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Evaluation of Striped Bass Stocks in Virginia: Monitoring and Tagging Studies, 2004-2008, 1 September 2005 - 31 August 2006

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Annual Report

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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 September 2005 through 31 August 2006. It includes an assessment of the biological characteristics of striped bass taken from the 2006 spring spawning run, estimates of annual survival and fishing mortality based on annual spring tagging, and the preliminary results of the fall 2005 study that documents the prevalence of mycobacterial infections of striped bass in Chesapeake Bay. 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, closed periods and 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 for tagging 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). Commencing in 2005, these estimates of F were estimated from the striped bass tagged during the spring in the Rappahannock River.

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 Aaron Aunin, Chip Cotton, Danielle Johnson, Patrick McGrath, Tom Idhe, Jason Romine, and Troy Tuckey; the cooperating commercial fishermen Allan Ingraham, Ernest George, Joe Hinson, Stanley Oliff and Paul Somers; and Harry Hornick and Beth Versak of Maryland Department of Natural Resources (Md DNR).

Executive Summary

New Features: This year we began a cooperative effort with Maryland Department of Natural Resources to estimate fishing mortality and exploitation rates using the release and recapture matrix of male striped bass under 711 mm total length from the spring tagging program in the Rappahannock River. We also commenced a new tagging program designed to document the effects that mycobacterial infections have on striped bass in Chesapeake Bay. Expected benefits include estimates of disease progression and mortality and their implications for stock management.

I. Assessment of the spawning stocks of striped bass in the Rappahannock and James rivers, Virginia, spring 2006.

Catch Summaries:

1. In 2006, 776 striped bass were sampled between 30 March and 1 May from two commercial pound nets in the Rappahannock River. The samples were predominantly male (82.3%) and young (64.8% ages 2-4). Females dominated the age nine and older age classes (86.6%). The mean age of the male striped bass was 4.0 years. The mean age of the female striped bass was 9.0 years.

2. During the 30 March - 3 May period, the 2002 and 2003 year classes were the most abundant in the Rappahannock River pound net samples and were 98.4% male. The contribution of age six and older males was only 8.9% of the total aged catch. Age seven and older females, presumably repeat spawners, were 14.0% of the total catch but represented 66.9% of all females caught.

3. In 2006, 335 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 (82.1%) and young (53.1% ages 2-4). Females dominated the age nine and older age classes (68.8%). The mean age of the male striped bass was 4.7 years. The mean age of the female striped bass was 8.8 years.

4. During the 30 March - 3 May period, the 2002 and 2003 year classes were the most abundant in the Rappahannock River gill net samples and were 98.3% male. The contribution of age seven and older males was only 9.9% of the total catch. Age seven and older females, presumably repeat spawners, were 13.4% of the total catch but were 80.4% of the total females caught.

5. In 2006, 1,284 striped bass were sampled between 30 March and 3 May in two experimental anchor gill nets (mile 62) in the James River. The samples were predominantly male (90.7%) and young (50.7% ages 2-4). Females dominated the age nine and older age classes (78.9%). The mean age of the male striped bass was 4.5 years. The mean age of the female striped bass was 9.6 years.

6. During the 30 March - 3 May period, the 2001-2003 year classes were the most abundant in the James River gill net samples and were 98.5% male. The contribution of age seven and older males was only 6.2% of the total catch. Age seven and older females, presumably repeat spawners, were 6.6% of the total aged catch, but represented 78.3% of all females caught.

Spawning Stock Biomass Indexes (SSBI)

7. The Spawning Stock Biomass Index (SSBI) from the Rappahannock River pound nets was 25.8 kg/day for male striped bass and 24.7 kg/day for female striped bass. The male index was the sixth highest in the 1991-2006 time series and 10.9% above the 16-year average. However the 2006 index was 9.8% lower than the index for 2005. However, the female index was 36.7% below the 2005 index, near the median for the time series, and 17.7% below the 16-year average.

8. The SSBI for the Rappahannock River gill nets was 49.2 kg/day for male striped bass and 39.6 kg/day for female striped bass. The male index was the third lowest in the 1991-2006 time series and 37.9% below the 16-year average. The female index was the sixth highest in the 1991-2006 time series and was 11.6% above the 16-year average.

9. The SSBI for the James River gill nets was 213.1 kg/day for male striped bass and 99.5 kg/day for female striped bass. The male index was the second highest in the 1994-2006 time series, and was 66.7% above the 13-year average. The female index was the third highest in the 13-year time series and was 64.7% above the 13-year average.

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 2006 Egg Production Potential Index (EPPI, millions of eggs/day) for the Rappahannock River pound nets was 4.0 million eggs/day. This was the third lowest EPPI of the 2001-2006 time series. Older (8+ years) female stripers were responsible for 91.2% of the index.

11. The 2006 EPPI for the Rappahannock River gill nets was 6.3 million eggs/day. This was the second highest EPPI of the 2001-2006 time series and was almost double the 2005 index. Older (8+years) female striped bass were responsible for 92.5% of the index.

12. The 2006 EPPI for the James River gill nets was 15.1 million eggs/day. This was the highest EPPI of the 2001-2006 time series and was more than triple the 2005 index. Older (8+ years) female striped bass were responsible for 91.6% 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 (22.1 fish/day) was the fourth highest in the1991-2006 time series. There was an increase in the 2002 and 2003 year classes from the 2005 values. The cumulative catch rate of male striped bass (18.5 fish/day) was the fourth highest in the time series and was 46.1% higher than the rate in 2005. The cumulative catch rate of female striped bass (3.5 fish/day) was near the median in the 1991-2006 time series but 31.2% lower than the rate in 2005.

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 0.516-0.7509 (mean = 0.616). The geometric mean survival rates differed greatly between sexes. Mean survival rates for male stripers (1985-1997 year classes) varied from 0.317-0.560 (mean = 0.430) but mean survival rates of female stripers (1983-1991 year classes) varied from 0.462-0.658 (mean = 0.602).

15. The cumulative catch rate (all age classes, sexes combined) from Rappahannock River gill nets (33.5 fish/day) was the fourth lowest value in the 1991-2006 time series, but 4.0% higher than in 2005. Cumulative catch rate of male stripers (27.9 fish/day) was the fourth lowest in the time series and 5.4% lower than the rate in 2005. The cumulative catch rate of female striped bass (5.6 fish/day) was near the median in the time series and more than double the catch rate in 2005.

16. Year class-specific estimates of annual survival for gill net data varied widely between years. The geometric mean S of the 1984-1997 year classes varied from 0.408-0.659 (mean = 0.551). The mean survival rates for male stripers (1987-1997) varied from 0.150-0.558 (mean = 0.356). The mean survival rates for female stripers (1984-1993) varied from 0.501-0.707 (mean = 0.585).

17. The cumulative catch rate (all age classes, sexes combined) from James River (mile 62) gill nets (128.3 fish/day) was the third highest catch rate in the 1994-2006 time series. The catch rate was 56.5% higher than the rate in 2005. The cumulative catch rate for male striped bass (116.4 fish/day) was also the third highest of the 1994-2006 time series, and was 47.3% higher than the rate in 2005. The cumulative catch rate of female striped bass (12.0 fish/day) was 400.0% higher than the rate in 2005, and was the highest value since 1999.

