Effect of Female Size and Propagation Methods on Larval Production at a South Carolina Striped Bass (*Morone saxatilis*) Hatchery[1]

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Larval production as a function of female size and hatchery propagation methods was examined for a South Carolina striped bass (*Morone saxatilis*) hatchery from 1988 to 1990. Female weight was not related to egg size or embryo survival among years or between source rivers of females. However, female weight was strongly related to number of hatched embryos due to its collinearity with fecundity. In 1988 and 1990, the offspring of 14 females contributed to 50% of hatchery production. In 1989, only six females contributed to 50% of larval production. In 1990, changes in propagation methods associated with improved female response to hormone injection resulted in more consistent rates of larval production among broods. While the deleterious effects of inbreeding on striped bass populations remain unknown, results indicate that extensive use of large females by hatcheries in fishery recovery programs could decrease effective population size.

Nous avons examiné de 1988 à 1990 la production de larves en fonction de la taille des femelles et des méthodes de propagation utilisées dans une écloserie de bar d'Amérique (*Morone saxatilis*) de Caroline du Sud. Le poids des femelles n'était pas relié à la taille des oeufs ni à la survie des embryons d'une année à l'autre ni selon le cours d'eau d'origine des femelles. Toutefois, le poids était fortement corrélé au nombre d'embryons éclos du fait de son lien colinéaire avec la fécondité. En 1988 et 1990, la progéniture de 14 femelles constituait 50 % de la production de l'écloserie. En 1989, six femelles seulement ont été responsables de 50 % de la production de larves. En 1990, des changements dans les méthodes de propagation, associés à une amélioration de la réponse des femelles à l'injection d'hormones, a permis d'obtenir des taux de production de larves plus réguliers entre les couvées. On ne connaît par les effets néfastes de la consanguinité sur les populations de bar d'Amérique, mais les résultats indiquent que l'emploi à grande échelle de femelles de grande taille dans les écloseries pour les programmes de rétablissement de la pêche pourrait faire baisser la taille effective des populations.

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Over the past decade, artificial propagation techniques have been used to supplement recruitment in declining striped bass (*Morone saxatilis*) fisheries. If hatchery techniques substantially increase early rates of survival and growth of embryos, larvae, and juveniles over those expected under natural conditions, then stocking programs can compensate for lost nursery habitat, spawning biomass, or environmental or anthropogenic perturbations.

The Moncks Corner (South Carolina) Hatchery was the first to develop and apply mass-propagation techniques to striped bass (Harrell 1984; Stevens 1984; Whitehurst and Stevens 1990). During each of its operating years, hundreds of large adult striped bass were collected with electroshocking equipment, principally from the Cooper River but also from the Santee River (Fig. 1). Their offspring were stocked into lakes and reservoirs throughout the United States. In 1986, the Jack D. Bayless Research Fisheries Hatchery (Bayless Hatchery) replaced the Moncks Corner Hatchery in compensation for a large water diversion project. Concurrent with hatchery relocation was a decline in fry (larvae) production (Fig. 2). The production decline was also coincident with a decline in the size and number of brood females available to the hatchery.

Since the early 1980s, serious declines in recruitment (White and Lamprecht 1989) required that stocking into the Santee–Cooper fishery be used as a method for augmenting natural recruitment. Similar or greater numbers of juveniles are stocked as those which naturally recruit (White 1989), and hatchery contribution rates to year-class strengths have exceeded 80% since 1989 (M. White, South Carolina Department of Wildlife and Marine Resources (SCDWMR), Bonneau, SC, pers. comm.). Hence, there is concern about the conservation of the

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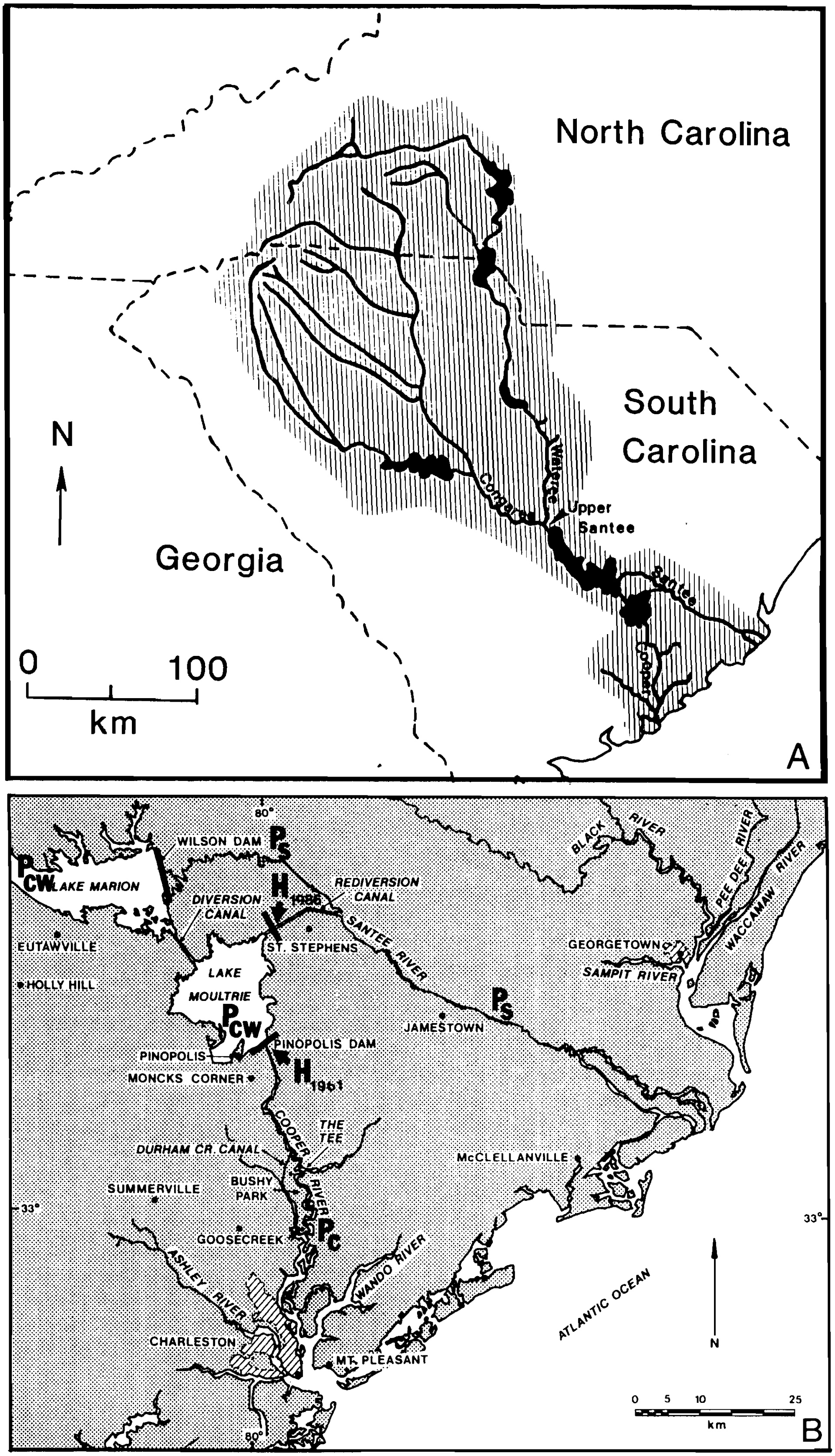

