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Year-Class Component, Growth, and Movement of Juvenile Red Drum Stocked Seasonally in a South Carolina Estuary

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Abstract.—Red drum *Sciaenops ocellatus* have been classified by the Atlantic States Marine Fisheries Commission as overfished in the Atlantic off the southeastern USA. A study was conducted to evaluate stocking hatchery-reared fish as a management tool to increase abundance of red drum in South Carolina estuaries. Multiple groups of juveniles, at mean sizes of 22–56 mm total length, were released after being marked by immersion in 15 g/L salinity brackish water containing oxytetracycline HCl (500 mg/L active). Fish were released into a small (535-ha) part of the available nursery habitat (total = 25,000 ha) in the Port Royal Sound estuary each fall and spring from fall 1995 through spring 1997. During fall 1995 and spring 1996, 347,000 fish were stocked; during fall 1996 and spring 1997, the number was 1,228,000. Movement of hatchery fish from the release site was monitored for at least 2 years after release. Overall, hatchery fish accounted for 19.0% of the 627 fish (age 0 to age 2) captured from the 1995 year-class and 19.4% of the 687 fish (age 0 to age 2) captured from the 1996 year-class. The portion of each year-class that was of hatchery origin was greatest at the release site (1995 year-class = 58.6%; 1996 year-class = 77.3%). However, marked hatchery fish from the 1996 year-class (range, 8–38%) were also captured after more than 2 years at large and as far as 35 km from the release site. The presence of hatchery fish did not appear to reduce the growth of wild fish even at the higher stocking density tested (2,295 fish/ha). Sex ratios of hatchery and wild fish were not significantly different. Hatchery fish released in the fall were captured 1.5 times more often than fish released in the spring. Additional studies are necessary to determine whether hatchery releases can be used to increase overall abundance.

The red drum *Sciaenops ocellatus* is an estuarine-dependent marine finfish species that matures at age 4–5, can live more than 50 years (Ross et al. 1995), and has supported commercial and recreational fisheries from New Jersey to Texas. Red drum are also one of the top three fish species targeted by saltwater anglers in the southeastern USA (Hussey et al. 2000). In the early 1980s it became apparent that the red drum population along the Atlantic coast was declining, primarily because of unregulated fishing that targeted all ages (Mercer 1984). After additional decreases in the population were observed, federal waters were closed in 1991 to both recreational and commercial harvest (ASFMC 2002). During a succession of additional management actions over the past decade, size and creel limits have become progressively more restrictive in an effort to increase escapement (i.e., allow maturing fish to escape the estuarine component of the fishery) of red drum and rebuild the spawning stock biomass (ASMFC 2002). During that time the spawning potential ratio increased from 3% in 1989 to nearly 17% in 1999 (Vaughan and Carmichael 2000). However, after nearly 15 years of intensive management, the spawning potential ratio is still far below the 40% level believed necessary to reach the theoretical optimum sustainable yield for the fishery (Vaughan and Carmichael 2000). Furthermore, data collected on juvenile red drum abundance in South Carolina during the 1990s indicated that, although the portion of a year-class that survived to broodstock size was increasing, the actual number of fish making up the juvenile population appeared to have declined at a rate of 12%/year (Wenner 2000).

In 1989, researchers in South Carolina began to examine the feasibility of using stocking as a tool for red drum management (Smith et al. 1997). Using the ''responsible approach'' to stock enhancement (Blankenship and Leber 1995), this small-scale program began to systematically address key issues associated with stock enhancement of red drum. Early efforts focused on the release of 5,000–10,000 large (>100 mm total length [TL]), externally marked juveniles each year (Smith et al. 1997). During these trials, stocked fish never made up more than 5% of the population in the

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stocked area (Smith et al. 1997). A series of subsequent studies focused on such issues as size and season of release (Smith et al. 1997), marking method and retention (Jenkins et al. 2002), tag reporting rate (Denson et al. 2002; Jenkins et al. 2000), and population genetics (Chapman et al. 2002). Here we report the results of a study of the effects of releasing 1–2-month-old juvenile (20–50 mm TL) red drum. The objectives of the study were to (1) compare two stocking densities, (2) determine the movement of hatchery fish from the release site, (3) determine the size of the hatchery component of each stocked year-class, (4) monitor the relative return of fish stocked in the fall and spring, (5) monitor the growth of stocked fish and wild conspecifics, and (6) document the sex ratio of hatchery-produced fish.

Methods

Fish production, marking, and release.—Fish produced for release were progeny of locally captured wild broodstock that were replaced annually. Adults were tank-spawned with use of photo-thermal conditioning (Roberts et al. 1978). Three-day-old larvae were stocked in fertilized ponds at the Waddell Mariculture Center (WMC) in Bluffton, South Carolina, for rearing to juvenile size (Geiger and Turner 1990).

Fish that reached a minimum size of 20 mm TL were harvested from culture ponds at night and placed in oxygenated holding tanks at a biomass density of 40 g/L for treatment with oxytetracycline HCl (OTC). All fish were treated with OTC in compliance with U.S. Food and Drug Administration approved protocols under Investigational New Animal Drug permit 8054. Fish were treated at a salinity of 15 g/L by a 4-h immersion in a 500 mg/L active solution of OTC, as described by Jenkins et al. (2002). After treatment, fish were released into recovery ponds filled with 15 g/L salinity water, where they were left for at least 5 d to recover from the stress of handling and marking. During this time, salinity and temperature were adjusted to ambient conditions by addition of water from the adjacent Port Royal Sound estuary. Fish were then reharvested, weighed to estimate their number, and transported to a nearby (distance = 3 km) boat landing. At the boat landing, fish were transferred in nets to boat-mounted hauling tanks for final transport to the release site. A subsample (minimum *n* = 100) from each release group was retained in captivity for at least 90 d to allow the fish to grow large enough for us to examine their otoliths for the presence of an OTC mark.

