

Maryland Striped Bass: Recruitment Declining below Replacement

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Abstract

A mathematical technique was developed to examine interrelationships among first-year survival rates, adult fecundity, and adult survival of striped bass *Morone saxatilis* based on indices of year-class strength. Application of this technique to striped bass in Maryland waters of the Chesapeake Bay provided evidence for reduced survival in the life cycle. If adult fecundity and survival have remained constant, first-year survival declined significantly from 1969 to 1983, and averaged less than that needed for replacement for the last 10 years. Treatment of the individual spawning grounds separately indicated that the downward trend in survival for the pooled data was the result of declines in the upper bay and, to a lesser extent, in the Choptank River. Alternatively, if first-year survival and adult fecundity were assumed to have remained constant, an annual decline of about 1.9% in adult survival would have been required to produce the observed trend in the pooled year-class data. This would be consistent with increased fishing mortality and implies declining recruitment because of declining stock size. Continuing declines in first-year or adult survival would eliminate the Maryland striped bass stock and the fishery it supports. Conversely, an increase in adult survival could offset the effect of the unknown factor or factors responsible for the apparent decline in first-year survival.

The striped bass *Morone saxatilis* is an anadromous species indigenous to the Gulf of Mexico and Atlantic Ocean coasts of North America. Within this native range, the species supports important sport and commercial fisheries from North Carolina through Massachusetts. Historically, production of young in the tributaries of the Chesapeake Bay has supported the bulk of the fishery that occurs both within the bay and in the inshore waters along the coast (Koo 1970). However, a recent decline in the stock available to fishermen along the Atlantic coast (Strand et al. 1980) has stimulated interest in research (Chafee 1980) and management (Leverone 1980) of the species.

We wished to determine whether or not there is statistical support for the notion that the Chesapeake Bay population is in difficulty and, if so, to infer why and to suggest corrective measures.

For this purpose, we examined the interrelationships among first-year survival, adult fecundity, and adult survival, based on data on year-class strengths in Maryland. We selected these variables for analysis so that we could contrast the magnitudes of possible changes in first-year survival with those associated with possible increased fishing, which also would be consistent with the apparent decline in the recruitment.

Methods

The year-class-strength data are from a standardized beach haul-seine survey, conducted during late summer each year since 1954 (Boone 1980; Goodyear 1985, this issue). These data, which indicate the absence of a strong year class since 1970, are the only extensive time series of year-class strength in the Chesapeake Bay and have served as the foundation of a number of

studies (Schaefer 1972; Florence 1980; Kohlenstein 1980; Polgar 1980). First-year survival for year t , $s_0(t)$, was estimated as the ratio of an index of the number of 1-year-old female fish in year $t + 1$ to an index of the number of female eggs produced in year t by the method of Cohen et al. (1983). The index of the number of 1-year-old females in year $t + 1$ was the average catch of young of the year per seine haul in year t . We assumed that the fraction of fish that survive from the survey period in late summer and early autumn to the following spawning season in spring has been constant over the period for which data are available based on the relation between the index and reported landings (Goodyear 1985). The number of female eggs, $E(t)$, deposited in year t was estimated as

$$E(t) = \sum_{i=1}^{15} [E_i Y_i(t)]$$

where E_i is the average number of female eggs spawned by a female of age i and $Y_i(t)$ is the number of age- i females in year t . From the young-of-the-year survey data, we calculated $Y_i(t)$ as

$$Y_i(t) = Y_1[t - (i - 1)] \prod_{j=1}^{i-1} s_j, \\ i = 2, \dots, 15$$

where s_j is the annual survival probability for females from age j to age $j + 1$. Each value of $Y_1(t)$ is the index of year-class strength from the survey in year $t - 1$. We assume that the total number of young differs from the number of young females only by a constant of proportionality; thus the index of year-class strength is also an index of the relative number of females entering the population.

The average number of female eggs per female for each age was estimated as the product of age at maturity estimated by Merriman (1941) and estimated fecundity of mature females. Fecundity of mature females was estimated by converting lengths at annulus formation for females to weight (Mansueti 1961) and calculating the number of eggs from the weight-fecundity relationship reported by Lewis and Bonner (1966). The number of eggs then was divided by 2 based on the assumption that half would be females upon fertilization.