FIG. 1. (A) Santee River drainage basin. Rivers in which striped bass spawn are labeled. (B) Location of Santee–Cooper "subpopulations" and hatcheries within the lower Santee–Cooper system. Note that the Moncks Corner Hatchery (H1961) and the Bayless Hatchery (H1986) are located adjacent to the St. Stephens Dam and the Pinapolis Dam (indicated by bars), respectively. Juveniles are typically stocked into lower Lake Moultrie but in 1990 were also stocked into upper Lake Marion. P_c = Cooper River subpopulation; P_s = Santee River subpopulation; P_{cw} = Congaree/Wateree River subpopulation. Maps adapted from Kjerve (1989).

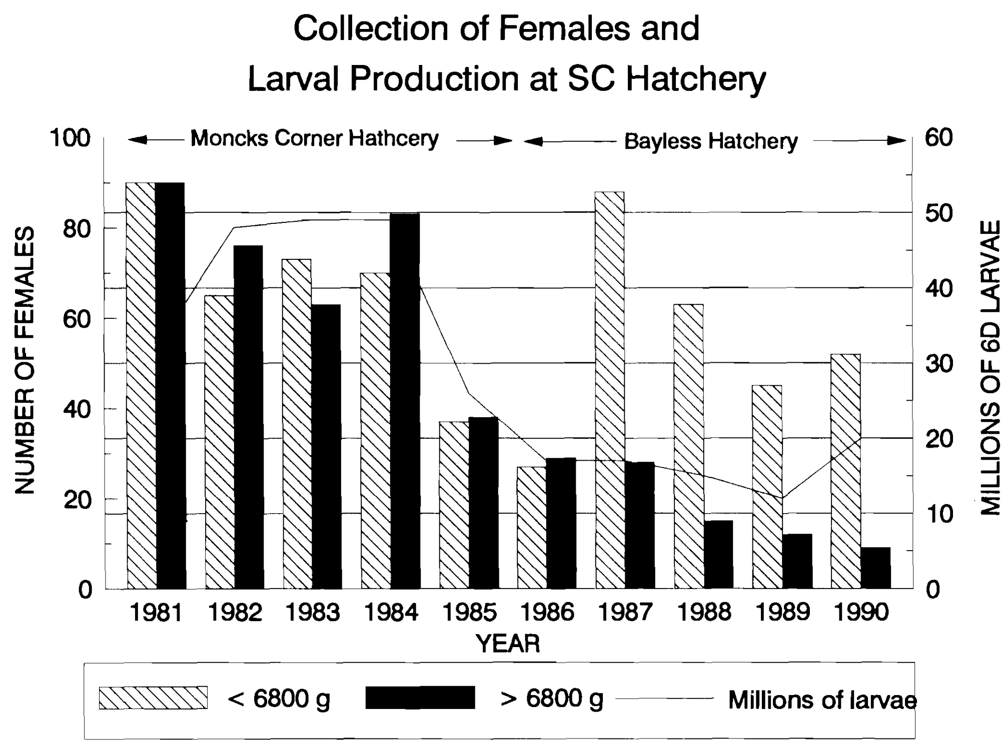

FIG. 2. Decline in brood female size and numbers and reduction of larvae since 1981. In 1984, rediversion began of the Santee–Cooper system's flow into the Santee River. In 1986, hatchery location changed from the Pinopolis Dam to the St. Stephens Dam.

genetic diversity in the Santee–Cooper population, especially during a period when declining numbers and sizes of females were available to the South Carolina hatchery.

Recent hatchery practices in South Carolina and elsewhere are to select the largest females available for propagation purposes (Kerby and Harrell 1990). This strategy is based on the assumption that these fish contribute the most and the highest quality eggs. Fecundity increases linearly with female weight (Lewis and Bonner 1966), and recent studies on Chesapeake Bay striped bass indicate that female size is positively related to egg size, quality, and viability (Zastrow et al. 1989; Monteleone and Houde 1990). However, hatchery propagation methods could affect fecundity and egg size relationships, and the advantage of using only large females at hatcheries has not been evaluated.