18. Year class-specific estimates of annual survival in the James River varied widely between years. The geometric mean S of the 1984-1998 year classes varied from 0.347-0.783 (mean = 0.595). The mean survival rates of male stripers (1988-1998 year classes) varied from 0.286-0.672 (mean = 0.456). The mean survival rates of female stripers (1984-1995 year classes) varied from 0.347-0.874 (mean = 0.650).

Catch rate histories of the 1987-1998 year classes

19. Plots of year class-specific catch rates vs. year in the James and Rappahannock rivers from 1991-2005 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 areas 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 1987-1998. In the James River, the 1995-1997 year classes were the strongest and 1987 and 1988 year classes the weakest.

Growth rate of striped bass derived from annuli measurements

21. The scales of 286 striped bass were digitally measured and the increments between annuli were used to determine their growth history.

22. On average, striped bass grow about 142 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 295 specimens from 11 size ranges were aged by reading both scales and otoliths. The mean age of the otolith-aged striped bass was 0.21 years older than from the scale-aged striped bass. The two methodologies agreed on the age of the striped bass on 30.1% of the specimens and within one year 80.3% of the time.

25. Tests of symmetry applied to the age matrix indicated that the differences (higher or lower in age) between the two ageing methodologies were random (p= 0.083).

26. A paired t-test of the mean of the age differences produced by the two ageing methodologies found that the mean difference were significantly different from zero (p= 0.011).

27. A Kolmogorov-Smirnov test of the age structures produced by the two ageing methodologies also indicated xxx overall significant difference, indicating that the two resultant age structures did not represent an equivalent population. The differential ageing between the two methodologies on the age-ten striped bass was the source of the significant difference.

II. Mortality estimates of striped bass (*Morone saxatilis*) that spawn in the Rappahannock River, Virginia, spring 2005-2006.

1. A total of 669 striped bass were tagged and released from pound nets in the Rappahannock River between 27 March and 4 May, 2006. Of this total, 494 were between 457-710 mm total length and considered to be predominantly resident striped bass and 175 were considered to be predominantly migrant striped bass (>710 mm TL). The median date of the tag releases was 24 April for the resident striped bass and 13 April for the migrant striped bass.

2. A total of 42 (out of 921) striped bass (>457 mm TL), tagged during spring 2005, were recaptured between 28 April, 2005 and 23 April, 2006 (the respective midpoints of the two tag release totals), and were used to estimate mortality. Twenty seven of these recaptures were harvested (64.3%) and the rest were re-released into the population. In addition, 40 striped bass tagged in previous springs were recaptured during the recovery interval and were used to complete the input data matrix. Most recaptures (62.1%) were caught within Chesapeake Bay (38.9% in Virginia, 23.2% in Maryland). However, other recaptures came from Massachusetts (16.8%), New Jersey (6.3%), Rhode Island ,New York, Delaware and North Carolina (3.2 % each), Maine and Connecticut (1.1% each).

3. A total of 16 (out of 284) migratory striped bass (>710 mm total length), tagged during spring 2005, were recaptured between 28 April, 2005 and 12 April, 2006, and were used to estimate the mortality. Twelve of these recaptures were harvested (75.0%), 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. Most recaptures (36.2%) came from Chesapeake Bay (34.0% in Virginia, 2.1% in Maryland). Other recaptures came from Massachusetts (27.7%), Rhode Island ,New York, New Jersey , Delaware and North Carolina (6.4% each), Maine and Connecticut (2.1% each).

4. The ASFMC Striped Bass Tagging Subcommittee established a data analysis protocol that involves deriving survival estimates from a suite of Seber models. Thirteen 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 0.606-0.785 over the time series. The 2005 survival rate was the highest overall, otherwise 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 fishing mortality(assuming natural mortality is 0.15) ranged from 0.062-0.335 and only infrequently, and by slight margins, exceeded the fisheries target values.

5. 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.

6. After adjusting for tag-induced mortality, reporting rate of recaptured striped bass and hook-and-release mortality, the 2005 estimate of exploitation rate for Virginia was 0.05 and the estimate of fishing mortality was 0.06. When pooled with the Maryland and Potomac River data, the final (after including non-harvest mortality) Chesapeake Bay estimate was 0.24.

III. The role of Mycobacteriosis in elevated Natural Mortality of Chesapeake Bay striped bass: disease progression and developing better models for stock assessment and Management.

1. Mycobacteriosis in striped bass is a chronic disease caused by various species of bacteria in the genus *Mycobacterium*. The disease appears as grey granulomatous nodules in internal organs and externally as ulcerous skin lesions. Mycobacteriosis in captive fishes is generally thought to be fatal, but this has not been established for wild striped bass.

2. The impact of the disease is poorly understood. Fundamental questions, such as mode of transmission, duration of disease stages, effects on fish movements, feeding, reproduction and mortality rates associated with the disease are unknown.

3. A total of 1, 816 striped bass were tagged, assessed for external diseases indications, photographed and released from two pound nets in the upper Rappahannock (n=250) and five pound nets in the lower Rappahannock (n=1,566) River during fall, 2005. Only 22.5% of the total tagged were without any external sign of mycobacteriosis.

4. A total of 570 striped bass were tagged, assessed for external diseases indications, photographed and released from two pound nets in the upper Rappahannock (n=68) and five pound nets in the lower Rappahannock (n=502) River during spring, 2006. Only 31.8% of the total tagged were without any external sign of mycobacteriosis.

5. A total of 150 striped bass tagged during fall, 2005 were recaptured prior to 20 September, 2006. Although 22.5% of the releases were assessed as clean and 6.5% were assessed as heavily infected, the recaptures rates were 16.0% for the clean and 17.3 % for the heavily infected striped bass releases.

6. A total of 65 striped bass bass tagged during spring, 2006 were recaptured prior to 20 September, 2006. Although 31.8% of the releases were assessed as clean and 11.6% were assessed as heavily infected, the recaptures rates were 24.6% for the clean and 6.2 % for the heavily infected striped bass releases.

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I. Assessment of spawning stocks of striped bass in the Rappahannock and James rivers, Virginia, spring 2005.

I. Assessment of the spawning stocks of striped bass in the Rappahannock and James rivers, Virginia, spring, 2006.

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Introduction

Every year, striped bass migrate along the US east coast from offshore and coastal waters and 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 13-19^0 C (Grant and Olney 1991). Spawning is often completed by mid-May, but may continue until June (Chapoton and Sykes 1961). Spawning grounds have been associated with rock-strewn coastal rivers characterized by rapids and strong currents on the Roanoke and the Susquehanna rivers (Pearson 1938). In Virginia, spawning occurs over the first 40 km of 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 River between 30 March - and 1 May, 2006. Samples (the entire catch of striped bass from each gear) were taken twice-weekly (Monday and Thursday) from a pair of commercial pound nets (river miles 45 and 46) in the Rappahannock River. A third pound net located at river mile 47 was damaged by a commercial vessel and was not available for sampling. 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 at river mile 48 on the Rappahannock River and two at 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 in the second net 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 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 stratified subsample of the striped bass, processed for aging, and compared to their scale-derived ages.

The otolith subsample was the first 10 striped bass of each sex 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. These 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 at least twice at different times by each of two readers using the methods described by Wischniowski and Bobko (1998).