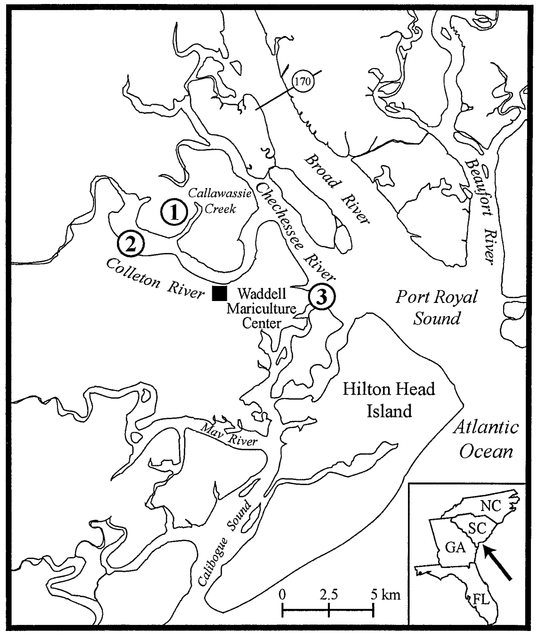

FIGURE 1.—Map of the location of the hatchery (Waddell Mariculture Center), the stocking site (1), Rose Hill Flats (2) Chechessee River (3), and the South Carolina Highway 170 bridge across the Broad River. Sampling occurred throughout Port Royal Sound and up to 35 river km (mouth of May River) from the stocking site in Calibogue Sound.

Fish were spawned and released during two seasons: the natural fall spawning and nursery season (September–November) and approximately 6 months out of phase during spring (April–June). During each stocking event, fish were released in small batches throughout Callawassie Creek, a small tributary of the Colleton River, which is part of the Port Royal Sound estuary (total available *Spartina alterniflora* marsh nursery habitat = 25,000 ha; Figure 1). The Callawassie Creek drainage, which contains approximately 535 ha of nursery habitat, was chosen as the release site for three reasons: (1) it was characteristic of red drum nursery habitat in South Carolina (Wenner 1992); (2) the adjacent high land was relatively undeveloped and used primarily for tree farming; and (3) we wanted to avoid possible interactions with studies monitoring the wild red drum population in other estuaries in the state.

Each release was conducted near high tide to allow fish access to the maximum nursery area and to provide time for acclimation and dispersal before low tide. Mean tidal amplitude in the area was 2.5 m (NOS 1997). Fish released in the fall and those released in the following spring were large enough to recruit to the sampling gear at approximately the same time each year (summer). Thus, they are labeled as contributing to the same year-class; for example, fish stocked in spring 1996 are referred to subsequently as 1995 YC (year-class) spring.

Sampling techniques.—To determine prestocking population characteristics, we began sampling the wild population in September 1995, approximately 10 months before the first batch of stocked fish would recruit to the sampling gear. For initial sampling of the prestocked and poststocked year-classes we used hook and line. When stocked fish were large enough (~200 mm TL, late summer 1996), a trammel net (183 m long with one inner panel of 6.3-cm stretch mesh and two outer panels of 17.8-cm stretch mesh) deployed over the transom of a Florida net boat while the boat was underway became the primary sampling gear. This net also captured wild fish from year-classes prior to stocking.

Sampling was not random but relied on selecting sites where fish were routinely captured or where schools of red drum were located visually before the net was deployed. After the net was set, the area within the net was agitated manually to scare fish into the webbing. The net was then immediately retrieved and the fish removed. All captured red drum less than 500 mm TL were killed and retained for biological examination. For fish larger than 500 mm TL, only a random sample of at least 10% of these fish was killed to determine the contribution of the stocked fish. This subsampling of large fish was to minimize possible population impacts. Unneeded captured fish were immediately released.

Biological sampling included measuring total length to the nearest millimeter and removing a fin clip for future genetic analysis. Sagittae of all retained fish were removed, washed in tap water, dried, and stored in envelopes.

Sampling was conducted an average of 3 d/month, primarily along the banks of the entire Colleton, Chechessee, and lower Broad rivers to determine local movements (Figure 1). Other secondary locations, including the May, upper Broad (above the South Carolina Highway 170 bridge), and Beaufort rivers, were sampled less frequently to assess dispersal (Figure 1). Among primary sample sites, three were fished regularly to allow quantitative comparisons of movement of hatchery fish: the mouth of Callawassie Creek; Rose Hill Flats in the Colleton River (3 km from the release site); and near the confluence of Gilbert, Mackay, and Skull creeks in the Chechessee River (14 km from the release site; Figure 1). The distance to each sample site was estimated by using an analog map measurer (Forestry Suppliers, Inc., Jackson, Mississippi) to track the shortest distance by water from the center of the release site to the center of the sample site on a nautical chart.

Otolith preparation.—The right sagitta from each killed fish was sectioned and examined by two independent readers to determine the presence or absence of OTC marks, following methods outlined by Jenkins et al. (2002). Each section was examined under blue-violet light (wavelength = 436 nm), in which the OTC mark appears as a yellow fluorescent band. Sagittae with an OTC mark were classified as being from fish of hatchery origin. Examination of sagittae collected from fish retained from each release batch was used to determine the efficacy of OTC marking.

Aging.—Red drum in South Carolina typically spawn in late August to early September. For purposes of age determination, wild fish and fall-released hatchery fish were assigned a birth date of September 1 (Ross et al. 1995). Typically, annuli are not visible on otoliths until approximately age 18 months, after the second winter of life (Ross et al. 1995). Sectioned otoliths from fish older than 18 months at capture were measured as follows: At 63× under white ligh, the distance to the nearest ocular micrometer unit (16.26 μm) was measured from the core to the distal edge of the first annulus, taken proximally along the ventral side of the sulcus acousticus. Distances recorded were used as a surrogate for estimating size at age (Doersbacher et al. 1988). Using this technique, we could infer relative size at age 18 months (February) for wild year-classes that had recruited to the population before we had initiated the stocking, regardless of time of capture (e.g., first annulus location for a fish from the 1993 YC collected in fall 1997 could be pooled with that of a fish from the same year-class collected in summer 1995). The distance to the first annulus was compared among wild fish from year-classes before and during stocking.

