blythe et al. 1994, Will et al. 2000b). All digital ultrasonic images were recorded on a separate VCR (8-mm video tape). Ovary measurement consisted of the mean of five cross-sectional ovary areas taken uniformly from the anterior of the ovary to the posterior vent. When using the 3.5/5.0 MHZ curved array probe, measurements were obtained in the field with image measurement software installed within the portable ultrasound machine. When using the 6.0/8.0 MHZ linear array probe, measurements were obtained in the lab by using image analysis software (Sigma-Scan from Jandel Inc.) from the recorded images.

Five striped bass sampled were sacrificed to validate the position and identity of ultrasound images from the 3.5/5.0 MHZ curved array probe. Volume measurements (ml) from the two individual ovaries in the five sacrificed fish (N=10) were used as response variables in a regression model. This model was used to evaluate the accuracy of the 3.5/5.0 MHZ curved array probe in predicting ovary volumes as compared to the 6.0/8.0 MHZ linear array probe used by Will et al. (2000b).

Maturation Status

A sample of ovarian tissue (. 1 ml) was collected from all mature striped bass used for ultrasonic imaging. An additional two samples (N=3) was collected from some fish to help delineate numerical variability from egg enumeration data. Tissue samples were collected by catheter (a 3.0-mm diameter glass tube attached

to a syringe) and preserved in 10% histological-grade formalin. Oocytes were enumerated manually and then processed into slides by the University of Georgia's School of Veterinary Medicine Histological Lab. Prepared slides were examined and oocytes were staged and measured (minimum and maximum diameters; units = μm) with image-analysis software (Sigma-Scan from Jandel Inc.) and a computer equipped with a frame-grabbing board. Measurement of oocytes was performed without prior knowledge of fish size or date of capture. Using criteria established by Berlinsky and Specker (1991), Mylonas et al. (1997), and Tao et al. (1993) oocytes were classified into the following categories:

- 1) primary growth - undeveloped, consisting of ooplasm only;
- 2) secondary growth - presence of translucent spheres in the periphery of the ooplasm;
- 3) vitellogen - larger translucent spheres of lipids; centrally located germinal vesicle (nucleus); presence small putative vitellogen vesicles;
- 4) post-vitellogenic - lipid droplets starting to coalesce; germinal vesicle starting to migrate to the periphery;
- 5) final oocyte maturity - lipid droplets fully coalesced into a single mass; germinal vesicle fully migrated to the periphery;
- 6) atretic - lacking germinal vesicles; irregular shaped; degenerating.

Following procedures established by Will et al. (2000b), the 20 most-advanced oocytes containing a germinal vesicle from each sample were staged, measured, and used to assess maturational status.

Statistical Analysis

Regression analysis was used to develop a model that would predict ovary volumes based on the mean of five cross-sectional ovary areas obtained through ultrasonic imaging. Since the variables span several log scales (i.e., they contained relatively small and large observed values), a log transformation (log base 10) was performed before the analysis.

Based on the regression model, predicted ovary volumes were integrated with the egg enumeration data (from the ovarian tissue samples) to estimate the total fecundity of mature striped bass. Analysis of variance was used to compare mean fecundity estimates among four size classes (size class I = < 800 mm TL, size class II = 800-899 mm TL, size class III = 900-999 mm TL, and size class IV = >1000 mm TL). Differences ($p < 0.05$) between mean fecundity estimates would suggest one size class was more or less fecund. Differences among size class were evaluated with a Bonferroni mean separation test.

Regression analysis was used to predict fecundity estimates based on both striped bass length (TL, mm) and weight (kg). All statistical tests were performed with SAS for Microcomputer (SAS Institute 1999) and evaluated at an alpha level of 0.05.

