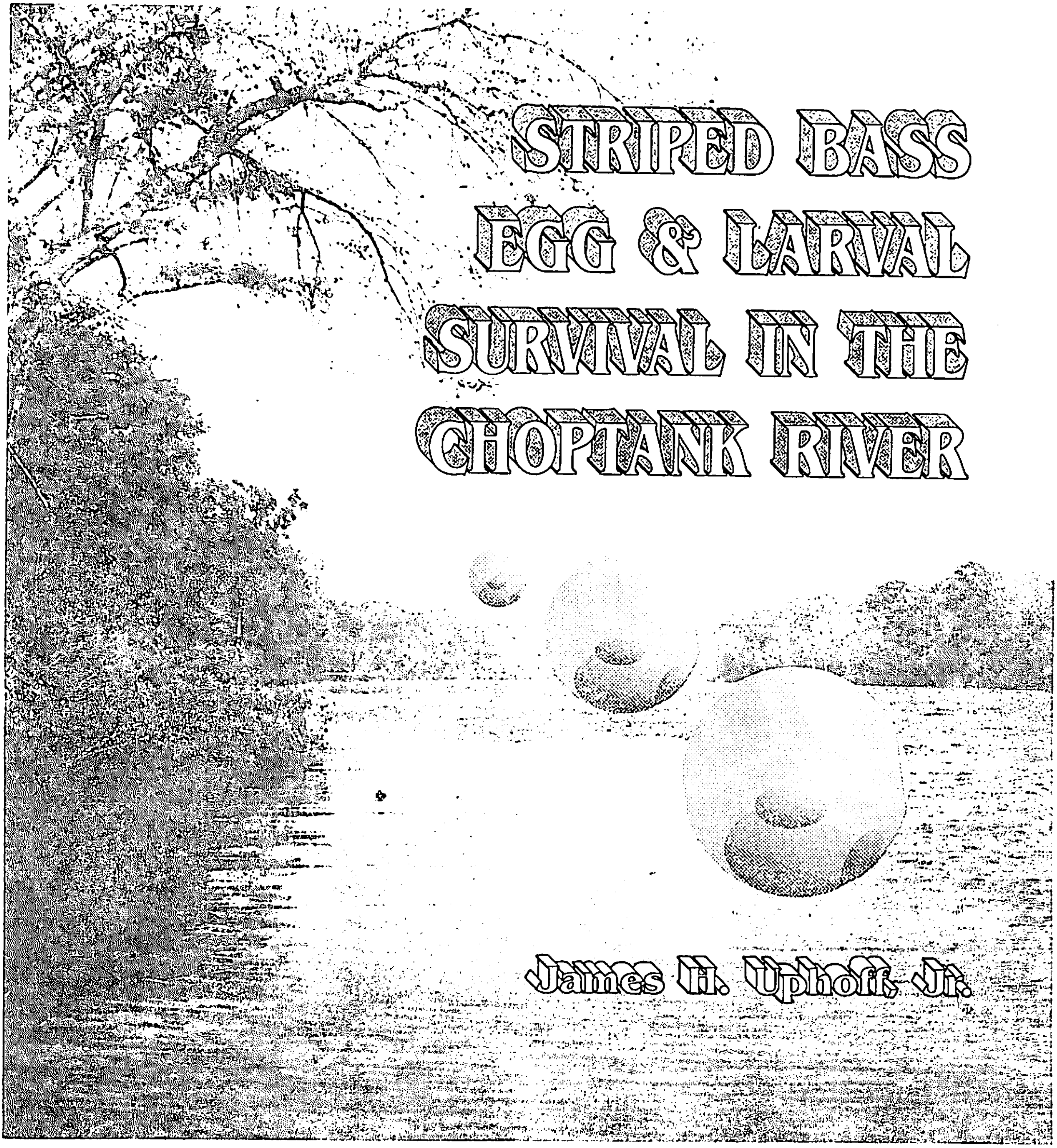

# STRIPED BASS EGG & LARVAL SURVIVAL IN THE CHOPTANK RIVER

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Maryland Department of Natural Resources
Tidewater Administration

CHESAPEAKE BAY RESEARCH
AND MONITORING DIVISION

CBRM-HI-92-1

As Secretary of the Maryland Department of Natural Resources, I am convinced that public support of DNR's mission is essential if we are to restore the State's once bountiful natural resources, especially the Chesapeake Bay, to the level which earned the title "America in Miniature". The information in this publication is designed to increase your understanding of our program and of Maryland's natural resources.

Torrey C. Brown, M.D.

PRINTED ON RECYCLED PAPER

# Survival of Eggs, Larvae, and Juveniles of Striped Bass in the Choptank River, Maryland, in Relation to Environmental Conditions During 1980-1988

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January 1992

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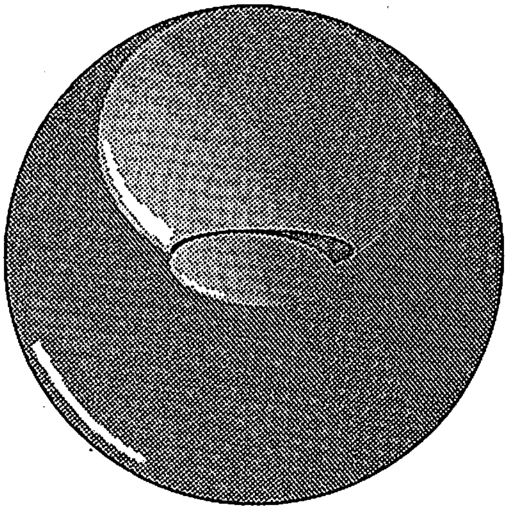
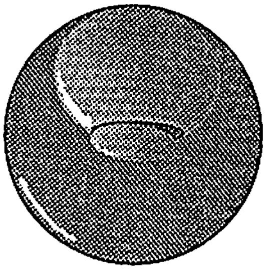
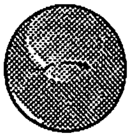
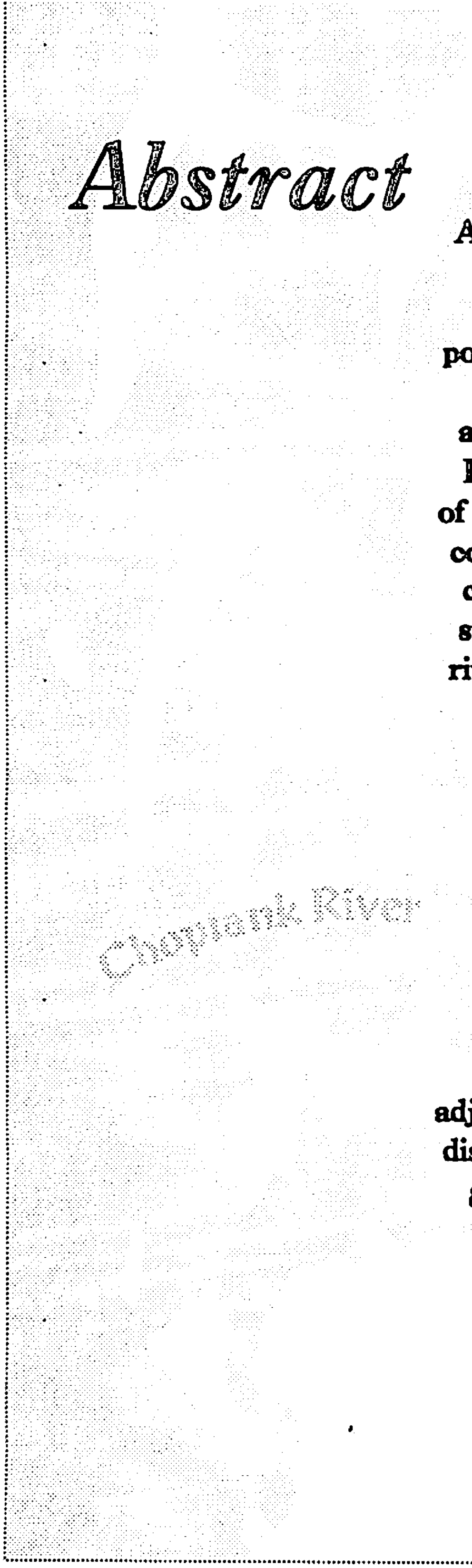


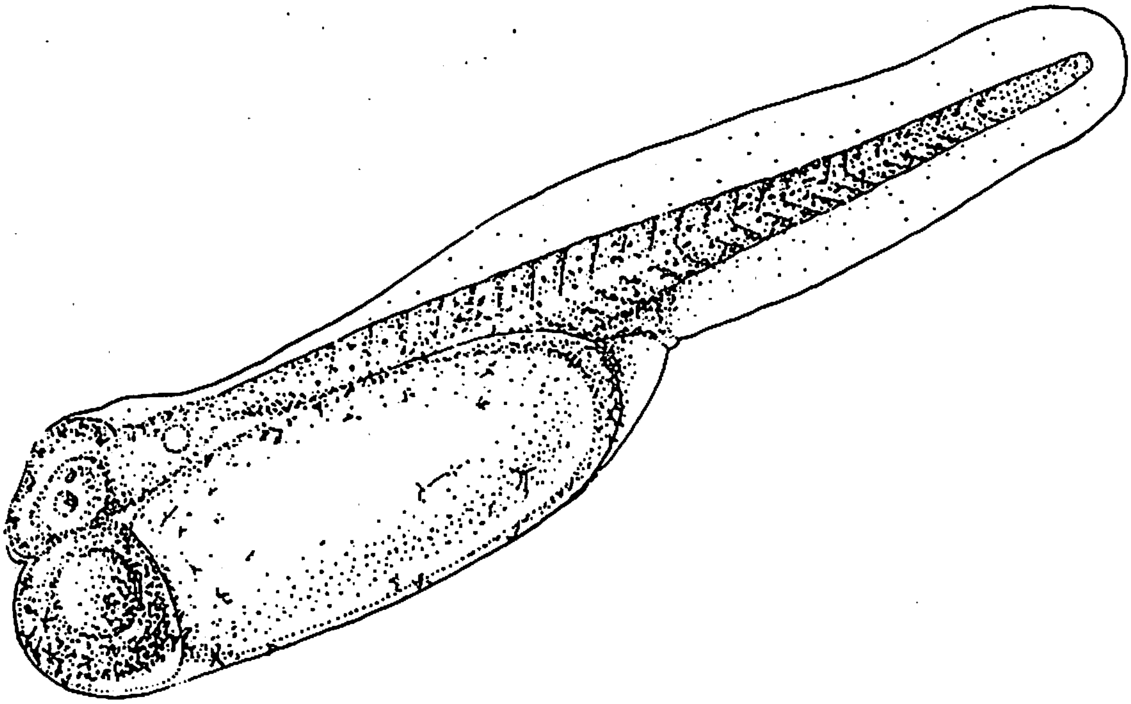




# Abstract

Eggs, prolarvae, and early juvenile striped bass *Morone saxatilis* were sampled weekly from April to mid-June 1980-1988 in the Choptank River, Maryland. Survival estimates varied from 0.3% to 37% for eggs and prolarvae and 0.9-41% for postlarvae. Year-class success was significantly related to minimum water temperature during peak spawn and mean river flow during the postlarval life stage. Low water temperatures (11-12° C) reduced survival of eggs and prolarvae. River discharge was negatively correlated with postlarval survival and growth. Mean conductivity was positively associated with postlarval survival and growth. Significant correlations between river discharge, mean conductivity, and minimum pH suggested that these variables were not independent influences on survival or growth. Concentrations of dissolved copper, lead, and cadmium (available for 1986 and 1987 only) approached or exceeded U.S.E.P.A. chronic and acute freshwater water quality criteria. Early life stage survival explained 63-83% of the variation in the Choptank River juvenile index. No statistically significant parent-progeny relationship was determined from abundance of eggs and 12 mm larvae after adjustment for climatic effects. Moderate to high river discharge apparently depressed postlarval survival and growth by diluting ionic concentrations and creating acidic, potentially stressful, and toxic conditions.