All readable scales from the otolith-scale comparison 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 fishing effort by the mature female (age 4+) 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= 776) were sampled between 30 March and 1 May, 2006, from the pound nets in the Rappahannock River. The number of striped bass sampled was higher than was sampled in 2005 (n= 613) and was 28.6% above the 16-year average. Total catches varied from 34-119 striped bass, with a peak catch on 30 March (Table 1). Surface water temperature increased rapidly from 10 EC on 27 March to 14 EC on 3 April, then increased slowly to 19 EC on 1 May. For the third consecutive year, dry weather persisted throughout April, resulting in

lower river flows than had been present in 2001-2003. Catches of female striped bass peaked on 30 March and 3 April, and were dominated by the pre-1998 year classes. Males made up 82.3% of the total catch, which was above the 16-year average (78.2%). The 2002-2004 year classes comprised 64.8% of the total catch. Males dominated the 2002-2004 year classes (98.4%) and the 1998-2001 year classes (72.9%), but females dominated the 1989-1997 year classes (86.6%).

Biomass catch rates (g/day) of male striped bass peaked on 30 March and on 27 April and female striped bass were highest on 30 March (Table 2). The numeric catch rate of males exceeded that of females on every sampling date. In contrast to previous years, the biomass catch rates for male striped bass exceeded that for females overall (1.04:1), peaking on 1 May (2.56:1). The mean ages of male striped bass varied from 3.8-4.3 years by sampling date, with the oldest mean ages occurring on 13 and 27 April. The mean ages of females varied from 7.6-11.2 years by sampling date, but only varied from 8.9-10.2 years from 13 April – 1 May.

There was a peak in abundance of striped bass (mostly male) between 410-510 mm total length in the pound net samples (Table 3). This size range accounted for 51.4% of the total sampled. There was a secondary peak in abundance of striped bass between 760-910 mm total length, accounting for 14.9% of the total sampled. However, the striped bass from 610-710 mm total length accounted for only 0.1% 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 19.1%.

During the 30 March - 3 May period, the 2003 (35.6%) and 2002 (28.9%) year classes were the most abundant (Table 4). These year classes were 98.4% male. The contribution of males age six and older (the pre-2001 year classes) was 5.6% 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 14.0% of the total aged catch, but was also 66.9% of the total females captured. The catch rate (fish/day) of male striped bass was 18.6, which is 20.8% above the 14-year average (Table 5). The catch rate of female striped bass (3.6 fish/day) was 16.3% below the 14-year average, and was the lowest since 2002. The biomass catch rate (kg/day) of male striped bass was slightly above the average of the 14-year time series. However, the biomass catch rate (kg/day) of female striped bass was well below the 14-year average. The mean age (30 March – 3 May) of the male striped bass was below the 14-year average and was the lowest since 2000. The mean age of the female striped bass was the lowest since 2002, but was still above the 14-year average.

Experimental gill nets: Striped bass (n= 335) were also sampled between 30 March and 3 May, 2006 from two multi-mesh experimental gill nets in the Rappahannock River. The total catch was slightly greater than in 2005 (322). Total catches peaked on 6 April, due to the large number of three to four year old males (Table 6). Total catches of female striped bass varied between 5 and 10 from 30 March – 20 April. Males made up 82.1% of the total catch. Males dominated the 2002-2004 year classes (98.3%) and the 1998-2001 year classes (77.6%), but the 1989-1997 year classes were 68.8% female.

Biomass catch rates (g/day) of both male female striped bass were highest on 6 April (Table 7). The catch rate (fish/day) of males exceeded that of females on every sampling occasion. The mean ages of male striped bass varied from 3.7-6.1 years by sampling date, with the oldest males being most abundant from 6-13 April. The mean ages of females varied from 6.6-10.0 years by sampling date, with the oldest females (age nine and older) being most abundant from 30 March-20 April.

There was a peak in the distribution of length frequencies of striped bass in the gill net samples between 410-520 mm TL (Table 8). In previous years, there was a distinct secondary peak of larger striped bass, but this was less apparent in 2006. In contrast to previous years, the total contribution of striped bass greater than 840 mm total length was similar from both the gill nets (12.7%) and the pound nets (11.1%). The total contribution of striped bass greater than 710 mm total length was 21.8% in the gill nets.

During the 30 March - 3 May period, the 2003 (27.5%) and 2002 (24.5%) year classes were most abundant (Table 9). These year classes were 98.3% male. The contribution of males age six and older (the pre-2001 year classes) was 16.8% 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 13.5% of the total aged catch but was 80.4% of the total females captured. The catch rate (fish/day) of male striped bass was the third lowest in the 14-year time series and was 41.9% below the average (Table 10). The catch rate of female striped bass was also the sixth highest in the time series and was near the 14-year average. The biomass catch rates (g/day) for male striped bass was the second lowest in the time series and was 29.9% below the 14-year average. The biomass catch rate for female striped bass was the sixth highest in the time series and was 22.0% above the 14-year average.

James River:

Experimental gill nets: Striped bass (n= 1,284) were sampled between 30 March and 3 May, 2006, from two multi-mesh experimental gill nets at mile 62 in the James River. Total catches peaked on 3 April. Young, male striped bass were primarily responsible for the peak catches (Table 11). Catches of female striped bass peaked from 13-20 April. Males dominated the 2002-2004 year classes (99.8%) and the 1998-2001 year classes (93.4%), but the 1989-1997 year classes were predominantly female (78.9%).
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Biomass catch rates (g/day) of male striped bass peaked strongly on 3 April, but were high from 30 March – 24 April (Table 12). The catch rates of female striped bass were highest on 13 April. The biomass catch rate of males exceeded that of females on every sampling date except 17 April (2.1:1 for the season). The mean ages of male striped bass varied from 4.1-4.9 years by sampling date. The mean ages of females varied from 7.3-11.6 years by sampling date.

There was a broad peak of striped bass 410- 600 mm total length in the gill net length frequencies (Table 13). This size range accounted for 71.2% of the striped bass sampled. In contrast to the samples from Rappahannock River, the striped bass greater than 840 mm total length accounted for only 7.8% of the total sampled. The total contribution of striped bass greater than 710 mm total length was 11.1%.

During the 30 March - 3 May period, the 2002 (28.8%), 2001 (26.2%) and 2003 (21.5%) year classes were the most abundant in the gill nets (Table 14). These year classes were 98.5% male. The contribution of males age seven and older (the pre-2000 year classes) was only 6.2% 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 only 6.6% of the total aged catch.

The catch rate (fish/day) of male striped bass was higher than for 2005, and was 62.3% above the 12-year average (Table 15). Likewise, the catch rate of female striped bass was the third highest of the time series and was 23.7% above the 12-year average. The biomass catch rate (g/day) of male striped bass was also higher than 2005, and was 62.0% above the average. The biomass catch rate of female striped bass was higher than in 2005, and was 75.8% above the 12-year average. The mean age of male striped bass has varied from only 4.3-4.7 years by sampling year, while the mean age of female striped bass varied from 6.3-9.6 years.

Spawning Stock Biomass Indexes

Rappahannock River:

Pound nets: The Spawning Stock Biomass Index (SSBI) for spring 2006 was 25.8 kg/day for male striped bass and 24.7 kg/day for female striped bass. The index for male striped bass was the sixth highest in the 16-year time series, although 9.8% less than the index for 2005, and 10.9% above the 16-year average (Table 16). The magnitude of the index for male striped bass was largely determined by the 2002 (29.8%) and 2003 (22.5%) year classes. The index for female striped bass was near the median of the 16-year time series, and 36.7% below the index for 2005, and 17.7% below the 16-year average (Table 16). The magnitude of the index for the females was largely determined by the 1993-1997 year classes (76.9%).

