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**Evaluation of striped bass stocks in Virginia : monitoring and tagging studies, 2004-2008 Annual report 1 September 2003 - 31 August 2004**

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**Evaluation of Striped Bass Stocks in Virginia:  
Monitoring and Tagging Studies, 2004-2008**

**Annual Report**

**Contract Number:** F-77-R-17  
**Project Period:** 1 September 2003 - 31 September 2004  
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## Preface

This report presents the results of striped bass (*Morone saxatilis*) tagging and monitoring activities in Virginia during the period 1 August 2003 through 31 August 2004. It includes an assessment of the biological characteristics of striped bass taken from the 2004 spring spawning run, estimates of annual survival based on annual spring tagging, and the results of the fall 2003 directed mortality study that is a collaborative effort 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.

Striped bass 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 in their native range are found in 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 sub-populations from the Hudson River, James River, Rappahannock - York rivers, and upper Chesapeake Bay (Raney 1957). The Roanoke River striped bass may represent another distinct sub-population (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 a multi-jurisdictional concern as spawning success in one area probably influences fishing success in many areas. Furthermore, recent evidence suggests the presence of divergent migratory behavior at intra-population levels (Secor 1999). The extent to which these levels of behavioral complexity impact management strategies in Chesapeake Bay and other stocks is unknown.

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 coast-wide 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 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. An experimental fyke net was established in the James River to assess its potential as a source of tagable striped bass. 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 annual 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).

## **Acknowledgments**

We are deeply indebted to many people for their participation and/or contributions to the striped bass tagging and spawning stock assessment program. These include: the Anadromous Fishes Program staff; Fisheries Department students of the Virginia Institute of Marine Science Chip Cotton, Julia Ellis, Donna Grusha, Patrick McGrath, Sarah Muffleman, Jason Romine, and John Walter; the cooperating commercial fishermen Allan Ingraham, David Callas, Ernest George, Joe Hinson, Raymond Kellum, Steve Kellum, Stanley Oliff, Jamie Saunders; Jim Goins of the Virginia Institute of Marine Science and Harry Hornick and Beth Versak of Maryland Department of Natural Resources (Md DNR).

## Executive Summary

### New Features:

Sections III and IV describing alternative tagging models is new; portions on growth rates and on catch rate summaries by cohort have been added to Section I.

### I. Assessment of the spawning stocks of striped bass in the Rappahannock and James rivers, Virginia, spring 2004.

#### Catch Summaries:

1. In 2004, 951 striped bass were sampled between 30 March and 3 May from three commercial pound nets in the Rappahannock River. The samples were predominantly male (74.0%) and young (47.1% ages 3-5). Females dominated the age nine and older age classes (85.9%). The mean age of the male striped bass was 4.3 years. The mean age of the female striped bass was 8.5 years.
2. During the 30 March - 3 May period, the 1999 and 2000 year classes were the most abundant in the Rappahannock River pound net samples and were 97.1% male. The contribution of age eight and older males was only 9.9% of the total catch. Age eight and older females, presumably repeat spawners, were 23.4% of the total catch but represented 90.3% of all females caught.
3. In 2004, 827 striped bass were sampled between 30 March and 3 May in two experimental anchor gill nets in the Rappahannock River. The samples were predominantly male (91.1%) and young (56.0% ages 3-5). For the first time males were more prevalent than females in the age eight and older age classes (50.8%). The mean age of the male striped bass was 4.3 years. The mean age of the female striped bass was 7.4 years.
4. During the 30 March - 3 May period, the 2000 and 2001 year classes were the most abundant in the Rappahannock River gill net samples and were 99.4% male. The contribution of age eight and older males was only 7.6% of the total catch. Age eight and older females, presumably repeat spawners, were 7.4% of the total catch but were 82.4% of the total females caught.
5. In 2004, 1,447 striped bass were sampled between 30 March and 3 May in two experimental anchor gill nets (mile 62) in the James River. Males dominated the 1996-2002 year classes (98.3%). Females dominated the 1987-1995 year classes (66.7%). The mean age of the male striped bass was 4.3 years. The mean age of the female striped bass was 8.7 years.

6. During the 30 March - 3 May period, the 1999-2001 year classes were the most abundant in the James River gill net samples and were 99.7% male. The contribution of age eight and older males was only 2.2% of the total catch. Age eight and older females, presumably repeat spawners, were 2.8% of the total catch but represented 80.0% of all females caught.

### **Spawning Stock Biomass Indexes (SSBI)**

7. The Spawning Stock Biomass Index (SSBI) from the Rappahannock River pound nets was 58.5 kg/day for male striped bass and 65.4 kg/day for female striped bass. The male and female indexes were the highest in the 1991-2003 time series and more than double the 14-year average.
8. The SSBI for the Rappahannock River gill nets was 171.9 kg/day for male striped bass and 52.0 kg/day for female striped bass. The male index was the second highest in the 1991-2004 time series and more than double the 14-year average. The female index was the highest since 1995 in the 1991-2004 time series and was well above the 14-year average.
9. The SSBI for the James River gill nets was 207.0 kg/day for male striped bass and 31.2 kg/day for female striped bass. The male index was the second highest in the 1991-2004 time series, and more than double the 11-year average. The female index 11.3% below the index for 2003 and was well 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 (EPPI, millions of eggs/day) for the Rappahannock River pound nets was 10.6 million eggs/day. This was the highest EPPI of the 2001-2004 time series. Older (8+ years) female stripers were responsible for 96.3% of the index.
11. The EPPI for the Rappahannock River gill nets was 8.4 million eggs/day. This was the highest EPPI of the 2001-2004 time series and was more than double the 2003 index. Older (8+ years) female striped bass were responsible for 91.7% of the index.
12. The EPPI for the James River gill nets was 4.9 million eggs/day. This was the lowest EPPI of the 2001-2004 time series and was 18.5 % lower than the 2003 index. Older (8+ years) female striped bass were responsible for 91.2% of the index.

### Estimates of Annual Survival (S) based on age-specific catch rates

13. The cumulative catch rate (all age classes, sexes combined) from the Rappahannock River pound nets (31.7 fish/day) was the second highest in 1991-2004 time series. There was an increase in the 1995-2002 year classes from the 2003 values. The cumulative catch rate of male striped bass (23.4 fish/day) was the third highest in the time series but more than double the rate in 2003. The cumulative catch rate of female striped bass (8.2 fish/day) was the highest in the 1991-2004 time series.
14. Year class-specific estimates of annual survival (S) for pound net data varied widely between years. The geometric mean S of the 1983-1997 year classes varied from 0.516-0.845 (mean = 0.665). The geometric mean survival rates differed greatly between sexes. Mean survival rates for male stripers (1985-1997 year classes) varied from 0.317-0.668 (mean = 0.477) but mean survival rates of female stripers (1983-1990 year classes) varied from 0.587-0.762 (mean = 0.648).
15. The cumulative catch rate (all age classes, sexes combined) from Rappahannock River gill nets (87.1 fish/day) was the second highest value in the 1991-2004 time series, and 65.8% higher than in 2003. Cumulative catch rate of male stripers (79.2 fish/day) was also the second highest in the time series and 60.7% higher than the rate in 2003. The cumulative catch rate of female striped bass (7.6 fish/day) was the sixth highest in the time series more than double the catch rate in 2003.
16. Year class-specific estimates of annual survival for gill net data varied widely between years. The geometric mean S of the 1984-1996 year classes varied from 0.408-0.785 (mean = 0.556). The mean survival rates for male stripers (1984-1996) varied from 0.150-0.692 (mean = 0.380). The mean survival rates for female stripers (1984-1990) varied from 0.501-0.669 (mean = 0.587).
17. The cumulative catch rate (all age classes, sexes combined) from James River (mile 62) gill nets (131.6 fish/day) was the second highest catch rate in the 1994-2004 time series. The catch rate was 44.1% higher than the rate in 2003, and was the first increase since the peak in 2000. The cumulative catch rate for male striped bass (127.0 fish/day) was also the second highest of the 1994-2004 time series, and was 39.1% higher than the rate in 2003. However, the cumulative catch rate of female striped bass (4.6 fish/day) was 25.7% lower than the rate in 2003 and was the second lowest in the time series.
18. Year class-specific estimates of annual survival in the James River varied widely between years. The geometric mean S of the 1984-1996 year classes varied from 0.339-0.763 (mean = 0.541). The mean survival rates of male stripers (1988-1996 year classes) varied from 0.286-0.562 (mean = 0.453). The mean survival rates of female stripers (1984-1995 year classes) varied from 0.347-0.813 (mean = 0.565).



### **Catch rate histories of the 1987-1994 year classes**

19. Plots of year class-specific catch rates vs. year in the James and Rappahannock rivers from 1991-2004 showed a consistent trend of a peak in the abundance of male striped bass followed by a steep decline. There was also a secondary peak of (mostly) female striped bass, usually around age 10.
20. The area under the catch curves indicate that the 1987-1989, 1993 and 1996 year classes were the strongest, and the 1990 and 1991 year classes the weakest in the Rappahannock River from 1987-1996.

### **Growth rate of striped bass derived from annuli measurements**

21. The scales of 3,179 striped bass were digitally measured and the increments between annuli were used to determine their growth history.
22. On average, striped bass grow about 160 mm fork length in their first year. The growth rate decreases with age to about 50 mm per year by age 10.
23. Striped bass were estimated to reach the minimum legal length for the resident fishery (18 in. total length) at age 3.5 and reach the minimum length for the coastal fishery (28 in. total length) at age seven.

### **Age determinations using scales and otoliths**

24. A total of 270 specimens from 11 size ranges were aged by reading both scales and otoliths. The mean age of the otolith-aged striped bass was 0.16 years older than from the scale-aged striped bass. The two methodologies agreed on the age of the striped bass on 33.7% of the specimens.
25. Tests of symmetry applied to the age matrix indicated that the two ageing methodologies were not interchangeable ( $p=0.0000$ ). The age at which the divergence in ages became apparent was determined to be age 10.
26. Otoliths were 1.24 times more likely to give an older age than the scale from the same specimen. The otoliths were 1.5 times more likely to produce an age difference of two years or greater.
27. A paired t-test of the mean of the age differences produced by the two ageing methodologies found that the mean difference was significantly different from zero ( $p=0.0000$ ).

28. A Kolmogorov-Smirnov test of the age structures produced by the two ageing methodologies did not indicate an overall significant difference, indicating that the two resultant age structures represented an equivalent population. This was due the small relative proportion of older (age 10+) striped bass in the total population sampled.

## II. Mortality estimates of striped bass (*Morone saxatilis*) that spawn in the Rappahannock River, Virginia, spring 2003-2004.

1. A total of 1,477 striped bass were tagged and released from pound nets in the Rappahannock River between 30 March and 3 May, 2004. Of this total, 790 were between 457-710 mm total length and considered to be predominantly resident striped bass and 687 were considered to be predominantly migrant striped bass (>710 mm TL). The median date of the tag releases was 18 April for the resident stripers and 20 April, 2004 for the migrant striped bass.
2. A total of 178 striped bass were tagged and released from three haul seines in the James River between 26 March and 2 April, 2004. Of this total, 118 were resident and 60 were migrant striped bass. This was a demonstration effort to determine the feasibility of establishing a spring tagging program in the James River.
3. A total of 55 (out of 852) resident striped bass (>458 mm TL), tagged during spring 2003, were recaptured between 28 April, 2003 and 18 April, 2004 (the respective midpoints of the two tag release totals), and were used to estimate mortality. Thirty-two of these recaptures were harvested (58.2%) and the rest were re-released into the population. In addition, 49 striped bass tagged in previous springs were recaptured during the recovery interval and were used to complete the input data matrix. Most recaptures (43.6%) were caught within Chesapeake Bay (30.9% in Virginia, 12.7% in Maryland). However, other recaptures came from Massachusetts (20.0%), New Jersey (18.2%), New York (7.3%), Rhode Island (5.6%), North Carolina (3.6%), and Connecticut (1.8%).
4. A total of 35 (out of 400) migratory striped bass (>710 mm total length), tagged during spring 2003, were recaptured between 21 April, 2003 and 18 April, 2004, and were used to estimate the mortality. Twenty-three of these recaptures were harvested (65.7%), and the rest were re-released into the population. In addition, 26 striped bass tagged in previous springs were recaptured during the recovery interval and were used to complete the input data matrix. Only five of the tagged striped bass were recaptured within Chesapeake Bay (14.3%), all in Virginia. Other recaptures came from New Jersey and Massachusetts (28.6% each), New York (11.4%), Rhode Island (8.6%), North Carolina (5.7%) and Connecticut (2.9%).
5. The ASFMC Striped Bass Tagging Subcommittee established a data analysis protocol that involves deriving survival estimates from a suite of Seber models. Twelve of these models were applied to the recapture matrix, each reflecting a different parameterization over time. Models that allowed parameters to be both time-specific and constant across time were specified. The model-averaged estimates of the bias-adjusted survival rates for migrant striped bass ranged from 0.610-0.626 over the time series. Survival was highest during the transitional fishery and decreased slightly thereafter. This trend was the result of a higher

proportion of annual tag recoveries being released back into the population in the early 1990's relative to more recent years. The corresponding estimates of  $F$  ranged from 0.128-0.328 and only infrequently, and by slight margins, exceeded the transitional and full fisheries target values. Both the survival and fishing mortality estimates were relatively constant.

6. Elements of the Rappahannock River tag-recovery matrix for resident striped bass did not allow these models to adequately fit the data. The low total number of tagged striped bass and resultant recaptures reported from the 1994 and 1996 cohorts (e.g. five from the 1996 cohort) relative to other years may account for the poor fit of the time-specific models. Unfortunately, numerical complications resulting from low sample size caused some of the more biologically reasonable models to not fit the Rappahannock River data well.

### III. Fishing mortality of striped bass in the Chesapeake Bay: a report to the Atlantic States Marine Fisheries Commission Striped Bass Technical Committee

1. This report deals with how fishing mortality,  $F$ , for striped bass greater than 457 mm in Chesapeake Bay should be estimated. In particular it compares methods based on ratios of recaptures: number tagged ( $r/m$  ratios) and based on fitting Brownie and instantaneous rates models to tagging data.
2. Estimates of  $F$  obtained from  $r/m$  ratios are unreliable, regardless of whether data from the summer/fall or spring tagging programs are used.
3. Estimates of  $F$  can be derived from estimates of either  $f$  (tag recovery rate) or  $S$  (annual survival rate) obtained from Brownie models fitted to the spring tagging data. The estimates of  $S$  from Brownie models fitted to fish  $> 457$  mm have not been accepted in the past in part because they indicate large year to year variation in survival that does not seem reasonable. The results based on interpreting  $f$  estimates are also unreliable and, in fact, opposite results can be obtained depending on whether one uses the  $S$  or the  $f$  to obtain the fishing mortality rate.
4. Instantaneous rates models fitted to the Rappahannock River spring tagging data produced estimates that were credible in the sense of having low year to year variability. The instantaneous rates model incorporates into the tagging model the assumptions made when interpreting Brownie models, and result in a model with 15 parameters to estimate instead of the 24 parameters in the year-specific Brownie model. Thus, some reduction in the variability of the mortality rate estimates over time is not unexpected because measurement error is reduced.
5. The instantaneous rates model also indicates that there is a problem with nonmixing occurring; this can be accommodated using a model that explicitly accounts for nonmixing of newly tagged animals into the population.
6. The instantaneous rates models also indicate that natural mortality for fish  $> 457$  mm was around  $0.34 \text{ yr}^{-1}$  from 1990 through 1998 and was around  $0.56 \text{ yr}^{-1}$  after that when reporting rate was assumed to be 0.45 (and was 0.42 and 0.62, respectively, when reporting rate was assumed to be 0.7).
7. The implications of this work are that: a) for the Chesapeake,  $r/m$  ratios should be abandoned for determining fishing mortality in favor of instantaneous rates models, and b) the apparent higher value of natural mortality than what has been assumed, and the apparent increase in natural mortality over time, should be examined further to see if the claim stands up, and the implications of different natural mortality rates on the stock assessment should be investigated.

#### IV. Estimation of mortality rates for Atlantic striped bass – a blueprint for action

It is suggested the following elements could be implemented.

1. Verification of preliminary results. The analyses of Hoenig and colleagues for Rappahannock striped bass should be repeated for data from Maryland and the results compared in terms of a) does the instantaneous rates model produce more credible estimates (less year to year variability) for Maryland, as it did for the Rappahannock; b) do the data indicate higher natural mortality rates in Maryland than previously believed, and do they suggest an increase in natural mortality over time.
2. Examination of tagging data for fish > 457 mm from other programs should be made using instantaneous rates models to a) see if more credible results can be obtained (relative to those obtained with Brownie models) and b) examine the estimates of natural mortality over space.
3. Assuming the result about increased natural mortality over time holds up, collaboration on a manuscript for publication on changes in natural mortality over time in the Chesapeake would be in order.
4. The application of instantaneous rates models to Chesapeake Bay and other striped bass tagging studies should be reviewed in an appropriate forum with a view to changing methodology if the instantaneous rates model is found more appropriate.
5. New developments by Pollock and colleagues on parsimonious age-structured modeling and incorporation of catch and release fishing directly into the model should be reviewed.
6. Software should be developed, documented and made available. Currently, a program in Splus called Avocado is available from Hoenig. It will do much of what is needed but it does not include age-structured analysis or catch and release fishing. Catch and release fishing could be added. The program is being converted to R which is a freeware product that will make it easier to distribute the program.
7. Training sessions may be needed to instruct users in the use of instantaneous rates models and the associated software.
8. Collaboration between the Striped Bass Assessment Subcommittee and Striped Bass Tagging Subcommittee may be in order to ensure that relevant findings from the tagging work can be incorporated into the VPA.
9. These problems should be called to the attention of the ASMFC Striped Bass Board.

**V. Fishing mortality estimates of the fall 2003 resident striped bass fishery in the Chesapeake Bay, Virginia.**

1. The fall 2003 striped bass recreational season (1 June - 31 November in Maryland, 4 October - 31 December in Virginia) in Chesapeake Bay was divided in seven rounds in Maryland and three rounds in Virginia (22 September – 2 October, 24 October – 2 November and 17-25 November). Each recovery round was of approximately 30 days in duration.
2. On 16 September, hurricane Isabelle struck the Chesapeake Bay, causing severe damage to the nets of our cooperating fishermen, damaging marinas and access ramps and disrupting the normal distribution pattern of the resident striped bass. The tagging dates for round five were changed to 1-10 October and the dates for round six were changed to 27 October – 5 November.
3. Striped bass were tagged and released during ten-day intervals prior to the start of each recovery 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.
4. A total of 3,233 striped bass were tagged in Virginia. The number of stripers tagged and released were 696, 1,384 and 1,153 respectively for the three tagging rounds. The striped bass tagged in all three rounds were predominantly from the 1999 and 2000 year classes.
5. A total of 151 striped bass tagged in Virginia were recaptured by 31 December. Of these recaptures, 32 were recaptured within their round of release. Most recaptures occurred in their area of release, but recaptures were also recovered from the Chesapeake Bay in Maryland.
5. The Chesapeake Bay estimate of total fishing mortality (F) was 0.20. This is the sum of non-harvest (0.10) and harvest (0.10) mortality estimates. The target F for Chesapeake Bay is 0.28.

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**I. Assessment of the spawning stocks of striped bass in the Rappahannock and James rivers, Virginia, spring, 2004.**

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## Introduction

Every year, striped bass migrate along the US east coast from offshore and coastal waters then 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<sup>0</sup> 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 the 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 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 30 March - and 3 May, 2004. Samples (the entire catch of striped bass from each gear) were taken twice-weekly (Monday and Thursday) from a set of three commercial pound nets (river miles 45, 46 and 47) in 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, 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 1993-2001 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.

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 62 on the James River, Figures 1-2). 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, and 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. In 2004, a manufacturing error resulted in two nets of the first configuration being utilized.

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. 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. Otoliths were extracted from a subsample of the striped bass, processed for aging, and compared to their scale-derived ages.

The otolith subsample was the first 10 striped bass sampled from each of the following size ranges (fork length, in mm): 166-309, 310-419, 420-495, 496-574, 575-659, 660-724, 725-779, 780-829, 830-879 and 880-900. All striped bass greater than 900 mm fork length were sampled. The size ranges roughly correspond to age classes based on previous (scale-aged) data.

The otoliths were cleansed of external tissue material by soaking in bleach for 12-24 hours and rinsing in de-ionized water. The otoliths were prepared for ageing by placing the left sagitta on melted crystal bond and sectioned to a one millimeter thickness on a Buehler isomet saw. The sections were then polished on a Metaserv 2000 grinder. The polished section was immersed in a drop of mineral oil and viewed through an Olympus BX60 compound microscope at 4-20x. Each otolith was aged twice at different times by the same reader using the methods described by Wischniowski and Bobko (1998). If these ages differed, a third reading was made to make a final determination.

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. Scale ages were used exclusively except when a comparison with its companion otolith age was made.



The spawning stock biomass index (SSBI) for striped bass was defined (Sadler et al. 1999) as the 30 March - 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, the geometric mean of the egg counts of the gonad subsamples for each ripe female striped bass collected in 2001-2003 was calculated. A non-linear regression 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 the same 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). Separate estimates of survival were made for male and female striped bass, as well as the sexes combined.

Analysis of the differences in the ages estimated by reading the scales and otoliths from the same specimen were made using tests of symmetry (Evans and Hoenig 1998, Hoenig et al. 1995). Differences in the resultant mean ages from the two methods were tested using both two-tailed paired and unpaired t-tests (Zar 1999). The age class distributions resulting from the two ageing methods were compared using the non-parametric Kolmogorov-Smirnov two-sample test (Sokal and Rohlf 1981).

## Results

### Catch Summaries

#### Rappahannock River

**Pound nets:** Striped bass (n= 951) were sampled between 1 April and 3 May, 2004, from the pound nets in the Rappahannock River. The number of striped bass sampled was more than twice that from 2003 (n= 470) and was 85% above the 14-year average. Total catches varied from 25-206 striped bass, with peak catches on 16, 26 and 29 April (Table 1). Surface water temperature was relatively stable at 12 EC from 30 March – 12 April, increased steadily to 15 EC on 19 April, then increased slowly through most of the rest of the sampling season, reaching 20 EC on 3 May. Dry weather persisted throughout April, resulting in lower river flows than had been present in 2003. Catches of female striped bass peaked on 22 April, but were generally high from 16-26 April. Males made up 74.0% of the total catch, but this was slightly below the 14-year

average (77.6%). The 1996-1999 year classes comprised 49.9% of the total catch. Males dominated the 2000-2002 year classes (98.9%) and the 1996-1999 year classes (83.4%), but females dominated the 1987-1995 year classes (85.9%).

Biomass catch rates (g/day) of male striped bass peaked on 29 April and female striped bass were highest on 19 and 22 April (Table 2). The numeric catch rate of females exceeded that of males only on 19 and 22 April (by 1.2:1 on 19 April). However, the biomass catch rates for female striped bass exceeded that for males overall (1.1:1), peaking on 19 April (3.3:1). The mean ages of male striped bass varied from 4.6-5.8 years by sampling date, with the oldest mean ages occurring from 19-26 April. The mean ages of females varied from 8.5-9.9 years by sampling date, but only varied from 9.4-9.9 years from 1-22 April.

There was a peak in abundance of striped bass (mostly male) between 480-630 mm total length in the pound net samples (Table 3). This size range accounted for 39.5% of the total sampled. There was a secondary peak in abundance of striped bass between 750-850 mm total length, accounting for 22.2% of the total sampled. However, the striped bass from 640-740 mm total length accounted for only 6.3% of the total sample. The total contribution of striped bass greater than 710 mm total length (the minimum total length for the coastal fishery) was 40.4%.

During the 30 March - 3 May period, the 1999 (18.6%) and 2000 (17.6%) year classes were the most abundant (Table 4). These year classes were 97.1% male. The contribution of males age six and older (the pre-1999 year classes) was 26.9% of the total aged catch. These year classes were most vulnerable to commercial and recreational exploitation within Chesapeake Bay. The contribution of females age seven and older, presumably repeat spawners, was 24.7% of the total aged catch, but was also 93.9% of the total females captured. The catch rate (fish/day) of male striped bass was 23.5, which is 50.6% above the 12-year average (Table 5). The catch rate of female striped bass (8.3 fish/day) was the highest of the 12-year time series. The biomass catch rates (kg/day) of both sexes were the highest of the 12-year time series. The mean ages (30 March – 3 May) of both sexes were above the 12-year averages.

**Experimental gill nets:** Striped bass (n= 827) were also sampled between 30 March and 3 May, 2004 from two multi-mesh experimental gill nets in the Rappahannock River. The total catch was 57.5% greater than in 2003. Total catches peaked on 19 April, due to the large number of three to six year old males (Table 6). Female striped bass were generally caught in low numbers throughout the sampling period. Males made up 91.1% of the total catch. Males dominated the 2000-2002 year classes (99.5%) and the 1996-1999 year classes (92.1%), but the 1987-1995 year classes were 82.7% female

Biomass catch rates (g/day) of male striped bass were highest on 12 April and again on 19-26 April (Table 7). The catch rates of female striped bass were highest on 22 April. The catch rate of males exceeded that of females except on 8 April and again on 3 May. The mean ages of male striped bass varied from 4.0-6.1 years by sampling date, with the oldest males (five- nine years) being most abundant from 19-22 April. The mean ages of females varied from 7.8-10.0 years by sampling date, with the oldest females (age nine and older) being most abundant from 19-26 April.

There was a bimodal distribution in the length frequencies of striped bass in the gill net samples, with the first peak broadly distributed from 320-670 mm total length and a secondary peak from 750-820 mm total length (Table 8). In contrast to the pound net samples, the total contribution of striped bass greater than 850 mm total length was 5.0% vs. 17.9% in the pound nets. The total contribution of striped bass greater than 710 mm total length was 26.7% in the gill nets.

During the 30 March - 3 May period, the 2001 (25.0%) and 2000 (18.4%) year classes were most abundant (Table 9). These year classes were 99.4% male. The contribution of males age six and older (the pre-1999 year classes) was 30.2% of the total aged catch. These year classes were most vulnerable to commercial and recreational exploitation within Chesapeake Bay. The contribution of females age seven and older, presumably repeat spawners, was 8.2% of the total aged catch but was 90.5% of the total females captured. The catch rate (fish/day) of male striped bass was the highest in the 12-year time series and was 57.7% above the average (Table 10). The catch rate of female striped bass was the third highest in the time series and was 32.2% above the 12-year average. The biomass catch rates (g/day) for both sexes were the highest in the time series.

### **James River**

**Experimental gill nets:** Striped bass (n= 1,447) were sampled between 30 March and 3 May, 2004, from two multi-mesh experimental gill nets at mile 62 in the James River. Total catches peaked first on 9 April and again from 20-30 April. Young male striped bass were primarily responsible for the peak catches (Table 11). Catches of female striped bass were consistent, although small. Males dominated the 2000-2002 year classes (99.8%) and the 1996-1999 year classes (95.8%), but the 1987-1995 year classes were mostly female (66.7%).

Biomass catch rates (g/day) of male striped bass peaked strongly on 20 April, but were high throughout the sampling season (Table 12). The catch rates of female striped bass were highest on 30 April. The biomass catch rate of males exceeded that of females on every sampling date (6.6:1 for the season). The mean ages of male striped bass varied from 4.1-5.1 years by sampling date, but varied from only 4.1-4.4 years from 16 April - 3 May. The mean ages of females varied from 5.0-10.0 years by sampling date, but varied from only 8.0-10.0 years from 30 March -23 April.

There was a peak of striped bass 430- 559 mm total length in the gill net length frequencies (Table 13). This size range accounted for 48.6% of the striped bass sampled. In contrast to the samples from the gill nets (5.0%) and pound nets (17.9%) from the Rappahannock River, striped bass greater than 850 mm total length accounted for only 2.1% of the total sampled. The total contribution of striped bass greater than 710 mm total length was 7.5%.

During the 30 March - 3 May period, the 2000 (23.6%), 2001 (22.9%) and 1999 (21.4%) year classes were the most abundant in the gill nets.(Table 14). These year classes were 99.7% male. The contribution of males age six and older (the pre-1999 year classes) was only 14.6% of the total aged catch. These year classes were most vulnerable to commercial and recreational

exploitation within Chesapeake Bay. The contribution of females age seven and older, presumably repeat spawners, was only 3.2% of the total aged catch.

The catch rate (fish/day) of male striped bass was slightly less than for 2003 but was 90.9% above the 10-year average (Table 15). However, the catch rate of female striped bass was the second lowest of the time series and was 52.1% below the 10-year average. Likewise, the biomass catch rate (g/day) of male striped bass was lower than 2003 but was 70.1% above the average while the biomass catch rate of female striped bass was only higher than in 2000, and was 44.1% below the 10-year average. The mean age of male striped bass varied from only 4.3-4.9 years by sampling date, while the mean age of female striped bass varied from 6.3-8.6 years.

## **Spawning Stock Biomass Indexes**

### **Rappahannock River**

**Pound nets:** The Spawning Stock Biomass Index (SSBI) for spring 2004 was 58.5 kg/day for male striped bass and 65.4 kg/day for female striped bass. The index for male striped bass was the highest in the 14-year time series, more than double the index for 2003, and 152.2% above the 14-year average (Table 16). The magnitude of the index for male striped bass was largely determined by the 1996 (20.9%) and 1999 (18.9%) year classes. The index for female striped bass was also the highest of the 14-year time series and 119.5% above the average (Table 16). The magnitude of the index for the females was largely determined by the 1992-1996 year classes (89.3%).

**Experimental gill nets:** The Spawning Stock Biomass Index for spring 2004 was 171.9 kg/day for male striped bass and 52.0 kg/day for female striped bass. The index for male striped bass was the second highest of the time series, almost double the 2003 index, and was 107.1% above the 14-year average (Table 16). The 1996-2000 year classes contributed 86.7% of the biomass in the male index. Likewise, the index for female striped bass was more than double the 2003 index, and was 49.4% above the 14-year average. The 1994-1996 year classes contributed 73.8% of the biomass in the female index.

### **James River**

**Experimental gill nets:** The Spawning Stock Biomass Index for spring 2004 was 207.04 kg/day for male striped bass and 31.24 kg/day for female striped bass. The male index was the second highest in the 11-year time series, 42.1% higher than the 2003 index, and was 94.0% above the average (Table 17). The 1998-2000 year classes contributed 69.0% of the biomass in the male index. The female index was 11.3% lower than the 2003 index, and was 43.1% lower than the 11-year average. The 1992-1996 year classes accounted for 91.4% 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 length-egg production estimates for each river. The pooled data (2001-2003) produce a fork length-oocyte count relationship as follows:

$$N_o = 0.00857 \times FL^{3.1373}$$

Where  $N_o$  is the total number of oocytes and FL is the fork length (>400) in millimeters. Using this relationship, the predicted egg production was 125,000 oocytes for a 400-mm female and 3,719,000 oocytes for a 1180-mm female striped bass (Table 18). The 2004 Egg Production Potential Indexes (EPPI, Table 19) for the Rappahannock River were 10.55 (pound nets) and 8.432 (gill nets). The 2004 EPPI for the James River was 4.922. The indexes for the Rappahannock River were heavily dependent on the egg production potential of the older (8+ years) females (96.3% in the pound nets, 91.7% in the gill nets). The James River index was also dependent on the older females (91.2%). Previous values for the EPPI for 2001-2003 from the Rappahannock River were 3.992, 1.764 and 9.829 (pound nets) and 4.039, 6.070 and 3.724 (gill nets). Previous values for the EPPI for 2001-2003 from the James River were 5.286, 6.709 and 6.037 respectively (Sadler et al 2001, 2002, 2003). Modest changes in the methodology (utilizing fully mature ovaries solely rather than ovaries in various states of maturation) in the 2001-2004 indexes preclude direct comparison with the 1999 and 2000 indexes.

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

### Rappahannock River

**Pound nets:** Numeric catch rates (fish/day) of individual year classes from the 1991-2004 samples are presented in Tables 20-22. The cumulative annual catch rate of all year classes for 2004 was the 2nd highest in the time series and was double the cumulative catch rate for 2003 (Tables 20a,b). The increase was the result of higher catch rates of the 1995-2000 year classes. The catch rate of males was dominated by four and five year-olds (1999 and 2000 year classes, Tables 21a,b). However, these two age classes contributed only 47.5% on the total catch. Previously, these two age classes had contributed more than 50% of the total male catches in every year except 1995 and 1996. 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. No pre-1992 year class males were captured. The cumulative catch rate of female stripers was the highest of the time series and was 32.1% more than the catch rate in 2003 (Tables 22a,b). The increase in the cumulative catch rate of female striped bass continued a reversal what had been a general decline from 1993-2002. No pre-1989 year class females were captured in 2004.

The range of overall ages was unchanged from 1991-2004, consisting of 2-10 year old males and 4-16 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 five (1992-1994) to age four (1997-2002). The catch rate of four and five year olds were near equal in 2003 and 2004. 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 0.134-0.468 (mean = 0.294) as their cumulative catch rate ranged from 0.75-2.08 fish/day (mean = 1.32). From 1997-2001 the range in the cumulative proportion of females age eight and older increased to 0.770-0.872 (mean = 0.825) as cumulative catch rates ranged from 1.44-4.45 fish/day (mean = 2.84). In 2002, the cumulative proportion of female striped bass age eight and older decreased to 0.508. In 2003, the cumulative catch rate of females age eight and older rebounded to 0.875 and in 2004 increased to 0.903 (the highest of the time series).

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 rates (1991-2004) of the 1983-1997 year classes (sexes combined) varied from 0.516-0.845 (Tables 23a,b) with an overall mean survival rate of 0.665. 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 (1991-2004) of the 1985-1997 year classes of males varied from 0.317-0.668 (Tables 24a,b) with an overall mean survival rate of 0.477. These year classes have been the major target of the fall recreational and commercial fisheries that reopened in 1993. The geometric mean survival rate (1991-2004) of the 1983-1990 year classes of females varied from 0.587-0.762 (Tables 25a,b) with an overall mean survival rate of 0.648. The high catch rates of 1992-1998 year class females in 2003 precluded estimation of survival rates for these strippers in 2004.

**Experimental gill nets:** Numeric catch rates (fish/day) of individual years classes from 1991-2004 are presented in Tables 26-28. The cumulative annual catch rate (all age classes, sexes combined) for 2004 from the gill nets was 1.5 times the median value in the time series and 65.8% higher than in 2003 (Tables 26a,b). The increase was the result of much higher catch rates of three and four year old males (Tables 27a,b). The cumulative catch rate was driven by the catch rates of the 2000 and 2001 year classes of striped bass. The age of peak abundance was three years old. The age of peak abundance had changed from age five (1992-1996, 2002) to age four (1997, 1998, 2000, 2001 and 2003) and age three (1999 and 2004). In contrast to the pound net catches, the cumulative catch rate of female striped bass was the sixth highest of the time series, but was more than double the cumulative catch rate in 2003 (Tables 28a,b).