Spring-stocked fish are actually approximately 10 months old at the time of first annulus deposition. However, because an annulus is present on the otolith of such fish, the reader would assign it an age of 18 months (apparent age). For the remainder of this report, the age of spring-stocked fish is expressed as apparent age, unless otherwise

TABLE 1.—Number of red drum marked and released into Callawassie Creek, Port Royal Sound, South Carolina, 1995–1997, and capture levels of hatchery fish from each release period.

Release dates	Year	Batches (n)	Mean total length (range, mm)	Number released	Number captured	Capture level [a]
Oct 16, Nov 20	1995	2	35–40	78,000	46	59.0
May 16–May 29	1996	4	39–56	269,000	73	27.1
Sep 24–Nov 14	1996	5	22–53	523,000	74	14.1
May 22–Jun 4	1997	4	33–39	705,000	59	8.3

[a] Number captured per 100,000 released.

noted. Jenkins et al. (1997) indicated that spring-spawned fish that had been reared in captivity for a longer period than in the present study could be differentiated from wild fish by measuring the distance from the core to the first annulus, a distance that was significantly smaller for spring-spawned fish. We tested this approach in the current study by examining the distance to the first annulus of OTC-marked fish that had been segregated from the catch by size and classified as spring-stocked fish. Using a combination of size at age and presence or absence of an OTC mark, we classified each fish as having either wild or hatchery origin and further segregated the latter into fall- and spring-release groups. If the section of the otolith was damaged or otherwise unreadable, it was either resectioned or the second sagitta from the fish was processed.

Sex determination.—Gonad samples from field-collected fish were preserved in 10% formalin and seawater and later transferred to 50% isopropanol. Tissues were then vacuum-infiltrated and blocked in paraffin. Sections cut from each gonad were stained with Harris hematoxylin, and counter-stained with eosin. After examination at 100× for the presence of spermatocytes or basophilic oocytes, the fish was classified as male, female, or undifferentiated.

Data analysis.—Data were analyzed by using parametric and nonparametric statistics as appropriate. Analysis of size at age was divided into two groups, based on age of fish at capture: fish older than 18 months and fish 9–15 months old, the latter being a period of the year when growth is linear (Doersbacher et al. 1988). Fish 16–18 months old were excluded from the analysis because little or no growth occurs during winter. For fish older than18 months, we used a Kruskal–Wallis analysis of variance (ANOVA) on ranks to identify differences in distance from the core of each otolith to the first annulus for each year-class of wild fish and each season of release and year-class of stocked fish. Dunn's method was used to identify differences between these groups of otoliths. For fish 9–15 months old when collected, a linear regression analysis of length at age was performed with the SAS general linear model (SAS Institute, Cary, North Carolina) to examine parallelism of growth rates of wild and hatchery-released fish within each year-class and to test for differences in growth rates between wild year-classes (Kleinbaum and Kupper 1978). Chi-square analysis was used to determine whether there were differences between expected and observed sex ratios of wild and hatchery fish. The alpha value for all statistical comparisons was 0.05.

Results

During the study, 15 groups of fish were treated with OTC and released. Approximately 78,000 fish were released in the fall of 1995 and about 269,000 in the following spring, resulting in a cumulative stocking density of 648 fish/ha for the 1995 YC (Table 1). The stocking density for the 1996 YC was 3.5 times greater (2,295/ha): 523,000 fish were released in the fall and 705,000 in the spring (Table 1). Mean lengths at release ranged from 22 to 56 mm TL.

Between September 1995 and March 1999, 316 angling trips and 434 net sets captured 437 fish (44 >500 mm TL) by hook and line and 1,248 fish (562 >500 mm TL) in the trammel net that were killed to determine their origin. An additional 1,722 red drum larger than 500 mm TL were measured and released. The fish collected were from year-classes before (1993, 1994), during (1995, 1996), and after (1997) stocking. Seventy-one percent (n = 225) of the angling trips and 52% (n = 227) of the net sets were conducted at the three primary sites: Callawassie Creek (62 angling trips and 84 net sets), Rose Hill Flats (65 angling trips and 46 net sets), and Chechessee River (98 angling trips and 97 net sets).

Mark Efficacy

Water temperature during marking events ranged from 17°C to 27°C. Although varying in

TABLE 2.—Results of a Kruskal–Wallis analysis of variance on ranks comparing mean distance (±SD) in micrometers from nucleus to first annulus on the sagitta, by year-class and season of spawning, for both stocked and wild fish. Values in columns followed by the same uppercase letter and those in rows followed by same lowercase letter are not significantly different ($P > 0.05$).

	Incremental distance (μm)		
Year-class	Wild fish	Fall-stocked fish	Spring-stocked fish[a]
1993	1,096 ± 148 ZY (n = 23)		
1994	1,165 ± 160 Z (n = 102)		
1995	1,029 ± 124 Yz (n = 249)	1,056 ± 52 Zz (n = 5)	802 ± 143 Zy (n = 12)
1996	1,081 ± 122 Zz (n = 253)	1,111 ± 144 Zz (n = 26)	715 ± 60 Zy (n = 28)

[a] Spring-stocked fish contributed to the previous year-class and are included as such (e.g., fish released in spring 1996 are classified as 1995 year-class).

intensity, marks were observed on 100% of sagittae from the control groups retained from each of the 15 release groups. In addition, one group of fish was retained in captivity and sampled regularly over 4.4 years. During that holding period, OTC marks were visible on 100% of the sagittae examined (Jenkins et al. 2002).

Otolith Morphology

Annulus distance among wild fish.—Incremental distance to the first annulus on otoliths was compared among the wild fish from 1993, 1994, 1995, and 1996 YCs. No significant differences in core to first annulus distance could be detected among the wild fish from the 1993, 1994, and 1996 YCs. The incremental distance for 1995 YC wild fish was not significantly different from that of the 1993 YC wild fish (df = 7, H = 178.22, $P < 0.001$; Table 2). The incremental distance for the 1994 and 1996 YC wild fish, however, was significantly greater than that for 1995 YC wild fish (Table 2).