Experimental gill nets: The Spawning Stock Biomass Index for spring 2006 was 49.2 kg/day for male striped bass and 39.6 kg/day for female striped bass. The index for male striped bass was the third lowest of the time series, 11.6% below the 2005 index, and was 37.9% below the 16-year average (Table 16). The 2001-2003 year classes contributed 55.1% of the biomass in the male index. The index for female striped bass was nearly double the 2005 index, and was 11.6% above the 16-year average. The 1994-1998 year classes contributed 87.5% of the biomass in the female index.

James River:

Experimental gill nets: The Spawning Stock Biomass Index for spring 2006 was 213.1 kg/day for male striped bass and 99.5 kg/day for female striped bass. The male index was the second highest in the 13-year time series, 44.3% higher than the 2005 index, and was 66.7% above the average (Table 17). The 2001 and 2002 year classes contributed 55.2% of the biomass in the male index. The female index was the third highest in the time series, 461% higher than the 2005 index, and was 64.7% higher than the 13-year average. The 1993-1997 year classes accounted for 71.0% 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:

$$N_o = 0.000857 \times FL^{3.1373}$$

where N_0 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 2006 Egg Production Potential Indexes (EPPI, Table 19) for the Rappahannock River were 4.01 (pound nets) and 6.27(gill nets). The 2006 EPPI for the James River was 15.10. The indexes for both the Rappahannock and James rivers were heavily dependent on the egg production potential of the 1996 and 1997 year class females (54.3% in the pound nets, 43.8% in the Rappahannock gill nets and 41.2% in the James River gill nets). Previous values for the EPPI for 2001-2005 from the Rappahannock River were 3.992, 1.764, 9.829, 10.55 and 6.30 (pound nets) and 4.039, 6.070, 3.724, 8.432 and 3.06 (gill nets). Previous values for the EPPI for 2001-2005 from the James River were 5.286, 6.709, 6.037, 4.922 and 3.24 respectively (Sadler et al 2001, 2002, 2003, 2004, and 2005). Thus, the EPPI values for the two gears in the Rappahannock River gave mixed signals as to the status of the spawning stock, while the EPPI value for the James River was its maximum value. Modest changes in the methodology (utilizing fully mature ovaries solely rather than ovaries in various states of maturation) in the 2001-2005 indexes preclude direct comparison with the 1999 and 2000 indexes.

Estimates of Annual Survival (S) based on Catch-Per-Unit-ffort

Rappahannock River:

Pound nets: Numeric catch rates (fish/day) of individual year classes from the 1991-2006 samples are presented in Tables 20-22. The cumulative annual catch rate of all year classes for 2006 was the fourth highest in the time series and was 25.1% higher than the cumulative catch rate for 2005 (Tables 20a,b). The increase was the result of high catch rates for the 2002 and 2003 year classes. The catch rate of males was dominated by three and four year-olds (2002 and 2003 year classes, Tables 21a,b). These two age classes contributed 76.0% of the total catch. 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-1994 year class males were captured. The cumulative catch rate of female stripers was also the seventh highest of the time series, but was 30.2% lower than the catch rate in 2005 (Tables 22a,b). No pre-1992 year class females were captured in 2006.

The range of overall ages was unchanged from 1991-2006, consisting mainly 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, but the peak was age three in 2005. 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 0.75-2.1 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 1.4-4.5 fish/day (mean = 2.84). In 2002, the cumulative proportion of female striped bass age eight and older decreased to 0.508. The cumulative proportion of the catch rate of females age eight and older rebounded to 0.875, 0.903 in 2004 (the highest of the time series) and 0.883 in 2005 but decreased back to 0.787 in 2006.

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 (1991-2006) of the 1983-1997 year classes (sexes combined) varied from 0.516-0.709 (Tables 23a,b) with an overall mean survival rate of 0.616. 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 (1991-2006) of the 1985-1997 year classes of males varied from 0.317-0.560 (Tables 24a,b) with an overall mean survival rate of 0.430. These year classes have been the major target of the fall recreational and commercial fisheries that reopened in 1993. The geometric mean survival rate (1991-2006) of the 1983-1991 year classes of females varied from 0.462-0.658 (Tables 25a,b) with an overall mean survival rate of 0.602. The high catch rates of 1992-1998 year class females in 2003 precluded estimation of survival rates for these stripers in 2006.

Experimental gill nets: Numeric catch rates (fish/day) of individual years classes from 1991-2006 are presented in Tables 26-28. The cumulative annual catch rate (all age classes, sexes combined) for 2006 from the gill nets was the fourth lowest in the time series but was 4.0% higher than in 2005 (Tables 26a,b). The cumulative catch rate was driven by the catch rates of the 2002 and 2003 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, 2004 and 2006). The cumulative catch rate of male striped bass was the fourth lowest in the time series and was 5.4% less than in 2005 (Tables 27 a,b). The cumulative catch rate of female striped bass was the seventh highest of the time series, and was more than double the cumulative catch rate in 2005 (Tables 28a,b).

The overall age structure from 1991-2006 consisted of 2-12 year old males (Tables 27a,b) and 2-14 year old females (Tables 28a,b). The proportion of males age six and older (0.20) was nearly equal to that in 2005 (0.21). The proportion of males age six and older was also 0.2 in 2002 and 2003 after being 0.03-0.06 from 1997-2001. The proportion of female striped bass age eight and older was 0.79 in 2006. 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 declined in 2006, and was the lowest value since 2002 (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 2006 cumulative catch (all age classes) rate of female striped bass was much higher than the 2005 catch rate (Tables 28a,b). In 2004, the increased catch rates for 8-14 year-old females gave evidence of secondary peak of abundance across several year classes. This was not evident from the catches in 2005 or 2006. This bimodal distribution of abundance with age had been noted for the pound net catches, but has 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 (1991-2005) of the 1984-1997 year classes (sexes combined) varied from 0.408-0.659 (Tables 29a,b) with an overall mean survival of 0.551. There were widely divergent estimates of annual survival of male and female striped bass. The geometric mean survival rate (1991-2006) of the 1987-1997 year classes of males varied from 0.150-0.558 (Tables 30a,b) with an overall mean survival of 0.356. These year classes have been the major target of the fall recreational and commercial fisheries that reopened in 1993. The geometric mean survival rate (1991-2005) of the 1984-1993 (excluding 1991) year classes of females varied from 0.501-0.707 (Tables 31a,b) with an overall mean survival rate of 0.585. 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 to the relative rareness of the oldest females in the samples.

James River:

Experimental gill nets: Numeric catch rates (fish/day) of individual years classes from 1984-2006 are presented in Tables 32-34. The cumulative annual catch rate (all age classes, sexes combined) for 2006 was the third highest of the time series, and was a 56.5% greater than the catch rate for 2005 (Tables 32a,b). The cumulative catch rate was driven by high catch rates for the three to five year old (2001-2003 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, up to two to11 years by 2005 (Tables 33a,b). The age structure of female striped bass was stable from 1994-2005, consisting of three to14 year old females (Tables 34a,b). The cumulative proportion of males age six and older has varied from 0.091-0.191 in 2000-2005 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 0.700 in 2005.

