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Evaluation of Striped Bass Stocks in Virginia: Monitoring and Tagging Studies, 1999-2003

Annual Report

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Preface

Striped bass (*Morone saxatilis*) have historically supported one of the most important recreational and commercial fisheries along the Atlantic coast. In colonial times striped bass were abundant in most coastal rivers from New Brunswick to Georgia but overfishing, pollution and reduction of spawning habitat have resulted in periodic crashes in stocks and an overall reduction of biomass (Merriman 1941, Pearson 1938). Striped bass populations at the northern and southern extremes of the Atlantic are apparently non-migratory (Raney 1957). Presently, important sources of striped bass are limited to the Roanoke, Delaware and Hudson rivers and the major tributaries of Chesapeake Bay (Lewis 1957) with the Chesapeake Bay and Hudson River being the primary sources of the coastal migratory population (Dorazio *et al.* 1994).

Examination of meristic characteristics indicate that the coastal migratory population consists of distinct subpopulations from the Hudson River, James River, Rappahannock - York rivers, and upper Chesapeake Bay (Raney 1957). The Roanoke River striped bass may represent another distinct subpopulation (Raney 1957). The relative contribution of each area to the coastal population varies. Berggren and Lieberman (1978) concluded from a morphological study that Chesapeake Bay striped bass were the major contributor (90.8%) to the Atlantic coast fisheries, and the Hudson River and Roanoke River stocks were minor contributors. However, they estimated that the exceptionally strong 1970 year class constituted 40% of their total sample. Van Winkle *et al.* (1988) estimated that the Hudson River stock constituted 40% - 50% of the striped bass caught in the Atlantic coastal fishery in 1965. Regardless of the exact proportion, management of striped bass is truly a multi-jurisdiction concern as spawning success in one area certainly influences fishing success in many areas.

Concern about the decline in striped bass landings along the Atlantic coast since the mid-1970s prompted the development of an interstate fisheries management plan (FMP) under the auspices of the Atlantic States Marine Fisheries Management Program (ASMFC 1981). Federal legislation was enacted in 1984 (Public Law 98-613, the Atlantic Striped Bass Conservation Act) which enables Federal imposition of a moratorium for an indefinite period in those states that fail to comply with the coastwide plan. To be in compliance with the plan, coastal states have imposed restrictions on their commercial and recreational striped bass fisheries ranging from combinations of catch quotas, size limits and time-limited to year-round moratoriums. Due to an improvement in spawning success, as judged by increases in annual values of the Maryland juvenile index, a limited fishery was established in fall, 1990. This transitional fishery existed until 1995 when spawning stock biomass reached sufficiently healthy levels (Field 1997). ASMFC subsequently declared Chesapeake Bay stocks to have reached benchmark levels and adopted Amendment 5 to the original FMP that allowed expanded state fisheries.

To document continued compliance with Federal law, the Anadromous Fishes Program of the Virginia Institute of Marine Science (VIMS) has monitored the size and age composition, sex ratio and maturity schedules of the spawning striped bass stock in the Rappahannock River since December 1981 utilizing commercial pound nets and, since 1991, variable-mesh experimental gill nets. Spawning stock assessment was expanded to include the James River in 1994 utilizing commercial fyke nets and variable-mesh experimental gill nets. The use of fyke nets was discontinued after 1997. In conjunction with the monitoring studies, tagging programs have been conducted in the James and Rappahannock rivers since 1987 . These studies were established to document the migration and relative contribution of these Chesapeake Bay stocks to the coastal population and to provide a means to estimate inter-year survival rates (S). With the re-establishment of fall recreational fisheries in 1993, the tagging studies were expanded to include the York River and western Chesapeake Bay to provide a direct estimation of the resultant fishing mortality (F).

This document reports the results of our tagging and monitoring activities during the period 1 September 1999 through 31 October 2000. It includes an assessment of the biological characteristics of striped bass taken from the 2000 spring spawning run, estimates of annual survival based on annual spring tagging, and the results of the fall 1999 directed mortality study that is cooperative with the Maryland Department of Natural Resources. The information contained in this report is required by the Atlantic States Marine Fisheries Commission and is used to implement a coordinated management plan for striped bass in Virginia, and along the eastern seaboard.

Acknowledgments

We are deeply indebted to numerous parties for their participation and/or contributions to the striped bass tagging and spawning stock assessment program. These include, but are not limited to: the support personnel from the Virginia Institute of Marine Science; Mary Lynn Aiken, Pat Crewe, Susan Denny, Brett Falterman, John Foster, Jim Goins, Dean Grubbs, Dan Hepworth, Gail Holloman, Curtis Leigh, Kristin Maki, Todd Mathes, Jason Romine, John Walter and Brian Watkins; the cooperating commercial fishermen; Bobby Brown, Donnie Green, Allan Ingraham, Raymond Kellum, Randy Kirby, Stanley Oliff, Jamie Saunders and Greg Swift; Cynthia Goshorn and Beth Rodgers of Maryland Department of Natural Resources (MDNR) and David Smith of the U.S. Geological Survey.

Executive Summary

I. Assessment of the spawning stocks of striped bass in the Rappahannock and James rivers, Virginia, spring 2000.

Catch Summaries:

1. In 2000, 2,018 striped bass were sampled between 27 March and 4 May from four commercial pound nets in the Rappahannock River. The samples were predominantly male (96.0%) and young (86.1% ages 2-4). Females dominated the age eight and older age classes (73.8%). The mean age on the male striped bass was 3.7 years. The mean age of the female striped bass was 8.7 years.

2. During the 30 March - 3 May period, the 1996 and 1997 year classes were the most abundant and were 99.9% male. The contribution of age six and older males was only 1.0% of the total catch. Age eight and older females, presumably repeat spawners, were 2.7% of the total catch but represented 72.4% of all females caught.

3. In 2000, 612 striped bass were sampled between 27 March and 4 May in two experimental anchor gill nets in the Rappahannock River. The samples were predominantly male (95.4%) and young (79.2% ages 2-4). All the pre-1991 year class stripers sampled were female. The mean age of the male striped bass was 3.8 years. The mean age of the female striped bass was 7.5 years.

4. During the 30 March - 3 May period, the 1996-1997 year classes were the most abundant and were 99.2% male. The contribution of age six and older males was only 4.3%. Age eight and older females, presumably repeat spawners, were 2.0% of the total catch but were 44.4% of the total females caught.

5. In 2000, 1,710 striped bass were sampled between 27 March and 4 May in two variable-mesh gill nets in the James River. Males dominated the 1996-1998 year classes (99.2%) and the 1992-1995 year classes (95.7%). Females dominated the 1985-1991 year classes (80.0%). The mean age of the male striped bass was 4.3 years. The mean age of the female striped bass was 6.4 years.

6. During the 30 March - 3 May period, the 1996 and 1997 year classes were the most abundant and were 98.4% male. The contribution of age six and older males was only 7.4% of the total catch. Age eight and older females, presumably repeat spawners, were 0.8% of the total catch but represented 34.1% of all females caught.

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Spawning Stock Biomass Indexes (SSBI)

7. The Spawning Stock Biomass Index from the Rappahannock River pound nets was 42.7 kg/day for male striped bass and 14.6 kg/day for female striped bass. The male index was the highest in the time series and double the 10-year average. The female index was the lowest since 1991 and was 56.4% below the average index value.

8. The SSBI for the Rappahannock River gill nets was 65.3 kg/day for male striped bass and 16.5 kg/day for female striped bass. Relative to the 1991-2000 time series, the male index was the fifth highest (13.0% below the ten-year average). The female index, although slightly higher than in 1999, was still 51.9% below the ten-year average, and continued a trend of declining indexes since 1993.

9. The SSBI for the James River gill nets was 241.4 kg/day for male striped bass and 21.2 kg/day for female striped bass. Relative to the 1994-2000 time series, the male index was by far the highest (362.5% above the seven-year average). In contrast, the female index was the lowest to date and was 66.9% below the average index value.

Egg Production Potential Indexes (EPPI)

10. An index of potential egg production was derived from laboratory estimates of weight- and length-specific numbers of oocytes in the ovaries of mature females. The Egg Production Potential Index (millions of eggs/day) for the Rappahannock River pound nets was 2.06. Older (8+ years) female stripers were responsible for 86.5% of the index.

11. The EPPI for the Rappahannock River gill nets was 2.34. Older (8+years) female striped bass were responsible for 61.4% of the index.

12. The EPPI for the James River gill nets was 3.18. Older (8+ years) female striped bass were responsible for 56.0% of the index.

Estimates of Annual Survival (S) based on catch-per-unit-effort

13. The cumulative catch rate (sexes combined) from the Rappahannock River pound nets (39.7 fish/day) was the highest in the 1991-2000 time series. This was the result of very high catch rates of 1996 and 1997 year class stripers, mostly male, while the catch rates of most other year classes were less than or equal to those from 1999. The cumulative catch rate of male striped bass (37.8 fish/day) was the highest in the time series, while the cumulative catch rate of female striped bass (1.9 fish/day) was the lowest.

14. Year class-specific estimates of annual survival (S) for pound net data varied widely between years. The geometric mean S of the 1983-1992 year classes varied from 0.48 - 0.70 (mean = 0.600). The geometric mean survival rates differed greatly between sexes. Mean survival rates for male stripers (1987-1992 year classes) varied from 0.33 - 0.47 (mean = 0.412) but mean survival rates of female stripers (1983-1989 year classes) varied from 0.58 - 0.83 (mean = 0.635).

15. The cumulative catch rate (sexes combined) from Rappahannock River gill nets (51.9 fish/day) was 9.6% below the 1991-2000 time series average and was the third consecutive year of decline from the peak in 1997. Catch rates were high for the 1996 and 1997 year classes and catch rates for most other year classes declined from the 1999 catch rates.

16. Year class-specific estimates of annual survival for gill net data varied widely between years. The geometric mean S of the 1984-1991 year classes varied from 0.41 - 0.60 (mean = 0.50). The mean survival rates for male stripers (1984-1991) varied from 0.23 - 0.52 (mean = 0.35). The mean survival rates for female stripers (1984-1990) varied from 0.41 - 0.80 (mean = 0.60).

17. The cumulative catch rate (sexes combined) from James River gill nets (75.3 fish/day) was the highest of the 1994-2000 time series. Catch rates were highest for the 1995-1997 year classes, while the catch rates from all other year classes showed a decline from 1999. The cumulative catch rates for male striped bass (73.5 fish/day) was the highest of the time series, while the cumulative catch rate for female striped bass (2.2 fish/day) was the lowest.

18. Year class-specific estimates of annual survival varied widely between years. The geometric mean S of the 1984-1992 year classes varied from 0.33 - 0.69 (mean = 0.49). The mean survival rates of male stripers (1988-1992 year classes) varied from 0.28 - 0.67 (mean = 0.42). The mean survival rates of female stripers (1984-1990 year classes) varied from 0.34 - 0.62 (mean = 0.47).

II. Mortality estimates of Striped Bass (*Morone saxatilis*) that spawn in the Rappahannock River, Virginia.

19. Tagging data from 1988-1999 of Rappahannock River striped bass that were > 711mm TL at the time of tagging were analyzed using two similar but independent modeling approaches.

20. The primary analysis protocol, as established by the ASFMC Tagging Subcommittee, specifies the derivation of survival estimates from a suite of reformulated Brownie models. Application of a suite of 12 models yielded survival estimates that ranged from 0.73 to 0.64 over the 12-year period under the assumption that the tag reporting rate (λ) was 0.64.

21. As a means of comparison, multiyear tagging models that yield estimates of instantaneous mortality rates were applied to the Rappahannock River striped bass tagging data set. Application of the time-specific model yielded estimates of *F* that ranged from 0.09 to 0.17 over the 12-year period. The estimate of *M* from that model was 0.34, which is more the double the natural mortality estimate assumed by the ASFMC Tagging Subcommittee.

22. For the purposes of model evaluation, a series of diagnostics were applied to both the reformulated Brownie models and the instantaneous rates models. These diagnostics led to the discovery of problems in the data that appear to be cohort-specific. These problems forced the software program to impose constraints during the estimation process and, as a result, several survival and tag reporting rate parameters took on nonsensical estimates.

23. It is unclear exactly how the presence of cohort-specific problems affects the overall data analysis. Further research in the form of simulation studies is needed to adequately understand how multiyear tagging models behave when cohort-specific problems are present. Hence, it is impossible to confidently state that the parameter estimates presented in this report represent the true survival/mortality rates of striped bass tagged in the Rappahannock River.

III. Estimate of the 1999 Striped Bass Rate of Fishing Mortality in Chesapeake Bay

24. The fall 1999 striped bass recreational season (15 June - 30 Nov in Maryland, 4 Oct - 31 Dec in Virginia) in Chesapeake Bay was divided in seven rounds in Maryland and three rounds in Virginia. Each round was of approximately 30 days in duration.

25. Striped bass were tagged and released during six-day intervals prior to the start of each round and the recaptures that occurred within that round were used for analysis. Adjustments were made for tag loss, mortality and for mixing of the newly tagged fish into the population.

26. A total of 4,173 striped bass were tagged in Maryland and 2,707 striped bass were tagged in Virginia. The number of stripers tagged and released per round varied from 284-1,040 in Maryland and from 453-1,155 in Virginia.

27. A total of 26 striped bass tagged in Maryland were recaptured within their round of release. A total of 24 striped bass tagged in Virginia were recaptured within their round of release.

28. The Chesapeake Bay estimate of total fishing mortality (F) was 0.30. This is the sum of non-harvest (0.10) and harvest (0.20) mortality estimates. The target F for Chesapeake Bay is 0.28.

Table of Contents

List of Tables

I. Assessment of the spawning stocks of striped bass in the Rappahannock and James rivers, Virginia, spring 2000.

II. Mortality estimates of Striped Bass (*Morone saxatilis*) that spawn in the Rappahannock River, Virginia

III. Estimate of the 1999 Striped Bass of Fishing Mortality in Chesapeake Bay

List of Figures

I. Assessment of spawning stocks of striped bass in the Rappahannock and James rivers, Virginia, spring 2000.

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Introduction

Every year, striped bass migrate along the US east coast from offshore and coastal waters and enter brackish or fresh water to spawn. Historically, the principal spawning areas in the northeastern US have been the Hudson, Delaware and Chesapeake estuarine systems (Hardy 1998). The importance of the Chesapeake Bay spawning grounds to these stocks has long been recognized (Merriman 1941, Raney 1952). In the Virginia tributaries of Chesapeake Bay, peak spawning activity is usually observed in April and is associated with rapidly rising water temperatures in the range of 13-19^0 C (Grant and Olney 1991). Spawning is often completed by mid-May, but may continue until June (Chapoton and Sykes 1961). Spawning grounds have been associated with rock-strewn coastal rivers characterized by rapids and strong currents on the Roanoke and the Susquehanna rivers (Pearson 1938). In Virginia, spawning occurs over the first 40 km of tidal freshwater portions of the James, Rappahannock, Pamunkey and Mattaponi rivers (Grant and Olney 1991; Olney et al. 1991; McGovern and Olney 1996).

The Atlantic States Marine Fisheries Commission (ASMFC) declared that the Chesapeake Bay spawning stocks were fully recovered in 1995 after a period of very low stock abundance in the 1980's. This statement of recovered status was based on estimated levels of spawning stock biomass that were found in 1995 to be equal or greater than the average levels of the 1960-72 period (Rugulo et al. 1994). Thus, continued assessment of spawning stock abundance is an important component of ASMFC mandated monitoring programs. To this end, the Anadromous Fishes Program at the Virginia Institute of Marine Science (VIMS) began development of spawning indexes that depict annual changes in catch rates of striped bass on the spawning grounds of the James and the Rappahannock rivers. These rivers represent the major contributors to the Chesapeake bay stocks that originate from Virginia waters.

Materials and Methods

Samples of striped bass for biological characterization of the spring spawning stocks were obtained from the Rappahannock and James rivers between 27 March - 4 May, 2000. Samples (the entire catch of striped bass from each gear) were taken twice-weekly (Monday and Thursday) from a set of two commercial pound nets (river miles 44 and 47) on the Rappahannock River. Pound nets are fixed commercial gears that have been the historically predominant gear type used in the river and are presumed to be non size-selective in their catches of striped bass. The established protocol (Sadler *et al.* 1999) was to alternate the choice of the net sampled but weather constraints often dictated whether that net could be sampled. In addition to the pound nets, samples were also obtained twice-weekly from variable-mesh experimental anchored gill nets (two each at river mile 48 on the Rappahannock River and river mile 59 on the James River, Figures 1-2). The gill nets in the James River were in a different location than in 1994-1999 and were set and fished by a different waterman.

In addition, data from pound nets sampled in 1991 and 1992 were included to expand the time series. These samples were consistent in every respect to the 1993-2000 samples with the following exceptions in 1991: two samples (3 and 17 April) came from a pound net at river mile 25 and samples were obtained weekly vs. twice weekly.

The variable-mesh gill nets deployed on both rivers were constructed of ten panels, each measuring 30 feet (9.14 m) in length, and 10 feet (3.05 m) in depth. The ten stretched-mesh sizes (in inches) were 3.0, 3.75, 4.5, 5.25, 6.0, 6.5, 7.0, 8.0, 9.0, 10.0. These mesh sizes correspond to those used for spawning stock assessment by the Maryland Department of Natural Resources. The order of the panels was determined by a randomized stratification scheme. The mesh sizes were divided into two groups, the five smallest and the five largest mesh sizes. One of the two groups was randomly chosen as the first group, and one mesh size from that group was randomly chosen as the first panel in the net. The second panel was randomly chosen from the second group, the third from the first group, and so forth, until the order was complete. The order of the panels in the first net was (in inches) 8.0, 5.25, 9.0, 3.75, 7.0, 4.5, 6.5, 6.0, 10.0, and 3.0, and the order was (in inches) 8.0, 3.0, 10.0, 5.25, 9.0, 6.0, 6.5, 3.75, 7.0, and 4.5 in the second net.

Data from gill net samples collected in 1991 and 1992 from the Rappahannock River were also included in the time series. These data were consistent to the 1993-2000 samples in every respect.

Striped bass collected from the monitoring sites were measured and weighed on a Limnoterra FMB IV electronic fish measuring board interfaced with a Mettler PM 30000-K electronic balance. The board records lengths (FL and TL) to the nearest mm, receives weight (g) input from the balance, and allows manual input of sex and gonad maturity into a data file for subsequent analysis. Gonad weight (g) was taken for all female striped bass sampled, and two or three subsections extracted from ovaries in the hydrated state, as described by Barbieri and Barbieri (1993). A 2-3 gram subsample was taken, weighed and washed through a 30 micron screen and stored in 2% formalin for subsequent counting. Scales were collected from between the spinous and soft dorsal fins above the lateral line for subsequent aging, using the method established by Merriman (1941), except that impressions made in acetate sheets replaced the glass slide and acetone.

All readable scales were aged using the microcomputer program DISBCAL of Frie (1982), in conjunction with a sonic digitizer-microcomputer complex (Loesch et al. 1985). Growth increments were measured from the focus to the posterior edge of each annulus. In order to be consistent with ageing techniques of other agencies, all striped bass were considered to be one year older on 1 January of each year. Mean age was determined by the sum of the relative contribution of each age class to the total (aged) catch.

The spawning stock biomass index (SSBI) for striped bass was defined (Sadler et al. 1999) as the 30 Mar - 3 May mean CPUE (kg/net day) of mature males (age-3 years and older), females (age-4 years and older) and the combined sample (males and females of the specified ages). An alternative index, based on the fecundity potential of the female striped bass, sampled was investigated and the results compared with the index based on mean female biomass.