# INTRODUCTION

Recruitment and landings of Chesapeake Bay striped bass *Morone saxatilis* declined steeply after 1970 and were low from 1980-1988 (Boreman and Austin 1985). This decline was attributed to decreased first year survival, overfishing of adults, or a combination of these factors (Goodyear et al. 1985). Striped bass population levels historically have displayed large annual fluctuations. Ulanowicz and Polgar (1980), Logan (1985), and Uphoff (1989) suggested year-class success was largely independent of adult abundance and dependent upon environmental conditions which affected early life stage survival. However, Goodyear and Christensen (1984) warned that the effects of broodstock on striped bass recruitment would be difficult to detect because of the influence of environmental factors. The larval stage is believed to be the most critical; larval survival rates determine juvenile numbers and year-class strength is established before the juvenile life stage (Polgar 1977; Goodyear et al. 1985; Uphoff 1989).

The decline in yield of striped bass resulted in greater concern for management of striped bass and for research to identify the responsible factors (Goodyear 1985b). The two most commonly stated reasons for this decline were overfishing and toxic contaminants in the environment. Both factors affect yield similarly and their simultaneous effects would be indistinguishable from either factor acting alone. Toxic contaminants may depress survival of young in the freshwater reaches of the spawning grounds or accumulate in the organs of spawners and reduce their fecundity (Goodyear 1985b). Inorganic contaminants and changes in water quality have been implicated in the reduction of striped bass young-of-the-year production in some Chesapeake Bay spawning rivers during some years (Hall 1988). Body burdens of some hydrocarbons in Chesapeake Bay striped bass have been reported at levels which could affect reproduction and survival (Setzler-Hamilton et al. 1988).

Austin and Ingham (1978) and Crecco and Savoy (1984, 1987) recommended an empirical-statistical approach for resolving the effects of environment on fish recruitment. They recommended offering a working hypothesis and then testing its validity with empirical data and a thorough statistical analysis, rather than regressing lagged environmental and recruitment data in hopes of obtaining significant statistical fits. Once a causal relationship is established, the environmental factors known to affect recruitment can be incorporated into parent-progeny (stock-recruitment) models to measure density-dependent effects (Crecco and Savoy 1987). Treating environmental and stock effects together provides a unified approach to understanding recruitment variability (Gulland 1983; Crecco et al. 1986).

I used data from the Choptank River, Maryland, collected during the 1980-1988 striped bass spawning seasons to investigate two working hypotheses postulated for the decline of Chesapeake Bay striped bass populations: (1) survival of young was depressed due to inorganic contaminants in the spawning grounds; and (2) year-class success was attributable to stock size (Goodyear 1985b). The established effect of low water temperature on year-class success (Uphoff 1989) was factored into the analysis.

# METHODS

## Collection and Laboratory Procedures

### *Early life stages*

Striped bass eggs and larvae were sampled weekly from April to mid-June 1980-1988 with a 3.05 m box trawl made of 1.27 cm stretch mesh knotless nylon and with a 1.53 m x 1.53 m midwater trawl. The mouth of the midwater trawl (approximately 1 m deep) was made of 3.18 cm stretch mesh nylon and the remainder of the net was 1.27 cm stretch mesh nylon. Cod ends of both nets had 0.5 mm liners; net openings were maintained by 0.5 m diameter hoops. All trawls were towed at 3.7 km/h for 2 min in the same direction as the tidal current. Sampling was conducted during daylight hours (usually in the morning).

In 1980-1986, four stations were sampled within the Choptank River striped bass spawning area (hereafter referred to as "spawning area"): river km (Rkm) 47.2, 56.8, 67.0, and 79.0 (Figure 1). One site per day was sampled and all samples collected during a weekly sample interval were taken within five days of each other. The uppermost site was moved from Rkm 79.9 to 79.0 after the 1980 season to avoid excessive detritus concentrations which negatively affected trawl performance. Two bottom (about 5-8 m deep) and two midwater tows (0.5-2 m below surface) were made in the channel at all four stations. Two inshore bottom trawls (1-2 m) per station were made at Rkm 47.2-67.0. Use of this gear was not possible at Rkm 79.0 because shallow areas were not extensive enough for trawling above Rkm 67.0.

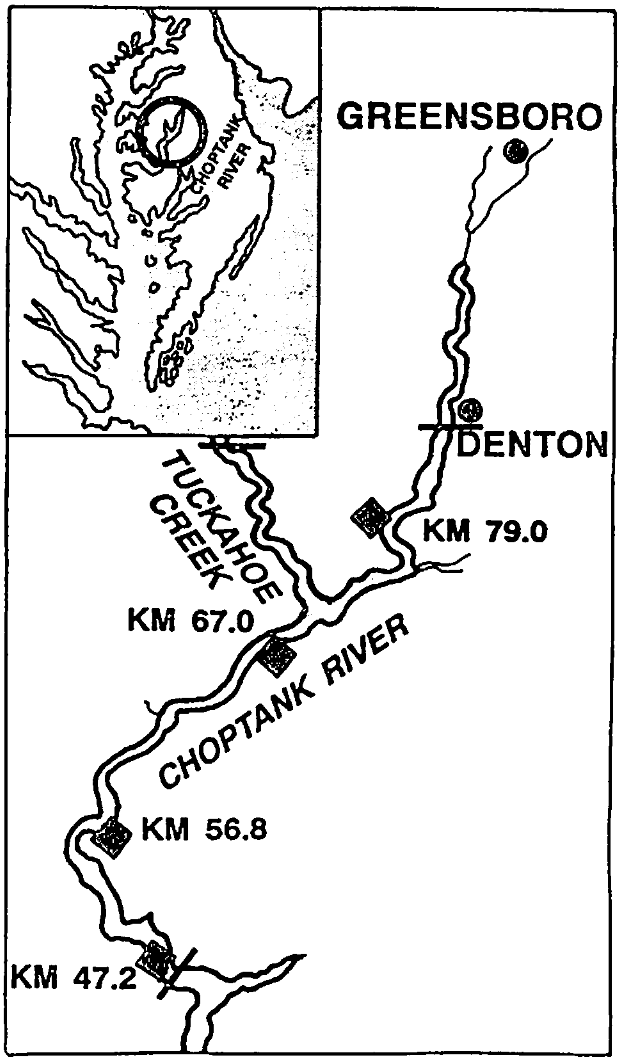


Figure 1.-Location of sampling stations for striped bass eggs and larvae within the Choptank River, Maryland, striped bass spawning area. Diamonds were the locations of fixed stations used during 1980-1986. Bars denote the upper and lower limits of the 1987-1988 sampling area; alternating clear and shaded areas are 1.61 km segments used in the stratified-random design. KM = river kilometers measured from the mouth of the river.

During 1987-1988, stratified random sampling was conducted. The Choptank River spawning area, starting at Rkm 47.2 and proceeding upstream, was divided into 1.61 km segments (Figure 1), 17 in the river proper and four in Tuckahoe Creek (starting at the mouth). These segments were aggregated into four subareas, three subareas were roughly bounded by the four fixed stations sampled from 1980-1986 and Tuckahoe Creek was the remaining subarea. These subareas maintained the geographic coverage of the fixed stations used previously and incorporated a suspected important tributary. The lower Choptank area consisted of the first 5 segments; the middle, segments 6-11; the upper, 12-17; and the Tuckahoe, 18-21. Sampling locations were visited randomly within a week, with each subarea having a minimum of one visit. I sampled 8-12 stations per week. Based upon Uphoff (1989), a bottom and a midwater trawl were made at each visit prior to the last week of May to sample prolarvae and postlarvae. An additional inshore tow was made, where possible, from the last week of May through the end of sampling (early June through mid-July) to sample early juveniles (Uphoff 1989). Inshore trawls were not possible above the mouth of Tuckahoe Creek because of increasingly sheer river channel walls and an absence of shoals.

Ichthyoplankton samples were stained with rose bengal and preserved in 10% formalin. In the laboratory, organisms were identified to the lowest practical taxonomic level and life stage. The structural definitions of Rogers et al. (1977) were used to differentiate life stages. Striped bass and white perch *Morone americana* larvae were abundant in samples; *Morone* specimens between 11 and 14 mm total length (TL) were cleared and stained to aid identification (Fritsche and Johnson 1981). The total lengths of striped bass prolarvae (larvae with yolk), postlarvae (larvae that had absorbed their yolks), and juveniles (post-metamorphic stages) were measured to the nearest millimeter. All striped bass larvae and juveniles in a sample were measured if there were fewer than 30. Otherwise, a subsample of 30 was selected.

### *Water quality*

Water quality measurements were routinely made within the spawning area at two fixed stations during 1983-1985, five fixed stations during 1986 (occasional samples were taken at five other stations), and at each station sampled for larvae during 1987-1988. Surveys were conducted two days per week during 1983 and 1985, and at least four days per week during the remaining years. Temperature, conductivity, and pH measurements were made with a Hydrolab at the surface, mid-depth, and bottom (2 m intervals in 1984). Integrated surface-to-bottom samples were drawn for alkalinity (1983-1988), hardness (1983-1985), and inorganic contaminants (1986-1988) at each station visited. Samples were placed in acid-washed containers and refrigerated immediately.

Total dissolved metals concentrations were determined using high performance ion chromatography on filtered (0.40 µm polycarbonate) samples acidified with Ultrex$^{tm}$ grade nitric acid. Lower detection limits for metals were 0.002 mg/L for Cd; 0.004 for Cr, Cu, Mn, and Zn; 0.020 for Ni; and 0.010 for Pb.

## Estimation of Vital Population Parameters

### *Temporal distribution of eggs, larvae, and juveniles*

Changes in life stage-specific weekly catches per trawl were used to determine the temporal distribution of eggs, larvae, and juveniles. The larval stage included both prolarvae and postlarvae.