Results and Discussion

Task 1: Gear detection thresholds, sampling efficiency, sampling for striped bass eggs and larvae, and total egg abundance in the SRE

Detection Threshold and Gear Calibration

In the spring of 1999, results from bead-release trials suggested that sampling efficiency primarily depends on channel morphology and egg distribution pathways. Specifically, the channel morphology of the Back River is narrow and shallow compared to that of the Front River. We sample a proportionately larger fraction of the water column in the Back River than in the Front River. Therefore, if equal numbers of eggs are in the Front and Back River, we would collect and report more eggs in the Back River than from the Front River. Further, beads released in the upper SRE disperse into the Front, Middle, and Back rivers. In the past, the contribution of striped bass spawning in the Front River may have been underestimated and be more important than previously thought. Also, the distributions of beads throughout all three channels suggest that the SRE should be thought of as a whole system and not as these separate channels (Will et al. 2000a).

Gear detection thresholds (DT), depending on varying densities of beads released, were consistent from 1999 to 2000 for beads released in the upper SRE and in the Back River. In the spring of 1999, detection thresholds averaged about 0.0005% (i.e., one bead per 200,000 released) for the two different releases of

about 1.2 million (DT = 0.0003%) and 2.1 million (DT = 0.0006%) beads at SR29. Increasing egg density did not increase DT, as trials at SR29 in 2000 (3.6 and 6.8 million), produced results similar to those observed at lower densities (DT = 0.0007% and 0.0006%, respectively; Figures 3a and c). If about 155,000 eggs are in the SRE, our sampling gear will collect one. In 1999, gear detection threshold from the 1.8 million beads released at BR15 was about 0.002%, or one bead per 50,000 released. From the three trials performed in the Back River (0.9, 0.9, and 2.7 million beads), gear sensitivity averaged 0.006%, but ranged from 0.001% to 0.009% (Figures 3b, d and h). The probability of our gear collecting eggs in the Back River ranged from one in 10,000 to 100,000.

Gear detection thresholds also varied according to the location and timing of release. Releases on low, incoming tides at SR29 resulted in average gear DT of about 0.0006%. Releases on high ebb tides at SR26 resulted in an average gear DT of about 0.0002% (Figures 3e and g), and releases on a high flood tide above the mouth of UC resulted in a DT of about 0.0006% (Figure 3f). Also, from the first release of beads at SR26, one of the two recaptured beads was collected in the Back River, and beads released in UC were collected in the all three channels (Front River n=2, Middle River n=7, and Back River n=2), further strengthening the idea that the SRE is a whole system. Considering all releases across the varying tides and locations, at worst, our sampling gear will capture one egg in one million striped bass eggs at large, roughly equivalent to one large female spawning.

Overall, the standardized egg sampling methods are adequate for monitoring striped bass egg abundance and distribution in the SRE and allow stronger inferences about the adequacy of striped bass egg sampling during a spawning season. More specifically, our detection threshold ranged from one egg per 140,000 at large (DT. 0.0007%) to one egg per million at large (DT. 0.0001%). One large (about 900 mm TL) female striped bass has the potential of releasing about one million eggs during a spawning event. Therefore, our standardized sampling methods should sufficiently detect 1-2 female striped bass spawning in the SRE. If a striped bass spawns in the Back River, our sampling gear should collect a large number of eggs.

Spatial and Temporal Striped Bass Egg Abundances

A total of 965 ichthyoplankton samples were collected (three replicates x 330 station/date combinations; some replicates and some days were missed because of weather or mechanical difficulties). Of these samples, 114 contained a total of 923 striped bass eggs (Table 1). Two striped bass larvae were collected, and larvae of other fishes were common in the samples (Appendix A).

Striped bass spawning in the estuary occurred in brief pulses or peaks, each lasting 3-12 days (Figure 4). These spawning events produced temporary peaks of high egg abundance rather than evenly distributed counts that would have occurred if spawning were continuous. Spawning generally corresponded with warming

trends when river temperature was 18-21EC. The first spawning peaks occurred in late March and early April.