To determine fecundity, each ovary subsample was mixed in 500 ml of water and stirred until a homogenous suspension resulted. A two-milliliter aliquot was extracted and the contents counted under a dissecting scope. The resultant count was then extrapolated to account for the entire subsample. The geometric mean of the egg counts of the subsamples for each fish was calculated. A non-linear regression curve was fitted to data of total oocytes versus fork length. The resultant equation was then applied to the fork lengths of all mature (4+ years old) females from the pound net and gill net samples and the Egg Production Potential Index (EPPI) was defined as the mean number of eggs potentially produced per day of effort of the mature female striped bass sampled from 30 March - 3 May.

Estimates of survival (S, the fraction surviving after becoming fully recruited to the stock) were calculated by dividing the catch rate (number/day) of a year class in year a+1 by the catch rate (number/day) of a year class in year a. If the survival estimate between successive years was >1, the estimate was derived by interpolating to the following year. The geometric mean of S was used to estimate survival over periods exceeding one year (Ricker 1975)

Results

Catch Summary

Rappahannock River

Pound nets: Striped bass (n= 2,018) were sampled between 27 March and 4 May, 2000 from the pound nets in the Rappahannock River. Total catches peaked from 17-27 April and again on 4 May, due to large numbers of young (2-4 year old) males (Table 1). Catches of female striped bass were highest on 17 April, but were generally available throughout April and early May. Males made up 96.0% of the total catch. Males dominated the 1996-1998 year classes (99.9%) and the 1992-1995 year classes (83.7%), but females dominated the 1984-1991 year classes (87.8%).

Catch rates (g/day) of male striped bass were highest from 17-24 April and on 4 May (Table 2). The catch rates of female striped bass were highest from 3-6 April and on 17 April. The catch rate of males greatly exceeded that of females from 27-30 March and again from 10 April - 4 May (14.7:1 on 4 May). Catch rates of females exceeded that for males only from 3-6 April (2.0:1 on 6 April). The mean ages of male striped bass varied from 3.5-4.2 years with the youngest mean ages occurring on the dates with the maximum catches. The mean ages of females varied from 6.0-11.0 years.

During the 30 March - 3 May period, the 1996 (34.1%) and 1997 (29.4%) year classes were the most abundant (Table 3). These year classes were 99.9% male. The contribution of males age-6 and older (the pre-1995 year classes) was only 1.0% of the total aged catch. These year classes were most vulnerable to commercial and recreational exploitation within Chesapeake Bay. The contribution of females age-8 and older, presumably repeat spawners, was 2.7% of the total aged catch but was also 72.4% of the total females captured.

Experimental gill nets: Striped bass (n= 612) were also sampled between 27 March and 4 May, 2000 from two multi-mesh experimental gill nets in the Rappahannock River. Total catches peaked sharply from 27-30 March and again on 13 April, due to large numbers of young (2-4 year old) males (Table 4). Catches of female striped bass were highest on 13 April, but were generally caught only in low numbers throughout the sampling period. Males made up 95.4% of the total catch. Males dominated the 1996-1998 year classes (99.4%) and the 1992-1995 year classes (85.5%), but the 1984-1990 year classes were exclusively female.

Catch rates (g/day) of male striped bass were highest from 27 March - 3 April (Table 5). The catch rates of female striped bass were highest from 3-6 April. The catch rate of males exceeded that of females except on 6,17 and 27 April. The mean ages of male striped bass varied from 3.3-4.5 years with the youngest males (2-3 years) being prevalent for the first half of the sampling period. The mean ages of females varied from 5.5-13.0 years but these means were based on very low total catches.

The mean age of the female striped bass captured from the gill nets younger than that estimated for those captured in the pound nets, illustrating a relative scarcity of older (age-8+) females in gill-net catches. Only eight age-8+ females were captured in gill nets, and all of these were taken from 27 March - 13 April.

During the 30 March - 3 May period, the 1996 (33.1%) and 1997 (28.2%) year classes were prevalent (Table 6). These year classes were 99.2% male. The contribution of males age-6 and older (the pre-1995 year classes) was only 4.3% of the total aged catch. These year classes were most vulnerable to commercial and recreational exploitation within Chesapeake Bay. The contribution of females age-8 and older, presumably repeat spawners, was 2.0% of the total aged catch but was 44.4% of the total females captured.

James River

Experimental gill nets: Striped bass (n= 1,710) were sampled between 27 March and 4 May, 2000 from the two multi-mesh experimental gill nets in the James River. Total catches peaked from 11-17 April, due to large catches of 2-4 year old males (Table 7). Catches of female striped bass were consistent, although small, before peaking on 17 April. Males dominated the 1996-1998 year classes (99.2%) and the 1992-1995 year classes (95.7%), but females were prevalent in the 1985-1991 year classes (80.0%).

Catch rates (g/day) of male striped bass were highest from 27-30 March and from 11-17 April (Table 8). The catch rates of female striped bass were highest from 3-6 April and on 17 April. The catch rate of females exceeded that of males only on 1 May. Catch rates of males greatly exceeded that for females from 27 March - 24 April (42.6:1 on 27 March). The mean ages of male striped bass varied from 3.9-5.0 years, but varied from only 4.1-4.4 years between 27 March and 17 April. The mean ages of females varied from 4.0-10.0 years, but varied from 5.2-9.8 years for dates with more than a single specimen.

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Catch rates (g/day) of male striped bass were highest from 27 March - 3 April (Table 5). The catch rates of female striped bass were highest from 3-6 April. The catch rate of males exceeded that of females except on 6,17 and 27 April. The mean ages of male striped bass varied from 3.3-4.5 years with the youngest males (2-3 years) being prevalent for the first half of the sampling period. The mean ages of females varied from 5.5-13.0 years but these means were based on very low total catches.

The mean age of the female striped bass captured from the gill nets younger than that estimated for those captured in the pound nets, illustrating a relative scarcity of older (age-8+) females in gill-net catches. Only eight age-8+ females were captured in gill nets, and all of these were taken from 27 March - 13 April.

During the 30 March - 3 May period, the 1996 (33.1%) and 1997 (28.2%) year classes were prevalent (Table 6). These year classes were 99.2% male. The contribution of males age-6 and older (the pre-1995 year classes) was only 4.3% of the total aged catch. These year classes were most vulnerable to commercial and recreational exploitation within Chesapeake Bay. The contribution of females age-8 and older, presumably repeat spawners, was 2.0% of the total aged catch but was 44.4% of the total females captured.

James River

Experimental gill nets: Striped bass (n= 1,710) were sampled between 27 March and 4 May, 2000 from the two multi-mesh experimental gill nets in the James River. Total catches peaked from 11-17 April, due to large catches of 2-4 year old males (Table 7). Catches of female striped bass were consistent, although small, before peaking on 17 April. Males dominated the 1996-1998 year classes (99.2%) and the 1992-1995 year classes (95.7%), but females were prevalent in the 1985-1991 year classes (80.0%).

Catch rates (g/day) of male striped bass were highest from 27-30 March and from 11-17 April (Table 8). The catch rates of female striped bass were highest from 3-6 April and on 17 April. The catch rate of females exceeded that of males only on 1 May. Catch rates of males greatly exceeded that for females from 27 March - 24 April (42.6:1 on 27 March). The mean ages of male striped bass varied from 3.9-5.0 years, but varied from only 4.1-4.4 years between 27 March and 17 April. The mean ages of females varied from 4.0-10.0 years, but varied from 5.2-9.8 years for dates with more than a single specimen.

During the 30 March - 3 May period, the 1996 (40.9%) and 1995 (21.4%) year classes were the most abundant (Table 9). These year classes were 98.4% male. The contribution of males age-6 and older (the pre-1994 year classes) was only 1.6% of the total aged catch. These year classes were most vulnerable to commercial and recreational exploitation within Chesapeake Bay. The contribution of females age-8 and older, presumably repeat spawners, was only 0.8% of the total aged catch but was also 34.1% of the total females captured.

Spawning Stock Biomass Indexes

Rappahannock River

Pound nets: The Spawning Stock Biomass Index (SSBI) for spring 2000 was 42.7 kg/day for male striped bass and 14.6 kg/day for female striped bass. The index for male striped bass was the highest of the 1991-2000 time series and double the 10-year average (Table 10). The magnitude of the index for male striped bass was largely determined by the 1996 and 1997 year classes (77.8%). The index for female striped bass was the second lowest since 1991 and was 56.4% below the 10-year average (Table 10). The magnitude of the index for the females was largely the result of the pre-1993 year classes (87.0%).

Experimental gill nets: The Spawning Stock Biomass Index for spring 2000 was 65.3 kg/day for male striped bass and 16.5 kg/day for female striped bass. The index for male striped bass was the fifth highest since 1991,but was 13.0% below the 10-year average (Table 10). The 1995-1997 year classes contained 81.3% of the biomass in the male index. The index for female striped bass, although slightly higher than in 1999, was still 51.9% below the 10-year average, and continues a trend of declining indexes since 1993. The pre-1993 year classes accounted for 66.1% of the biomass in the female index.

James River

Experimental gill nets: The Spawning Stock Biomass Index for spring 2000 was 241.4 kg/day for male striped bass and 21.2 kg/day for female striped bass. The male index was by far the highest index to date and was 362.5% above the seven-year average (Table 11). The 1995 and 1996 year classes accounted for 71.7% of the biomass in the male index. In contrast, he female index was the lowest index to date and was 66.9% below the seven-year average. The pre-1993 year classes accounted for 61.3% of the biomass in the female index.

Egg Production Potential Indexes

The number of gonads sampled, especially of the larger females, was insufficient to produce separate estimates for each river. The pooled data produce a fork length-oocyte count relationship as follows:

$$N_o = 0.11 \times FL^{2.4}$$

Where N_o is the total number of oocytes and FL is the fork length (>400) in millimeters. Thus, the predicted egg production increased from 193,000 for a 400 mm female to 2,594,000 for a 1180 mm female striped bass (Table 12). The Egg Production Potential Indexes (EPPI, Table 13) for the Rappahannock River were 2.06 (pound nets) and 2.339 (gill nets). The EPPI for the James River was 3.181. The indexes for the Rappahannock River were heavily dependent on the egg production potential of the older (8+ years) females (86.5% in the pound nets, 61.4% in the gill nets), while the James River index was more evenly distributed among age groups. Modest changes in the methodology (utilizing only ovaries with hydrated eggs) preclude comparison with the 1999 indexes.

Estimates of Annual Survival (S) based on catch-per-unit-effort

Rappahannock River

Pound nets: Catch rates (number of fish/day) of individual years classes from 1991-2000 are presented in Tables 14-16. The cumulative annual catch rate for 2000 was greater than for any of the previous years and 32.9% greater than the catch rate for 1999 (Table 14). The cumulative catch rate was driven by high catch rates of 1996 and 1997 year class (3 and 4 year old) stripers and the catch rates of most other year classes were less than or equal to those from 1999.

The cumulative catch rate of male striped bass mirrored the trends of the combined data with the 2000 catch rate being the overall highest and 37.4% greater than in 1999 (Table 15). Using the maximum catch rate of the resident males as an indicator, the 1995-1997 year classes were strongest and the 1990 and 1991 year classes were the weakest. Male catch rates decline rapidly after age five or six and rarely are captured past the age of nine. The 2000 cumulative catch rate of female striped bass was the lowest in the time series and continues a trend of decreasing cumulative catches since peaking in 1997 (Table 16).

The range of overall ages was unchanged from 1991-2000, consisting of 2-10 year old males and 4-15 year old females, but sex-specific changes in the age-structure have occurred.
The age at which abundance peaked for males has decreased from age 5 (1992-1994) to age 4 (1997-2000). There has been an even more significant change in the age composition of the female spawning stock. From 1991-1996, the cumulative proportion of females age eight and older ranged from 0.167-0.446 (mean = 0.290), but from 1997-2000 the range in the cumulative proportion of females age eight and older increased to 0.754-0.853 (mean = 0.806).

Catch rates for male striped bass decreased rapidly subsequent to their peak of abundance at age four or five (Figure 3). Catch rates of female striped bass also show a steep decline after their initial peak in abundance, but also exhibit a secondary peak in the catch rates of 9-11 year old females that was persistent across several year classes.

Estimates of annual survival (S) for the individual year classes and their overall geometric means are presented in tables 17-19. While annual survival estimates varied widely among years, due to strong or weak overall catches, the geometric mean survival rate (1991-2000) of the 1983-

1992 year classes (sexes combined) varied from 0.476-0.702 (Table 17) with an overall mean survival of 0.600. These year classes have survival estimates across a minimum of four years. There were widely divergent estimates of annual survival of male and female striped bass. The geometric mean survival rate (1991-2000) of the 1987-1992 year classes of males varied from 0.345-0.469 (Table 18) with an overall mean survival of 0.412. These year classes have been the major target of the fall recreational and commercial fisheries that reopened in 1993. The geometric mean survival rate (1991-2000) of the 1983-1989 year classes of females varied from 0.576-0.826 (Table 19) with an overall mean survival of 0.635.

Experimental gill nets: Catch rates (number of fish/day) of individual years classes from 1991-2000 are presented in Tables 20-22. The cumulative annual catch rate (sexes combined) for 2000 was the lowest since 1996 and 9.6% below the 10-year average (Table 20). The cumulative catch rate was driven by the catch rates of the1996-1997 year classes (3- 4 year old) of striped bass. The age of peak abundance for each year has declined steadily from age 5 (1992-1996) to age 4 (1997, 1998 and 2000) and age 3 (1999).

The cumulative catch rate of male striped bass decreased for the third consecutive year after peaking in 1997 (Table 21). Using the maximum catch rate of the resident males as an indicator, the 1993, 1994 and 1996 year classes were the strongest and the 1990 and 1991 year classes the weakest. Catch rates of the male striped bass declined rapidly after ages five or six. The 2000 cumulative catch rate of female striped bass was slightly higher than the 1999 catch rate and ended a pattern of decline that had occurred every year since 1993 (Table 22). Catch rates increased for 7-10 year-old females but decreased for the older age classes. The overall age structure from 1991-2000 consisted of 2-12 year old males and 2-14 year old females, but the 2000 catches contained no males older than eight or females older than 12. The rapid decline in male catch rates for the 1987-1994 year classes are illustrated in Figure 4. but the secondary peak of older females found in the pound nets was not evident in the gill nets.

Estimates of annual survival (S) for the individual year classes and their overall geometric means are presented in Tables 23-25. While annual survival estimates varied widely among years, due to strong or weak overall catches, the geometric mean survival rate (1991-2000) of the 1984-1991 year classes (sexes combined) varied from 0.406-0.598 (Table 23) with an overall mean survival of 0.502. There were widely divergent estimates of annual survival of male and female striped bass. The geometric mean survival rate (1991-2000) of the 1984-1991 year classes of males varied from 0.231-0.523 (Table 24) with an overall mean survival of 0.347. These year classes have been the major target of the fall recreational and commercial fisheries that reopened in 1993. The geometric mean survival rate (1991-2000) of the 1984-1990 year classes of females varied from 0.406-0.803 (Table 25) with an overall mean survival of 0.603. The survival estimates of both sexes of striped bass were slightly lower than those calculated from the pound nets. The estimate of female survival rates was based on fewer years than the estimate from the pound nets due the rareness of the oldest females in the samples.

James River

Experimental gill nets: Catch rates (number of fish/day) of individual years classes from 1994-2000 are presented in Tables 26-28. The cumulative annual catch rate for 2000 was the highest of the time series, and was 56.2% greater than the catch rate for 1999 (Table 26). The cumulative catch rate was driven by higher catch rates for the 1995-1997 year classes. The age of peak abundance for each year has been ages 4 and 5 in each year.

The cumulative catch rate of male striped bass mirrored the trends of the combined data with the 2000 catch rate being the highest overall and nearly triple the cumulative catch rate for 1999 (Table 27). Using the maximum catch rate of the resident males as an indicator, the 1990, and the 1995-1997 year classes were strongest and the 1992 and 1993 year classes the weakest. Male catch rates declined rapidly after ages five or six, but not as rapidly as on the Rappahannock River. In contrast, the 2000 cumulative catch rate of female striped bass was the lowest in the time series, and was less than one tenth the catch rates for 1999 (Table 28). Catch rates for every year class captured in 2000 were lower than in 1999. The age structure of male striped bass, which had expanded from 3-6 years in 1994 to 2-11 years in 1999, contained no fish older than eight. The age structure of female striped bass was stable from 1994-2000, consisting of 2-14 year old females. The changes in catch rates for the 1987-1994 year classes are illustrated in Figure 5. The secondary peak of older females found in the Rappahannock River pound nets was not evident in the gill nets.

Estimates of annual survival (S) for the individual year classes and their overall geometric means are presented in tables 29-31. While annual survival estimates varied widely among years, due to strong or weak overall catches, the geometric mean survival rate (1994-2000) of the 1984 - 1992 year classes (sexes combined) varied from 0.330-0.691 (Table 29), with an overall mean survival of 0.487. There were widely divergent estimates of annual survival of male and female striped bass. The geometric mean survival rate (1994-2000) of the 1988-1992 year classes of males varied from 0.281-0.672 (Table 30) with an overall mean survival of 0.417. These year classes have been the major target of the fall recreational and commercial fisheries that reopened in 1993. The geometric mean survival rate (1994-2000) of the 1984-1990 year classes of females varied from 0.340-0.617 (Table 31) with an overall mean survival of 0.468.

Discussion

Striped bass stocks had recovered sufficiently by 1993 to allow the re-establishment of limited commercial and recreational fisheries in Virginia. The monitoring efforts summarized in this report were intended to document changes in the abundance and age composition of spawning stocks in the James and Rappahannock rivers during the period of selective harvest by these fisheries.

The main advantage of pound nets is that the gear provides large catches (often in excess of 100 fish per day) that are presumably not sex- or size-biased. However, each pound net has a different fishing characteristic, and our sampling methods, established in 1993, may have introduced additional variability. The down-river net (mile 44) was set in a shallow, flat-bottomed portion of the river with a leader that extended farther into the bay. The upriver net (mile 47) was set in a constricted portion of the river that abutted the channel, and had a leader that extended almost to the shoreline. Ideally, each net was sampled weekly, but uncontrollable factors (especially tide, weather and market conditions) affected this schedule. In addition, weekly sampling occurred each Monday and Thursday, a schedule that translated to fishing efforts of 96 hrs (Thursday through Monday) or 72 hrs (Monday through Thursday). However, on 30 March the effort was only 48 hrs. and on 27 April the effort was 196 hrs.

In past years efforts as low as 24 hrs. and as great as 196 hrs. were encountered if the fisherman was unable to fish the scheduled net on the scheduled sampling date. Although these events were uncommon, we were unable to assess whether or not they influenced estimates of catch rate. The 1997 and 1998 data include a pound net at mile 46, which had an orientation and catch characteristics similar to the net at mile 47. The 1991 data included samples taken from a pound net at river mile 25 and were weekly vs. twice-weekly samples, but with similar total effort. While this net is far enough within the Rappahannock to preclude significant contamination from stocks from other rivers, it does not meet the criteria established in 1993, restricting sampling to gears located within the designated spawning grounds (above river mile 37). The catches from these other nets were similar in sex and age composition to the nets presently used and their exclusion would adversely affect our ability to assess the status of the spawning stocks in those years.

Variable-mesh gill nets were set by commercial fishermen and fished by scientists after 24 hours on designated sampling days. As a result, there were fewer instances of sampling inconsistencies. However, on 6 April one of the two nets (net#1) in the Rappahannock River broke free of one of it's anchors and its catch was disregarded. The two nets were set approximately 100 meters apart and along the same depth contours on both rivers. Although the down-river net did not always contain the greater catches, removal by one net may have affected the catch rates of its companion.