Our purpose was to investigate the influence of female attributes and hatchery production methods on striped bass embryo survival and hatchery output. This was studied during a 3-yr survey of practices and performance measures at the Bayless Hatchery. Questions considered included (1) how does female size influence hatchery production?, (2) how many brood females are successfully spawned, and effectively contribute to hatchery production?, (3) what are the relationships between artificial propagation techniques and survival of embryos and larvae?, and (4) what are the implications of using large females on genetic representation of offspring (effective population size). Analyses addressing these questions included size/fecundity relationships, the consequences of egg size on larval production, and among-brood variation in larval production (family size).

Methods

Hatchery Survey

Hatchery methods are described in detail in Bayless (1972) and Rees and Harrell (1990), and a description of specific hatchery operations over the period of the hatchery survey (1988–90) is given in Secor (1990). Females were collected by electrofishing in either the Cooper River or the Santee River. Fish were transported similar distances (in 1988 and 1989) from these rivers. In 1988 and 1989, it was apparent that Cooper River females were not producing as many larvae as Santee River females. Therefore, only Santee River broodstock were collected in 1990. In that year, a rediversion canal flowing into the Santee River and in greater proximity to the hatchery, was used as an additional source of Santee River broodstock (Fig. 1). Females were injected with 275–300 IU of human chorionic gonadotropin per kilogram of body weight to promote vitellogenesis and egg ripening. In 1990, hatchery well water (17°C) was heated to 19°C to increase the effectiveness of the hormone (J. Van Tassel, Department of Natural Resources, Maryland, P.O. Box 1136, Prince Frederick, MD 20678, pers. comm.).

Hatchery Operations and Female Measures

Data were collected on each brood female (Table 1). Measures related to hatchery operations were year (YEAR), site (RIVER), and collection date (DATE) of gravid females and response time to HCG injection (INJ). Measures related to the female were weight of the gravid female (WT), total weight of eggs stripped from the female (prior to fertilization and acti-

TABLE 1. Classification and abbreviations of hatchery measures and estimates.

Hatchery operations

YEAR: year (1988, 1989, 1990)
RIVER: river source for brood females (Santee or Cooper rivers)
DATE or D: day of the year when female collected
INJ or I: injection response (hours from HCG injection to ovulation)

Brood female

WT or W: total weight of female (kg)
ROE or R: total weight of stripped eggs (g)
EGGNO or E: total estimated number of stripped eggs

Egg size

WETEGG: wet egg weight (mg; used to estimate EGGNO)
ADJEGG: wet egg weight adjusted for water hardening (mg)
CHOR: chorion diameter (mm; used to adjust WETEGG)
YOLK or Y: yolk diameter (mm)
OIL or O: oil globule diameter (mm)
EGGWT or Ew: dry egg weight (μg)

Performance

FERT: fertilization rate estimated 3–4 h after stripping
HATCH: hatching rate estimated 40 h after stripping
SURV: overall survival of embryos (estimated as FRYNO/EGGNO)
FRYNO: estimated total number of hatched prolarvae

vation) (ROE), and total number of eggs (EGGNO). Total number of eggs was estimated by dividing total egg weight by individual wet egg weight which was measured from formalin-fixed samples.

Egg Size Measures

Measures related to egg size were oil globule (OIL) and yolk (YOLK) diameters and dry weight (EGGWT). Egg samples from brood females were taken after stripping and prior to fertilization and placed in 5% unbuffered formalin (Bulak et al. 1985). Egg samples could not be obtained from all females, but samples were not biased with respect to year, river, or date (Secor 1990). Twenty eggs were individually measured under a compound microscope at 120×. Oil globule, yolk, and chorion perimeters were digitized using a ZIDAS digitizing board and software. For each perimeter, a mean diameter was calculated. For dry weight measures, 30 eggs from each brood were immersed in distilled water for 2 min and placed in preweighed aluminum boats. Eggs were dried at 40°C for 24 h, placed in a vacuum desiccator to cool, and then weighed on an electronic microbalance. To determine individual wet egg weight, 30 eggs were drained on a piece of polyester screen and weighed on an analytical balance. Most egg samples partially hardened following fixation (e.g. chorion diameter was usually greater than egg diameter). To compensate, egg and chorion volumes were calculated using mean diameters. The average difference of these volumes was converted to weight by assuming a density of 1.0, and this difference was subtracted from the average wet egg weight to give adjusted wet egg weight (ADJEGG) for each brood. Precision error averaged 5% or less for all egg measures except for ADJEGG which averaged 10% (Secor 1990).

Performance Measures

Measures of hatchery performance were fertilization rate (FERT), hatching rate (HATCH), embryo survival rate (SURV), and total number of hatched embryos (FRYNO). Fertilization and hatching rates and number of hatched embryos were determined as part of hatchery procedure. Survival rate incorporated all sources of mortality from stripping to hatching and was calculated by dividing FRYNO by EGGNO. An analysis and discussion of precision of performance measures is given in Secor (1990).

Analysis

A subjective classification of production measures was applied to facilitate discussion of correlations (Table 1). To relate hatchery production measures, matrices of simple Pearson correlation coefficients were constructed. Linear regression models were used to relate individual production measures. Performance models were developed using a backward stepwise regression technique. Analysis of covariance (ANCOVA) was used to determine year and river effects on production relationships. Statistical analysis was performed using mainframe SAS and PC Statgraphic statistical software.