### *Growth*

Instantaneous growth rates (G) were estimated by fitting the weekly increase in mean length (TL) to the exponential growth equation

$$\log_e L_t = \log_e L_0 + G(X_t)$$

where $L_t$ = mean length during week t, $X_t$ = number of days from the first week to week n, and $L_0$ = length at hatch.

By using mean length to estimate growth, it was assumed that all individuals followed the same growth trajectory. This estimate described growth of individuals under average conditions, but not growth variations which individual larvae might have exhibited under different conditions (Kaufmann 1981).

*Mortality*

Weekly length-abundance distributions were constructed by multiplying the proportion of fish in each 1-mm length interval ($p_i$) of the length-frequency distribution by weekly total catch ($n_i$). Weekly length-abundance ($N_i = p_i * n_i$) estimates for 1987-1988 were adjusted to an effort of 22 trawls, the weekly effort for 1980-1986. Weekly catch totals of fish in each length interval were then summed across the entire sampling season. To compare relative abundance among years, seasonal catch totals ($\sum N_i$) were adjusted to the season of least sampling effort by multiplying by the proportion $T_m/T_n$; $T_m$ was the number of trawls during the year of least effort, and $T_n$ was the number of trawls during season n. Adjusted weekly efforts were summed to calculate $T_n$ for 1987 and 1988.

Each year's instantaneous growth rate was applied as a time scale to the length-abundance distribution to develop an instantaneous mortality rate estimate for postlarvae. For convenience, 6-12 mm fish were categorized as postlarvae, although late prolarvae and early juveniles were also present in this length group (Uphoff 1989). Between 6 and 12 mm, each 1-mm length interval was assigned a relative age (in days) according to that year's growth equation by back-calculating the time needed to grow from 6 mm to a given length. Relative age was calculated as

$$X_t = (\log_e L_n - \log_e 6) / G$$

where $X_t$ = relative age or days past 6 mm, $L_n$ = 1-mm length interval from 6-12 mm, and G = instantaneous growth rate.

To estimate postlarval mortality (average for all cohorts), I regressed the natural logarithm of abundance in the catch at each millimeter size class against relative age. Mortality rates were calculated for each year as

$$\log_e N_{12} = \log_e N_6 - Zt$$

where Z = instantaneous mortality rate for the entire length interval, $N_{12}$ = predicted number of 12 mm larvae at age t, and $N_6$ = number of 6 mm larvae at the beginning of the time interval.

Daily mortality rate (M) was calculated as

$$M = 1 - e^{-Z}$$

The accuracy of this estimate depended on how well estimated growth rates depicted actual growth and whether fish within the selected size range were equally susceptible to the sampling gear (Uphoff 1989).

Larvae smaller than 6 mm declined in relative abundance with decreasing size in samples (Uphoff 1989), so I estimated egg ($N_E$) and 6 mm larvae ($N_L$) abundance (described below) and used $N_L$ / $N_E$ to estimate survival through the egg and prolarval stages. This equation was used to estimate prolarval survival, although postlarvae are present at 5 and 6 mm (Uphoff 1989). I chose this estimate of survival because it did not require an age estimate. Estimates of fish survival based on this ratio often are used, but have been shown to be somewhat too large (Ricker 1975). I also used $\log_e$-transformed catch abundance of 6 mm larvae as an indicator of relative yearly survival through the prolarval stage. This estimate was potentially biased by changes in stock abundance.

*Abundance*

Yearly abundance indices were calculated from the densities of eggs ($N_E$), early postlarvae (6 mm larvae, $N_L$), and prejuveniles (12 mm larvae, $N_{Jd}$). Water volume sampled by each tow was calculated from the fishing time, trawling speed, and cross-sectional area of the mouth of the liner (Kernehan et al. 1981). Density was calculated by dividing the catch of eggs or larvae in a trawl by the water volume sampled. I assumed that the liner had a circular opening while fishing and the targeted stages were only retained by the liner and not the trawl. No adjustments were made for extrusion or gear efficiency, therefore, standing crop estimates underestimated population size (Polgar 1977; Dey 1981). For 1980-1986, weekly mean density of each life stage in a segment between two fixed stations was multiplied by segment river volume (Cronin 1971). The volumes of the upper (km 79.0 to 67.0), middle (km 67.0 to 56.8), and lower (km 56.8 to 47.2) segments were $9.7 \times 10^6$, $21.0 \times 10^6$, and $26.5 \times 10^6$ m$^3$, respectively. The three segment abundances were summed to obtain a weekly standing crop estimate for the spawning area. Weekly standing crops for 1987-1988 were estimated by multiplying weekly mean density by the Choptank River spawning area volume ($57.2 \times 10^6$ m$^3$). The yearly abundance index equalled the summed weekly standing crop estimates. Tuckahoe Creek was not included in this analysis because stations were not located in this tributary during all years. A second prejuvenile (12 mm larvae) abundance index ($N_{Jm}$) based on abundance of 6 mm larvae and postlarval mortality rates was calculated by

$$\log_e N_{Jm} = \log_e N_L - Zt$$

where Z is the instantaneous mortality for the 6 to 12 mm interval; $N_{Jm}$ is the prejuvenile abundance index at age t; and $N_L$ is the 6 mm abundance index. Previously discussed estimates of $N_L$, Z, and t were used.

Abundance indices included yearly differences in spatial distribution which were not accounted for by measures of relative abundance in the catch. The influence of spatial distribution on estimating relative abundance was investigated by regressing the log$_e$-transformed total catch of eggs, 6 mm, or 12 mm larvae (adjusted for differences in seasonal effort by multiplying by $T_m/T_n$) with their respective log$_e$-transformed abundance indices.

## Statistical Analysis

### *Early life stage abundance versus recruitment*

Correlations between recruitment, measured by the Choptank River juvenile index (CJI, mean catch per standard seine haul) from 1980-1988 (Boone 1985; Goodyear 1985a; Early 1988) and early life stage catch per effort, total catch, and abundance were examined. Yearly catch totals of individual size-groups between 3 and 23 mm and the CJI were correlated to examine at what sizes and life stage year-class trends emerged. The relative abundance of late postlarvae and early juveniles, measured by the log$_e$-transformed catch per trawl (all trawls combined) for the last two weekly sampling intervals in common among years (last week of May and first week of June) was correlated with the log$_e$-transformed CJI. I correlated log$_e$-transformed egg, 6 mm larvae, and prejuvenile abundance estimates with the CJI to test their potential as indices of recruit abundance.

### *Hydrographic fluctuations, larval survival, larval growth, and recruitment*

Each sampling season was partitioned into peak spawn and postlarval time periods for correlation and regression analyses (Uphoff 1989). The time interval needed to collect 85% of the eggs was designated as the peak spawning period for each year. The postlarval period began one week after the midpoint of the last weekly sample interval during peak spawning and lasted for the time estimated for larvae to grow in length from 6 to 12 mm. This approach simplified the entire spawning period into a single larval cohort.

The effects of water temperature on survival between the egg and prolarval stages was tested with linear regressions of both log$_e$-transformed catch of 6 mm larvae and $N_L/N_E$ against minimum water temperature (recorded in the spawning area) during peak spawning. Postlarval survival or instantaneous growth rates were correlated with minimum and mean water temperature, total rainfall (measured by the National Oceanic and Atmospheric Administration at Denton, Maryland), and mean river flow (measured by the United States Geological Survey at Greensboro, Maryland) during the postlarval period (Uphoff 1989). River flow, water temperature, and rainfall were chosen because of their documented effect on fish populations (Crecco and Savoy 1984). Both survival and growth were analyzed because environmental factors usually affect rates rather than absolute numbers (Ricker 1975) and modest changes in either rate could have caused major changes in recruitment levels (Houde 1987).. Nonlinear regressions were used to test relationships between the CJI and the joint effects of environmental factors significantly associated with (1) egg and prolarval survival; and (2) postlarval survival (Uphoff 1989). The multiplicative effect of environmental conditions on year-class success required the use of nonlinear regression because variables could not be transformed to satisfy the assumptions of linear models (Afifi and Clark 1984; Crecco and Savoy 1987).

|  |  | Station Boundaries (km from river mouth) |  |  |
|---|---|---|---|---|
| Year | Area | Lower | Upper | *N* |
| 1983 | Choptank | 56.8 | 67.0 | 2 |
|  | Tuckahoe | - | - | - |
| 1984 | Choptank | 59.1 | 69.1 | 2 |
|  | Tuckahoe | - | - | - |
| 1985 | Choptank | 56.8 | 67.0 | 2 |
|  | Tuckahoe | - | - | - |
| 1986 | Choptank | 56.8 | 79.0 | 9 |
|  | Tuckahoe | - | 6.4 | 1 |
| 1987 | Choptank | 60.0 | 80.6 | 10 |
|  | Tuckahoe | 1.6 | 6.4 | 3 |
| 1988 | Choptank | 56.8 | 79.0 | 11 |
|  | Tuckahoe | 0.0 | 6.4 | 4 |

**Table 1. Station boundaries (km from river mouth) and number of stations within boundaries used to summarize water quality conditions in the Choptank River and Tuckahoe Creek during 1983-1988 postlarval periods. Boundaries represent lower and upper stations where striped bass larvae were found. Dash indicates no stations were sampled.**

*Water quality and postlarval survival*

Water quality data collected during the postlarval period from stations where striped bass larvae were present (Table 1) was compared to postlarval survival and growth. I correlated mean and minimum pH, conductivity, and alkalinity with survival and growth. I compared 1986 and 1987 metals data to U.S. Environmental Protection Agency (1987) freshwater acute and chronic water quality criteria to judge their potential effect on postlarval survival. Inorganic contaminants data were not available for 1988. The detection limits for Cd (0.002 mg/L) and Pb (0.010) were greater than the freshwater chronic values (0.0011 and 0.003 mg/L, respectively) and detrimental levels of these contaminants may not have been detected.

*Parent-progeny relationships*

The parent-progeny relationship for Choptank River striped bass was explored by using the egg abundance index as an estimate of parent stock and the 6 mm or 12 mm larval abundance index which correlated best ($P \leq 0.05$ and highest $r$) with the CJI as an index of progeny abundance. Climatically induced variation was removed from the larval index ($N_j$) by multiplying residuals (predicted index/actual index) from the nonlinear regression of $N_j$ versus environmental factors by the geometric mean $N_j$ for 1980-1988 (Crecco et al. 1986). Removing quantitative effects of environmental factors from progeny abundance should enable a parent-progeny (stock-recruitment) relationship to be determined with greater confidence (Ricker 1975; Gulland 1983). These adjusted indices were used in Ricker and Beverton-Holt models (Ricker 1975). The Ricker model:

$$R = APe^{bP}$$

where R is predicted progeny abundance, A is a coefficient of density independence, P is parent stock, and b is the coefficient of density dependence, implies that recruitment reaches a maximum at some moderate parent stock size and then declines at high stock sizes due to density-dependent mortality (Crecco et al. 1986).