The overall age structure from 1991-2004 consisted of 2-12 year old males (Tables 27a,b) and 2-14 year old females (Tables 28a,b), although no males older than 10 years were captured in 2004. The proportion of males age-six and older (0.32) continued to increase. The proportion of males age six and older was 0.2 in 2002 and 2003 after being 0.03-0.06 from 1997-2001. The proportion of females age eight and older increased from 0.148 to 0.652 from 1991 to 1996, declined from 0.652 to 0.315 from 1996 to 2002 (except 0.707 in 2001), then rebounded to 0.594 in 2003 and 0.843 in 2004.

The cumulative catch rate (all age classes) of male striped bass rebounded in 2004, and was second only to the peak value found in 1997 (Tables 27a,b). Using the maximum catch rate of the resident males as an indicator, the 1993, 1994 and 1997 year classes were the strongest and the 1990, 1991 and 2000 year classes the weakest. The catch rates of male striped bass declined rapidly after ages five or six. These year classes are the primary target of the recreational and commercial fisheries.

The 2004 cumulative catch (all age classes) rate of female striped bass was more than double the 2003 catch rate and was comparable to the values found from 1992-1995 and 2000 (Tables 28a,b). The increased catch rates for 8-14 year-old females gave evidence of secondary peak of abundance across several year classes. This bimodal distribution of abundance with age had been noted for the pound net catches, but had not been evident in the gill net catches.

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 (1991-2004) of the 1984-1996 year classes (sexes combined) varied from 0.408-0.785 (Tables 29a,b) with an overall mean survival of 0.556. There were widely divergent estimates of annual survival of male and female striped bass. The geometric mean survival rate (1991-2004) of the 1987-1996 year classes of males varied from 0.150-0.692 (Tables 30a,b) with an overall mean survival of 0.380. These year classes have been the major target of the fall recreational and commercial fisheries that reopened in 1993. The geometric mean survival rate (1991-2004) of the 1984-1990 year classes of females varied from 0.501-0.669 (Tables 31a,b) with an overall mean survival rate of 0.587. The survival estimates of both sexes of striped bass were 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:** Numeric catch rates (fish/day) of individual years classes from 1984-2004 are presented in Tables 32-34. The cumulative annual catch rate (all age classes, sexes combined) for 2004 was the second highest of the time series, and was a 44.1% increase in the catch rate for 2003. It reversed three consecutive years of decline from the peak in 2000 (Tables 32a,b). The cumulative catch rate was driven by high catch rates for the three to five year old (1999-2001 year classes), mostly male striped bass.

The overall age structure of the samples has remained stable throughout the time series, starting at age two or three, and ranging up to 11-14 years (Tables 32a,b). The age structure of male striped bass has expanded from three to six years in 1994, to two to 12 years by 2004 (Tables 33a,b). The age structure of female striped bass was stable from 1994-2004, consisting of three-14 year old females (Tables 34a,b). The cumulative proportion of males age six and older has varied from 0.091-0.144 in 2000-2004 after peaking at 0.201-0.299 from 1996-1998. The cumulative proportion of females age eight and older, which had decreased from 0.531-0.266 from 1997-1999, rebounded to 0.426 in 2001 and was 0.802 in 2004.

The cumulative catch rate of male striped bass mirrored the trends of the combined data with the 2004 catch rate being the second highest overall, and 49.2% higher than the cumulative catch rate for 2003 (Tables 33a,b). Using the maximum catch rate of the resident males as an indicator, the 1995-1997 and the 2000 year classes were strongest and the 1992 and 1993 year classes the weakest. Male catch rates declined after ages five or six, but not as rapidly as on the Rappahannock River. In contrast, the 2004 cumulative catch rate of female striped bass was 25.7% lower than in 2003, and was the second lowest in the time series (Tables 34a,b). There was no secondary peak in catch rates of females 1988-1991 year classes similar to that noted in the Rappahannock River data.

Estimates of annual survival (S) for the individual year classes and their overall geometric means are presented in tables 35-37. While annual survival estimates varied widely among years, due to strong or weak overall catches, the geometric mean survival rate (1994-2004) of the 1984 -1996 year classes (sexes combined) varied from 0.339-0.763 (Table 35), with an overall mean survival rate of 0.541. There were widely divergent estimates of annual survival of male and female striped bass. The geometric mean survival rate (1994-2004) of the 1988-1996 year classes of males varied from 0.286-0.562 (Table 36) with an overall mean survival rate of 0.453. These year classes have been the major target of the fall recreational and commercial fisheries that reopened in 1993. The geometric mean survival rate (1994-2004) of the 1984-1995 year classes of females varied from 0.347-0.813 (Table 37) with an overall mean survival rate of 0.565.

### **Catch rate histories of the 1987-1996 year classes**

The catch rate histories of the 1987-1996 year classes from each sampling gear (sampling on the James River commenced in 1993) are depicted in figures 3-11. Consistent among the year classes are a peak of male striped bass at age four or five followed by a rapid decline in the catch rate and a secondary peak of mostly female striped bass around age 10. This secondary peak is best defined from the pound net data. The gill nets appear to be less efficient at catching larger, therefore older, striped bass.

Numeric catch rates for male striped bass decreased rapidly subsequent to their peak of abundance at age four or five in both gears. These fish are the primary target for the commercial and recreational fisheries within Chesapeake Bay. Catch rates of female striped bass also show a steep decline after their initial peak in abundance, presumably due to their migratory behavior, but, at least in the Rappahannock River, also exhibit a secondary peak in the catch rates of 9-11 year old females that was persistent across several year classes. This secondary peak is due to the relative lack of intermediate sized (590-710 mm TL) striped bass in the samples. This pattern was not evident in the catches from 1991-1996 but has been persistent thereafter.

**1987 Year class:** The catch history of the 1987 year class commences at age four from the Rappahannock River and age seven from the James River. Peak abundance of male striped bass occurred at age four and the peak abundance of female striped bass occurred at age six in the



Rappahannock River (Figure 3). Abundances of both sexes declined rapidly with age, although there was a distinctive secondary peak in the abundance of female striped bass captured from the pound nets. Using the calculated area under the catch curve (CCA) at age eight (the oldest year comparable among the 10 year classes) as an indicator of year class strength, the 1987 year class was near the mean for the 1987-1996 year classes (Table 38) in the pound net samples. However, the 1987 year class was below the mean in the gill net samples in the Rappahannock River (Table 39). Since the time series does not include catches at ages two and three, the values of the catch curve area are underestimated.

**1988 Year class:** The catch history of the 1988 year class commences at age three from the Rappahannock River and age six from the James River. Age three was the apparent age of full recruitment to both sampling gears. Peak abundance of both male and female striped bass occurred at age five (Figure 4). Abundances decreased rapidly with age, although the pound net samples again had a secondary peak of female striped bass at age nine. The 1988 year class was above the mean CCA in the pound net samples (Table 38), but slightly below the mean from gill net samples in the Rappahannock River.

**1989 Year class:** The catch history of the 1989 year class, fully recruited to the gears in the Rappahannock River, commenced at age five in the James River samples. Peak abundance of male striped bass occurred at age four (pound nets) and five (gill nets in both rivers, Figure 5). Peak abundance of female striped bass occurred at five in the Rappahannock River (both gears) and age six in the James River. There was a secondary peak in abundance of female striped bass at age nine in the pound net samples. The CCA from both gears in the Rappahannock River was below the mean (Tables 38, 39).

**1990 Year class:** The catch history of the 1990 year class commenced at age four in the James River. Peak abundance of male striped bass occurred at age four (gill nets) and five (pound nets) in the Rappahannock River and age four in the James River (Figure 6). The peak abundance of female striped bass occurred at age five in the gill net samples from both rivers, but was age eight in the pound net samples. The CCA was the second lowest of the time series from both gears in the Rappahannock River (Tables 38, 39). The CCA for the James River, though lacking values for ages two and three, was also below the mean (Table 40).

**1991 Year class:** The catch history of the 1991 year class commenced at age three in the James River and was fully recruited to the sampling gear. Peak abundance of male striped bass occurred at age four in the James River and at age five in the Rappahannock River (both gears, Figure 7). Peak abundance of female striped bass occurred at age eight in the James River and at age 10 in the Rappahannock River. It is interesting to note that age five and six female striped bass were not caught in the same relative abundance as in the 1987-1990 year classes. The CCA was the lowest of the year classes compared in the Rappahannock River in both sampling gears (Tables 38, 39) and well below the mean in the James River (Table 40).

**1992 Year class:** Peak abundance of male striped bass occurred at age three in the pound nets in the Rappahannock River and in the gill nets in the James River, but occurred at age five in the gill nets in the Rappahannock River (Figure 8). Peak abundance of female striped bass occurred

at age seven in the James River but occurred at age nine (gill nets) and 11 (pound nets) in the Rappahannock River. Again, there were relatively few age five and six female striped bass captured in the Rappahannock River. The CAA was higher than for the 1990 and 1991 year classes but was still below the mean in the Rappahannock River (Tables 38, 39), but was the lowest value for the James River (Table 40).

**1993 Year class:** Peak abundance of male striped bass occurred at age four in the Rappahannock (both gears) and the James rivers (Figure 9). Peak abundance of female striped bass occurred at age six on the James River, but not until ages nine (gill nets) and 10 (pound nets) in the Rappahannock River. Again, there were relatively few age five and six female striped bass captured in the Rappahannock River. The CAA was the highest of all the year classes from the pound net samples, but was only near the mean from the gill net samples in the Rappahannock River (Tables 38, 39). The CAA for the James River was well below the mean (Table 40).

**1994 Year class:** Peak abundance of male striped bass occurred at age four in the Rappahannock River (both gears) and at age six in the James River (Figure 10). Peak abundance of female striped bass occurred at age five on the James River, but not until age 10 in the Rappahannock River (both gears). Again, there were relatively few age five and six female striped bass captured in the Rappahannock River. The CAA was well above the mean from the pound net samples but near the mean from the gill net samples in the Rappahannock River (Tables 38, 39). The CAA for the James River was higher than for the 1991-1993 year classes but was still below the mean (Table 40).

**1995 Year class:** Peak abundance of male striped bass occurred at age three (gill nets) and four (pound nets) in the Rappahannock River and occurred at age five in the James River (Figure 11). Peak abundance of female striped bass occurred at age four in the James River but not until age nine in the Rappahannock River (both gears). Again, there were relatively few age five and six female striped bass captured in the Rappahannock River. The CAA was below the mean in the Rappahannock River (both gears, Tables 38, 39), but was above the mean in the James River (Table 40).

**1996 Year class:** Peak abundance of male striped bass occurred at age three (gill nets) and four (pound nets) in the Rappahannock River and occurred at age four in the James River (Figure 12). Peak abundance of female striped bass occurred at age six in the James River and at age eight in the Rappahannock River (both gears). Again, there were relatively few age five and six female striped bass captured in the Rappahannock River. Thus, what had been a secondary peak of abundance for the 1987-1990 years classes has been the primary peak in subsequent year classes. The CAA was the highest amongst the year classes from the gill net samples in the Rappahannock River (Table 39) and well above the mean in the pound net samples (Table 38). The CAA for the James River was by far the highest of any of the year classes (Table 40).

## Growth rate of striped bass derived from annuli measurements

The scales of 3,179 striped bass were digitally measured and the increments between annuli were used to determine their growth history. The back-calculated length-at-age of striped bass was 160mm at age one (Table 41a). The rate of growth was about 105 mm in their second year and decreased gradually with age to about 80 mm in their fifth year and to about 50 mm in their 10<sup>th</sup> year (Tables 41a,b). Interestingly, the growth rates of the most recent year classes were the highest, although the growth rate of the oldest year classes were based on very few specimens. Based on these growth estimates, an 18 inch (457 mm) total length striped bass would be 3.5 years of age during the fall recreational fishery in Chesapeake Bay. These striped bass reach the 28 inch (711 mm) total length minimum for the coastal fishery at age seven.

## Age determinations using scales and otoliths

A total of 270 striped bass from 11 size ranges were aged by reading both their scales and otoliths. Scale and otolith ages from the same specimen were in agreement 33.7% (91/ 270) of the time and within one year 79.6% (215/270) of the time. Differences between the two age determination methods were first analyzed utilizing tests of symmetry. A chi-square test was performed to test the hypothesis that an  $m \times m$  contingency table (Table 42) consisting of two classifications of a sample into categories is symmetric about the main diagonal. The test statistic is

$$X^2 = \sum_{i=1}^{m-1} \sum_{j=i+1}^m \frac{(n_{ij} - n_{ji})^2}{n_{ij} + n_{ji}}$$

where  $n_{ij}$  = the observed frequency in the  $i$ th row and  $j$ th column and  $n_{ji}$  = the observed frequency in the  $j$ th row and  $i$ th column (Hoenig et al., 1995).

A test of symmetry that is significant indicates that there is a systematic difference between the aging methods. The number of degrees of freedom is equal to the number of non-zero age pair comparisons (here = 32). We tested the hypothesis that the observed age differences were randomly distributed about the main table diagonal (Table 42). The hypothesis was rejected ( $\chi^2 = 94.25$ ,  $p = 0.0000$ ), indicating non-random differences between the two ageing methodologies.

Following the extension of the symmetry test outlined by Hoenig et al. (1995), the point at which the asymmetry begins can be determined by repeatedly collapsing the data to form a Aplus@ group. The resulting chi-square test is then performed sequentially until the result is no longer significant. Non-random differences between otolith and scale ages occurred in striped bass age ten and older. The otolith-aged 11 year-old class was the largest contributor to the

variability. In the striped bass aged 11 and older using otoliths (n = 111), the otolith age was equal to (n=17) or older (n=59) 68.5% of the time.

Differences between the scale and otolith age from the same specimen ranged from zero to eight years (Figure 13). The otolith-derived age exceeded the scale age 36.7% of the total examined (55.3% of the non-zero differences). When the differences in ages were greater than one year, the otolith age was even more likely to be the older age (60.0%). Another test of symmetry that compared the negative and positive differences of the same magnitude (i.e. -4 and 4, -3 and 3, etc., Evans and Hoenig, 1998) failed to reject the hypothesis that these differences were random ( $\chi^2 = 10.49$ ,  $df = 5$ ,  $p = 0.0658$ ). This test has far fewer degrees of freedom than did the previous test of symmetry. Thus, the results indicate that the second test has less power to resolve questions of symmetry rather than contradicting the first test.

Next, t-tests of the resultant means of the two ageing methods were performed. A two-tailed t-test was made to test the null hypothesis that the mean ages determined by the two methods were not different. The mean age of the sample (n=270) determined by reading the otoliths was greater than the mean age determined by reading the scales (by 0.16 years, Table 39). The test results were:

$$\begin{aligned} \bar{Age}_{otolith} &= 9.29 & \bar{Age}_{scale} &= 9.13 \\ S_{otolith} &= 3.24 & S_{scale} &= 3.03 \\ t &= 0.603 \\ df &= 538 \\ p &= .5468 \end{aligned}$$

Therefore the null hypothesis was not rejected.

A paired t-test was also performed on the ages determined for each specimen by the two methodologies. The null hypothesis tested was that the mean of the difference resultant from the two methods was not different from zero. The paired t-test results were highly significant ( $t=15.688$ ,  $df=269$ ,  $p=.00x00$ ) and the null hypothesis was rejected.

To determine whether the distribution of age classes that resulted from the two ageing methodologies were representative of the same population, a Kolmogorov- Smirnov test was performed on the relative proportion that each assigned age class contributed to the total sample (Table 39). This compares the maximum difference in the relative proportions that an age class contributes to the test statistic ( $K_{.05}$ ):

$$\begin{aligned} D_{\max} &= 0.1111 & K_{.05} &= 1.3581 \\ D_{.05} &= 1.3581 \sqrt{\frac{270+270}{270^2}} = 0.1169 \end{aligned}$$

The maximum difference did not exceed the test statistic, so the null hypothesis, that the age structures derived by the two ageing methods represent the same population, was not rejected.

## **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 managed 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 (due to differences in depth, bottom, fetch, nearness to shoals or channels, etc.), and our sampling methods (in use since 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 scheduled to be sampled weekly, but uncontrollable factors (especially tide, weather and market conditions) affected this schedule. Since spring 2002 the down-river net has not been set and was replaced by a net across the river at mile 45. This net had been utilized since 1997 as a source for tagging striped bass, but had been excluded from the spawning stock assessment in order to keep the sampling methodology as consistent as possible with the 1991-1996 data. 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).

In past years, duration of the pound net set was as low as 24 hrs., and as large as 196 hrs., 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 varying effort influenced estimates of catch rate. The 1997 and 1998 data include a pound net at mile 46 that had an orientation and catch characteristics similar to the net at mile 47. This net was also sampled on one date (7 April) in 2003. 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. The two nets were set approximately 300 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. In 2004, a manufacturing error resulted in two nets of the no. 1 configuration being fished on both the James and Rappahannock rivers. Also, on one date (30 March) in 2004 only one of the two nets was sampled in the James River after one end broke free of its anchor.

The gill net captured proportionally more males than did the pound nets. Anecdotal information from commercial fishermen suggests that spawning males are attracted to conspecifics that have become gilled in the net meshes. Thrashing of gilled fish may emulate spawning behavior (termed Arock 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 (900+ mm FL) striped bass.

The biological characterization of the spawning stock of striped bass in the Rappahannock River changed dramatically from 1991-2004. There was a steady decrease in the relative abundance of five to seven year-old striped bass from 1991-2001, but these ages were proportionally more abundant in 2002-2004. The males in these age classes had been the target of the recreational and commercial fisheries, but with the increase in the availability of larger striped bass in recent years, the younger striped bass may be under less fishing pressure. 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. The catches of older females from the pound nets were again higher in 2004, after having decreased in 2002. This pattern was also noted after low catches in 1992 and in 1996. However, catches of the older females in the Rappahannock River gill nets was historically low.

Of note in the 2004 samples was the relative abundance of 1992 year class (12 year old) male and female stripers. The catch/effort of this year class at age nine was second only to the 1989 year class and indicates that the strength of the 1992 year class may have been previously underestimated. In spring 1996, when the maximum catch/effort of four year old males would have been expected, the weather was abnormally cold and wet and catches across all year classes were down from the previous year (Sadler *et al.* 1998).

The 2004 values of the Spawning Stock Biomass Index (SSBI) for the Rappahannock River were higher than in 2003 for male striped bass from both gears and for female striped bass from the pound nets only. The SSBI for female striped bass captured in the pound nets was the highest in the 1991-2004 time series. The increase was due to increased numbers across almost every age class when compared to 2002. In contrast, the decrease in the SSBI for female striped bass in the gill nets was due to lower catches of virtually every age class when compared to 2003.

The 1991-2004 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 value in 2004 was driven by increased catches of 1998-2000 year classes of males, and the values of both sexes were historical peaks. The female biomass from pound nets showed no reliance upon any age groups but rather an increase in catches across all ages. The male biomass from the gill nets is driven by the number of Asuper catches@, when the net is literally filled by males seeking to spawn,that occur differentially among the years (most notably in 1994, 1997 and 2004). The female SSBI was highest from 1992-1996 due to catches of four-seven year old stripers. 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. Local fishermen that low temperatures alter the catchability of striped bass. It is also possible that the spawning migration continued past the end of sampling in those years.

The 2004 values of the SSBI in the James River were higher than in 2003 for male striped bass, but declined slightly for females. The male index was driven by large catches of the 1999-2001 year classes while the female index was driven by the catches of the 1995 and 1996 year classes. Because of the changes in location and in the methodology utilized by the new fisherman starting in 2000, the values are not directly comparable with those of previous years. The below normal river flow conditions noted for the Rappahannock River, apply to the James River as well. The relative scarcity of larger, predominantly female, striped bass from the gill nets in the James River (compared to pound net catches) 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 2001 Rappahannock River pound net data the contribution of 8+ year old females was 75.2% of the total number of mature females (the basis of our index prior to 1998), 94.1% of the mature female biomass (the basis of the current index) and 94.3% of the calculated egg potential. As noted previously, the catches in 2002 were less reliant on older fish than in the preceding years so that the contribution of 8+ year old females was 46% of the total number of mature females, but still 69.1% of the female biomass and 68.4% of the potential egg production. In 2003, the contribution of 8+ year old females was 87.7% of the total number, 95.5% of the biomass and 95.5% of the calculated egg potential. It should be noted that our fecundity estimates are well below those reported by Setzler et al. (1980). Our methodology differs from the previous studies, but the relative contribution in potential egg production of the older females may be underestimated at present.

In our analysis of pound net catch rates, we observed a distinctive bimodal distribution of female striped bass in the 1987-1990 year classes. These striped bass appeared in greatest abundance at age five or six (especially males), at lower abundance at age six to eight (both sexes), and then higher abundance at ages nine to 12 (especially females). 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 1991-1995 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 1997-2003 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 2000-2002. 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. The relative abundance of ten-year old, 1992 year class, striped bass of both sexes in both 2001 and 2002, indicate that the 1992 year class was also strong. 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 the instantaneous rates of survival of the year classes using catch curves, especially for the 1983-1996 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 0.65 in pound nets and 0.59 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 0.48 in pound nets and 0.38 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 0.45 for male striped bass and approximately 0.57 for female striped bass.

The catch histories of the 1987-1996 year classes in the Rappahannock River show two distinct patterns. The 1987-1990 year classes had initial peaks of abundance of both sexes at ages four or five and a secondary peak in the abundance of female striped bass after age eight. Subsequent year classes did not have the initial peak in abundance of female striped bass, but only what was the secondary peak of eight to 12 year-olds. Since catches of larger, thus older, striped bass was less consistent in the gill net catches, this pattern was less apparent in that data set. Using the area under the catch curve as an indicator of year class strength, the 1993 and 1996 year classes were the strongest and the 1990 and 1991 year classes were the weakest.

Back-calculation of the growth based on measurements between scale annuli indicated that striped bass grow about 160 mm (fork length) in their first year. Growth averaged 105 mm in their second year and decreased gradually to about 50 mm by age 10. Thus, striped bass reach the 18 in. (457 mm) minimum total length for the Chesapeake Bay resident fishery at 3.5 years



of age (the 2001 year class in 2004) and the 28 in. (711 mm) minimum total length for the coastal fishery at age seven.

The ages of striped bass determined by reading both their scales and otoliths were found to differ by as much as eight years (though only for a single specimen). The age difference determined for the largest, and oldest, specimens was 1-8 years (13-16 years by reading the scale vs 15-21 years by reading the otolith). The maximum age determined by reading scales has remained constant at 16 years since 1991, while there has been an annual progression in the maximum age determined by reading otoliths. Agreement between the two ageing methodologies was only 33.7% and was slightly lower than the results from 2002 and 2003. When there was disagreement between methodologies, the otolith age was 1.24 times more likely to have been aged older than the respective scale-derived age and 1.5 times as likely to produce a difference of two or more years older. The differences were found to be statistically non-random and different from zero. The age at which the divergence became significant was age 10. However, the relative contributions of the age classes and their overall mean age did not statistically differ between the two methodologies. Thus, by using otoliths to age the striped bass, the age structure extends back to the 1983 year class, while scale ageing limits the age structure to the 1987 year class. Previous ageing method comparison studies (Secor, et al. 1995, Welch, et al. 1993) concluded that otolith-based and scale-based ages of striped bass became increasingly divergent, with otolith ages being older, especially after 900 mm in size or 10-12 years in age. We plan to continue these comparisons in future years.

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**Table 1.** Numbers of striped bass in three age categories (year classes 2000-2002, 1996-1999 and 1987-1995) from pound nets in the Rappahannock River, by sampling date, spring, 2004.

Date	n	Year Class							
		2000 - 2002		1996 - 1999		1987 - 1995		Not aged	
		M	F	M	F	M	F	M	F
<b>1 April</b>	37	19	0	9	3	1	5	0	0
<b>8 April</b>	25	11	0	7	1	0	6	0	0
<b>12 April</b>	85	27	0	33	6	4	14	1	0
<b>16 April</b>	206	96	1	56	13	4	34	2	0
<b>19 April</b>	74	10	0	23	14	0	27	0	0
<b>22 April</b>	89	10	0	27	14	6	32	0	0
<b>26 April</b>	178	24	2	101	14	7	25	5	0
<b>29 April</b>	173	49	0	93	8	2	17	4	0
<b>3 May</b>	84	23	0	47	6	3	5	0	0
<b>Total</b>	<b>951</b>	<b>269</b>	<b>3</b>	<b>396</b>	<b>79</b>	<b>27</b>	<b>165</b>	<b>12</b>	<b>0</b>

**Table 2.** Net-specific summary of catch rates and ages of striped bass (n= 951) in pound nets on the Rappahannock River, spring, 2004. 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
<b>1 April</b>	S462	37	29.0	8.0	60,569.7	67,232.8	4.6	9.5
<b>8 April</b>	S454	25	4.5	1.8	11,628.1	15,107.8	5.1	9.6
<b>12 April</b>	S473	85	16.3	5.0	50,013.1	39,941.2	5.5	9.4
<b>16 April</b>	S454	206	39.5	12.0	83,770.2	98,059.1	4.7	9.5
<b>19 April</b>	S454	74	11.0	13.7	35,131.0	114,306.7	5.8	9.5
<b>22 April</b>	S473	89	14.3	15.3	52,029.1	125,299.2	6.5	9.9
<b>26 April</b>	S454	178	34.3	10.3	93,929.8	69,730.9	5.7	8.7
<b>29 April</b>	S473	173	49.3	8.3	105,511.3	71,293.5	5.1	9.6
<b>3 May</b>	S454	84	18.3	2.8	40,227.4	17,955.6	5.2	8.5
<b>Totals</b>	S454	567	22.1	7.8	53,874.5	60,333.3	5.2	9.2
	S462	37	29.0	8.0	60,569.7	67,232.8	4.6	9.5
	S473	347	25.6	9.1	67,267.4	74,954.3	5.4	9.7
<b>Season</b>		<b>951</b>	<b>23.5</b>	<b>8.2</b>	<b>58,561.9</b>	<b>65,437.0</b>	<b>5.3</b>	<b>9.4</b>

**Table 3.** Length frequencies (TL in mm) of striped bass sampled from the pound nets in the Rappahannock River, spring, 2004.

TL	n	TL	n	TL	n	TL	n	TL	n	TL	n
300-	0	460-	24	620-	22	780-	20	940-	9	1100-	1
310-	0	470-	9	630-	12	790-	20	950-	8	1110-	1
320-	0	480-	18	640-	8	800-	15	960-	13	1120-	0
330-	1	490-	17	650-	14	810-	32	970-	4	1130-	0
340-	0	500-	22	660-	8	820-	20	980-	6	1140-	0
350-	0	510-	21	670-	8	830-	23	990-	1	1150-	0
360-	1	520-	38	680-	2	840-	19	1000-	9	1160-	0
370-	3	530-	21	690-	2	850-	15	1010-	8	1170-	2
380-	3	540-	31	700-	0	860-	9	1020-	4	1180-	0
390-	17	550-	33	710-	1	870-	12	1030-	3	1190-	0
400-	7	560-	24	720-	1	880-	8	1040-	8	1200-	0
410-	13	570-	26	730-	7	890-	12	1050-	2	1210-	0
420-	13	580-	19	740-	9	900-	13	1060-	0	1220-	0
430-	22	590-	27	750-	15	910-	5	1070-	1	1230-	0
440-	20	600-	25	760-	16	920-	6	1080-	1	1240-	0
450-	16	610-	20	770-	16	930-	9	1090-	0	1250-	0

**Table 4.** 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, 2004.

Year Class	Sex	n	Fork Length		Weight		CPUE	
			Mean	SD	Mean	SD	F/day	W/day
2002	male	1	312.0		369.5		0.0	12.3
2001	male	104	389.5	21.0	754.1	121.7	3.5	2,614.1
2000	male	164	462.3	24.5	1,294.1	217.9	5.5	7,074.2
	female	3	465.0	19.1	1,393.7	454.6	0.1	139.4
1999	male	170	528.8	22.5	1,951.2	283.3	5.7	11,056.9
	female	7	535.1	25.3	2,106.0	321.1	0.2	491.4
1998	male	101	592.4	30.3	2,747.5	434.8	3.4	9,249.9
	female	5	569.2	43.1	2,679.8	618.0	0.2	446.6
1997	male	58	709.1	24.3	4,540.6	571.5	1.9	8,778.6
	female	9	716.3	32.5	4,581.7	645.2	0.3	1,374.5
1996	male	67	751.3	18.8	5,471.5	437.7	2.2	12,219.6
	female	58	767.4	19.3	5,902.7	544.9	1.9	11,412.0
1995	male	16	795.7	15.2	6,337.3	441.2	0.5	3,379.9
	female	54	811.8	23.8	7,041.7	762.7	1.8	12,675.1
1994	male	6	849.7	16.4	8,161.7	842.8	0.2	1,632.3
	female	44	865.3	26.5	8,914.2	1,116.8	1.5	13,074.2
1993	male	3	919.0	22.5	10,468.0	822.0	0.1	1,046.8
	female	27	911.3	27.0	10,306.7	1,461.7	0.9	9,276.0
1992	male	2	957.0	1.4	10,555.5	913.3	0.1	703.7
	female	31	949.8	46.1	11,569.0	2,003.8	1.0	11,954.6
1991	female	5	988.8	19.2	14,619.7	1,217.4	0.2	2,436.6
1990	female	2	1,010.0	39.6	16,168.8	737.6	0.1	1,077.9
1989	female	2	1,078.5	37.5	16,179.7	3,079.4	0.1	1,078.6
n/a	male	12	522.0	71.0	1,984.0	759.5	0.4	793.6

n/a: not ageable



**Table 5.** Summary of the season mean (30 March - 3 May) catch rates and ages, by sex, from the pound nets in the Rappahannock River, 30 March - 3 May, 1993-2004.

Year	n	CPUE (fish/day)		CPUE (g/day)		Mean age	
		M	F	M	F	M	F
2004	951	23.5	8.3	58,561.9	65,437.0	5.3	9.4
2003	470	9.4	6.2	22,767.3	53,560.9	5.2	9.5
2002	170	3.5	1.8	7,057.2	11,422.9	4.6	7.8
2001	577	15.2	3.4	24,193.2	26,298.6	4.3	9.1
2000	1,508	37.4	1.9	42,233.1	14,704.5	3.7	8.8
1999	836	27.7	2.1	31,370.7	16,821.7	3.7	9.9
1998	401	10.3	4.0	15,598.6	32,930.6	4.0	9.5
1997	406	14.4	5.9	22,400.0	49,700.0	4.0	9.2
1996	430	10.1	2.2	14,300.0	9,400.0	3.9	7.9
1995	363	11.2	3.3	13,500.0	20,000.0	3.3	7.2
1994	375	8.4	5.4	17,400.0	30,900.0	4.5	7.2
1993	565	14.4	7.3	31,400.0	37,500.0	4.6	6.9
<b>Mean</b>	<b>587.7</b>	<b>15.6</b>	<b>4.3</b>	<b>25,065.2</b>	<b>30,723.0</b>	<b>4.3</b>	<b>8.5</b>

**Table 6.** Numbers of striped bass in three age categories (year classes 2000-2002, 1996-1999 and 1987-1995) from gill nets in the Rappahannock River, by sampling date, spring, 2004.

Date	n	Year Class							
		2000 - 2002		1996 - 1999		1987 - 1995		Not aged	
		M	F	M	F	M	F	M	F
<b>30 March</b>	30	11	0	14	0	1	1	3	0
<b>1 April</b>	14	5	0	4	2	1	2	0	0
<b>8 April</b>	32	6	0	16	4	2	3	1	0
<b>12 April</b>	171	81	0	83	1	2	4	0	0
<b>16 April</b>	23	4	0	12	4	0	3	0	0
<b>19 April</b>	210	142	0	55	3	1	7	2	0
<b>22 April</b>	138	56	0	59	7	2	14	0	0
<b>26 April</b>	178	85	1	77	6	0	7	2	0
<b>29 April</b>	23	8	0	14	1	0	0	0	0
<b>3 May</b>	8	0	1	4	1	0	2	0	0
<b>Total</b>	<b>827</b>	<b>398</b>	<b>2</b>	<b>338</b>	<b>29</b>	<b>9</b>	<b>43</b>	<b>8</b>	<b>0</b>

**Table 7.** Summary of catch rates and mean ages of striped bass (n=827) from the two gill nets in the Rappahannock River, spring 2004. 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
<b>30 March</b>	30	58.0	2.0	146,644.6	16,342.0	5.1	10.0
<b>1 April</b>	14	10.0	4.0	35,218.4	27,583.1	5.5	8.5
<b>8 April</b>	32	25.0	7.0	59,771.2	88,181.3	6.1	9.4
<b>12 April</b>	171	166.0	5.0	446,616.2	35,641.1	5.1	8.8
<b>16 April</b>	23	16.0	7.0	58,019.9	46,387.1	6.0	8.6
<b>19 April</b>	210	200.0	10.0	300,042.0	71,126.7	4.0	8.8
<b>22 April</b>	138	117.0	21.0	269,096.9	157,260.3	4.9	9.0
<b>26 April</b>	178	164.0	14.0	308,275.4	88,031.6	4.6	8.3
<b>29 April</b>	23	22.0	1.0	58,034.0	5,399.6	5.3	8.0
<b>3 May</b>	8	4.0	4.0	9,062.2	24,158.0	5.3	7.8
<b>Season</b>	<b>827</b>	<b>79.3</b>	<b>7.8</b>	<b>170,258.8</b>	<b>58,098.9</b>	<b>4.8</b>	<b>8.7</b>

Note: only one net was fished on 29 March (effort = 0.5)

**Table 8.** Length frequencies (TL in mm) of striped bass sampled from the experimental gill nets in the Rappahannock River, spring, 2004.