The cumulative catch rate of male striped bass mirrored the trends of the combined data with the 2006 catch rate being the third highest overall, and 47.3% higher than the cumulative catch rate for 2005 (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. The 2006 cumulative catch rate of female striped bass was quadruple the catch rate in 2005, and was the third highest in the time series (Tables 34a,b). There was no secondary peak in catch rates of females 1988-1994 year classes similar to that noted in the Rappahannock River pound net 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 (1994-2006) of the 1984 -1998 year classes (sexes combined) varied from 0.347-0.783 (Table 35), with an overall mean survival rate of 0.595. There were widely divergent estimates of annual survival of male and female striped bass. The geometric mean survival rate (1994-2006) of the 1988-1998 year classes of males varied from 0.286-0.672 (Table 36) with an overall mean survival rate of 0.456. These year classes have been the major target of the fall recreational and commercial fisheries that reopened in 1993. The geometric mean survival rate (1994-2006) of the 1984-1995 year classes of females varied from 0.347-0.874 (Table 37) with an overall mean survival rate of 0.650.

Catch Rate Histories of the 1987-1998 Year Classes

The catch rate histories of the 1987-1998 year classes from each sampling gear (sampling on the James River commenced in 1993) are depicted in Figures 3-14. 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. In both gears the catch rates of male striped bass was an order of magnitude greater than the catch rates of female 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 exhibited a secondary peak in the catch rates of 9-11 year old females that persisted across several year classes. This secondary peak was 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 12 year classes) as an indicator of year class strength, the 1987 year class was near the mean for the 1987-1998 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. No 1987 year class striped bass were captured in 2006.

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 the gill net samples in the Rappahannock River (Table 39). No 1988 year class striped bass were captured in 2006.

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). One female 1989 year class striped bass was captured (in the James River) in 2006.

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). Four female 1990 year class striped bass (all in the James River) were captured in 2006.

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 to the Rappahannock River in both sampling gears (Tables 38, 39) and well below the mean in the James River (Table 40). Three female 1991 year class striped bass (all in the James River) were captured in 2006.

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 age eleven (pound nets) in the Rappahannock River. Again, there were relatively few ages five and six female striped bass captured in the Rappahannock River. Thus, what had been a secondary peak of abundance for the 1987-1989 years classes has been the primary peak in the 1990-1992 year classes. The CCA was higher than for the 1990 and 1991 year classes, but was still below the mean in the Rappahannock River (Tables 38, 39), and was the lowest value for the James River (Table 40). Five female 1992 year class striped bass (four in the Rappahannock and one in the James) were captured in 2006.

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 age ten (pound nets) in the Rappahannock River. Again, there were relatively few ages five and six female striped bass captured in the Rappahannock River. The CCA was the highest of all the year classes from the gill net samples, but was only near the mean from the pound net samples in the Rappahannock River (Tables 38, 39). The CCA for the James River was well below the mean (Table 40). Twenty female 1993 year class striped bass (11 in the James and nine in the Rappahannock) were captured in 2006.

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 ten in the Rappahannock River (both gears). Again, there were relatively few ages five and six female striped bass captured in the Rappahannock River. The CCA was below the mean from the pound net samples but well above the mean from the gill net samples in the Rappahannock River (Tables 38, 39). The CCA for the James River was higher than for the 1991-1993 year classes but was still below the mean (Table 40). Twenty five (21 female and four male) 1994 year class striped bass (15 in the Rappahannock and 10 in the James) were captured in 2006.

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 ages five and six female striped bass captured in the Rappahannock River. The CCA was above the mean in the Rappahannock River pound nets (Table 38), but below the mean in the gill nets (Table 39). The CCA was above the mean in the James River (Table 40). The 1993-1995 year classes were characterized as having a primary peak of young, male striped bass and a secondary peak of older, female striped bass. Twenty two (20 female and two male) 1995 year class striped bass (12 in the Rappahannock and 10 in the James) were captured in 2006.

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 ages five and six female striped bass captured in the Rappahannock River. The CCA was the highest amongst the year classes from the pound samples in the Rappahannock River (Table 38) and well above the mean in the gill net samples (Table 39). The CCA for the James River was by far the highest of any of the year classes (Table 40). Ninety eight (85 female and 13 male) 1996 year class striped bass (59 in the Rappahannock and 39 in the James) were captured in 2006.

1997 Year class: Peak abundance of male striped bass occurred at age three (pound nets) and age four (gill nets) in the Rappahannock River and occurred at age four in the James River (Figure 13). Age eight females showed an increase in abundance in the Rappahannock River pound nets and James River gill nets but were rare in the Rappahannock River gill nets. The CCA was the second highest in the Rappahannock River pound nets (Table 38) and James River gill nets (Table 40), and the third highest in the Rappahannock River gill nets (Table 39). Seventy five (44 female and 31 male) 1997 year class striped bass (46 in the Rappahannock and 29 in the James) were captured in 2006.

1998 Year class: Peak abundance of male striped bass occurred at age five (gill nets) and age six (pound nets) in the Rappahannock River and occurred at age four in the James River (Figure 14). Age eight females showed an increase in abundance verses their abundance in 2005 (at age seven) in both rivers. The CCA was the lowest since the 1992 year class and the fourth lowest overall in the Rappahannock River pound nets (Table 38) and well below average in the gill nets (Table 39). The CCA was above average in the James River (Table 40), but was the lowest since the sampling location was changed to its present location in 2003. Seventy seven (50 male and 27 female) 1998 year class striped bass (51 in the Rappahannock and 26 in the James) were captured in 2006.

Growth Rate of Striped Bass Derived from Annuli Measurements

The scales of 286 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 142mm at age one (Table 41a). The rate of growth was about 100 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^{th} 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

Tests of symmetry: A total of 295 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 30.1% (119/ 295) of the time and within one year 80.3% (237/295) 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* x *m* contingency table (Table 42) consisting of two classifications of a sample into categories is symmetric about the main diagonal. The test statistic is

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

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 = 30). We tested the hypothesis that the observed age differences were symetrically distributed about the main table diagonal (Table 42). The hypothesis was not rejected ($\chi^2 = 41.42$, p= 0.083), indicating random differences between the two ageing methodologies. The two ageing methods were found to be non-random in 2004 and 2005.

Differences between the scale and otolith age from the same specimen ranged from zero to four years (Figure 15). The otolith-derived age exceeded the scale age 33.6% of the total examined (56.3% 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 (72.4%). 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) rejected the hypothesis that these differences were random (X^2 = 13.26, df = 4, p= 0.01). 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.

T-tests: 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=295) determined by reading the otoliths was greater than the mean age determined by reading the scales (by 0.21 years, Table 43). The test results were:

$\bar{A}ge_{otolith} = 9.02$ $\bar{A}ge_{scale} = 8.81$

$S_{otolith} = 3.18$ $S_{scale} = 3.13$

$$t = 0.692$$
$$df = 588$$
$$p = .4894$$

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=2.56, df=294, p=.011) and the null hypothesis was rejected.

Kolmogorov-Smirnov test: 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 43). This compares the maximum difference in the relative proportions that an age class contributes to the test statistic ($K_{.05}$):

$D_{\max} = 0.1926$ $K_{.05} = 1.3581$

$$D_{.05} = 1.3581\sqrt{\frac{295+295}{295^2}} = 0.1118$$

The maximum difference exceeded the test statistic, so the null hypothesis, that the age structures derived by the two ageing methods represent the same population, was 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. In 2005 this net was substituted entirely for the net at mile 47 due to extensive damage to the net at mile 47 in a maritime accident. 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, although in 2004, a manufacturing error resulted in two nets of the number one configuration being fished on both rivers. 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.