Precise data on the age-specific survival proportions are lacking. Annual survival of females appears to be lowest at age 3 and to increase thereafter (Kohlenstein 1980; Polgar 1980). The annual survival of females beyond age 6 was estimated (Kohlenstein 1980; Polgar 1980) to be in the range of 0.68 to 0.82. However, analysis of mark-recapture studies conducted by Young (1976) in New York waters indicated that the probability of surviving fishing alone is in the range of 0.41 to 0.64. Because of the uncertainty of these post-egg survival estimates, we have performed analyses over a wide range of possible adult survival probabilities. In each case, the ratios of the annual survival probabilities for ages 3, 4, 5, and 6 to the survival probabilities for older ages were 0.85, 0.9, 0.95, and 0.975, respectively, to be consistent with those previously reported (Polgar 1980). The annual survival proportion of ages 7-15 was assumed to be 0.45 (case 1), 0.60 (case 2), or 0.75 (case 3).

Because the data from 1954 to 1968 are needed to construct the adult age structure, we can only estimate first-year survival for eggs spawned during the period 1969 to 1981. We computed $s_0(t)$ values for each of the separate spawning areas sampled in the young-of-the-year survey and for all spawning grounds pooled. Because a declining population can result from either declining survival or mean survival below that required for replacement, we examined the data for trends in survival and tested the mean of recent survival estimates against the mean survival required for replacement, s_r . The first-year survival of eggs required for replacement, s_r , at each assumed level of adult survival was taken as the value of s_0 that gives the Leslie matrix representation of the population a dominant eigenvalue of 1 (Van Winkle et al. 1974; Vaughan and Saila 1976). This s_r is the mean survival required for replacement if all age-specific fecundities and survival proportions are constant over time.

The assumption of constant adult vital rates in these calculations results in the inclusion of the impact of any trends in these parameters in the estimates of first-year survival. The magnitude of a possible trend of decreasing adult survival that would be consistent with our estimates of first-year survival was evaluated by modifying the adult survival proportions by the factor e^{-ct} , where c controls the rate of decline in the simulated adult survival. The value of c was varied by trial and error to obtain a regression of first-