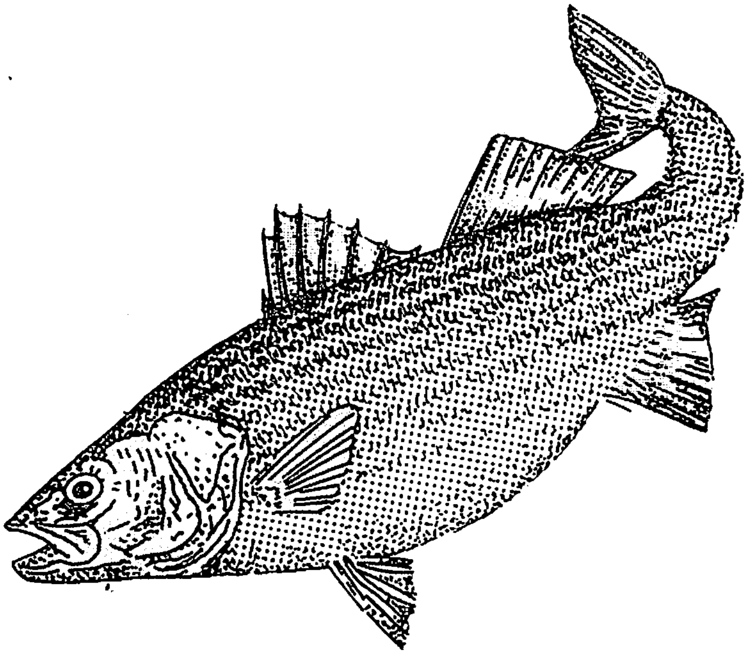
The Beverton-Holt model:

$$R = P/(A + bP)$$

suggests that recruitment rises to an asymptote at high parent stocks (Crecco et al. 1986). Both models were fitted by nonlinear regression. The nonlinear method would provide asymptotic standard errors to test whether the compensatory exponent (b) differed significantly from zero (Crecco et al. 1986).

*Relationship of early life stage survival and recruitment*

As an alternative to stock-recruitment analysis, linear regression was used to examine the relationship between Choptank River striped bass survival from egg to 12 mm and the CJI for 1980-1988. Survival from egg to 12 mm was estimated by (1) multiplying the fractions surviving from egg to 6mm (determined from $N_L / N_E$) and 6mm to 12 mm (determined from $e^{-Zt}$), and (2) by dividing the density-based 12 mm abundance index by the egg abundance index. Variation in year-class success not accounted for by the regression models would indicate the potential influence of stock size on recruitment.



# RESULTS

### *Temporal distribution of eggs, larvae, and juveniles*

Peak egg catches occurred from the second through the last week of April (Figure 2). Eggs collected during April accounted for 63 to 99.9% of the 1980-1988 annual totals. During 1980, 1981, 1983, 1984, and 1987, larvae were generally most numerous from late April to early May (Figure 2). Larval catches declined rapidly before stabilizing in late May. Declines were not evident during 1982, 1985, 1986, and 1988. Juveniles were prevalent after late May.

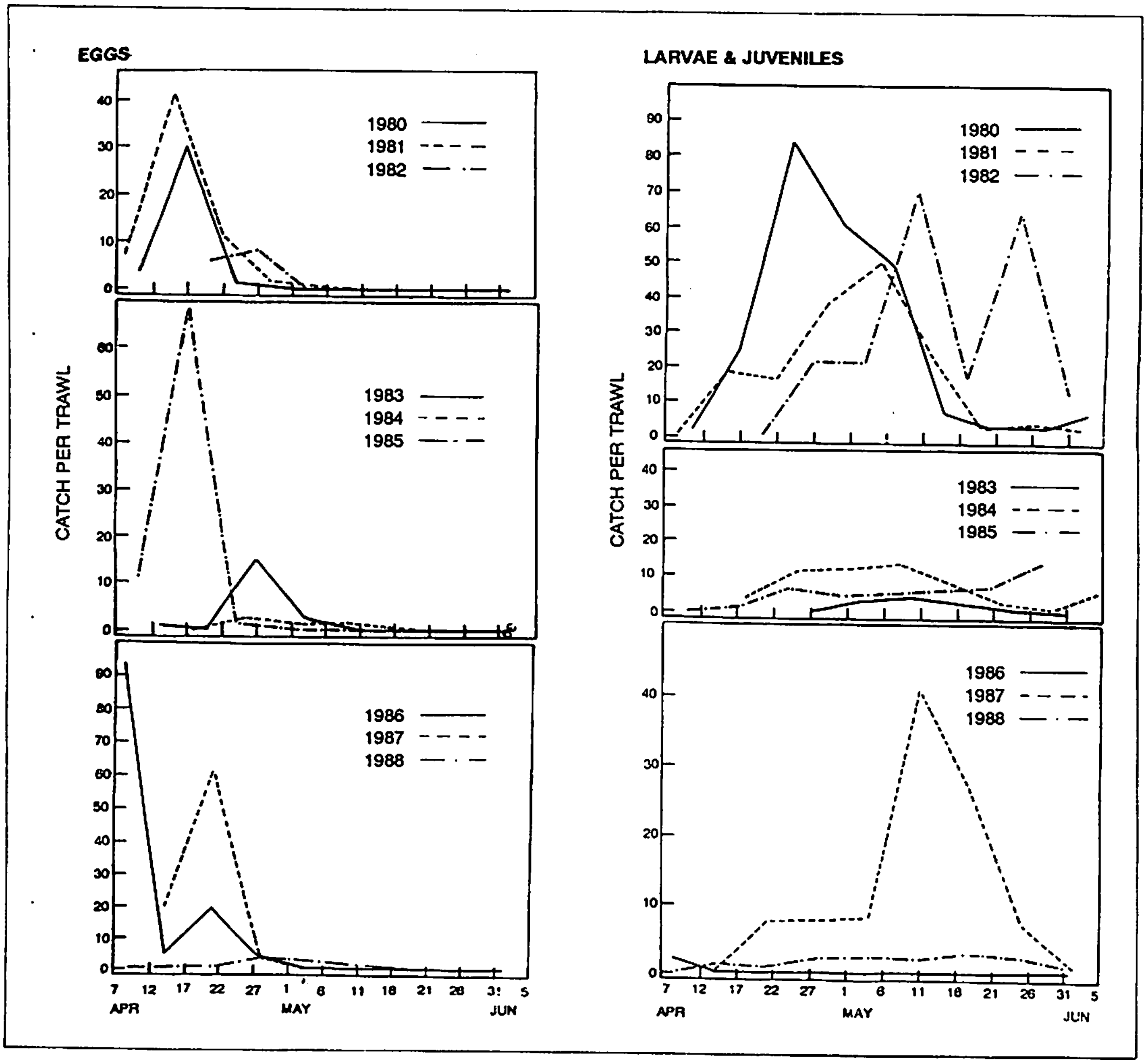


Figure 2. Catches per trawl of striped bass eggs, larvae, and juveniles in the Choptank River, Maryland, 1980-1988.

### *Growth*

Instantaneous growth rates (Table 2) were between 0.030 (1981) and 0.044 (1985). Estimated slopes of log-transformed weekly mean length regressed on time were significantly different from zero ($P \leq 0.05$) for all years.

| Year | $G_i$ | week | $P$ | $r^2$ | CI (±) |
|---|---|---|---|---|---|
| 1980 | 0.031 | 11 | 0.0001 | 0.98 | 0.0031 |
| 1981 | 0.030 | 12 | 0.0001 | 0.96 | 0.0044 |
| 1982 | 0.034 | 11 | 0.0001 | 0.96 | 0.0036 |
| 1983 | 0.034 | 8 | 0.0001 | 0.98 | 0.0039 |
| 1984 | 0.034 | 8 | 0.0002 | 0.90 | 0.0087 |
| 1985 | 0.044 | 7 | 0.0001 | 0.98 | 0.0059 |
| 1986 | 0.039 | 6 | 0.0001 | 0.99 | 0.0033 |
| 1987 | 0.034 | 7 | 0.0001 | 0.96 | 0.0059 |
| 1988 | 0.036 | 5 | 0.0054 | 0.95 | 0.0099 |

**Table 2.** Statistics for exponential growth equations derived from the increase in weekly mean length of striped bass larvae in the Choptank River, Maryland, 1980 -1988. $G_i$ = instantaneous growth; week = Number of weeks analyzed; CI = 95% confidence interval; and degrees of freedom = week - 1.

### *Mortality*

Prolarval survival varied between 37% (1980) and 0.3-0.4% (1986 and 1985 respectively), a 120-fold difference (Figure 3). Postlarval survival fluctuated between 0.9% (1980) and 40.8% (1985), a 45-fold difference (Table 3; Figure 4). Postlarval instantaneous mortality rates fell into two distinct groups. Mortality rates were 0.05-0.11 (5-10% $d^{-1}$) in 1982 and 1985-1988, and 0.16-0.19 (15-19% $d^{-1}$) for the remaining years. Based upon 95% confidence intervals of instantaneous mortality rates, all high mortality years were significantly different from the

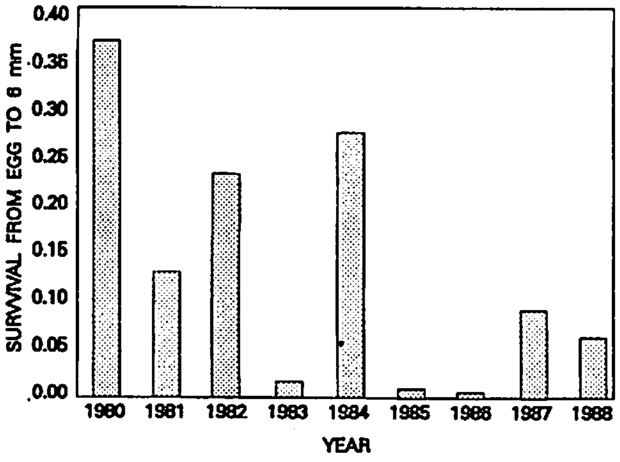


**Figure 3.**-Estimates of total survival from eggs to 6 mm larvae for striped bass in the Choptank River, Maryland, 1980-1988.

| Year | Relative age (d) | Survival to 12 mm (%) | Z | CI (±) | $r^2$ | M (% $d^{-1}$) |
|---|---|---|---|---|---|---|
| 1980 | 22.4 | 00.9 | .222 | 0.023* | 0.99 | 19.3 |
| 1981 | 23.2 | 01.0 | .199 | 0.041* | 0.94 | 18.0 |
| 1982 | 19.4 | 15.5 | .096 | 0.039* | 0.85 | 09.2 |
| 1983 | 19.4 | 04.2 | .160 | 0.008* | 0.98 | 14.8 |
| 1984 | 19.4 | 02.2 | .196 | 0.041* | 0.94 | 17.8 |
| 1985 | 15.8 | 40.8 | .055 | 0.088 | 0.23 | 05.4 |
| 1986 | 16.9 | 15.6 | .110 | 0.110 | 0.44 | 10.4 |
| 1987 | 19.4 | 26.2 | .069 | 0.007* | 0.84 | 06.7 |
| 1988 | 18.3 | 20.3 | .087 | 0.145 | 0.22 | 08.3 |

**Table 3.** Mortality of striped bass postlarvae (6-12 mm total length, TL) in the Choptank River Maryland, 1980-1988. Relative age of fish greater than 6 mm TL was derived by rearranging the exponential growth equation. Z = instantaneous mortality rate; CI = 95% confidence interval for Z; M = daily mortality rate; Asterisk denotes $P \leq 0.05$.