TL	n	TL	n	TL	n	TL	n	TL	n	TL	n
300-	1	460-	17	620-	9	780-	19	940-	0	1100-	0
310-	4	470-	21	630-	11	790-	15	950-	2	1110-	0
320-	13	480-	15	640-	17	800-	12	960-	3	1120-	0
330-	19	490-	23	650-	14	810-	14	970-	0	1130-	0
340-	21	500-	18	660-	10	820-	16	980-	0	1140-	0
350-	23	510-	18	670-	11	830-	8	990-	1	1150-	0
360-	21	520-	16	680-	8	840-	4	1000-	2	1160-	0
370-	15	530-	14	690-	3	850-	8	1010-	0	1170-	0
380-	14	540-	14	700-	6	860-	4	1020-	0	1180-	0
390-	17	550-	13	710-	11	870-	7	1030-	1	1190-	0
400-	13	560-	15	720-	3	880-	4	1040-	1	1200-	0
410-	14	570-	16	730-	8	890-	5	1050-	0	1210-	0
420-	12	580-	20	740-	9	900-	1	1060-	0	1220-	0
430-	24	590-	14	750-	18	910-	5	1070-	0	1230-	0
440-	23	600-	11	760-	16	920-	3	1080-	0	1240-	0
450-	30	610-	10	770-	18	930-	1	1090-	0	1250-	0

**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 Rappahannock River, 30 March - 3 May, 2004.

Year Class	Sex	n	Fork Length		Weight		CPUE	
			Mean	SD	Mean	SD	F/day	W/day
2002	male	39	305.9	11.2	361.7	41.2	4.1	1,484.8
2001	male	207	367.0	34.7	649.5	186.9	21.8	14,151.9
2000	male	152	456.6	23.8	1,275.7	224.8	16.0	20,410.6
	female	2	469.0	15.6	1,524.3	115.5	0.2	320.9
1999	male	100	530.8	21.0	2,028.6	304.9	10.5	21,353.6
	female	2	550.0	15.6	2,692.2	288.6	0.2	566.8
1998	male	92	610.2	30.2	3,153.3	481.4	9.7	30,537.6
	female	3	592.7	14.0	3,200.3	258.0	0.3	1,010.6
1997	male	92	702.3	28.1	4,604.1	518.9	9.7	44,587.0
	female	6	695.8	42.0	4,877.4	502.5	0.6	3,080.4
1996	male	54	753.9	18.0	5,655.7	612.3	5.7	32,148.4
	female	18	766.2	18.7	5,903.4	777.8	1.9	11,194.8
1995	male	6	796.5	18.6	6,979.4	858.3	0.6	4,408.0
	female	20	809.3	19.7	7,399.3	697.2	2.1	15,577.4
1994	male	3	843.0	11.4	8,434.9	1,204.6	0.3	2,663.7
	female	13	850.5	21.4	8,469.2	962.5	1.4	11,589.4
1993	female	6	902.8	20.3	9,877.2	1,198.1	0.6	3,119.1
1992	female	4	958.5	20.8	13,132.4	863.1	0.4	5,529.4
N/A	male	8	490.6	86.7	1,833.1	1,001.4	0.8	1,543.7

N/A: not ageable

**Table 10.** Summary of the season mean (30 March - 3 May) catch rates and ages, by sex, from the experimental gill nets in the Rappahannock River, 1993-2004.

Year	n	CPUE (fish/day)		CPUE (g/day)		Mean age	
		M	F	M	F	M	F
2004	827	79.3	7.8	170,528.8	58,098.9	4.8	8.7
2003	525	52.0	3.3	98,466.7	20,716.8	4.5	8.0
2002	323	24.5	7.8	53,606.9	40,727.5	4.8	7.0
2001	622	58.1	4.1	86,827.2	31,011.3	4.3	8.3
2000	493	47.8	3.1	64,955.7	18,196.0	3.8	7.5
1999	671	64.8	2.3	55,997.3	13,331.0	3.3	7.2
1998	603	57.1	2.9	65,500.0	12,200.0	3.9	7.3
1997	824	80.6	1.8	103,600.0	14,100.0	4.0	7.8
1996	498	45.2	4.6	54,300.0	26,600.0	3.6	6.6
1995	226	15.6	7.0	45,600.0	47,700.0	4.7	7.0
1994	516	41.5	10.1	82,700.0	54,900.0	4.7	6.9
1993	527	36.6	16.0	66,900.0	56,500.0	4.9	6.3
<b>Mean</b>	<b>554.6</b>	<b>50.3</b>	<b>5.9</b>	<b>79,081.9</b>	<b>32,840.1</b>	<b>4.3</b>	<b>7.4</b>

**Table 11.** Numbers of striped bass in three age categories (year classes 2000-2002, 1996-1999 and 1987-1995) in gill nets in the James River by sampling date, spring, 2004.

Date	n	Year Class							
		2000 - 2002		1996 - 1999		1987 - 1995		Not aged	
		M	F	M	F	M	F	M	F
<b>30 March</b>	79	41	0	27	3	1	4	3	0
<b>2 April</b>	55	18	1	26	2	1	3	4	0
<b>7 April</b>	95	38	0	55	0	0	0	2	0
<b>9 April</b>	188	123	1	59	1	2	1	1	0
<b>13 April</b>	51	25	0	22	0	0	4	0	0
<b>16 April</b>	120	70	0	48	1	0	0	1	0
<b>20 April</b>	233	137	0	80	3	1	5	7	0
<b>23 April</b>	170	116	0	45	1	1	5	2	0
<b>27 April</b>	193	130	0	57	3	1	0	2	0
<b>30 April</b>	171	107	0	52	6	4	0	2	0
<b>3 May</b>	92	61	0	27	2	0	0	2	0
<b>Total</b>	<b>1,447</b>	<b>866</b>	<b>2</b>	<b>498</b>	<b>22</b>	<b>11</b>	<b>22</b>	<b>26</b>	<b>0</b>

**Table 12.** Summary of catch rates and mean ages of striped bass (n=1,447) from the gill nets in the James River, spring 2004. 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
<b>30 March</b>	79	72.0	7.0	142,962.0	54,220.5	4.6	9.0
<b>2 April</b>	55	49.0	6.0	125,829.0	42,108.6	5.1	8.2
<b>7 April</b>	95	95.0	0.0	185,650.8	0.0	4.7	
<b>9 April</b>	188	185.0	3.0	296,327.2	18,563.1	4.2	8.0
<b>13 April</b>	51	47.0	4.0	96,679.9	30,679.3	4.7	9.5
<b>16 April</b>	120	119.0	1.0	185,867.1	5,677.5	4.4	8.0
<b>20 April</b>	233	225.0	8.0	372,304.2	56,433.6	4.3	9.0
<b>23 April</b>	170	164.0	6.0	232,565.7	55,615.8	4.1	10.0
<b>27 April</b>	193	190.0	3.0	282,647.8	13,817.4	4.3	7.0
<b>30 April</b>	171	161.0	10.0	231,947.9	62,599.7	4.2	8.3
<b>3 May</b>	92	90.0	2.0	126,238.5	3,898.0	4.2	5.0
<b>Total</b>	<b>1,447</b>	<b>127.0</b>	<b>4.5</b>	<b>207,191.9</b>	<b>31,237.6</b>	<b>4.3</b>	<b>8.7</b>



**Table 13.** Length frequencies (TL in mm) of striped bass sampled from the experimental gill nets in the James River, spring 2004.

TL	n	TL	n	TL	n	TL	n	TL	n	TL	n
300-	0	460-	63	620-	29	780-	5	940-	2	1100-	0
310-	1	470-	62	630-	10	790-	6	950-	0	1110-	0
320-	0	480-	62	640-	17	800-	6	960-	0	1120-	0
330-	1	490-	62	650-	12	810-	6	970-	1	1130-	0
340-	2	500-	70	660-	15	820-	6	980-	0	1140-	0
350-	7	510-	57	670-	8	830-	8	990-	1	1150-	0
360-	10	520-	61	680-	5	840-	4	1000-	2	1160-	0
370-	3	530-	57	690-	14	850-	5	1010-	1	1170-	0
380-	16	540-	42	700-	5	860-	3	1020-	0	1180-	0
390-	23	550-	60	710-	3	870-	3	1030-	0	1190-	0
400-	33	560-	45	720-	1	880-	4	1040-	1	1200-	0
410-	45	570-	44	730-	8	890-	2	1050-	0	1210-	0
420-	53	580-	38	740-	4	900-	2	1060-	0	1220-	0
430-	69	590-	29	750-	5	910-	3	1070-	0	1230-	0
440-	71	600-	37	760-	9	920-	1	1080-	0	1240-	0
450-	69	610-	31	770-	7	930-	0	1090-	0	1250-	0

**Table 14.** 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, 2004.

Year Class	Sex	n	Fork Length		Weight		CPUE	
			Mean	SD	Mean	SD	F/day	W/day
2002	male	4	315.0	19.4	399.3	59.6	0.4	145.2
2001	male	336	390.2	25.3	781.4	178.6	30.5	23,868.4
2000	male	526	455.6	24.0	1,208.8	198.9	47.8	57,803.3
	female	2	476.0	1.4	1,297.3	10.1	0.2	235.9
1999	male	304	529.9	23.8	1,902.2	325.3	27.6	52,569.6
	female	2	532.0	4.2	1,949.2	135.2	0.2	354.4
1998	male	126	594.8	30.5	2,831.5	506.5	11.4	32,433.3
	female	4	629.3	18.0	3,331.2	296.9	0.4	1,211.7
1997	male	43	688.7	32.5	4,452.2	639.1	3.9	17,404.0
	female	2	727.0	2.8	4,807.1	168.6	0.2	874.0
1996	male	25	754.4	19.5	5,722.0	577.2	2.3	13,004.5
	female	14	775.8	28.3	6,374.6	684.3	1.2	8,113.1
1995	male	6	785.5	22.0	6,506.9	574.1	0.5	3,549.2
	female	9	806.1	18.5	7,248.9	837.3	0.8	5,930.9
1994	female	11	847.0	22.2	7,764.8	921.5	1.0	7,764.8
1993	female	3	921.7	33.3	11,573.2	1,717.4	0.3	3,156.3
1992	male	1	938.0		11,883.3		0.1	1,080.3
	female	3	946.0	33.5	13,188.3	1,959.7	0.3	3,596.8
N/A	male	26	541.6	85.8	2,253.2	1,145.6	2.4	5,325.8

N/A: not ageable

**Table 15.** Summary of the season mean (30 March - 3 May) catch rates and ages, by sex, from experimental gill nets in the James River, 1995-2004.

Year	mile	n	CPUE (fish/day)		CPUE (g/day)		Mean age	
			M	F	M	F	M	F
2004	62	1,447	127.0	4.5	207,183.6	31,237.6	4.4	8.6
2003	62	639	132.4	8.7	234,255.6	55,043.2	4.5	7.6
2002	62	824	81.4	10.1	173,663.8	47,591.2	4.7	6.4
2001	62	1,050	98.1	6.9	181,512.7	41,347.7	4.4	7.2
2000	62	1,437	139.6	4.1	241,966.4	20,396.6	4.3	6.7
1999	55	482	25.3	22.9	45,886.4	103,362.7	4.3	6.3
1998	55	199	14.9	7.2	33,000.0	46,500.0	4.7	7.5
1997	55	160	11.1	6.7	23,900.0	44,600.0	4.9	7.8
1996	55	183	10.9	7.4	23,800.0	43,500.0	4.8	7.4
1995	55	419	24.0	22.6	52,400.0	125,300.0	4.4	6.7
<b>Mean</b>		<b>684.0</b>	<b>66.5</b>	<b>9.4</b>	<b>121,756.9</b>	<b>55,887.9</b>	<b>4.5</b>	<b>7.2</b>

**Table 16.** Values of the spawning stock biomass index (SSBI) for male and female striped bass, by gear, in the Rappahannock River, 30 March - 3 May, 1991-2004.

Year	Pound nets					Gill nets				
	N		SSBI (kg/day)			N		SSBI (kg/day)		
	M	F	M	F	M+F	M	F	M	F	M+F
<b>2004</b>	703	247	58.5	65.4	123.9	714	74	171.9	52.0	223.9
<b>2003</b>	283	187	22.8	53.6	76.4	467	31	97.3	20.7	118.0
<b>2002</b>	113	57	7.1	11.4	18.5	240	78	53.4	40.7	94.1
<b>2001</b>	470	105	24.2	27.6	51.8	572	41	88.6	30.9	119.5
<b>2000</b>	1,436	71	42.7	14.6	57.3	452	27	65.3	16.5	81.8
<b>1999</b>	738	61	30.5	19.8	50.3	532	21	51.4	13.2	64.6
<b>1998</b>	273	113	14.8	36.4	51.2	485	27	81.5	18.5	100.0
<b>1997</b>	277	115	22.2	49.6	71.7	801	18	177.8	19.1	197.0
<b>1996</b>	334	73	14.1	9.3	23.4	433	46	63.7	30.2	93.9
<b>1995</b>	207	76	12.4	19.8	32.2	162	69	43.9	56.7	100.6
<b>1994</b>	195	141	17.1	30.9	48.0	391	100	101.6	64.7	166.3
<b>1993</b>	357	188	31.2	37.5	68.7	361	160	85.6	74.1	159.6
<b>1992</b>	51	100	5.4	19.4	24.8	61	74	15.0	32.2	47.2
<b>1991</b>	153	70	21.3	21.5	42.8	406	47	65.0	17.8	83.8
<b>Mean</b>	<b>399</b>	<b>115</b>	<b>23.2</b>	<b>29.8</b>	<b>52.9</b>	<b>434</b>	<b>58</b>	<b>83.0</b>	<b>34.8</b>	<b>117.9</b>

**Table 17.** 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, 1994-2004. 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
2004	62	1,393	50	207.04	31.24	238.28
2003	62	590	43	145.74	35.20	180.94
2002	62	728	92	173.51	47.59	221.10
2001	62	978	68	181.40	41.31	222.71
2000	62	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
<b>Mean</b>		<b>536</b>	<b>88</b>	<b>106.71</b>	<b>54.89</b>	<b>161.60</b>

**Table 18.** Predicted values of fecundity (in millions of eggs) of female striped bass with increasing fork length (mm), James and Rappahannock rivers combined, spring 2004.

<b>FL</b>	<b>Fecundity</b>	<b>FL</b>	<b>Fecundity</b>	<b>FL</b>	<b>Fecundity</b>	<b>FL</b>	<b>Fecundity</b>
<b>400</b>	0.125	<b>600</b>	0.446	<b>800</b>	1.099	<b>1000</b>	2.212
<b>420</b>	0.146	<b>620</b>	0.494	<b>820</b>	1.187	<b>1020</b>	2.354
<b>440</b>	0.168	<b>640</b>	0.546	<b>840</b>	1.280	<b>1040</b>	2.502
<b>460</b>	0.194	<b>660</b>	0.601	<b>860</b>	1.378	<b>1060</b>	2.656
<b>480</b>	0.221	<b>680</b>	0.660	<b>880</b>	1.482	<b>1080</b>	2.817
<b>500</b>	0.251	<b>700</b>	0.723	<b>900</b>	1.590	<b>1100</b>	2.984
<b>520</b>	0.284	<b>720</b>	0.789	<b>920</b>	1.703	<b>1120</b>	3.157
<b>540</b>	0.320	<b>740</b>	0.860	<b>940</b>	1.822	<b>1140</b>	3.337
<b>560</b>	0.359	<b>760</b>	0.935	<b>960</b>	1.947	<b>1160</b>	3.525
<b>580</b>	0.401	<b>780</b>	1.015	<b>980</b>	2.077	<b>1180</b>	3.719

**Table 19.** Total, age-specific, estimated total egg potential (E, in millions of eggs/day) from mature (ages 4 and older) female striped bass, by river and gear type, 30 March - 3 May 2004. 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	3	0.020	0.2%	2	0.044	0.5%	2	0.040	0.8%
5	7	0.073	0.7%	2	0.072	0.9%	2	0.056	1.1%
6	5	0.064	0.6%	3	0.136	1.6%	4	0.188	3.8%
7	9	0.234	2.2%	6	0.452	5.3%	2	0.148	3.0%
8	58	1.868	17.7%	18	1.822	21.6%	14	1.274	25.9%
9	54	2.076	19.7%	20	2.402	28.4%	9	0.922	18.7%
10	44	2.067	19.6%	12	1.672	20.0%	11	1.316	26.8%
11	27	1.492	14.1%	6	1.016	12.0%	3	0.470	9.5%
12	31	1.960	18.6%	4	0.816	9.7%	3	0.508	10.3%
13	5	0.356	3.4%	0			0		
14	2	0.153	1.4%	0			0		
15	2	0.187	1.8%	0			0		
16	0			0			0		
<b>Total</b>	247	<b>10.55</b>	100.0%	73	<b>8.432</b>	100.0%	50	<b>4.922</b>	100.0%

**Table 20a.** Catch rates (fish/day) of year classes of striped bass (sexes combined) sampled from pound nets in the Rappahannock River, 30 March - 3 May, 1991-2004. Maximum catch rate for each 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	<b>15.61</b>
1996								0.19	11.54	<b>18.13</b>
1995							0.60	2.15	<b>11.50</b>	3.34
1994					0.04	0.51	3.90	<b>6.33</b>	2.79	0.11
1993					3.04	3.97	<b>8.10</b>	1.48	0.11	0.50
1992			0.12	1.44	<b>4.80</b>	2.86	1.25	0.04	0.50	0.50
1991		0.20	0.57	0.48	1.00	<b>1.63</b>	0.05	0.52	0.43	0.40
1990	0.42	0.50	1.04	1.33	<b>2.24</b>	1.26	0.70	0.70	0.32	0.29
1989	0.33	0.60	3.58	<b>4.59</b>	0.68	0.89	0.80	0.78	0.36	0.37
1988	3.58	1.60	<b>9.54</b>	2.22	0.60	0.37	1.50	0.89	0.39	0.05
1987	<b>8.00</b>	2.75	3.65	1.15	0.68	0.37	1.00	0.89	0.43	0.05
1986	<b>2.67</b>	1.15	0.65	0.59	0.40	0.09	1.00	0.22	0.04	0.00
1985	<b>1.67</b>	0.30	0.42	0.52	0.08	0.00	0.35	0.15	0.11	0.00
1984	0.50	0.40	<b>0.58</b>	0.33	0.28	0.00	0.35	0.07	0.04	0.00
1983	0.25	0.20	<b>0.46</b>	0.33	0.08	0.03	0.20	0.00	0.00	
>1983	<b>0.75</b>	0.45	0.73	0.33	0.00	0.00				
N/A	0.58	0.30	0.38	0.56	0.60	0.32	0.50	0.44	0.54	0.32
<b>Total</b>	<b>18.75</b>	<b>8.45</b>	<b>21.72</b>	<b>13.87</b>	<b>14.52</b>	<b>12.30</b>	<b>20.30</b>	<b>14.85</b>	<b>29.89</b>	<b>39.70</b>



**Table 20b.** Catch rates (fish/day) of year classes of striped bass (sexes combined) sampled from pound nets in the Rappahannock River, 30 March - 3 May, 1991-2004. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)			
	2001	2002	2003	2004
2001				3.47
2000			0.76	5.57
1999	0.07	0.51	3.00	<b>5.90</b>
1998	2.74	1.44	3.33	<b>3.50</b>
1997	7.49	1.38	0.37	2.23
1996	4.29	0.25	1.83	4.16
1995	0.10	0.68	1.40	2.33
1994	0.58	0.41	1.70	1.67
1993	0.87	0.28	1.43	1.00
1992	0.87	0.19	1.13	1.10
1991	0.81	0.06	0.33	0.17
1990	0.45	0.00	0.27	0.07
1989	0.26	0.00	0.07	0.07
1988	0.10	0.00	0.00	0.00
1987	0.00	0.03	0.03	0.00
N/A	0.00	0.00	0.00	0.40
<b>Total</b>	<b>18.63</b>	<b>5.23</b>	<b>15.65</b>	<b>31.71</b>

**Table 21a.** Catch rates (fish/day) of year classes of male striped bass sampled from pound nets in the Rappahannock River, 30 March - 3 May, 1991-2004. Maximum catch rate for each 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	<b>15.61</b>
1996								0.19	11.54	<b>18.11</b>
1995							0.55	2.15	<b>11.46</b>	3.21
1994					0.04	0.51	3.80	<b>6.19</b>	2.68	0.08
1993					2.88	3.83	<b>7.50</b>	1.37	0.07	0.26
1992			0.12	1.22	<b>4.68</b>	2.66	1.15	0.00	0.36	0.11
1991		0.15	0.54	0.48	0.92	<b>1.34</b>	0.05	0.30	0.21	0.05
1990	0.17	0.35	0.96	1.30	<b>2.00</b>	0.94	0.35	0.11	0.00	0.03
1989	0.17	0.40	3.46	<b>3.52</b>	0.08	0.43	0.55	0.04	0.04	0.03
1988	3.25	0.90	<b>7.54</b>	1.11	0.12	0.03	0.20	0.00	0.00	0.00
1987	<b>6.08</b>	0.65	1.23	0.22	0.00	0.09	0.00	0.00		
1986	<b>2.58</b>	0.30	0.15	0.11	0.04	0.00	0.00			
1985	<b>0.50</b>	0.05	0.04	0.04	0.00	0.00				
1984	0.08	<b>0.15</b>	0.08	0.00	0.00					
<1984	0.00	0.00	0.00	0.04	0.00					
N/A	0.25	0.10	0.27	0.41	0.44	0.23	0.25	0.33	0.54	0.32
<b>Total</b>	<b>13.08</b>	<b>3.05</b>	<b>14.39</b>	<b>8.45</b>	<b>11.20</b>	<b>10.06</b>	<b>14.40</b>	<b>10.68</b>	<b>27.69</b>	<b>37.84</b>

**Table 21b.** Catch rates (fish/day) of year classes of male striped bass sampled from pound nets in the Rappahannock River, 30 March - 3 May, 1991-2004. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)			
	2001	2002	2003	2004
2001				3.47
2000			0.76	<b>5.47</b>
1999	0.07	0.44	2.93	<b>5.67</b>
1998	2.74	1.38	3.07	<b>3.37</b>
1997	7.42	1.25	0.30	1.93
1996	4.03	0.25	1.50	2.23
1995	0.10	0.16	0.56	0.53
1994	0.39	0.03	0.23	0.20
1993	0.16	0.03	0.07	0.10
1992	0.19	0.00	0.00	0.07
1991	0.13	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00
N/A	0.00	0.00	0.00	0.40
<b>Total</b>	<b>15.23</b>	<b>3.54</b>	<b>9.42</b>	<b>23.44</b>

**Table 22a.** Catch rates (fish/day) of year classes of female striped bass sampled from pound nets in the Rappahannock River, 30 March - 3 May, 1991-2004. Maximum catch rate for each 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	0.00	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	<b>0.59</b>	0.32	0.26
1989	0.17	0.20	0.12	<b>1.07</b>	0.60	0.46	0.25	0.74	0.32	0.34
1988	0.33	0.70	<b>2.00</b>	1.11	0.48	0.34	1.30	0.89	0.39	0.05
1987	1.92	2.10	<b>2.42</b>	0.93	0.68	0.29	1.00	0.89	0.43	0.05
1986	<b>1.08</b>	0.85	0.50	0.48	0.36	0.09	1.00	0.22	0.04	0.00
1985	<b>1.17</b>	0.25	0.39	0.48	0.08	0.00	0.35	0.15	0.11	0.00
1984	0.42	0.25	<b>0.50</b>	0.33	0.28	0.00	0.35	0.07	0.04	0.00
1983	0.25	0.20	<b>0.46</b>	0.33	0.08	0.03	0.20	0.00	0.00	
>1983	0.58	0.45	<b>0.73</b>	0.26	0.00	0.00	0.00			
N/A	0.25	0.20	0.12	0.15	0.16	0.09	0.25	0.11	0.00	0.00
<b>Total</b>	<b>6.42</b>	<b>5.40</b>	<b>7.36</b>	<b>5.40</b>	<b>3.32</b>	<b>2.24</b>	<b>5.90</b>	<b>4.18</b>	<b>2.19</b>	<b>1.87</b>

**Table 22b.** Catch rates (fish/day) of year classes of female striped bass sampled from pound nets in the Rappahannock River, 30 March - 3 May, 1991-2004. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)			
	2001	2002	2003	2004
2000				0.10
1999		0.06	0.07	<b>0.23</b>
1998		0.06	<b>0.27</b>	0.17
1997	0.07	0.13	0.07	<b>0.30</b>
1996	0.26	0.00	0.37	<b>1.93</b>
1995	0.00	0.63	0.80	<b>1.80</b>
1994	0.19	0.38	<b>1.47</b>	<b>1.47</b>
1993	0.71	0.25	<b>1.37</b>	0.90
1992	0.68	0.19	<b>1.13</b>	1.03
1991	<b>0.68</b>	0.06	0.33	0.17
1990	0.45	0.00	0.26	0.07
1989	0.26	0.00	0.07	0.07
1988	0.10	0.00	0.00	0.00
1987	0.00	0.03	0.03	0.00
N/A	0.00	0.00	0.00	0.00
<b>Total</b>	<b>3.40</b>	<b>1.79</b>	<b>6.24</b>	<b>8.24</b>

**Table 23a.** 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, 1991-2004.

Year Class	Survival (S)									
	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01
2001										
2000										
1999										
1998										
1997										0.480
1996										0.237
1995									0.290	0.914
1994								0.441	0.884	0.884
1993							0.183	0.993	0.993	0.993
1992					0.596	0.437	0.983	0.983	0.983	0.983
1991						0.869	0.869	0.869	0.869	0.869
1990					0.563	0.745	0.745	0.863	0.863	0.863
1989				0.440	0.440	0.899	0.975	0.689	0.689	0.703
1988			0.233	0.877	0.877	0.877	0.593	0.438	0.506	0.506
1987	0.675	0.675	0.315	0.954	0.954	0.954	0.890	0.483	0.116	0.843
1986	0.431	0.972	0.972	0.972	0.972	0.972	0.220	0.182	0.000	-----
1985	0.678	0.678	0.678	0.876	0.876	0.876	0.429	0.733	0.000	-----
1984			0.881	0.881	0.881	0.881	0.200	0.571	0.000	-----
1983			0.717	0.846	0.846	0.846	0.000	-----	-----	-----

**Table 23b.** 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, 1991-2004.

Year Class	Survival (S)			
	01-02	02-03	03-04	Mean
1998		-----	-----	-----
1997	0.668	0.668	0.668	0.615
1996	0.990	0.990	0.990	0.692
1995	0.914	0.914	0.914	0.727
1994	0.884	0.884	0.982	0.801
1993	0.993	0.993	0.699	0.742
1992	0.983	0.983	0.973	0.845
1991	0.638	0.638	0.515	0.753
1990	0.775	0.775	0.259	0.680
1989	0.646	0.646	0.646	0.658
1988		0.000	-----	0.516
1987	0.843	0.843	0.000	0.559
1986			-----	0.581
1985			-----	0.621
1984			-----	0.571
1983			-----	0.610

**Table 24a.** 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, 1991-2004.

Year Class	Survival (S)									
	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01
2001										
2000										
1999										
1998										
1997										0.475
1996										0.223
1995									0.280	0.559
1994								0.433	0.381	0.381
1993							0.183	0.436	0.436	0.615
1992					0.568	0.432	0.560	0.560	0.726	0.726
1991						0.473	0.473	0.700	0.787	0.787
1990					0.470	0.372	0.314	0.522	0.522	0.000
1989				0.539	0.539	0.539	0.270	0.270	0.750	0.000
1988			0.147	0.565	0.565	0.565	0.000	-----	-----	-----
1987	0.450	0.450	0.179	0.640	0.640	0.000	-----	-----	-----	-----
1986	0.116	0.500	0.733	0.364	0.000	-----	-----	-----	-----	-----
1985	0.100	0.894	0.894	0.000	-----	-----	-----	-----	-----	-----
1984		0.533	0.000	-----	-----	-----	-----	-----	-----	-----



**Table 24b.** 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, 1991-2004.

Year Class	Survival (S)			
	01-02	02-03	03-04	Mean
2001		-----	-----	-----
2000		-----	-----	-----
1999		-----	-----	-----
1998		-----	-----	-----
1997	0.638	0.638	0.638	0.593
1996	0.821	0.821	0.821	0.593
1995	0.559	0.559	0.946	0.541
1994	0.768	0.768	0.870	0.564
1993	0.855	0.855	0.855	0.540
1992	0.716	0.716	0.716	0.668
1991		0.000	-----	0.508
1990		0.000	-----	0.353
1989			-----	0.395
1988			-----	0.345
1987			-----	0.372
1986			-----	0.317
1985			-----	0.409
1984			-----	0.238

**Table 25a.** 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, 1991-2004.

Year Class	Survival (S)									
	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01
1998										
1997										
1996										
1995										
1994										
1993										
1992										
1991										
1990								0.914	0.914	0.914
1989				0.912	0.912	0.912	0.912	0.678	0.678	0.765
1988			0.898	0.898	0.898	0.898	0.685	0.438	0.506	0.506
1987			0.802	0.802	0.802	0.802	0.890	0.483	0.116	0.843
1986	0.987	0.987	0.987	0.987	0.987	0.987	0.220	0.181	0.000	-----
1985	0.743	0.743	0.743	0.900	0.900	0.900	0.429	0.733	0.000	-----
1984			0.914	0.914	0.914	0.914	0.200	0.571	0.000	-----
1983			0.717	0.846	0.846	0.846	0.000	-----	-----	-----

**Table 25b.** 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, 1991-2004.

Year Class	Survival (S)			
	01-02	02-03	03-04	Mean
1998	-----	-----	-----	-----
1997	-----	-----	-----	-----
1996	-----	-----	-----	-----
1995	-----	-----	-----	-----
1994	-----	-----	-----	-----
1993	-----	-----	0.657	0.657
1992	-----	-----	0.919	0.919
1991	0.697	0.697	0.515	0.630
1990	0.760	0.760	0.269	0.701
1989	0.646	0.646	0.646	0.762
1988	0.000	-----	-----	0.606
1987	0.843	0.843	0.000	0.623
1986			-----	0.646
1985			-----	0.649
1984			-----	0.587
1983			-----	0.610

**Table 26a.** Catch rates (fish/day) of year classes of striped bass (sexes combined) sampled from gill nets in the Rappahannock River, 30 March - 3 May, 1991-2004. Maximum catch rate for each 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
2000										
1999										
1998										1.47
1997								11.70	18.11	
1996							0.11	<b>35.80</b>	21.26	
1995					0.83	<b>11.67</b>	10.60	5.79		
1994				1.90	29.50	<b>32.78</b>	3.20	1.79		
1993			4.50	20.00	<b>83.00</b>	7.00	0.80	2.00		
1992		2.78	7.00	11.40	<b>14.33</b>	0.78	1.20	0.63		
1991		0.50	2.56	1.88	<b>5.70</b>	2.83	1.33	0.50	0.32	
1990	0.12	0.56	1.50	<b>8.22</b>	7.75	3.50	2.17	0.33	0.10	0.21
1989	1.41	0.78	8.60	<b>27.56</b>	4.50	2.50	0.67	0.33	0.20	0.11
1988	9.53	1.89	<b>25.40</b>	8.22	2.88	1.50	1.17	0.33	0.20	0.11
1987	<b>23.65</b>	5.89	10.40	2.11	1.75	1.60	0.50	0.11	0.10	0.00
1986	<b>11.18</b>	3.33	1.60	0.44	1.38	0.30	0.00	0.22	0.00	0.00
1985	<b>4.12</b>	1.22	0.40	1.67	0.75	0.20	0.00	0.00	0.20	0.00
1984	<b>1.64</b>	0.78	0.40	0.67	0.25	0.00	0.00			
1983	0.35	0.11	<b>1.30</b>	0.56	0.13	0.00	0.00			
>1983	0.47	0.44	0.60	0.22	0.00	0.00				
N/A	0.82	0.00	1.10	2.33	1.00	1.20	2.50	2.00	2.50	0.11
<b>Total</b>	<b>53.29</b>	<b>15.00</b>	<b>51.80</b>	<b>57.34</b>	<b>33.77</b>	<b>49.80</b>	<b>137.50</b>	<b>57.00</b>	<b>67.10</b>	<b>51.91</b>

**Table 26b.** Catch rates (fish/day) of year classes of striped bass (sexes combined) sampled from gill nets in the Rappahannock River, 30 March - 3 May, 1991-2004. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)			
	2001	2002	2003	2004
2002		<b>4.10</b>		
2001		2.70	<b>21.78</b>	
2000		0.50	8.80	<b>16.22</b>
1999	0.90	1.10	<b>16.00</b>	10.74
1998	9.50	8.80	<b>12.60</b>	10.00
1997	<b>27.00</b>	10.20	4.60	10.32
1996	17.70	4.60	4.20	7.58
1995	2.10	3.50	1.60	2.74
1994	1.50	1.20	1.30	1.68
1993	1.00	1.00	0.50	0.64
1992	1.10	0.30	0.00	0.42
1991	0.90	0.30	0.00	0.00
1990	0.10	0.00	0.10	0.00
1989	0.10	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00
1987	0.10	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00
1985	0.20	0.00	0.00	0.00
N/A	0.20	0.80	0.10	0.84
<b>Total</b>	<b>62.40</b>	<b>32.30</b>	<b>52.50</b>	<b>87.06</b>

**Table 27a.** Catch rates (fish/day) of year classes of male striped bass sampled from gill nets in the Rappahannock River, 30 March - 3 May, 1991-2004. Maximum catch rate for each 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
2000										
1999										
1998										1.47
1997									11.60	18.11
1996								0.11	<b>35.70</b>	20.95
1995							0.83	<b>11.67</b>	10.60	5.68
1994						1.90	29.50	<b>32.56</b>	2.60	1.26
1993					4.50	20.00	<b>82.67</b>	6.44	0.60	1.37
1992				2.78	6.88	11.30	<b>14.00</b>	0.56	0.90	0.11
1991			0.50	2.56	1.75	<b>5.60</b>	2.50	0.67	0.30	0.00
1990	0.12	0.44	1.50	<b>8.22</b>	7.00	3.20	1.83	0.22	0.00	0.00
1989	1.29	0.78	8.30	<b>25.33</b>	2.63	1.40	0.50	0.00	0.00	0.00
1988	9.41	1.33	<b>20.30</b>	4.89	1.13	0.50	0.17	0.00	0.10	0.00
1987	<b>22.82</b>	2.78	4.20	0.33	0.13	0.10	0.00	0.00	0.10	0.00
1986	<b>10.23</b>	1.22	0.90	0.11	0.00	0.00	0.00	0.00	0.00	
1985	<b>2.35</b>	0.11	0.00	0.33	0.00	0.00				
1984	<b>0.71</b>	0.11	0.10	0.11	0.00	0.00				
<1984	0.00	0.00	0.10	0.00						
N/A	0.82	0.00	0.80	1.56	0.88	1.20	2.50	1.78	2.30	0.11
<b>Total</b>	<b>47.75</b>	<b>6.77</b>	<b>36.70</b>	<b>46.22</b>	<b>24.90</b>	<b>45.20</b>	<b>134.50</b>	<b>54.00</b>	<b>64.80</b>	<b>49.06</b>

**Table 27b.** Catch rates (fish/day) of year classes of male striped bass sampled from gill nets in the Rappahannock River, 30 March - 3 May, 1991-2004. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)			
	2001	2002	2003	2004
2002		<b>4.10</b>		
2001			2.70	<b>21.78</b>
2000		0.50	8.80	<b>16.00</b>
1999	0.90	1.10	<b>15.90</b>	10.52
1998	9.40	8.70	<b>12.10</b>	9.68
1997	<b>27.00</b>	8.80	4.30	9.68
1996	17.00	3.30	3.80	5.68
1995	1.90	1.40	1.20	0.64
1994	1.30	0.20	0.40	0.32
1993	0.40	0.20	0.00	0.00
1992	0.00	0.00		
1991	0.00			
1990				
1989				
N/A	0.20	0.80	0.10	0.84
<b>Total</b>	<b>58.10</b>	<b>25.00</b>	<b>49.30</b>	<b>79.24</b>