Results

River and Year Differences

Over the first 2 yr of the survey, significant differences in production measures occurred between females collected in the Cooper and Santee rivers (Table 2). Santee River fish were slightly smaller but performed much better in terms of response time to injection, fertilization, hatching, and survival rates and average number of hatched embryos. Due to these differences and the proximity of the rediversion canal to the hatchery (see Methods, Fig. 1), only Santee River broodstock was used during the 1990 hatchery season. To eliminate the confounding influence of this shift in hatchery procedures, RIVER effects were only examined for data from 1988 and 1989 and YEAR effects were analyzed for only Santee River brood females. Since YEAR effects were significant for DATE and YOLK (Table 2B) and comparisons of means showed that 1988 and 1989 were similar but significantly less than 1990 measures, 1988 and 1989 data were pooled and compared with 1990. Three Pearson correlation matrices were also constructed: (1) Cooper River broods from 1988 and 1989 (Table 3A), (2) Santee River broods from 1988 and 1989 (Table 3B), and (3) Santee River broods from 1990 (Table 3C). River comparisons are between matrices 1 and 2 and year comparisons are between matrices 2 and 3.

Hatchery Operation Effects

Santee River broods were not as strongly affected by DATE or INJ as Cooper River broods (Table 3A versus 3B). Date was positively correlated with egg size and performance measures for both rivers and indicated improvement of hatchery performance later in the season. Cooper River brood measures EGGNO, OIL, and EGGWT were also significantly related to date, suggesting that Cooper River fish might not be as prepared to ovulate as Santee River fish over the hatchery season. Duration of female response to hormone injection was inversely related to egg size for all years (Table 3A and 3B) and fertilization in 1988 and 1989 (Fig. 3). Cooper River brood performance parameters were more tightly linked to INJ (Table 3A versus 3B), again suggesting that these fish were not as advanced in their reproductive cycle as were Santee River fish.

In 1990, changes in hatchery methods appear to have reduced the effect of hatchery operations on performance (Table 3B ver-

TABLE 2. Comparison of means (t-test) between (A) rivers and (B) years. River comparisons were made for only 1988 and 1989; year comparisons were made for only Santee River broods. *significant difference in comparison at $P = <0.05$; SD = standard deviation. For hatchery abbreviations and units of measurements on hatchery estimates, see Table 1.

A. River comparisons for 1988 and 1989 data

	Santee River		Cooper River			
Measure	$\bar{X}$ (SD)	N	$\bar{X}$ (SD)	N	t	P
DATE	106 (10)	42	109 (12)	62	−1.3	0.2
INJ*	38.5 (5.9)	42	41.9 (5.9)	62	−2.9	0.004
WT*	5642 (2045)	39	6376 (1441)	59	−2.1	0.04
ROE	746 (520)	40	833 (347)	56	−1.0	0.3
EGGNO × 1000	826 (535)	34	1010 (433)	45	−1.7	0.09
YOLK	1.03 (0.07)	37	1.03 (0.08)	48	0.3	0.7
OIL	0.61 (0.047)	37	0.61 (0.05)	48	−0.3	0.7
EGGWT	256 (40)	37	259 (43)	48	−0.4	0.7
FERT*	0.43 (0.23)	42	0.32 (0.22)	60	2.4	0.02
HATCH*	0.84 (0.28)	41	0.71 (0.16)	45	2.0	0.05
SURV*	0.30 (0.25)	34	0.17 (0.16)	45	2.7	0.009
FRYNO × 1000*	290 (344)	42	175 (174)	62	2.2	0.03

B. River comparisons for Santee River data

	1988–89		1990			
Measure	$\bar{X}$ (SD)	N	$\bar{X}$ (SD)	N	t	P
DATE*	106 (10)	42	100 (12)	61	2.9	0.00 4
INJ	38.5 (5.9)	42	40.1 (7.0)	61	−1.3	0.2
WEIGHT	5641 (2045)	39	5634 (1479)	61	0.02	1.0
ROE	746 (520)	40	831 (346)	60	−1.0	0.3
EGGNO × 1000	826 (535)	34	1026 (520)	43	−1.7	0.1
YOLK*	1.03 (0.07)	37	1.09 (0.05)	44	−4.1	0.0001
OIL	0.61 (0.047)	37	0.63 (0.03)	44	−1.4	0.2
EGGWT	256 (40)	37	249 (33)	44	−0.8	0.4
FERT	0.43 (0.23)	42	0.42 (0.22)	59	0.4	0.7
HATCH	0.84 (0.28)	41	0.80 (0.31)	61	0.5	0.6
SURV	0.30 (0.25)	34	0.36 (0.20)	43	−1.2	0.2
FRYNO × 1000*	290 (344)	42	322 (251)	61	−0.5	0.6

sus 3C). However, significant negative correlations did occur between reproductive output (ROE and EGGNO) and DATE; the weight and number of eggs decreased as the season progressed. Most noteworthy is the absence of INJ effects on all performance measures (Table 3C).

Female Effects

Female weight was highly correlated with ROE and EGGNO across rivers and years. The relationship of egg number to female weight was not affected by year (ANCOVA; Cooper River data excluded: $N = 76$; $F = 2.57$; $P = 0.083$) or river (ANCOVA; 1990 data excluded: $N = 78$; $F = 0.10$; $P = 0.75$). Fecundity for mature females was estimated at 230 000 eggs/kg (Fig. 4) which is consistent with published reports of Atlantic Coast striped bass populations (Setzler-Hamilton et al. 1980). FRYNO was also highly correlated with female weight; correlations were stronger for Santee River broods than for Cooper River broods (Fig. 5). Female weight was not related to egg size among years or between rivers (Table 3). Santee River data for 1988–89 showed significant correlation between female weight and egg survival (Table 3B), but as shown below, this was probably due to colinearity of female weight with ROE where ROE explained most of the variation in egg survival (see Best Model for Hatchery Production).