The gill net captured proportionally more males than did the pound nets. Anecdotal information from commercial fishermen suggests that spawning males are attracted to con-specifics that have become gilled in the net meshes. Thrashing of gilled fish may emulate spawning behavior (termed "rock fights" by local fishermen) and enhance catches of males. The pound net catches contained a greater relative proportion of older female striped bass than did the catches from the gill nets. This trend has been persistent over several years. Thus, given the presence of large females in the spawning run, it is clear that the gill nets do not adequately sample large (1000+ mm FL) striped bass.

The biological characterization of the spawning stock of striped bass in the Rappahannock River changed dramatically from 1991-2000. There was a steady decrease in the relative abundance of five to seven year-old striped bass. The males in these age classes are targeted by the recreational and commercial fisheries. Current regulations protect females from harvest during their annual migration by higher minimum lengths in the coastal fishery (711 mm TL vs. 458 mm TL within Chesapeake Bay) and the closure of the fishery in the bay during the April spawning run. The result has been a general increase in the abundance of older females throughout the period. However, the relative contribution of virgin spawners (four through seven years) has decreased.

The 2000 values of the Spawning Stock Biomass Index (SSBI) for the Rappahannock River were higher than in 1999 for male striped bass from both gears and for female striped bass from the gill nets only. The increase in the male indexes was due to the influx of strong 1996 and 1997 year classes into the spawning stock. The increase in the index of female striped bass from the gill nets was only slightly higher than in 1999 and the female indexes from both gears were well below the 1991-2000 average. There was a decrease in the proportion of 10 year and older females in both gears, which reversed a trend of increased abundance of these age classes. However, these older age classes still represent a larger proportion of the female spawning stock than was the case from 1991-1996.

The 1991-2000 values of the SSBI in the Rappahannock River were not consistent between pound nets and gill nets. In the pound nets, male biomass peaked in 1993 due to strong 1988 and 1989 year classes, and again in 1999 and 2000 due to strong 1996 and 1997 year classes. The female biomass from pound nets show a trend of increasing reliance on fewer, but older (and heavier) striped bass. The male biomass from the gill nets is driven by the number of "super catches", when the net is literally filled by males seeking to spawn, that occur differentially among the years. Due to the highly selective nature of the gill nets (significantly fewer large females), the female SSBI from these nets is less reliable. The low biomass values from both gears of both sexes in 1992 and 1996 are probably an underestimate of spawning stock strength since water temperatures were below normal in those years, which the local fishermen say alters the catchability of the striped bass. It is also possible that the spawning migration continued past the end of sampling in those years.

The 2000 values of the SSBI in the James River were highest for males and lowest for females since the survey began in 1994. The male index was driven by large catches of the 1995-1997 year classes. Because of the changes in location and in the methodology utilized by the new waterman, the values are not directly comparable with those of previous years. The below normal water temperatures noted for the Rappahannock River in 1996 apply to the James River as well and probably produced a similar under-estimation of spawning stock abundance. The scarcity of larger, predominantly female, striped bass from the gill nets in the James River implies a similar limitation in fishing power as shown in the Rappahannock River but comparative data are not available since there are no commercial pound nets on the James River.

The Egg Production Potential Index (EPPI) is an attempt to better define the reproductive potential of the spawning stocks, especially as they become more heavily dependent on fewer, but larger, female striped bass. For example, in the 2000 Rappahannock River pound net data the contribution of 8+ year old females was 77.5% of the total number of mature females (the basis of our index prior to 1998), 88.2% of the mature female biomass (the basis of the current index) and 86.5% of the calculated egg potential. The egg-size relationship for 2000 is limited by small sample size and the lack of any females over 1000 mm fork length with ovaries at the proper maturation state. It should be noted the egg-size relationship from the current study produced fecundity estimates well below those reported by other authors (Setzler et al. 1980), so the relative contribution in potential egg production of the older females may be underestimated at present. We will continue to evaluate and refine this new approach.

In our analysis of pound net catch rates, we observed a distinctive bimodal distribution of female striped bass in the 1987-1989 year classes. These striped bass appeared in greatest abundance at age five or six, at lower abundance at age six to eight, and then higher abundance at ages nine to12. Also, prior to 1995, the peak catch rates of male and female striped bass (ages four and five) were similar. The catches of these age classes are now almost exclusively male. Thus, the 1990-1992 year classes actually showed greater abundance at ages nine to 12 years than at any other age. Age estimation of larger striped bass by scales is problematic because re-absorption or erosion of outer margins of scales may cause under-estimation of age. Under-ageing errors might tend to lump catches of old fish (>12 years) into younger categories (nine to 12 years). However, ignoring age, we also observed a bimodal size distribution, one group from 470-590 mm fork length, presumably young, and the second group of 850-1200 mm fork length, presumably older. This trend became increasingly apparent in the 1997-1999 data and its significance has not been determined.

The time series of the catch rates by age class and by year class indicate that the age of peak abundance in the rivers has changed from five or six years in 1992-1994 to three to four years in 2000. Changes in the annual catch rates by year class in the Rappahannock River indicated that strong year classes occurred in 1988, 1989, 1996 and 1997, and weak year classes occurred in 1990 and 1991. Likewise the data for the James River indicated that strong year classes occurred in 1989, 1993, 1994 and 1996, and weak year classes occurred in 1990 and 1991.

The time series allows estimates of survival of the year classes using catch curves, especially for the 1985-1991 year classes that were captured for four or five years subsequent to their peak in abundance at age four or five. The survival estimates of female striped bass of these year classes in the Rappahannock River were approximately 0.64 in pound nets and 0.60 in gill nets. The lower capture rates of larger (older) females in the gill nets resulted in lower estimates. The survival estimates of male striped bass were approximately 0.41 in pound nets and 0.35 in gill nets. The high survival estimates for the females may be the result of their differential maturation rates. These differences cause lower peaks in abundance (usually at age five) as only fractions of each year class mature and are depicted in their lower peak abundance values. The large differences between the sexes also reflect a management strategy that targets males. Similarly, survival estimates for these year classes in the James River were approximately 0.42 for male striped bass and approximately 0.47 for females.

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Table 1. Numbers of striped bass in three age categories (year classes 1996-1998, 1992-1995 and 1984-1991) in pound nets in the Rappahannock River by sampling date in spring 2000.

Date	n	Year Class 1996 - 1998 M	F	1992 - 1995 M	F	1984 - 1991 M	F	Not aged M	F
27 March	104	87	0	12	2	2	1	0	0
30 March	45	40	0	4	1	0	0	0	0
3 April	62	39	0	10	6	1	6	0	0
6 April	55	36	0	5	3	0	10	1	0
10 April	76	61	0	8	2	0	5	0	0
13 April	35	23	0	8	2	0	2	0	0
17 April	448	404	0	21	9	0	9	5	0
20 April	202	171	1	24	1	0	3	2	0
24 April	308	262	0	37	6	0	2	1	0
27 April	207	183	0	17	0	3	1	3	0
1 May	70	63	0	5	0	0	2	0	0
4 May	406	368	1	29	3	0	2	3	0
Total	**2018**	**1737**	**2**	**180**	**35**	**6**	**43**	**15**	**0**

Table 2. Net-specific summary of catch rates and ages of striped bass (n= 2,018) in pound nets on the Rappahannock River, spring 2000. Values in bold are grand means for each column.

Date	Net ID	n	CPUE (fish/day)		CPUE (g/day)		Mean age	
			M	F	M	F	M	F
27 March	S473	104	25.3	0.8	33,651.5	6,956.1	3.8	9.3
30 March	S441	45	22.0	0.5	28,550.4	2,156.6	3.7	6.0
3 April	S473	62	12.5	3.0	19,005.8	26,435.8	4.1	9.0
6 April	S454	55	14.0	4.3	18,949.6	38,405.7	4.0	9.8
10 April	S473	76	17.3	1.8	20,362.6	15,279.5	3.8	9.7
13 April	S441	35	10.3	1.3	15,799.3	10,444.9	4.2	8.8
17 April	S473	448	107.5	4.5	105,982.5	31,843.0	3.5	8.3
20 April	S441	202	65.7	1.7	72,654.8	11,676.2	3.8	8.6
24 April	S473	308	75.0	2.0	86,415.3	11,481.3	3.8	7.6
27 April	S441	207	29.4	0.1	34,488.0	1,844.1	3.8	11.0
1 May	S473	70	17.0	0.5	18,545.4	4,097.2	3.7	9.0
4 May	S441	406	133.3	2.0	133,542.2	9,076.2	3.6	7.0
Totals	S441	895	48.8	0.9	53,583.7	6,156.3	3.7	8.1
	S454	55	14.0	4.3	18,949.6	38,405.7	4.0	9.8
	S473	1068	42.4	2.1	47,327.2	16,015.5	3.7	8.7
Season		**2018**	**43.1**	**1.8**	**47,937.9**	**13,564.5**	**3.7**	**8.7**

Table 3. Mean fork length (mm), weight (g), standard deviation (SD) and CPUE (fish per day; weight per day), of striped bass from pound nets in the Rappahannock River, 30 March - 3 May 2000.

Year Class	Sex	n	Fork Length Mean	Fork Length SD	Weight Mean	Weight SD	CPUE F/day	CPUE W/day
1998	male	1	315.0		381.8		0.0	10.0
1997	male	593	399.8	18.8	784.6	115.1	15.6	12,243.2
1996	male	688	453.1	21.6	1,159.3	209.4	18.1	20,988.6
	female	1	466.0		1,300.5		0.0	34.2
1995	male	122	525.6	24.4	1,874.6	270.8	3.2	6,018.4
	female	5	516.8	33.8	2,011.8	297.4	0.1	264.7
1994	male	3	606.7	54.9	3,136.9	1,189.0	0.1	247.7
	female	1	684.0		4,313.1		0.0	113.5
1993	male	10	734.7	21.5	5,116.2	612.2	0.3	1,346.4
	female	9	742.7	23.0	5,520.2	931.8	0.2	1,307.4
1992	male	4	746.3	17.9	5,742.3	464.9	0.1	604.5
	female	15	787.2	27.4	6,797.1	899.5	0.4	2,683.1
1991	male	2	800.0	21.2	7,529.9	355.7	0.1	396.3
	female	13	841.7	20.7	8,339.3	849.8	0.3	2,852.9
1990	male	1	867.0		7,939.6		0.0	208.9
	female	10	876.9	22.5	9,889.5	1,139.2	0.3	2,602.5
1989	male	1	971.0		10,181.9		0.0	267.9
	female	13	914.6	41.2	10,220.1	1,151.4	0.3	3,496.3
1988	female	2	987.5	46.0	11,325.5	1,526.3	0.1	596.1
1987	female	2	1,022.5	24.8	12,610.5	2,106.5	0.1	663.7
N/A	male	12	442.7	51.5	1,113.7	444.6	0.3	351.7

N/A: not ageable

Table 4. Numbers of striped bass in three age categories (year classes 1996-1998, 1992-1995 and 1984-1991) in gill nets in the Rappahannock River by sampling date in spring 2000.

Date	n	Year Class							
		1996 - 1998		1992 - 1995		1984 - 1991		Not aged	
		M	F	M	F	M	F	M	F
27 March	112	90	0	20	0	0	1	1	0
30 March	167	154	0	13	0	0	0	0	0
3 April	85	49	0	31	1	0	3	1	0
6 April	17	13	1	0	2	0	1	0	0
10 April	41	30	0	9	0	0	2	0	0
13 April	121	99	1	16	4	0	1	0	0
17 April	15	9	0	2	4	0	0	0	0
20 April	11	9	0	1	1	0	0	0	0
24 April	14	7	1	5	1	0	0	0	0
27 April	11	8	0	0	3	0	0	0	0
1 May	11	7	0	3	1	0	0	0	0
4 May	7	7	0	0	0	0	0	0	0
Total	**612**	**482**	**3**	**100**	**17**	**0**	**8**	**2**	**0**

Table 5. Summary of catch rates and mean ages of striped bass (n=612) from the two gill nets in the Rappahannock River, spring 2000. Values in bold are grand means for each column.

Date	n	CPUE (fish/day)		CPUE (g/day)		Mean age	
		M	F	M	F	M	F
27 March	112	111.0	1.0	166,936.5	13,640.8	3.9	13.0
30 March	167	166.0	0.0	197,649.8		3.5	
3 April	85	81.0	4.0	142,807.8	39,584.1	4.4	9.5
6 April	17	26.0	8.0	33,439.6	50,893.2	3.8	7.3
10 April	41	39.0	2.0	62,796.6	19,013.7	4.0	10.5
13 April	121	115.0	6.0	136,652.3	25,617.9	3.7	6.5
17 April	15	11.0	4.0	13,612.5	20,423.4	4.0	7.0
20 April	11	10.0	1.0	10,808.5	5,744.5	3.8	7.0
24 April	14	12.0	2.0	22,187.0	5,544.9	4.5	5.5
27 April	11	8.0	3.0	8,819.5	12,195.0	3.6	6.7
1 May	11	10.0	1.0	14,621.4	2,943.8	4.3	6.0
4 May	7	7.0	0.0	6,162.1		3.3	
Season	**612**	**50.7**	**2.4**	**69,545.5**	**14,796.1**	**3.8**	**7.5**

Note: the catch of 6 April consisted of only one net (effort = ½ net day)

Table 6. Mean fork length (mm), weight (g), standard deviations (SD) and CPUE (number per day; weight per day) of striped bass from gill nets in the Rappahannock River, 30 March - 3 May, 2000.

Year Class	Sex	n	Fork Length		Weight		CPUE	
			Mean	SD	Mean	SD	F/day	W/day
1998	male	14	315.1	10.8	416.5	37.2	1.5	613.8
1997	male	172	394.4	24.2	818.8	150.7	18.1	14,824.6
1996	male	199	455.8	21.5	1,248.7	198.7	20.9	26,157.0
	female	3	463.7	31.5	1,586.3	482.8	0.3	500.9
1995	male	54	535.8	24.3	2,123.3	337.9	5.7	12,069.3
	female	1	504.0		2,108.0		0.1	221.9
1994	male	12	637.3	23.6	3,691.2	504.4	1.3	4,662.6
	female	5	621.6	22.4	3,401.7	438.3	0.5	1,790.4
1993	male	13	711.5	25.9	4,960.2	536.5	1.4	6,787.6
	female	6	710.3	35.6	5,082.7	592.2	0.6	3,210.1
1992	male	1	748.0		6,169.8		0.1	649.5
	female	5	762.2	25.0	6,318.4	871.7	0.5	3,325.5
1991	female	3	834.0	29.5	9,001.4	1,399.9	0.3	2,842.5
1990	female	2	893.5	16.3	11,153.1	1,535.9	0.2	2,348.0
1989	female	1	925.0		10,728.6		0.1	1,129.3
1988	female	1	965.0		12,293.0		0.1	1,294.0
N/A	male	1	516.0		1,387.9		0.1	146.1

N/A: not ageable

Table 7. Numbers of striped bass in three age categories (year classes 1996-1998, 1992-1995 and 1985-1991) in gill nets in the James River by sampling date in spring 2000.

Date	n	Year Class							
		1996 - 1998		1992 - 1995		1985 - 1991		Not aged	
		M	F	M	F	M	F	M	F
27 March	201	120	3	74	2	1	0	1	0
30 March	201	124	1	70	3	1	1	1	0
3 April	123	70	0	48	1	0	3	1	0
6 April	153	106	0	41	1	0	3	2	0
11 April	242	159	0	80	1	0	1	1	0
13 April	328	208	1	112	3	0	2	2	0
17 April	216	143	3	61	8	0	1	0	0
20 April	28	12	0	15	0	0	1	0	0
24 April	131	79	0	47	5	0	0	0	0
27 April	13	9	1	3	0	0	0	0	0
1 May	2	0	0	1	1	0	0	0	0
4 May	72	48	0	22	1	1	0	0	0
Total	**1710**	**1078**	**9**	**574**	**26**	**3**	**12**	**8**	**0**

Table 8. Summary of catch rates and mean ages of striped bass (n=1,710) from the two gill nets in the James River, spring 2000. Values in bold are grand means for each column.

Date	n	CPUE (fish/day)		CPUE (g/day)		Mean age	
		M	F	M	F	M	F
27 March	201	196.0	5.0	353,793.8	8,313.5	4.3	5.2
30 March	201	196.0	5.0	349,454.0	20,747.8	4.3	6.0
3 April	123	119.0	4.0	216,121.7	36,431.0	4.4	9.0
6 April	153	149.0	4.0	228,803.2	36,288.5	4.1	9.8
11 April	242	240.0	2.0	409,654.6	15,190.6	4.2	7.5
13 April	328	322.0	6.0	566,179.0	17,949.2	4.3	6.2
17 April	216	204.0	12.0	339,759.0	38,241.5	4.2	5.4
20 April	28	27.0	1.0	57,569.6	9,956.2	4.7	10.0
24 April	131	126.0	5.0	235,668.5	22,263.2	4.4	6.2
27 April	13	12.0	1.0	14,962.8	1,479.7	3.9	4.0
1 May	2	1.0	1.0	1,491.3	5,417.9	5.0	7.0
4 May	72	71.0	1.0	108,041.1	1,941.2	4.2	5.0
Totals	**1710**	**138.6**	**3.9**	**240,124.9**	**17,851.7**	**4.3**	**6.4**

Table 9. Mean fork length (mm), weight (g), standard deviations (SD) and CPUE (number per day; weight per day) of striped bass from gill nets in the James River, 30 March - 3 May, 2000.

Year Class	Sex	n	Fork Length		Weight		CPUE	
			Mean	SD	Mean	SD	F/day	W/day
1998	male	15	300.7	14.7	366.0	60.8	1.5	549.0
1997	male	204	406.6	29.9	958.8	276.4	20.4	19,559.5
	female	1	414.0		981.4		0.1	98.1
1996	male	691	459.9	24.7	1,381.7	243.7	69.1	95,475.5
	female	5	477.6	4.2	1,507.9	59.0	0.5	754.0
1995	male	352	537.1	29.6	2,203.5	379.1	35.2	77,563.2
	female	12	571.1	76.7	2,851.2	1,351.8	1.2	3,421.4
1994	male	100	615.9	32.4	3,339.3	559.2	10.0	33,393.0
	female	5	641.8	35.6	3,818.5	653.3	0.5	1,909.3
1993	male	16	708.9	38.6	4,925.8	789.4	1.6	7,881.3
	female	4	719.5	25.1	5,154.9	735.1	0.4	2,062.0
1992	male	11	757.7	52.9	6,013.8	894.6	1.1	6,615.2
	female	2	762.5	24.8	7,062.9	206.6	0.2	1,412.6
1991	female	6	845.5	20.0	8,787.2	284.9	0.6	5,272.3
1990	female	4	881.8	22.3	9,498.9	746.1	0.4	3,799.6
1989	female	1	938.0		12,963.1		0.1	1,296.3
1988	female	1	930.0		12,497.0		0.1	1,249.7
N/A	male	7	451.3	47.5	1,332.8	480.2	0.7	933.0

N/A: not ageable

Table 10. Values of the spawning stock biomass index (SSBI) for male and female striped bass by gear in the Rappahannock River, 30 March - 3 May, 1991-2000.

