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EFFECTS OF FISHING ON THE REPRODUCTIVE CAPACITY OF STRIPED BASS IN CHESAPEAKE BAY, MARYLAND

by

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Abstract

The lifetime fecundity of an age 1 female (eggs per recruit, EPR) is calculated as a function of fishing mortality and age at entry to the fishery for the Maryland population of striped bass. Combined with recruitment indices for the Maryland population, 1954-1984, EPR values are used to estimate relative egg deposition by the population each year, and project relative egg deposition with varying reductions in fishing mortality rates. Egg deposition declined steadily from 1976 to 1985, and will continue to decline with no reduction in fishing mortality. The Atlantic States Marine Fisheries Commission (ASMFC) plan for striped bass management along the Atlantic Coast is insufficient to stop the decline in annual egg deposition by the Maryland population; interim measures recently adopted by the ASMFC to reduce fishing mortality rates an additional 55% should lead to an increase in egg deposition.

Introduction

Year class strength of striped bass (*Morone saxatilis*) in Maryland waters of Chesapeake Bay has declined in recent years to levels that are at or near the lowest on record (Boreman and Austin 1985). Assuming natural mortality rates remain constant, an immediate action that could be taken to stem the decline in production is the reduction of fishing mortality, thus leading to an increase in the total annual egg deposition. This consideration was a basis for recommendations in a coastwide management plan for striped bass prepared by the Atlantic States Marine Fisheries Commission (ASMFC 1981).

The degree of response by the Maryland population of striped bass to a reduction in fishing mortality depends on the extent to which the population's reproductive capacity was already reduced by fishing mortality prior to the reduction. The purpose of this paper is to determine the status of the reproductive capacity of Maryland striped bass when the coastwide management plan was published, and to examine the potential increase in reproductive capacity that would be caused by reductions in fishing mortality recommended in the plan.

Methods

The measure of reproductive capacity used in this analysis is the lifetime egg deposition of a female striped bass (eggs per recruit, EPR) in the Maryland population. This measure assumes that males will always be available for spawning, fish from outside the Maryland population do not spawn in Maryland waters, and age at maturity, natural mortality, and age-specific fecundity are independent of population size (i.e., demographics are density-independent). The EPR value is based on the female's maturity, fecundity, and mortality schedules:

$$EPR_j = N_j P_j E_j; \quad (1A)$$

$$EPR = \sum_{j=1}^{n} N_j P_j E_j; \quad (1B)$$

where EPR_j equals the eggs per recruit at age j, P_j equals the proportion of age j females that are mature, E_j equals the average fecundity of an age j female, $N_1 = 1$ so Equation 1 is on a per-recruit basis, n is the maximum age in the spawning population, and

$$N_{j+1} = N_j \exp-(F_j + M_j), \quad (2)$$

where F_j equals the instantaneous rate of fishing mortality and M_j equals the instantaneous rate of natural mortality for age j females.

The maximum age in the spawning population (n) was chosen to be 30, which corresponds to the the oldest aged striped bass on record (Merriman 1941). The value of M_j is assumed equal to 0.15 for all ages $j \geq 1$ and is consistent with values used in yield-per-recruit analyses of the Maryland striped bass population performed by Kohlenstein (1980), Polgar (1980), and Goodyear (1984). The value of F_j was held constant for all fishable ages and varied between 0 and 1, and the age at entry to the fishery was varied from 2 to 16.

Maturity-at-age values (P_j) were based on a study of the coastal migratory stock of striped bass performed by Merriman (1941), who found that all female striped bass are mature by 7 years of age:

j	P_j (%)
1	0
2	0
3	0
4	25
5	75
6	95
7–30	100

These data were collected more than 40 years ago and may not reflect current population characteristics. However, they are the only maturity data available that were collected away from the spawning rivers and, therefore, are less influenced by the possibility that most immature fish do not participate in spawning migrations.

Fecundity-at-age values (E_j) for Maryland striped bass are based on a relationship between fecundity and body weight developed by Lewis and Bonner (1966) for the striped bass population in the Roanoke River, North Carolina:

$$E_j = 555{,}182 + 75{,}858\ (W_j - 7.3); \qquad (3)$$

where W_j equals the average body weight (pounds) of an age j female. The North Carolina data set relating fecundity to female body size is the most complete set available and, for the present analysis, is assumed to be representative of the Maryland population. Body weight for each age j was calculated from a von Bertalanffy growth equation (Ricker 1975) using length data collected on female striped bass in Maryland waters of Chesapeake Bay and converting the length data to weight using the length-weight equation for females presented in the same paper (Mansueti 1961).