Annulus distance among wild and hatchery fish.—Otoliths collected from wild and fall-stocked hatchery fish from the 1995 and 1996 YCs had significantly greater (df = 7, H = 178.221, $P < 0.0001$) core to first annulus distances than did OTC-marked fish separated from the catch by size as being of spring-stocked origin (Table 2).

Growth

Wild fish and hatchery fish released during the natural fall spawning season began to recruit to the sampling gear at age approximately 9 months (May). In general, spring-stocked fish were recruited to the gear in July (actual age = 3 months; apparent age = 11 months; Figure 2). Linear regressions of length (mm TL) versus actual age (months) of wild fish from the 1994, 1995, 1996, and 1997 YCs and fall- and spring-stocked hatchery fish from the 1995 and 1996 YCs were examined (Table 3). Growth (change in length) for each year-class of wild fish collected during May–November (ages 9–15 months) showed no difference in slope between the 1994 YC (prestocking) and 1995 YC (during stocking, low density) wild fish (t = 0.69, P = 0.4876) or the 1994 YC (prestocking) and 1997 YC (poststocking) wild fish (t = −1.38, P = 0.1668). However, differences in growth were detected between 1995 YC and 1996 YC (during stocking) wild fish (t = −3.23, P = 0.0013), the 1996 YC wild fish growing significantly faster. Growth rate of the 1996 YC wild fish (39.44 mm/month) was also significantly greater than that of the wild fish in both prestocking (1994) and poststocking (1997) year-classes. Growth of 1996 YC fall-stocked hatchery fish was not significantly different from their wild conspecifics from the 1996 YC (Table 3; Figure 2). Fall 1995 YC hatchery fish grew significantly more slowly than fish from all other year-classes (Table 3).

The fish stocked in spring from both year-classes were significantly smaller (shorter) each year than the wild or fall-released fish and could be separated from the catch by size (Figure 2). The growth rate for 1995 YC spring-stocked fish was significantly greater than that of wild (t = −5.35, P = < 0.001) or fall-stocked (t = 3.49, P = 0.0005) fish from the same year-class. However, the growth for the 1996 YC spring-stocked fish was significantly slower than for its wild- or fall-stocked cohorts, probably because the small sample size was insufficient to represent the high variability in

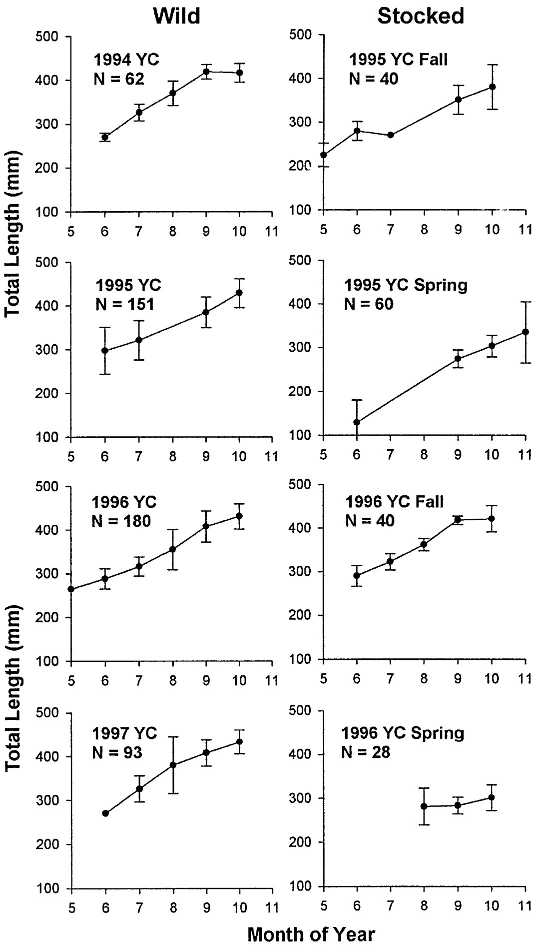

FIGURE 2.—Mean size (mm TL) ± SD for young of the year fish captured between May (month 5) and November (month 11) from the 1994, 1995, 1996, and 1997 (actual age, 9–15 months) wild year-classes and the 1995 and 1996 YC hatchery fish stocked in the fall (actual age, 9–15 months) and spring (actual age, 1–7 months).

growth; this is reflected by the low correlation coefficient associated with this group.

Hatchery Component

Of the 627 fish collected from the 1995 YC, 19.0% were of hatchery origin, whereas 19.4% of 687 fish collected from the 1996 YC were hatchery fish (Table 4). Fish of hatchery origin accounted for the largest segment of each year-class in the area immediately adjacent to the stocking site, 58.6% (1995 YC) and 77.3% (1996 YC) of all fish captured from the appropriate year-class being of hatchery origin (Table 5). Hatchery fish made up a larger portion of the population at age 0 and 1 than at age 2 (Table 4).

Spring versus Fall Release

During the study, approximately 974,000 fish were released in the spring and 601,000 in the fall (Table 1). A total of 252 fish of hatchery origin were captured and killed for further study. Fish classified as originating from spring releases were more numerous (132 fish) in the catch than those released in the fall (120 fish). However, given that 62% more fish were released in the spring, the weighted capture value for spring was less (13.6/100,000 fish released) than for the fall-released fish (20.0/100,000).

Sex Ratio

Most fish collected during the study were younger than age 2 and thus had not yet reached sexual maturity. This was especially true for the stocked fish. However, sex could be determined for 760 wild fish and 70 hatchery-origin fish. Among wild fish 52.4% were female and 47.6% were male, whereas 58.6% of hatchery-origin fish were female and 41.4% were male. Chi-square analysis indicated that the sex ratios of both wild and hatchery fish did not deviate significantly ($P > 0.05$) from

TABLE 3.—Regression statistics for total length (mm) versus actual age for wild fish (age 9–15 months) and hatchery fish released in the fall (age 9–15 months) and spring (age 1–7 months) and captured between May and November for the years 1994–1997. Total length = $\beta_0 + M\beta_1$. In this formula M = actual fish age in months, β_0 = intercept, and β_1 = slope. Growth rates followed by the same letter are not significantly different ($P > 0.05$).