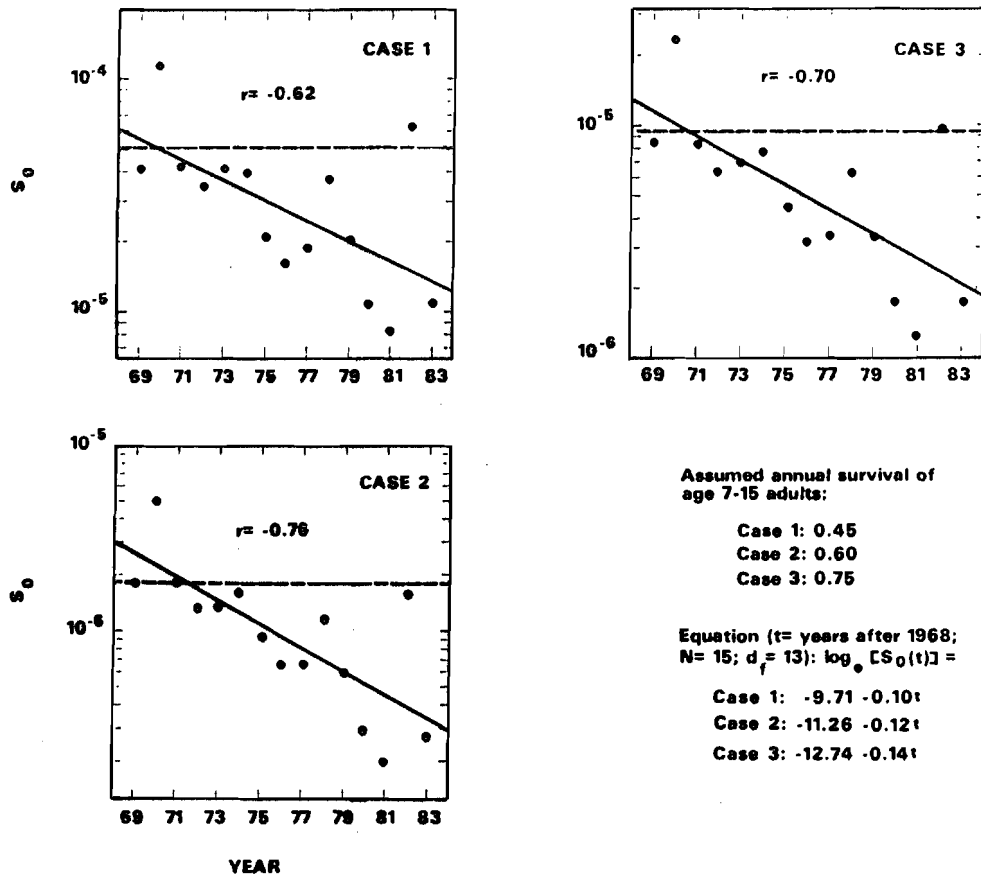


FIGURE 1.—Regressions of log of first-year survival on year spawned for striped bass produced in Maryland waters of the Chesapeake Bay. The dashed lines indicate the level of first-year survival required for replacement.

year survival on year with a slope of 0.0. This value of c is an estimate of the decline in survival of fish beyond age 1 that would be required to produce the observed decline in recruitment if there has been no decline in first-year survival.

Results

Regression of $\log_e[s_0(t)]$ against year for the pooled data set resulted in a significant negative correlation for each assumed annual survival proportion of the adult stock (Fig. 1). The slopes ranged from -0.1 to -0.14 , implying that survival probability has been declining by about 9–13% per year. To discern whether the decline is continuing below replacement, we determined the mean $s_0(t)$ of the period 1974–1983 for the pooled data set and compared it to the replacement survival probability using the likelihood-ratio test (Cohen et al. 1983). It was significantly

below the s_r required for replacement for each of the assumed levels of survival in the adult population (Table 1).

We also applied the same procedures to individual spawning grounds (Table 1) to determine which areas were contributing to the trends in the pooled data set. Significant negative correlations of survival with year were found for the upper bay for all levels of assumed adult survival and for the Choptank at the highest level of adult survival examined. The correlations between $s_0(t)$ and t were not significant in the Potomac and Nanticoke rivers. These findings indicate that the observed negative trend in the pooled data set resulted from declines in the upper bay, and to a lesser extent, in the Choptank River.

Mean survival in the individual spawning grounds was significantly below replacement for the period 1974–1983 only in the Nanticoke at

TABLE 1.—Correlations (r) of natural logarithm of first-year survival of Maryland Chesapeake Bay striped bass with year, and tests for differences between replacement survival and mean survival for the last 10 years of observations (1974–1983) based on the likelihood ratio (LR) test ($-2 \log_e LR$). Case 1 assumes adult survival of 0.45 per year; case 2, 0.6; and case 3, 0.75.

Case	Test	Location				
		Pooled	Upper bay	Choptank	Potomac	Nanticoke
1	r	-0.62	-0.79	-0.38	0.38	-0.02
	P	0.01	<0.01	0.16	0.16	0.94
	$-2 \log_e LR$	5.32	1.83	1.74	0.94	2.39
	P	0.02	0.18	0.19	0.33	0.12
2	r	-0.70	-0.81	-0.50	0.39	-0.18
	P	<0.01	<0.01	0.06	0.15	0.66
	$-2 \log_e LR$	5.32	1.45	2.13	1.44	3.68
	P	0.02	0.23	0.14	0.23	0.05
3	r	-0.76	-0.83	-0.58	0.35	-0.32
	P	<0.01	<0.01	0.02	0.08	0.24
	$-2 \log_e LR$	5.00	1.00	2.09	2.18	4.70
	P	0.03	0.32	0.15	0.14	0.03

the highest level of adult survival examined. However, survival has been below replacement in each of the last 9 years in the upper bay and in 8 of the last 10 years in each of the other spawning grounds. As a consequence, it would appear that the mean survival determined for the pooled data set is not strongly influenced by conditions in any single spawning area.

The assumption to which these results are most vulnerable is that adult annual survival proportions and age-specific fecundities have been constant since 1954. Systematic changes in these parameters with time would cause bias in the estimates of $s_0(t)$ that would increase with time. For example, a trend of decreasing survival or decreasing age-specific fecundities of successive cohorts of adults with time would cause a systematic temporal bias in the ratio of the model-generated egg production to the realized egg production. In this situation, the model egg production would overstate the true egg production and thereby underestimate first-year survival by a greater fraction each year, which could result in a negative correlation of first-year survival with time—as was observed in these results.