Egg Size Effects

The relation of egg size to performance varied dramatically between rivers and years. Most egg size measures were correlated with performance during 1988 and 1989, but no correlations occurred for 1990 (Table 3; Fig. 6). This may be the result of less variance in egg size and performance measures for 1990 (Table 2B). Peformance for Cooper River broods was related to all measures of egg size in contrast with performance for Santee River broods which was only related to yolk diameter and dry egg weight.

Best Model for Hatchery Production

Because many measures might be collinear in their effects, a stepwise regression analysis was used to model performance measures for each data group. Significant differences in models occurred between rivers and years (Table 4). In the Santee River (1988, 1989), performance was related to INJ and reproductive output measures (Table 4A). Because female weight was not selected in this procedure, its effects on fertilization rate (Table 3A) must be collinear with reproductive output measures. Cooper River performance was almost exclusively related to INJ (Table 4B). In 1990, only FRYNO showed significant correlation with surveyed measures; SURV, HATCH, and FERT were all independent of hatchery operations, female, and egg size effects (Table 4C).

TABLE 3. Pearson correlation matrices for various measures and estimates. (A) 1988–89, Cooper River data; (B) 1988–89, Santee River data; (C) 1990, Santee River data. Coefficients are only listed if significant at $P < 0.05$; otherwise, a dash is listed. For abbreviations and units of measurements on hatchery estimates, see Table 1.

	D	I	W	R	E	Y	O	Ew
A. 1988–89, Cooper River								
Hatchery operations								
DATE	1							
INJ	−0.50	1						
Female effects								
WT	—	—	1					
ROE	—	—	0.69	1				
EGGNO	−0.28	—	0.58	0.89	1			
Egg size								
YOLK	0.73	−0.53	—	—	—	1		
OIL	0.55	−0.49	—	—	—	0.76	1	
EGGWT	0.37	−0.61	—	0.37	—	0.77	0.69	1
Performance								
FERT	0.46	−0.60	—	—	—	0.54	0.39	0.61
HATCH	—	−0.52	—	—	—	0.35	0.32	0.50
SURV	0.38	−0.61	—	—	—	0.49	0.38	0.50
FRYNO	—	−0.43	0.29	0.50	0.38	—	—	0.39
B. 1988–1989: Santee River								
Hatchery operations								
DATE	1							
INJ	−0.52	1						
Female effects								
WT	—	—	1					
ROE	—	—	0.92	1				
EGGNO	—	—	0.88	0.94	1			
Egg size								
YOLK	0.55	−0.66	—	—	—	1		
OIL	—	−0.43	—	—	—	0.70	1	
EGGWT	—	−0.49	—	—	—	0.63	0.68	1
Performance								
FERT	0.43	−0.64	0.51	0.56	—	0.51	—	0.33
HATCH	—	−0.46	—	—	—	0.35	—	0.34
SURV	0.48	—	0.40	0.44	0.36	0.47	—	—
FRYNO	—	—	0.84	0.89	0.38	0.21	—	—
C. 1990, Santee River								
Hatchery operations								
DATE	1							
INJ	−0.44	1						
Female effects								
WT	—	—	1					
ROE	−0.30	—	0.85	1				
EGGNO	−0.32	—	0.82	0.90	1			
Egg size								
YOLK	0.38	−0.41	—	—	—	1		
OIL	—	—	—	—	—	0.50	1	
EGGWT	—	−0.40	—	—	—	0.80	0.71	1
Performance								
FERT	—	—	—	—	—	—	—	—
HATCH	—	—	—	—	—	—	—	—
SURV	—	—	—	—	—	—	—	—
FRYNO	—	—	0.55	0.58	0.61	—	—	—

Variance in Hatchery Peformance: Year, River, and Brood

The number of hatched embryos per female was significantly greater for Santee River broods than for Cooper River broods (Table 2). Performance was much more strongly related to female weight in the Santee River than in the Cooper River (Fig. 5). The plot for the Santee River showed that most of the production came from the eight largest females.

To examine yearly variation in production rates among broods, females were ranked in ascending order of performance and plotted against cumulative number of fry for each year. River data were combined for this analysis (Fig. 7). Note that for all years, the top-ranked female produced about 10% of the entire year's production. In 1988 and 1990, 14 females contributed to 50% and 40 females contributed to 90% of hatchery