**Table 28a.** Catch rates (fish/day) of year classes of female striped bass sampled from gill nets in the Rappahannock River, 30 March - 3 May, 1991-2004. Maximum catch rate for each 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
2000										
1999										
1998										
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					0.25	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	0.00	0.00	<b>0.75</b>	0.30	0.33	0.11	0.10	0.21
1989	0.12	0.00	0.30	<b>2.22</b>	1.88	1.10	0.17	0.33	0.20	0.11
1988	0.12	0.56	<b>5.10</b>	3.33	1.75	1.00	1.00	0.33	0.10	0.11
1987	0.82	3.11	<b>6.20</b>	1.78	1.63	1.50	0.50	0.11	0.00	0.00
1986	0.94	<b>2.11</b>	1.70	0.33	1.38	0.30	0.00	0.22	0.00	0.00
1985	<b>1.76</b>	1.11	0.40	1.33	0.75	0.20	0.00	0.00	0.20	0.00
1984	<b>0.94</b>	0.67	0.30	0.56	0.25	0.00	0.00			
1983	0.35	0.11	<b>1.30</b>	0.56	0.13	0.00	0.00			
>1983	0.47	0.44	<b>0.50</b>	0.22	0.00	0.00				
N/A	0.00	0.00	0.30	0.78	0.13	0.00	0.00	0.22	0.20	0.00
Total	<b>5.52</b>	<b>8.22</b>	<b>16.10</b>	<b>11.11</b>	<b>9.03</b>	<b>4.60</b>	<b>3.00</b>	<b>3.00</b>	<b>2.30</b>	<b>2.87</b>



**Table 28b.** Catch rates (fish/day) of year classes of female striped bass sampled from gill nets in the Rappahannock River, 30 March - 3 May, 1991-2004. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)			
	2001	2002	2003	2004
2000				<b>0.22</b>
1999			0.10	<b>0.22</b>
1998	0.10	0.10	<b>0.50</b>	0.32
1997	0.00	<b>1.40</b>	0.30	0.64
1996	0.70	1.60	0.40	<b>1.90</b>
1995	0.20	2.10	0.40	<b>2.10</b>
1994	0.20	1.00	0.90	<b>1.36</b>
1993	0.60	<b>0.80</b>	0.50	0.64
1992	<b>1.10</b>	0.30	0.00	0.42
1991	<b>0.90</b>	0.30	0.00	0.00
1990	0.10	0.00	0.10	0.00
1989	0.10	0.00	0.00	
1988	0.00	0.00	0.00	
1987	0.10	0.00	0.00	
N/A	0.00	0.80	0.00	
<b>Total</b>	<b>4.10</b>	<b>8.40</b>	<b>3.20</b>	<b>7.62</b>

**Table 29a.** 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, 1991-2004.

Year Class	Survival (S)									
	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01
1999										
1998										
1997										
1996								0.594	0.833	
1995								0.908	0.546	0.777
1994								0.098	0.559	0.984
1993							0.084	0.535	0.535	0.707
1992							0.289	0.289	0.957	0.957
1991						0.496	0.470	0.878	0.878	0.878
1990				0.943	0.452	0.620	0.152	0.798	0.798	0.781
1989				0.163	0.556	0.268	0.500	0.606	0.550	0.909
1988			0.324	0.350	0.521	0.780	0.282	0.606	0.550	0.000
1987	0.663	0.663	0.203	0.829	0.914	0.313	0.220	0.969	0.969	0.969
1986	0.298	0.480	0.928	0.928	0.217	0.856	0.856	0.000	-----	-----
1985	0.740	0.740	0.740	0.449	0.802	0.802	0.802	0.802	0.802	0.802
1984	0.476	0.927	0.927	0.373	0.000	-----	-----	-----	-----	-----
1983			0.431	0.232	0.000	-----	-----	-----	-----	-----

**Table 29b.** 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, 1991-2004.

Year Class	Survival (S)			
	01-02	02-03	03-04	Mean
1999	-----	-----	0.671	0.671
1998	-----	-----	0.794	0.794
1997	0.726	0.726	0.726	0.726
1996	0.754	0.754	0.754	0.637
1995	0.777	0.884	0.884	0.785
1994	0.984	0.984	0.984	0.610
1993	0.707	0.800	0.800	0.499
1992	0.725	0.725	0.725	0.603
1991	0.333	0.000	-----	0.528
1990	0.781	0.781	0.000	0.489
1989		0.000	-----	0.418
1988		-----	-----	0.408
1987		0.000	-----	0.570
1986		-----	-----	0.530
1985		0.000	-----	0.659
1984				0.497
1983				0.208

**Table 30a.** 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, 1991-2004.

Year Class	Survival (S)									
	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01
1998										
1997										
1996									0.587	0.811
1995								0.908	0.536	0.335
1994								0.080	0.707	0.707
1993							0.078	0.461	0.461	0.292
1992							0.254	0.254	0.122	0.000
1991						0.446	0.268	0.448	0.000	-----
1990				0.852	0.457	0.572	0.120	0.000	-----	-----
1989				0.104	0.532	0.357	0.000	-----	-----	-----
1988			0.241	0.231	0.442	0.340	0.767	0.767	0.000	-----
1987	0.429	0.429	0.079	0.394	0.937	0.937	0.937	0.937	0.000	-----
1986	0.119	0.738	0.122	0.000	0.000	-----	-----	-----	-----	-----
1985	0.520	0.520	0.520	0.000	-----	-----	-----	-----	-----	-----
1984	0.537	0.537	0.537	0.000	-----	-----	-----	-----	-----	-----

**Table 30b.** 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, 1991-2004.

Year Class	Survival (S)			
	01-02	02-03	03-04	Mean
1999	-----	-----	0.701	0.701
1998	-----	-----	0.800	0.800
1997	0.710	0.710	0.710	0.710
1996	0.694	0.694	0.694	0.692
1995	0.737	0.857	0.533	0.616
1994	0.555	0.555	0.800	0.461
1993	0.500	0.000	-----	0.283
1992		0.000	-----	0.150
1991				0.276
1990				0.366
1989				0.231
1988				0.373
1987				0.520
1986				0.215
1985				0.369
1984				0.382

**Table 31a.** Estimated annual and geometric mean survival (S) rates for year classes of female striped bass sampled from gill nets in the Rappahannock River, 30 March - 3 May, 1991-2004.

Year Class	Survival (S)									
	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01
1998										
1997										
1996										
1995										
1994										
1993										
1992										
1991										
1990					0.663	0.663	0.860	0.860	0.860	0.781
1989				0.847	0.585	0.548	0.548	0.606	0.550	0.909
1988			0.654	0.526	0.756	0.756	0.330	0.577	0.577	0.000
1987			0.287	0.916	0.920	0.333	0.220	0.969	0.969	0.969
1986		0.806	0.901	0.901	0.217	0.856	0.856	0.000	-----	-----
1985	0.911	0.911	0.911	0.564	0.719	0.719	0.719	0.719	0.000	-----
1984	0.713	0.914	0.914	0.446	0.000	-----	-----	-----	-----	-----
1983			0.431	0.232	0.000	-----	-----	-----	-----	-----
1982		0.431	0.232	0.000	-----	-----	-----	-----	-----	-----

**Table 31b.** Estimated annual and geometric mean survival (S) rates for year classes of female striped bass sampled from gill nets in the Rappahannock River, 30 March - 3 May, 1991-2004.

Year Class	Survival (S)			
	01-02	02-03	03-04	Mean
1999				-----
1998	-----	-----	0.640	0.640
1997		0.457	0.457	0.457
1996	-----	-----	-----	-----
1995	-----	-----	-----	-----
1994	-----	-----	-----	-----
1993	-----	0.894	0.894	0.894
1992	0.725	0.725	0.725	0.725
1991	0.333	0.000	-----	0.155
1990	0.781	0.781	0.000	0.669
1989		0.000	-----	0.550
1988		0.000	-----	0.501
1987		0.000	-----	0.572
1986				0.604
1985				0.659
1984				0.554
1983				0.208
1982				0.200

**Table 32a.** Catch rates (fish/day) of year classes of striped bass (sexes combined) sampled from gill nets in the James River, 30 March - 3 May, 1994-2004. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)									
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
2001										0.86
2000									0.44	15.43
1999								0.40	3.78	<b>31.29</b>
1998							1.58	13.50	<b>29.67</b>	28.86
1997						0.20	21.58	<b>42.40</b>	39.33	8.00
1996						9.10	<b>73.26</b>	32.60	11.00	2.86
1995					1.22	10.30	<b>38.32</b>	8.40	2.56	1.57
1994			0.10	1.55	7.11	<b>11.70</b>	11.05	2.60	1.11	0.57
1993		0.67	1.70	4.44	5.22	<b>6.10</b>	2.10	1.60	0.89	0.86
1992		<b>4.33</b>	2.90	3.33	3.00	2.90	1.37	1.00	0.89	0.28
1991	2.40	<b>9.00</b>	4.50	2.00	1.67	2.20	0.63	1.50	0.22	0.14
1990	<b>12.40</b>	11.11	3.10	2.00	0.78	1.40	0.42	0.50	0.11	0.14
1989	<b>12.00</b>	9.78	2.60	0.89	1.11	1.20	0.11	0.00	0.00	0.14
1988	<b>3.20</b>	2.67	1.00	1.44	0.78	0.40	0.11	0.00	0.00	0.00
1987	0.80	<b>2.67</b>	1.00	1.11	0.67	1.00	0.00	0.00		
1986	0.80	<b>1.78</b>	0.80	0.33	0.11	0.30	0.00	0.00		
1985	0.80	<b>1.22</b>	0.30	0.22	0.11	0.10	0.00	0.00		
1984	<b>1.20</b>	0.78	0.20	0.11	0.00	0.00				
>1984	<b>1.20</b>	0.56	0.00	0.00						
N/A	0.80	2.00	0.20	0.33	0.33	1.30	0.74	0.50	1.56	0.28
<b>Total</b>	<b>35.60</b>	<b>46.56</b>	<b>18.40</b>	<b>17.78</b>	<b>22.11</b>	<b>48.20</b>	<b>151.27</b>	<b>105.00</b>	<b>91.56</b>	<b>91.28</b>



**Table 32b.** Catch rates (fish/day) of year classes of striped bass (sexes combined) sampled from gill nets in the James River, 30 March - 3 May, 1994-2004. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)
	2004
2002	<b>0.36</b>
2001	<b>30.54</b>
2000	<b>48.00</b>
1999	28.00
1998	11.82
1997	4.08
1996	3.56
1995	1.36
1994	1.00
1993	0.28
1992	0.38
1991	0.00
1990	
1989	
1988	
1987	
1986	
1985	
1984	
>1984	
N/A	2.36
<b>Total</b>	<b>131.56</b>

**Table 33a.** Catch rates (fish/day) of year classes of male striped bass sampled from gill nets in the James River, 30 March - 3 May, 1994-2004. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)									
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
2001										0.86
2000									0.44	15.43
1999								0.30	3.78	<b>31.29</b>
1998							1.58	13.50	<b>28.89</b>	26.00
1997						0.20	21.47	<b>41.90</b>	35.56	7.57
1996						7.30	<b>72.74</b>	31.00	8.33	2.57
1995					1.22	8.00	<b>37.05</b>	7.60	2.00	1.00
1994			0.10	1.56	6.78	5.20	<b>10.53</b>	1.70	0.67	0.00
1993		0.67	1.70	<b>3.89</b>	3.78	2.50	1.68	1.10	0.11	0.14
1992		<b>4.22</b>	2.80	2.33	1.67	1.10	1.16	0.20	0.00	0.00
1991	2.40	<b>7.89</b>	3.60	1.44	1.00	0.10	0.00	0.40	0.00	0.00
1990	<b>10.60</b>	6.33	1.50	1.33	0.22	0.30	0.00	0.00		
1989	<b>8.00</b>	2.33	0.70	0.44	0.00	0.00	0.00	0.00		
1988	<b>1.40</b>	0.56	0.30	0.11	0.11	0.10	0.00	0.00		
1987	0.00	<b>0.44</b>	0.10	0.00	0.00	0.00				
1986	0.00	<b>0.11</b>	0.00	0.00						
N/A	0.80	1.44	0.10	0.00	0.11	0.50	0.74	0.40	1.56	0.28
<b>Total</b>	<b>23.20</b>	<b>24.00</b>	<b>10.90</b>	<b>11.11</b>	<b>14.89</b>	<b>25.30</b>	<b>146.95</b>	<b>98.10</b>	<b>81.33</b>	<b>85.14</b>

**Table 33b.** Catch rates (fish/day) of year classes of male striped bass sampled from gill nets in the James River, 30 March - 3 May, 1994-2004. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)
	2004
2002	<b>0.36</b>
2001	<b>30.54</b>
2000	<b>47.82</b>
1999	27.64
1998	10.46
1997	3.90
1996	2.28
1995	0.54
1994	1.00
1993	0.00
1992	0.10
1991	0.00
1990	
1989	
1988	
1987	
1986	
1985	
1984	
>1984	
N/A	2.36
<b>Total</b>	<b>127.00</b>

**Table 34a.** Catch rates (fish/day) of year classes of female striped bass sampled from gill nets in the James River, 30 March - 3 May, 1994-2004. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)									
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
2000										
1999								0.10	0.00	0.00
1998								0.00	0.78	<b>2.86</b>
1997							0.11	0.50	<b>3.78</b>	0.43
1996						1.80	0.53	1.60	<b>2.67</b>	0.28
1995						<b>2.30</b>	1.26	0.80	0.56	0.57
1994					0.33	<b>6.50</b>	0.53	0.90	0.44	0.57
1993				0.56	1.44	<b>3.60</b>	0.42	0.50	0.78	0.71
1992		0.11	0.10	1.00	1.33	<b>1.80</b>	0.21	0.80	0.89	0.28
1991		1.11	0.90	0.56	0.67	<b>2.10</b>	0.63	1.10	0.22	0.14
1990	1.80	<b>4.78</b>	1.60	0.67	0.56	1.10	0.42	0.50	0.11	0.14
1989	4.00	<b>7.44</b>	1.90	0.44	1.11	1.20	0.11	0.00	0.00	0.14
1988	<b>2.20</b>	2.11	0.70	1.33	0.67	0.30	0.11	0.00	0.00	0.00
1987	0.80	<b>2.22</b>	0.90	1.11	0.67	1.00	0.00	0.00		
1986	0.80	<b>1.67</b>	0.80	0.33	0.11	0.30	0.00	0.00		
1985	0.40	<b>1.22</b>	0.30	0.22	0.11	0.10	0.00	0.00		
1984	<b>1.20</b>	0.78	0.20	0.11	0.00	0.00				
1983	<b>0.80</b>	0.33	0.00	0.00						
1982	<b>0.40</b>	0.22	0.00	0.00						
N/A	0.00	0.56	0.10	0.33	0.22	0.80	0.00	0.10	0.00	0.00
Total	<b>12.40</b>	<b>22.56</b>	<b>7.50</b>	<b>6.67</b>	<b>7.22</b>	<b>22.90</b>	<b>4.33</b>	<b>6.90</b>	<b>10.22</b>	<b>6.14</b>

**Table 34b.** Catch rates (fish/day) of year classes of female striped bass sampled from gill nets in the James River, 30 March - 3 May, 1994-2004. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)
	2004
2001	
2000	<b>0.18</b>
1999	<b>0.18</b>
1998	0.36
1997	0.18
1996	1.28
1995	0.82
1994	1.00
1993	0.28
1992	0.28
1991	0.00
1990	
1989	
1988	
1987	
1986	
1985	
1984	
>1984	
N/A	
<b>Total</b>	<b>4.56</b>

**Table 35.** 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, 1994-2004.

Year Class	Survival (S)										Mean
	94-95	95-96	96-97	97-98	98-99	99-00	00-01	01-02	02-03	03-04	
1999										0.970	0.970
1998									0.973	0.410	0.632
1997								0.928	0.203	0.510	0.458
1996						0.445	0.751	0.751	0.751		0.659
1995						0.219	0.305	0.613	0.866		0.434
1994						0.944	0.235	0.427	0.949	0.949	0.611
1993						0.344	0.762	0.556	0.966	0.326	0.540
1992		0.877	0.877	0.901	0.967	0.472	0.730	0.890	0.653	0.653	0.763
1991		0.500	0.788	0.788	0.788	0.826	0.826	0.147	0.636	0.000	0.557
1990	0.896	0.279	0.645	0.837	0.837	0.598	0.598	0.529	0.529	0.000	0.551
1989	0.815	0.266	0.773	0.773	0.773	0.584	0.584	0.584	0.584	0.000	0.551
1988				0.834	0.734	0.734	0.542	0.513	0.275	0.000	0.491
1987					-----	0.645	0.645	0.948	0.948	0.000	0.593
1986					-----	0.449	0.413	0.953	0.953	0.000	0.508
1985					-----	0.245	0.733	0.500	0.909	0.000	0.440
1984							0.650	0.256	0.550	0.000	0.339
1983									0.413	0.000	0.189
1982									0.555	0.000	0.245

**Table 36.** Estimated annual and geometric mean survival (S) rates for year classes of male striped bass sampled from gill nets (mile 62) in the James River, 30 March - 3 May, 1994-2004.

Year Class	Survival (S)										
	94-95	95-96	96-97	97-98	98-99	99-00	00-01	01-02	02-03	03-04	Mean
1999										0.883	0.883
1998									0.900	0.402	0.601
1997								0.849	0.213	0.515	0.453
1996						0.426	0.269	0.309	0.887		0.421
1995						0.205	0.263	0.500	0.540		0.347
1994						0.161	0.843	0.843	0.843		0.557
1993				0.971	0.662	0.672	0.655	0.357	0.357	0.000	0.495
1992		0.663	0.833	0.717	0.833	0.833	0.172	0.794	0.794	0.794	0.562
1991				0.456	0.401	0.694	0.737	0.737	0.737	0.000	0.513
1990					0.597	0.237	0.887	0.474	0.474	0.000	0.417
1989						0.292	0.300	0.629	0.000		0.286
1988					0.400	0.535	0.606	0.606	0.909	0.000	0.482
1987									0.227	0.000	0.108
1986										0.000	0.000

**Table 37.** Estimated annual and geometric mean survival (S) rates for year classes of female striped bass sampled from gill nets (mile 62) in the James River, 30 March - 3 May, 1994-2004.

Year Class	Survival (S)										
	94-95	95-96	96-97	97-98	98-99	99-00	00-01	01-02	02-03	03-04	Mean
1999											-----
1998									0.126		0.126
1997								0.114	0.419		0.219
1996								0.692	0.692		0.692
1995						0.548	0.898	0.898	0.898	0.898	0.813
1994						0.688	0.688	0.688	0.688	0.688	0.688
1993						0.601	0.601	0.601	0.910	0.394	0.600
1992						0.791	0.791	0.791	0.561	0.561	0.689
1991						0.724	0.724	0.200	0.636	0.000	0.423
1990		0.335	0.883	0.883	0.883	0.674	0.674	0.529	0.529	0.000	0.571
1989		0.255	0.858	0.858	0.858	0.613	0.613	0.613	0.613	0.000	0.559
1988				0.960	0.795	0.795	0.504	0.448	0.367	0.000	0.520
1987				-----		0.707	0.707	0.949	0.949	0.000	0.617
1986				-----		0.479	0.413	0.953	0.953	0.000	0.515
1985				-----		0.245	0.733	0.500	0.909	0.000	0.440
1984							0.650	0.286	0.550	0.000	0.347
1983									0.413	0.000	0.189
1982									0.550	0.000	0.245



**Table 38.** Comparison of the area under the catch curve (fish/ day) of the 1987-1996 years classes of striped bass from pound nets in the Rappahannock River, 1991-2004.

age	year class										mean
	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	
2			0.2	0.2	0.3	0.7	1.5	0.3	0.3	0.1	<b>0.5</b>
3		3.6	0.8	0.7	0.8	5.5	5.5	4.2	2.5	11.6	<b>4.0</b>
4	8.0	5.2	4.4	1.8	1.8	8.4	13.6	10.5	14.0	29.7	<b>10.2</b>
5	10.8	14.7	8.9	3.1	3.4	9.6	15.1	13.3	17.3	34.0	<b>13.3</b>
6	14.4	17.0	9.6	5.3	3.5	9.7	15.2	13.4	17.4	34.3	<b>14.3</b>
7	15.6	17.6	10.5	6.6	4.0	10.2	15.7	14.0	18.1	36.1	<b>15.2</b>
8	16.2	17.9	11.3	7.3	4.4	10.7	16.6	14.4	19.5	40.3	<b>16.2</b>
9	16.6	19.4	12.1	8.0	4.8	11.5	16.8	16.1	21.8		<b>17.2</b>
10	17.6	20.3	12.5	8.3	5.6	11.7	18.3	17.8			<b>18.1</b>
11	18.5	20.7	12.8	8.6	5.7	12.9	19.3				<b>18.8</b>
12	18.9	20.7	13.1	9.0	6.0	14.0					<b>19.2</b>
13	19.0	20.7	13.1	9.0	6.2						<b>19.3</b>
14	19.0	20.7	13.2	9.3							<b>19.3</b>
15	19.0	20.7	13.2								<b>19.3</b>
<b>area</b>	<b>19.0</b>	<b>19.1</b>	<b>13.2</b>	<b>9.3</b>	<b>6.2</b>	<b>14.0</b>	<b>19.3</b>	<b>18.0</b>	<b>21.8</b>	<b>40.3</b>	<b>19.3</b>

**Table 39.** Comparison of the area under the catch curve (fish/ day) of the 1987-1996 years classes of striped bass from gill nets in the Rappahannock River, 1991-2004.

age	year class										mean
	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	
2			0.7	0.3	0.3	1.4	2.3	1.0	0.4	0.1	<b>0.8</b>
3		9.5	1.5	1.8	2.8	8.4	22.3	30.5	12.1	35.9	<b>13.9</b>
4	23.7	11.4	10.1	10.0	4.7	19.8	105.3	63.2	22.7	57.1	<b>34.2</b>
5	29.6	36.8	37.6	17.8	10.4	34.1	112.3	66.4	28.5	74.8	<b>46.2</b>
6	40.0	45.0	42.1	21.3	13.2	34.9	113.1	68.2	30.6	79.4	<b>50.2</b>
7	42.1	47.9	44.6	23.5	14.6	36.1	115.1	69.7	34.1	83.6	<b>52.5</b>
8	43.9	49.4	45.3	23.8	15.1	36.7	116.1	70.9	35.7	91.2	<b>54.2</b>
9	45.5	50.6	45.6	23.9	15.4	37.8	117.1	72.2	38.4		<b>55.3</b>
10	46.0	50.9	45.8	24.1	16.3	38.1	117.6	73.9			<b>56.0</b>
11	46.1	51.1	46.0	24.2	16.6	38.1	118.2				<b>56.2</b>
12	46.2	51.2	46.1	24.2	16.6	38.6					<b>56.3</b>
13	46.2	51.2	46.1	24.3	16.6						<b>56.3</b>
14	46.3	51.2	46.1	24.3							<b>56.4</b>
15	46.3	51.2	46.1								<b>56.4</b>
<b>area</b>	<b>46.3</b>	<b>51.2</b>	<b>46.1</b>	<b>24.3</b>	<b>16.6</b>	<b>38.6</b>	<b>118.2</b>	<b>73.9</b>	<b>38.4</b>	<b>91.2</b>	<b>56.4</b>

**Table 40.** Comparison of the area under the catch curve (fish/ day) of the 1987-1996 years classes of striped bass from gill nets in the James River, 1994-2004.

age	year class										mean
	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	
2						0.0	0.3	0.1	0.0	0.0	<b>0.1</b>
3					2.4	4.3	2.0	1.6	1.2	9.1	<b>3.5</b>
4				12.4	11.4	7.2	6.5	8.7	11.5	82.4	<b>20.6</b>
5			12.0	23.5	15.9	10.5	11.7	20.4	49.8	115.0	<b>35.4</b>
6		3.2	21.8	26.6	17.9	13.5	17.8	31.5	58.4	126.0	<b>41.9</b>
7	0.8	5.9	24.4	28.6	19.6	16.4	19.9	34.1	60.8	128.8	<b>44.2</b>
8	3.5	6.9	25.3	29.4	21.8	17.8	21.5	35.2	62.4	132.4	<b>45.9</b>
9	4.5	8.3	26.4	30.8	22.4	18.8	22.4	35.7	63.7		<b>46.9</b>
10	5.6	9.1	27.6	31.2	23.9	19.7	23.3	36.7			<b>47.9</b>
11	6.3	9.5	27.7	31.7	24.1	20.0	23.5				<b>48.2</b>
12	7.3	9.6	27.7	31.8	24.3	20.4					<b>48.4</b>
13	7.3	9.6	27.7	32.0	24.3						<b>48.4</b>
14	7.3	9.6	27.8	32.0							<b>48.4</b>
15	7.3	9.6	27.8								<b>48.4</b>
<b>area</b>	<b>7.3</b>	<b>9.6</b>	<b>27.8</b>	<b>32.0</b>	<b>24.3</b>	<b>20.4</b>	<b>23.5</b>	<b>36.7</b>	<b>63.7</b>	<b>132.4</b>	<b>48.4</b>

**Table 41a.** Back-calculated length-at-age (FL, in mm) for striped bass sampled from the James and Rappahannock rivers during spring, 2004.

Year Class	n	length-at-age (FL, in mm)							
		1	2	3	4	5	6	7	8
2003	0								
2002	44	172.6							
2001	647	168.8	278.2						
2000	849	161.8	268.8	368.8					
1999	585	155.6	261.0	360.7	452.9				
1998	333	153.7	256.6	357.1	449.9	531.7			
1997	209	156.7	258.7	358.8	455.1	548.2	629.8		
1996	236	155.1	251.5	343.6	435.9	527.0	613.2	690.3	
1995	110	152.8	249.1	338.7	426.7	510.6	595.6	675.4	745.5
1994	77	151.0	244.2	327.3	410.7	491.5	570.1	647.4	724.9
1993	39	152.4	240.5	325.8	407.1	486.6	562.8	637.9	711.1
1992	41	154.7	246.7	330.8	411.8	492.9	570.4	642.4	713.0
1991	5	151.1	239.7	316.5	394.6	472.0	543.2	610.3	676.9
1990	2	145.5	228.0	313.7	394.3	464.8	529.7	599.4	668.4
1989	2	156.6	236.1	312.4	410.5	501.2	578.6	650.4	711.7
all	3,179	159.7	264.0	358.0	444.0	525.2	604.8	671.5	728.0

**Table 41b.** Back-calculated length-at-age (FL, in mm) for striped bass sampled from the James and Rappahannock rivers during spring, 2004.

Year Class	n	length-at-age (FL, in mm)							
		9	10	11	12	13	14	15	16
2003	0								
2002	44								
2001	647								
2000	849								
1999	585								
1998	333								
1997	209								
1996	236								
1995	110								
1994	77	793.2							
1993	39	781.1	847.5						
1992	41	782.9	847.1	901.7					
1991	5	745.6	810.1	877.2	934.6				
1990	2	726.9	790.3	847.3	910.4	962.0			
1989	2	774.5	837.7	895.3	959.1	1,001.3	1,037.7		
all	3,179	785.3	843.7	896.8	934.7	981.6	1,037.7		

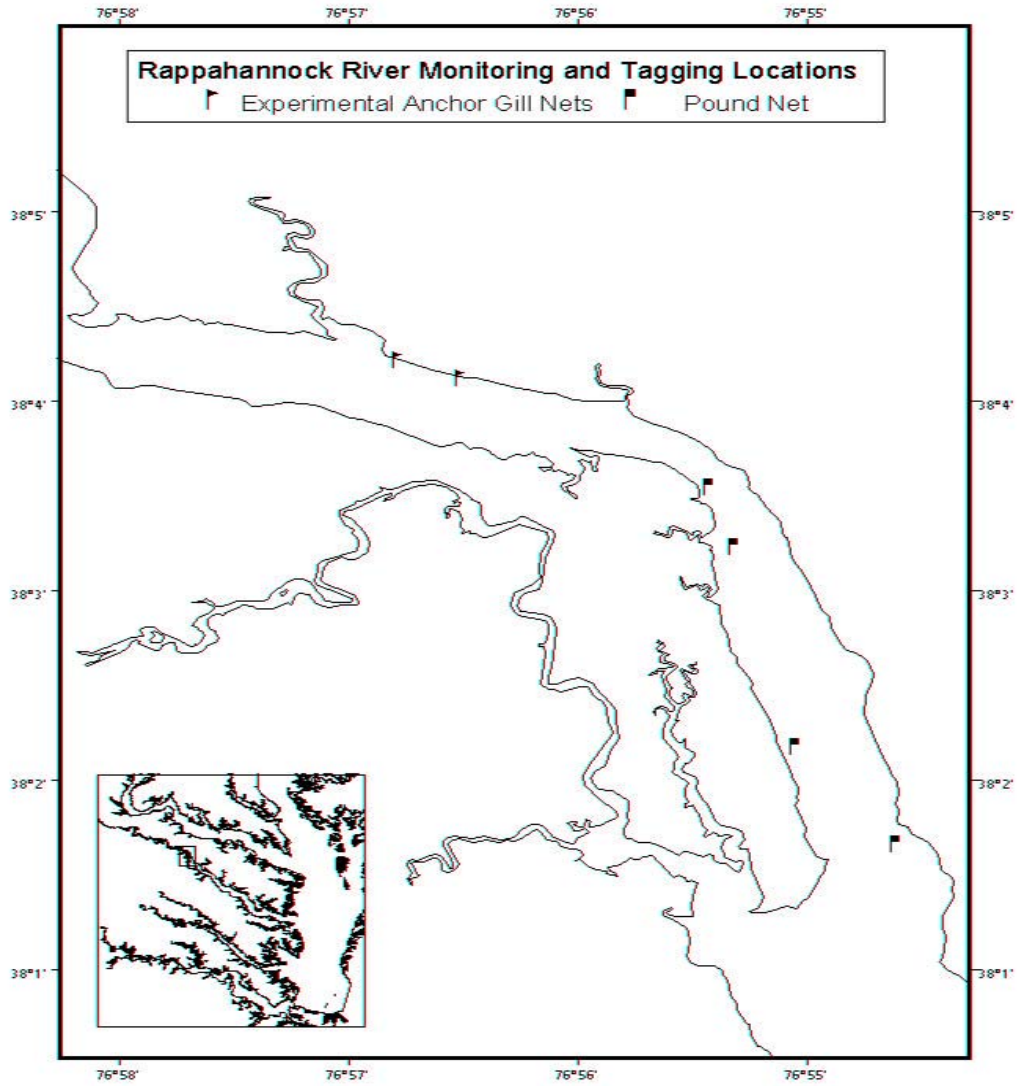
**Table 42.** Data matrix comparing scale (SA) and otolith ages for chi-square test of symmetry. Values are the number of the respective readings of each combination of ages. Values along the main diagonal (methods agree) are highlighted for reference.

S A	Otolith age																			
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
2	<b>0</b>																			
3		<b>12</b>	1																	
4		4	<b>11</b>																	
5			6	<b>1</b>	5	1		2												
6				1	<b>3</b>	3	2													
7						<b>3</b>	11	1												
8							<b>27</b>	8	4											
9							14	<b>11</b>	2	5										
10							4	6	<b>6</b>	21	7									
11							1	3	1	<b>9</b>	11	1	1							
12								4	1	13	<b>7</b>									
13										4	12	<b>1</b>				1				1
14										1	4	1	<b>0</b>	1			1			
15														<b>0</b>	2	4	1			
16															<b>0</b>	1				1
17																<b>0</b>				
18																	<b>0</b>			
19																		<b>0</b>		
20																			<b>0</b>	
21																				<b>0</b>

**Table 43.** Relative contributions of striped bass age classes as determined by ageing specimens (n = 270) by reading both their scales and ooliths.

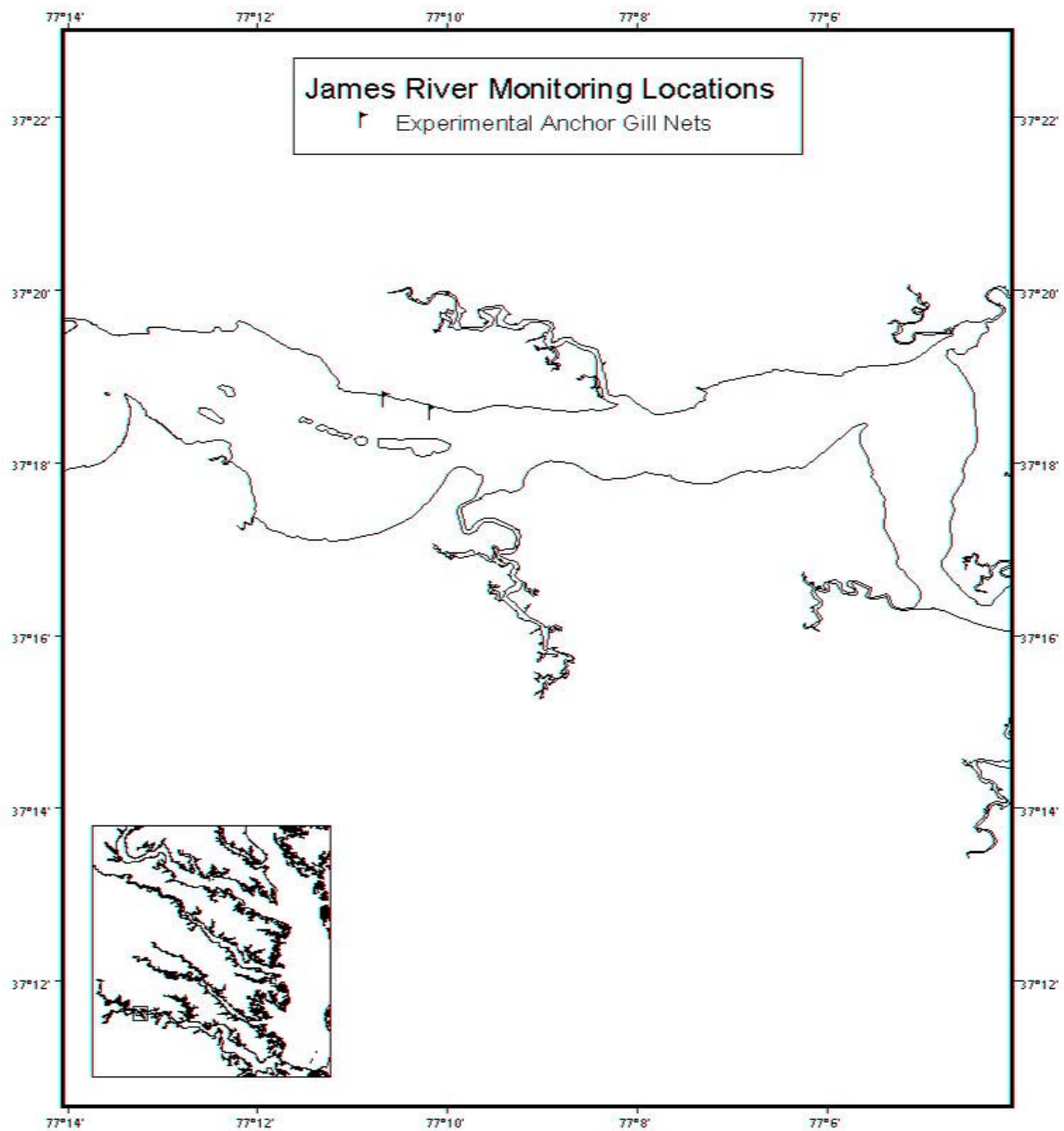
Age	scale		otolith	
	n	prop.	n	.prop
2	0	.0000	0	.0000
3	13	.0481	16	.0593
4	15	.0556	18	.0667
5	15	.0556	2	.0074
6	9	.0333	8	.0296
7	15	.0556	7	.0259
8	39	.1444	59	.2185
9	32	.1185	35	.1296
10	44	.1630	14	.0519
11	27	.1000	53	.1963
12	25	.0926	41	.1519
13	19	.0704	3	.0111
14	8	.0296	1	.0037
15	8	.0296	1	.0037
16	1	.0037	2	.0074
17	0	.0000	6	.0222
18	0	.0000	2	.0074
19	0	.0000	0	.0000
20	0	.0000	0	.0000
21	0	.0000	2	.0074
	$\bar{Age} = 9.13$		$\bar{Age} = 9.29$	

**Figure 1.** Locations of the commercial pound nets and experimental gill nets sampled in spring spawning stock assessments of striped bass in the Rappahannock River, 1991-2004.