Results

Results of the EPR analysis are expressed in terms of the percentage of maximum EPR (EPR_{max}), which occurs when F = 0 for all ages in the population. A plot of percentages of EPR_{max} obtained with varying fishing mortality rates and ages at entry to the fishable stock is presented in Figure 1.

Also plotted in Figure 1 are results of two yield-per-recruit analyses. One analysis was performed by Goodyear (1984) using a modification of the Ricker (1975) method to allow for variable growth, and age- and sex-specific migration and fishing mortality patterns. The second analysis was based a Thompson and Bell (1934) yield-per-recruit model with the same mortality and growth input parameters used to derive the EPR values. Results of the two analyses are expressed as F_{max}, which represents the fishing mortality rate that results in the maximum yield per recruit for a given age at entry to the fishery, and $F_{0.1}$, which represents the fishing mortality rate at which the slope of the yield-per-recruit curve is equivalent to 10% of the slope of the curve at the origin. F_{max} values lie along the 20-40% EPR_{max} isopleths, and $F_{0.1}$ values lie along the 40-60% EPR_{max} isopleths.

The lifetime egg deposition of a female striped bass is strongly influenced by the level of fishing mortality she will experience. Under the conditions of no fishing throughout her lifetime (EPR_{max}), she will produce an estimated 8.6 million eggs. However, under the conditions of F = 0.4 and an age at entry to the fishery of 3 years, her estimated total lifetime fecundity will be reduced to 800,000 eggs (an 11-fold reduction). Delaying age at entry to the fishery from age 3 to age 7 and maintaining F = 0.4, or reducing the instantaneous fishing mortality rate to F = 0.15 and maintaining an age at entry to the fishery of 3 years, will result in a 3-fold increase in the EPR estimate (Figure 1).

Annual Egg Deposition Index

By multiplying the EPR_j values derived in equation 1A by an index of abundance for the year class they represent, an index of total annual egg deposition of the Maryland spawning population can be calculated:

$$EGG_t = \sum_{j=1}^{n} EPR_j YOY_{t-j}, \qquad (4)$$

where EGG_t equals the total egg deposition of the Maryland population in year t and YOY_{t-j} is the juvenile abundance index for the Maryland population in year t-j. The juvenile abundance index for the Maryland population is the average number of juvenile striped bass caught per seine haul in the four major spawning regions (Potomac River, Nanticoke River, Choptank River, and upper Chesapeake Bay region) in a given year. The juvenile index time series began in 1954 (Table 1) and is directly related to subsequent landings of striped bass in Maryland waters (Goodyear 1985); it is, therefore, considered an index of recruitment in the present analysis.

The sex ratio of eggs in each female is assumed to be 1:1 males to females. The maximum age of females in the population was chosen to be 15 years to be consistent with recently published models of the Maryland population of striped bass (Cohen et al. 1983; Goodyear 1984). As such, the minimum value for t in Equation 4 is equal to 1969. If 30 ages were used, only two EGG_t-values (t = 1984 and t = 1985) could be calculated.

An age of entry to the fishery of 2 years was used in the present analysis, equivalent to approximately 260 mm FL (10 inches FL). Two sets of fishing mortality rates were used: F_{2+} = 0.4 and F_{2+} = 0.6. These rates are within ranges estimated by Kohlenstein (1980) for the fishery in the Chesapeake Bay and by Boreman (1982) for the fishery along the Atlantic Coast.

Indices of annual egg deposition by the Maryland population, based on Equation 4, are listed in Table 1. The egg deposition indices are less variable than the juvenile indices because of the iteroparous spawning characteristic of striped bass; the range in egg deposition index values varies 2- to 3-fold, while the range in juvenile index values varies 25-fold during the same period of years.

A measure of survival is calculated by dividing the egg deposition index for a particular year into the juvenile index for the same year (Cohen et al. 1983):

$$S_t = YOY_t/EGG_t, \tag{5}$$

where S_t equals the survival between the egg and juvenile life stages in year t. Assuming survival between the juvenile and spawning adult life stages has been stable, the S_t value indicates a downward trend from 1969 to 1984 (solid lines in Figure 2). An equally plausible explanation for the apparent decline in S_t is an increasing trend in fishing mortality during 1969-1984. Using an iterative process, Goodyear (unpublished data) was able to detrend the S_t values by increasing the fishing mortality rate 0.022 per year, assuming the average fishing mortality rate was 0.4 or 0.6 (broken lines in Figure 2). Thus, the decline in juvenile abundance indices may have been caused by an increasing trend in mortality between the egg and juvenile life stages, an increasing trend in mortality between the juvenile and spawning adult life stages, or both.