The gill nets captured proportionally more males than did the pound nets. Anecdotal information from commercial fishermen suggests that spawning males are attracted to con-specifics that have become gilled in the net meshes. Thrashing of gilled fish may emulate spawning behavior (termed 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. However, in 2006 the oldest striped bass were captured in the James River gill nets.

The biological characterization of the spawning stock of striped bass in the Rappahannock River changed dramatically from 1991-2006. 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 2002-2006. 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 and gill nets were somewhat lower in 2006. They had increased dramatically in 2003 and 2004, after having decreased in 2002. This pattern was also noted after low catches in 1992 and in 1996. However, there was an increase in the number of older striped bass in the gill nets in the James River.

Of note again in the 2006 samples was the relative abundance of 1996 year class (10 year old) male and female stripers. This year class has been above-average in abundance since recruiting to the gears at age three, which indicates that it is a very strong year class. The 1992 year class (13 years old) also showed increased abundance relative to previous year classes at that age. 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 2006 value of the Spawning Stock Biomass Index (SSBI) for the Rappahannock River pound nets was the lowest since 2002. The SSBI for male striped bass captured in the pound nets was above the mean in the 1991-2006 time series, but the SSBI for female striped bass was below the mean. The decrease in the SSBI was due to decreased numbers across almost every age class when compared to 2005. In contrast, the 2006 SSBI for the Rappahannock River gill nets increased from the 2005 value, mainly due to an increased catch rate for female striped bass.

The 1991-2006 values of the SSBI in the Rappahannock River were often inconsistent 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 2005 was driven by decreased catches of 1998-2000 year classes of males, after strong catches in 2004. The female biomass from pound nets showed no reliance upon any age groups. 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). 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 believe 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 2006 values of the SSBI in the James River were much higher than in 2005 for both male and female striped bass. The male index was driven by large catches of the 2001-2003 year classes while the female index had higher catch rates of the 1994-1997 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. 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 2006, the contribution of 8+ year old females was again 78.7% of the total number, 90.8% of the biomass and 91.2% of the calculated egg potential. It should be noted that our fecundity estimates for individual striped bass 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 1987-1997 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 to12 (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 1991-1996 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. In 2004-2006, the second group was expanded to 750-1200 mm as the strong 1996 and 1997 year classes were caught in abundance.

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 1983-1997 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 0.59 in pound nets and 0.56 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 0.42 in pound nets and 0.37 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 0.43 for male striped bass and approximately 0.63 for female striped bass.

The catch histories of the 1987-1998 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 140 mm (fork length) in their first year. Growth averaged 115 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 2002 year class in fall 2005) 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 four years (though only for a single specimen). The age difference determined for the largest, and oldest, specimens was 0-4 years (13-18 years by reading the scale vs 13-17 years by reading the otolith). The maximum age determined by reading scales has generally remained constant at 16 years since 1991 (although three 17 and one 18-year olds were aged in 2006), while there has been an annual progression in the maximum age determined by reading otoliths. Agreement between the two ageing methodologies was only 30.1% and was lower than the results from 2005. When there was disagreement between methodologies, the otolith age was 1.29 times more likely to have been aged older than the respective scale-derived age and 2.62 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. However, test of symmetry and t-test of the means gave contradictory results in 2006. In 2004 and 2005, the differences in ages from the two ageing methodologies were found to be non-random. However, the relative contributions of the age classes and their overall mean age were statistically different between the two methodologies. 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 2002-2004, 1998-2001 and 1989-1997) from pound nets in the Rappahannock River, by sampling date, spring, 2006. M = males, F = females.

Date	n	Year Class							
		2002 - 2004		1998 - 2001		1989 - 1997		Not aged	
		M	F	M	F	M	F	M	F
30 March	119	79	6	14	6	1	13	0	0
3 April	91	54	1	9	15	1	9	2	0
6 April	57	30	1	12	2	0	12	0	0
10 April	66	45	0	1	12	0	5	3	0
13 April	34	18	0	8	2	0	5	1	0
17 April	38	18	0	7	2	0	10	1	0
20 April	90	68	0	10	1	2	9	0	0
24 April	96	67	0	13	2	4	8	2	0
27 April	96	58	0	23	3	3	8	1	0
1 May	89	58	0	24	0	2	5	0	0
Total	**776**	**495**	**8**	**121**	**45**	**13**	**84**	**10**	**0**

Table 2. Net-specific summary of catch rates and mean ages of striped bass (n= 776) in pound nets on the Rappahannock River, spring, 2006. Values in bold are grand means for each column. M = male, F = female.

Date	Net ID	n	CPUE (fish/day)		CPUE (g/day)		Mean age	
			M	F	M	F	M	F
30 March	S454	119	31.3	8.3	41,284.7	47,401.7	3.8	7.6
3 April	S462	91	16.5	6.3	21,287.0	32,682.8	3.8	7.6
6 April	S462	57	14.0	5.0	18,984.3	38,943.3	4.0	9.8
10 April	S454	66	15.0	1.5	22,412.5	13,267.5	4.0	11.2
13 April	S462	34	9.0	2.3	16,784.7	16,032.9	4.3	8.9
17 April	S454	38	6.5	3.0	8,613.9	21,749.0	3.9	9.6
20 April	S462	90	26,7	3.3	33,094.7	31,367,2	3.8	10.5
24 April	S454	96	21.5	2.5	31,510.9	18,735.9	4.0	9.8
27 April	S462	96	28.3	3.7	41,915.6	25,281.0	4.3	9.8
1 May	S454	89	21.0	1.3	27,862.3	10,879.5	4.2	10.2
Totals	S454	408	18.4	3.1	25,550.1	21,091.2	4.0	9.0
	S462	368	18.8	4.3	26,092.9	29,100.3	4.0	9.0
Season		776	**18.6**	**3.6**	**25,798.2**	**24,752.5**	**4.0**	**9.0**

Table 3. Length frequencies (TL in mm) of striped bass sampled from the pound nets in the Rappahannock River, spring, 2006.

TL	n	TL	n	TL	n	TL	n	TL	n	TL	n
300-	0	**460-**	24	**620-**	1	**780-**	3	**940-**	7	**1100-**	0
310-	0	**470-**	35	**630-**	0	**790-**	6	**950-**	2	**1110-**	0
320-	0	**480-**	32	**640-**	0	**800-**	4	**960-**	3	**1120-**	0
330-	3	**490-**	29	**650-**	0	**810-**	4	**970-**	2	**1130-**	0
340-	3	**500-**	22	**660-**	0	**820-**	8	**980-**	4	**1140-**	0
350-	4	**510-**	28	**670-**	0	**830-**	3	**990-**	0	**1150-**	0
360-	7	**520-**	18	**680-**	0	**840-**	10	**1000-**	1	**1160-**	0
370-	12	**530-**	21	**690-**	0	**850-**	3	**1010-**	3	**1170-**	0
380-	28	**540-**	20	**700-**	0	**860-**	9	**1020-**	1	**1180-**	0
390-	20	**550-**	22	**710-**	0	**870-**	5	**1030-**	1	**1190-**	0
400-	20	**560-**	16	**720-**	4	**880-**	4	**1040-**	0	**1200-**	0
410-	47	**570-**	8	**730-**	2	**890-**	9	**1050-**	0	**1210-**	0
420-	52	**580-**	13	**740-**	5	**900-**	10	**1060-**	1	**1220-**	0
430-	46	**590-**	9	**750-**	2	**910-**	10	**1070-**	1	**1230-**	0
440-	49	**600-**	4	**760-**	6	**920-**	6	**1080-**	0	**1240-**	0
450-	35	**610-**	0	**770-**	7	**930-**	2	**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, 2006 (n/a: not ageable).