	Pound nets					Gill nets				
	N		SSBI (kg/day)			N		SSBI (kg/day)		
Year	**M**	**F**	**M**	**F**	**M+F**	**M**	**F**	**M**	**F**	**M+F**
2000	1,436	71	42.7	14.6	57.3	452	27	65.3	16.5	81.8
1999	738	61	30.5	19.8	50.3	532	21	51.4	13.2	64.6
1998	273	113	14.8	36.4	51.2	485	27	81.5	18.5	100.0
1997	277	115	22.2	49.6	71.7	801	18	177.8	19.1	197.0
1996	334	73	14.1	9.3	23.4	433	46	63.7	30.2	93.9
1995	207	76	12.4	19.8	32.2	162	69	43.9	56.7	100.6
1994	195	141	17.1	30.9	48.0	391	100	101.6	64.7	166.3
1993	357	188	31.2	37.5	68.7	361	160	85.6	74.1	159.6
1992	51	100	5.4	19.4	24.8	61	74	15.0	32.2	47.2
1991	153	70	21.3	21.5	42.8	406	47	65.0	17.8	83.8
Mean	**402**	**101**	**21.2**	**25.9**	**47.0**	**408**	**59**	**75.1**	**34.3**	**109.5**

Table 11. Values of the spawning stock biomass index (SSBI) calculated from gill net catches of male and female striped bass in the James River, 30 March - 3 May, 1994-2000. The 1994 data consisted of one gill net (GN # 1) and were adjusted by the proportion of the biomass that gill net # 2 captured in 1995-1998 (1.8 x GN #1 for males; 1.9 x GN #1 for females).

Year	River Mile	n		SSBI (kg/day)		
		Male	Female	Male	Female	Combined
2000	**60**	1,381	40	241.41	21.18	262.59
1999	**55**	251	211	45.81	101.98	147.79
1998	**55**	134	65	32.97	46.48	79.45
1997	**55**	100	60	23.89	44.59	68.48
1996	**55**	108	74	23.70	43.35	67.05
1995	**55**	210	202	52.10	125.15	177.25
1994*	**55**	119	64	46.27	65.74	112.01
Mean		**329**	**102**	**66.59**	**64.07**	**130.66**

Table 12. Predicted values of fecundity (in millions of eggs) of female striped bass with increasing fork length (mm), James and Rappahannock rivers combined, spring 2000.

FL	Fecundity	FL	Fecundity	FL	Fecundity	FL	Fecundity
400	0.193	**600**	0.512	**800**	1.020	**1000**	1.743
420	0.217	**620**	0.554	**820**	1.083	**1020**	1.828
440	0.248	**640**	0.597	**840**	1.147	**1040**	1.915
460	0.270	**660**	0.643	**860**	1.214	**1060**	2.005
480	0.299	**680**	0.691	**880**	1.283	**1080**	2.097
500	0.330	**700**	0.741	**900**	1.354	**1100**	2.191
520	0.363	**720**	0.792	**920**	1.427	**1120**	2.288
540	0.397	**740**	0.846	**940**	1.503	**1140**	2.388
560	0.434	**760**	0.902	**960**	1.702	**1160**	2.489
580	0.472	**780**	0.960	**980**	1.661	**1180**	2.594

Table 13. Total, age-specific, estimated total egg potential (E, in millions of eggs/day) mature (ages 4 and older) female striped bass, by river and gear type, 30 March - 3 May 2000. The Egg Production Potential Indexes (millions of eggs/day) are in bold.

Age	Rappahannock River						James River		
	Pound Nets			Gill Nets			Gill Nets		
	n	E	%	n	E	%	n	E	%
4	1	0.007	0.4%	3	0.087	3.7%	5	0.156	4.9%
5	5	0.047	2.3%	1	0.035	1.5%	12	0.590	18.6%
6	1	0.018	0.9%	5	0.294	12.6%	5	0.318	10.0%
7	9	0.202	9.8%	6	0.486	20.8%	4	0.334	10.5%
8	15	0.388	18.8%	5	0.479	20.5%	2	0.192	6.0%
9	13	0.395	19.1%	3	0.357	15.2%	6	0.737	23.2%
10	10	0.335	16.2%	2	0.280	12.0%	4	0.543	17.1%
11	13	0.483	23.4%	1	0.152	6.5%	1	0.157	4.9%
12	2	0.089	4.3%	1	0.168	7.2%	1	0.154	4.8%
13	2	0.097	4.7%	0			0		
14	0			0			0		
15	0			0			0		
Total	71	**2.063**	100.0%	27	**2.339**	100.0%	40	**3.181**	100.0%

Table 14. Catch rates (fish/day) of year classes of striped bass (sexes combined) sampled from pound nets in the Rappahannock River, 30 March - 3 May, 1991-2000. Maximum catch rate for any year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)									
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1998										**0.03**
1997									0.79	**15.61**
1996								0.19	11.54	**18.13**
1995							0.60	2.15	**11.50**	3.34
1994					0.04	0.51	3.90	**6.33**	2.79	0.11
1993					3.04	3.97	**8.10**	1.48	0.11	0.50
1992			0.12	1.44	**4.80**	2.86	1.25	0.04	0.50	0.50
1991		0.20	0.68	0.48	1.00	**1.63**	0.05	0.52	0.43	0.40
1990	0.42	0.50	1.04	1.33	**2.24**	1.26	0.70	0.70	0.32	0.29
1989	0.33	0.60	3.58	**4.59**	0.68	0.89	0.80	0.78	0.36	0.37
1988	3.58	1.60	**9.54**	2.22	0.60	0.37	1.50	0.89	0.39	0.05
1987	**8.00**	2.75	3.65	1.15	0.68	0.37	1.00	0.89	0.43	0.05
1986	**2.67**	1.15	0.65	0.59	0.40	0.09	1.00	0.22	0.04	
1985	**1.67**	0.30	0.42	0.52	0.08	0.00	0.35	0.15	0.11	
1984	0.50	0.40	**0.58**	0.33	0.28	0.00	0.35	0.07	0.04	
1983	0.25	0.20	**0.46**	0.33	0.08	0.03	0.20			
1982	0.17	0.30	**0.31**	0.19						
1981	**0.50**	0.15	0.27	0.07						
1980	0.08		**0.15**	0.04						
1979				0.04						
N/A	0.58	0.30	0.38	0.56	0.60	0.32	0.50	0.44	0.54	0.32
Total	18.75	8.45	21.83	13.89	14.52	12.29	20.30	14.85	29.88	39.69

N/A: not ageable

Table 15. Catch rates (fish/day) of year classes of male striped bass sampled from pound nets in the Rappahannock River, 30 March - 3 May, 1991-2000. Maximum catch rate for any year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)									
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1998										**0.03**
1997									0.79	**15.61**
1996								0.19	11.36	**18.11**
1995							0.55	2.15	**11.46**	3.21
1994					0.04	0.51	3.80	**6.19**	2.68	0.08
1993					2.88	3.83	**7.50**	1.37	0.07	0.26
1992			0.12	1.22	**4.68**	2.66	1.15	0.00	0.36	0.11
1991		0.15	0.54	0.48	0.92	**1.34**	0.05	0.30	0.21	0.05
1990	0.17	0.35	0.96	1.30	**2.00**	0.94	0.35	0.11	0.00	0.03
1989	0.17	0.40	3.46	**3.52**	0.08	0.43	0.55	0.04	0.04	0.03
1988	3.25	0.90	**7.54**	1.11	0.12	0.03	0.20			
1987	**6.08**	0.65	1.23	0.22	0.00	0.09				
1986	**2.58**	0.30	0.15	0.11	0.04					
1985	**0.50**	0.05	0.04	0.04						
1984	0.08	**0.15**	0.08	0.00						
1983				0.00						
1982				0.04						
N/A	0.25	0.10	0.27	0.41	0.44	0.23	0.25	0.33	0.54	0.32
Total	**13.08**	**3.05**	**14.38**	**8.44**	**11.20**	**9.98**	**14.40**	**10.68**	**27.52**	**37.82**

N/A: not ageable

Table 16. Catch rates (fish/day) of year classes of female striped bass sampled from pound nets in the Rappahannock River, 30 March - 3 May, 1991-2000. Maximum catch rate for any year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)									
	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
1997										
1996										**0.03**
1995							0.05		0.04	**0.13**
1994							0.10	**0.15**	0.11	0.03
1993					0.16	0.14	**0.60**	0.11	0.04	0.24
1992				0.22	0.12	0.20	0.10	0.04	0.14	**0.40**
1991		0.05	0.04	0.00	0.08	0.29	0.00	0.22	0.21	**0.34**
1990	0.25	0.15	0.08	0.04	0.24	0.31	0.35	**0.59**	0.32	0.26
1989	0.17	0.20	0.12	**1.07**	0.60	0.46	0.25	0.74	0.32	0.34
1988	0.33	0.70	**2.00**	1.11	0.48	0.34	1.30	0.89	0.39	0.05
1987	1.92	2.10	**2.42**	0.93	0.68	0.29	1.00	0.89	0.43	0.05
1986	**1.08**	0.85	0.50	0.48	0.36	0.09	1.00	0.22	0.04	
1985	**1.17**	0.25	0.39	0.48	0.08	0.00	0.35	0.15	0.11	
1984	0.42	0.25	**0.50**	0.33	0.28	0.00	0.35	0.07	0.04	
1983	0.25	0.20	**0.46**	0.33	0.08	0.03	0.20			
1982	0.17	0.30	**0.31**	0.15						
1981	**0.50**	0.15	0.27	0.07						
1980	0.08		0.15	0.04						
1979				0.04						
N/A	0.25	0.20	0.12	0.15	0.16	0.09	0.25	0.11	0.00	0.00
Total	**6.59**	**5.40**	**7.35**	**5.44**	**3.32**	**2.23**	**5.90**	**4.19**	**2.18**	**1.87**

N/A: not ageable

Table 17. Estimated annual and geometric mean survival (S) rates for year classes of striped bass (sexes combined) sampled from pound nets in the Rappahannock River, 30 March - 3 May, 1991-2000.

Year Class	91-92 S	92-93 S	93-94 S	94-95 S	95-96 S	96-97 S	97-98 S	98-99 S	99-00 S	Mean S
1997									------	------
1996								------	------	------
1995							------	------	0.291	0.291
1994						------	------	0.436	0.038	0.129
1993					------	------	0.183	0.581	0.581	0.395
1992				------	0.595	0.438	0.737	0.737	0.737	0.636
1991			------	------	------	0.564	0.564	0.828	0.921	0.702
1990		------	------	------	0.561	0.748	0.748	0.456	0.900	0.664
1989	------	------	------	0.439	0.439	0.903	0.978	0.688	0.688	0.657
1988	------	------	0.233	0.877	0.877	0.877	0.593	0.442	0.134	0.476
1987	0.675	0.675	0.314	0.955	0.955	0.955	0.889	0.472	0.124	0.571
1986	0.431	0.569	0.795	0.676	0.822	0.822	0.822	0.162	0.000	0.536
1985	0.678	0.678	0.678	0.877	0.877	0.877	0.423	0.723	0.000	0.619
1984	------	------	0.884	0.884	0.884	0.884	0.211	0.486	0.000	0.562
1983	------	------	0.721	0.843	0.843	0.843	0.000			0.609
1982	------	------	0.601	0.000						0.265
1981	0.735	0.735	0.275	0.000						0.400
1980	------	------	0.241	0.000						0.114

Table 18. Estimated annual and geometric mean survival (S) rates for year classes of male striped bass sampled from pound nets in the Rappahannock River, 30 March - 3 May, 1991-2000.

Year Class	91-92 S	92-93 S	93-94 S	94-95 S	95-96 S	96-97 S	97-98 S	98-99 S	99-00 S	Mean S
1998									------	------
1997									------	------
1996								------	------	------
1995							------	------	0.280	0.280
1994						------	------	0.433	0.029	0.112
1993					------	------	0.183	0.438	0.438	0.327
1992				------	0.568	0.438	0.557	0.557	0.294	0.469
1991			------	------	------	0.467	0.467	0.723	0.248	0.445
1990		------	------	------	0.472	0.371	0.317	0.483	0.483	0.419
1989	------	------	------	0.539	0.539	0.539	0.256	0.256	0.722	0.442
1988	------	------	0.147	0.565	0.565	0.565	0.000			0.345
1987	0.450	0.450	0.180	0.622	0.622	0.000				0.367
1986	0.116	0.513	0.721	0.216	0.000					0.287
1985	0.100	0.894	0.894	0.000						0.409
1984	------	0.513	0.000							0.230

Table 19. Estimated annual and geometric mean survival (S) rates for year classes of female striped bass sampled from pound nets in the Rappahannock River, 30 March - 3 May, 1991-2000.

Year Class	91-92 S	92-93 S	93-94 S	94-95 S	95-96 S	96-97 S	97-98 S	98-99 S	99-00 S	Mean S
1996									------	------
1995								------	------	------
1994							------	0.723	0.243	0.419
1993						------	0.734	0.734	0.734	0.734
1992					------	------	------	------	------	------
1991				------	------	------	------	------	------	------
1990			------	------	------	------	------	0.541	0.819	0.666
1989		------	-----	0.911	0.911	0.911	0.911	0.679	0.679	0.826
1988	------	------	0.898	0.898	0.898	0.898	0.684	0.442	0.135	0.595
1987	------	------	0.802	0.802	0.802	0.802	0.889	0.483	0.124	0.580
1986	0.987	0.987	0.987	0.987	0.987	0.987	0.222	0.162	0.000	0.643
1985	0.744	0.744	0.744	0.899	0.899	0.899	0.429	0.723	0.000	0.648
1984	------	------	0.915	0.915	0.915	0.915	0.211	0.486	0.000	0.576
1983	------	------	0.721	0.843	0.843	0.843	0.000			0.609
1982	------	------	0.481	0.000						0.217
1981	0.733	0.733	0.275	0.000						0.399
1980	------	------	0.240	0.000						0.114

Table 20. Catch rates (fish/day) of year classes of striped bass (sexes combined) sampled from gill nets in the Rappahannock River, 30 March - 3 May, 1991-2000. Maximum catch rate for any year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)									
	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
1998										**1.47**
1997									11.70	**18.11**
1996								0.11	**35.70**	21.26
1995							0.83	**11.67**	10.60	5.79
1994						1.90	29.50	**32.78**	3.20	1.79
1993					4.50	20.00	**83.00**	7.00	0.80	2.00
1992				2.78	7.00	11.40	**14.33**	0.78	1.20	0.63
1991			0.50	2.56	1.88	**5.70**	2.83	1.33	0.50	0.32
1990	0.11	0.56	1.50	**8.22**	7.75	3.50	2.17	0.33	0.10	0.21
1989	1.33	0.78	8.60	**27.56**	4.50	2.50	0.67	0.33	0.20	0.11
1988	9.00	1.89	**25.40**	8.22	2.88	1.50	1.17	0.33	0.20	0.11
1987	**23.44**	5.89	10.40	2.11	1.75	1.60	0.50	0.11	0.10	
1986	**10.56**	3.33	2.60	0.44	1.38	0.30		0.22	0.00	
1985	**3.89**	1.22	0.40	1.67	0.75	0.20			0.20	
1984	**1.56**	0.78	0.40	0.67	0.25					
1983	0.33	0.11	**1.30**	0.56	0.13					
1982	0.22	**0.44**	0.40	0.22						
1981	**0.22**		0.00							
1980			**0.20**							
1979										
N/A	0.78	0.00	1.10	0.78	1.00	1.20	2.50	2.00	2.50	0.11
Total	**50.33**	**15.00**	**52.80**	**55.78**	**33.75**	**49.80**	**137.50**	**57.00**	**64.50**	**51.90**

N/A: not ageable

Table 21. Catch rates (fish/day) of year classes of male striped bass sampled from gill nets in the Rappahannock River, 30 March - 3 May, 1991-2000. Maximum catch rate for any year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)									
	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
1998										**1.47**
1997									11.60	**18.11**
1996								0.11	**35.70**	20.95
1995							0.83	**11.67**	10.60	5.68
1994						1.90	29.50	**32.56**	2.60	1.26
1993					4.50	20.00	**82.50**	6.44	0.60	1.37
1992				2.78	6.75	11.30	**14.00**	0.56	0.90	0.11
1991			0.50	2.56	1.75	**5.60**	2.50	0.67	0.30	
1990	0.11	0.44	1.50	**8.22**	7.00	3.20	1.83	0.22	0.00	
1989	1.22	0.78	8.20	**25.33**	2.63	1.40	0.50		0.00	
1988	8.89	1.33	**20.30**	4.89	1.13	0.50	0.17		0.10	
1987	**21.56**	2.78	4.20	0.33	0.13	0.10			0.10	
1986	**9.67**	1.22	0.90	0.11	0.04					
1985	**2.22**	0.11	0.00	0.33						
1984	**0.67**	0.11	0.10	0.11						
1983			0.00							
1982			0.10							
N/A	0.78	0.00	0.80	1.56	0.88	1.20	2.50	1.78	2.30	0.11
Total	**45.11**	**6.78**	**36.60**	**46.22**	**24.75**	**45.20**	**134.33**	**54.00**	**64.80**	**49.06**

N/A: not ageable

Table 22. Catch rates (fish/day) of year classes of female striped bass sampled from gill nets in the Rappahannock River, 30 March - 3 May, 1991-2000. Maximum catch rate for any year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)									
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1997									0.10	0.00
1996									0.10	**0.32**
1995									0.00	**0.11**
1994								0.22	**0.60**	0.53
1993							0.33	0.56	0.20	**0.63**
1992					0.13	0.10	0.33	0.22	0.30	**0.53**
1991					0.13	0.10	0.33	**0.67**	0.20	0.32
1990		0.11			**0.63**	0.30	0.33	0.11	0.10	0.21
1989	0.11	0.00	0.30	**2.22**	1.88	1.10	0.17	0.33	0.20	0.11
1988	0.11	0.56	**5.10**	3.33	1.75	1.00	1.00	0.33	0.10	0.11
1987	0.78	3.11	**6.10**	1.78	1.63	1.50	0.50	0.11	0.00	
1986	0.89	**2.11**	1.70	0.33	1.38	0.30		0.22	0.00	
1985	**1.67**	1.11	0.40	1.33	0.75	0.20			0.20	
1984	**0.89**	0.67	0.30	0.56	0.25					
1983	0.33	0.11	**1.30**	0.56	0.13					
1982	0.22	**0.44**	0.30	0.22						
1981	**0.22**		0.00							
1980			0.20							
1979										
N/A	0.00	0.00	0.30	0.79	0.13	0.00	0.00	0.22	0.20	0.00
Total	**5.22**	**8.22**	**16.00**	**11.11**	**8.75**	**4.60**	**3.00**	**2.78**	**2.30**	**2.84**

N/A: not ageable

Table 23. Estimated annual and geometric mean survival (S) rates for year classes of striped bass (sexes combined) sampled from gill nets in the Rappahannock River, 30 March - 3 May, 1991-2000.

Year Class	91-92 S	92-93 S	93-94 S	94-95 S	95-96 S	96-97 S	97-98 S	98-99 S	99-00 S	Mean S
1997									------	------
1996								------	0.595	0.595
1995							------	0.908	0.546	0.704
1994						------	------	0.098	0.559	0.234
1993					------	------	0.084	0.534	0.534	0.288
1992				------	------	------	0.289	0.289	0.525	0.353
1991			------	------	------	0.496	0.470	0.376	0.640	0.487
1990		------	------	0.943	0.452	0.620	0.152	0.798	0.798	0.543
1989	------	------	------	0.163	0.556	0.268	0.500	0.667	0.550	0.406
1988	------	------	0.324	0.350	0.521	0.780	0.282	0.667	0.550	0.466
1987	0.666	0.666	0.203	0.829	0.914	0.313	0.220	0.909	0.000	0.488
1986	0.315	0.781	0.729	0.729	0.217	0.856	0.856	0.000		0.526
1985	0.754	0.754	0.754	0.449	0.718	0.718	0.718	0.718	0.000	0.598
1984	0.500	0.927	0.927	0.373	0.000					0.502
1983	------	------	0.431	0.232	0.000					0.208
1982	------	0.909	0.550	0.000						0.436
1981	0.000									------

Table 24. Estimated annual and geometric mean survival (S) rates for year classes of male striped bass sampled from gill nets in the Rappahannock River, 30 March - 3 May, 1991-2000.