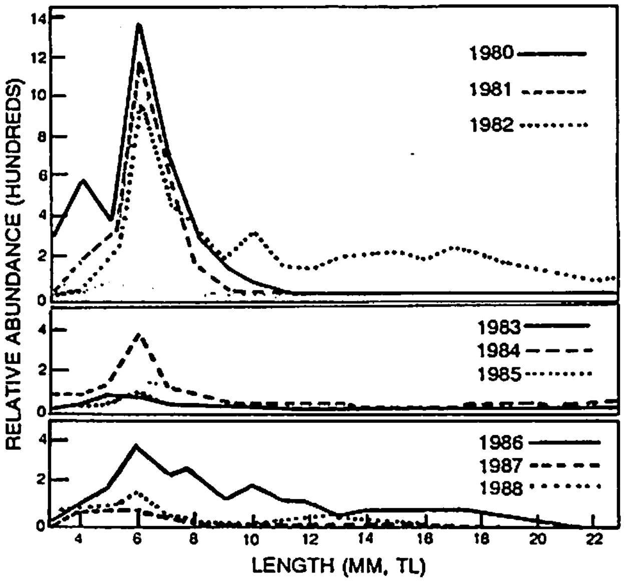


**Figure 4.**-Relative abundance of striped bass larvae and juveniles in the Choptank River, Maryland, by length and year. TL = total length.

1982, 1985, and 1987 low mortality years. Slopes were all significantly different from zero ($P \leq 0.05$) for all years except 1985, 1986, and 1988.

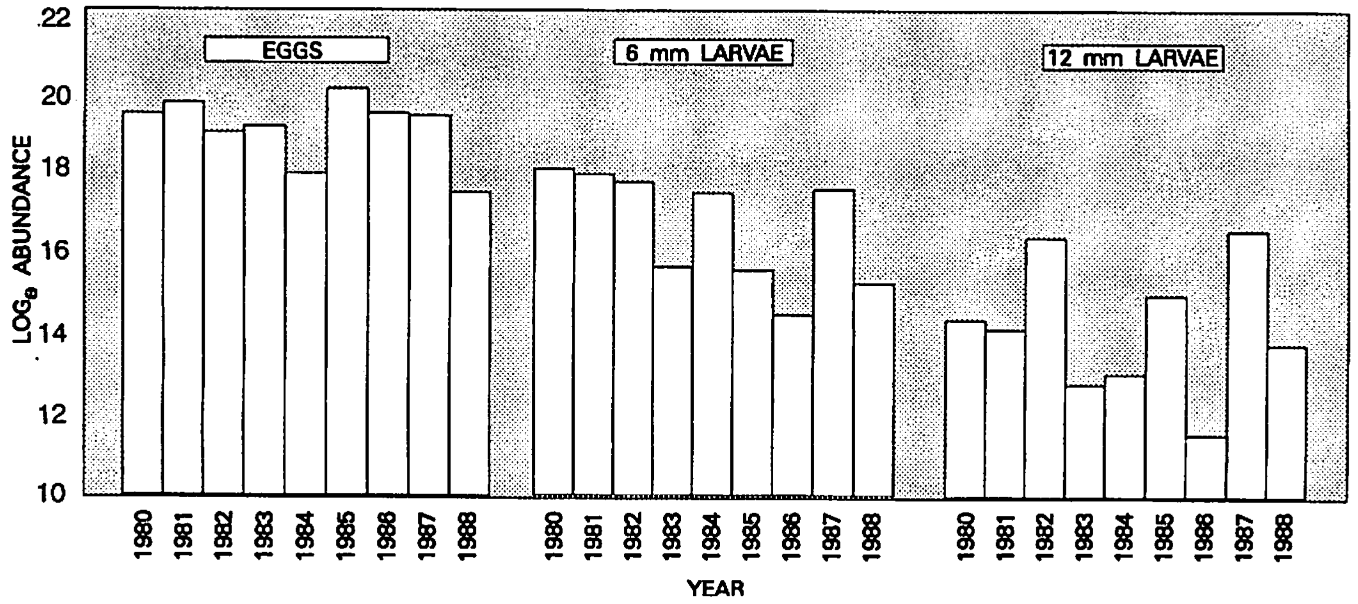


Figure 5.-Comparison of abundance indices for striped bass eggs, 6 mm larvae, and 12 mm larvae in the Choptank River, Maryland, by year.

*Abundance*

Abundance estimates for 1980-1988 ranged from 0.65 to 14.1 x $10^8$ for eggs, 0.18 to 1.3 x $10^7$ for 6 mm larvae, and 0.05 to 14.4 x $10^6$ for 12 mm larvae (Figure 5). Regressions of $\log_e$-transformed catch totals and abundance estimates were significant ($P \leq 0.001$) for eggs ($r^2$ = 0.94), 6 mm larvae ($r^2$ = 0.92), and 12 mm larvae ($r^2$ = 0.79 for mortality based estimate, $r^2$ = 0.98 for density based estimate). Spatial distribution did not significantly alter trends in relative abundance.

*Early life stage abundance versus recruitment*

Year-class success in the Choptank River appeared to have been established as early as the middle of the postlarval stage; the CJI was significantly correlated ($P \leq 0.05$) with three indices of advanced postlarval and early juvenile abundance. The total catch of individual size-groups from 9 to 20 mm correlated significantly ($P \leq 0.05$) with the CJI (Figure 6). The $\log_e$-transformed catch per trawl during the last week

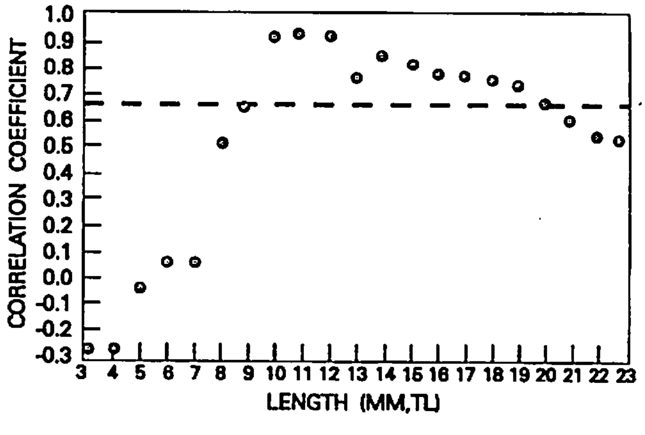


Figure 6. Correlation coefficients for the relationship between relative yearly abundance of length groups and the juvenile index for striped bass in the Choptank River, Maryland, 1980-1988. The juvenile index is the mean catch per standard seine haul. For each comparison, degrees of freedom = 7. Points on or above the dotted line a significant ($P \leq 0.05$). TL = total length.

of May and first week of June (Figure 7) was significantly associated with the $\log_e$-transformed CJI ($r = +0.78$, $P \leq 0.01$). The association of the mortality rate-based 12 mm abundance and the CJI ($N_{Jm}$, $r = +0.93$, $P \leq 0.0003$) had a larger correlation coefficient than the density-based index and the CJI ($N_{Jd}$, $r = +0.77$, $P \leq 0.02$; Table 4). Egg and 6 mm larvae abundance indices were not significantly correlated ($P \leq 0.05$) with the 12 mm abundance indices or the juvenile index (Table 4).

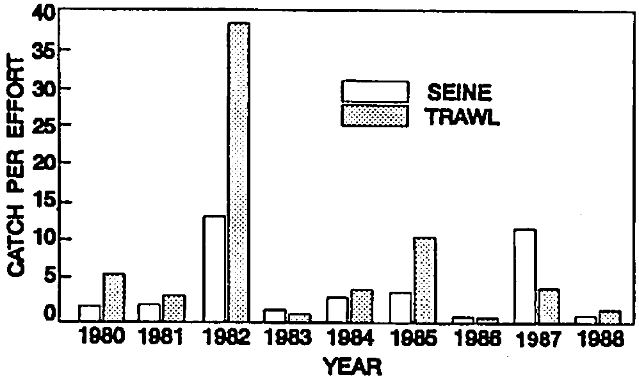


Figure 7.-Comparison of catch per trawl of striped bass during the last week of May and first week of June with the juvenile index (catch per standard seine haul during July, August, and September) in the Choptank River, Maryland, by year. Life stages sampled by trawling were primarily late postlarvae and early juveniles.

| | Log$_e$ | Log$_e$ $N_E$ | Log$_e$ $N_L$ | Log$_e$ $N_{Jd}$ | $N_{Jm}$ |
|---|---|---|---|---|---|
| JI | $r$ | 0.11 | 0.37 | 0.77 | 0.93 |
| | $P$ | 0.78 | 0.33 | 0.02 | 0.0002 |
| Log$_e$ $N_{Jm}$ | $r$ | 0.15 | 0.55 | 0.91 | - |
| | $P$ | 0.70 | 0.12 | 0.0006 | - |
| Log$_e$ $N_{Jd}$ | $r$ | 0.15 | 0.58 | - | - |
| | $P$ | 0.70 | 0.10 | - | - |
| Log$_e$ $N_L$ | $r$ | 0.11 | - | - | - |
| | $P$ | 0.78 | - | - | - |

Table 4. Correlations of the juvenile index (JI) and $\log_e$-transformed abundance indices of eggs ($N_E$), 6 mm larvae ($N_L$), and 12 mm larvae ($N_{Jd}$ and $N_{Jm}$) for the Choptank River, 1980-1988. $N_{Jd}$ was determined from density estimates; $N_{Jm}$ was determined from $N_L$ and estimated survival from 6 to 12 mm.

*Hydrographic fluctuations, larval survival, growth, and recruitment*

Peak spawning periods used in correlations of hydrographic data with larval survival, growth, and recruitment varied from early April to mid-May, early postlarval periods from late April through May, and postlarval periods from late April through early June (Table 5).

| | | Periods | |
|---|---|---|---|
| Year | Peak Spawn | Early Postlarval | Postlarval |
| 1980 | April 10-17 | April 22-May 5 | April 22-May 13 |
| 1981 | April 6-17 | April 22-May 5 | April 22-May 13 |
| 1982 | April 19-28 | May 5-15 | May 5-22 |
| 1983 | April 12-29 | May 4-14 | May 4-23 |
| 1984 | April 16-May 4 | May 8-18 | May 8-27 |
| 1985 | April 9-18 | April 22-30 | April 22-May 6 |
| 1986 | April 7-25 | April 30-May 11 | April 30-May 18 |
| 1987 | April 13-24 | May 1-13 | May 1-20 |
| 1988 | April 18-May 13 | May 18-20 | May 18-June 5 |

Table 5. Dates corresponding to time periods used in correlations and regressions of temperature, rainfall, and river flow with egg and larval striped bass survival in the Choptank River, Maryland, 1980-1988. Postlarvae are those fish that have absorbed their yolks.