Year Class	Sex	n	Fork Length Mean	Fork Length SD	Weight Mean	Weight SD	CPUE F/day	CPUE W/day
2004	male	3	305.7	2.5	365.7	30.2	0.1	31.3
2003	male	272	382.1	23.7	747.2	155.1	7.8	5,806.7
	female	4	380.0	28.4	791.8	213.5	0.1	90.5
2002	male	220	447.0	23.4	1,225.2	226.2	6.3	7,701.1
	female	4	456.0	33.7	1,385.0	352.7	0.1	158.3
2001	male	102	513.3	21.7	1,832.8	242.6	2.9	5,341.3
	female	9	525.0	24.9	2,024.5	204.4	0.3	520.6
2000	male	3	544.3	33.6	2,133.7	304.6	0.1	182.9
	female	2	561.0	15.6	2,462.5	19.1	0.1	140.7
1999	male	7	709.0	15.4	4,415.3	365.9	0.2	883.1
	female	11	705.2	20.0	4,350.1	449.2	0.3	1,367.2
1998	male	20	749.1	27.9	5,419.1	739.8	0.6	3,096.6
	female	12	747.7	33.1	5,590.8	914.2	0.3	1,916.8
1997	male	10	786.4	27.0	5,947.1	904.9	0.3	1,699.2
	female	20	812.6	25.6	6,885.4	1,035.3	0.6	3,934.5
1996	male	1	806.0		6,448.0		0.0	184.2
	female	40	848.7	26.6	8,159.1	1,210.9	1.1	9,324.7
1995	female	8	889.3	35.0	9,484.4	1,203.0	0.2	2,167.9
1994	male	2	828.0	14.1	6,320.9	548.1	0.1	361.2
	female	5	910.6	57.9	10,436.1	2,838.8	0.1	1,490.9
1993	female	7	924.0	30.9	10,417.7	1,436.5	0.2	2,083.5
1992	female	4	980.0	27.6	13,623.6	1,300.2	0.1	1,557.0
N/a	male	10	501.2	82.7	1,787.3	1,065.9	0.3	510.7

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, 1993-2006. M = male, F = female.

Year	n	CPUE (fish/day)		CPUE (g/day)		Mean age	
		M	F	M	F	M	F
2006	776	18.6	3.6	25,798.2	24,752.5	4.0	9.0
2005	617	12.7	4.9	26,463.2	38,962.0	4.5	9.7
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
Mean	**603.2**	**15.4**	**4.3**	**25,217.4**	**30,885.1**	**4.3**	**8.7**

Table 6. Numbers of striped bass in three age categories (year classes 2002-2004, 1998-2001 and 1989-1997) from gill nets in the Rappahannock River, by sampling date, spring, 2006. M = male, F = female.

Date	n	Year Class							
		2002 - 2004		1998 - 2001		1989 - 1997		Not aged	
		M	F	M	F	M	F	M	F
30 March	29	13	0	5	4	2	5	0	0
3 April	19	1	0	9	3	0	6	0	0
6 April	72	42	0	17	1	5	7	0	0
10 April	22	14	0	1	5	1	1	0	0
13 April	53	23	1	18	2	4	5	0	0
17 April	34	24	1	5	3	0	1	0	0
20 April	48	34	0	6	3	1	4	0	0
24 April	35	15	1	12	2	1	3	1	0
27 April	13	7	0	5	0	1	0	0	0
1 May	10	2	0	5	1	0	1	1	0
Total	**335**	**175**	**3**	**83**	**24**	**15**	**33**	**2**	**0**

Table 7. Summary of catch rates and mean ages of striped bass (n=335) from the two gill nets in the Rappahannock River, spring 2006. 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
30 March	29	20.0	9.0	39,108.0	62,708.0	4.5	9.3
3 April	19	10.0	9.0	23,893.0	67,804.0	5.3	9.2
6 April	72	64.0	8.0	136,503.0	78,167.0	4.7	10.0
10 April	22	20.0	2.0	41,251.0	15,013.0	4.4	9.0
13 April	53	45.0	8.0	97,493.3	56,237.2	6.1	8.6
17 April	34	29.0	5.0	36,172.7	22,590.5	3.7	6.6
20 April	48	41.0	7.0	54,101.5	48,396.1	3.9	9.0
24 April	35	29.0	6.0	59,284.8	31,696.6	5.0	8.0
27 April	13	13.0	0.0	25,220.7	0.0	4.7	
1 May	10	8.0	2.0	16,641.1	12,902.3	5.4	9.0
Season	335	**27.9**	**5.6**	**52,966.9**	**39,551.5**	**4.7**	**8.8**

Table 8. Length frequencies (TL in mm) of striped bass sampled from the experimental gill nets in the Rappahannock River, spring, 2006.

TL	n	TL	n	TL	n	TL	n	TL	n	TL	n
300-	0	460-	12	620-	2	780-	3	940-	0	1100-	0
310-	1	470-	16	630-	1	790-	4	950-	3	1110-	0
320-	1	480-	13	640-	10	800-	3	960-	1	1120-	0
330-	2	490-	10	650-	3	810-	4	970-	2	1130-	0
340-	5	500-	4	660-	4	820-	5	980-	0	1140-	0
350-	3	510-	12	670-	5	830-	2	990-	3	1150-	0
360-	1	520-	12	680-	1	840-	3	1000-	1	1160-	0
370-	4	530-	9	690-	1	850-	7	1010-	1	1170-	0
380-	6	540-	6	700-	2	860-	1	1020-	0	1180-	0
390-	10	550-	5	710-	1	870-	3	1030-	0	1190-	0
400-	7	560-	7	720-	3	880-	4	1040-	1	1200-	0
410-	12	570-	7	730-	0	890-	3	1050-	0	1210-	0
420-	15	580-	6	740-	1	900-	2	1060-	0	1220-	0
430-	14	590-	6	750-	0	910-	5	1070-	0	1230-	0
440-	9	600-	4	760-	1	920-	1	1080-	0	1240-	0
450-	11	610-	3	770-	2	930-	3	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, 2006.