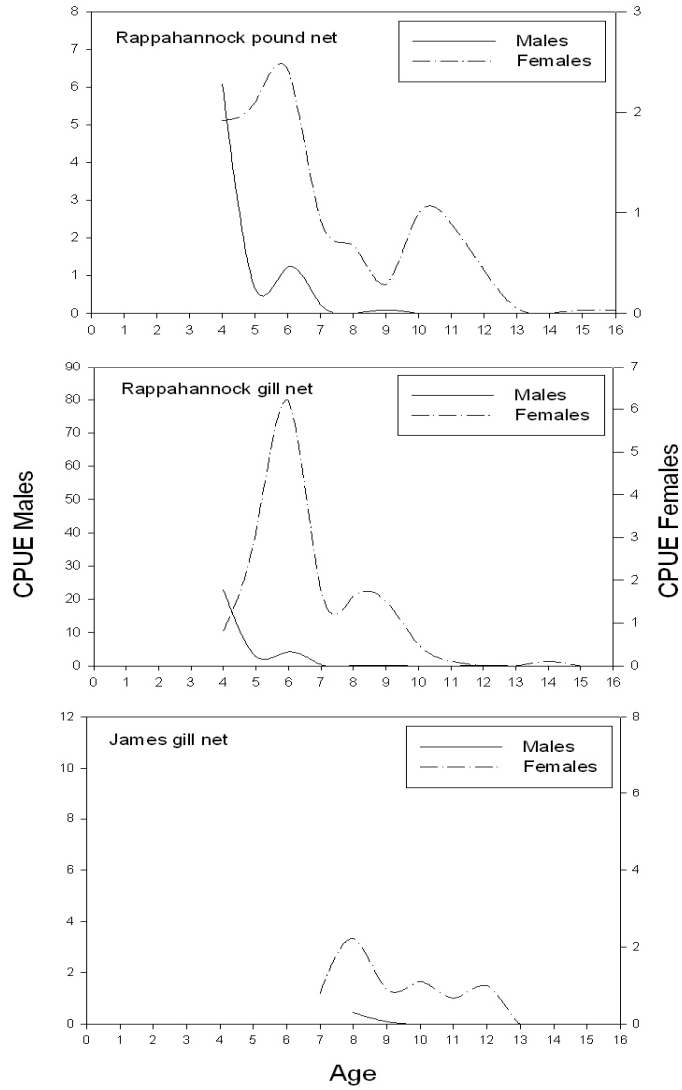




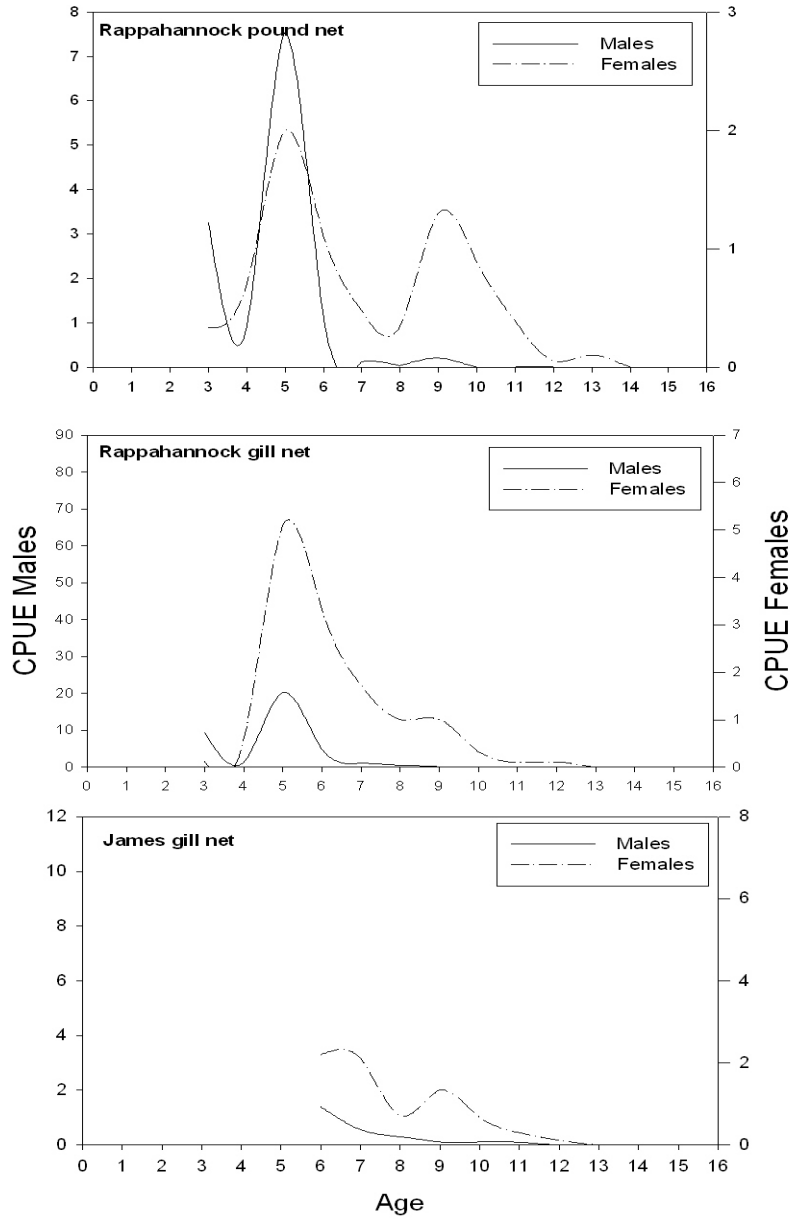
**Figure 2.** Locations of the experimental anchor gill nets sampled in spring spawning stock assessments of striped bass in the James River, spring 2004.



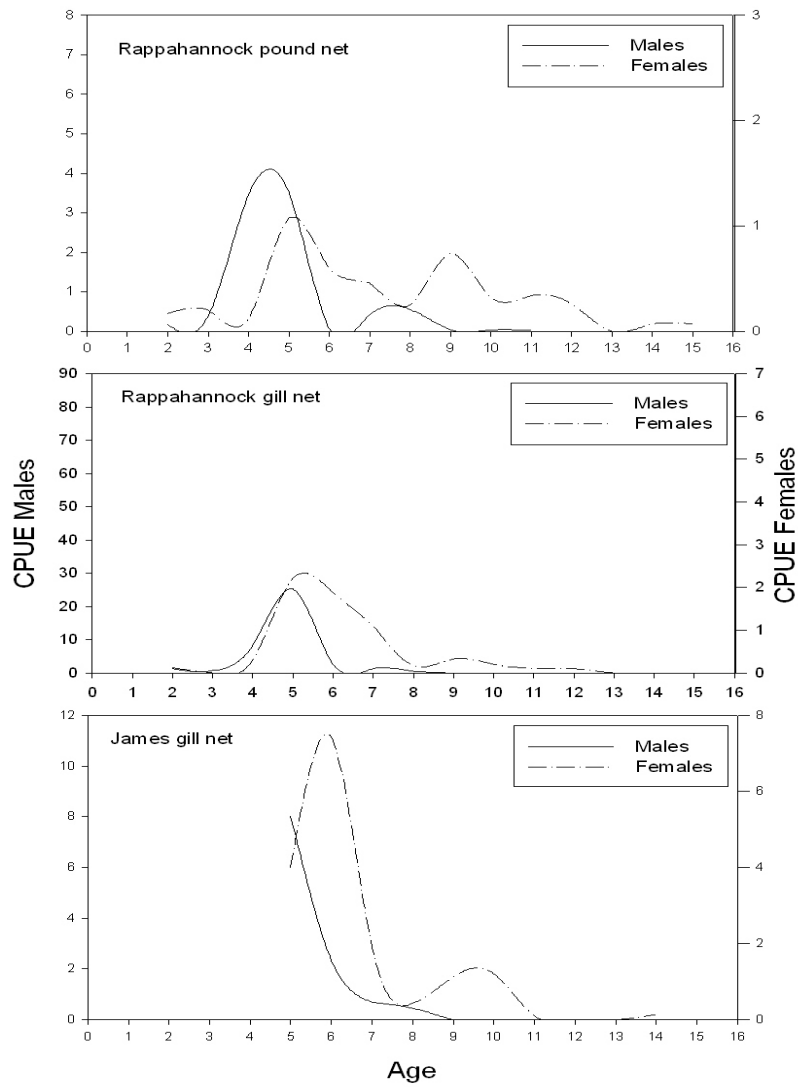
**Figure 3.** Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1987 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1991-2004.



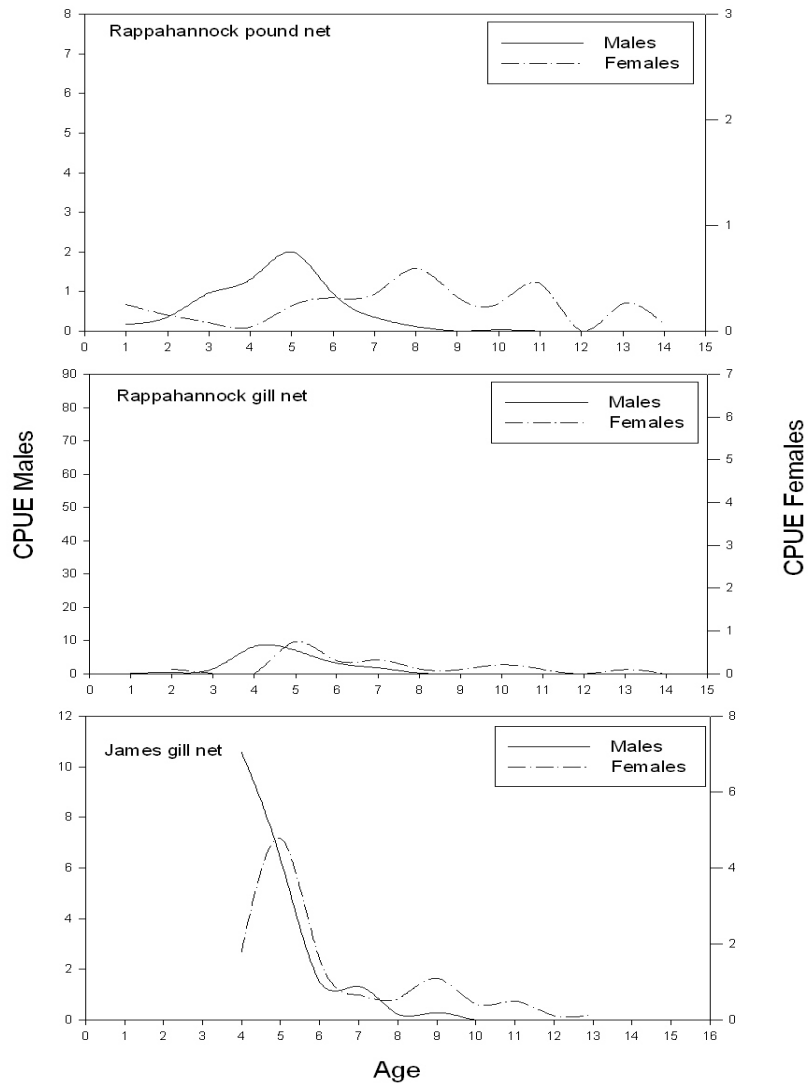
**Figure 4.** Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1988 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1991-2004.



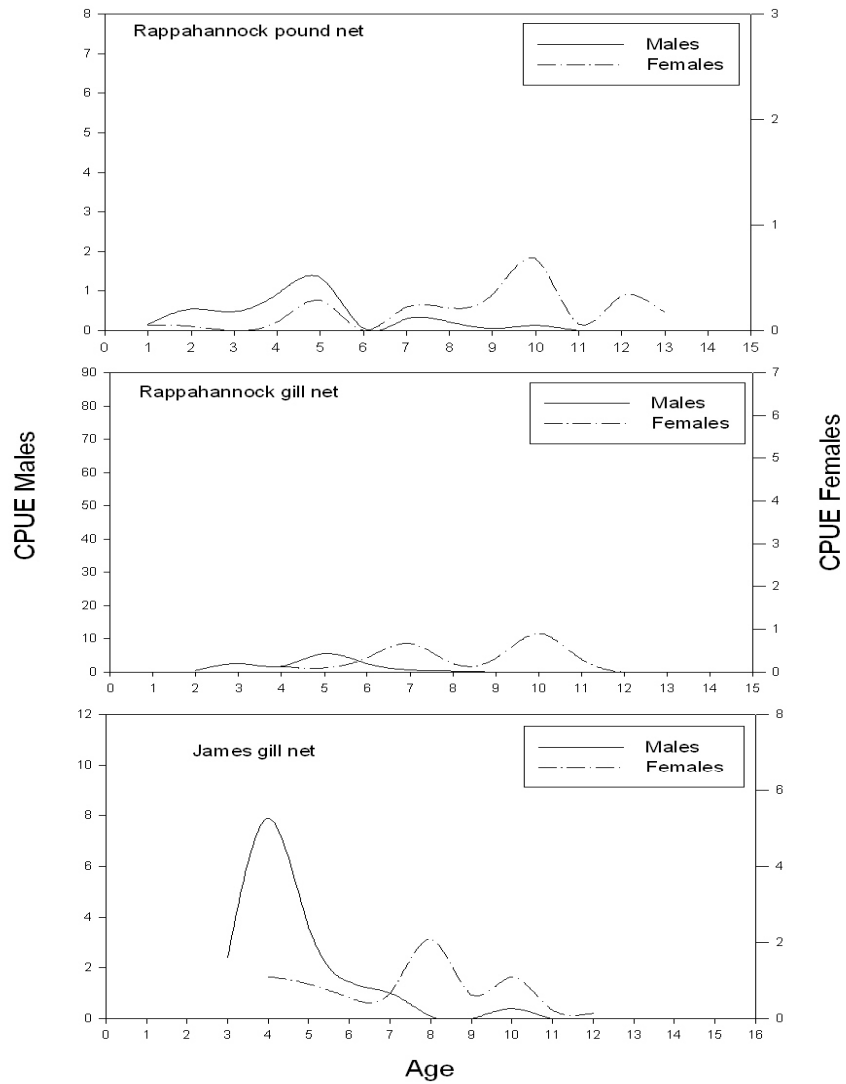
**Figure 5.** Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1989 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1991-2004.



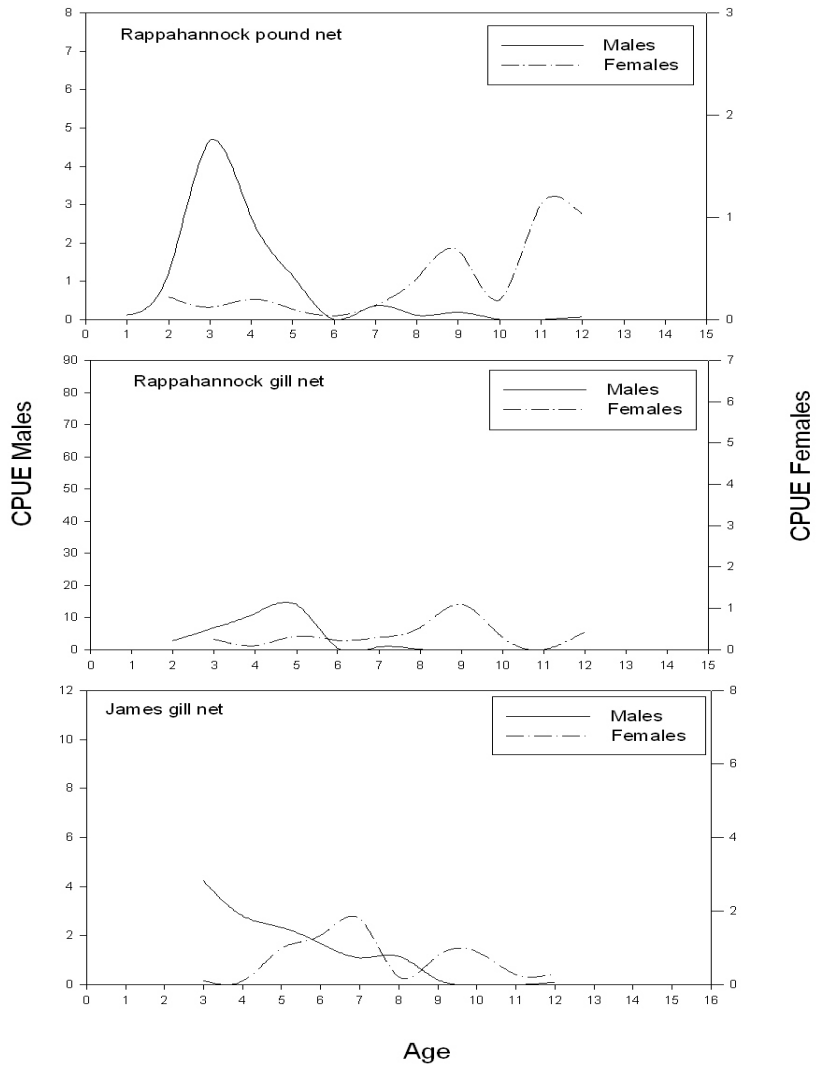
**Figure 6.** Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1990 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1991-2004.



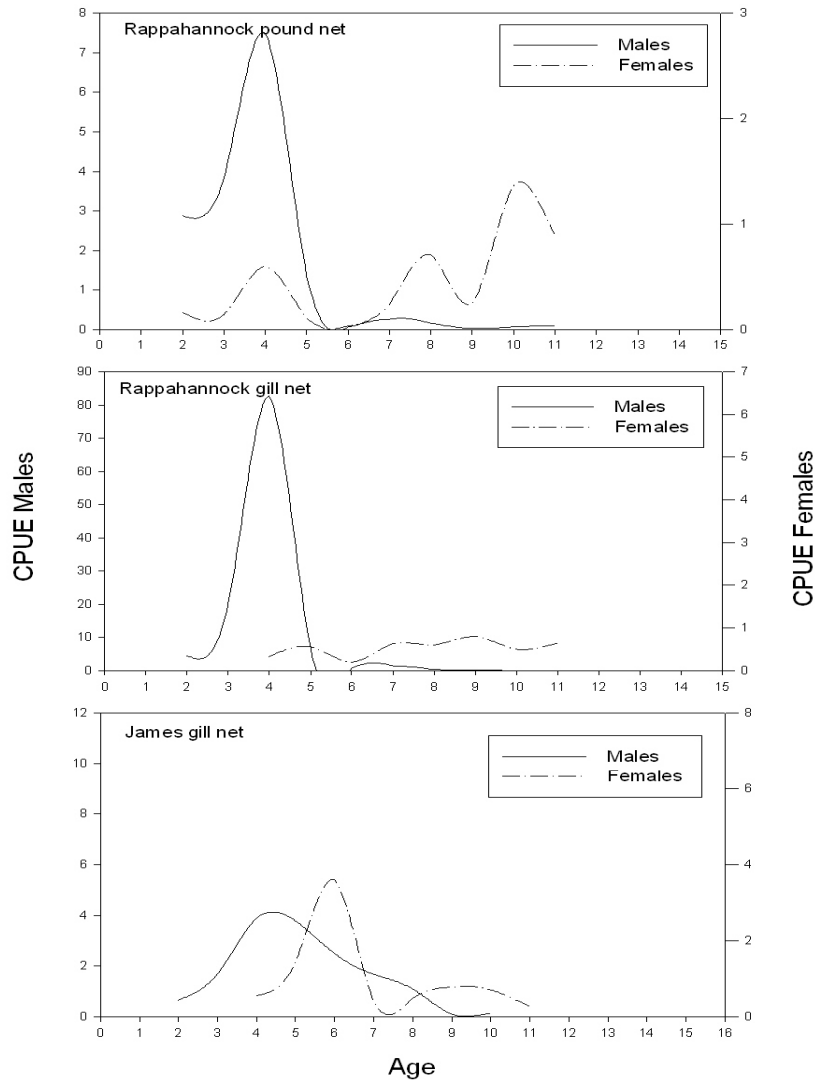
**Figure 7.** Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1991 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1992-2004.



**Figure 8.** Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1992 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1993-2004.

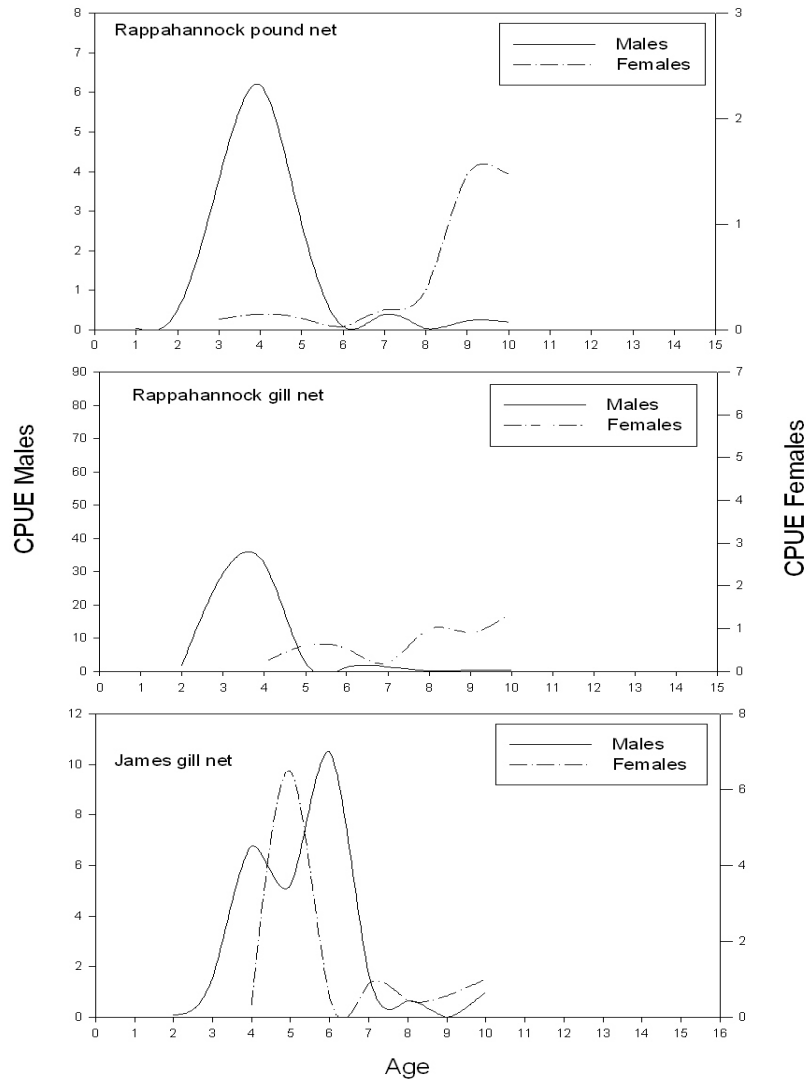


**Figure 9.** Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1993 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1995-2004.

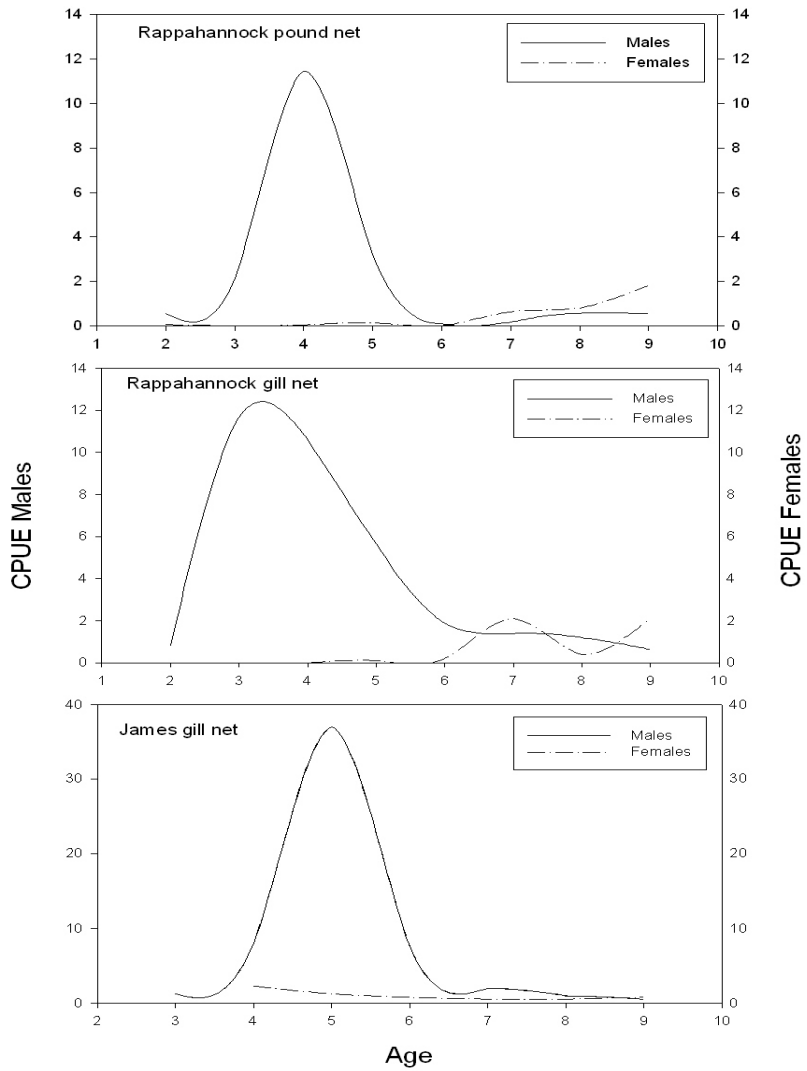




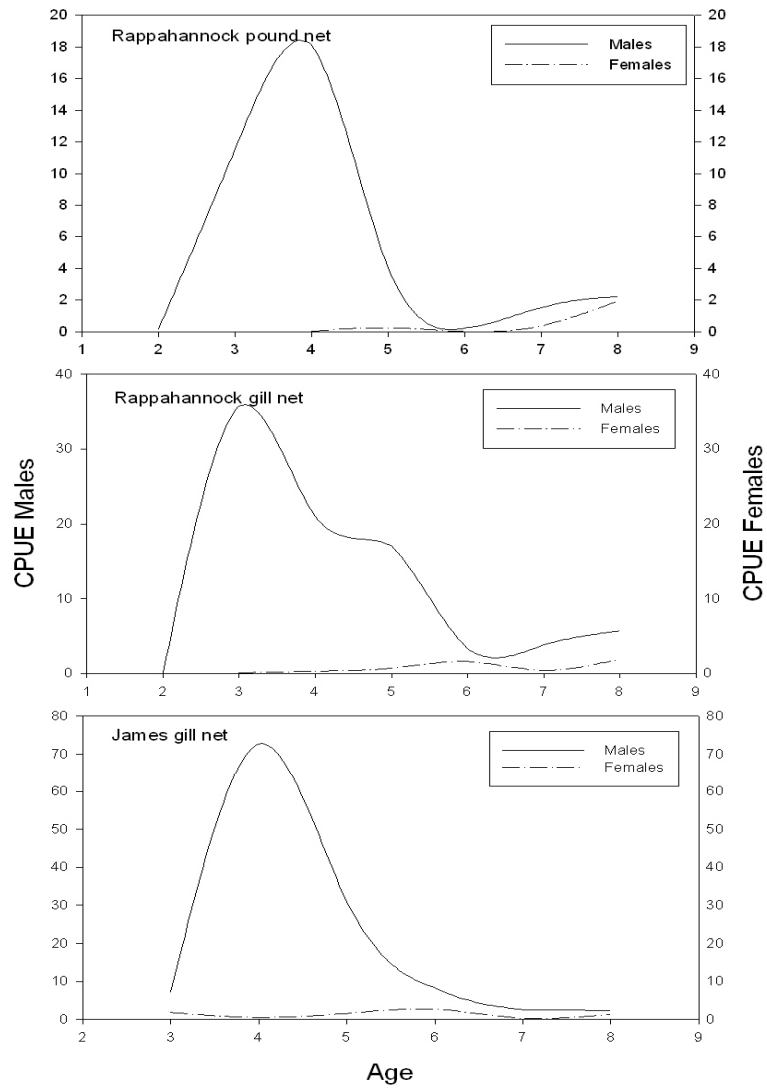
**Figure 10.** Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1994 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1995-2004.



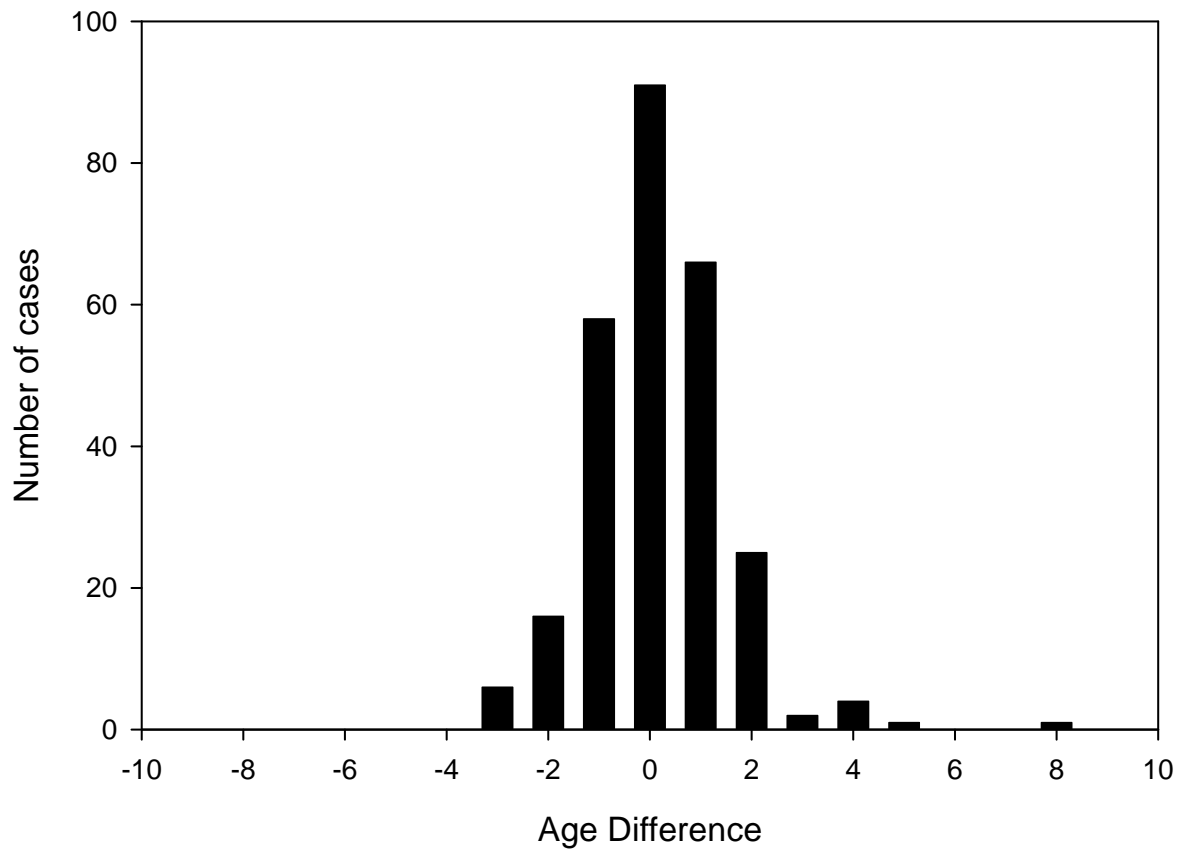
**Figure 11.** Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1995 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1997-2004.



**Figure 12.** Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1996 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1998-2004.



**Figure 13.** Magnitude of the age differences (otolith age – scale age) resulting from ageing specimens of striped bass (n=270) by reading both their scales and otoliths.



**II. Mortality estimates of striped bass (*Morone saxatilis*) that spawn in the Rappahannock River, Virginia, spring, 2003-2004**

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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. The FMP was modified three times from 1984-1985 to further restrict fishing (Weaver *et al.* 1986). The first two amendments emphasized the need to reduce fishing mortality and to set target mortality rates. The third amendment was directed specifically at Chesapeake Bay stocks and focused on ensuring success of the 1982 and later year classes by recommending that states protect 95% of those females until they had the opportunity to spawn at least once.

Due to an improvement in spawning success, as judged by increases in annual values of the Maryland juvenile index, a fourth amendment to the FMP established a limited fishery in the fall of 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 a fifth amendment to the original FMP in order to allow expanded state fisheries.

The Striped Bass 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 1988 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 coast-wide 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.

Although the initial purpose of the coast-wide tagging study was to evaluate efforts to restore Atlantic striped bass stocks (Wooley *et al.* 1990), tagging data are now being collected to monitor striped bass mortality rates in a recovered fishery. Thus far, these extensive data have not been formally summarized.

This section is an update material provided for this report by Latour (2001). He did a comprehensive analysis of the Rappahannock River striped bass tagging data, gave a detailed description of the ASFMC analysis protocol and presented annual survival (S) estimates derived from tag-recovery models developed by Seber (1970) as well as estimates of instantaneous fishing mortality (F) that followed when S was partitioned into its components using auxiliary information.

### Multi-year 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

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

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.).

**Seber models:** White and Burnham (1999) reformulated the original Brownie et al. (1985) models in the way originally suggested by Seber (1970) 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. For time-specific parameterization of the Seber models, the matrix of expected values associated with equation (1) would be

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

where  $N_i$  is the number tagged in year  $i$ ,  $S_i$  is the survival rate in year  $i$  and  $r_i$  is the probability a tag is recovered from a killed fish regardless of the source of mortality.

The Seber 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 (Ricker 1975)

$$S = e^{-Z} \quad (3)$$

and, if information about  $M$  is available, estimates of  $F$  can be recovered. Given estimates of the instantaneous rates, it is possible to recover estimates of  $u$  if the timing of the fishery (Type I or Type II) is known (Ricker 1975).