Projections

The index of egg deposition by the Maryland population exhibited a steady decline since 1976 (Table 1 and Figure 3). Projections of annual egg deposition can be calculated with the assumption that the survival conditions (Figure 2) will stabilize and be equivalent to the average for recent years. Future indices of year class strength (i.e., future juvenile indices) were derived by multiplying the annual egg deposition index (EGG_t in Equation 4) by the average survival (S_t in Equation 5) for the period 1980–1984 ($S_{1980-1984} = 2.428 \times 10^{-6}$ for $F_{2+} = 0.4$; and $S_{1980-1984} = 7.449 \times 10^{-6}$ for $F_{2+} = 0.6$). Future egg deposition indices based on the derived juvenile indices were calculated using the method previously described.

With no change in fishing mortality, the egg deposition index will continue to decline (Figure 4). A 50% reduction in fishing mortality across all ages following the 1985 spawning season will cause an eventual positive slope for the annual egg deposition index. A total cessation of fishing mortality on all age groups following the 1985 spawning season will result in a substantial increase in annual egg deposition.

The reduction in fishing mortality necessary to achieve a zero slope in the egg index can be calculated from the following relationship:

$$EPR = 1/S_E, \qquad (6)$$

where S_E is the survival between the egg and juvenile life stages needed to acheive equilibrium conditions given the EPR value. Assuming $S_E = S_{1980-1984}$, a value of 411,862 eggs per recruit is necessary to satisfy conditions of Equation 6 with $F_{2+} = 0.4$, and a value of 134,246 eggs per recruit is necessary with $F_{2+} = 0.6$.

Therefore, at least a 38% reduction in F is needed with F_{2+} = 0.4, and at least a 27% reduction in F is needed with F_{2+} = 0.6, to acheive an eventual positive growth in the egg deposition index. Positive growth in the index may also be acheived by delaying age at entry to the fishery until age 5 if F_{2+} = 0.4, or age 4 if F_{2+} = 0.6.

Effectiveness of ASMFC Management Recommendations

In 1981, the ASMFC recommended several management measures to increase egg production in the anadromous striped bass populations along the Atlantic Coast (ASMFC 1981). The minimum size limit recommended for the Chesapeake Bay fishery was equivalent to an approximate age of 2.5 years (356 mm or 14 inches TL); the minimum size limit recommended for coastal waters outside of Albemarle Sound, the Chesapeake Bay, and the Hudson River was equivalent to an approximate age of 5 years (610 mm or 24 inches TL). The ASMFC also recommended an allowance for retention of four fish or 5% of the catch less than 24 inches TL (610 mm) per day by each person fishing.

To simulate the reductions in fishing mortality rates implicit in the ASMFC plan, different fishing mortality patterns were established for the females in the Maryland population that remain in Chesapeake Bay and for those emigrating to the coastal regions. Half of the age 3 females were assumed to emigrate from the Bay, based on an analysis performed by Kohlenstein (1981). Once out of the Bay, these fish were assumed not to return until age 5+. The fishing mortality patterns for the Bay residents and coastal migrants did not allow for retention of four fish or 5% per day under 24 inches TL because of the lack of available estimates of the relationship between the retention allowance and fishing mortality rates.

With these fishing patterns following the 1985 spawning season and $S_{1985+} = S_{1980-1984}$, the egg deposition index will continue to decline with $F_{2+} = 0.4$ prior to 1985, and be slightly above zero slope with $F_{2+} = 0.6$ prior to 1985 (Figure 5). This suggests that the regulations of the coastwide plan are not sufficient to reverse the declining trend in egg production by Maryland striped bass. Although the reduction will cause positive growth in the egg deposition index assuming $F_{2+} = 0.6$ prior to 1985, incorporation of the unknown additional fishing mortality caused by the allowance of retention of a limited number of fish under 24 inches TL would probably be sufficient to keep the egg index below the replacement level.

Aware that the recommended management measures were inadequate, based on an analysis using the population model presented in Goodyear et al. (1985), the ASMFC asked member states to reduce the fishing mortality rate on anadromous striped bass in their waters an additional 55% beyond the reduction that would occur upon enactment of the coastwide plan and elimination of the retention allowance for fish under 24 inches TL. This additional reduction will result in an increase in the egg index for the Maryland population assuming $F_{2+} = 0.4$ or assuming $F_{2+} = 0.6$ prior to 1985 (Figure 5).