Origin	Year class	Sample size (N)	β_0	β_1	r^2	Growth rate (mm/month)
Wild	1994	61	−49.76	34.78	0.74	34.8 y
Wild	1995	151	−31.85	32.38	0.65	32.4 y
Wild	1996	176	−115.79	39.44	0.83	39.4 z
Wild	1997	93	−77.30	36.65	0.69	36.6 y
Hatchery, fall	1995	37	54.74	22.26	0.66	22.3 x
Hatchery, spring	1995	58	46.27	44.72	0.78	44.7 z
Hatchery, fall	1996	38	−99.89	38.72	0.87	38.7 zy
Hatchery, spring	1996	26	186.69	19.22	0.39	19.2 x

TABLE 4.—Number of red drum stocked into each year-class, total number of red drum field collected, and number and percentage that were from hatchery releases, by age, in Port Royal Sound, South Carolina.

		Number Captured											
		Age 0			Age 1			Age 2			Sum all ages[a]		
Year-class	Number stocked	Total	Hatchery	%	Total	Hatchery	%	Total	Hatchery	%	Total	Hatchery	%
1995	347,000	65	21	32.3	354	93	26.3	204	5	2.5	627	119	19.0
1996	1,228,000	106	15	14.2	396	106	26.8	185	12	6.5	687	133	19.4

[a] Four age-3 fish were collected from the 1995 year-class; none were of hatchery origin. Fish from the 1996 year-class had not reached age 3 when collections ended in March 1999.

the expected 1:1 ratio reported previously for red drum in North Carolina (Ross et al. 1995).

Movement

Movement data analysis was restricted to the three primary sample sites. Fish of all ages were captured at other locations (e.g., Colleton and lower Broad rivers) but are not included in this analysis because of the limited sample size per site.

1995 year-class.—Fish from the 1995 YC began to recruit to the sampling gear at age 0 in the summer of 1996. Examination of fish captures at the three primary sites found that nearly all (fall 92.9%, spring 100%) of the age-0 hatchery fish were captured near the stocking site (site 1; Figure 3). Conversely, age-0 wild fish were captured at all three sites (Figure 3). At age 1, wild and hatchery fish from both fall and spring releases were collected at each of the three sites (Figure 3). At age 2, 86.1% of wild and 100% of fall-released hatchery fish were captured in the Chechessee River (site 3), 14 km from the release site (Figures 1, 3). Forty percent of spring-released hatchery fish in the 1995 YC were also captured at age 2 in the Chechessee River (site 3), while 60.0% were collected at Rose Hill Flats (site 2).

1996 year-class.—At age 0, few of the wild fish collected (7.3%) and no spring-released hatchery fish were captured near the release site (Figure 4). However, 29.2% of the age-0 fall-released hatchery fish were captured near the release site (Figure 4). Wild fish of all ages (0–2) were collected primarily on the large mudflats in the Chechessee River (site 3) near the main part of the sound (Figures 1, 4). Age-1 and−2 fall-released hatchery fish were captured at sites 2 and 3, but no age-2 spring-spawned fish were captured at any of the three sites (Figure 4).

Maximum documented extent of dispersal.—Between January 1997 and March 1999, samples were collected at sites outside the primary sampling area in the upper reaches of the Broad River (upstream from Highway 170 bridge) 30 km to the north (26 net sets), at the mouth of the Beaufort River 32 km to the east (5 net sets), and in the May River 35 km to the south (5 net sets). Sampling was expanded to these areas in an attempt to determine whether hatchery fish were moving out of the primary sampling area (Figure 1). No hatchery fish from the 1995 YC were recaptured at any of the remote sites. In addition, no hatchery fish were ever collected in the Beaufort River. However, 1996 YC hatchery fish began to be captured in the upper Broad River in November 1997 (at age 1), when 21.0% of the catch was of hatchery origin. During the next year, 16 of 91 (17.6%) fish collected in the upper Broad River were from 1996 YC hatchery releases. In January 1999, when we collected the final sample from the upper Broad River, 38.5% of the fish (5 of 13 fish retained from

TABLE 5.—Total number and percentage of all fish (ages 0–2) captured at each of three sample sites that were of hatchery origin for each of the two year-classes into which fish were stocked.

Sample site	Distance from release site (km)	Year-class	Total Number captured	Hatchery origin: Number	Hatchery origin: Percent
Callawassie Creek	0	1995	87	51	58.6
		1996	22	17	77.3
Rose Hill Flats	3	1995	95	31	32.6
		1996	96	48	50.0
Chechessee River	14	1995	190	27	14.2
		1996	277	36	13.0

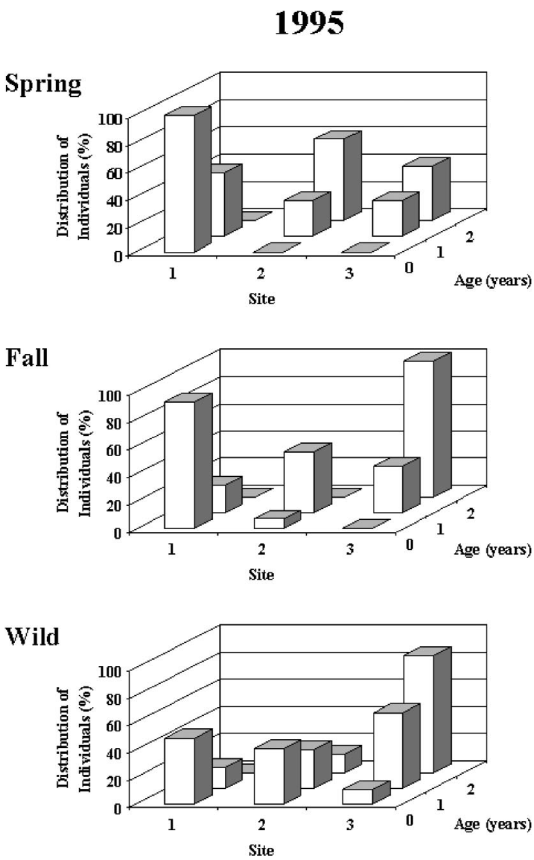

FIGURE 3.—Distribution of captures of individuals from the 1995 YC for wild fish and fall- and spring-stocked fish, by age (years), at the three primary sample sites. Percentages express the portion of each age-group that was captured at a particular site.