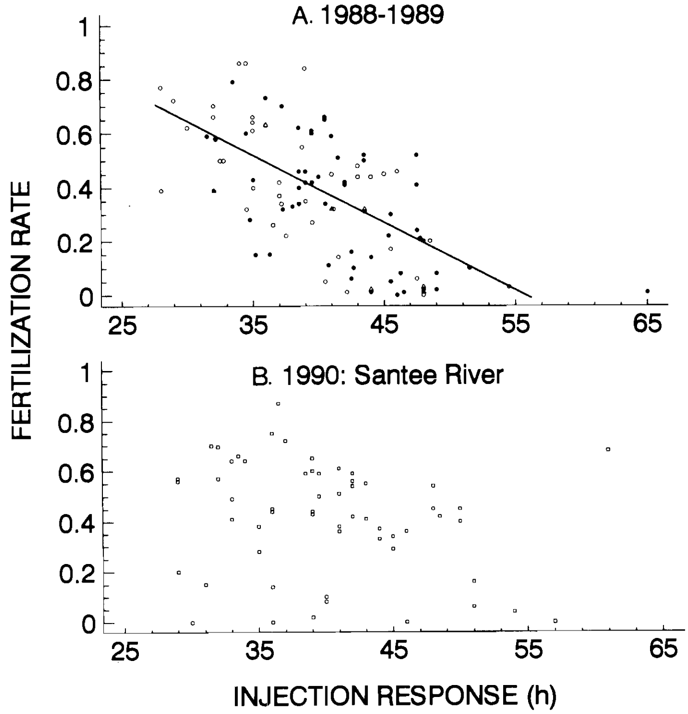

FIG. 3. Injection response versus fertilization rate for (A) 1988–89 data and (B) 1990 data. Cooper and Santee rivers are shown by solid and open symbols, respectively. (A) 1988–89 (regression from pooled Santee and Cooper River data): FERT (%) = 1.328 − 0.0239 · INJ (h); N = 111; F = 56; P = 0.0001; R^2 = 0.34. (B) 1990: FERT (%) = 0.710 − 0.000729 · INJ (h); N = 59; F = 3.3; P = 0.07; R^2 = 0.05. 1990 (outlier removed): FERT (%) = 0.777 − 0.00955 · INS; N = 58; F = 40; P = 0.05; R^2 = 0.068.

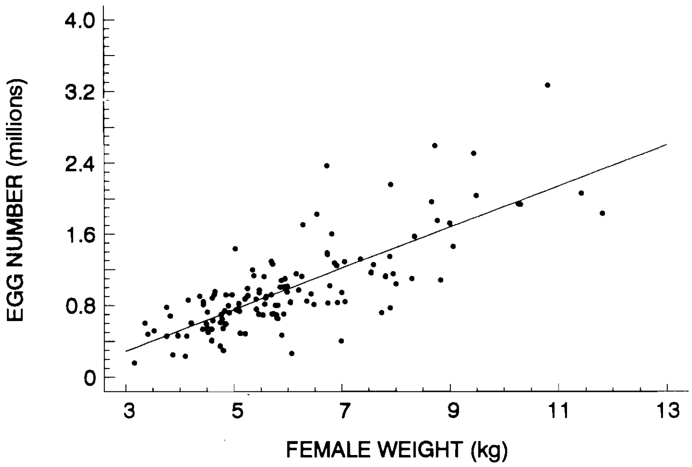

FIG. 4. Female weight versus number of eggs stripped. EGGNO = −400,193 + 230 722 · WT (g); N = 129; F = 185; P = 0.0001; R^2 = 0.59.

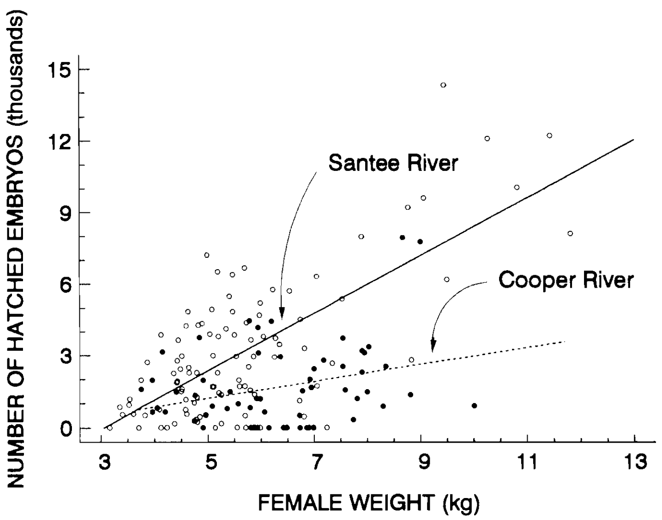

FIG. 5. Female weight versus number of hatched embryos for 1988–89 data. Santee River (open symbols): FRYNO = −51 535 + 144 487 · WT (g); N = 39; F = 91; P = 0.0001; R^2 = 0.71. Cooper River (solid symbols): FRYNO = −55 694 + 35 365 · WT (g); N = 59; F = 5.5; P = 0.02; R^2 = 0.09.

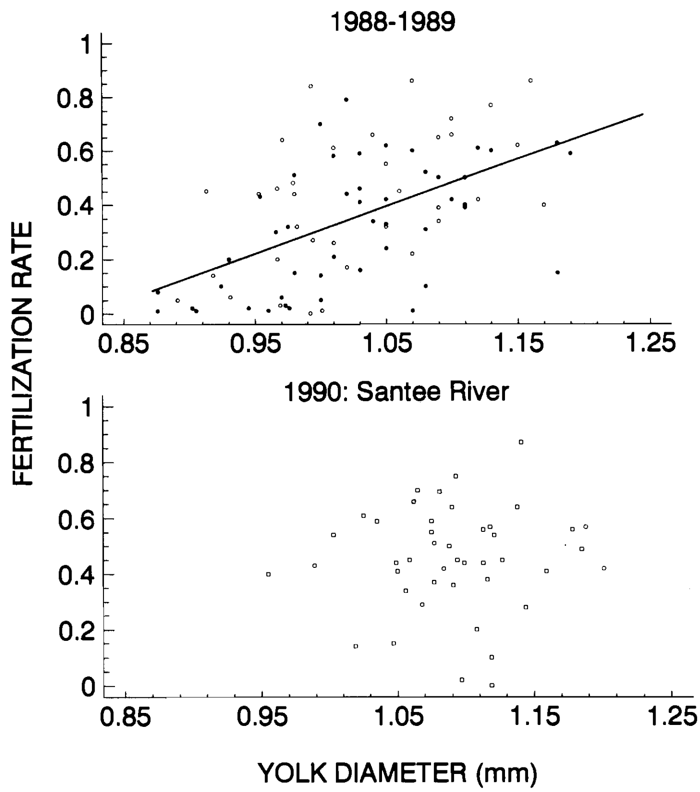

FIG. 6. Mean yolk diameter versus fertilization rate for (A) 1988–89 data and (B) 1990 data. Cooper and Santee Rivers are shown by solid and open symbols, respectively. (A) 1988–89 (regression from pooled Santee and Cooper River data): FERT (%) = −1.399 + 1.713 · YOLK (mm); N = 91; F = 28.5; P = 0.0001; R^2 = 0.24. (B) 1990: FERT (%) = 0.205 + 0.227 · YOLK (mm); N = 44; F = 0.2; P = 0.7; R^2 = 0.00.

production. In contrast, the 1989 season produced 50% of its production from only six females and 90% of its production from 16 females.