Discussion

The technique used in this paper to assess the potential impact of reduced fishing mortality on the reproductive capacity of Maryland striped bass requires the assumption that the relationship between the number of eggs deposited and the surviving number of juvenile recruits is linear. Although no direct evidence is available, Merriman (1941), Koo (1970), and others have suggested that dominant year classes of striped bass in Chesapeake Bay are produced by relatively small brood stock sizes. This implies that the relationship between spawners and recruits is non-linear. Density-dependent mortality rates between the egg and juvenile life stages would tend to reduce the slope of increasing and decreasing trends in the egg index caused by alterations of fishing mortality if the rates are compensatory, or increase the slopes in the trends if the rates are depensatory. As such, projections made with the density-independent EPR technique should be interpreted only as changes in reproductive potential caused by reductions in fishing mortality rather than long-term population trends caused by those reductions.

The decline in the survival index for the Maryland population (Figure 2) is probably due to a combination of increasing fishing mortality and an increase in mortality during the young-of-the-year life stages. Projections of the egg index applied the assumption that the survival rate between the egg and juvenile life stages will stabilize at a level representative of the most recent years. If survival rates during age 0 are declining, and will continue to decline, projections of the egg index based on reductions in fishing mortality will overestimate the true index values. A number of factors have been identified that might have increased the mortality rates in egg and larval life stages of the Maryland population of striped bass (Anonymous 1984); however, trends in the degree of influence of these factors have not been detected.

As shown in figures 4 and 5, the initial fishing mortality rates have a strong influence on the response of the population's reproductive capacity to a reduction in those rates; the higher the initial rates, the greater the response for a given percentage of reduction. If survival of age 0 striped bass in the Maryland population stabilizes at the 1980-1984 level, an egg-per-recruit value of 5-15% of the maximum (depending on the assumed value of F) appears to be adequate to maintain egg production at recent levels. This requires at least a 27-38% reduction in the current fishing mortality rate across all ages assuming F is 0.4-0.6. This value may vary from population to population depending on lifetime survival conditions and should not be accepted as a "rule of thumb" for all anadromous striped bass populations along the Atlantic coast.

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Table 1.-Indices of juvenile abundance, expressed as the average catch per beach seine haul, and annual egg deposition (x 10^{-6}) for the Maryland population of striped bass, 1954-1984.

Year	Juvenile Index[1]	Egg Deposition Index $F_{2+} = 0.4$	Egg Deposition Index $F_{2+} = 0.6$
1954	5.2		
1955	5.5		
1956	15.2		
1957	3.2		
1958	19.2		
1959	1.6		
1960	7.1		
1961	16.9		
1962	12.2		
1963	4.0		
1964	23.5		
1965	7.4		
1966	22.1		
1967	7.8		
1968	7.2		
1969	10.2	1.94	0.77
1970	30.4	2.10	0.83
1971	11.8	2.24	0.88
1972	8.5	2.15	0.80
1973	9.0	2.02	0.71
1974	10.1	2.05	0.78
1975	6.7	2.41	0.97
1976	4.9	2.48	0.96
1977	4.9	2.33	0.84
1978	8.4	2.13	0.74
1979	4.2	1.98	0.67
1980	1.9	1.73	0.57
1981	1.2	1.51	0.48
1982	8.4	1.34	0.44
1983	1.4	1.25	0.42
1984	3.2	1.12	0.36

[1]Source: Maryland Tidewater Fisheries Administration (unpublished data)