By simulating a temporal trend in adult survivals, we found that the observed correlations between $s_0(t)$ and t were eliminated by an annual decline in survival of 1.80% for an initial adult survival of 0.75, 1.87% for an initial adult survival of 0.60, and 1.94% for an initial adult survival of 0.45. Thus, the correlations between $s_0(t)$

(calculated from the pooled data set) and t may have been the result of a long-term decline in adult survival.

Discussion

It is possible that our results are due entirely to increased fishing mortality, either as a result of an increase in angler participation in the region (Merriner 1976) or through an increase in vulnerability as Coutant (1985) hypothesized. A decreasing adult survival caused by fishing would require an increase in the level of first-year survival required for replacement each year, $s_r(t)$. Thus, although the actual value of $s_0(t)$ may not be declining with time, the ratio, $s_0(t)/s_r(t)$, would be declining. The population consequence of declining $s_0(t)$ or rising $s_r(t)$ is the same. For the possibility described above, where declining adult survival is assumed responsible for the observed negative correlation between calculated $s_0(t)$ and t , we found for the pooled data set that the ratio $s_0(t)/s_r(t)$ was negatively correlated with t ($P \leq 0.01$) for each level of assumed initial survival and that, with the exception of 1982, $s_0(t)$ has been below $s_r(t)$ each year since 1970.

Systematic increases in survival or age-specific fecundities of successive cohorts would have the opposite effect. The true correlation of $s_0(t)$ with t and the true slopes of the regressions would be more strongly negative than those calculated if constant vital rates are assumed. The values of $s_0(t)$ would be increasingly overestimated with

time by our method. However, the true mean value of first-year survival required for replacement would decrease, and its departure from the value s_T calculated with an assumed constant adult survival and fecundity would occur at a faster rate than the bias in the estimates of $s_0(t)$ would increase with t . A decline in fishing mortality in response to declining stock would introduce this type of error in our calculations. Others, however, have argued that market forces will tend to keep mortality rates from falling with declines in the stock (Strand et al. 1980). Nonetheless, it is possible that some decline in fishing mortality and some increase in age-specific fecundity has occurred, particularly in the most recent years. If so, actual first-year survival has declined more rapidly than our analysis indicates, but the mean actual first-year survival may not be significantly below replacement. If this is the case and if survival does not continue to decline, the population may eventually stabilize near its present low level.

Strong density-dependent mortality of the young related to the size of the spawning stock can cause survival of the young to go through periodic cycles of increase and decrease (Goodyear 1980; Levin and Goodyear 1980). Such cycles conceivably could produce patterns of survival such as we observed for the Maryland striped bass. However, density-dependent mortality of this sort would introduce periodic fluctuations in the adult stock (Levin and Goodyear 1980). Spectral analysis of data on commercial landings has revealed no periodicities consistent with this possible mechanism (Van Winkle et al. 1979).

Our results may be caused by a trend of increasing fishing mortality, or by an extended period of unfavorable environmental conditions in the spawning areas due to natural or to unknown anthropogenic causes, or both. In either case, the persistence of the Maryland stocks would be threatened by the continuation of the recent trend. Management to reduce fishing mortality could lower the level of first-year survival required for replacement. For optimal effectiveness, such management measures would have to apply throughout the area from North Carolina to Maine due to the complex migration patterns of the Chesapeake stocks (Goodyear 1978). If stringent enough, such management measures could reduce the level of the first-year survival required for replacement sufficiently to arrest the decline

in the stock. If the ratio $s_0(t)/s_T(t)$ continues to decline, management measures must become more stringent with time to preserve the stock.

One possible outcome of the recent trend in Chesapeake Bay is exemplified by the history of the striped bass population in the Delaware River, which was once an important spawning area but now produces few young (Chittenden 1971). In addition to management measures, research is needed to identify those factors important for survival of the young striped bass to aid in the management or restoration of the Maryland stocks.