Embryo survival rates averaged from 17 to 30% between rivers and from 22 to 36% among years. This is approximately twofold higher than embryo survival rates reported in Virginia rivers (Olney et al. 1991).

Discussion

The hatchery currently stocks the Santee–Cooper reservoirs at a rate of 2–3 million juveniles per year. Natural recruitment in the Congaree/Wateree stock was estimated to be between 200 000 and 800 000 juveniles per year in 1983 and 1984 (White 1989). If survival of stocked juveniles is even a small fraction of natural juvenile survival (e.g. 5%), then the hatchery

TABLE 4. Best models for hatchery performance. (A) 1988–89, Santee River; (B) 1988–89, Cooper River; (C) 1990, Santee River. Variable inclusion based on backwards stepwise regression procedure. For hatchery abbreviations and units of measurements on hatchery estimates, see Table 1.

Performance measure	Selected variables	Coefficient	t	P	R^2
		A. 1988–89, Santee River			
FERT	Constant	1.070	—	—	—
	INJ	−0.0213	−5.0	0.000	—
	ROE	0.000245	5.1	0.000	0.67
HATCH	Constant	1.711	—	—	—
	INJ	−0.0232	−3.0	0.005	0.20
SURV	Constant	1.197	—	—	—
	INJ	−0.0261	−5.3	0.000	—
	EGGNO	1.490	2.6	0.01	0.52
FRYNO	Constant	5.223	—	—	—
	INJ	−1.865	−5.2	0.000	—
	EGGNO	0.607	14.5	0.000	0.88
		B. 1988–89, Cooper River			
FERT	Constant	0.422	—	—	—
	INJ	−0.0144	−2.5	0.02	—
	EGGWT	0.00194	2.3	0.02	0.45
HATCH	Constant	2.119	—	—	—
	INJ	−0.0341	−4.3	0.000	0.29
SURV	Constant	0.852	—	—	—
	INJ	−0.0160	−5.1	0.000	0.36
FRYNO	Constant	5.090	—	—	—
	INJ	−1.311	−3.8	0.000	—
	ROE	261.4	4.2	0.000	0.44
		C. 1990, Santee River			
FERT	—	—	—	—	—
HATCH	—	—	—	—	—
SURV	—	—	—	—	—
FRYNO	Constant	1.615	—	—	—
	ROE	450.2	5.7	0.000	—
	OIL	−2.635	−2.8	0.008	0.46

is making a notable contribution (e.g. 13%) to local stocks. Preliminary studies on poststocking survival based on recent collections by SCDWMR of marked juveniles and young adults (Secor et al. 1991) indicate contribution rates which are substantially higher than this hypothetical case (M. White, SCDWMR, Bonneau, SC, pers. comm.).

Broodstock Effects

The Santee–Cooper hatcheries have typically targeted the biggest females in their collections because large females were thought to produce not only greater numbers of eggs but better quality eggs. Results of the survey show that, for the size range tested, female size was related neither to egg size nor egg viability. Female size was correlated with number of fry in all years and egg viability for Santee River in 1988 and 1989 due to its collinearity with number of eggs. Therefore, hatchery production rates have declined as a result of declines in overall numbers of eggs rather than egg quality.

The lack of a positive relationship between female size, egg size, and egg survival was unexpected, given research on other striped bass populations. Rogers and Westin (1981) collected eggs from the Moncks Corner Hatchery and hatcheries on the Hudson River and Chesapeake and found a positive correlation between combined data for egg weights and female lengths. However, their fig. 4 (p. 106) shows no correlations for either the Santee–Cooper or Hudson populations. The significance of the least squares regression from data of the combined populations was entirely due to the Chesapeake population which also showed the greatest range in female length and egg weight. Zastrow et al. (1989) collected eggs from two hatcheries on the Chesapeake and observed strong correlations between egg size and female weight and egg size and embryo survival and weaker correlations between female size and embryo survival. Egg dry weights for the Chesapeake females (170–430 μg) were only slightly greater than those for Santee–Cooper females (130–370 μg). However, over half of the Chesapeake females ranged between 9 and 23 kg whereas fewer than 10% of the Santee–Cooper females ranged above 9 kg and the biggest female weighed 12.2 kg. The lack of correspondence of the survey's results with those of Zastrow et al. (1989) could be due to the differences in range of female weights, differences in populations, or differences in hatchery operations.