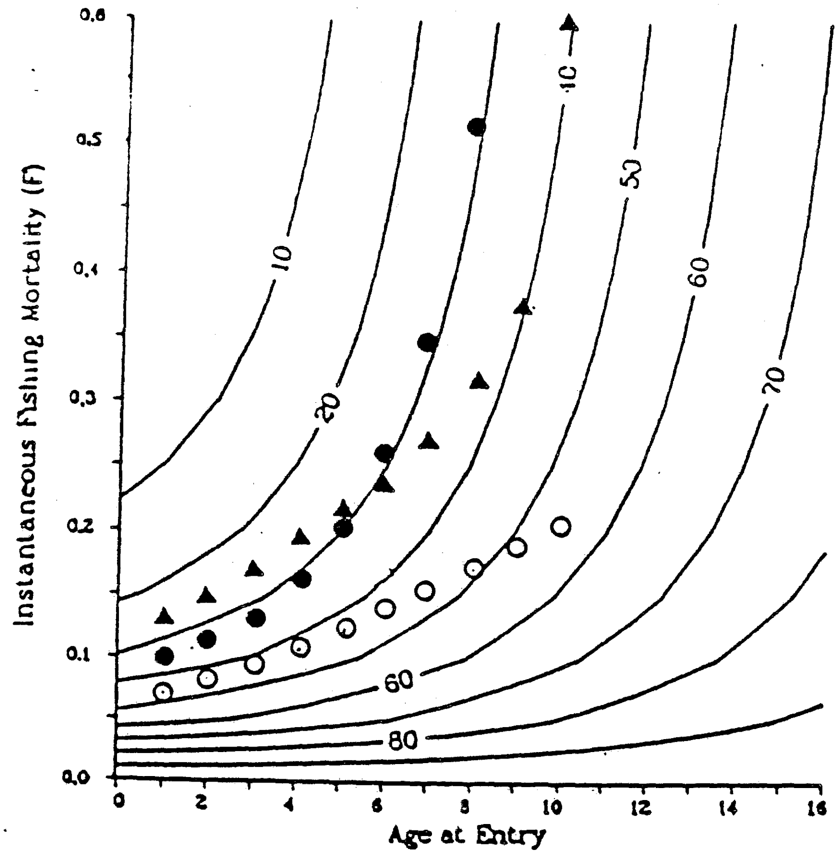

Figure 1.—Isopleths of percentage of maximum eggs per recruit for the Maryland striped bass population under varying fishing mortality rates and ages at entry to the fishery. Also plotted are estimates of F_{max} (solid triangles) from Goodyear (1984) and F_{max} (solid circles) and $F_{0.1}$ (open circles) from a Thompson and Bell yield-per-recruit model.