Year Class	91-92 S	92-93 S	93-94 S	94-95 S	95-96 S	96-97 S	97-98 S	98-99 S	99-00 S	Mean S
1998									------	------
1997									------	------
1996								------	0.587	0.587
1995							------	0.908	0.536	0.698
1994						------	------	0.080	0.484	0.197
1993					------	------	0.078	0.461	0.461	0.255
1992				------	------	------	0.254	0.254	0.122	0.199
1991			------	------	------	0.446	0.268	0.448	0.000	0.276
1990		------	------	0.852	0.457	0.572	0.120	0.000		0.366
1989	------	------	------	0.104	0.532	0.357	0.000			0.231
1988	------	------	0.241	0.231	0.442	0.340	0.767	0.767	0.000	0.373
1987	0.441	0.441	0.079	0.394	0.937	0.937	0.937	0.937	0.000	0.523
1986	0.126	0.738	0.122	0.364	0.000					0.245
1985	0.529	0.529	0.529	0.000						0.375
1984	0.548	0.548	0.548	0.000						0.388

Table 26. Catch rates (fish/day) of year classes of striped bass (sexes combined) sampled from gill nets in the James River, 30 March - 3 May, 1994-2000. Maximum catch rate for any year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)						
	1994	1995	1996	1997	1998	1999	2000
1998							**0.789**
1997						0.200	**10.790**
1996						9.100	**36.631**
1995					1.222	10.300	**19.158**
1994			0.100	1.556	7.111	**11.700**	5.526
1993		0.667	1.600	4.444	5.222	**6.100**	1.053
1992		**4.333**	2.900	3.333	3.000	2.900	0.684
1991	2.400	**8.889**	4.500	2.000	1.667	2.200	0.316
1990	**12.400**	11.111	3.100	2.000	0.778	1.400	0.211
1989	**12.200**	9.778	2.700	0.889	1.111	1.200	0.053
1988	**3.600**	2.667	1.000	1.444	0.778	0.400	0.053
1987	0.800	**2.667**	1.000	1.111	0.667	1.000	
1986	0.800	**1.889**	0.800	0.333	0.111	0.300	
1985	0.800	**1.222**	0.300	0.222	0.111	0.100	
1984	**1.200**	0.778	0.100	0.111			
1983	**0.800**	0.333					
1982	**0.400**	0.222					
N/A	0.800	2.000	0.200	0.333	0.333	1.300	0.368
Total	35.800	44.556	18.300	17.778	22.112	48.200	75.301

N/A: not ageable

Table 27. Catch rates (fish/day) of year classes of male striped bass sampled from gill nets in the James River, 30 March - 3 May, 1994-2000. Maximum catch rate for any year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)						
	1994	1995	1996	1997	1998	1999	2000
1998							**0.789**
1997						0.200	**10.737**
1996						7.300	**36.368**
1995					1.222	8.000	**18.526**
1994			0.100	1.556	**6.778**	5.200	5.263
1993		0.667	1.600	**3.889**	3.778	2.500	0.842
1992		**4.222**	2.800	2.333	1.667	1.100	0.579
1991	2.400	**7.889**	3.600	1.444	1.333	0.100	
1990	**10.600**	6.333	1.500	1.333	0.222	0.300	
1989	**8.000**	2.333	0.800	0.444	0.000	0.000	
1988	**1.400**	0.556	0.300	0.111	0.111	0.100	
1987		**0.444**	0.100				
1986		0.111					
N/A	0.800	1.444	0.100	0.000	0.111	0.500	0.368
Total	**23.200**	**24.000**	**10.900**	**11.110**	**15.222**	**25.300**	**73.472**

N/A: not ageable

Table 28. Catch rates (fish/day) of year classes of female striped bass sampled from gill nets in the James River, 30 March - 3 May, 1994-2000. Maximum catch rate for any year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)						
	1994	1995	1996	1997	1998	1999	2000
1997							0.053
1996						**1.800**	0.263
1995						**2.300**	0.632
1994					0.333	**6.500**	0.263
1993				0.556	1.444	**3.600**	0.211
1992		0.111	0.100	1.000	1.333	**1.800**	0.105
1991		1.000	0.900	0.556	0.667	**2.100**	0.316
1990	1.800	**4.778**	1.500	0.667	0.556	1.100	0.211
1989	4.000	**7.444**	1.900	0.444	1.111	1.200	0.053
1988	**2.200**	2.111	0.700	1.333	0.667	0.300	0.053
1987	0.800	**2.222**	0.900	1.111	0.667	1.000	
1986	0.800	**1.778**	0.800	0.333	0.111	0.300	
1985	0.400	**1.222**	0.300	0.222	0.111	0.100	
1984	**1.200**	0.778	0.200	0.111			
1983	**0.800**	0.333					
1982	**0.400**	0.222					
N/A	0.000	0.556	0.100	0.333	0.222	0.800	0.000
Total	**12.400**	**22.556**	**7.400**	**6.667**	**7.222**	**22.900**	**2.160**

N/A: not ageable

Table 29. Estimated annual and geometric mean survival (S) rates for year classes of striped bass (sexes combined) sampled from gill nets in the James River, 30 March - 3 May, 1994-2000.

Year Class	94-95 S	95-96 S	96-97 S	97-98 S	98-99 S	99-00 S	Mean S
1995					------	------	------
1994				------	------	0.472	0.472
1993			------	------	------	0.173	0.173
1992		0.877	0.877	0.900	0.967	0.236	0.691
1991	------	0.506	0.788	0.788	0.788	0.144	0.513
1990	0.896	0.279	0.767	0.767	0.767	0.151	0.507
1989	0.801	0.276	0.763	0.763	0.763	0.044	0.404
1988	0.741	0.736	0.736	0.539	0.514	0.133	0.495
1987	------	0.645	0.645	0.948	0.948	0.000	0.593
1986	------	0.423	0.417	0.949	0.949	0.000	0.503
1985	------	0.245	0.740	0.500	0.901	0.000	0.439
1984	0.648	0.378	0.378	0.000			0.330
1983	0.416	0.000					0.190
1982	0.555	0.000					0.247

Table 30. Estimated annual and geometric mean survival (S) rates for year classes of male striped bass sampled from gill nets in the James River, 30 March - 3 May, 1994-2000.

Year Class	94-95 S	95-96 S	96-97 S	97-98 S	98-99 S	99-00 S	Mean S
1995					-------	------	------
1994			------	------	0.881	0.881	0.881
1993		------	------	0.971	0.662	0.337	0.601
1992		0.663	0.833	0.715	0.660	0.526	0.672
1991	------	0.456	0.401	0.923	0.075	0.000	0.334
1990	0.597	0.237	0.889	0.474	0.474	0.000	0.417
1989	0.292	0.342	0.555	0.000			0.281
1988	0.397	0.540	0.608	0.608	0.901	0.000	0.482
1987	------	0.444	0.100	0.000			0.107
1986	------	0.000					0.000

Table 31. Estimated annual and geometric mean survival (S) rates for year classes of female striped bass sampled from gill nets in the James River, 30 March - 3 May, 1994-2000.

Year Class	94-95 S	95-96 S	96-97 S	97-98 S	98-99 S	99-00 S	Mean S
1996						0.146	0.146
1995						0.275	0.275
1994					------	0.040	0.040
1993				------	------	0.059	0.059
1992			------	------	------	0.058	0.058
1991			------	------	------	0.150	0.150
1990	------	0.314	0.902	0.902	0.902	0.192	0.536
1989	------	0.255	0.836	0.836	0.836	0.044	0.366
1988	0.960	0.795	0.795	0.500	0.450	0.177	0.538
1987	------	0.707	0.707	0.949	0.949	0.000	0.617
1986	------	0.450	0.416	0.949	0.949	0.000	0.508
1985	------	0.245	0.740	0.500	0.901	0.000	0.439
1984	0.648	0.257	0.555	0.000			0.340
1983	0.416	0.000					0.190
1982	0.555	0.000					0.247

Figure 1. Locations of commercial pound nets and experimental gill nets sampled in spring spawning stock assessments of striped bass in the Rappahannock River, 1991-2000.

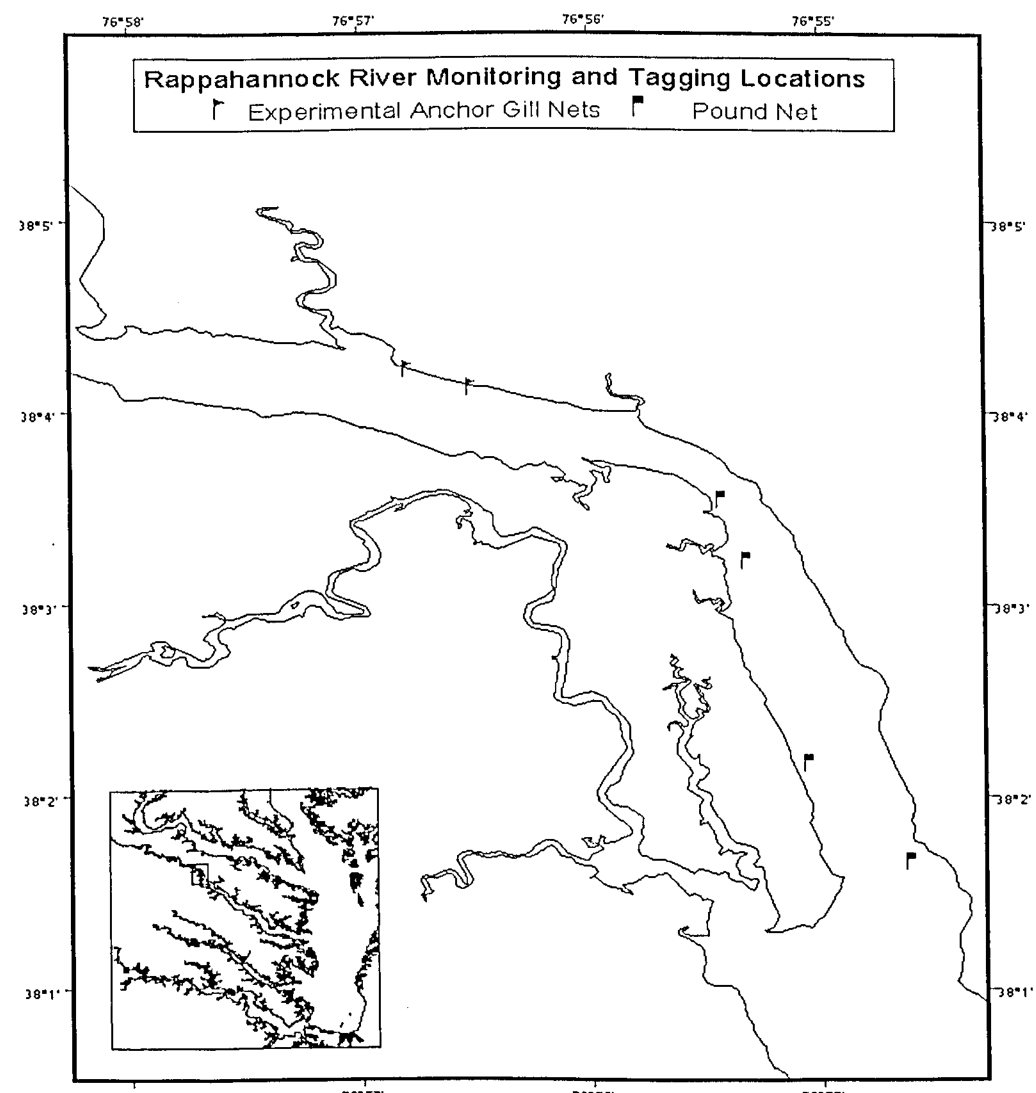


Figure 2. Locations of experimental anchor gill nets sampled in spring spawning stock assessments of striped bass in the James River, spring 2000.

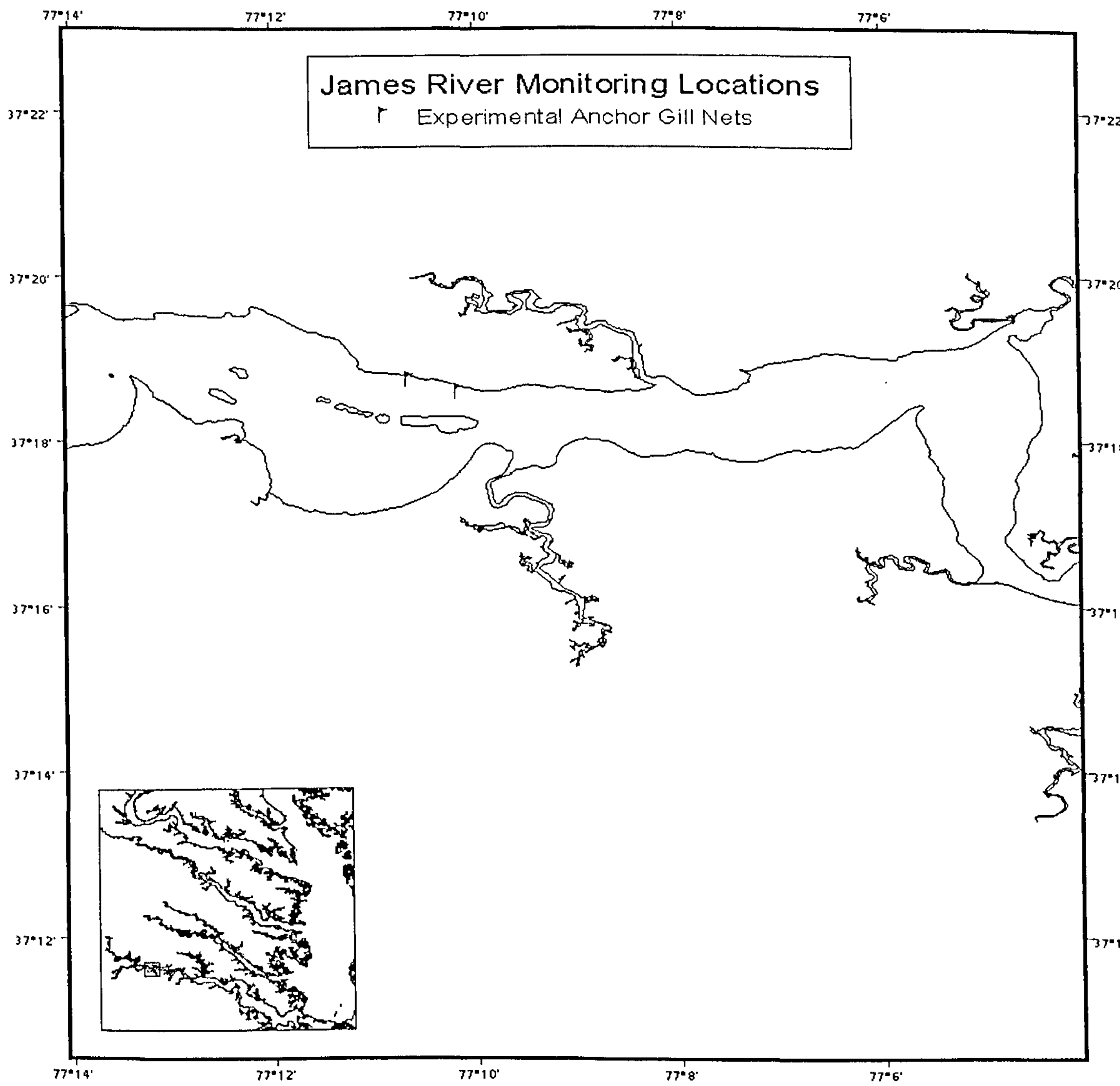


Figure 3. Catch rates (number of fish per day) of eight year classes (1987-1994) of male and female striped bass in pound nets in the Rappahannock River, 30 March - 3 May, 1991-2000.

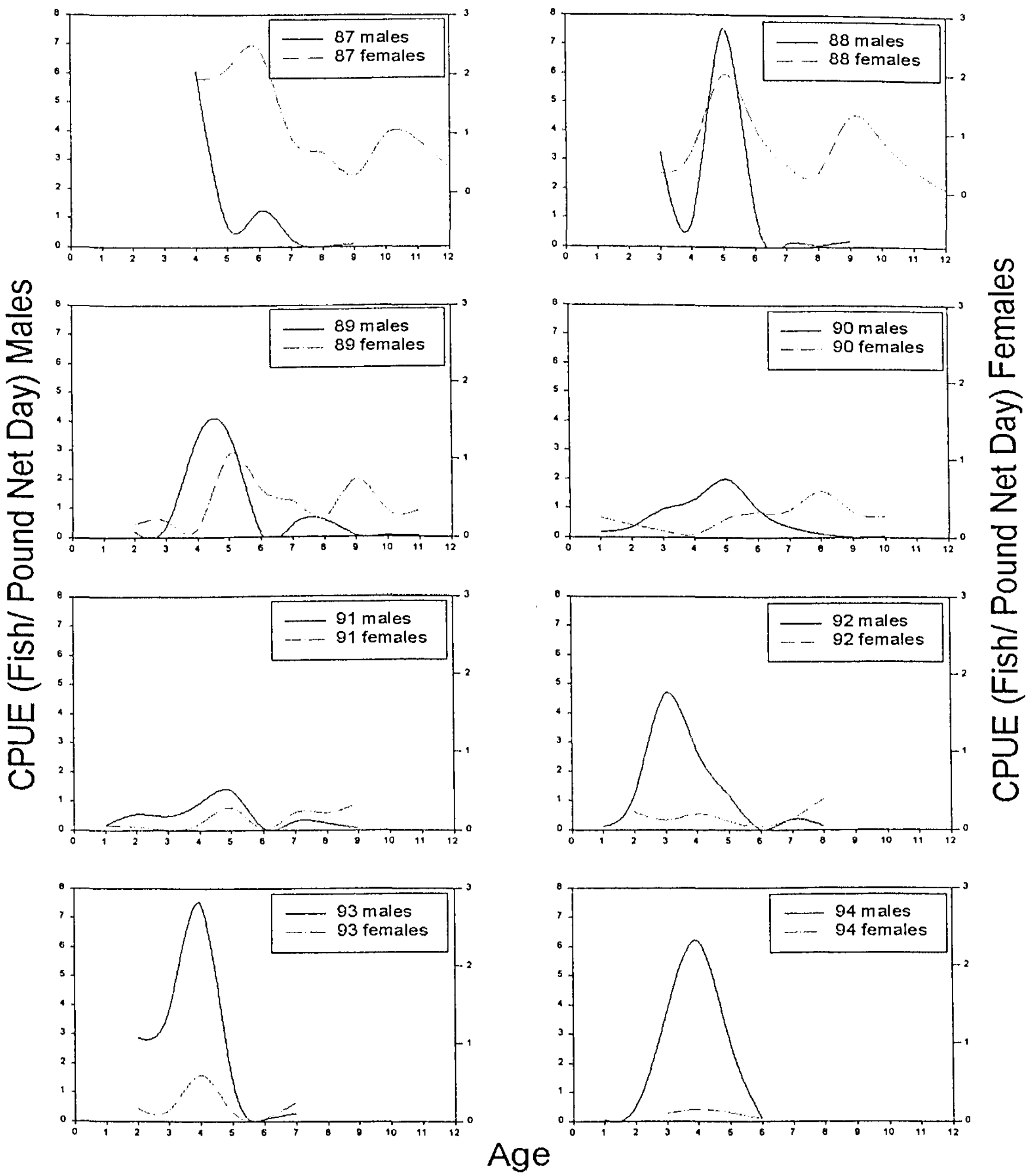


Figure 4. Catch rates (number of fish per day) of eight year classes (1987-1994) of male and female striped bass in experimental gill nets in the Rappahannock River, 30 March - 3 May, 1991-2000.