Artificial Propagation Effects

Hatchery operations themselves were probably more important in production results than were broodstock effects. For instance, larger Cooper River females did not produce proportionately greater amounts of larvae. Also, greater numbers of larvae were produced in 1990 than in previous years without an increase in female size. Heating hatchery water to promote injection response and using exclusively Santee River females

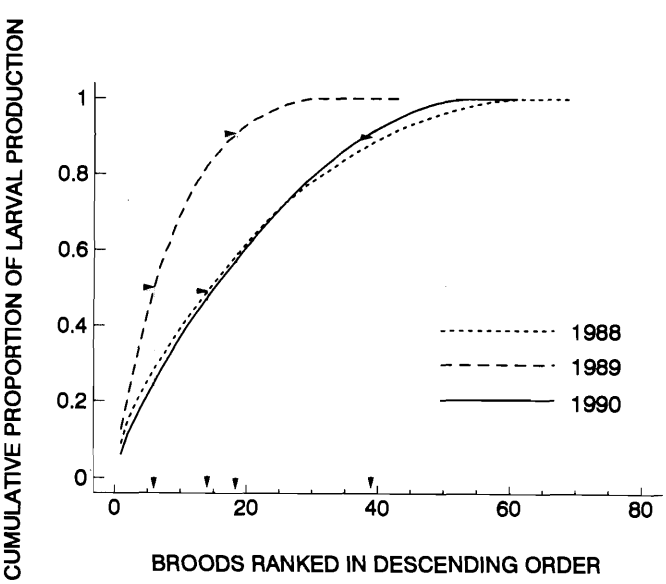

FIG. 7. Ranked broods versus cumulative production rates. Broods are ranked each year by FRYNO in descending order and plotted against percentage of annual production of larvae. Arrows indicate 50 and 90% larval production rates (see text).

in 1990 significantly reduced the effects of hatchery operations (DATE and INJ) and simultaneously increased performance.

An alternative explanation for the reduced effect of hatchery operations in 1990 is decreased transport time of the females due to greater proximity of the hatchery to the collection site. Typical transport time (time in hauling tank) was between 30 and 60 min in 1988 and 1989 and between 5 and 10 min in 1990. In 1988–89, a 1900-L hauling tank with oxygenated water was used and no immediate mortality was observed. Occasionally, females were held for periods of up to 3 h with no mortality observed. In 1990, single females were hauled in 300 L of water. It is our belief that mortality due to transport is related to handling rather than transport time. Because the number of times individual fish were handled was similar among years, we attribute the lack of hatchery effects in 1990 to the change in temperature at which females were held for ripening at the hatchery.

Temperature effects on larval production can be indirectly related to date and river source of broodstock. The Bayless Hatchery starts its season as soon as females can be collected to insure that it meets stocking demands. Water temperature varies between 13°C at the beginning and 21°C at the end of the season (F. W. Sessions, pers. obs.). Peak spawning in the Congaree and Wateree rivers typically occurs at a temperature of 20°C (Bulak et al. 1985). If Santee and Cooper females spawn at similar temperatures, then natural spawning should occur during the latter part of the hatchery season. This could explain the positive correlation between date, egg size, and performance. The Cooper River is typically several degrees cooler than the Santee River during April, and therefore, performance was reduced for Cooper River females. The lack of an effect of date on egg size and performance in 1990 was probably due to heating the water in which females were held to 19°C, a temperature close to that occurring during peak spawning in nature. In 1988 and 1989, females were held in hatchery water at 17°C and presumably egg development was retarded (Rees and Harrell 1990).

Eggs spawned in nature may be larger on average than those produced artificially. Oil globules from a sample of field-collected eggs range from 3 to 15% larger than hatchery-collected egg oil globules (Secor 1990). We speculate that hatchery-spawned eggs are smaller because vitellogenesis has been accelerated by artificial means and is therefore incomplete. To some extent, this may be rectified by raising the temperature during final egg ripening, as was done at the Bayless Hatchery in 1990.

Because egg performance was related to hatchery operations, we cannot discount the effect of female size on egg quality in naturally spawning populations. Large females could be very important members of a spawning population due to either increased egg quality or reproductive output (Zastrow et al. 1989; Monteleone and Houde 1990). However, in the hatchery, female size caused increased hatchery output only through increased fecundity and did not improve egg viability. Therefore, a prudent strategy for minimizing the hatchery's impact on the genetic structure of natural populations would be to use many smaller females rather than fewer larger ones.

Hatchery Contribution to Natural Stocks

In 1990, the overwhelming majority of stocked juveniles in upper Lake Marion (a primary stocking site for the Santee–Cooper system) were the offspring of a single female (92%). While this may be a rare occurrence for the Santee–Cooper Recovery Program, other state and federal agencies typically use very few females in their stocking programs (Kerby and Harrell 1990). Clearly, the topic of genetic conservation in recovery programs is relevant to most striped bass populations.

Effective population number (N_e) is used to evaluate the potential for inbreeding in small populations which do not meet the criteria of an ideal population (Falconer 1981; Gall 1987). The probability of inbreeding is inversely related to N_e (Falconer 1981). To contrast genetic representation of hatchery-produced progeny among years, N_e was calculated to correct for unequal family sizes (Crow and Kimura 1970). Under the assumption of an equal male to female ratio, calculated N_e values were 92, 59, and 110 for 1988, 1989, and 1990, respectively. The lower N_e in 1989 could not be completely accounted for by the fewer females used that year. For instance, 28% fewer females were used in 1989 than in 1990, but N_e was 46% less for 1989 than for 1990. Genetic representation of larvae was affected by variance of family sizes which was influenced by female size and hatchery propagation methods. Recommended levels of N_e for broodstock used in fishery recovery programs range from 200 (Kincaid 1976) to 424 (Tave 1986).

The effect of genetic bottlenecks and inbreeding is complex in striped bass, which are iteroparous, long-lived, and have highly variable recruitment rates. Information on the genetic structure of striped bass populations is limited (Chapman 1989, 1990; Wirgin et al. 1989) but suggests that observed low levels of genetic variation are related to migratory and spawning behaviors which periodically restrict N_e (Chapman 1990). Until more is known about the deleterious effects of inbreeding in striped bass populations, a conservative strategy towards increasing N_e in stocking programs would be prudent. This would include selecting female sizes which are representative of their proportion in the natural spawning population (Falconer 1981). In the absence of dominant year classes, this will mean using greater numbers of small females which should result in more consistent production and increased N_e.

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