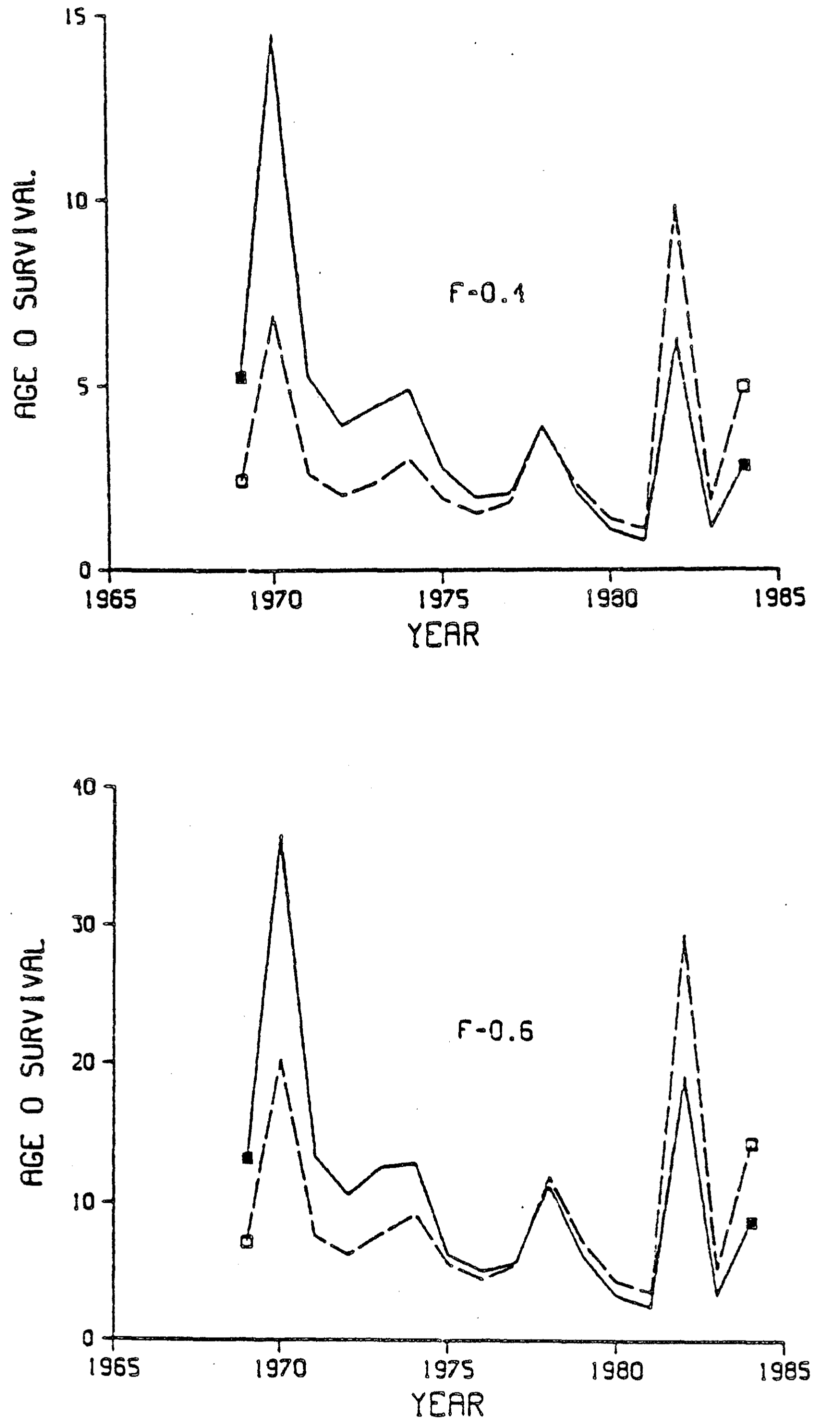

Figure 2.-Egg to juvenile survival rate (x 10^{6}) for the Maryland striped bass population, 1969-1984, assuming the fishing mortality rate was constant at F=0.4 or F=0.6 (solid lines), and assuming the fishing mortality rate increased 0.022 per year with an average of F=0.4 or F=0.6 (broken lines).

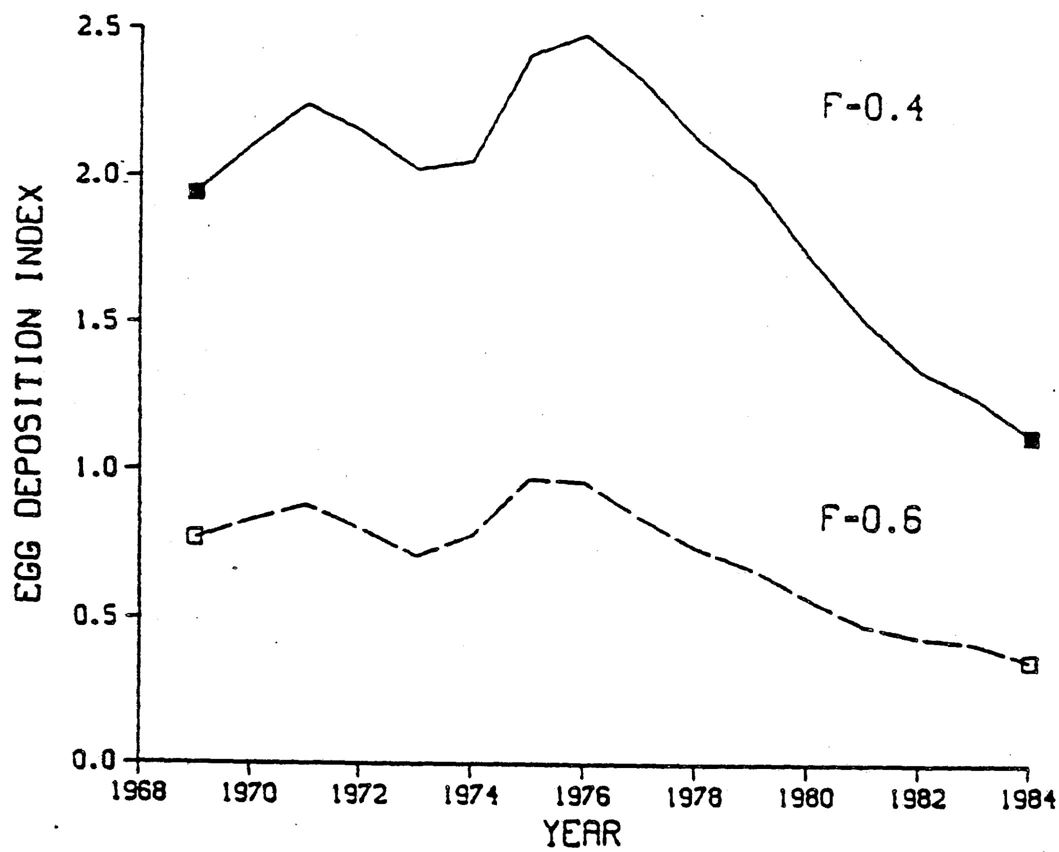

Figure 3.-Estimates of the annual egg deposition index (x 10^{-4}) for the Maryland striped bass population, 1969-1984, assuming the fishing mortality rate was constant at F=0.4 or F=0.6.