**Instantaneous rate 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. 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



$$E(r) = \begin{bmatrix} N_1 \phi \lambda u_1(F_1, M) & N_1 \phi \lambda u_2(F_2, M) e^{-(F_1+M)} & \dots & N_1 \phi \lambda u_J(F_J, M) e^{-\left(\sum_{k=1}^{J-1} F_k + (J-1)M\right)} \\ - & N_2 \phi \lambda u_2(F_2, M) & \dots & N_2 \phi \lambda u_J(F_J, M) e^{-\left(\sum_{k=2}^{J-1} F_k + (J-2)M\right)} \\ \vdots & \vdots & \ddots & \vdots \\ - & - & - & N_J \phi \lambda u_J(F_J, M) \end{bmatrix}$$

(4)

where  $\phi$  is the probability of surviving being tagged and retaining the tag in the short-term,  $\lambda$  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.

These models are not as simple as the Seber models, but they do yield direct estimates of  $F$  and, depending on the information available, either  $M$  or  $\phi\lambda$ . Also, they can be parameterized to allow for non-mixing of newly and previously tagged animals (Hoenig *et al.* 1998b). 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  $\phi\lambda$ .

In either case, the auxiliary information needed (i.e.,  $\phi\lambda$  or  $M$ ) can often be difficult to obtain in practice, and since  $F$ ,  $M$  and  $\phi\lambda$  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.* 2001a).

## Material and Methods

### Capture and Tagging Protocol

Each year from 1991 to 2004, during the months of March, 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 a cooperating commercial fisherman. 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. In 2004, striped bass were also obtained from haul seines made in the James River in late March and early April. Haul seines are also non-size selective and had been used successfully to obtain striped bass for tagging in springs from 1988-1992.

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 dip-netted 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 and 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 from between the dorsal fins and above the lateral line 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

**ASMFC:** The ASMFC Striped Bass Tagging Subcommittee established a data analysis protocol that involves deriving survival estimates from a suite of Seber (1970) models. The protocol is used by each state and federal agency participating in the cooperative tagging study. Tag recoveries from striped bass greater than 457 mm total length are analyzed from known producer areas (including Chesapeake Bay). Tag recoveries from striped bass that were greater than 711 mm total length (TL) at the time of tagging are analyzed from all coastal states since those fish are believed to be fully recruited to the fishery and also because they constitute the coastal migratory population (Smith *et al.* 2000).

The protocol consists of six 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). The candidate models for striped bass survival (S) and tag recovery (r) rates are:

S(.)r(.)	Survival and tag-recovery rates are constant over time.
S(t)r(t)	Survival and tag-recovery rates are time-specific.
S(.)r(t)	Survival rate is constant and tag-recovery rates are time-specific.
S( $p_1$ )r(t)	Survival rates vary by regulatory periods ( $p_1$ =constant 1990-1994 and 1995-2003) and tag-recovery rates are time-specific.
S( $p_1$ )r( $p_1$ )	Survival and tag-recovery rates vary by regulatory period.
S(.)r( $p_1$ )	Survival rate is constant and tag-recovery rates vary by regulatory periods.

$S(t)r(p_1)$	Survival rates are time-specific and tag-recovery varies by regulatory periods.
$S(p_2)r(p_1)$	Survival and tag-recovery rates vary over different regulatory periods ( $p_2 =$ constant 1990-1994, 1995-2002 and 2003).
$S(p_3)r(p_1)$	Survival and tag-recovery rates vary over different regulatory periods ( $p_3 =$ constant 1990-1994, 1995-2001, 2002 and 2003).
$S(Tp_1)r(Tp_1)$	Survival and tag-recovery rates have linear trends within regulatory periods.
$S(Tp_1)r(p_1)$	Survival rates have a linear trend within regulatory periods and tag-recovery rates vary by regulatory period.
$S(Tp_1)r(t)$	Survival rates have a linear trend within regulatory periods and tag-recovery rates are time-specific.
$S(p_4)r(p_4)$	Survival and tag-recovery rates vary over regulatory periods ( $p_4 =$ constant 1990-1992, 1993-1994 and 1995-2003).

The striped bass tagging data contain a large number of tag-recoveries reflecting catch-and-release practices (i.e., the tag of a captured fish is clipped off for the reward and the fish released back into the population). Analysis utilizing these data leads to biased survival estimates. The fifth step applies a correction term (Smith *et al.* 2000) to offset the re-release-without-tag bias assuming a tag reporting rate of 0.43 (D. Kahn, Delaware Division of Fish and Wildlife, personal communication). The sixth step converts estimates of  $S_i$  to  $F_i$  via equation (3), assuming that M is 0.15 (Smith *et al.* 2000).

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 kept in outdoor holding pools for 180 days. Their holding experiment revealed that the survival rates of both tagged and control fish were not significantly different over a 24-hour period. A similar study conducted on resident striped bass within the York River, Virginia, yielded survival in the presence of tagging activity and short-term tag retention rates each in excess of 98% (Sadler *et al.* 2001). Based on these results, the ASMFC analysis protocol specifies making no attempts to adjust for the presence of short-term tag-induced mortality or acute tag-loss.

## Results

### Spring 2004 tag release summary

A total of 1,477 striped bass were tagged and released from the pound nets in the Rappahannock River between 29 March and 29 April, 2004 (Table 1). There were 790 resident striped bass (457-710 mm TL) tagged and released. These stripers were predominantly male (95.7%), but the female stripers were larger on average. The median date of these tag releases, to be used as the beginning of the 2004-2005 recapture interval, was 18 April. There were 687 migrant striped bass (>710 mm TL) tagged and released. These stripers were predominantly

female (59.2%) and their average size was larger than for the male striped bass. The median date of these tag releases was 20 April.

A total of 178 striped bass were tagged and released from three haul seines in the James River between 26 March and 2 April, 2004 (Table 2). There were 118 resident and 60 migrant striped bass tagged. The resident striped bass were predominantly male (70.1%) although the females were larger on average. The migrant striped bass were predominantly female (88.3%) and were also larger on average than were the males. The median date of these tag releases was 2 April.

### **Mortality estimates, 2003-2004**

**Tag recapture summary:** A total of 55 (out of 852) resident striped bass (>458 mm TL), tagged during spring 2003, were recaptured between 28 April, 2003, and 18 April, 2004 (the respective midpoints of the two tag release totals), and were used to estimate mortality. Thirty-two of these recaptures were harvested (58.2%) and the rest were re-released into the population (Table 3). The proportion of tagged striped bass recaptured from 1991-2004 in their first year after release varied from 0.056 (21/376) to 0.111 (162/1,464). Since 1997 the initial recapture rates have only varied from 0.063-0.077. In addition, 49 striped bass tagged in previous springs were recaptured during the 2003-2004 recovery interval and were used to complete the input data matrix. The largest source of recaptures (43.6%) in the 2003-2004 recovery interval was Chesapeake Bay (30.9% in Virginia, 12.7% in Maryland, Table 4). Other recaptures came from Massachusetts (20.0%), New Jersey (18.2%), New York (7.3%), Rhode Island (5.6%), North Carolina (3.6%), and Connecticut (1.8%). There was a primary peak of recaptures in June and July and a secondary peak in November and December.

A total of 35 (out of 400) migratory striped bass (>710 mm total length), tagged during spring 2003, were recaptured between 21 April, 2003, and 18 April, 2004 (the 2003-2004 recovery interval) and were used to estimate the mortality of this sub-group. Twenty-three of these recaptures were harvested (65.7%), and the rest were re-released into the population (Table 5). The proportion of tagged striped bass recaptured from 1991-2004 in their first year after release varied from 0.015 (1/66) to 0.152 (24/158). In addition, 26 striped bass tagged in previous springs were recaptured during the recovery interval and were used to complete the input data matrix. Only five of the recaptured tagged striped bass came from Chesapeake Bay (14.3%), all in Virginia (Table 6). Other recaptures came from New Jersey and Massachusetts (28.6% each), New York (11.4%), Rhode Island (8.6%), North Carolina (5.7%) and Connecticut (2.9%). The peak month for recaptures was July, but some migrant striped bass were recaptured from every month except March.

**ASMFC protocol:** Survival estimates were made utilizing the mark-recapture data for the Rappahannock River from 1990-2003. The suite of Seber (1970) models consisted of 13 models that each reflected a different parameterization over time. Models that allowed parameters to be both time-specific and constant across time were specified. Since Atlantic striped bass have been subjected to a variety of harvest regulations since 1990, 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 stable coast-wide harvest regulations were also specified.

Prior to 2003, survival estimates from Virginia for striped bass greater than 457 mm (18") total length were suspect and not reported to the Stock Assessment Committee. Only one model (S(t) R(t)) fit the data (Table 7) and the previous results over time had spikes in survival that were not possible (i.e. > 1.0). The 2003  $F$  estimate was high (0.62, Table 8). This was likely over-estimated due to linear monotonic trend models (Welsh personal comm.).

Survival estimates were obtained for striped bass greater than 710 mm (28") total length. Of the 13 proposed models, eight had  $\Delta AICc$  values less than 7.0 (Table 9). A  $\Delta AICc$  of 7.0 receives a weighting of 0.01 and is used as the threshold for inclusion in the analysis. Of the eight models, the calculated weight of the constant survival and tag recovery model (i.e., S(.)r(.)) was larger than the other models. The constant survival, regulatory-based reporting model (S(.) R( $p_1$ )) and the regulatory-based survival and reporting model were also heavily weighted. Models that reflected more general time-specific parameterizations tended to not fit the data well. The ranking of the models was inversely related to the number of associated parameters.

The VIMS model-averaged estimates of the bias-adjusted survival rates for striped bass greater than 710 mm ranged from 0.610-0.626 over the time series (Table 10). Survival was highest during the transitional fishery and decreased slightly during the recovered fishery. This trend was the result of a higher proportion of annual tag recoveries being released back into the population in the early 1990's relative to more recent years. The corresponding estimates of  $\hat{F}$  ranged from 0.128-0.328 and only infrequently, and by slight margins, exceeded the transitional and full fisheries target values. Both the survival and fishing mortality estimates were relatively constant. This was to be expected, with calculated QAIC weights of the S(.)r(.), S(.)r( $p_1$ ) and the S(.)r(t) models totaling 0.621.

## Model evaluation

Latour et al. (2001b) proposed a series of diagnostics that can be used in conjunction with AIC and GOF measures to assess the performance of tag-recovery models. In essence, they suggested that the fit of a model could be critically evaluated by analyzing model residuals and that patterns would be evident if particular assumptions were violated.

For the time-specific Seber (1970) model, Latour et al. (2002) 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 Anever seen again@ category must also always be zero unless parameter estimates fall on a boundary condition. Latour et al. (2001c) also scrutinized the residuals associated with the instantaneous rates model and found the residual matrix of this model possessed fewer constraints than the time-specific Seber model. Although the row sums category must total zero, the column sums and the associated residuals can assume any value.

**ASMFC protocol:** Given that management regulations applied to striped bass during the 1990s have specified a wide variety of harvest restrictions, it would be reasonable to assume that the time-specific models (e.g.  $S(t)r(t)$ ,  $S(p_1)r(t)$ ,  $S(t)r(p_1)$ , etc.) were most appropriate for data analysis. However, elements of the Rappahannock River tag-recovery matrix did not allow these models to adequately fit the data. The low total number tagged of striped bass releases, and the resultant low numbers of recaptures reported from the 1994 and 1996 cohorts (e.g. five from the 1996 cohort) relative to other years, may have resulted in the poor fit of the time-specific models. Unfortunately, numerical complications resulting from low sample size may have caused some of the more biologically reasonable models to not fit the Rappahannock River data well.

## Discussion

The survival estimate for migrant striped bass for 2003-2004 was 0.615. The annual survival estimates from 1990-2003 have varied from only 0.610-0.629. The estimate of fishing mortality for 2003-2004 was 0.275. The estimates of fishing mortality from 1990-2003 varied from 0.128-0.328 and exceeded the ASMFC threshold of 0.30 only in 1996 and 1997. The models that assume constant survival and/or reporting rate and the models that partition the time series into two periods (1990-1994 and 1995-2003) were found to best fit the data and contributed most heavily to the analysis. These are the models that use the fewest parameters to produce the estimates of survival and fishing mortality.

Our analyses of the resident striped bass are problematic. The 2003-2004 estimates of survival (0.445) and fishing mortality (0.616) were derived after eliminating the time-dependent model (this model does not provide a terminal year estimate). However, in the original analysis this was the only model that the data fit (0.9998 of the weighting). While the new results for survival and fishing mortality, based mainly on the trend model, are plausible, the range of values are extreme, highly variable, and even include negative estimates of fishing mortality for other years. Given the poor fit on the data to the trend model in the original analysis, we have little confidence in the result. We intend to investigate the problems and their causes of these analyses and hopefully provide more credible future estimates.

Recently, we have begun using instantaneous rates models to study mortality rates of resident striped bass as an alternative to the Seber-Brownie models. These models are more efficient in that they require fewer parameters. This provides greater flexibility in modeling mortality over time. Preliminary results suggest that the models provide more reasonable results than the present method and that natural mortality is higher than previously thought and has been increasing over time. If true, then fishing mortality has been lower than previously estimated. Results from these models are presented in section III of this report.

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**Table 1.** Summary data of striped bass tagged and released from pound nets in the Rappahannock River, spring 2004.

Date	total tagged	457 - 710 mm TL				> 710 mm TL			
		Males		females		males		females	
		n		n		n		n	
<b>29 March</b>	195	132	508.9	5	483.0	32	730.9	26	822.4
<b>1 April</b>	189	120	514.6	3	588.0	34	727.9	32	809.9
<b>8 April</b>	70	27	508.8	2	532.0	12	740.1	29	837.7
<b>12 April</b>	147	51	489.8	3	501.7	54	745.4	39	823.6
<b>19 April</b>	179	54	504.5	4	511.5	38	752.3	83	841.3
<b>22 April</b>	184	42	505.1	9	536.6	42	749.9	91	831.2
<b>26 April</b>	285	171	538.8	3	533.3	40	751.2	71	825.6
<b>29 April</b>	228	159	527.1	5	555.8	28	746.3	36	837.4
<b>Total</b>	1,477	756	518.6	34	529.5	280	743.9	407	830.3

**Table 2.** Summary data of striped bass tagged and released from haul seines in the James River, spring, 2004.

Date	total tagged	457 - 710 mm TL				> 710 mm TL			
		Males		females		males		females	
		n		n		n		n	
<b>26 March</b>	39	21	489.0	9	537.2	0		8	733.5
<b>1 April</b>	12	9	487.2	0		1	737.0	2	750.5
<b>2 April</b>	127	53	496.3	26	581.6	6	735.0	42	755.9
<b>Total</b>	178	83	493.5	35	570.2	7	735.2	52	752.2

**Table 3.** Recapture matrix of striped bass (>457 m TL) that were tagged and released in the Rappahannock River, springs 1990-2003. The second (bottom) number is the number of those recaptures that were killed.

Year	n	recaptures													
		90	91	92	93	94	95	96	97	98	99	00	01	02	03
1990	1,464	162	64	47	25	12	10	3	2	3	1	1	0	0	1
		21	20	24	10	8	9	2	0	0	1	1	0	0	1
1991	2,481	---	167	81	53	29	6	5	2	2	4	1	0	0	1
		---	48	38	22	14	3	1	2	1	4	0	0	0	1
1992	130	---	---	14	8	6	5	1	1	1	1	0	0	0	0
		---	---	7	4	1	3	0	0	0	1	0	0	0	0
1993	621	---	---	---	50	37	17	8	9	2	0	1	0	0	0
		---	---	---	18	17	12	5	4	1	0	0	0	0	0
1994	195	---	---	---	---	13	10	5	4	4	0	0	0	0	0
		---	---	---	---	6	7	4	1	2	0	0	0	0	0
1995	698	---	---	---	---	---	55	30	20	5	4	2	3	0	1
		---	---	---	---	---	24	12	9	4	1	1	2	0	1
1996	376	---	---	---	---	---	---	21	18	7	3	1	1	1	0
		---	---	---	---	---	---	3	10	3	2	1	1	1	0
1997	712	---	---	---	---	---	---	---	47	26	14	3	0	1	2
		---	---	---	---	---	---	---	26	17	10	2	0	1	1
1998	784	---	---	---	---	---	---	---	---	55	26	2	3	3	1
		---	---	---	---	---	---	---	---	28	16	1	3	1	0
1999	853	---	---	---	---	---	---	---	---	---	66	23	9	5	3
		---	---	---	---	---	---	---	---	---	30	7	4	2	2
2000	1,765	---	---	---	---	---	---	---	---	---	---	122	51	23	16
		---	---	---	---	---	---	---	---	---	---	44	23	11	7
2001	797	---	---	---	---	---	---	---	---	---	---	---	61	23	16
		---	---	---	---	---	---	---	---	---	---	---	32	14	5
2002	315	---	---	---	---	---	---	---	---	---	---	---	---	20	8
		---	---	---	---	---	---	---	---	---	---	---	---	10	4
2003	852	---	---	---	---	---	---	---	---	---	---	---	---	---	55
		---	---	---	---	---	---	---	---	---	---	---	---	---	32

**Table 4.** Location of striped bass (> 457 mm TL), recaptured in 2003, that were originally tagged and released in the Rappahannock River during springs 1988-2003 and used for mortality analysis.

State	Month												total
	J	F	M	A	M	J	J	A	S	O	N	D	
Massachusetts	0	0	0	0	0	2	8	0	0	0	0	1	11
Rhode Island	0	0	0	0	0	0	0	1	2	0	0	0	3
Connecticut	0	0	0	0	0	0	0	1	0	0	0	0	1
New York	0	0	0	0	1	1	0	1	0	0	0	1	4
New Jersey	0	0	0	0	2	3	0	1	1	1	2	0	10
Maryland	0	0	0	0	1	1	1	2	1	0	1	0	7
Virginia	0	0	0	1	2	3	1	0	0	2	3	5	17
North Carolina	1	1	0	0	0	0	0	0	0	0	0	0	2
Total	1	1	0	1	6	10	10	6	4	3	6	7	55

**Table 5.** Recapture matrix of striped bass (>710 m TL) that were tagged and released in the Rappahannock River, springs 1990-2003. The second (bottom) number is the number of those recaptures that were killed.

Year	n	recaptures													
		90	91	92	93	94	95	96	97	98	99	00	01	02	03
1990	301	26 10	9 2	15 7	2 2	4 3	6 6	1 1	0 0	2 1	1 1	1 0	0 0	0 0	1 1
1991	390	---	41 21	24 11	16 12	11 9	3 2	2 2	2 2	1 0	2 2	0 0	0 0	0 0	1 1
1992	40	---	---	4 2	3 2	2 1	2 2	0 0	0 0	0 0	1 1	0 0	0 0	0 0	0 0
1993	212	---	---	---	22 12	18 11	7 6	4 4	7 5	0 0	0 0	1 1	0 0	0 0	0 0
1994	123	---	---	---	---	9 5	7 6	5 5	1 1	2 1	0 0	0 0	0 0	0 0	0 0
1995	209	---	---	---	---	---	28 22	10 8	8 5	3 2	3 3	2 1	3 3	0 0	1 1
1996	66	---	---	---	---	---	---	1 0	3 3	1 1	0 0	0 0	0 0	0 0	0 0
1997	212	---	---	---	---	---	---	---	15 13	13 12	8 6	3 1	0 0	1 1	2 1
1998	158	---	---	---	---	---	---	---	---	24 18	13 9	2 0	3 3	2 1	0 0
1999	162	---	---	---	---	---	---	---	---	---	17 14	5 2	2 2	3 2	2 1
2000	365	---	---	---	---	---	---	---	---	---	---	27 13	19 12	12 6	9 5
2001	269	---	---	---	---	---	---	---	---	---	---	---	19 12	14 8	4 2
2002	359	---	---	---	---	---	---	---	---	---	---	---	---	10 7	6 3
2003	400	---	---	---	---	---	---	---	---	---	---	---	---	---	35 23

**Table 6.** Location of striped bass (> 710 mm TL), recaptured in 2003, that were originally tagged and released in the Rappahannock River during springs 1988-2003 and used for mortality analysis.

State	Month												total
	J	F	M	A	M	J	J	A	S	O	N	D	
Massachusetts	0	0	0	0	0	2	8	0	0	0	0	0	10
Rhode Island	0	0	0	0	0	0	0	1	2	0	0	0	3
Connecticut	0	0	0	0	0	0	0	1	0	0	0	0	1
New York	0	0	0	0	1	1	0	0	1	0	0	1	4
New Jersey	0	0	0	0	2	3	0	1	1	1	2	0	10
Maryland	0	0	0	0	0	0	0	0	0	0	0	0	0
Virginia	0	0	0	1	0	0	1	0	0	0	2	1	5
North Carolina	1	1	0	0	0	0	0	0	0	0	0	0	2
Total	1	1	0	1	3	6	9	3	4	1	4	2	35

**Table 7.** Performance statistics (>457 mm TL), based on quasi-likelihood Akaike Information Criteria (QAIC), used to assess the Seber (1970) models utilized in the ASMFC analysis protocol. Model notations: S (f) and r (f) indicate that survival (S) and tag-reporting rate (r) are functions (f) of the factors within the parenthesis; constant parameters across time (.); parameters constant from 1990-1994 and 1995-2003 ( $p_1$ ); parameters vary in 2003 ( $p_2$ ), otherwise the same as  $p_1$ ; parameters vary in 2002 and 2003 ( $p_3$ ), otherwise the same as  $p_1$ ; parameters constant from 1990-1992, 1993-1994 and 1995-2003 ( $p_4$ ); assumption of linear trends from 1990-1994 and 1995-2003 ( $Tp_1$ ); and parameters are time-specific (t).

Model	$QAIC_c$	$\Delta QAIC_c$	$QAIC_c$ weight	number of parameters
<b>S(t)r(t)</b>	10019.26	0.00	0.99982	27
<b>S(<math>Tp_1</math>)r(t)</b>	10037.95	18.69	0.00009	18
<b>S(<math>p_1</math>)r(t)</b>	10039.83	20.57	0.00003	16
<b>S(<math>Tp_1</math>)r(<math>Tp_1</math>)</b>	10040.14	20.88	0.00003	8
<b>S(.)r(t)</b>	10041.83	22.57	0.00001	15
<b>S()r(<math>p_1</math>)</b>	10043.03	23.77	0.00001	6
<b>S(<math>p_4</math>)r(<math>p_4</math>)</b>	10043.81	24.55	0.00000	6
<b>S(<math>p_1</math>)r(<math>p_1</math>)</b>	10044.35	25.09	0.00000	4
<b>S(<math>p_3</math>)r(<math>p_1</math>)</b>	10045.71	26.45	0.00000	6
<b>S(<math>p_2</math>)r(<math>p_1</math>)</b>	10046.35	27.09	0.00000	5
<b>S(t)r(<math>p_1</math>)</b>	10046.50	27.24	0.00000	16
<b>S(.)r(<math>p_1</math>)</b>	10050.18	30.92	0.00000	3
<b>S(.)r(.)</b>	10067.45	48.19	0.00000	2



**Table 8.** Seber (1970) model estimates (VIMS) of unadjusted survival ( $\hat{S}$ ) rates and adjusted rates of survival ( $\hat{S}_{adj}$ ) and fishing mortality ( $\hat{F}$ ) of striped bass (> 457 mm FL) derived from the proportion of recaptures released alive ( $P_i$ ) in the Rappahannock River, 1990-2003.

Year	$\hat{S}$	SE ( $\hat{S}$ )	$P_i$	bias	$\hat{S}_{adj}$	$\hat{F}$	95%CI $\hat{F}$
1990	0.816	0.086	0.519	-0.142	0.951	-0.100	-0.23, 0.22
1991	0.276	0.051	0.524	-0.076	0.299	1.057	0.73, 1.43
1992	0.804	0.162	0.408	-0.132	0.927	-0.074	-0.26, 0.75
1993	0.604	0.129	0.456	-0.098	0.669	0.251	-0.05, 0.81
1994	0.573	0.126	0.402	-0.085	0.626	0.318	0.00, 0.88
1995	0.689	0.135	0.262	-0.050	0.725	0.172	-0.08, 0.74
1996	0.629	0.130	0.279	-0.037	0.654	0.275	0.00, 0.83
1997	0.552	0.103	0.330	-0.053	0.583	0.390	0.10, 0.84
1998	0.405	0.077	0.371	-0.057	0.430	0.695	0.37, 1.10
1999	0.380	0.067	0.294	-0.057	0.403	0.759	0.45, 1.39
2000	0.426	0.067	0.436	-0.069	0.457	0.633	0.36, 0.98
2001	0.609	0.158	0.367	-0.063	0.649	0.282	-0.05, 1.00
2002	0.540	0.160	0.382	-0.048	0.567	0.417	0.02, 1.20
2003	0.445	0.000	0.279	-0.043	0.465	0.616	0.36, 0.93

**Table 9.** Performance statistics (>711 mm TL), based on quasi-likelihood Akaike Information Criteria (QAIC), used to assess the Seber (1970) models utilized in the ASMFC analysis protocol. Model notations: S (f) and r (f) indicate that survival (S) and tag-reporting rate (r) are functions (f) of the factors within the parenthesis; constant parameters across time (.); parameters constant from 1990-1994 and 1995-2003 ( $p_1$ ); parameters vary in 2003 ( $p_2$ ), otherwise the same as  $p_1$ ; parameters vary in 2002 and 2003 ( $p_3$ ), otherwise the same as  $p_1$ ; parameters constant from 1990-1992, 1993-1994 and 1995-2003 ( $p_4$ ); assumption of linear trends from 1990-1994 and 1995-2003 ( $Tp_1$ ); and parameters are time-specific (t).

Model	$QAIC_c$	$\Delta QAIC_c$	$QAIC_c$ weight	number of parameters
<b>S(.)r(.)</b>	3434.75	0.00	0.34506	2
<b>S(.)r(<math>p_1</math>)</b>	3435.20	0.46	0.27477	3
<b>S(<math>p_1</math>)r(<math>p_1</math>)</b>	3435.95	1.20	0.18906	4
<b>S(<math>p_2</math>)r(<math>p_1</math>)</b>	3437.94	3.19	0.06999	5
<b>S(<math>Tp_1</math>)r(<math>p_1</math>)</b>	3438.97	4.22	0.04183	6
<b>S(<math>p_4</math>)r(<math>p_4</math>)</b>	3439.06	4.31	0.03993	6
<b>S(<math>p_3</math>)r(<math>p_1</math>)</b>	3439.94	5.19	0.02578	6
<b>S(<math>Tp_1</math>)r(<math>Tp_1</math>)</b>	3441.49	6.74	0.01187	8
<b>S(.)r(t)</b>	3446.29	11.54	0.00108	15
<b>S(<math>p_1</math>)r(t)</b>	3448.22	13.47	0.00041	16
<b>S(t)r(<math>p_1</math>)</b>	3450.35	15.60	0.00014	16
<b>S(<math>Tp_1</math>)r(t)</b>	3451.81	17.07	0.00007	18
<b>S(t)r(t)</b>	3458.03	23.28	0.00000	27

**Table 10.** Seber (1970) model estimates (SBTC) of unadjusted survival ( $\hat{S}$ ) rates and adjusted rates of survival ( $\hat{S}_{adj}$ ) and fishing mortality ( $\hat{F}$ ) of striped bass (> 711 mm FL) derived from the proportion of recaptures released alive ( $P_i$ ) in the Rappahannock River, 1990-2003.

Year	$\hat{S}$	SE ( $\hat{S}$ )	$P_i$	bias	$\hat{S}_{adj}$	$\hat{F}$	95%CI
1990	0.626	0.026	0.577	-0.127	0.717	0.182	0.11, 0.27
1991	0.626	0.025	0.560	-0.131	0.721	0.178	0.10, 0.26
1992	0.626	0.025	0.535	-0.172	0.757	0.128	0.06, 0.21
1993	0.629	0.027	0.349	-0.093	0.694	0.216	0.14, 0.31
1994	0.629	0.028	0.318	-0.070	0.677	0.240	0.16, 0.34
1995	0.610	0.024	0.204	-0.078	0.662	0.263	0.19, 0.35
1996	0.611	0.024	0.125	-0.016	0.620	0.328	0.26, 0.41
1997	0.611	0.023	0.167	-0.036	0.634	0.305	0.24, 0.38
1998	0.612	0.023	0.217	-0.087	0.670	0.251	0.18, 0.33
1999	0.612	0.023	0.200	-0.058	0.650	0.281	0.21, 0.36
2000	0.613	0.024	0.349	-0.071	0.659	0.267	0.23, 0.35
2001	0.613	0.024	0.298	-0.050	0.645	0.289	0.22, 0.37
2002	0.614	0.026	0.295	-0.065	0.657	0.271	0.19, 0.36
2003	0.615	0.029	0.246	-0.059	0.653	0.275	0.19, 0.38

**III. Fishing mortality of striped bass in the Chesapeake Bay: a report to the Atlantic States  
Marine Fisheries Commission Striped Bass Technical Committee**

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Note: this material was presented to the Atlantic States Marine Fisheries Commission Striped  
Bass Technical Committee on September 21, 2004, and revised on September 22, 2004

## Summary

1. This report deals with how fishing mortality,  $F$ , for striped bass greater than 457 mm in Chesapeake Bay should be estimated. In particular it compares methods based on ratios of recaptures: number tagged ( $r/m$  ratios) and based on fitting Brownie and instantaneous rates models to tagging data.
2. We conclude the following:
  - a. Estimates of  $F$  obtained from  $r/m$  ratios are unreliable, regardless of whether data from the summer/fall or spring tagging programs are used.
  - b. Estimates of  $F$  can be derived from estimates of either  $f$  (tag recovery rate) or  $S$  (annual survival rate) obtained from Brownie models fitted to the spring tagging data. The estimates of  $S$  from Brownie models fitted to fish  $> 457$  mm have not been accepted in the past in part because they indicate large year to year variation in survival that does not seem reasonable. The results based on interpreting  $f$  estimates are also unreliable and, in fact, opposite results can be obtained depending on whether one uses the  $S$  or the  $f$  to obtain the fishing mortality rate.
  - c. Instantaneous rates models fitted to the Rappahannock River spring tagging data produced estimates that were credible in the sense of having low year to year variability. The instantaneous rates model incorporates into the tagging model the assumptions made when interpreting Brownie models, and result in a model with 15 parameters to estimate instead of the 24 parameters in the year-specific Brownie model. Thus, some reduction in the variability of the mortality rate estimates over time is not unexpected because measurement error is reduced.
  - d. The instantaneous rates model also indicates that there is a problem with nonmixing occurring; this can be accommodated using a model that explicitly accounts for nonmixing of newly tagged animals into the population.
  - e. The instantaneous rates models also indicate that natural mortality for fish  $> 457$  mm was around  $0.34 \text{ yr}^{-1}$  from 1990 through 1998 and was around  $0.56 \text{ yr}^{-1}$  after that when reporting rate was assumed to be 0.45 (and was 0.42 and 0.62, respectively, when reporting rate was assumed to be 0.7).
3. The implications of this work are that: a) for the Chesapeake,  $r/m$  ratios should be abandoned for determining fishing mortality in favor of instantaneous rates models, and b) the apparent higher value of natural mortality than what has been assumed, and the apparent increase in natural mortality over time, should be examined further to see if the claim stands up, and the implications of different natural mortality rates on the stock assessment should be investigated.

## Analysis of Data

### Virginia: spring r/m ratios

The fishing mortality rate (F) was obtained from r/m ratios from spring tagging on the Rappahannock River, Virginia, assuming various values for natural mortality, M, and assuming reporting rate  $\lambda = 0.43$  and hooking mortality = .08 (Table 1, Figure 1). Note that the estimates of F are highly variable over time, ranging from 0.12 in 2003 to 0.40 in 1992 (when M is fixed at .15). If natural mortality is higher than has been assumed, the standard procedure (based on M = .15) underestimates the fishing mortality (Table 1). The shaded areas in Table 1 represent the two time periods used when estimating how natural mortality has changed over time.

### Maryland: spring r/m ratios

Depending on the method used, the Maryland estimates range from around 0.12 to 0.23 (method 1) or 0.11 to 0.27 (method 2) when M is assumed to be 0.15 (Figure 2). A higher range would result if M were assumed to be higher. Note that the Maryland estimates start with 1993 so we don't see how the r/m methods perform around 1991 when, depending on model, there was either a spike or dip in fishing mortality or average fishing mortality (see section on estimates derived from the Brownie model below).

### Brownie S's and f's for spring Rappahannock River data

Results of fitting the Brownie model to Virginia's tagging data from the Rappahannock River were obtained from Robert Harris and Philip Sadler (Table 2). Estimates of survival, S, were converted into estimates of instantaneous mortality, Z, by the relationship  $Z = -\ln(S)$ . Then, natural mortality was subtracted out to produce an estimate of fishing mortality, F (Table 3, Figure 3). Estimates of f were converted into estimates of exploitation rate, u, by dividing by the tag reporting rate. The catch equation  $u = (F/(F+M))(1 - \exp(-F-M))$  was then solved for F using Excel's solver (Table 4, Figure 4).

Several points are noteworthy. First, estimates of F derived from the survival estimates range from close to zero to greater than one (Figure 3), which doesn't seem credible given the history of the fishing regulations. Estimates of F derived from the f values vary from 0.15 to 0.45 (Figure 4) and are reasonably flat except for the first few years. Note the slight downward trend over time after 1993 – this point will be returned to in the section on instantaneous rates models. Another point to consider is that survival-based estimates seem to show the opposite of what is seen in the f-based estimates (Figure 5). It would appear that when few fish are recovered the f-based estimate interprets this as meaning exploitation was low whereas the S-based estimate interprets this as meaning survival was low, hence fishing mortality was high. Desmond Kahn presented a paper to the ASMFC Striped Bass Tagging Subcommittee in July, 2004, that presented annual estimates of F. His procedure was to divide the r/m ratio by the reporting rate to obtain an estimate of exploitation rate and to equate the exploitation rate with its expectation

$$\frac{r}{m\lambda} = u = \frac{F}{Z}(1 - \exp(-Z)) = \frac{F}{-\ln(S)}(1 - S)$$

Values of S were obtained from the Seber model (using program Mark) and the resulting equation was solved for F. We used a similar procedure except that we used the f parameter from the Brownie model instead of the r/m ratio. The results are shown in Figures 5a and 5b.

### **Spring instantaneous rates models for Rappahannock River.**

An instantaneous rates model was fitted to the spring tagging data from the Rappahannock River using the computer program Avocado. Year-specific F's and a constant M were estimated, and reporting rate was fixed at 0.7. Note that the instantaneous rates model provides results with much less variability over time than does the Brownie model. Also note that the Brownie model does not estimate survival (or Z) in the most recent year unless additional structure is specified, such as a linear trend over time. The results for the instantaneous rates model is not very sensitive to the value of reporting rate, providing the reporting rate is large (say, above 0.4 yr<sup>-1</sup>, Figures 7 and 8).