Most spawning activity in 2000 occurred upriver of the Hoolihan Bridge in the Front River (mile 21.5); some eggs were captured at BR10 in the historically-productive Back River. Most eggs (91.4%) were collected at stations SR24, SR26, and SR31 (n=150, n=581, n=113, respectively); 62.9% of total eggs were collected at SR26 (Table 1). Eggs were not collected below BR10 in the Back River and only 4 eggs were collected below the Hoolihan Bridge in the Front River.

Data on egg developmental stages also indicate that most spawning activity occurred in the upper portion of the estuary (Table 2). Most (86%) of the stageable eggs captured at SR26 were Stage 2 or 3 (10-19 hr and 19-26 hr old, respectively), which indicates that spawning had occurred very near this station. Most of the stageable eggs from SR24 were Stage 3, and there were nearly equal numbers of stages 2 and 4 (26-33 hr old), further indicating that spawning was occurring in the upper reaches of the SRE. Stageable eggs captured at BR10 included stages 2, 3, and 4, and stageable eggs captured at BR15 included all stages (0-44 hr old), which indicate that spawning had occurred in the vicinity of that station and slightly upriver. SR31 had eggs from all stages as well, which indicates that some spawning was occurring even further upriver.

Surface (~1 m) salinity on egg collection dates generally were low (Table 3). During sample collection, mean surface salinity at the upriver stations (SR24, SR26, and SR31) was below 0.5 ppt, and mean surface salinity was 1.31 (SD =

1.00) for MR2 and was 0.78 (SD = 0.63) for BR10. Mean surface salinity for the most seaward station (SR12) was 9.81 ppt (SD = 3.06) but ranged from 3.1-16.3 ppt. Mean surface salinity for the most downstream Back River station (BR2) was 10.11 ppt (SD = 3.24). Water temperature when eggs were collected ranged from 17.6 to 19.6 °C (Table 3).

Salinity concentrations (ppt) recorded during Spring 2000 were greater than concentrations reported in past years (Reinert et al. 1996, 1998; Will et al. 2000a) and may have been related to low river flows (see Figure 2). Salinity at SR26, where most striped bass eggs were collected, was \approx 0.5 ppt for all spring and neap tides. Also, salinity at SR31 and BR15 did not exceed 0.5 ppt. The historic spawning area (BR10) was fresh or nearly-so (<1.7 ppt) for all months and tides except for March spring tide when the salinity ranged from 0.1 to 1.6 ppt and April neap tide when salinity ranged from 0.7-2.4 (Figure 5a). The Middle River station (MR2.0) was characterized by salinity <1.3 ppt throughout all low-slack tides, but ranged from 1.9 to 8.2 ppt for both spring and neap high-slack tides (Figure 4b). Salinity at stations in the lower portion of the estuary (SR12, SR19, BR2 and BR6) generally increased with depth, which indicates the presence of a wedge of higher salinity water lying beneath less saline surface waters (Figures 4c-f). The largest documented change in saltwater concentrations occurred at SR24. Will et al. (2000a) reported salinities up to 3.6 ppt at SR24 in 1999, and during the high slack neap tide in March 2000 salinities ranged from 3.2 to 11.0 ppt (Figure 5g).

Since eggs and larvae are passive drifters, transport to areas that are unsuitable for only a portion of the tidal cycle may still cause recruitment failure. The 9.0 ppt halocline is noteworthy, as this level has been shown to be the upper bound of suitable habitat for Savannah River striped bass eggs and larvae (Winger and Lasier 1994). On the Back River, the 9.0 ppt halocline was detected as far upstream as BR6 on high-slack tides in both March and April. On the Front River, the 9.0 ppt halocline was detected as far upstream as SR24 on a high-slack neap tide in March, and at SR19 during both high and low-slack neap tides during April. Therefore, in Spring 2000, striped bass eggs may have been exposed to toxic or lethal salinity below SR24 on the Front River and BR6 on the Back River. Although lethal salinity intruded farther upstream than has been reported previously, this intrusion may be related to the low river flows. Hence, the increase in the numbers of eggs collected in Spring 2000 was encouraging.