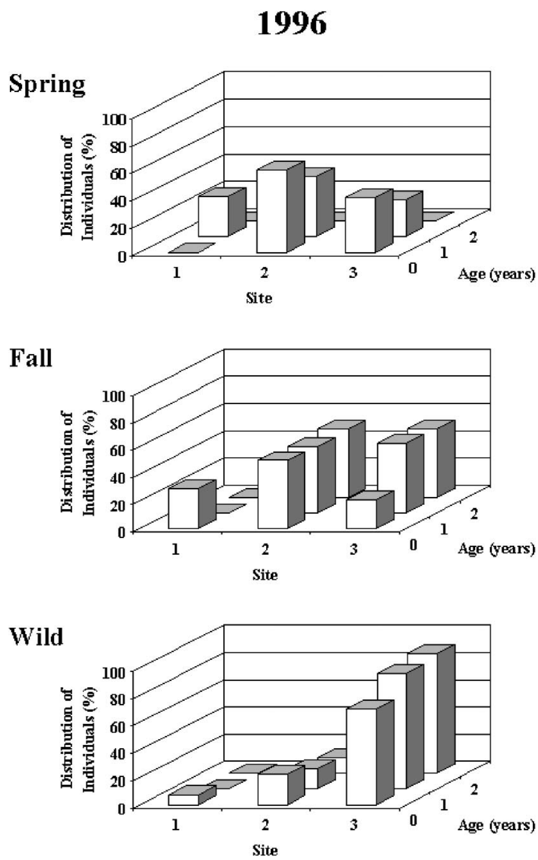

FIGURE 4.—Distribution of captures of individuals from the 1996 YC for wild fish and fall- and spring-stocked fish, by age (years) at the three primary sample sites. Percentages express the portion of each age-group that was captured at a particular site.

a catch of 40 fish >500 mm TL) were of hatchery origin. The May River site was sampled on only two occasions: February 6, 1997 (4 net sets) and March 3, 1999 (1 net set). During February 1997, 13 fish were retained from the 1995 YC but none were of hatchery origin. In March 1999, 12 fish were retained from the 1996 YC, of which one was of hatchery origin (8.3%).

Discussion

This study provides the first information available on the long-term interactions of stocked and wild red drum in the environment. Most previous work has relied on differences in mean size and short-term (90 d) monitoring of the hatchery population component in the wild (McEachron et al. 1995, 1998). The use of OTC to mark fish before release allowed positive identification of hatchery fish (Jenkins et al. 2002). Use of the trammel net allowed simultaneous data collection from multiple age- and size-classes of wild and hatchery fish as well as live release of nontarget species and 1,722 large red drum.

The study demonstrates that red drum stocked as early juveniles do survive and make up a large component of the local population in the 2 years immediately after stocking. There was no difference in growth of the 1996 YC wild or fall-released hatchery fish. However, fish stocked in 1995 at the lower density (629/ha) appeared to grow more slowly than did wild fish from the same and other year-classes. The cause for this difference is not apparent. Similar growth rates of wild fish from year-classes before (1994) and during (1995 and 1996) stocking suggest that the presence of stocked fish did not adversely affect the growth of wild fish. In addition, wild fish from the 1997 YC (poststocking) grew at the same rate as 1996 YC fall-released hatchery fish but not as fast as wild fish from the 1996 YC. Finally, growth rates of the 1996 YC wild and fall-released hatchery fish were among the fastest observed, suggesting that the high stocking density did not depress growth.

Otolith analysis allowed estimates of size at age 18 months, regardless of time of capture, for year-classes before stocking began. As with size at age, analysis of otolith characteristics did not reveal any pattern associated with stocking. For example, the incremental distance in the1993 YC was similar to that recorded during the stocking period, whereas the distance for the 1994 YC was significantly larger than that recorded for the 1995 YC. The lack of clear trends in either otolith characteristics or growth between year-classes indicates that the differences observed are more likely related to natural phenomena (e.g., hurricanes, year-class strength, wind direction during spawning season, rainfall, and winter water temperatures; Matlock 1987; Scharf 2000) than to the presence of stocked fish.

Stocking juveniles in the spring produced fish that were smaller than wild fish or fall-released hatchery fish at the same apparent age. Examination of otolith incremental distance for spring-released fish revealed that although the mean distances were larger than previously reported (Jenkins et al. 1997), spring-released fish still had significantly shorter distances to the first annuli than did either wild or fall-released hatchery fish. Validation of the utility of this technique indicates that it could be used for examining the contribution of spring-stocked fish that are not marked by some other method before release. The lower recapture rate observed for spring-stocked fish in the present study indicates that the efficacy of this stocking strategy needs further examination, particularly by programs that release red drum during multiple seasons (McEachron and Daniels 1995).

Releasing 3.5 times as many fish into the small nursery area for the 1996 YC as for the 1995 YC did not result in a proportional increase in the component of the year-class that consisted of hatchery-origin fish (19.4% versus 19.0%, respectively). The lack of difference in hatchery component between stocked year-classes may have been due to increased mortality of 1996 YC stocked and wild fish, the result of within-species competition for food and available habitat in the limited area stocked. This hypothesis is supported somewhat by the observed distribution at age 0 of both 1996 YC wild and spring-released hatchery fish after 523,000 fish were released in the fall. In contrast, when only 78,000 fish were stocked in the fall of 1995, fish from all three groups (wild and fall- and spring-stocked) were captured near the release site at age 0. However, the data are insufficient to distinguish between a density-dependent effect and other possible causes.