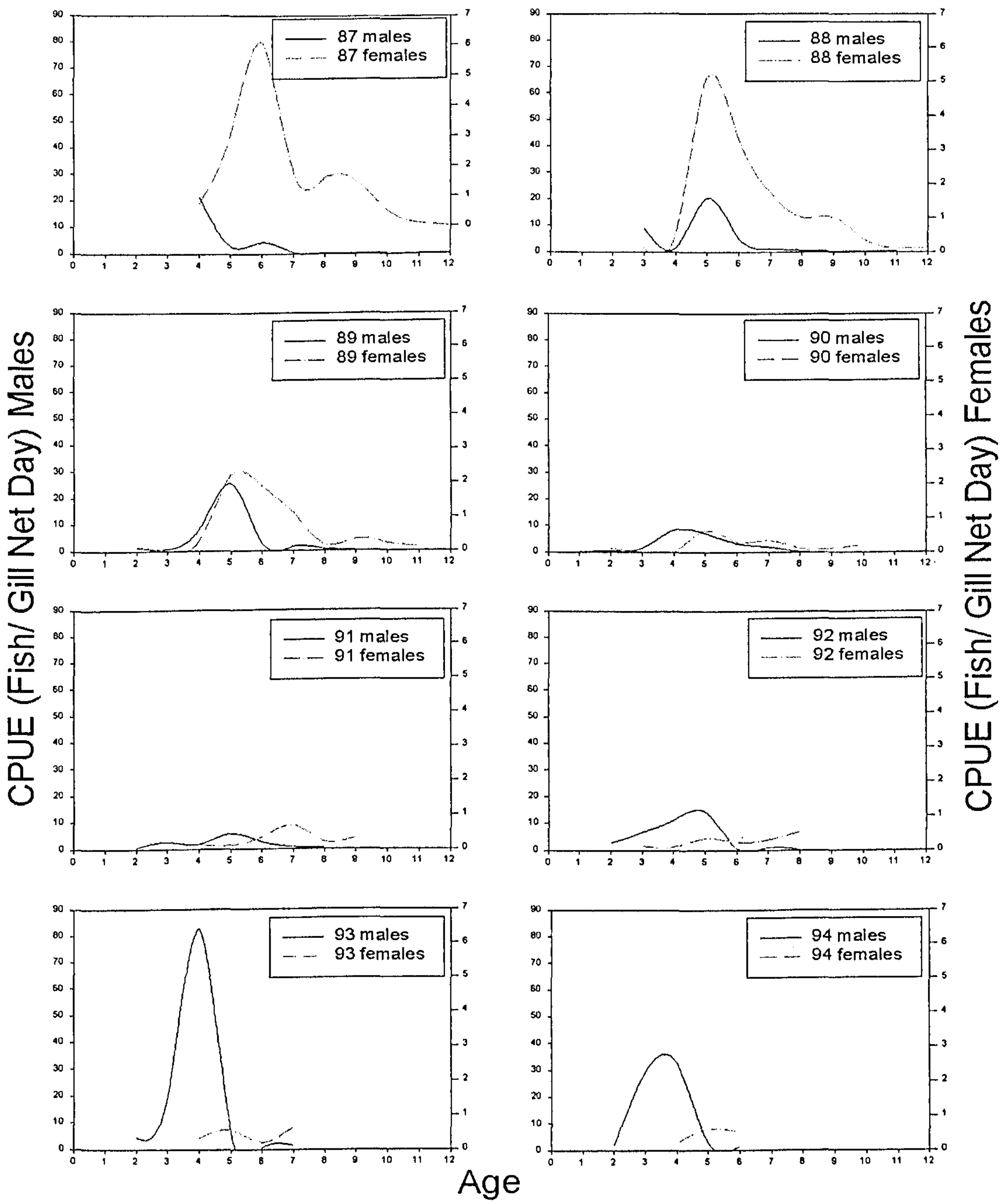
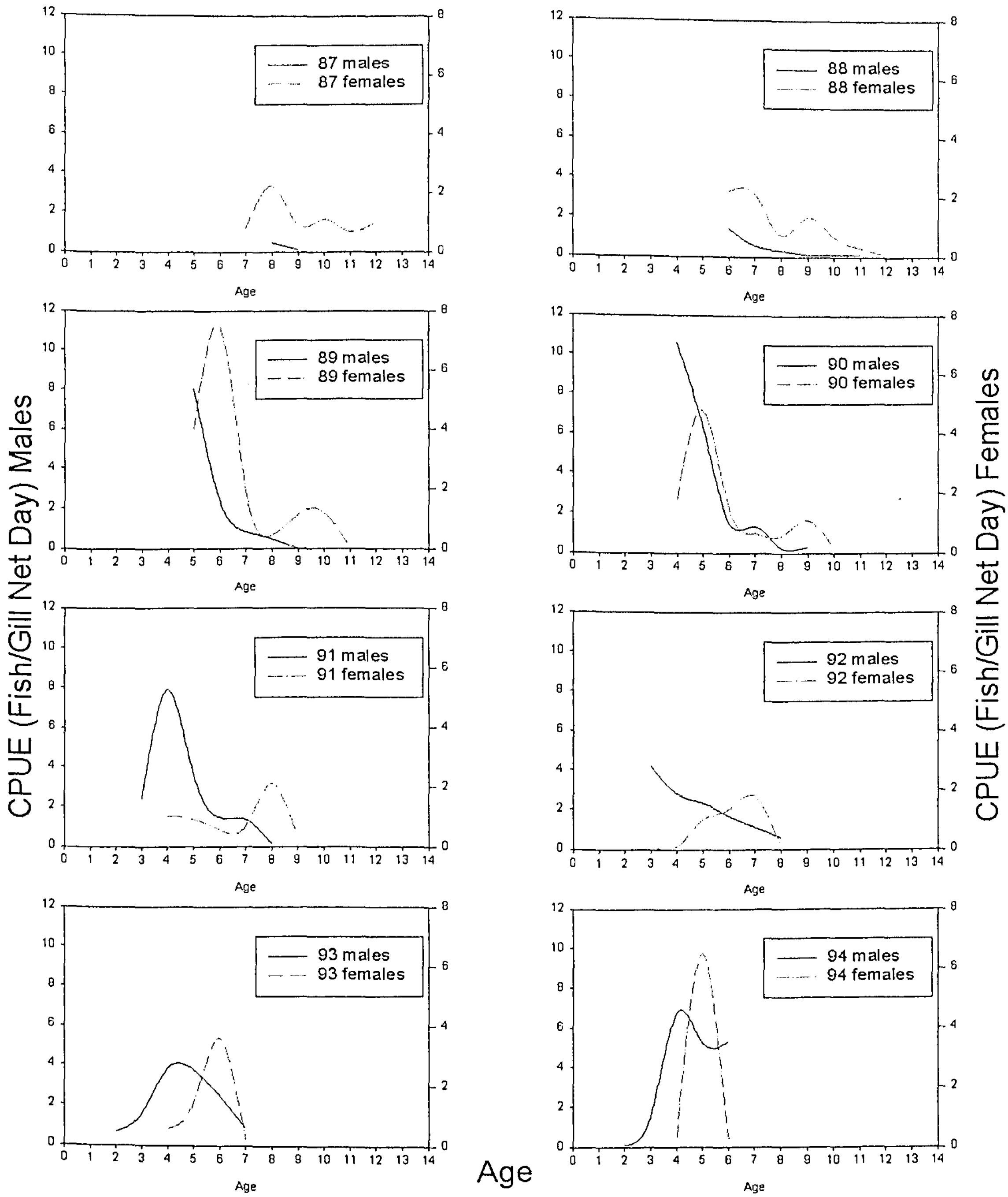


Figure 5. Catch rates (number of fish per day) of eight year classes (1987-1994) of male and female striped bass in experimental gill nets in the James River, 30 March - 3 May, 1994-2000.



II. Mortality estimates of striped bass (*Morone saxatilis*) that spawn in the Rappahannock River, Virginia

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Introduction

Striped bass (*Morone saxatilis*) have historically supported one of the most important recreational and commercial fisheries along the Atlantic coast. The species is one of the most important economical and social components of finfish catches in the Chesapeake Bay area. From 1965 to 1972, annual commercial landings of striped bass in Virginia fluctuated from about 554 to 1,271 metric tons (MT). Recreational harvests, although not well documented, may have reached equivalent levels (Field 1997). Beginning in 1973, a dramatic decrease in catches occurred, and during the period 1978 through 1985, annual commercial landings in Virginia averaged about 162 MT. This decline in Virginia's striped bass landings was reflected in similar catch statistics from Maine to North Carolina.

Concern about the decline in striped bass landings along the Atlantic coast since the mid-1970's prompted the development of an interstate fisheries management plan (FMP) under the auspices of the Atlantic States Marine Fisheries Commission (ASMFC) as part of their Interstate Fisheries Management Program (ASMFC 1981). Federal legislation was enacted in 1984 (Public Law 98-613, The Atlantic Striped Bass Conservation Act), which enables Federal imposition of a moratorium for an indefinite period in those states that fail to comply with the coastwise plan. To be in compliance with the plan, coastal states have imposed restrictions on their commercial and recreational striped bass fisheries ranging from combinations of catch quotas, size limits, and time-limited moratoriums to year-round moratoriums. Due to an improvement in spawning success, as judged by increases in annual values of the Maryland juvenile index, a limited fishery was established in fall 1990. This transitional fishery existed until 1995 when spawning stock biomass in the Chesapeake Bay reached extremely healthy levels (Field 1997). The ASMFC subsequently declared Chesapeake stocks to have reached benchmark levels and the states adopted an amendment to the original FMP in order to allow expanded state fisheries.

The Anadromous Fishes Program of the Virginia Institute of Marine Science (VIMS) has monitored the size and age composition, sex ratio and maturity schedules of the spawning striped bass stock in the Rappahannock River since 1981. In conjunction with the monitoring studies, VIMS established a tagging program in 1987 to provide information on the migration, relative contribution to the coastal population, and annual survival of striped bass that spawn in the Rappahannock River. This program is part of an active cooperative tagging study that currently involves 15 state and federal agencies along the Atlantic coast. The U.S Fish and Wildlife Service manages the coastwide tagging database. Hence, commercial and recreational anglers that target striped bass are encouraged to report all recovered tags to that agency. The analysis protocol, as established by the ASFMC Striped Bass Tagging Subcommittee, involves fitting a suite of reformulated Brownie models (Brownie et al. 1985; White and Burnham 1999) to the tag return data.

In this section, we present a comprehensive analysis of the Rappahannock River striped bass tagging data. We begin with a detailed description of the ASFMC analysis protocol and present survival estimates (S) from 1988 to 1999 that were generated from the application of a suite of reformulated Brownie models. For the purposes of comparison and model validation, we follow the reformulated Brownie results with estimates of instantaneous fishing (F) and natural (M) mortality. These parameter estimates were obtained by applying the recently developed instantaneous rates formulation of the Brownie models (Hoenig et al. 1998a). The results from both methods were thoroughly examined and a discussion pertaining to the performance of the models and the reliability of the subsequent parameter estimates is included.

Multiyear Tagging Models

Tag return data is generally represented by constructing an upper triangular matrix of tag recoveries, where each cell of the matrix contains the number of tag returns from a particular year of tagging and recovery. For example, a study with I years of tagging and J years of recovery would yield the following data matrix

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1J} \\ - & r_{22} & \cdots & r_{2J} \\ \vdots & \vdots & \ddots & \vdots \\ - & - & - & r_{IJ} \end{bmatrix}, \qquad (1)$$

where r_{ij} is the number of tags recovered in year j that were released in year i (note, $J \geq I$). Tagging periods do not necessarily have to be yearly intervals; however, data analysis is easiest if all periods are the same length and all tagging events are conducted at the beginning of each period. Application of tagging models involves constructing an upper triangular matrix of expected values and comparing them to the observed data. Since the data are known to follow a multinomial distribution, the method of maximum likelihood can be used to obtain parameter estimates. Analytical solutions for the maximum likelihood parameter estimates are generally not available. Hence, several software packages that numerically maximize a product multinomial likelihood function have been developed for application of tagging models. They include programs SURVIV (White 1983), MARK (White and Burnham 1999), and AVOCADO (Hoenig et al. in prep.).

Reformulated Brownie models

White and Burnham (1999) reformulated the original Brownie et al. (1985) models to create a consistent framework for modeling mark-recapture data (Smith et al. 2000). This framework served as the foundation for program MARK, which is a comprehensive software package for the application of capture-recapture models. The matrix of expected values associated with a time-specific reformulated Brownie model would be

$$E(R)=\begin{bmatrix} N_1(1-S_1)r_1 & N_1S_1(1-S_2)r_2 & \cdots & N_1S_1\cdots S_{J-1}(1-S_J)r_J \\ - & N_2(1-S_2)r_2 & \cdots & N_2S_2\cdots S_{J-1}(1-S_J)r_J \\ \vdots & \vdots & \ddots & \vdots \\ - & - & - & N_I(1-S_I)r_I \end{bmatrix}. \qquad (2)$$

This model expresses the tag recovery rate from Brownie et al. (1985) as $f_i = (1 - S_i)r_i$, where r_i is the probability at which tags are reported from killed fish regardless of the source of mortality.

The reformulated Brownie models are simple and robust, but they do not yield direct information about exploitation (u) or instantaneous rates of mortality ($Z = F + M$), which are often of interest to fisheries managers. Estimates S can be converted to Z via the equation $S = e^{-Z}$ (Ricker 1975), and if information about M is available, then estimates of F can be recovered. If information about the tag reporting rate (λ) is known, then estimates of u can be obtained via the equation

$$u = \frac{f}{\lambda} = \frac{(1-S)r}{\lambda},$$

(Pollock et al. 1991; White and Burnham 1999), and estimates of F can be recovered if information about the timing of the fishery is known. Specifically, for a pulse (Type I) fishery, the relationship

$$u = (1 - e^{-F})$$

holds, while for a continuous (Type II) fishery, the relationship

$$u = \frac{F}{F+M}(1-e^{-(F+M)})$$

holds (Ricker 1975). Note that when fishing is continuous, information about M is again required to calculate estimates of F.

Instantaneous rates models

Hoenig et al. (1998a) modified the Brownie et al. (1985) models to allow for the estimation of instantaneous rates of fishing and natural mortality. This extension showed how information on fishing effort could be used as an auxiliary variable and also discussed generalizing the pattern of fishing within the year. Hoenig et al. (1998b) extended the instantaneous rates formulation further by showing how to account for nonmixing of newly tagged fish for all or part of the first year after tagging. The matrix of expected values corresponding to equation (1) for a model that assumes time-specific fishing mortality rates and a constant natural mortality rate would be

$$E(R) = \begin{bmatrix} N_1\phi\lambda u_1(F_1, M) & N_1\phi\lambda u_2(F_2, M)e^{-(F_1+M)} & \cdots & N_1\phi\lambda u_J(F_J, M)e^{-(\sum_{k=1}^{J-1} F_k + (J-1)M)} \\ - & N_2\phi\lambda u_2(F_2, M) & \cdots & N_2\phi\lambda u_J(F_J, M)e^{-(\sum_{k=2}^{J-1} F_k + (J-2)M)} \\ \vdots & \vdots & \ddots & \vdots \\ - & - & - & N_I\phi\lambda u_J(F_J, M) \end{bmatrix}, \qquad (3)$$

where φ is the probability of surviving being tagged and retaining the tag in the short-term, λ is the tag-reporting rate, and $u_k(F_k,M)$ is the exploitation rate in year k which, as mentioned above, depends on whether the fishery is Type I or Type II (Ricker, 1975).

These models are not as simple as the reformulated Brownie models, but they do yield direct estimates of F and, depending on the information available, either M or $\varphi\lambda$. Also, they can be parameterized to allow for nonmixing of newly and previously tagged animals (well-mixed cohorts of tagged animals is an assumption required by the reformulated Brownie models but often violated in practice). If the goal of a particular tagging study is to estimate F and M, then auxiliary information on the tag reporting and tag-induced mortality/handling rate is required to apply the instantaneous rates formulation. However, if M is known, perhaps from a study that related it to life history characteristics (Beverton and Holt 1959; Pauly 1980; Hoenig 1983; Roff 1984; Gunderson and Dygert 1988), then these models can be used to estimate F and $\varphi\lambda$. In either case, the auxiliary information needed (i.e., $\varphi\lambda$ or M) can often be difficult to obtain in practice, and since F, M and $\varphi\lambda$ are related functionally in the models, the reliability of the parameters being estimated is directly related to the accuracy of the estimated auxiliary parameter (Latour et al. in press (a)).

Capture and Tagging Protocol

Each year from 1987 to 1999, during the months of April and May, VIMS scientists obtained samples of mature striped bass on the spawning grounds of the Rappahannock River. Samples were taken twice-weekly from pound nets owned and operated by cooperating commercial fishermen. The pound net is a fixed trap that is presumed to be non-size selective in its catch of striped bass and has been historically used by commercial fishermen in the Rappahannock River.

All captured striped bass were removed from each pound net and placed into a floating holding pocket (1.2m x 2.4m x 1.2m deep, with 25.4mm mesh and a capacity of approximately 200 fish) anchored adjacent to the gear. Fish were dipnetted from the holding pocket and examined for tagging. Fork length (FL) and total length (TL) measurements were taken and whenever possible the sex of each fish was determined. Striped bass not previously marked larger than 458 mm TL were tagged with sequentially numbered internal anchor tags (Floy Tag and Manufacturing, Inc.). Each internal anchor tag was applied through a small incision in the abdominal cavity of the fish. A small sample of scales adjacent to the dorsal fin on the left side was removed and used to estimate age. Each fish was released at the site of capture immediately after receiving a tag.

Analysis protocol

The ASFMC Striped Bass Tagging Subcommittee established a data analysis protocol that involves deriving survival estimates from a suite of reformulated Brownie models. The protocol is used by each state and federal agency participating in the cooperative tagging study. Tag recoveries from striped bass that were > 711 mm total length (TL) at the time of tagging are analyzed since those fish are believed to be fully recruited to the fishery and also because they constitute the coastal migratory population. The protocol consists of five steps. First, prior to data analysis, a set of biologically reasonable candidate models is identified. Characteristics of the stock being studied (i.e., Chesapeake Bay, Hudson River, Delaware Bay, etc.) and time are used as factors in determining the parameterizations of the candidate models. These models are then fit to the tagging data, and Akaike's Information Criterion (AIC) (Akaike 1973; Burnham and Anderson 1992), quasi-likelihood AIC (QAIC) (Akaike 1985), and goodness-of-fit (GOF) diagnostics are used to evaluate their fit (Burnham et al. 1995). The overall estimates of survival are calculated as a weighted average of survival from the best fitting models, where the weight is related to the model fit (i.e., the better the fit, the higher the weight) (Buckland et al. 1997; Burnham and Anderson 1998; Smith et al. 2000). The final step involves adjusting the survival estimates for bias induced by the presence of live recaptures in the data (tag-recovery models are generally intended for the analysis of data where a recapture implies that the tagged individual has been removed from the population). The coastwide striped bass tagging data contains a large number of live recaptures, where an angler releases the fish alive after either removing the streamer of the tag or simply recording the tag number. The methodology developed by Smith et al. (2000) is used to adjust for the bias caused by including these recaptures in the analysis.