Although, egg densities in 2000 were not significantly higher than previous years, the trend of increasing egg abundance is promising. Egg density at five routinely-sampled stations declined from 1977 through the 1980's and have remained low through 2000 (Table 4). However, egg densities for SR24 were higher than the past eight reporting years (data were not collected in 1992 and 1993), and egg densities for BR10 were higher than the past nine reporting years. Egg density at SR26 was the highest recorded since 1986 and density at SR31 was the highest since 1988. If egg abundances in the SRE continue to increase,

the establishment of a self-sustaining striped bass population will depend on the availability of suitable nursery habitat for the developing larvae and juveniles.

Total Egg Abundance in the SRE

Gear detection in the Front River was 0.0006% (but ranged from 0.0001% to 0.0007%) or one egg captured for every 167,000 at large (with a range of 143,000 to 1,000,000). Throughout the entire sampling period, 848 eggs were captured in the Front River. Total egg abundance in the Front River, based on eggs captured and our calculated gear efficiency, is estimated at 141 million eggs (with a range of 121 million to 848 million).

Gear detection in the Back River was an order of magnitude higher than in the Front River, probably because of channel morphology, and was calculated to be 0.006% (range: 0.001% - 0.009%) or 1 egg captured for every 16,700 eggs at large (range: 11,000 - 100,000). Gear efficiency was not determined for the Middle River, but the channel depth and morphology are similar to the Back River. If we include eggs captured in the Middle River with those captured in the Back River, a total of 75 were captured during the sampling period. Therefore, an estimated 1.25 million eggs (with a range of 833,000 to 7.5 million) were at large in the Back and Middle rivers during Spring 2000. As noted previously, a single, large female may produce over 1 million eggs in a single spawning event. Because eggs were captured over a 28-day period (March 23 - April 20) at the two Back River stations and one Middle River station and were from various developmental stages, these

eggs probably were not spawned in the Back River itself. We would have caught many more eggs over shorter periods of time if a spawning event had occurred in the Back River. The captured eggs most likely are the result of a spawning event in the Front River or Union Creek and were distributed down the Back River from McCoy's Cut.

An estimated 142 million eggs (range: 122 million - 856 million) were in the SRE during Spring 2000. Data from Will et al. (2000a) suggest that an estimated 37 million eggs were at large during Spring 1999. Egg abundance in Spring 2000 may represent a 4-fold increase over the previous year (but may be as high as 23 times higher). Although encouraging, this result is tempered by the lack of spawning activity attributed to the historically productive Back River. Additionally, 142 million eggs may represent less than 150 mature females in the SRE.

Task 2: Maturity scheduling and ultrasonic imaging of adult striped bass.

Striped bass collection

Twenty-eight female striped bass (>600 mm TL) were used for ultrasonic imaging (Table 5). Five of the 28 fish were sacrificed for image verification; actual ovary measurements of these fish were used for statistical modeling. Ovarian tissue samples were collected from all striped bass used for ultrasound imaging. Of the 28 fish from which tissue samples were collected, five had undeveloped ovaries, one had spent ovaries (i.e., the fish had released its eggs), and 22 had

mature ovaries. One 1-ml sample was taken from each striped bass having undeveloped or spent ovaries (n=6). Of the 22 mature striped bass, one 1-ml sample was taken from 4 fish, and three 1-ml samples were taken from each of the remaining 18 fish (n=58), for a total of 64 ovarian tissue samples collected.

Ovary Volume

A regression model predicting ovary volumes and based on images captured by the 3.5/5.0 MHZ curved array probe resulted in the following:

$$V = 0.7226 + 1.4818(x) \text{ (adj. } r^2 = 0.97) \quad (1)$$

where, V = log ovary volume, x = log of the mean of the five cross sectional areas. Overall, the model accurately reflected ovary volumes from ultrasonic imaging and was then used to predict ovary volumes for all striped bass released alive. The Spring 2000 relationship compared favorably to that determined in Spring 1999 (Figure 6; Will et al. 2000b).