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References

- BOONE, J. G. 1980. Estuarine fish recruitment survey—July 1, 1979 through June 30, 1980. Maryland Department of Natural Resources, Federal Aid in Fish Restoration F-27-R-6, performance report, Annapolis, Maryland, USA.
- CHAFEE, J. H. 1980. The outlook for striped bass recovery. Pages 5-7 in H. Clepper (1980).
- CHITTENDEN, M. E., JR. 1971. Status of the striped bass, *Morone saxatilis*, in the Delaware River. Chesapeake Science 12:131-136.
- CLEPPER, H., editor. 1980. Marine recreational fisheries 5. Sport Fishing Institute, Washington, D.C., USA.
- COHEN, J. E., S. W. CHRISTENSEN, AND C. P. GOODYEAR. 1983. A stochastic age-structured population model of striped bass (*Morone saxatilis*) in the

- Potomac River. *Canadian Journal of Fisheries and Aquatic Sciences* 40:2170-2183.
- COUTANT, C. C. 1985. Striped bass, temperature, and dissolved oxygen: a speculative hypothesis for environmental risk. *Transactions of the American Fisheries Society* 114:31-61.
- FLORENCE, B. M. 1980. Harvest of the northeastern coastal striped bass stocks produced in the Chesapeake Bay. Pages 29-44 in H. Clepper (1980).
- GOODYEAR, C. P. 1978. Management problems of migratory stocks of striped bass. Pages 75-84 in H. Clepper, editor. *Marine recreational fisheries 3. Sport Fishing Institute, Washington, D.C., USA.*
- GOODYEAR, C. P. 1980. Oscillatory behavior of a striped bass population model controlled by a Ricker function. *Transactions of the American Fisheries Society* 109:511-516.
- GOODYEAR, C. P. 1985. Relationship between reported commercial landings and abundance of young striped bass in Chesapeake Bay, Maryland. *Transactions of the American Fisheries Society* 114:92-96.
- KOHLNSTEIN, L. C. 1980. Aspects of the population dynamics of striped bass (*Morone saxatilis*) spawning in the Maryland tributaries of the Chesapeake Bay. Doctoral dissertation. Johns Hopkins University, Baltimore, Maryland, USA.
- KOO, T. S. Y. 1970. The striped bass fishery in the Atlantic states. *Chesapeake Science* 11:73-93.
- LEVERONE, M. F. 1980. Regional management of striped bass. Pages 159-164 in H. Clepper (1980).
- LEVIN, S. A., AND C. P. GOODYEAR. 1980. Analysis of an age-structured fishery model. *Journal of Mathematical Biology* 9:245-274.
- LEWIS, R. M., AND R. R. BONNER, JR. 1966. Fecundity of the striped bass, *Roccus saxatilis* (Walbaum). *Transactions of the American Fisheries Society* 95:328-331.
- MANSUETI, R. J. 1961. Age growth, and movements of the striped bass, *Roccus saxatilis*, taken in size selective fishing gear in Maryland. *Chesapeake Science* 2:9-36.
- MERRIMAN, D. 1941. Studies on the striped bass (*Roccus saxatilis*) of the Atlantic coast. United States Fish and Wildlife Service Fishery Bulletin 50(35).
- MERRINER, J. V. 1976. Differences in management of marine recreational fisheries. Pages 123-131 in H. Clepper, editor. *Marine recreational fisheries. Sport Fishing Institute, Washington, D.C., USA.*
- POLGAR, T. T. 1980. Is striped bass a manageable resource? Pages 189-202 in H. Clepper (1980).
- SCHAEFFER, R. H. 1972. A short-range forecast function for predicting the relative abundance of striped bass in Long Island waters. *New York Fish and Game Journal* 19:178-181.
- STRAND, I. E., V. J. NORTON, AND J. G. ADRIANCE. 1980. Economic aspects of commercial striped bass harvest. Pages 51-62 in H. Clepper (1980).
- VAN WINKLE, W., B. L. KIRK, AND B. W. RUST. 1979. Periodicities in Atlantic coast striped bass (*Morone saxatilis*) commercial fisheries data. *Journal of the Fisheries Research Board of Canada* 36:54-62.
- VAN WINKLE, W., B. W. RUST, C. P. GOODYEAR, S. R. BLUM, AND P. THALL. 1974. A striped bass population model and computer programs. Oak Ridge National Laboratory, ORNL-TM-4578, Oak Ridge, Tennessee, USA.
- VAUGHAN, D. S., AND S. B. SAILA. 1976. A method for determining mortality rates using the Leslie matrix. *Transactions of the American Fisheries Society* 105:380-383.
- YOUNG, B. 1976. A study of striped bass in the marine district of New York. New York Department of Environmental Conservation, Division of Marine Resources, Completion Report AFC-8, Albany, New York, USA.