The regression of $\log_e$-transformed catch of 6 mm larvae ($\log_e N_6$) and minimum temperature (T, °C) during peak spawning was described by the equation

$$\log_e N_6 = 1.01T - 7.60;\ r^2 = 0.64,\ P \leq 0.01$$

The effect of temperature on estimated survival during the egg and prolarval stages ($S_E = N_L / N_E$) was described by the equation

$$S_E = 0.084T - 0.96;\ r^2 = 0.67,\ P \leq 0.007 \text{ (Figure 8)}$$

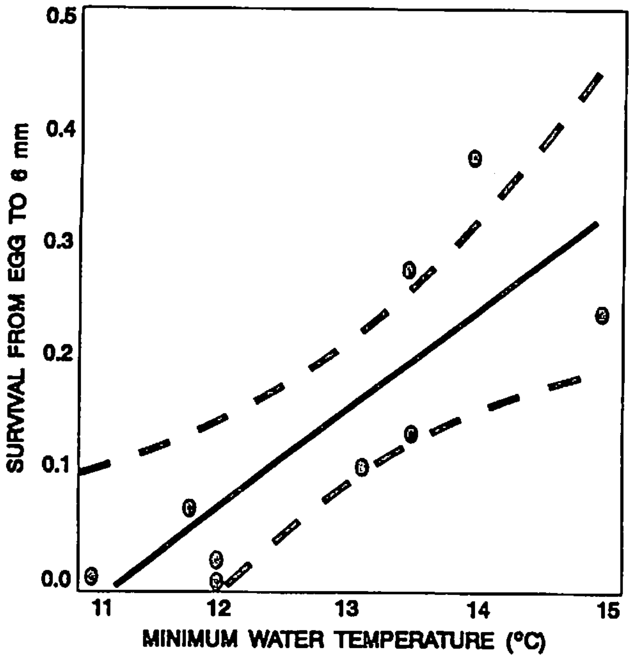


Figure 8.-Linear regression of total survival from eggs to 6 mm larvae on minimum water temperature (°C) during peak spawn for striped bass in the Choptank River spawning area, Maryland, 1980-1988. Dotted lines indicate 95% confidence interval. See Table 5 for dates corresponding to the peak spawn period.

Mean river flow during the postlarval period was the only hydrographic factor significantly correlated with postlarval survival ($r = -0.70$, $P \leq 0.03$) and instantaneous growth rate ($r = -0.74$, $P \leq 0.02$; Table 6). Instantaneous growth rate and survival were significantly correlated ($r = +0.83$, $P \leq 0.006$) with each other, reflecting their common associations with river flow.

The relationship of minimum water temperature during peak spawn (T, °C), postlarval period mean river flow (Q, m$^3$/s), and the predicted CJI ($J_p$), modeled by nonlinear regression, was described by the equation:

$$J_p = 0.016\, e^{(0.50T - 0.28Q)} \text{ (Figure 9)}$$

| | Survival | | Growth | |
|---|---|---|---|---|
| Variable | *r* | *P* | *r* | *P* |
| Total Rainfall | -0.55 | 0.12 | -0.59 | 0.09 |
| Mean Flow | -0.70 | 0.03 | -0.74 | 0.02 |
| Mean Temperature | 0.52 | 0.15 | 0.55 | 0.13 |
| Minimum Temperature | 0.40 | 0.29 | 0.52 | 0.15 |

Table 6. Correlations of postlarval survival or instantaneous growth rate with postlarval period total rainfall, mean river flow, average and minimum water temperature for the Choptank River, Maryland, 1980-1988. See Table 5 for dates corresponding to the postlarval period.

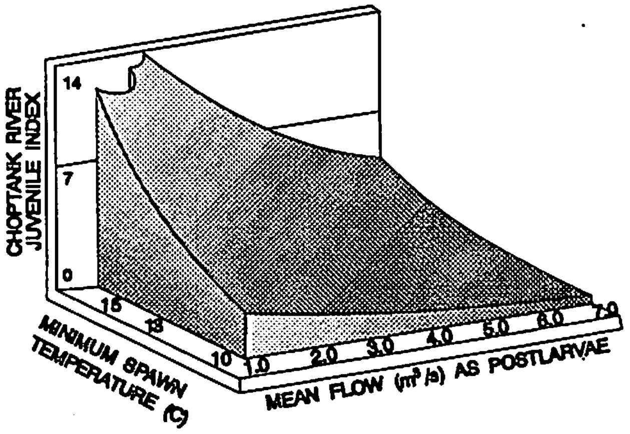


Figure 9.-Relationship of the Choptank River striped bass juvenile index to minimum water temperature (°C) in the spawning area during peak spawning and mean river flow (m$^3$/s, measured at Greensboro, Maryland) during the postlarval period. See Table 5 for dates corresponding to the postlarval period.

The selected environmental factors accounted for 55% of the variation in year-class success ($P \leq 0.02$). Nonlinear models of recruitment and T or Q alone were not significant ($P \leq 0.05$, $r = +0.61$ for T, and $r = -0.27$ for Q).

*Water quality versus postlarval survival and growth*
Confidence intervals (95%) for postlarval period mean alkalinity, hardness, and conductivity did not overlap between years of low (1983-1984) and high (1985-1988) postlarval survival estimates, but did overlap for mean temperature and pH (Table 7). Mean conductivity for 1983-1988 was the only water quality variable significantly correlated ($r = +0.90$, $P \leq 0.001$) with postlarval survival (Table 8), while growth was significantly associated with mean conductivity ($r = +0.96$, $P \leq 0.002$) and minimum pH ($r = +0.86$, $P \leq 0.03$). Mean river discharge during the postlarval period correlated negatively with log$_e$-transformed mean conductivity ($r = -0.82$, $P \leq 0.04$) and minimum pH ($r = -0.98$, $P \leq 0.0007$). Mean conductivity was positively correlated with minimum pH ($r = 0.81$, $P \leq 0.05$). Correlations between river discharge, mean conductivity, and minimum pH suggested that these variables were not independent influences on survival or growth. Postlarval period concentrations of Cu (1986 and 1987) and Pb (1986) exceeded freshwater chronic toxicity values (0.012 mg/L for Cu and 0.003 mg/L for Pb; U.S.E.P.A 1987). Cu (1986 and 1987) approached or equalled the freshwater acute criterion (0.018 mg/L; Table 9). Other inorganic contaminants were present below water quality criteria concentrations.

| Variable[a] | *N* | Mean ± 95% CI[b] | Range | |
|---|---|---|---|---|
| | | | minimum | maximum |
| **1983** | | | | |
| pH | 135 | 6.69 ± 0.04 | 6.2 | 7.5 |
| Conductivity | 158 | 190 ± 31 | 60 | 2300 |
| Alkalinity | 14 | 17.4 ± 1.5 | 10.0 | 21.1 |
| Hardness | 15 | 50 ± 7 | 24 | 139 |
| Temperature | 35 | 18.6 ± 0.2 | 17.3 | 19.1 |
| **1984** | | | | |
| pH | 244 | 6.92 ± 0.04 | 6.4 | 8.0 |
| Conductivity | 235 | 290 ± 21 | 120 | 1610 |
| Alkalinity | 29 | 21.8 ± 1.2 | 16.2 | 32.7 |
| Hardness | 16 | 69 ± 21 | 34 | 182 |
| Temperature | 36 | 18.7 ± 0.8 | 16.0 | 22.9 |
| **1985** | | | | |
| pH | 109 | 7.07 ± 0.02 | 6.7 | 7.9 |
| Conductivity | 108 | 3320 ± 345 | 690 | 7200 |
| Alkalinity | 11 | 29.2 ± 3.7 | 18.0 | 37.0 |
| Hardness | 11 | 473 ± 170 | 122 | 960 |
| Temperature | 36 | 20.0 ± 0.2 | 19.0 | 21.2 |
| **1986[c]** | | | | |
| pH | 145 | 7.17 ± 0.06 | 6.6 | 9.2 |
| Conductivity | 145 | 1353 ± 243 | 137 | 7200 |
| Alkalinity | - | - | - | - |
| Temperature | 145 | 18.3 ± 0.2 | 15.6 | 21.8 |
| **1987** | | | | |
| pH | 87 | 6.74 ± 0.04 | 6.4 | 7.6 |
| Conductivity | 87 | 874 ± 186 | 157 | 3460 |
| Alkalinity | 26 | 26.5 ± 1.4 | 20.0 | 35.0 |
| Temperature | 87 | 17.9 ± 0.6 | 14.0 | 22.9 |
| **1988** | | | | |
| pH | 54 | 6.71 ± 0.09 | 6.3 | 8.7 |
| Conductivity | 54 | 1247 ± 593 | 268 | 8270 |
| Alkalinity | 17 | 33.3 ± 2.7 | 24.0 | 42.0 |
| Temperature | 54 | 22.6 ± 0.4 | 20.5 | 25.6 |

[a] pH was converted to $H^+$ concentration to calculate mean and confidence intervals.

[b] Mean ± CI represents the 95% confidence interval about the mean.

[c] Alkalinity was not measured during 1986. Hardness was not measured after 1985.

**Table 7.** Mean and range of pH, conductivity (µmho/cm), alkalinity (mg/L), hardness (mg/L), and temperature (°C) from the spawning area of the Choptank River, Maryland during the postlarval period, 1983-1988. See Table 5 for dates corresponding to the postlarval period.

| Variable | | Mean | | Minimum | |
|---|---|---|---|---|---|
| | | *r* | *P* | *r* | *P* |
| pH[a] | S | 0.28 | 0.59 | 0.66 | 0.15 |
| | G | 0.70 | 0.11 | 0.86 | 0.03 |
| Conductivity | S | 0.90 | 0.01 | 0.77 | 0.08 |
| | G | 0.96 | 0.002 | 0.76 | 0.08 |
| Alkalinity[b] | S | 0.70 | 0.19 | 0.51 | 0.38 |
| | G | 0.43 | 0.47 | 0.14 | 0.82 |

[a] pH was converted to $H^+$ concentration to calculate mean.

[b] Alkalinity data was not available for 1986.

**Table 8.** Correlations of striped bass postlarval survival and growth with mean and minimum water pH, conductivity, and alkalinity during postlarval period, 1983-1988, in the Choptank River, Maryland. S = survival. G = instantaneous growth rate. See Table 5 for dates corresponding to the postlarval period.

### *Parent-progeny relationships*

Density-dependent effects were not detected with nonlinear Ricker ($r^2 = 0.05$, $P \leq 0.57$) or Beverton-Holt ($r^2 = 0.04$, $P \leq 0.63$) parent-progeny models using egg and climate-adjusted 12 mm larvae abundance estimates (Figure 10). Environmental factors accounted for 55% of the variation ($P \leq 0.02$) in the 12 mm abundance index.