Fecundity estimation

Predicted ovary volumes were integrated with the egg enumeration data (from the ovarian tissue samples) to estimate the total fecundity of mature striped bass (Table 6). Twenty-two of the 28 fish were used for fecundity estimates. Oocytes from five fish were too immature to enumerate and one fish had spawned recently.

Fecundity estimates for Savannah River striped bass varied by fish size ($P < 0.05$; Figure 7). Fecundity increased from size class I ($\bar{O} = 404,590$; $SD = 167,133$) to size class IV ($\bar{O} = 1,731,617$; $SD = 626,394$). Generally, fecundity estimates for striped bass in the SRE are similar to estimates reported for striped bass in the Roanoke River, North Carolina (Olsen and Rulifson, 1992; Lewis and Bonner, 1966) and in the SRE in 1999 (Will et al. 2000b; Figure 8). Collection efforts for striped bass in the SRE in Spring 1999 only yielded four striped bass > 900 mm TL as compared 10 fish > 900 mm TL collected in Spring 2000. These larger fish strengthened fecundity estimates for female striped bass in the SRE. Also, our ability to collect and produce fecundity estimates from a wide size range (640 mm to 1055 mm, TL) of female striped bass, facilitated the development of a fecundity model based on general field measurements (TL, mm and weight, kg).

Three separate regression analysis evaluating fecundity based on fish length and weight resulted in the following models:

$$F = -2823.38 + 4.24 (a) \text{ (adj. } r^2 = 0.69) \quad (2)$$

$$F = -410.31 + 124.95 (b) \text{ (adj. } r^2 = 0.77) \quad (3)$$

$$F = -486.53 + .12 (a) + 121.90 (b) \text{ (adj. } r^2 = 0.76) \quad (4)$$

where, F = fecundity in thousands, a = total length (mm), and b = weight (kg).

Regression models 2 and 4 seem to follow the fecundity trend well (Figure 9), but the model based solely on striped bass weight (Model 3) produced the best fit to the data (adj. $r^2=0.77$). Therefore, striped bass weight is the best overall field measurement for predicting fecundity in SRE female striped bass. As resource

agencies continue to monitor the SRE striped bass population, fecundity models based on general field weights can improve their ability in assessing the fishery.

Maturation Status

All maturational stages (primary oocytes, secondary oocytes, vitellogenic oocytes, post-vitellogenic oocytes, final oocyte maturity, and atretic oocytes) were identified in all ovarian tissue samples collected (N=64). At least two different maturational stages were identified in each individual sample. Identifying two maturational stages within a sample is common since striped bass exhibit group-synchronous development (Wallace and Selman 1981). Group-synchronous oocyte production implies that at least two distinguishable oocyte populations exist within the ovary. Generally, there is a clutch of larger oocytes to be released and a heterogeneous population of smaller oocytes from which future clutches are recruited (Wallace and Selman 1981).

From the 20 most advanced oocytes staged, female striped bass development appeared to differ from Spring 1999 to Spring 2000. In Spring 2000, measured oocytes were not vitellogenic and most (72%) were post-vitellogenic, as compared to Spring 1999, when 43% were vitellogenic and 41% were post-vitellogenic (Will et al. 2000b). Whether this difference was related to environmental cues needed to progress oocyte development or some relationship in the condition of the female striped bass is undetermined. However, documenting higher percentage of oocytes progressing to the final stages of maturity is encouraging.

Further, 5% of the measured oocytes were in the final stages of maturity. Finding mature oocytes (final oocyte maturity) is rare, considering that these oocytes only remain in the ovary for 6-12 hours (Rees and Harrell 1990). Therefore, fish with mature oocytes probably were about to spawn in the general location where they were collected.