Dunning et al. (1987) quantified the rates of tag-induced mortality and tag retention for Hudson River striped bass. They found retention of internal anchor tags placed into the body cavity via an incision midway between the vent and the posterior tip of the pelvic fin was 98% for fish at liberty over 1 year. Their holding experiment revealed that the survival rates of both tagged and control fish were not significantly different over the 180-day period the fish were held. A similar study conducted on resident striped bass within the York River, Virginia yielded tag-induced mortality and short-term tag retention rates each in excess of 98% (Latour and Olney, Fall 2000 Chesapeake Bay Directed *F* Study). Hence, no attempts were made to adjust for bias due to these sources. The cohorts of tagged fish used in the analysis were comprised primarily of tagged fish known to be at liberty for at least 7 days. Exceptions were made for fish recaptured within the 7 days as long as fish were released alive with the tag intact. Since the annual tagging periods were lengthy (> 1 month), the recovery periods were assumed to begin at the median week of the tagging period (i.e., the week at which 50% of the tags were released in that year). Imposition of this assumption created unequal recovery periods, however, program MARK possesses a feature that will adjust survival estimates by $\hat{S}_i^{52/t}$, where $\hat{S}_i$ is the survival estimate in year i and t is the number of weeks between the median week of tagging in successive years (Smith et al. 2000).

Analysis of Tagging Data From 1988-1999

Reformulated Brownie models

The proposed suite of reformulated Brownie models consisted of 12 models that each reflected a different parameterization of time. Models that allowed parameters to be both time-specific and constant across time were specified. Also, since Atlantic striped bass have been subjected to a variety of harvest regulations since 1988, it was hypothesized that these harvest regulations would influence survival and catch rates. Hence, models that allowed parameters to be constant for the time periods coinciding with coastwide harvest regulations (i.e., 1988-1989, 1990-1994, and 1995-1999) were also specified.

The candidate models were fit to a tag-recovery matrix that contained data reflecting known removals from the population and live recaptures (Appendix A). Of the 12 proposed models, 7 had ΔAICc values less than 10 (Table 1). Of those 7 models, the calculated weight of the constant survival and tag reporting model (i.e., S(.)r(.)) was significantly larger that of the other models. Comparatively, the weight values associated with the period-specific models (those parameterized in accordance with harvest regulations) were next largest and similar in magnitude. Models that reflected more general time-specific parameterizations tended to not fit the data well.

Since the overall estimates of survival are derived as a weighted average of survival from the best fitting models, and since the S(.)r(.) model received the largest weighted value, it follows that the proposed suite of models would yield a series of relatively uniform survival rates. Model averaged estimates of the unadjusted survival rates (i.e., not accounting for the bias induced by including live recaptures in the data set) were highest during the moratorium (1988-1989) and only slightly decreased during the transitional (1990-1994) and full fisheries (1995-present) (Table 2a). Bias corrected survival estimates were obtained assuming tag reporting estimates of 0.55 (Delaware; D. Kahn, personal communication, Delaware Division of Fish and Wildlife), 0.75 (Maryland; Rugulo et al. 1994), and 0.64 (Maryland and Virginia; 1999 Chesapeake Bay reporting rate study). These estimates tended to fluctuate over the 12 year time period with the maximum and minimum survival rate occurring in 1988 and 1996, respectively (Table2b). Estimates of F were recovered from these bias adjusted rates of total survival assuming a value of 0.15 for M (Smith et al. 2000). It should be noted that establishment of the transitional and full fisheries was a direct result of a continuous increase in Chesapeake Bay striped bass abundance from 1988 to 1999 (Field 1997). Given this trend in abundance and the drastically different management regulations that have been applied to striped bass, it seems unlikely that survival has remained relatively constant during those years, even though the S(.)r(.) was the best fitting model.

Instantaneous rates models

A series of instantaneous rates model were applied to a modified 12-year tagging matrix where recoveries reflected only known removals from the population (Appendix B). The instantaneous rates formulation is based on data where each recovered tag is known to represent a fish that was harvested. Three different parameterizations of equation (3) were specified and the models were fit assuming different values for $\varphi\lambda$. Since tag-induced mortality was negligible, the values of $\varphi\lambda$ considered were based primarily on the results of the aforementioned high reward tagging studies designed to estimate the tag reporting rate in Delaware ($\varphi\lambda$=0.55), Maryland ($\varphi\lambda$=0.75), and combined Maryland and Virginia ($\varphi\lambda$=0.64). The rate of natural mortality was assumed to be constant over all years for each model and fishing mortality was assumed to be continuous over the entire year. The models reflected a time-specific, period-specific (in accordance with the aforementioned harvest regulations), and constant parameterization of F.

For the time-specific model, the estimates of F did not exhibit a systematic increasing pattern as expected given the documented trend in harvest regulations (Table 3a). The estimates fluctuated over the 12-year period with highest F occurring in 1995 and the lowest occurring in both 1990 and 1991 for all values of $\varphi\lambda$ considered. Relative to 1995, both 1998 and 1999 showed the next highest F values. The estimates of M ranged from 0.35 to 0.32 as the value of $\varphi\lambda$ decreased from 0.75 to 0.55. These values are more than double the 0.15 value assumed by the ASFMC analysis protocol. The period-specific model yielded F estimates of 0.08 for the first two periods, and an increased estimate of 0.13 for the third period under the assumption that $\varphi\lambda$ is 0.75 (Table 3b). The same qualitative pattern with the F estimates was evident as the value of $\varphi\lambda$ decreased. Specifically, when $\varphi\lambda$ was reduced to 0.55, period-specific estimates of F were 0.11, 0.11, and 0.18, respectively. The period-specific model yielded estimates of M that were again fairly high. As $\varphi\lambda$ decreased, the estimates ranged from 0.34 to 0.31. The constant F model yielded F and M estimates of 0.10, 0.11, 0.13 and 0.32, 0.30, and 0.28 as $\varphi\lambda$ ranged from 0.75 to 0.55, respectively (Table 3c).

Model evaluation

Latour et al. (in review) proposed a series of diagnostics that can be used in conjunction with AIC and GOF measures to assess the performance of Brownie-type tag-recovery models. In essence, they suggested that the fit of a model could be critically evaluated by analyzing the model residuals and that distinct patterns in those residuals will be evident if particular assumptions are in violation.

For the time-specific Brownie et al. (1985) model (i.e., Model 1), Latour et al. (in review) proved the existence of several characteristics about the residuals. Specifically, they showed that row and column sums of the residuals matrix must total zero, and further, they showed that the residuals associated with the "never seen again" category must also always be zero. For the time-specific reformulated Brownie model, it was not possible to formally prove the existence of the same characteristics because analytical formulae for the maximum likelihood parameter estimates were not available (Brownie et al. (1985, p.16) provided formulae for the parameter estimates of Model 1). However, an exhaustive number of datasets were investigated and in each instance the aforementioned characteristics were expressed in the residuals matrix of the time-specific reformulated Brownie model.

Latour et al. (in review) also scrutinized the residuals associated with the time-specific instantaneous rates model. They determined that the residuals matrix of this model possessed fewer constraints that of Model 1 and the time-specific reformulated Brownie model. Although the row sums must again total zero, the column sums and the residuals associated with the "never seen again" category can assume any value. This flexibility allows row patterns to be more definitely expressed since for a particular row, the residual of the "never seen again" category can offset the emergence of consistent pattern of all positive or all negative values among the other residuals in that row. The ability to detect row patterns combined with fewer constraints about particular residuals always being zero suggests that the residuals from *IR* models may serve as better diagnostic tools for the assessment of model performance than those from *Model 1*or the time-specific reformulated Brownie model.

Brownie et al. (1985) and reformulated Brownie models

Model 1 was applied to the Rappahannock River striped bass tagging data and examination of the residuals showed that there were problems with cohorts 2 and 9 (i.e., those fish tagged in 1989 and 1996). These problems were discovered because the residuals associated with the "never seen again" category of rows 1, 2, 8, and 9 were nonzero (which is a violation of the theory of Model 1). Examination of the recovery data for 1988 and 1989 revealed that in 1989 there were approximately twice as many fish tagged as in 1988, but comparatively only about half the number of tag returns were observed each year from the 1989 cohort. This trend in the data caused program MARK to yield an estimate 1.00 for S_1 and nonzero "never seen again" residuals for rows 1 and 2 under Model 1. A hand calculation of S_1 from the analytical solution yielded a value of 1.52, which implies the estimate from program MARK resulted from the imposition of the constraint that S_1 must be between 0.00 and 1.00. Given the sparseness of tag returns in 1989, it seems reasonable to speculate that the observed and actual numbers of fish tagged in 1989 were significantly different. One explanation (which is impossible to prove) is short-term tag-induced/handling mortality. Cohort 9 was also deemed problematic because the "never seen again" residuals of rows 8 and 9 were nonzero and a hand calculation of S_8 yielded an estimate of 1.29. However, this could simply be a result of low sample size since in 1996 only 66 fish were tagged and only a total of 5 recoveries were tabulated over the 4 years the cohort was at liberty.

Examination of the parameter estimates and residuals from the time-specific reformulated Brownie model reconfirmed the problems detected with cohorts 2 and 9, and also raised questions about cohort 12 (i.e., those fish tagged in 1999). The estimates of r in 1988, 1995, and 1998 were exactly 1.00, which suggests that program MARK was again forced to impose constraints to satisfy the fact that r is a probability. Also, the residuals associated with the "never seen again" category of rows 1, 2, 8, 9, 11, and 12 were nonzero. However, since 1999 is the most recent year of tagging and recovery, there is very little data available for examination, which renders it difficult to adequately assess cohort 12.

It is unclear exactly how the aforementioned cohort-specific problems influence the overall analysis of the time series. Since the data in row 2 and 9 are needed only for estimation of survival from 1988-1990 and 1995-1997, respectively, under a time-specific model, it seems reasonable to assume that the survival estimates for 1990-1994 and 1997-1998 from Model 1 are reliable. However, when survival is assumed to be period-specific or constant over all years, it is impossible to isolate the effects of rows 2 and 9 since those data contribute to the estimation of some or all of the survival estimates. Similarly, for the time-specific reformulated Brownie model, the survival estimates for 1990-1994 will likely be reliable, but again, the reliability of those for 1997-1998 and those from a constant or period-specific model parameterization is in doubt due to the data in rows 2, 9, and 12. This uncertainty is of great concern, particularly since the results yielded by the S(.)r(.) model represent 79.5% of the model averaged results.

Instantaneous rates models

Examination of the residuals matrix associated with the time-specific instantaneous rates model again confirmed that cohorts 2 and 9 are problematic. Specifically, rows 2 and 9 of the residuals matrix revealed negative residuals for 8 out of 11 and 3 out of 3 values, respectively. A row pattern of negative residuals is often seen when there is a substantial difference between the observed and actual number of fish tagged in that year (Latour et al. in review). Again, two possible explanations include short-term tag-induced/handling mortality and immediate tag loss. However, the presence or absence of those phenomena in 1989 and 1996 is impossible to prove.

Analysis of Tagging Data From 1990-1994

Reformulated Brownie models

Since analysis of the full data matrix revealed problems with cohorts 2, 9 and possibly 12, a reduced matrix reflecting tagging data from 1990 to 1994 was analyzed with the reformulated Brownie models (again, both known removals and live recaptures were included in the data set). Analysis of a reduced tag-recovery matrix was performed because it is unclear how the noted cohort-specific problems influence the analysis of the full matrix, particularly when survival is assumed to be period-specific or constant over time.

When the original suite of 12 models was applied to the reduced tag-recovery matrix, only 7 unique model parameterizations emerged (e.g., models $S(p_1)r(p_1)$ and $S(.)r(p_1)$ from the full matrix are the same as S(.)r(.) when applied to the reduced matrix). Of those 7 proposed models, each had ΔAICc values less than 10 (Table 4). The calculated weight of the linear trend model S(T.)r(T.) model was significantly larger that of the other models. Comparatively, the weight values associated with the time-specific models indicated that these models did not fit the data well.

Since the linear trend model had a dominating influence on the overall model averaged results, survival estimates from 1990 to 1994 were not expected to be uniform even though harvest regulations during those years remained unchanged. However, the trend model predicted that survival rates were increasing over the 5-year period, so model averaged estimates of the unadjusted survival rates ranged from 0.456 to 0.833 from 1990 to 1994, respectively (Table 5a). These results, along with the bias adjusted survival estimates (Table 5b) differed substantially from those generated from analysis of the full matrix. Again, estimates of *F* were recovered from the bias adjusted rates of total survival, however the estimated survival rate in 1994 was such the adjustment for an M of 0.15 led to a negative F value.

For the purposes of model evaluation, Model 1 was fit to the reduced data matrix and the associated residuals along with those from the time-specific reformulated model were examined for patterns. Unfortunately, additional problems were detected. The "never seen again" residuals in rows 4 and 5 from Model 1 were nonzero, and the estimate of survival that comes from the data in those rows (i.e., S_4) was exactly 1.00. This problem was also evident in the residuals of the reformulated Brownie model since the same "never seen again" residuals were nonzero and the estimate of r_4 was exactly 1.00. This information suggests that cohort 5 (those fish tagged in 1994) may be problematic and that the reliability of the parameter estimates may be in doubt (especially since the suite yielded survival estimates that exhibit a counterintuitive trend). Unfortunately, it is difficult to adequately assess cohort 5 since 1994 is the most recent year of tagging and recovery of the reduced matrix and very little data is available for examination.

Instantaneous rates models

To complement application of the reformulated Brownie models to the reduced tag-recovery matrix, two parameterizations of the instantaneous rates models were applied to the data from 1990 to 1994. Models reflecting a time-specific and a constant parameterization of F were fit to the data matrix. The same values of $\varphi\lambda$ and the same assumptions about the constancy of M and the timing of fishing that were used with the analysis of the full matrix were again imposed.

In general, the parameter estimates from both parameterizations were very similar to those from the analysis of the full matrix for 1990 to 1994. For the time-specific model, the estimates of F exhibited a systematic increasing pattern for all values of $\varphi\lambda$ considered (Table 6). Specifically, when $\varphi\lambda = 0.64$, the estimates of F increased from 0.07 in 1990 to 0.14 in 1994. Although this trend contradicts the results given by the reduced suite of reformulated Brownie models, it does coincide with harvest regulations specific to Virginia (recall from the caption of Table 1 that regulations in Virginia specified constant survival from 1990-1992 and 1993-1994, with more liberal catches allowed in recent years). As $\varphi\lambda$ increased from 0.55 to 0.75, the estimates of M increased from 0.35 to 0.38. Again these values were more than double the value specified by the ASFMC protocol. The constant model provided F and M estimates ranging from 0.10 to 0.07 and 0.26 to 0.28, respectively, as $\varphi\lambda$ increased from 0.55 to 0.75.

Conclusions

The Rappahannock River striped bass tagging data set was thoroughly investigated and estimates of annual survival and instantaneous rates of mortality were derived from two independent methodological approaches. The results of both analyses seem to indicate that mortality levels of striped bass are not extreme and, as a result, it appears that current management regulations are appropriate. However, during the data analysis, a series of problems that appear to be cohort-specific were detected and, at this point, it is unclear exactly how the presence of these problems influences the performance of the tagging models used in the analysis. Further research in the form of simulation studies is required to adequately assess the reliability of parameter estimates derived from Brownie-type models when cohort-specific problems like those previously documented are present in the data. Unfortunately, until those types of studies are completed, it is not possible to confidently state that the parameter estimates presented in this report represent the true survival rates of striped bass that spawn in the Rappahannock River.

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Table 1. Statistics used to assess the performance of the 12 proposed candidate models. Model notation: S(·) and r(·) indicate that survival and tag reporting rate are functions of the factors inside the parenthesis. Specifically, a (.) denotes when parameters were held constant across time; (p_1) denotes period effects where parameters were held constant between 1988-1989, 1990-1994, and 1995-1999; (p_2) is the same as (p_1) except the parameter in the most recent year is allowed to vary; (va) denotes period effects specific to Virginia where parameters were held constant between 1988-1989, 1990-1992, 1993-1994, and 1995-1999; (Tp_1) denotes the assumption of a linear trend within the periods 1990-1994 and 1995-1999 of (p_1); and (t) denotes when parameters were time-specific.

Model label	AICc	ΔAICc	Nos. pars.	Weight
S(.)r(.)	3412.2	0	2	0.795
S(.)r(p_1)	3416.2	3.97	4	0.11
S(p_1)r(p_1)	3418.1	5.9	6	0.042
S(p_2)r(p_1)	3419.2	7.02	7	0.024
S(va)r(va)	3420.8	8.63	8	0.011
S(Tp_1)r(Tp_1)	3421.5	9.29	10	0.008
S(Tp_1)r(p_1)	3421.7	9.5	8	0.007
S(.)r(t)	3423.5	11.34	13	0.003
S(p_1)r(t)	3425.2	13.05	15	0.001
S(Tp_1)r(t)	3426.3	14.1	17	0.001
S(t)r(t)	3426.3	14.13	24	0.001
S(t)r(p_1)	3430.8	18.62	15	0

Table 2. Model-averaged estimates of survival for striped bass > 711 TL at the time of tagging from 1988 to 1999; (a) unadjusted survival estimates; (b) biased adjusted survival estimates assuming a tag reporting rate estimate (λ) of 0.75, 0.64, and 0.55. Those survival estimates were then converted to instantaneous fishing mortality rates by assuming that natural mortality is 0.15.

(a) Unadjusted survival estimates for striped bass that spawn in the Rappahannock River, Virginia from 1988 to 1999. The 95% confidence intervals were based on a logit transformation of $\hat{S}_{unadj}$.

Year	$\hat{S}_{unadj}$	SE	95% CI
1988	0.632	0.033	(0.565, 0.694)
1989	0.632	0.033	(0.565, 0.694)
1990	0.621	0.02	(0.580, 0.659)
1991	0.621	0.02	(0.582, 0.659)
1992	0.622	0.019	(0.583, 0.659)
1993	0.622	0.02	(0.582, 0.661)
1994	0.623	0.02	(0.582, 0.662)
1995	0.617	0.023	(0.572, 0.661)
1996	0.617	0.023	(0.572, 0.660)
1997	0.617	0.023	(0.572, 0.660)
1998	0.617	0.023	(0.572, 0.661)
1999	0.615	0.026	(0.564, 0.665)

(b) Biased adjusted survival estimates and instantaneous rates of fishing mortality for striped bass that spawn in the Rappahannock River, Virginia from 1988 to 1999.

	Estimate $\hat{S}_{adj}(\hat{F})$		
Year	$\lambda = 0.75$	$\lambda = 0.64$	$\lambda = 0.55$
1988	0.71 (0.19)	0.73 (0.17)	0.75 (0.14)
1989	0.65 (0.27)	0.66 (0.26)	0.67 (0.25)
1990	0.66 (0.26)	0.67 (0.25)	0.69 (0.23)
1991	0.69 (0.22)	0.68 (0.24)	0.67 (0.25)
1992	0.71 (0.20)	0.69 (0.22)	0.68 (0.24)
1993	0.67 (0.25)	0.66 (0.26)	0.65 (0.27)
1994	0.65 (0.27)	0.65 (0.28)	0.64 (0.29)
1995	0.65 (0.28)	0.64 (0.29)	0.64 (0.29)
1996	0.62 (0.32)	0.62 (0.32)	0.62 (0.32)
1997	0.64 (0.30)	0.63 (0.31)	0.63 (0.31)
1998	0.67 (0.26)	0.66 (0.26)	0.65 (0.28)
1999	0.64 (0.30)	0.64 (0.30)	0.63 (0.31)

Table 3. Estimates of instantaneous fishing and natural mortality for striped bass > 711 TL at the time of tagging from 1988-1999 assuming a variable $\varphi\lambda$ value; (a) time-specific F model; (b) period-specific F model where F was held constant from 1988-1989, 1990-1994, and 1995-1999; (c) constant F model.