Using a single release site allowed us to monitor the dispersal of the stocked fish. This capability demonstrated the importance of protecting all essential fish habitat, given that fish stocked in a small (2%) portion of the total available nursery area dispersed to as far as 35 km from the site of release. In addition, nearly one in five fish collected from stocked year-classes in the estuary were of hatchery origin. In general, as hatchery-released fish grew older, they began to emigrate from the primary sampling area. Finding age-2 1996 YC hatchery-origin fish at both the May River (8% of captured fish) and the upper Broad River (38% of captured fish) during the last quarter of sampling (winter 1999) supports this conclusion.

Previous studies have documented that hatchery conditions result in skewed sex distributions in some species, for example, Japanese flounder *Paralichthys olivaceus* (Tanaka et al. 1998), Kemps Ridley sea turtles *Lepidochelys kempi* (Heppell and Crowder 1998), and Atlantic silversides *Menidia menidia* (Conover 1998). During the current study, we attempted to minimize the effects of hatchery selection and habituation to captive conditions by releasing the fish while they were still very young (30–45 d old). Providing for the fish to be at large for a long period after release allowed us to document that the sex ratio for the stocked fish mimicked that of the local and regional wild population (Ross et al. 1995). Documenting that hatchery-origin fish were maturing at the expected ratio, we demonstrated that, rather than being simply a ''put, grow, and take''-oriented program, the release of hatchery-produced red drum could result in the production of gametes and perhaps facilitate rebuilding of the spawning stock.

Unintended deleterious population genetic effects can be a concern when undertaking a stocking program (Utter and Epifanio 2002). However, based on mitochondrial DNA control region sequences, little population genetic structure has been identified among red drum along the Atlantic coast (Seyoum et al. 2000). This lack of population genetic structure may be due in part to the long life span of the species (>50 years) (Ross et al. 1995) and regular mixing of the offshore brood population (Seyoum et al. 2000). However, lack of an apparent genetic structure does not prove that the population is open. Several studies using techniques such as otolith composition or other characteristics have been useful in determining whether populations of various other species were truly open or closed (Thorrold et al. 2002). Microsatellite analysis of genetic samples collected statewide in South Carolina between 1990 and 1995 indicated that fewer than 300 families per year make a large contribution to each year-class (Chapman et al. 2002). This finding is similar to the ''sweepstakes effect'' described for Pacific oyster *Crassostrea gigas* recruitment (Li and Hedgecock 1998) and may be useful in understanding recruitment and population structure for species, like red drum, that exhibit high annual fecundity (Overstreet 1983). Chapman et al. (2002) also theorized that a properly managed hatchery program might be capable of increasing the effective population size.In combination, these findings suggest that stocking could be implemented with minimal danger of deleterious genetic effects, especially if only locally captured broodstock are used and are replaced annually.

Use of stocking as a management tool is an important component of fisheries management plans in freshwater reservoirs throughout the USA. In contrast, for anadromous and marine species, stocking is often viewed as having a greater potential for negative impacts than traditional management approaches (e.g., size and creel limits) do. This is especially true when inputs of stocked fish are used as an excuse to allow habitat destruction or overharvesting of wild fish (Meffe 1992). A growing body of recent evidence supports the efficacy of responsibly implemented marine fisheries enhancement (Blaxter 2000). The goal of traditional management and stocking are the same: increasing the abundance and sustainability of the target species population. The present study has produced new information about the fate of stocked fish in the wild. Stocking small fish (22–56 mm TL) resulted in the local hatchery component (contribution) being relatively large (approximately 19%), compared with a maximum of 5% observed in previous studies in South Carolina when larger (>100 mm TL) fish were stocked (Smith et al. 1997). Studies in Texas have also found that releasing small juveniles yields approximately a 20% contribution to the red drum populations in stocked bays (McEachron and Daniels 1995). Unfortunately, none of the studies completed to date has demonstrated conclusively that red drum abundance has been increased as a result of stocking. Now that culture, stocking, and marking techniques have been developed that result in the survival and detection of stocked fish in the wild, studies should begin to address the issue of supplementation versus displacement. This can be accomplished by focusing future experiments in areas for which long-term, randomly collected data on the abundance of red drum juveniles are available and by working in concert with population assessment biologists.

In conclusion, stocking has not previously been considered part of the regional management strategy for red drum. Based in part on the results of this and other studies, the Atlantic States Marine Fisheries Commission has recognized the need for evaluating the potential of using stocking to supplement wild populations of red drum (ASMFC 2002). Much remains to be learned about potential interactions with conspecifics, predator–prey relationships, and numerous other variables. However, by following a responsible approach, researchers can document the negative impacts and the benefits so that all appropriate management strategies can be used to achieve the overall management goal of a sustainable red drum population.

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References

ASMFC (Atlantic States Marine Fisheries Commission). 2002. Interstate fishery management plan for red drum, amendment 2. Fishery Management Report Number 38. Washington, D.C.

Blankenship, H. L., and K. M. Leber. 1995. A responsible approach to marine stock enhancement. Pages 167–175 *in* H. L. Schramm and R. G. Piper, editors. Uses and effects of cultured fishes in aquatic ecosystems. American Fisheries Society, Symposium 15, Bethesda, Maryland.

Blaxter, J. H. S. 2000. The enhancement of marine fish stocks. Pages 2–47 *in* A. J. Southward, P. A. Tyler, C. M. Young and L. A. Fuiman, editors. Advances in marine biology. Academic Press, New York.

Chapman, R. W., A. O. Ball, and L. R. Mash. 2002. Spatial homogeneity and temporal heterogeneity of red drum, *Sciaenops ocellatus*, microsatellites: effective population sizes and management implications Marine Biotechnology 4:589–603.

Conover, D. O. 1998. Local adaptation in marine fishes: evidence and implications for stock enhancement. Bulletin of Marine Science 62:477–493.

Denson, M. R., W. E. Jenkins, A. G. Woodward, and T. I. J. Smith. 2002. Sport angler's reporting of tagged estuarine dependant fish in South Carolina and Georgia. Fishery Bulletin 100:35–41.