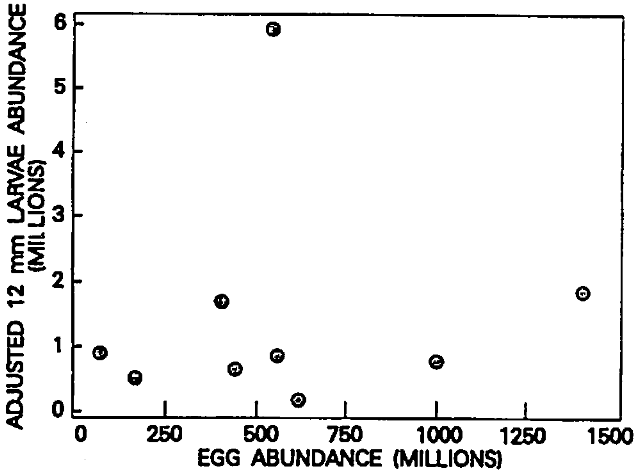


Figure 10.-Relationship between indices of striped bass egg and 12 mm larvae abundance in the Choptank River, Maryland, 1980-1988. The 12 mm larval abundance index was adjusted for variation due to minimum peak spawn temperature and postlarval period mean river discharge.

| | Year | |
|---|---|---|
| Metal (mg/L) | 1986 | 1987 |
| *N* | 39 | 33 |
| Cd | <0.002 | <0.002 |
| Cr | <0.004 - 0.008 | <0.004 - 0.005 |
| Cu | <0.004 - 0.018 | <0.004 - 0.017 |
| Mn | 0.030 - 0.073 | 0.041 - 0.106 |
| Ni | <0.020 - 0.025 | <0.020 |
| Pb | <0.010 - 0.012 | <0.010 |
| Zn | <0.010 - 0.028 | 0.011 - 0.037 |

Table 9.-Ranges of dissolved metal concentrations evaluated in the striped bass spawning area of the Choptank River during the postlarval period, 1986 and 1987. See Table 5 for dates corresponding to the postlarval period. *N* = number of samples.

### *Relationship of early life stage survival to recruitment*

Regressions of the CJI and survival from eggs to 12 mm larvae were significant ($P \leq 0.05$) and explained 63-83% of the variation in year-class success (Table 10). Yearly estimates of survival from the egg to prejuvenile stage in the Choptank River differed 700-fold between 1982 and 1986, but differences among the remaining years were 45-fold or less.

| | Survival Estimate | |
|---|---|---|
| Year | 1 | 2 |
| 1980 | 0.0033 | 0.0030 |
| 1981 | 0.0013 | 0.0014 |
| 1982 | 0.0361 | 0.0333 |
| 1983 | 0.0008 | 0.0004 |
| 1984 | 0.0060 | 0.0015 |
| 1985 | 0.0016 | 0.0015 |
| 1986 | 0.00005 | 0.00008 |
| 1987 | 0.0262 | 0.0138 |
| 1988 | 0.0132 | 0.0140 |
| | Regression | |
| Slope (SE) | 349.4 (59.2) | 355.0 (103.3) |
| Intercept (SE) | 0.56 (0.93) | 1.28 (1.33) |
| $P \leq$ | 0.0006 | 0.011 |
| $r^2$ | 0.83 | 0.63 |

Table 10.-Yearly estimates of survival (S) from eggs to 12 mm larvae for the Choptank River, 1980-1988, and linear regressions between survival and the Choptank River juvenile index (JI). Survival was estimated by 1) multiplying the estimated survival from the eggs to 6 mm larvae by estimated survival from 6 to 12 mm larvae; and 2) dividing the 12 mm larvae density based abundance index by the egg abundance index. SE is the standard error.

# DISCUSSION

Year-class success of striped bass in the Choptank River from 1980-1988 was largely controlled by environmental conditions affecting the growth and survival of eggs and larvae. The probability of survival during the first three to four weeks of life was influenced by temperature and river flow. Measurements of water quality variables associated with river flow and inorganic contaminants supported the hypothesis that acidic and toxic conditions were depressing year-class success. Stock size had the potential to exert a subtle to moderate influence on year-class success.

The use of correlations to establish a connection between environment and year-class success can be difficult when small numbers of observations are available (Gulland 1965). Correlations from small data sets should be treated with caution, supported with biological evidence of the mechanisms involved, and tested against observations in later years (Gulland 1983). Mean river flow for 1980-1988 was used as a proxy for habitat quality in some analyses with postlarval survival and growth and year-class success because time series of water quality data were limited (pH, conductivity, alkalinity, and hardness were measured after 1982; inorganic contaminants were measured after 1986). Proxy data can be used if there is a firm bridge of knowledge to the factor affecting the organism (Austin and Ingham 1978). Logical links between river flow, water quality, and inorganic contaminant conditions indicate the proxy relationship is reasonable, but not infallible, given the complex chemical interactions which create toxic conditions in aquatic habitats. The hypothesis that toxic contaminants were depressing year-class success was supported by positive associations of alkalinity, hardness, conductivity, and pH with postlarval survival and growth. These water quality parameters can influence the speciation and toxicity of inorganic contaminants (Palawski et al. 1985; Buckler et al. 1987; Mehrle et al. 1987) and the susceptibility of eggs and larvae to certain contaminants.

Estimating the general effects of contaminants on striped bass year-class success was confounded by several factors. Water samples were acidified prior to filtration, so they overestimated inorganic contaminants biologically available to striped bass larvae and must be considered "worst case" estimates. Variable survival of eggs and prolarvae due to low temperatures had to be accounted for to detect the effects of habitat conditions and contaminant levels on year-class success. Variations in rainfall acidity and amount, soil type, buffering capacity, groundwater displacement, surface runoff, vegetative cover, watershed saturation and use (agriculture, forest, wetland, etc.), organic acids, and toxic materials can also influence toxicity of contaminants to larval fish in general and striped bass larvae in particular (Haines and Schofield 1980; Henriksen 1982; Norton 1982; Palawski et al. 1985; Mehrle et al. 1987; Hall 1987). Variations in spawning locations or dates and larval drift or movements may have placed sensitive life stages in areas or time periods where survival was enhanced or lessened.

Another step in attempting to explain year-class variability was an exploratory analysis which took into account egg production by fitting descriptive environment-dependent parent-progeny curves. The relative importance of density-dependent factors on recruitment may be demonstrated by these models (Crecco et al. 1986). These curves may have had limited potential, however, because of biases inherent in the fitting procedures caused by inaccurate and imprecise data, and by autocorrelations (Peterman 1987). Spawning stocks can rarely be indexed without considerable sampling error, and observed values are rarely accurate enough to be used as an independent variable in regression and stock-recruitment analysis (Walters and Ludwig 1981; Goodyear and Christensen 1984). Detection of a statisically significant stock-recruitment relationship would also have been difficult if parent stock sizes did not vary far from replacement levels and environmentally induced recruitment variability was high (Lorda and Crecco 1987).

As an alternative, I examined the relationship between survival from egg to recruit and recruit abundance using the same life stages featured in the parent-progeny analyses (Gulland 1965). Removal of the effect of survival from egg to recruitment from recruit abundance provided insight into the potential influence of stock size on year-class success.

The validity of estimated mortality rates in the Choptank River hinged on the assumption that estimated growth was representative of actual fish growth. Estimated growth rates for the Choptank River were higher than those for wild and cultured striped bass (Lal et al. 1977; Rogers et al. 1977; Dey 1981; Eldridge et al. 1981; Rogers and Westin 1981) and were only exceeded by rates described in Humphries and Cummming (1973) and Houde et al. (1988). The significant, positive correlation ($P \leq 0.05$) of growth rate versus survival indicated that size selective mortality (small fish dying more frequently than large fish) did not bias growth estimates. If this bias had been large, growth in high-mortality years would have been greater than in low-mortality years (Uphoff 1989). Growth estimates could have been negatively biased due to the prolonged recruitment of newly hatched larvae and their inclusion in estimates of weekly mean length. Lo et al. (1989) found estimated mortality rates were biased high when larval growth was overestimated and biased low when growth was underestimated. Bias in mortality rate estimates was asymmetrically distributed and greatest when growth rate was substantially overestimated.

The accuracy of estimated mortality rates also depended on the assumption that fish within the selected size range were equally susceptible to the sampling gear (Uphoff 1989). However, this assumption is not necessary for relative comparisons of Choptank River mortality rates among years. Changes in catchability by size could have occurred, provided they were similar among years (Hoenig et al. 1990). Uphoff (1989) provided additional discussion of influences of gear selectivity and arrested growth and recovery on mortality estimates.

Environmental conditions influencing survival of eggs, prolarvae, and postlarvae largely determined year-class success of striped bass in the Choptank River between 1980 and 1988. Survival through the prolarval stage was positively linked to water temperature. Postlarval survival and growth were negatively correlated with river flow and positively correlated with mean conductivity and pH (growth only). Mean alkalinity and hardness were higher in years of high survival than years of low. These associations of water quality variables would be expected if the inorganic contaminant toxicity hypothesis were true. Concentrations of total soluble Cu and Pb during 1986 and 1987 suggested a potential for toxicity if other water quality conditions (indicated by conductivity, pH, hardness, and alkalinity) were poor. Environmental-dependent, parent-progeny models could not resolve the nature of the parent-progeny relationship. Regressions of survival from egg to prejuvenile with year-class success indicated stock size could have exerted a subtle to moderate influence on year-class success.

Estimates of egg through 6 mm larval survival (0.4 to 37%) for the Choptank River bracketed estimates for Potomac River striped bass eggs (0.3 to 10%) and prolarvae (2 to 15%; Dahlberg 1979). Daily mortality rates for larvae ranged from 6 to 19% per day for the Choptank River, compared to 7 to 32% per day for the Potomac River (Polgar 1977; Houde et al. 1988), and 15 to 18% per day for the Hudson River (Dey 1981). Ulanowicz and Polgar (1980) reported a 35-fold difference between highest and lowest survival in the Potomac River which was considerably less than the difference for the Choptank River. However, the relative difference in the highest and lowest juvenile indices was less in the Potomac River (5-fold) than the Choptank River (26-fold) over the course of these studies. Year-class success varied with survivorship in both systems.

Density-independent environmental variation played a large role in 1980-1988 Choptank River year-class success. Prolarval survival was linked to water temperature; postlarval survival and growth were correlated with river flow, mean conductivity, and pH (growth only). Hydrographic conditions had a multiplicative effect on prejuvenile abundance and the Choptank River juvenile index. Ulanowicz and Polgar (1980), Logan (1985), and Uphoff (1989) concluded that striped bass year-class success and annual survival conditions varied radically due to density-independent environmental factors. Two environmental factors were postulated by Uphoff (1989) as the main influences on year-class success in the Choptank River from 1980-1985: (1) eggs and prolarvae died after exposure to low water temperatures, and (2) increased mortality of postlarvae resulted from acidic, physiologically stressful, and toxic conditions associated with rainfall and river flow. Three additional years of data support this hypothesis.