Here, we introduce two possible complications. First, newly tagged animals may not be fully mixed throughout the population and thus have a different fishing mortality rate, F\*, than previously tagged animals, F. Second, there have been suggestions by Victor Crecco and Desmond Kahn that the natural mortality rate may have increased over time. Therefore, we fitted a model that allows for nonmixing of newly tagged animals and that estimates two different natural mortality rates, one for the period up to and including 1998 and the other for the period from 1999 through 2003. The results, shown in the next 3 graphs (Figure 9), are as follows: 1) in the nonmixing model, the fishing mortalities for the newly tagged animals, F\* (shown in pink) are different from the fishing mortalities for the previously tagged animals (F, shown in green), indicating that nonmixing is occurring and needs to be accounted for by using a nonmixing model. If the nonmixing is ignored in the model, the results will be biased. A model that assumes mixing is compared with one that allows for nonmixing in the second panel. The mixing model (blue line) shows a flat trend in fishing mortality over time whereas the nonmixing model indicates that fishing mortality declined over time until 2000 and then started increasing with a record high fishing mortality in the last year. The last panel shows that regardless of whether we assume mixing or allow for nonmixing, the data indicate that natural mortality has increased significantly over time.

### **Summer/fall tagging r/m ratios and instantaneous rates models**

Efforts to fit Brownie models to the summer/fall tagging data were not successful. Estimates of period-specific survival were sometimes 0, implying zero survival for the entire season.

Estimates of fishing mortality from the fall tagging study were obtained by fitting an instantaneous rates model with reporting rate fixed at either 0.75, 0.64, or 0.43 and natural mortality M fixed at 0.0 (Figure 10). Additional runs were made with M fixed at 0.03 per period.

Note that an  $M$  of 0.03 per period implies a natural mortality rate of 0.15 per season if there are 5 rounds of tagging. The results were very similar to those obtained when  $M$  was fixed at 0.0 and are not shown. The value of 0.43 for tag reporting rate was computed as a weighted average of the reporting rates for commercial and recreational fishers presented in tables 1 and 2 of Sharov and Jones (2003). (Combined commercial-recreational reporting rates were computed separately for 1993-1998 and 1999-2002. However, because the estimates were very close (.44 and .39, respectively), a single value of .43 was used for all years.) The weights used in computing the average were based on the relative magnitude of the commercial and recreational catches. These results are compared to the results presented in Sharov's and Jones' Figure 2. The trends over time are similar but the estimates of Sharov and Jones are higher than those obtained from the instantaneous rates model. It would appear that the reporting rates being used are different. The only discrepancy in the trend results of the two methods is that Sharov and Jones show a decline in  $F$  from 1999 to 2000 whereas the instantaneous rates model shows an increase. As the instantaneous rates estimate is based on more data, we would be inclined to give it more credibility. However, it does not appear that the instantaneous rates model offers any sort of substantial improvement over the  $r/m$  estimates.

### Conclusions

1. The data matrices of recaptures from the summer/fall tagging are sparse, and don't appear suitable for Brownie model estimates of survival. They might be useful for Brownie  $f$ 's and for instantaneous rates estimates of fishing mortality. However, it does not appear they offer a substantial improvement over interpretation of the spring tagging data.
2. The estimates of fishing mortality derived from  $r/m$  analysis, Brownie  $S$ 's, and Brownie  $f$ 's appear problematic and are not recommended. They show high year to year variability that is inexplicable, and they cannot detect nor handle the problem of lack of mixing of tagged animals into the population.
3. The instantaneous rates model appears to be the best option for estimating Chesapeake fishing mortality. It can accommodate nonmixing, provides for diagnostic procedures, has been extensively studied (Brooks et al. 1998; Frusher and Hoenig 2001, 2003; Hoenig et al. 1998a,b; Latour et al. 2001a,b, 2002; Latour, Pollock et al. 2001), is relatively insensitive to the value of tag reporting rate provided reporting rate is reasonably high, and provides information on the appropriate value of natural mortality rate. It provides results that pass one test of reasonableness: the estimates of fishing mortality do not show wild fluctuations from year to year.
4. In light of these findings, it is highly recommended that a) instantaneous rates models be used for estimating Chesapeake fishing mortality, b) a review of all data analytic procedures for striped bass be implemented to determine how mortality rates should be estimated from tagging data and to determine how tagging data can provide inputs into the VPA. Included in this analysis should be an investigation of age-effects, e.g., how



tagging data can provide information on the partial recruitment vector by looking at fraction of tagged fish recovered by age group.

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**Table 1.** r/m ratios and derived fishing mortalities from spring tagging on the Rappahannock. The first 6 columns are from material submitted to the Striped Bass Tagging Subcommittee by Robert Harris (corrected version, produced after the July meeting). The last three columns were obtained by solving the catch equation for F with Excel's Solver.

year	Number released	recaps killed	recaps Released alive	catch rate	exploitation rate	F, given M = .15	F, given M=.35	F, given M=.55
90	1464	97	143	0.381243	0.17	0.20	<b>0.23</b>	0.25
91	2481	134	169	0.284019	0.14	0.16	<b>0.18</b>	0.20
92	130	16	14	0.536673	<b>0.31</b>	<b>0.40</b>	<b>0.44</b>	<b>0.49</b>
93	621	57	49	0.396959	0.23	0.28	<b>0.31</b>	0.35
94	195	20	11	0.369708	0.25	0.31	<b>0.35</b>	0.38
95	698	54	39	0.309855	0.19	0.23	<b>0.25</b>	0.28
96	376	21	20	0.253587	0.14	0.16	<b>0.18</b>	0.20
97	712	57	26	0.271100	0.19	0.23	<b>0.26</b>	0.28
98	784	49	33	0.243237	0.15	0.18	<b>0.20</b>	0.22
99	853	45	39	0.229014	0.13	0.15	0.17	<b>0.19</b>
00	1765	86	88	0.229264	0.12	0.14	0.16	<b>0.17</b>
01	797	53	37	0.262613	0.16	0.19	0.21	<b>0.24</b>
02	315	16	13	0.214101	0.13	0.15	0.16	<b>0.18</b>
03	852	37	18	0.150126	<b>0.10</b>	<b>0.12</b>	<b>0.13</b>	<b>0.15</b>

**Table 2.** VIMS MARK results 1990-2003 Brownie model fish > 457mm, Rappahannock River spring tagging.

Parameter	Estimate	Standard Error	95% Confidence Interval	
			Lower	Upper
1: S1990	0.8159537	0.0715067	0.6355020	0.9185230
2: S1991	0.2762588	0.0421851	0.2015502	0.3659670
3: S1992	0.8045048	0.1349941	0.4334917	0.9567689
4: S1993	0.6040037	0.1074906	0.3873033	0.7863416
5: S1994	0.5730628	0.1052808	0.3660843	0.7572698
6: S1995	0.6888236	0.1130916	0.4404104	0.8616124
7: S1996	0.6293961	0.1084856	0.4056562	0.8086414
8: S1997	0.5518464	0.0863652	0.3831194	0.7094257
9: S1998	0.4050811	0.0639780	0.2880902	0.5339483
10: S1999	0.3797141	0.0557878	0.2778792	0.4933710
11: S2000	0.4258461	0.0560711	0.3211910	0.5375951
12: S2001	0.6085336	0.1321382	0.3438831	0.8217636
13: S2002	0.5397737	0.1343556	0.2889222	0.7719734
14: f1990	0.1106557	0.0081988	0.0955781	0.1277758
15: f1991	0.0628476	0.0043777	0.0547945	0.0719942
16: f1992	0.1239736	0.0189276	0.0913786	0.1660703
17: f1993	0.0881695	0.0090606	0.0719519	0.1076186
18: f1994	0.0860947	0.0144452	0.0616810	0.1189466
19: f1995	0.0766568	0.0084949	0.0615780	0.0950541
20: f1996	0.0560875	0.0088174	0.0411087	0.0760909
21: f1997	0.0672682	0.0079755	0.0532232	0.0846882
22: f1998	0.0644576	0.0076299	0.0510228	0.0811275
23: f1999	0.0786585	0.0083785	0.0637262	0.0967283
24: f2000	0.0666821	0.0055798	0.0565438	0.0784870
25: f2001	0.0713788	0.0078560	0.0574324	0.0883943
26: f2002	0.0540444	0.0104932	0.0368028	0.0787034
27: f2003	0.0645539	0.0084188	0.0498890	0.0831521

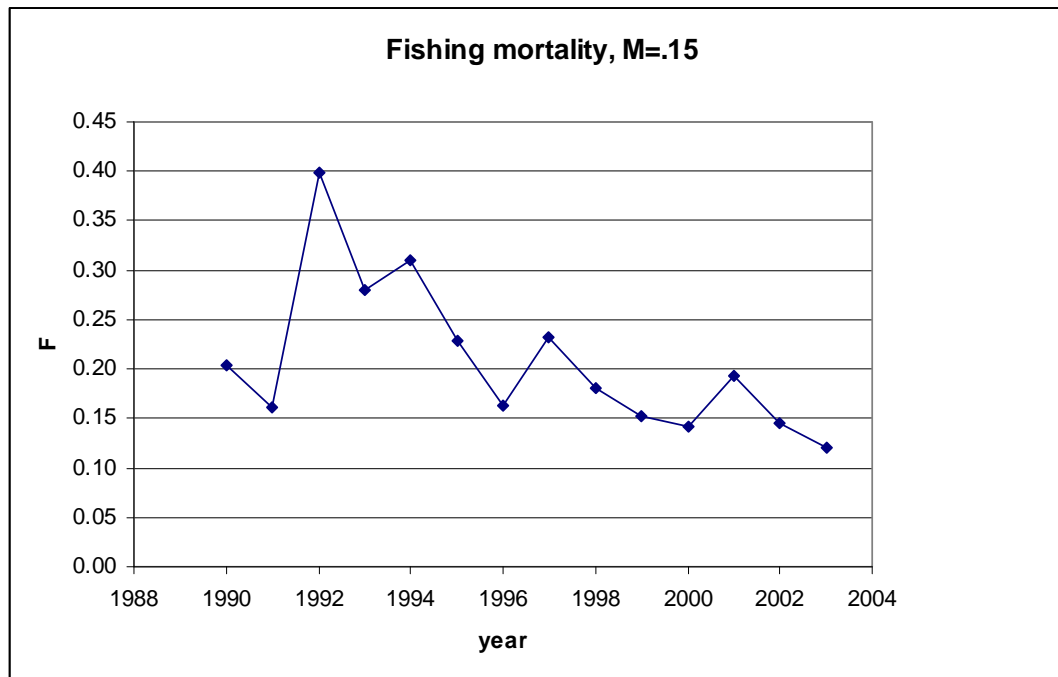
**Table 3.** Estimates of fishing mortality,  $F$ , obtained from the Brownie model, assuming various values for natural mortality rate,  $M$ . The survival estimate is converted to an estimate of total instantaneous mortality rate  $Z$ , and then natural mortality is subtracted off.

parameter	estimate	$F  $ $M=.15$	$F   M =$ .35	$F   M =$ .55
S1	0.82	0.05	-0.15	
S2	0.28	1.14	0.94	
S3	0.80	0.07	-0.13	
S4	0.60	0.35	0.15	
S5	0.57	0.41	0.21	
S6	0.69	0.22	0.02	
S7	0.63	0.31	0.11	
S8	0.55	0.44	0.24	
S9	0.41	0.75	0.55	0.35
S10	0.38	0.82	0.62	0.42
S11	0.43	0.70	0.50	0.30
S12	0.61	0.35	0.15	-0.05
S13	0.54	0.47	0.27	0.07

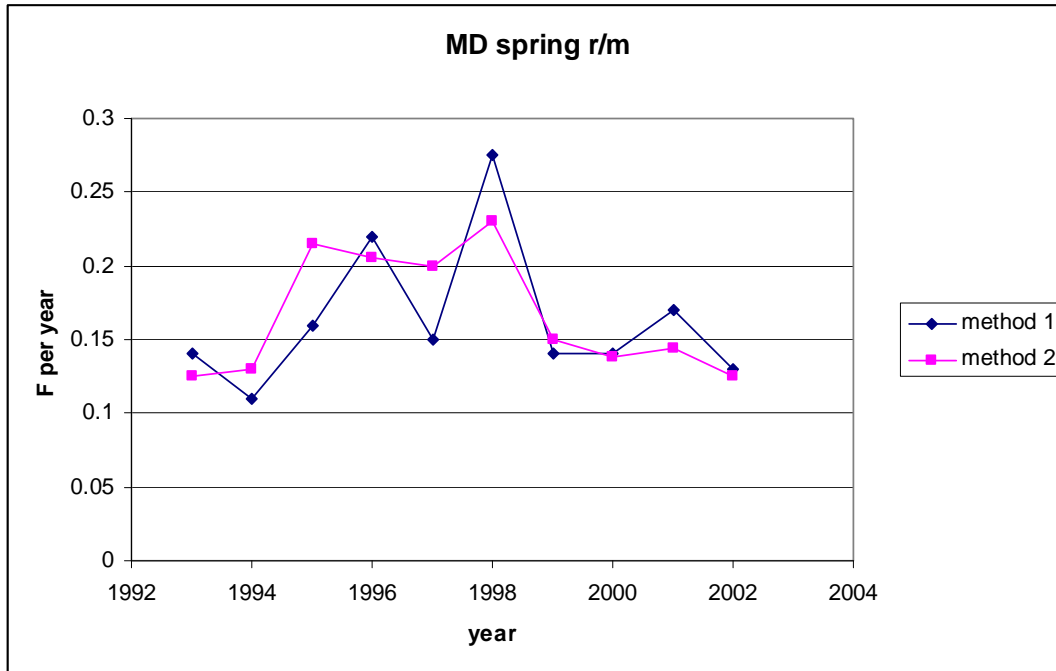
**Table 4.** Estimates of fishing mortality,  $F$ , obtained from the Brownie model, assuming various values for natural mortality rate,  $M$ . The tag recovery rate,  $f$ , is converted to an estimate of exploitation rate,  $u$ , and then the catch equation is solved for  $F$  using Excel's solver.

parameter	estimate	$u = f/.43$	$F   M$	$F   M$	$F   M$
			$=.15$	$=.35$	$=.55$
f1	0.11	0.26	0.32	0.36	0.40
f2	0.06	0.15	0.17	0.19	0.21
f3	0.12	0.29	0.37	0.41	0.46
f4	0.09	0.21	0.25	0.28	0.31
f5	0.09	0.20	0.24	0.27	0.30
f6	0.08	0.18	0.21	0.24	0.26
f7	0.06	0.13	0.15	0.17	0.18
f8	0.07	0.16	0.18	0.20	0.22
f9	0.06	0.15	0.18	0.19	0.21
f10	0.08	0.18	0.22	0.24	0.27
f11	0.07	0.16	0.18	0.20	0.22
f12	0.07	0.17	0.20	0.22	0.24
f13	0.05	0.13	0.15	0.16	0.18
f14	0.06	0.15	0.18	0.19	0.21

**Figure 1.** Fishing mortality obtained from  $r/m$  ratios from spring tagging on the Rappahannock River, Virginia, with an assumed reporting rate of 0.43 and a hooking mortality rate of 0.08. If an  $M$  of 0.55 is assumed for the last few years the right end of the curve will shift upwards (e.g., for 2004 the value becomes .15). See Table 1 for computational details.

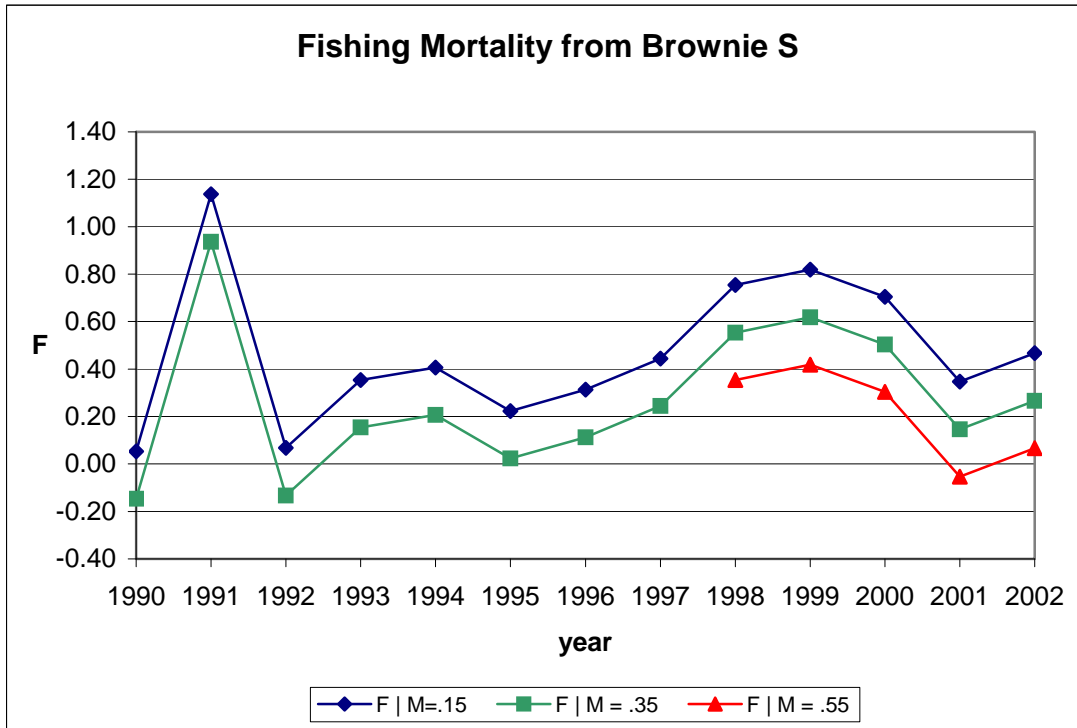


**Figure 2.** Fishing mortality from Maryland spring tagging  $r/m$  ratios, from Sharov and Jones (2003, Figure 2). For method 2, they used a combined (recreational + commercial) reporting rate of 0.43.

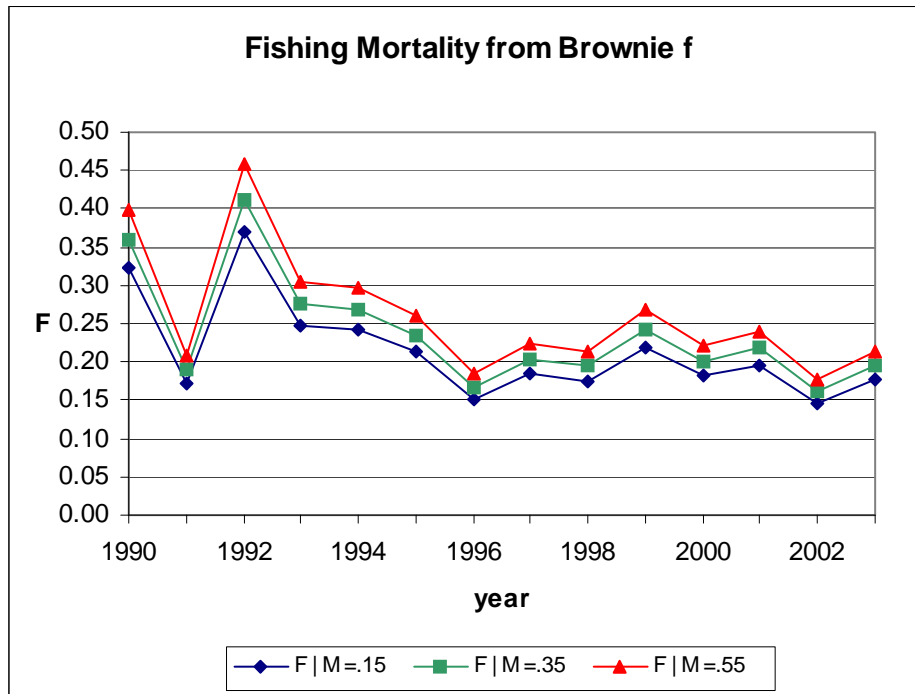




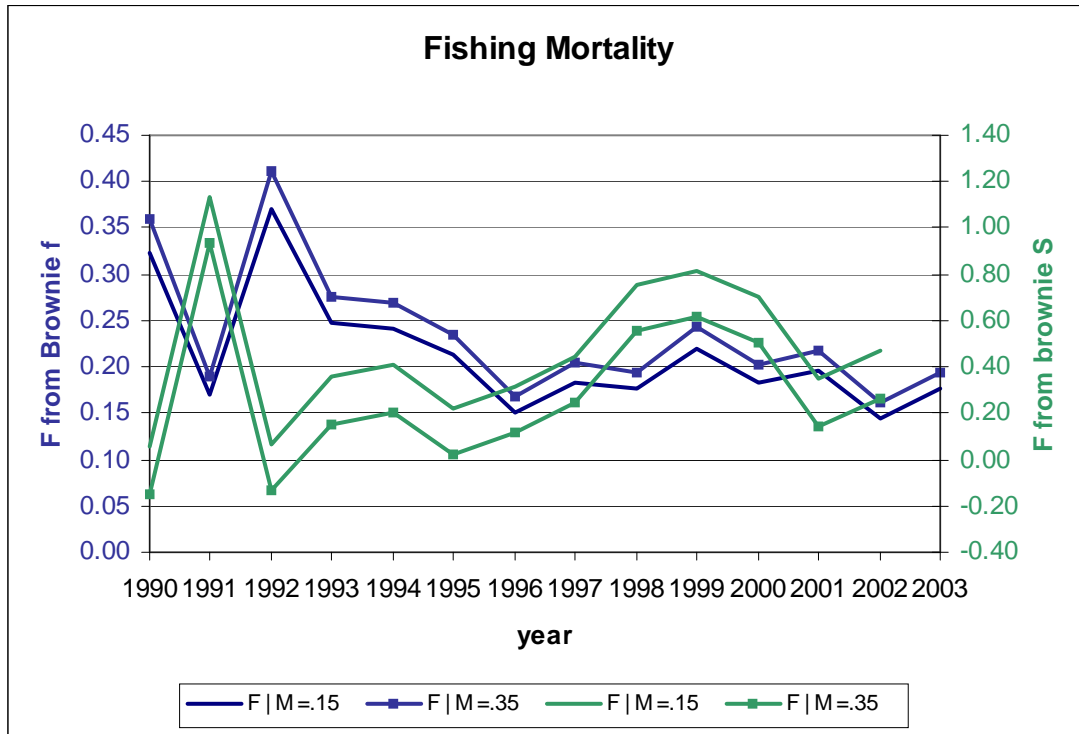
**Figure 3.** Estimates of fishing mortality,  $F$ , obtained from the Brownie model, assuming various values for natural mortality rate,  $M$ . The survival parameter,  $S$ , is converted into an estimate of total instantaneous mortality rate,  $Z$ , and then the natural mortality is subtracted off.



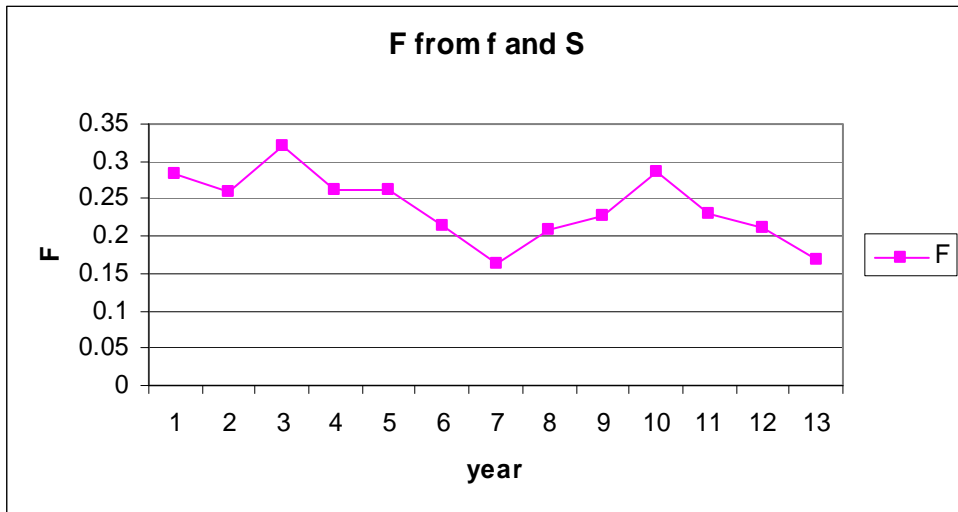
**Figure 4.** Estimates of fishing mortality,  $F$ , obtained from the Brownie model, assuming various values for natural mortality rate,  $M$ . The tag recovery parameter,  $f$ , is converted into an estimate of exploitation by dividing by an assumed value for tag reporting rate of 0.43. The equation  $u = F(1 - \exp(-F - M)) / (F + M)$  is then solved iteratively for  $F$ , given an assumed value for  $M$ .



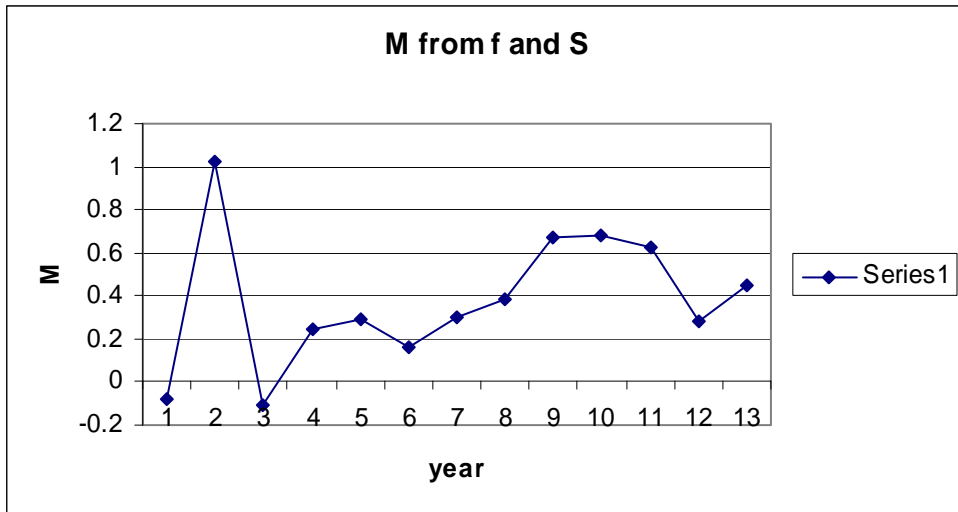
**Figure 5.** Comparison of estimates of fishing mortality derived from survival (S) and tag recovery (f) parameters. The two methods seem to show opposite effects. (Note the different scales for the two methods).



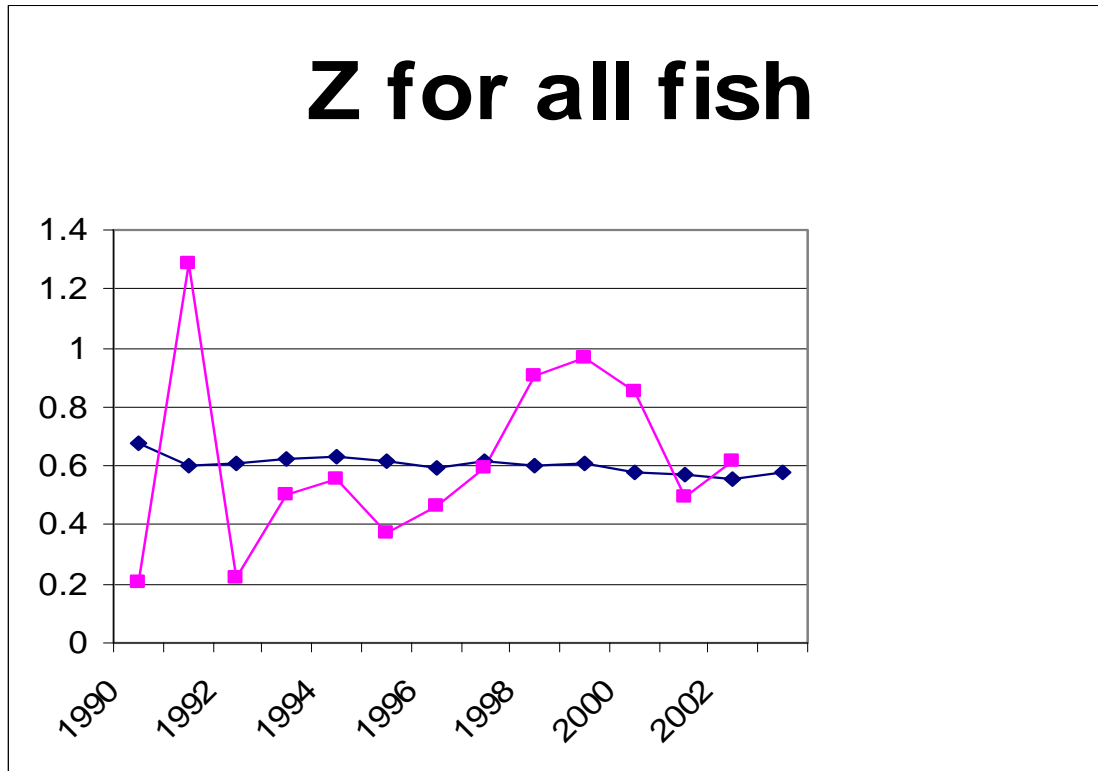
**Figure 5a.** Estimates of fishing mortality derived from Brownie estimates of  $f$  and  $S$  using a method similar to that used by Desmond Kahn.



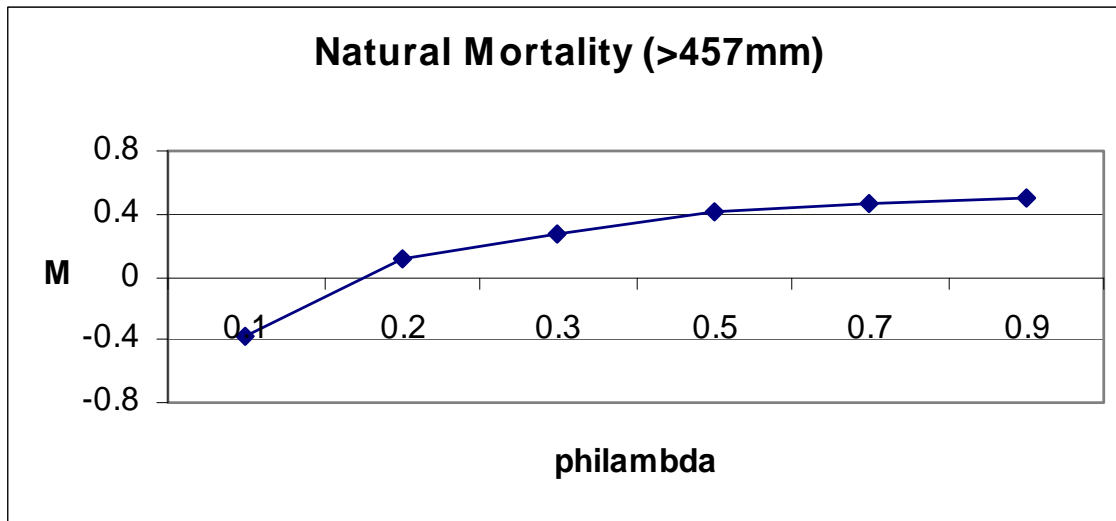
**Figure 5b.** Estimates of natural mortality derived from Brownie estimates of  $f$  and  $S$  using a method similar to that used by Desmond Kahn. There is a problem with the early years of the tagging program. But, after that, the results indicate an increase in natural mortality over time.



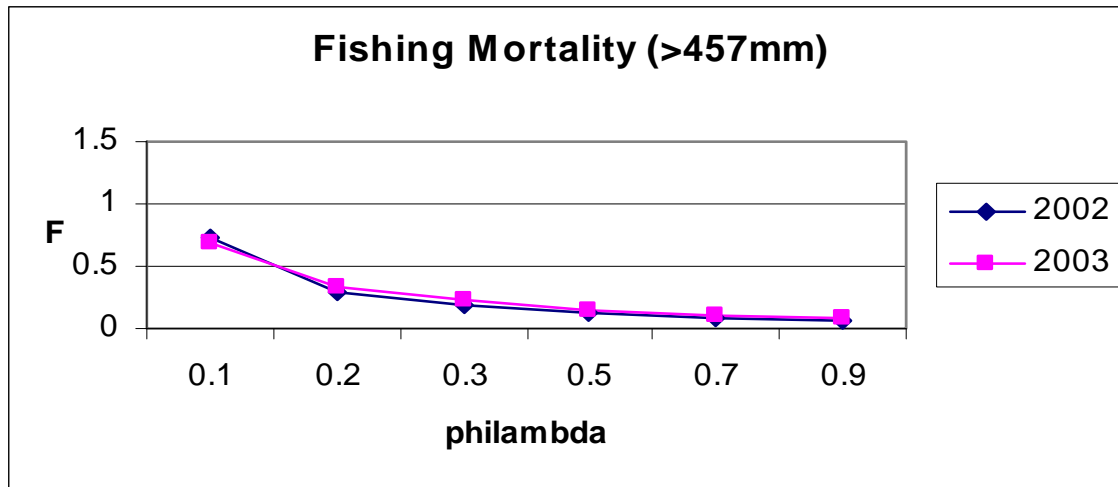
**Figure 6.** Comparison of total mortality rate,  $Z$ , from the Brownie model (obtained by converting estimates of  $S$ ) and  $Z$  from the instantaneous rates model (obtained by adding  $F$  and  $M$ , and assuming in the model that reporting rate = 0.7).



**Figure 7.** Effect of varying the tag reporting rate,  $\phi$ , on the estimate of natural mortality rate,  $M$ . When  $\phi$  is above 0.4, the results are not very sensitive to changes in  $\phi$ .