Doersbacher, J. F., A. W. Green, G. C. Matlock, and H. R. Osburn. 1988. A temperature compensated von Bertalanffy growth model for tagged red drum and black drum in Texas bays. Fisheries Research 6: 135–152.

Geiger, J. G., and C. J. Turner. 1990. Pond fertilization and zooplankton management techniques for production of fingerling striped bass and hybrid striped bass. Pages 79–98 *in* R. M. Harrell, J. H. Kerby, and R. V. Minton, editors. Culture and propagation of striped bass and its hybrids. American Fisheries Society, Bethesda, Maryland.

Heppell, S. S., and L. B. Crowder. 1998. Prognostic evaluation of enhancement programs using population models and life history analysis. Bulletin of Marine Science 62:495–507.

Hussey, S., R. Southwick, J. Bergstrom, and J. Teasley. 2000. A study of the economic dependence of fishing tackle retailers in the southeast on marine recreational fisheries. American Sportfishing Association, Alexandria, Virginia.

Jenkins, W. E., M. R. Denson, C. B. Bridgham, M. R. Collins, and T. I. J. Smith. 2002. Retention of oxytetracycline-induced marks on sagittae of red drum. North American Journal of Fisheries Management 22:590–594.

Jenkins, W. E., M. R. Denson, M. R. Collins, and T. I. J. Smith. 1997. Differentiating between hatchery and wild red drum by position of first annulus on sagitta. North American Journal of Fisheries Management 17:1001–1004.

Jenkins, W. E., M. R. Denson, and T. I. J. Smith. 2000. Determination of angler reporting level for red drum (*Sciaenops ocellatus*) in a South Carolina estuary. Fisheries Research 44:273–277.

Kleinbaum, D. G., and L. L. Kupper. 1978. Applied regression analysis and other multivariable methods. Duxbury Press, North Scituate, Massachusetts.

Li, G., and D. Hedgecock. 1998. Genetic heterogeneity, detected by PCR-SSCP, among samples of larval Pacific oysters (*Crassostrea gigas*) supports the hypothesis of large variance in reproductive success. Canadian Journal of Fisheries and Aquatic Sciences 55:1025–1033.

Matlock, G. C. 1987. The role of hurricanes in determining year class strength of red drum. Contributions in Marine Science 30:39–47.

McEachron, L. W., R. L. Colura, B. W. Bumguardner, and R. Ward. 1998. Survival of stocked red drum in Texas. Bulletin of Marine Science 62:359–368.

McEachron, L. W., and K. Daniels. 1995. Red drum in Texas: a success story in partnership and commitment. Fisheries 20(3):6–8.

McEachron, L. W., C. E. McCarty, and R. R. Vega. 1995. Beneficial uses of marine fish hatcheries: enhancement of red drum in Texas coastal waters. Pages 161–166 *in* H. L. Schramm and R. G. Piper, editors. Uses and effects of cultured fishes in aquatic ecosystems. American Fisheries Society, Symposium 15, Bethesda, Maryland.

Meffe, G. K. 1992. Techno-arrogance and halfway technologies: salmon hatcheries on the Pacific coast of North America. Conservation Biology 6:350–354.

Mercer, L. P. 1984. Fishery management plan for the red drum (*Sciaenops ocellatus*) fishery. North Carolina Department of Natural Resources and Community Development, Morehead City.

NOS (National Ocean Service). 1997. High and low water predictions: east coast of North and South America. International Marine, Camden, Maine.

Overstreet, R. M. 1983. Aspects of the biology of the red drum, *Sciaenops ocellatus*, in Mississippi Gulf Research Reports (Supplement 1):45–68.

Roberts Jr., D. E., B. V. Harpster, and G. E. Henderson. 1978. Conditioning and induced spawning of the red drum (*Sciaenops ocellatus*) under varied conditions of photoperiod and temperature. Proceedings of the World Aquaculture Society 9:311–332.

Ross, J. L., T. M. Stevens, and D. S. Vaughan. 1995. Age, growth, and reproductive biology of red drums in North Carolina waters. Transactions of the American Fisheries Society 124:37–54.

Scharf, F. S. 2000. Patterns in abundance, growth, and mortality of juvenile red drum across estuaries on the Texas coast with implications for recruitment and stock enhancement. Transactions of the American Fisheries Society 129:1207–1222.

Seyoum, S., M. D. Tringali, T. M. Bert, D. McElroy, and R. Stokes. 2000. An analysis of genetic population structure in red drum, *Sciaenops ocellatus*, based on mtDNA control region sequences. U.S. National Marine Fisheries Service Fishery Bulletin 98:127–138.

Smith, T. I. J., W. E. Jenkins, and M. R. Denson. 1997. Overview of an experimental stock enhancement program for red drum in South Carolina. Bulletin of the National Research Institute of Aquaculture, Japan (Supplement 3):109–115.

Tanaka, M., T. Seikai, E. Yamamoto, and S. Furuta. 1998. Significance of larval and juvenile ecophysiology for stock enhancement of the Japanese flounder, *Paralichthys olivaceus*. Bulletin of Marine Science 62:551–571.

Thorrold, S. R., G. P. Jones, M. E. Hellberg, R. S. Burton, S. E. Swearer, J. E. Niegel, S. G. Morgan, and R. R. Warner. 2002. Quantifying larval retention and connectivity in marine populations with artificial and natural markers. Bulletin of Marine Science (Supplement 70/1):291–308.

Utter, F., and J. Epifanio. 2002. Marine aquaculture: genetic potentialities and pitfalls. Reviews in Fish Biology and Fisheries 12:59–77.

Vaughan, D. S., and J. T. Carmichael. 2000. Assessment of Atlantic red drum for 1999: northern and southern regions. NOAA Technical Memorandum NMFS-SEFSC-447.

Wenner, C. A. 1992. Red drum natural history and fishing techniques in South Carolina. 1992. Educational Report 17, South Carolina Wildlife and Marine Resources Department, Charleston.

Wenner, C. A. 2000. Contributions to the biology of red drum *Sciaenops ocellatus*, in South Carolina. Final Report. National Marine Fisheries Service, St. Petersburg, Florida.