For a given maturational stage (e.g., post-vitellogenic), oocyte diameters were similar to other studies. In our study, mean oocyte diameter for post-vitellogenic oocytes ($751 \pm 72 \mu\text{m}$) was similar to those found by Will et al. 2000b ($764 \pm 6 \mu\text{m}$), Reinert et al. 1998 ($784 \pm 37 \mu\text{m}$), and Mylonas et al. 1997 ($838 \pm 18 \mu\text{m}$). Oocyte diameters generally increased with oocyte development (Figure 10) and fish length (Figure 11). However, a relationship between the size of oocyte and hatching success probably does not exist (Bob Rees, GA-DNR, personal communication).

None of the measured and recorded oocytes were identified as atretic; however, atretic oocytes were observed within the samples from one spent fish. Atresia is an irreversible finite process and may result from environmental stress (de Montalembert et al. 1978), poor nutrition (Rai 1966, cited in Wallace and Selman 1981), or insufficient gonadotropin (GtH) levels (Chester and Ball 1962, cited in Wallace and Selman 1981). Insufficient gonadotropin levels may be caused by fish immaturity or by toxic chemicals considered endocrine disruptors. The observed atretic oocytes were collected from a striped bass that had recently spawned. Atresia of oocytes is high at the end of the spawning season in spent fish

and is common in fish (e.g., striped bass) with indeterminate fecundity (Walker et al. 1994). Atresia is believed to happen because oocytes may be continually recruited into vitellogenesis during the spawning season and are considered surplus at the end of the season.

Oocyte development to final stages of maturity for striped bass collected in the SRE seems to be progressing normally. Sexual maturity in smaller striped bass (<800 mm TL) was variable (i.e., post-vitellogenic oocytes were found in some fish and secondary oocytes in others). Oocytes from samples collected from all but two larger (>800 mm TL) fish (one was spent and one was immature) were developing to final stages of maturity (Figure 12). Will et al. (2000b) observed a similar maturity trend for striped bass oocytes in fish >750 mm TL. Also, female striped bass normally require 5-6 years to grow to these sizes (Hill et al. 1989).

In Spring 1999, a correlation of maturing oocytes to increasing egg densities was observed, which suggests that oocytes are maturing properly and are being released. Maturation development also generally coincided with maximum egg densities collected in the SRE in Spring 2000 (Figure 13). Further, two striped bass with spent ovaries, which indicates a recent spawning event, were collected in Spring 1999 and one was collected in Spring 2000. Therefore, environmental cues necessary for oocyte development and release seem adequate and may not be a factor in the low abundance of striped bass eggs in the SRE.

Conclusions

The recovery of the Savannah River striped bass population may have already begun, but is still in the early stages. Low egg densities in the SRE may be a product of the time-lag associated with stocking juveniles and waiting for them to mature into large, highly fecund females (i.e., 8-10 years). How much additional time is necessary for the younger fish to grow to sizes where fecundity levels are greater is unknown, but stocking records from GA-DNR may provide insight to the question.

GA-DNR has been stocking striped bass in the SRE for the past 20 years. From 1980-1989, they stocked Phase I fingerlings (15-25 mm TL) but observed only negligible recruitment (Wallin and Van Den Avyle 1995). During 1990-1994, GA-DNR began supplementing their traditional stockings efforts with larger fingerlings (Advanced Phase I fingerlings, 50-80 mm TL and Phase II fingerlings 175-250 mm TL) and hoped that enough of these fish would recruit successfully to establish a self-maintaining population. Wallin and Van Den Avyle (1995) concluded that Phase II fingerling striped bass stocked in freshwater had a much higher survival rate than Phase I fingerlings. Based on the results of that study, GA-DNR optimized their stocking program in 1995 for juvenile striped bass survival. Although population monitoring has been ongoing since 1990, only recently has a possible resurgence in the striped bass population been observed. Catch-per-unit effort of age 2 + fish has increased to pre-tide gate levels and there has been a substantial increase in striped bass > 9 kg (GA-DNR, unpublished data). However, the current number of large (>900 mm), highly fecund individuals may still be low.

Females in this size-class probably contributed substantially to the egg densities observed prior to the decline. Therefore, if abundance of large fish increases, egg densities should increase accordingly.

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