(a) Time-specific F model

		Estimate (SE)		
Year	Parameter	$\varphi\lambda = 0.75$	$\varphi\lambda = 0.64$	$\varphi\lambda = 0.55$
1988	F_{88}	0.08 (0.06)	0.09 (0.07)	0.10 (0.08)
1989	F_{89}	0.08 (0.03)	0.09 (0.04)	0.11 (0.05)
1990	F_{90}	0.06 (0.02)	0.07 (0.02)	0.09 (0.03)
1991	F_{91}	0.06 (0.01)	0.07 (0.02)	0.08 (0.02)
1992	F_{92}	0.08 (0.02)	0.09 (0.02)	0.11 (0.03)
1993	F_{93}	0.10 (0.02)	0.11 (0.02)	0.13 (0.03)
1994	F_{94}	0.11 (0.02)	0.13 (0.03)	0.15 (0.03)
1995	F_{95}	0.15 (0.03)	0.18 (0.03)	0.21 (0.04)
1996	F_{96}	0.10 (0.03)	0.11 (0.03)	0.14 (0.04)
1997	F_{97}	0.11 (0.02)	0.14 (0.03)	0.16 (0.03)
1998	F_{98}	0.14 (0.03)	0.17 (0.03)	0.20 (0.04)
1999	F_{99}	0.14 (0.03)	0.17 (0.03)	0.20 (0.04)
1988-1999	M	0.35 (0.03)	0.34 (0.03)	0.32 (0.03)

(b) Period-specific F model

		Estimate (SE)		
Year	Parameter	$\varphi\lambda = 0.75$	$\varphi\lambda = 0.64$	$\varphi\lambda = 0.55$
1988-1989	$F_{88\text{-}89}$	0.08 (0.03)	0.09 (0.03)	0.11 (0.04)
1990-1994	$F_{90\text{-}94}$	0.08 (0.01)	0.09 (0.01)	0.11 (0.01)
1995-1999	$F_{95\text{-}99}$	0.13 (0.01)	0.15 (0.02)	0.18 (0.02)
1988-1999	M	0.34 (0.03)	0.33 (0.03)	0.31 (0.03)

(c) Constant F model

		Estimate (SE)		
Year	Parameter	$\varphi\lambda = 0.75$	$\varphi\lambda = 0.64$	$\varphi\lambda = 0.55$
1988-1989	$F_{88\text{-}89}$	0.10 (0.01)	0.11 (0.01)	0.13 (0.01)
1988-1999	M	0.32 (0.03)	0.30 (0.03)	0.28 (0.03)

Table 4. Statistics used to assess the performance of the 7 proposed candidate models when applied to the 1990 to 1994 tag-recovery matrix. Model notation follows that used in Table 1.

Model label	AICc	ΔAICc	Nos. pars.	Weight
S(T.)r(T.)	1491.6	0	4	0.695
S(.)r(.)	1495.1	3.52	2	0.119
S(T)r(t)	1495.9	4.32	7	0.08
S(va)r(va)	1496.2	4.57	4	0.071
S(t)r(t)	1499.3	7.66	9	0.015
S(.)r(t)	1499.8	8.19	6	0.012
S(t)r(.)	1500.5	8.94	6	0.008

Table 5. Model-averaged estimates of survival for striped bass > 711 TL at the time of tagging from 1990 to 1994; (a) unadjusted survival estimates; (b) biased adjusted survival estimates assuming a tag reporting rate estimate (λ) of 0.75, 0.64, and 0.55. Those survival estimates were then converted to instantaneous fishing mortality rates by assuming that natural mortality is 0.15.

(a) Unadjusted survival estimates for striped bass that spawn in the Rappahannock River, Virginia from 1990 to 1994. The 95% confidence intervals were based on a logit transformation of $\hat{S}_{unadj}$.

Year	$\hat{S}_{unadj}$	SE	95% CI
1990	0.456	0.086	(0.289, 0.624)
1991	0.569	0.049	(0.472, 0.661)
1992	0.669	0.063	(0.538, 0.778)
1993	0.775	0.085	(0.569, 0.900)
1994	0.883	0.099	(0.554, 0.952)

(b) Biased adjusted survival estimates and instantaneous rates of fishing mortality for striped bass that spawn in the Rappahannock River, Virginia from 1990 to 1994.

	Estimate $\hat{S}_{adj}(\hat{F})$		
Year	$\lambda = 0.75$	$\lambda = 0.64$	$\lambda = 0.55$
1990	0.49 (0.56)	0.50 (0.25)	0.50 (0.23)
1991	0.61 (0.34)	0.62 (0.32)	0.63 (0.30)
1992	0.73 (0.16)	0.74 (0.15)	0.76 (0.12)
1993	0.82 (0.05)	0.83 (0.04)	0.84 (0.03)
1994	0.86 (0.00)	0.87 (-0.01)	0.88 (-0.02)

Table 6. Estimates of instantaneous fishing and natural mortality for striped bass > 711 TL at the time of tagging from 1990-1994 assuming a variable $\varphi\lambda$ value; (a) time-specific F model; (b) constant F model.

(a) Time-specific F model

		Estimate (SE)		
Year	Parameter	$\varphi\lambda = 0.75$	$\varphi\lambda = 0.64$	$\varphi\lambda = 0.55$
1990	F_{90}	0.06 (0.02)	0.07 (0.02)	0.09 (0.03)
1991	F_{91}	0.06 (0.02)	0.07 (0.02)	0.08 (0.02)
1992	F_{92}	0.08 (0.02)	0.09 (0.03)	0.11 (0.03)
1993	F_{93}	0.10 (0.02)	0.12 (0.02)	0.13 (0.04)
1994	F_{94}	0.12 (0.03)	0.14 (0.03)	0.16 (0.05)
1990-1994	M	0.38 (0.09)	0.37 (0.09)	0.35 (0.09)

(b) Constant F model

		Estimate (SE)		
Year	Parameter	$\varphi\lambda = 0.75$	$\varphi\lambda = 0.64$	$\varphi\lambda = 0.55$
1990-1994	$F_{90\text{-}94}$	0.07 (0.01)	0.08 (0.01)	0.10 (0.01)
1990-1994	M	0.28 (0.08)	0.27 (0.08)	0.26 (0.07)

Appendix A. Tag recovery data (known removals and live recaptures) for striped bass > 711 mm TL that were tagged in the Rappahannock River, Virginia;

	Nos.	Recaptured in year											
Year	tagged	'88	'89	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99
1988	56	7	7	4	1	0	2	0	0	0	1	0	0
1989	101	--	4	4	3	3	0	2	0	0	0	1	0
1990	300	--	--	26	9	15	2	3	7	1	0	2	1
1991	390	--	--	--	41	24	16	11	3	2	2	1	2
1992	40	--	--	--	--	4	3	2	2	0	0	0	1
1993	212	--	--	--	--	--	22	18	7	5	6	0	0
1994	123	--	--	--	--	--	--	9	7	5	1	2	0
1995	209	--	--	--	--	--	--	--	28	10	8	3	3
1996	66	--	--	--	--	--	--	--	--	1	3	1	0
1997	212	--	--	--	--	--	--	--	--	--	15	13	8
1998	158	--	--	--	--	--	--	--	--	--	--	24	13
1999	162	--	--	--	--	--	--	--	--	--	--	--	16

Appendix B. Tag recovery data (known removals only) for striped bass > 711 mm TL that were tagged in the Rappahannock River, Virginia;

Year	Nos. tagged	Recaptured in year '88	'89	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99
1988	56	3	6	2	1	0	2	0	0	0	1	0	0
1989	101	--	1	2	2	3	0	2	0	0	0	1	0
1990	300	--	--	11	1	7	2	3	6	1	0	1	1
1991	390	--	--	--	21	11	12	9	2	2	2	0	2
1992	40	--	--	--	--	2	2	1	2	0	0	0	1
1993	212	--	--	--	--	--	12	11	6	5	5	0	0
1994	123	--	--	--	--	--	--	5	6	5	1	1	0
1995	209	--	--	--	--	--	--	--	22	8	5	2	3
1996	66	--	--	--	--	--	--	--	--	0	3	1	0
1997	212	--	--	--	--	--	--	--	--	--	13	12	6
1998	158	--	--	--	--	--	--	--	--	--	--	18	9
1999	162	--	--	--	--	--	--	--	--	--	--	--	14

III. Estimate of the 1999 Striped Bass Rate of Fishing Mortality in Chesapeake Bay

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Introduction

The primary objective of this study was to estimate a bay-wide rate of total fishing mortality for the recreational/charter and commercial components of the 1999 Chesapeake Bay striped bass fishery. The 1999 fishing mortality study was similar to the multiple release studies completed from 1995 through 1998 (Goshorn, et al. 1998 Goshorn, et al. 1999 and Goshorn, et al. 2000, Hebert, et. al. 1997). Tag recovery and release data were analyzed with logistic regression analysis to produce a Bay-wide instantaneous rate of fishing mortality for the recreational/charter and commercial components of the 1999 Chesapeake Bay striped bass fishery. An additional element of the 1999 study was to use high reward tags (HRT's) to reexamine the in-season tag reporting rate of standard tags. An examination of the reporting rate of tags for striped bass in Chesapeake Bay was previously done in 1993 (Rugolo, et al. 1994).

Tag release and recovery data were artificially stratified into two management jurisdictions (Maryland and Virginia), however, the final analysis is done on a bay-wide basis. Jurisdictional regions within the Chesapeake Bay were open for recreational striped bass fisheries for a combined total of approximately 29 weeks (6/14/99 - 12/31/99) during the 1999 fall season. Recreational seasons for each jurisdiction ran from 6/14/99 through 11/30/99 for Maryland, and from 10/4/99 through 12/31/99 for Virginia.

Study Design

Striped bass were tagged and released throughout the Chesapeake Bay prior to and during the recreational fishing seasons for each respective jurisdiction during pre-set release periods (Table 1). There were seven release rounds in Maryland, and three in Virginia. All tagging was done cooperatively with commercial watermen. Tag recoveries were handled and recorded by the USFWS and by each management jurisdiction. Standard USFWS internal anchor tags were applied to 6,880 striped bass and 1,064 striped bass were tagged with high reward tags. To insure random distribution of HRT's among the sample of standard tagged striped bass, every seventh tagged fish received a high reward tag. Rewards of $100 for each HRT were used to avoid the risk of potential non-reporting of a recovered HRT, since Nichols et al. (1991) determined that waterfowl tag rewards of $100 yielded reporting rates of almost 100%.

The multiple release design and analysis used in mark-recapture studies conducted between 1995 and 1998 were repeated for the 1999 study (Goshorn, et al. 1998 Goshorn, et al. 1999 and Goshorn, et al. 2000, Hebert, et. al. 1997). The numbers of tagged fish were adjusted for tag-induced mortality of 1.3% (Rugolo and Lange 1993) prior to analysis. Recoveries for the fishing mortality rate estimate were used from fish harvested from both jurisdictions combined in 1999. Recovery rounds were the same over both jurisdictions and began the day after at least 50% of the fish tagged in both jurisdictions were released (Goshorn et al. 2000) (Tables 1 and 2).

Analysis

A logistic model was applied to tag recovery and release data. Logistic models linearly relate proportions of a response variable to explanatory variables by transforming data using a logit function. The SAS Logistic Procedure (SAS 1989) was used. This SAS procedure fits linear logistic regression models to ordinal response data and calculates Maximum Likelihood Estimates (MLE) of model parameters. The proportion of the number of recovered tags to the number tags released was the response variable and the explanatory variables consisted of one categorical variable (interval number, which accounted for unequal interval lengths), and two binary variables, disposition and angler type.

The reporting rate (Q) was estimated by examining the difference in observed frequency of high reward tags versus standard tags recovered from the recreational fishery following the formula provided in Pollock el al. (1990). The value of Q was calculated for both jurisdictions combined, by recovery round, using standard tags and reward tags reported from striped bass harvested and caught and released, during the season (Tables 3, 4 and 5), then averaged over all rounds. Only recreational and charter angler recoveries were used in the determination of the reporting rate. Round 2 releases of standard tags and high reward tags were not included in the analysis to estimate reporting rate since there were no recreational or charter recaptures of either tag type during Round 2.

Results

Fish recovered prior to the start of a recovery interval, on the day of the release, or reported as an accidental death, found dead, or tag found only, were removed from the analysis. Since the harvest of interest was of striped bass harvested by recreational anglers, only tag recoveries reported by recreational and charterboat anglers within the Chesapeake Bay were used in the calculation of exploitation rate. Also, only fish with complete recovery dates were used in this analysis.

Estimates of rate of exploitation (U) were directly derived from modeling of tag recovery data from fish harvested by recreational anglers and were determined for the recreational/charter component of the fishery, bay-wide. The estimate of reporting rate of standard recovered tags for the recreational and charterboat fisheries is Q = 0.64. Estimates of exploitation for the recreational/charter season were converted to instantaneous rates (F_R). These estimates were then adjusted to include the resident portion of the commercial and recreational fisheries that occurred during summer 1999, winter 1999-2000 and during spring/early summer of 2000, respectively. The expanded estimates of F_T were calculated based on weighting of recreational/charter estimates of F_r by proportional additions of spring recreational or commercial harvest in numbers (Table 6).

Summary

The estimate of the bay-wide F (F_{Bay}) for 1999 is 0.30. Non-harvest mortality (0.10) was added to the point estimate of F_{Bay} = 0.20 to obtain the final estimate of bay-wide fishing mortality of F_{Bay} = 0.30 for 1999 (Table 6). The variance of 0.00187 converts to a Coefficient of Variation = 21%. The final estimate of bay-wide F (F_{Bay} = 0.30) is near the 1999 target fishing rate of F = 0.28 for the Chesapeake Bay. However, the Chesapeake Bay-wide harvest in total number of striped bass actually decreased from the 1998 and 1997 harvest estimates (1,522,670 striped bass in 1998 and 1,624,041 striped bass in 1997 (Table 7).

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Table 1. Release numbers (adjusted for tag-induced mortality of 1.3%) of tagged striped bass used to estimate instantaneous annual rate of fishing mortality in Chesapeake Bay for fall 1999. NA indicates that tagged fish were not released for indicated interval.

	Interval							
State	1	2	3	4	5	6	7	TOTAL
Maryland	452	563	284	616	1040	875	343	4173
Virginia	NA	NA	NA	NA	453	1155	1099	2707
BAYWIDE TOTAL	452	563	284	616	1493	2030	1442	6880
Dates of release	6/7/99- 6/14/99	7/6 /99- 7/10/99	8/2/99 - 8/7/99	8/30/99 - 9/4/99	9/27/99 - 10/2/99	10/25/99 - 10/30/99	11/17/99 11/20/99	

Table 2. Number of standard tagged striped bass released and subsequently harvested by recreational/charter anglers in each respective Bay jurisdiction of release during the fall 1999 recreational fishery, for use in the fishing mortality rate calculation. NA indicates that tagged fish were not released for indicated interval.

Recovery Interval								
State	1	2	3	4	5	6	7	TOTAL
Maryland	5	0	1	4	3	12	1	26
Virginia	NA	NA	NA	NA	5	6	13	24
BAYWIDE TOTAL	5	0	1	4	8	18	14	50
Dates of recovery periods	6/14/99-7/9/99	7/10/99-8/3/99	8/4/99-9/3/99	9/4/99-9/29/99	9/30/99-10/27/99	10/28/99-11/18/99	11/19/99-12/31/99	

Table 2. Number of standard tagged striped bass released and subsequently harvested by recreational/charter anglers in each respective Bay jurisdiction of release during the fall 1999 recreational fishery, for use in the fishing mortality rate calculation. NA indicates that tagged fish were not released for indicated interval.

	Recovery Interval							
State	1	2	3	4	5	6	7	TOTAL
Maryland	**5**	**0**	**1**	**4**	**3**	**12**	**1**	**26**
Virginia	**NA**	**NA**	**NA**	**NA**	**5**	**6**	**13**	**24**
BAYWIDE TOTAL	**5**	**0**	**1**	**4**	**8**	**18**	**14**	**50**
Dates of recovery periods	**6/14/99- 7/9/99**	**7/10/99- 8/3/99**	**8/4/99- 9/3/99**	**9/4/99- 9/29/99**	**9/30/99- 10/27/99**	**10/28/99- 11/18/99**	**11/19/99- 12/31/99**	

Table 3. Release numbers (adjusted for tag-induced mortality of 1.3%) of high reward tag (HRT) tagged striped bass used to examine tag reporting rate of standard regular tags in Chesapeake Bay for fall 1999. NA indicates that tagged fish were not released for indicated interval.

Interval								
State	1	2	3	4	5	6	7	TOTAL
Maryland	88	86	42	99	168	142	57	682
Virginia	NA	NA	NA	NA	62	166	154	382
BAYWIDE TOTAL	88	86	42	99	230	308	211	1064
Dates of release	6/7/99- 6/14/99	7/6 /99- 7/10/99	8/2/99 - 8/7/99	8/30/99 - 9/4/99	9/27/99 - 10/2/99	10/25/99 - 10/30/99	11/17/99- 11/20/99	

Table 4. Number of HRT tagged striped bass released and subsequently harvested or caught and released by recreational/charter anglers in each respective Bay jurisdiction during the fall 1999 recreational fishery, for use in the reporting rate calculation. NA indicates that tagged fish were not released for indicated interval.

Recovery Interval								
State	1	2	3	4	5	6	7	TOTAL
Maryland	2	0	1	3	1	3	2	12
Virginia	NA	NA	NA	NA	6	3	0	9
BAYWIDE TOTAL	2	0	1	3	7	6	2	21
Dates of recovery periods	6/14/99-7/9/99	7/10/99-8/3/99	8/4/99-9/3/99	9/4/99-9/29/99	9/30/99-10/27/99	10/28/99-11/18/99	11/19/99-12/31/99	

Table 5. Number of standard tagged striped bass released and subsequently harvested or caught and released by recreational/charter anglers in each respective Bay jurisdiction during the fall 1999 recreational fishery, for use in the reporting rate calculation. NA indicates that tagged fish were not released for indicated interval.

	Recovery Interval							
State	1	2	3	4	5	6	7	TOTAL
Maryland	7	0	3	6	7	14	2	39
Virginia	NA	NA	NA	NA	7	11	18	36
BAYWIDE TOTAL	7	0	3	6	14	25	20	75
Dates of recovery periods	6/14/99-7/9/99	7/10/99-8/3/99	8/4/99-9/3/99	9/4/99-9/29/99	9/30/99-10/27/99	10/28/99-11/18/99	11/19/99-12/31/99	

Table 6. Estimates of fishing mortality rate for 1999 fall recreational/charter (F_R) and commercial (F_C) components of Chesapeake Bay striped bass fisheries and combined bay-wide fishing mortality (F_{BAY}) in 1999.

	F_R	var (F_R)	F_C	F_{BAY}	var (F_{BAY})	CV
BAY	0.07	0	0.13	0.2	0.0019	0.2136

Table 7. Resident striped bass harvest (in numbers) in Chesapeake Bay for a twelve month period beginning with the initiation of the 1999 recreational season in Maryland (June 14, 1999). Harvest numbers were obtained from Marine Recreational Fisheries Statistics Survey (MRFSS) and monitoring programs from respective jurisdictions.

Fishery Component	Maryland	Potomac River	Virginia	Total
Fall recreational/charter *1	234784	----	283855	518639
Spring/Summer Recreational	14329	0	8230	22559
Commercial	738129	83538	121232	942899
TOTAL	987242	83538	413317	1484097

*1 Potomac fall recreational harvest is included within Maryland and Virginia numbers