Temperatures at or below 12°C are considered lethal to striped bass eggs and larvae (Rogers et al. 1977; Morgan et al. 1981; Crance 1984) and have been a suspected cause of high mortalities of eggs, prolarvae, and early postlarvae in upper Chesapeake Bay (Kernehan et al. 1981), the Potomac River (Hall 1988; Houde et al. 1988), the Hudson River (Dey 1981; Boreman 1983; Logan 1985), and the Choptank River (Uphoff 1989). The poor 1983, 1985, 1986, and 1988 year-classes in the Choptank River had minimum spawning period temperatures at or below 12°C which resulted in low prolarval survival. Hall (1988) attributed low survival of prolarvae in the 1986 Potomac River bioassays to sudden decreases in water temperature (to below 12.5°C) and inorganic contaminants. In the Choptank River, inorganic contaminants were detected at chronic effects levels during the 1986 and 1987 peak spawning periods. Peak spawning period measurements of Cu were as high as 0.010 mg/L (12.0°C minimum temperature) during 1986 and 0.009 mg/L (13.1°C minimum temperature) during 1987. Peak spawning period measurements of Cd (0.003 mg/L) during 1987 exceeded the chronic effects level and approached the acute toxicity level.

Years of high striped bass postlarval survival (1985-1988) in the Choptank River coincided with higher conductivity, hardness, and alkalinity; pH did not exhibit a discernable pattern during years of high survival (Figure 11). Low survival (1983-1984) occurred under dilute water conditions with low pH. Concentrations of Cu during the postlarval period reached the acutely toxic level in 1986 and approached this level during 1987. Concentrations of Pb exceeded chronic toxicity criteria during 1986; Cu exceeded this level during 1986 and 1987. However, other water quality conditions such as higher conductivity (which indicated increased salinity and hardness) and alkalinity may have decreased inorganic contaminant toxicity during these years (Palawski et al. 1985; Buckler et al. 1987; Mehrle et al. 1987). Osmoregulatory stress (from dilution and low pH) would contribute to the sensitivity of larvae to contaminants (Buckler et al. 1987).

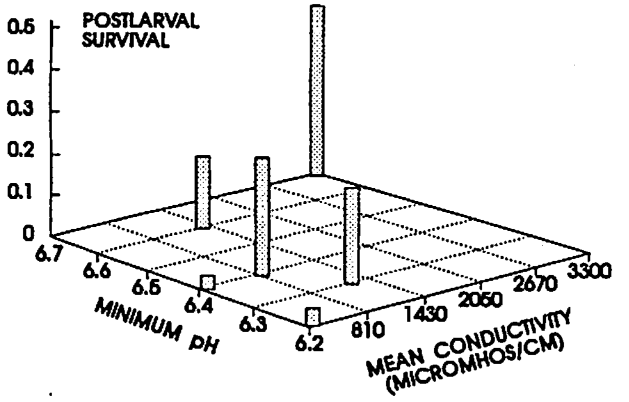


Figure 11.-Relationship of striped bass postlarval survival (6 to 12 mm larvae) and minimum pH and mean conductivity in the Choptank River spawning area, Maryland, during the 1983-1988 postlarval periods. See Table 2 for dates corresponding to postlarval periods.

Water quality conditions in the striped bass spawning areas of the Nanticoke, Potomac, and Choptank rivers that were implicated in poor to intermediate survival of prolarvae in bioassays were low pH (5.96-6.76), soft freshwater (24-136 mg/L), low alkalinities (15.5-19 mg/L), inorganic contaminants (monomeric Al, Cd, and Cu exceeded chronic or acute criteria), and sudden decreases in water temperature to 12.5°C or below (Hall et al. 1988; Hall 1988). Conductivities ranged between 85-700 mhos/cm. The presence of saline conditions (1.1-6$^{\circ}/_{\infty}$) and low or nondetectable concentrations of contaminants were linked to higher survival in the Chesapeake and Delaware Canal (Hall 1988; Hall et al. 1988). Conductivities in controls and bioassays with high survival were greater than 1,100 µmhos/cm.

Associations of postlarval growth and survival with river flow, conductivity, and pH indicated that catastrophic conditions need not have occurred to generate recruitment failures. Modest changes in larval growth and mortality rates could have caused major changes in recruitment (Houde 1987). The poor 1980 and 1981 Choptank River year-classes resulted after high populations of 6 mm larvae were reduced by low postlarval growth and survival rates. Striped bass 6 mm long corresponded to first-feeding larvae, a life stage of fish sensitive to low pH and metals (Peterson et al. 1982). Poor growth prolonged exposure of larvae to harmful conditions during the sensitive first-feeding stage, resulting in decreased survival (Ware 1975; Houde 1987; Uphoff 1989). Buckler et al. (1987) found acid and contaminant toxicity decreased with age for larval and juvenile striped bass.

Colby (1984) and Goodyear (1985b) found the effects of excessive mortality from contaminants or fishing on recruitment were indistinguishable without evidence of the source. In the absence of significant density-dependent effects, additional mortality from contaminants or fishing could have been be offset by reductions in fishing mortality (Goodyear 1985b). The expected mean number of recruits would have increased directly with egg deposition; increased population fecundity had the potential to offset contaminant losses (Goodyear 1985b). Potential gains in population fecundity could have been countered by contaminants accumulated in adults which could theoretically affect gametogenesis (Longwell and Hughes 1980). Parental tissues are an important source of chlorinated hydrocarbons in striped bass larvae; slightly better survival was observed in laboratory tests among larvae hatched from eggs with lower concentrations of organochlorine compounds (Westin et al. 1985). Body burdens of some hydrocarbons in Chesapeake Bay striped bass were found at levels which could affect reproduction and survival (Setzler-Hamilton et al. 1988). Modest changes in larval growth or mortality rates due to contaminants in the spawning area could have caused major changes in recruitment levels as well (Houde 1987). Evaluating effects of harvest regulations on recruitment requires knowledge of both stock size and early life stage survival.

Recruitment in the Choptank River was influenced, to a large extent, by at least two density-independent, random environmental factors (water temperature and dilute, acidic, and potentially toxic water conditions) that affected early life stage survival. Year-class success in the Nanticoke River and in the vicinity of the Chesapeake and Delaware Canal showed little correlation with egg and larval densities (Kernehan et al. 1981); density-independent environmental factors, including temperature and flow, were cited as major influences in those systems and the Potomac River (Ulanowicz and Polgar 1980). Random environmental events may mask parent-progeny relationships and present the danger of managing a fishery based upon the assumption of total stock independence (Gulland 1973, 1983; Ricker 1975; Walters and Ludwig 1981; Goodyear and Christensen 1984).

Failure to resolve a parent-progeny relationship after environmental effects were removed from the 12 mm abundance index did not mean a relationship did not exist. The regressions of early life stage survival and the CJI indicated that stock size had the potential to exert a subtle to moderate influence on year-class success. Stock size can be controlled through harvest oriented management decisions and, based on the apparent predominance of density-independent early life stage mortality in the Choptank River, recruitment should be enhanced (Goodyear 1985b). Increases in spawning stock should also increase the duration of the spawning season, diminishing the severity of losses due to low water temperature early in the spawning season and increasing the chance that adequate egg production would occur during periods of favorable water quality (Rago et al. 1989).

Misunderstanding the role of contaminants could have serious consequences for fishery managers as well. If contaminant effects were assumed to be minor or were ignored, a fishing level might be established which endangers the population (Schaaf et al. 1987). Conversely, effects could be overestimated, leading to a fishery more restricted than necessary (Schaaf et al. 1987).

Reducing the toxicity of the environment, even on a limited basis, will enhance recruitment because the relative power of environmentally dependent early life stage survival is great. Sources of inorganic contaminants in the Choptank River are unclear, however atmospheric deposition and agriculture are two potential origins. Levels of inorganic contaminants in the Choptank River are generally linked to the acidification problem in two ways: some ( Cd, Pb, and Cu) are deposited with strong acids in the watershed from the atmosphere and others (Al) become dissolved in greater concentrations as a result of more acidic surface waters reacting with soils (Peterson et al. 1982). Acidic soils and low buffering capacity of surface waters exacerbate the effect of acidic deposition (Hall 1987). Decreasing acid deposition could reduce the severity of larval mortality associated with the creation of acidic and toxic conditions. Heavy metals may be contained in phosphate ores used in fertilizers or as constituents of pesticides (Brady 1974; May and McKinney 1981). Reductions in runoff from agricultural areas could reduce inorganic contaminant loading. Adding limestone to raise pH and reduce the concentration of toxic heavy metals has proven economically and biologically practical in some situations (Flick et al. 1982).

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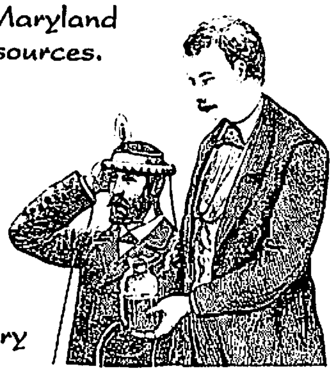

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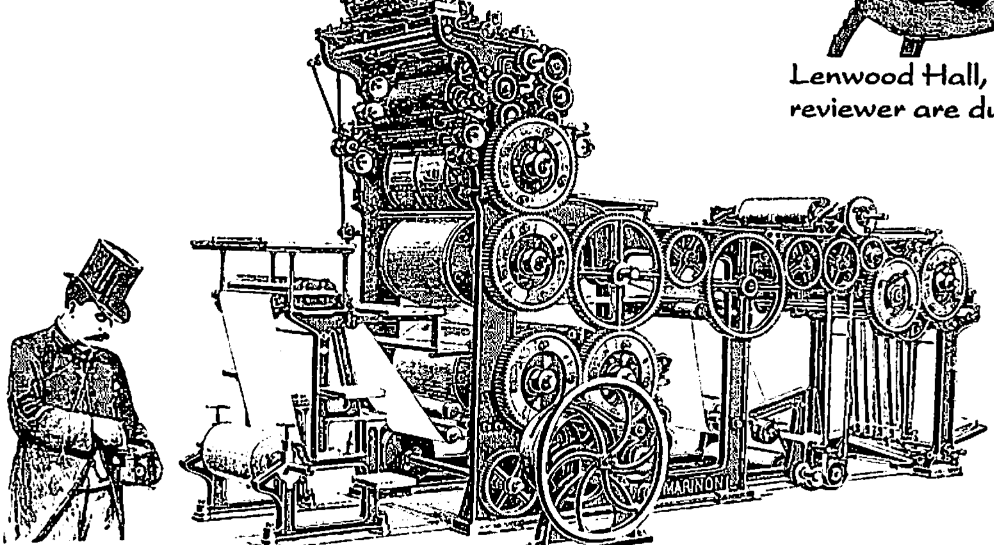

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