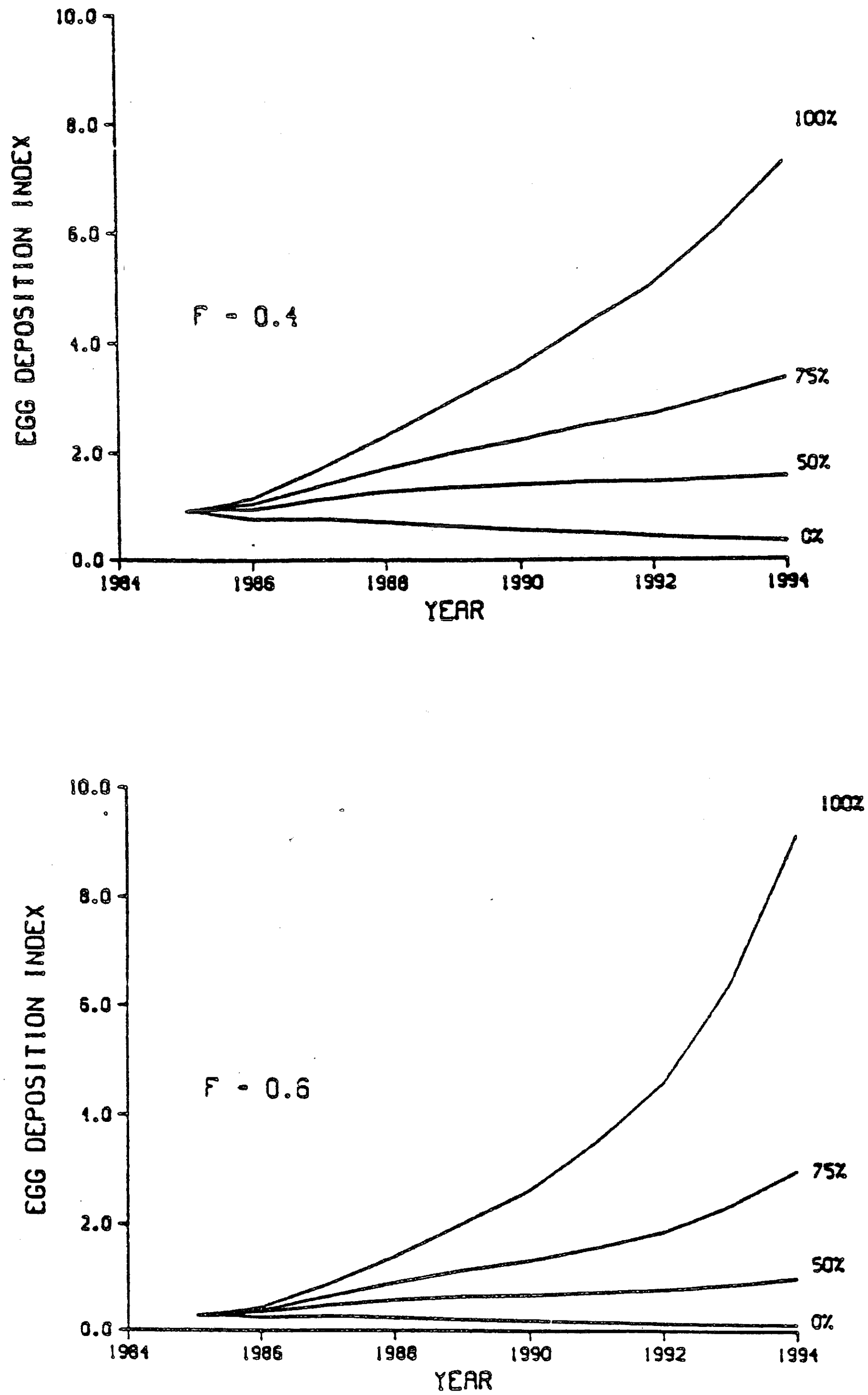

Figure 4.–Projections of the egg index (x 10^{-4}) for the Maryland striped bass population, 1985–1994, assuming a 0%, 50%, 75%, and 100% reduction in fishing mortality across all ages following the 1985 spawning season. Projections include the assumptions that the fishing mortality rate is constant and the rate prior to reduction is F=0.4 or F=0.6.