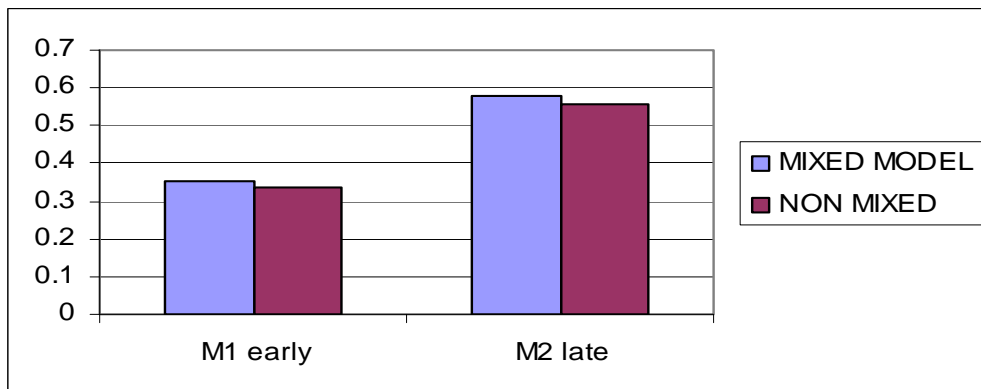
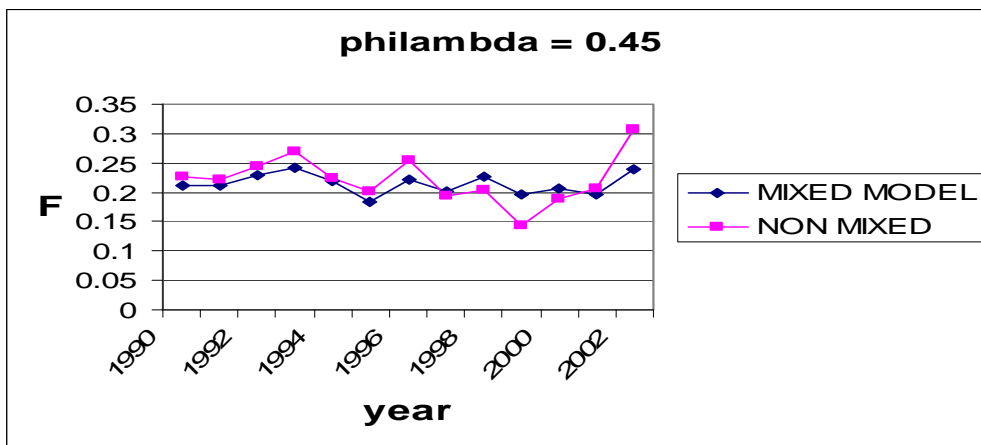
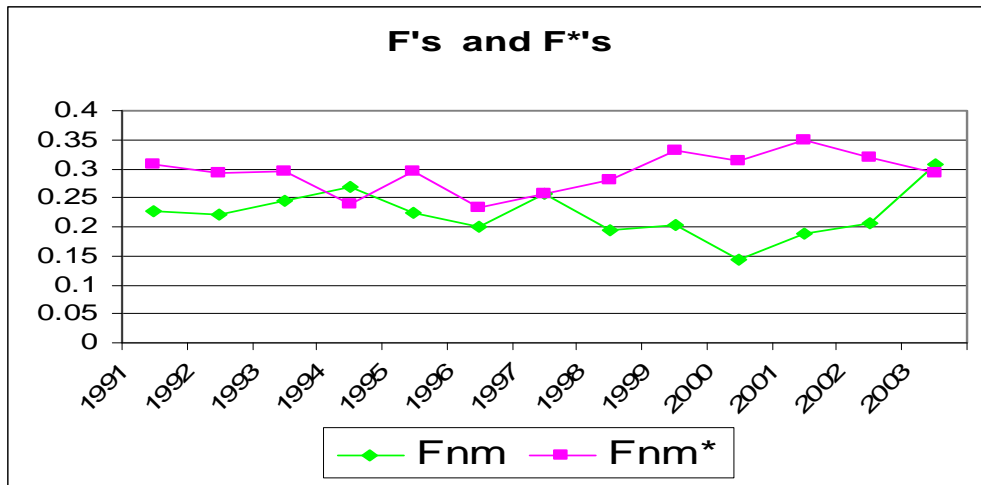


**Figure 8.** Effect of varying the tag reporting rate,  $\text{philambda}$ , on the estimate of fishing mortality rate,  $F$ , in the most recent two years. When  $\text{philambda}$  is above 0.4, the results are not very sensitive to changes in  $\text{philambda}$ . Similar results are obtained for the fishing mortality rates in earlier years.

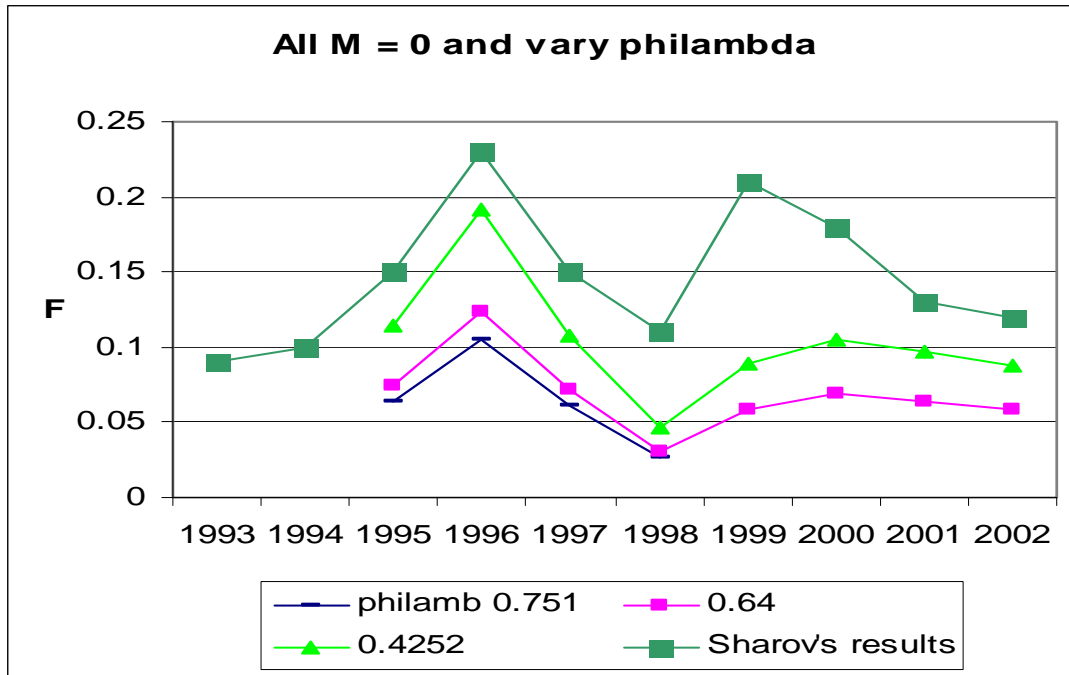




**Figure 9.** Comparison of two instantaneous rates models that specify year-specific fishing mortalities and period specific natural mortalities (first period = up to and including 1998, second period = 1999 to present). Top panel: comparison of fishing mortalities for newly tagged animals ( $F^*$ ) with that for previously tagged animals ( $F$ ) in the nonmixing model. Middle panel: comparison of fishing mortality estimates from the mixing and nonmixing models. Bottom panel: comparison of estimates of natural mortality for two time periods when models assuming mixing (blue) and nonmixing (purple) are fitted to the data.



**Figure 10.** Comparison of Sharov and Jones (2003) estimates of fishing mortality from the summer/fall direct enumeration study with estimates obtained from an instantaneous rates model under three assumptions of tag reporting rate ( $\phi$ ).



#### **IV. Estimation of mortality rates for Atlantic striped bass – a blueprint for action**

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Note: this material was presented to the Atlantic States Marine Fisheries Commission Striped Bass Technical Committee on September 21, 2004, and revised on September 22, 2004

## Background

1. Estimates of survival rates of striped bass > 457 mm have not been accepted and have not fed into the VPA. This is partly because the survival rates look low and have wide variability from year to year. These estimates have been derived from Brownie models and the very similar Seber models.
2. Data for striped bass > 457 mm have recently been analyzed using instantaneous rates models. These provide estimates that are more stable over time, though the total mortality rate remains high. Instantaneous rates models have further advantages: they automatically divide the total mortality into components, they allow for newly tagged animals to have an abnormal fishing mortality rate due to a lack of immediate mixing into the population, and they allow analysis of residuals. Further enhancements under development by Kenneth Pollock (North Carolina State University) and colleagues allow for catch and release fishing and parsimonious modeling of age-effects.
3. Analysis of tagging data from the Chesapeake using instantaneous rates models has provided indications that natural mortality rate for Chesapeake striped bass is higher than previously thought, declines with age, and has increased over time.
4. Recent work by Hoenig and colleagues has suggested that the instantaneous rates models are preferred over  $r/m$  ratios for estimating Chesapeake fishing mortality rates.

The implications of the work described above are that:

- a. A review should be undertaken of methodology used to estimate mortality rates of striped bass from tagging data. Specifically, instantaneous rates models should be evaluated to see if they should replace the Brownie-Seber models.
- b. Recent work by Hoenig and Pollock and colleagues should be examined to see if age-specific mortality rates can be accepted, to evaluate the new method for directly accounting for catch-and-release fishing in the tagging model, and to see if higher levels on natural mortality and increasing natural mortality over time can be accepted.
- c. Examination of how the findings from tagging models can be used to improve the virtual population analysis should be undertaken. Specifically, the tagging data can provide the following to “help” the VPA:
  - i. age- and period specific natural mortality
  - ii. partial recruitment vector (age-specific scaling of fishing mortality)

## Plan of action

It is suggested the following elements could be implemented.

1. Verification of preliminary results. The analyses of Hoenig and colleagues for Rappahannock striped bass should be repeated for data from Maryland and the results compared in terms of a) does the instantaneous rates model produce more credible estimates (less year to year variability) for Maryland, as it did for the Rappahannock; b) do the data indicate higher natural mortality rates in Maryland than previously believed, and do they suggest an increase in natural mortality over time.
2. Examination of tagging data for fish > 457 mm from other programs should be made using instantaneous rates models to a) see if more credible results can be obtained (relative to those obtained with Brownie models) and b) examine the estimates of natural mortality over space.
3. Assuming the result about increased natural mortality over time holds up, collaboration on a manuscript for publication on changes in natural mortality over time in the Chesapeake would be in order.
4. The application of instantaneous rates models to Chesapeake Bay and other striped bass tagging studies should be reviewed in an appropriate forum with a view to changing methodology if the instantaneous rates model is found more appropriate.
5. New developments by Pollock and colleagues on parsimonious age-structured modeling and incorporation of catch and release fishing directly into the model should be reviewed.
6. Software should be developed, documented and made available. Currently, a program in Splus called Avocado is available from Hoenig. It will do much of what is needed but it does not include age-structured analysis or catch and release fishing. Catch and release fishing could be added. The program is being converted to R which is a freeware product that will make it easier to distribute the program.
7. Training sessions may be needed to instruct users in the use of instantaneous rates models and the associated software.
8. Collaboration between the Striped Bass Assessment Subcommittee and Striped Bass Tagging Subcommittee may be in order to ensure that relevant findings from the tagging work can be incorporated into the VPA.
9. These problems should be called to the attention of the ASMFC Striped Bass Board.
10. It is important to ensure that the tag reporting rate is high so that the tagging data can be interpreted even if the exact value of tag reporting rate is not known. When the tag reporting rate is low, small errors in the value of the reporting rate have major impacts on

the computations. Offering a cap as a reward for returning a tag may simply be inadequate to ensure a high reporting rate. A cash reward of suitable value should be offered as an alternative. It is noted that people may become satiated if they already have several caps but people rarely become satiated from having too much money.

**V. Fishing mortality estimates of the fall, 2003 resident striped bass fishery in the Chesapeake Bay, Virginia.**

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Department of Fisheries Science  
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## **Introduction**

In contrast to the highly migratory, mostly female, coastal striped bass population, the Chesapeake Bay and its tributaries maintain a resident population of mature male striped bass in addition to pre-migrant (<2 years old), immature striped bass. These striped bass evidently exhibit little movement during the summer and early fall, remaining stationary in areas of abundant forage (Merrimen 1941, Vladykov and Wallace 1938, Mansueti 1961). In late fall, in response to falling water temperatures and movement of the schools of baitfish, resident striped bass migrate downriver to deeper parts of the tributaries and generally southward along the western side of Chesapeake Bay to over-winter in deeper portions of the bay (Vladykov and Wallace 1938, Mansueti 1961). These striped bass, supplemented by an infusion of southward migrating coastal fish in late November and December, form the basis of the historic annual fall recreational and commercial fisheries.

In 1993, the rebound in striped bass abundance allowed for a lifting of the moratorium on the recreational fishery. The Atlantic States Marine Fisheries Commission (ASMFC) established a target fishing mortality rate (F) of 0.25, which was further relaxed to a rate of 0.30 in 1995 in response to evidence of continued stock recovery (Field 1997). To document compliance with the ASMFC regulations, the VIMS Anadromous Program modified its fall tagging methodology, begun in 1987, to collaborate with the Maryland Department of Natural Resources (Md DNR) to estimate the recreational fishing mortality rate for Chesapeake Bay.

## **Materials and Methods**

### **Experimental design**

Commencing in 1995, a stratified tag release program was instituted in collaboration with Maryland DNR. The Virginia portion of the Chesapeake Bay was divided into the York, James and Rappahannock rivers and (western) main-stem Chesapeake Bay (Fig. 1). Multiple short-duration (< 10 days) tag release periods, synchronized with the Md DNR effort and separated by 3-4 weeks, were executed with the first tagging round occurring prior to the start of each fall recreational season (4 Oct in Virginia). The multiple-release protocol minimized the effects of immigration and emigration to the analysis. Optimal tagging quotas, proportionally based on historic catch data, were allotted to each area to facilitate the diffusion of tagged fish throughout Chesapeake Bay. From 1995-2003, striped bass were tagged from commercial pound nets, drift gill nets, fyke nets and haul seines at multiple sites within each system.

General protocols for tagging follow those described in previous mark-recovery studies (Rugulo et al. 1994, Shaefer and Rugulo 1996, Herbert et al. 1997). A Floy internal tag, with dimensions of 5 mm x 15 mm with an 85 mm external tube was used. Tags were inserted into the peritoneal cavity posterior to the pectoral fin on the left side of the fish. Lengths (FL, TL) were recorded for each striped bass and a scale sample was taken from between the two dorsal fins and above the lateral line for subsequent aging of the fish (Merrimen 1941). Only striped bass



greater than 458 mm total length (18 inches) were tagged. Physical parameters (time, air and surface water temperatures, and tidal stage) were recorded at each tagging location.

### **Analytical methods**

Commencing in 1997, the bay-wide estimate of fishing mortality for resident striped bass has been based on pooled data from the coordinated multiple-release tagging study in addition to harvest statistics from both states from the spring of the subsequent year. The bay-wide estimates are annual mortality rates, however, they pertain to a 12-month period that begins and ends in the late spring of each year (1 June - 31 May).

For purposes of tag release, the natural boundary between Maryland and Virginia was used to stratify Chesapeake Bay into two management jurisdictions. Despite having separate management jurisdictions, tagging efforts were synchronized during times when the fishing seasons on the two states overlapped. In all years, the first release in each jurisdiction began approximately one week prior to the start of the recreational season. The recovery interval began the day after at least one half of the stripers were tagged on a bay-wide basis in each release interval and continued up to the start of the next interval.

The tagging study requires making the assumption that the tagging process does not affect the behavior or the survival of the tagged fish and that there is no tag loss. Assessment of the short-term tag-induced mortality was done in Maryland (1995), and in Virginia (2000), and produced tagging mortality rates of 1.3% and 1.5% respectively (Latour *et al.* in prep). Determination of the reporting rate of recaptured tagged striped bass was done in 1999 by comparing the observed reporting rate with that of a subset of high-reward tags released simultaneously. The resulting tag reporting rates were 0.64 and 0.55 depending on the recovery interval specified (Rogers *et al.* 2000).

Tag recovery data were provided to the Md DNR for estimations of exploitation rate (U) and instantaneous fishing mortality (F). Estimates were calculated utilizing a logistic regression model based on reported tag recoveries that occurred between the midpoints (the date after which 50% of tag releases occurred) of consecutive tagging rounds. The proportion of the number of tags recovered to the number of tags released was the response variable and the explanatory variables consisted of one categorical variable (interval number) and two binary variables (disposition of the recapture and angler type). Note, however, that this procedure is identical to calculating simple ratios of recaptured to marked individuals. The logistic regression is simply an artifact from an earlier time when the incorporation of additional factors was contemplated. Tag release and recovery data for input into the model were adjusted to eliminate the following tag recoveries: those that occurred between the start of the tagging round but prior to the day after the midpoint of tag releases for that round; from stripers found dead or if only a tag was recovered (as opposed to a tagged striper, Goshorn, *et al.* 1999). The calculation of the recreational exploitation rate used only tag returns from striped bass harvested by recreational and charter fishermen.

## Results

### Tag release summary

Immediately prior to the start of the first tagging round in Virginia (round 5, 22 September – 2 October) hurricane Isabelle struck the Chesapeake Bay area. The high winds and extensive flooding destroyed the pound nets of our cooperating fishermen off Reedville (upper Chesapeake Bay), and damaged the nets of our other fishermen. Most marinas and private slips were also extensively damaged and many public access ramps were closed. The large influx of freshwater also displaced the resident striped bass from their normal fall distribution. Hence, the time intervals between tagging rounds, the distribution of tagged striped bass released and the amount of fishing effort were all adversely affected.

Despite Isabelle, in fall 2003, a total of 3,233 striped bass were tagged and released among three tagging rounds in Virginia (Table 1). The high variability of tag releases among the three rounds normally reflect the seasonal availability of striped bass to the commercial gears utilized in each sampling area, but this year it also represented which nets best survived the storm.

**Tagging round 5, 1-10 October:** The 696 striped bass tagged and released came primarily (77.0%) from middle Chesapeake Bay locations (Table 2). This was the only location to meet or exceed its desired quota. This overall lack of spatial diversity is typical of previous tagging rounds in September, but the striped bass normally caught in abundance in the upper Rappahannock River were evidently displaced to the lower parts of the river. Water temperatures during the tagging round were 20-22 EC. As water temperatures drop during October, the striped bass form large schools and migrate towards the deeper, open waters in the lower rivers and Chesapeake Bay and are more susceptible to capture in commercial gears.

The majority of the striped bass tagged and released were from the 2000 (54.3%) and 1999 (39.4%) year classes (Table 3). The mean ages of the striped bass from each jurisdiction varied from 3.13 years (Rappahannock River) to 3.84 years (James River). The mean size (FL) of the striped bass tagged and released from each jurisdiction varied from 475.5 mm (Rappahannock River) to 521.2 mm (James River). The midpoint of the tagging round was 7 October.

**Tagging round 6, 27 October – 5 November:** There was 1,384 striped bass tagged and released during the tagging interval. This reflects the typical increase in availability relative to September or early October (Table 4). Unfortunately, the striped bass displaced from the upper Rappahannock River by hurricane Isabelle did not return. The large amount of debris strewn along the banks of the James River hindered the haul seine efforts there. Water temperatures during the tagging round were 15-18 EC. The number of striped bass tagged and released exceeded the desired quotas only in the middle Chesapeake Bay and York River.

The majority of the striped bass tagged and released were from the 2000 (61.1%) and 1999 (33.9%) year classes (Table 5). The mean ages of the striped bass from each jurisdiction

varied from 3.34 years (Rappahannock River) to 3.58 years (York River). The mean sizes (FL) of the striped bass tagged and released from each jurisdiction varied from 483.2 mm (middle Chesapeake Bay) to 494.2 mm (York River). The midpoint of the tagging round was 31 October.

**Tagging round 7, 17-25 November:** There was 1,153 striped bass tagged and released in this tagging interval. This final tagging round used a different strategy relative to the previous tagging rounds. First, the Thanksgiving holidays (25-27 November) reduced the number of tagging days available. In addition a northeaster on 21 November was followed by unusually cold weather through the rest of the tagging round. Striped bass, usually abundant at most tagging locations, evidently moved into deeper waters away from our commercial gears. This was especially true for the haul seines utilized in the James River, and resulted in a failure to reach the desired release quotas in the James and upper Rappahannock rivers (Table 6). However, striped bass were abundant in the pound nets near the mouth of the Rappahannock River, so additional fish were tagged there to supplement the loss from the other areas. Water temperatures during the tagging round ranged from 10-14EC.

The majority of the striped bass tagged and released were from the 1999 (45.0%) and 2000 (40.8%) year classes (Table 7). The mean ages of the striped bass from each jurisdiction varied from 3.39 years (York River) to 4.13 years (Rappahannock River). The mean sizes of the striped bass tagged and released from each jurisdiction varied from 478.7 mm (York River) to 530.6 mm (Rappahannock River). The midpoint of the tagging round was 18 November.

### **Tag recapture summary**

A total of 151 of the striped bass tagged during the fall were recaptured from 1 October - 31 December, 2003 (Table 8). The overall proportion recaptured was 0.047 and varied by jurisdiction from 0.022 (James River) to 0.056 (Middle Chesapeake Bay). All recaptures from the James and upper Rappahannock rivers were recaptured within the same area they were tagged. Striped bass tagged in the York River were predominantly recaptured there (0.867), but were also recaptured in the lower Chesapeake Bay. Striped bass tagged near the mouth of the Rappahannock and Piankatank rivers (middle Chesapeake Bay) were predominantly recaptured in the lower Rappahannock River (0.853), but were also recaptured in the middle Chesapeake Bay (0.078), Chesapeake Bay in Maryland (0.031), lower Chesapeake Bay (0.023) and the James River (0.016). Unlike previous seasons, no striped bass were recaptured outside the bay in coastal Virginia or North Carolina. The striped bass recaptured from middle Chesapeake Bay releases were slightly larger and older than the striped bass recaptured from the other areas.

**Recapture interval 5, 8-31 October:** A total of 124 striped bass (17.8%) that were tagged in the fifth tagging round were recaptured by 31 December (0.17% per day). However, only 15 recaptures occurred within the fifth recapture interval (Table 9). Sport fishermen (recreational and charter anglers) accounted for only 37.5% of the recaptures during the fifth recapture interval. These anglers harvested 83.3% of these recaptured tagged striped bass. The five recaptured striped bass harvested by sport fishermen were the data used in the computation of fishing mortality. Commercial fishermen recaptured 62.5% of the total recaptures and harvested 20.0% of these striped bass. The Aother@ category consisted mainly of recaptured striped bass

encountered by VIMS tagging personnel at our research pound net in the York River or at the nets of cooperating fishermen at our tagging locations. These fish were re-released unharmed if deemed robust by the chief scientist in each tagging party.

**Recapture interval 6, 1-18 November:** A total of 18 striped bass (1.3%) that were tagged in the sixth tagging round were recaptured by 31 December (0.02% per day). However, nine of these recaptures (50.0%) occurred within the sixth recovery interval (Table 10). Sport fishermen accounted for only 22.2% of the recaptures during the sixth recapture interval. Half of the recaptured striped bass caught by anglers were harvested. The one recaptured striped bass harvested by sport fishermen was the datum used in the computation of fishing mortality. All commercially captured tagged striped bass during the recovery interval were released.

**Recapture interval 7, 19 November - 31 December:** A total of eight striped bass (0.7%) that were tagged in the seventh tagging round were recaptured by 31 December (0.02% per day). By design, all the recaptures occurred within the recovery interval (Table 11). Sport fisherman accounted for 25.0% of the recaptures during the recapture interval and released half. The one recaptured striped bass harvested by sport fishermen as the datum included in the computation of fishing mortality.

Several factors during the recapture interval, in addition to the effects from hurricane Isabelle, account for the low number of recaptures. Unusually harsh weather during the third tagging round reduced the targeted output of tagged striped bass by almost half. Also, most pound nets, including our research net in the York River, cease operations by Thanksgiving. In addition, an unusually prolonged and severe stretch of harsh winter weather persisted throughout late November through middle December which presumably reduced the recreational effort.

### Estimation of fishing mortality (F)

To obtain an estimate of a fishing mortality rate, the tag-recovery rate  $f_i$  must first be converted to a finite exploitation rate (Pollock *et al.* 1991):

$$u_i = \frac{f_i}{\lambda_R}$$

where  $u_i$  is the fall recreational/ charter exploitation rate in interval  $i$  and  $\lambda_R$  is the probability a recreational angler will report a tag recapture. Since the recovery interval was of short duration (20-40 days), natural mortality was deemed negligible and a type I (pulse) fishery was presumed to exist. The fishing mortality rate was then calculated as (Ricker 1975):

$$F = \sum_{i=1}^L -\log(1 - u_i)$$

where L is the total number of intervals.

Recreational fishing also occurs in the spring when tagging of the resident striped bass is not conducted. Hence, derivation of an overall resident fishing mortality rate was adjusted by:

$$F_r = F + (FP_s)$$

where  $F_r$  is the overall recreational/ charter fishing mortality rate and  $P_s$  is the proportion of the number of resident striped bass in the spring harvest relative to the total recreational harvest. Harvest statistics were obtained from the Marine Fisheries Statistics Survey (MRFSS).

The estimate of the Chesapeake Bay fishing mortality rate for 2003 was 0.10. A non-harvest mortality rate of 0.10 was added to produce the final estimate of a recreational/ charter fishing mortality of 0.20 (Hornick *et al.* 2003).

## Discussion

The number of striped bass tagged during the three tagging rounds in Virginia is generally a reflection of their areal and seasonal availability. In September, striped bass are generally scattered in small schools and are structure oriented. Striped bass are reliably captured in quantity from the pound nets of our cooperating fisherman in the upper Rappahannock River and occasionally from haul seines in some shallow bays in the middle James River, but are scarce and sporadic elsewhere. By late October falling water temperatures and the first fall storms apparently initiates a schooling and feeding response in striped bass and they become susceptible to commercial gears throughout western Chesapeake Bay. This trend generally continues through Thanksgiving, but most poundnetters start removing their nets in early November in response to falling catches in the general fisheries and to reduce exposing nets to potential damage from coastal storms. An abnormally wet summer, culminating with hurricane Isabelle, disrupted the normal seasonal pattern. Striped bass vacated the upper rivers in September and took refuge in the deeper, more saline waters in the lower rivers. Unusually harsh weather conditions in late November, 2003, reduced the number of striped bass released to below expectations. While these conditions undoubtedly affected fishing patterns and intensity, there is no way to adequately quantify the effect.

Both pound nets and haul seines are non size-selective, but the legal-sized (>458 mm FL) striped bass captured for tagging were overwhelmingly three and four year-old fish. Larger resident male striped bass are encountered in the spring tagging and spawning stock assessment studies, so their omission may create a size-bias in the estimation of fishing mortality of the resident population. Larger fish are generally targeted by recreational anglers and are less likely to be released when captured.

The high incidence of recapture of tagged striped bass within the same general geographic area in which they were released in the first two tagging rounds in Virginia (rounds five and six) indicate that the early fall migrations of the resident population is limited in scope (see Figure 1 for the areal breakdown). The prevalence of same-area recapture was highest in

Rappahannock River and was also very high in the James and York rivers. However, striped bass tagged from our middle Chesapeake Bay locations did show a wider pattern of dispersal. Striped bass tagged there were recaptured throughout the Chesapeake Bay (including Maryland) as well as in the James and Rappahannock rivers.

The Chesapeake Bay-wide estimate of resident striped bass fishing mortality was 0.20. This was the sum of the estimate of both non-harvest (0.10) and harvest (0.10) mortalities. Non harvest mortalities include natural deaths and handling-induced mortalities. In our fall 2003 study, 29.1% of the recaptures were released alive (21.9% of sport recaptures and 100% of research recaptures). The fishing mortality estimate was below the target rate desired for Chesapeake Bay established by the Atlantic States Marine Fisheries Commission (ASMFC). This year, VIMS undertook a review of the fall tagging program for the ASMFC. Results from this review are included in section III.

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**Table 1.** Striped bass tag release round dates, proposed tag release quotas and number of striped bass tagged and released in Chesapeake Bay, Virginia, fall, 2003. Note: tagging rounds 1-4 were in Maryland only.

Tagging round	Dates	Location	Quota	Releases
5	1-10 Oct.	Chesapeake Bay – upper	150	0
		Chesapeake Bay – middle	150	536
		Rappahannock River	350	46
		York River	100	17
		James River	250	97
		Subtotal	1,000	696
6	27 Oct–5 Nov.	Chesapeake Bay - upper	300	0
		Chesapeake Bay - middle	200	882
		Rappahannock River	300	45
		York River	100	432
		James River	300	25
		Subtotal	1,200	1,384
7	17-25 Nov.	Chesapeake Bay - upper	300	0
		Chesapeake Bay - middle	200	903
		Rappahannock River	200	37
		York River	100	201
		James River	200	12
		Subtotal	1,000	1,153

**Table 2.** Daily striped bass tag release totals, by area, during round 5 (1-10 October) of the fall, 2003 fishing mortality (F) study.

Tag release area	1 Oct	2 Oct	3 Oct	4 Oct	5 Oct	6 Oct	7 Oct	8 Oct	9 Oct	10 Oct
Chesapeake Bay (upper region)										
Chesapeake Bay (middle region)	219		76			75				166
Rappahannock River (upper region)						31			15	
York River (middle region)										17
James River (middle region)	53	28						16		
<b>totals</b>	272	28	76	0	0	106	0	16	15	183

**Table 3.** Age structure, by year class (YC), and mean fork length (FL, in mm) of striped bass tagged and released at each location during round 5 (1-10 October) of the fall, 2003 fishing mortality study.

Tagging location	year class	n	%	mean FL (mm)		mean age
				YC	total	
Chesapeake Bay (middle region)	2000	262	37.7	460.9	502.5	3.48
	1999	183	58.1	518.1		
	1998	21		584.4		
	1997	4	3.7	688.0		
	n/aged	66	0.5	479.6		
Rappahannock River	2000	40	87.0	454.3	475.5	3.13
	1999	6	13.0	502.0		
York River	2000	10	58.8	447.5	482.2	3.40
	1999	4	23.5	545.5		
	1997	1	5.9	660.0		
	n/aged	2	11.8	440.0		
James River (middle section)	2000	30	30.9	458.0	521.2	3.84
	1999	55	56.7	535.3		
	1998	10	10.3	600.3		
	1997	2	2.1	685.5		

**Table 4.** Daily striped bass tag release totals, by area, during round 6 (27 October-5 November) of the fall, 2003 fishing mortality (F) study.

Tag release area	27 Oct	28 Oct	29 Oct	30 Oct	31 Oct	1 Nov	2 Nov	3 Nov	4 Nov	5 Nov
Chesapeake Bay (upper region)										
Chesapeake Bay (middle region)		611			271					
Rappahannock River	26							19		
York River		385			17					30
James River (middle region)	24			1						
<b>totals</b>	50	996	0	1	288	0	0	19	0	30

**Table 5.** Age structure, by year class (YC), and mean fork length (FL, in mm) of striped bass tagged and released at each location during round 6 (27 October – 5 November) of the fall, 2003 fishing mortality study.

Tagging location	year class	n	%	mean FL (mm)		mean age
				YC	total	
Chesapeake Bay (middle region)	2001	1	0.1	431.0	483.2	3.36
	2000	568	64.4	464.1		
	1999	286	32.4	514.5		
	1998	13	1.5	594.0		
	1997	1	0.1	600.0		
	1995	1	0.1	832.0		
	n/aged	12	1.4	490.2		
Rappahannock River	2000	29	64.4	471.6	487.5	3.34
	1999	15	33.3	519.9		
	n/aged	1	2.2	464.0		
York River	2000	230	53.6	454.1	494.2	3.58
	1999	150	35.0	527.7		
	1998	38	8.9	578.2		
	1997	6	1.4	627.2		
	n/aged	5	1.2	536.0		
James River (middle section)	2000	11	44.0	462.1	493.9	3.56
	1999	14	56.0	518.8		

**Table 6.** Daily striped bass tag release totals, by area, during round 7 (17-25 November) of the fall, 2003 fishing mortality (F) study.

Tag release area	17 Nov	18 Nov	19 Nov	20 Nov	21 Nov	22 Nov	23 Nov	24 Nov	25 Nov	26 Nov
Chesapeake Bay (upper region)										
Chesapeake Bay (middle region)		736			167					
Rappahannock River (upper region)									37	
York River (middle region)	91				52					58
James River (middle region)	5							7		
<b>totals</b>	96	736	0	0	219	0	0	7	37	58

**Table 7.** Age structure, by year class (YC), and mean fork length (FL, in mm) of striped bass tagged and released at each location during round 7 (17-26 November) of the fall, 2003 fishing mortality study.

Tagging location	year class	n	%	mean FL (mm)		mean age
				YC	total	
Chesapeake Bay (middle region)	2000	328	36.3	471.4	523.6	3.86
	1999	445	49.3	524.9		
	1998	73	8.1	600.2		
	1997	24	2.7	690.8		
	1996	13	1.4	761.2		
	1995	7	0.8	821.4		
	1994	2	0.2	842.0		
	1993	1	0.1	951.0		
	n/aged	10	1.1	592.1		
Rappahannock River	1999	14	87.5	523.9	530.6	4.13
	1998	2	12.5	577.5		
York River	2000	126	62.7	453.1	478.7	3.39
	1999	55	27.4	516.2		
	1998	9	4.5	597.9		
	1997	1	0.5	624.0		
	n/aged	10	5.0	474.1		
James River	2000	7	58.3	446.3	490.3	3.42
	1999	5	41.7	552.0		

**Table 8.** Number, location, mean fork length (FL in mm) and mean age of recaptured striped bass, by release location, 1 October - 31 December, 2003.

Release location	Chesapeake Bay (Va.) recaptures*								
	total	location						mean	
		river			Chesapeake Bay			FL	age
		Rap.	York	James	upper	middle	lower		
<b>Rappahannock River</b>	4	4	0	0	0	0	0	473.8	3.3
<b>York River</b>	15	0	13	0	0	0	2	495.7	3.6
<b>James River</b>	3	0	0	3	0	0	0	598.7	5.0
<b>Chesapeake Bay (upper)</b>	0	0	0	0	0	0	0		
<b>Chesapeake Bay (middle)</b>	129	110	0	2	x	10	3	488.5	3.4

\*Other recaptures: (tagging location) (recapture location)

Chesapeake Bay (middle) Chesapeake Bay (Maryland) – 4



**Table 9.** Summary of the disposition of striped bass tagged during round 5 (1-10 October) and subsequently recaptured prior to 31 December, with emphasis on the fifth recapture interval (8 October – 31 October, 2003).

Release location	recaptures								
	total	1 Oct - 7 Oct	8 Oct – 31 Oct						1 Nov - 31 Dec
			commercial		sport		other		
			R	H	R	H	R	H	
Rappahannock River	1	0	1	0	0	0	0	0	0
York River	12	0	0	0	0	4	0	0	8
James River	3	0	0	0	0	0	0	0	3
Chesapeake Bay (upper)	0	0	0	0	0	0	0	0	0
Chesapeake Bay (middle)	108	11	7	2	1	1	0	0	86

R: released alive

H: harvested

**Table 10.** Summary of the disposition striped bass tagged during round 6 (27 October – 5 November) and subsequently recaptured prior to 31 December 2003, with emphasis on the sixth recapture interval (1–18 November).

Release location	recaptures								
	total	27 Oct - 31 Oct	1 Nov – 18 Nov						19 Nov - 31 Dec
			commercial		sport		other		
			R	H	R	H	R	H	
Rappahannock River	3	0	0	0	0	0	0	0	3
York River	3	0	0	0	0	0	2	0	1
James River	0	0	0	0	0	0	0	0	0
Chesapeake Bay (upper)	0	0	0	0	0	0	0	0	0
Chesapeake Bay (middle)	13	0	2	0	1	1	1	0	8

R: released alive

H: harvested

**Table 11.** Summary of the disposition of striped bass tagged during round 7 (17-25 November) and subsequently recaptured prior to 31 December, 2003.

Release location	recaptures							
	total	17 Nov - 18 Nov	19 Nov - 31 Dec					
			commercial		sport		other	
			R	H	R	H	R	H
<b>Rappahannock River</b>	0	0	0	0	0	0	0	0
<b>York River</b>	0	0	0	0	0	0	0	0
<b>James River</b>	0	0	0	0	0	0	0	0
<b>Chesapeake Bay (upper)</b>	0	0	0	0	0	0	0	0
<b>Chesapeake Bay (middle)</b>	8	0	4	2	1	1	0	0

R: released alive  
S: harvested

**Figure 1.** Delineation of western Chesapeake Bay, Virginia into tagging jurisdictions and location of tagging sites during fall, 2003.