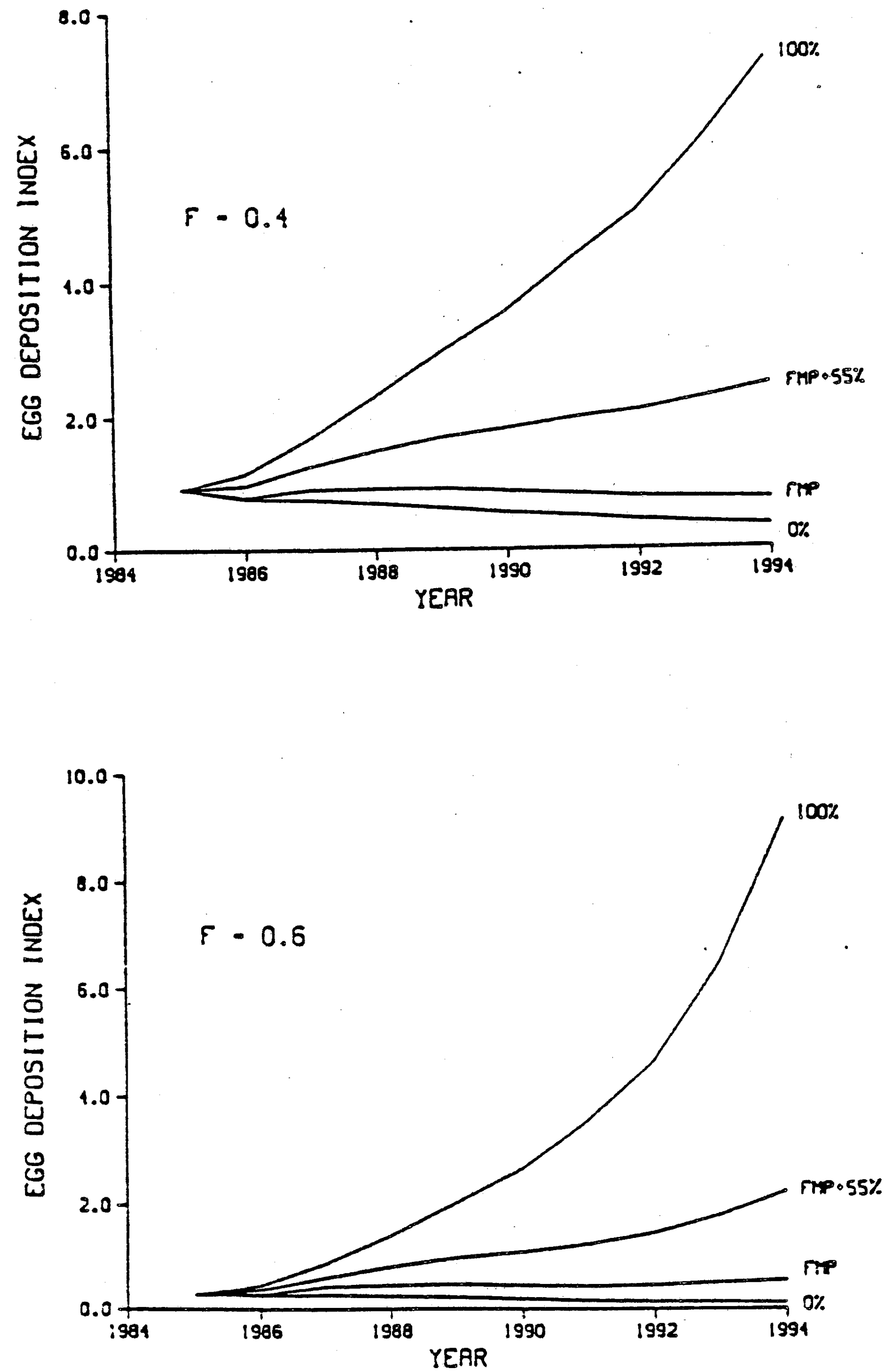

Figure 5.-Projections of the egg index (x 10^{-4}) for the Maryland striped bass population, 1985-1994, assuming enactment of regulations recommended by the ASMFC for the coastal states (FMP), and a 55% reduction in fishing mortality rates in addition to the reduction implicit in the ASMFC regulations (FMP + 55%). Projections include the assumptions that the fishing mortality rate is constant and the rate prior to reduction is F=0.4 or F=0.6.