Year Class	Sex	n	Fork Length		Weight		CPUE	
			Mean	SD	Mean	SD	F/day	W/day
2004	male	4	304.3	14.0	368.2	41.6	0.4	147.3
2003	male	92	380.4	30.4	763.8	198.7	9.2	7,026.9
2002	male	79	450.6	23.2	1,330.6	234.9	7.9	10,512.0
	female	3	451.0	22.9	1,302.0	317.8	0.3	390.6
2001	male	46	520.0	27.9	2,078.8	360.2	4.6	9,562.5
	female	3	520.3	13.2	2,144.5	117.0	0.3	643.4
2000	male	23	599.4	34.6	3,142.7	540.1	2.3	3,614.1
	female	5	615.2	40.1	3,296.7	536.2	0.5	1,648.4
1999	male	10	654.6	50.5	3,907.4	832.4	1.0	3,907.4
	female	1	737.0		4913.0		0.1	491.3
1998	male	8	748.4	64.3	5,327.3	1,111.1	0.8	4,261.8
	female	11	761.7	20.2	6,056.2	684.7	1.1	6,661.8
1997	male	7	756.0	30.0	5,646.0	681.6	0.7	3,952.2
	female	9	814.3	14.7	7,071.6	849.0	0.9	6,364.5
1996	male	6	791.5	67.3	6,921.8	1,648.5	0.6	4,153.1
	female	12	863.9	19.7	8,852.7	1,405.3	1.2	10,623.3
1995	male	1	800.0		6,448.0		0.1	644.8
	female	3	906.7	32.3	10,767.3	2,182.9	0.3	3,230.2
1994	male	1	864.0		8,735.0		0.1	873.5
	female	7	921.7	47.0	11,126.3	2,512.1	0.7	7,788.4
1993	female	2	875.5	55.9	8,548.0	1,676.6	0.2	1,709.7
N/A	male	2	623.5	51.6	3,486.0	234.0	0.2	697.2

N/A: not ageable

Table 10. Summary of the season mean (30 March - 3 May) catch rates and mean ages, by sex, from the experimental gill nets in the Rappahannock River, 1993-2006. M = male, F = female.

Year	n	CPUE (fish/day)		CPUE (g/day)		Mean age	
		M	F	M	F	M	F
2006	335	27.9	5.6	52,966.9	39,531.5	4.7	8.8
2005	322	29.7	2.7	55,674.5	19,857.3	4.8	9.2
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
Mean	**522.3**	**47.2**	**5.7**	**75,544.6**	**32,390.7**	**4.3**	**7.6**

Table 11. Numbers of striped bass in three age categories (year classes 2002-2004, 1998-2001 and 1989-1997) from gill nets in the James River by sampling date, spring, 2006. M = male, F = female.

Date	n	Year Class							
		2002 - 2004		1998 - 2001		1989 - 1997		Not aged	
		M	F	M	F	M	F	M	F
30 March	125	63	0	53	0	4	1	4	0
3 April	351	176	0	150	1	7	7	10	0
6 April	143	80	0	50	1	3	9	0	0
10 April	188	112	1	58	3	3	8	3	0
13 April	160	78	0	50	5	3	24	0	0
17 April	54	21	0	16	2	0	14	1	0
20 April	147	78	0	40	8	2	15	4	0
24 April	65	18	0	34	6	1	5	1	0
27 April	37	20	0	10	4	0	2	1	0
1 May	14	4	0	6	3	0	1	0	0
Total	**1,284**	**650**	**1**	**467**	**33**	**23**	**86**	**24**	**0**

Table 12. Summary of catch rates and mean ages of striped bass (n=1,284) from the gill nets in the James River, spring 2006. Values in bold are grand means for each column. M = males, F = female.

Date	n	CPUE (fish/day)		CPUE (g/day)		Mean age	
		M	F	M	F	M	F
30 March	125	124.0	1.0	270,333.2	9,807.5	4.7	10.0
3 April	351	343.0	8.0	650,946.0	94,017.0	4.6	11.6
6 April	143	133.0	10.0	229,143.0	105,180.0	4.4	10.8
10 April	188	176.0	12.0	315,347.0	92,161	4.3	8.5
13 April	160	131.0	29.0	238,205.0	267,988.0	4.5	10.3
17 April	54	38.0	16.0	59,466.3	136,716.6	4.2	10.6
20 April	147	124.0	23.0	195,584.0	168,286.2	4.2	9.2
24 April	65	54.0	11.0	108,655.7	73,834.2	4.9	8.0
27 April	37	31.0	6.0	43,916.3	28,356.8	4.1	7.3
1 May	14	10.0	4.0	19,816.2	19,783.2	4.8	7.5
Total	**1,284**	**116.4**	**12.0**	**213,141.3**	**99,613.1**	**4.5**	**9.6**

Table 13. Length frequencies (TL in mm) of striped bass sampled from the experimental gill nets in the James River, spring 2006.

TL	n	TL	n	TL	n	TL	n	TL	n	TL	n
300-	1	**460-**	43	**620-**	15	**780-**	1	**940-**	6	**1100-**	1
310-	0	**470-**	52	**630-**	18	**790-**	1	**950-**	4	**1110-**	0
320-	2	**480-**	43	**640-**	23	**800-**	2	**960-**	4	**1120-**	1
330-	5	**490-**	56	**650-**	14	**810-**	5	**970-**	2	**1130-**	0
340-	4	**500-**	45	**660-**	11	**820-**	5	**980-**	4	**1140-**	1
350-	5	**510-**	55	**670-**	14	**830-**	5	**990-**	4	**1150-**	0
360-	5	**520-**	62	**680-**	8	**840-**	9	**1000-**	3	**1160-**	0
370-	3	**530-**	51	**690-**	10	**850-**	4	**1010-**	0	**1170-**	0
380-	23	**540-**	45	**700-**	10	**860-**	3	**1020-**	1	**1180-**	0
390-	19	**550-**	45	**710-**	7	**870-**	7	**1030-**	1	**1190-**	0
400-	20	**560-**	45	**720-**	1	**880-**	6	**1040-**	3	**1200-**	0
410-	49	**570-**	39	**730-**	3	**890-**	9	**1050-**	2	**1210-**	0
420-	59	**580-**	42	**740-**	6	**900-**	3	**1060-**	2	**1220-**	0
430-	49	**590-**	23	**750-**	3	**910-**	5	**1070-**	0	**1230-**	0
440-	38	**600-**	24	**760-**	2	**920-**	6	**1080-**	2	**1240-**	0
450-	49	**610-**	17	**770-**	2	**930-**	6	**1090-**	1	**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, 2006.

Year Class	Sex	n	Fork Length		Weight		CPUE	
			Mean	SD	Mean	SD	F/day	W/day
2004	male	5	303.2	13.3	391.8	51.4	0.5	195.9
2003	male	276	384.2	24.1	821.6	159.0	27.6	22,871.0
2002	male	369	452.6	23.3	1,379.9	225.3	36.9	50,918.2
	female	1	469.0		1,598.0		0.1	158.8
2001	male	323	519.2	27.6	2,067.3	324.5	32.3	66,775.4
	female	14	538.9	22.5	2,369.5	292.4	1.4	3,317.4
2000	male	87	589.2	30.2	2,952.7	447.3	8.7	25,688.1
	female	11	614.4	24.6	3,434.5	560.9	1.1	3,777.9
1999	male	35	646.4	30.6	3,871.5	586.2	3.5	13,550.2
	female	4	679.0	26.8	4,531.9	718.0	0.4	1,812.8
1998	male	22	713.2	56.3	5,075.1	1,032.1	2.2	11,165.2
	female	4	770.0	32.3	5,851.7	334.5	0.4	2,340.7
1997	male	14	766.9	50.8	6,146.6	1,254.6	1.4	8,605.2
	female	15	805.7	24.6	7,286.9	701.2	1.5	10,930.3
1996	male	6	807.7	24.3	7,396.2	677.9	0.6	4,437.7
	female	33	857.8	25.4	8,730.7	1,109.8	3.3	28,811.3
1995	male	1	848.0		7,594.2		0.1	759.4
	female	9	895.0	24.8	10,149.5	1,056.6	0.9	9,134.6
1994	male	1	930.0		11,093.0		0.1	1,109.3
	female	9	918.1	28.6	11,591.7	1,035.6	0.9	10,432.6
1993	female	11	954.1	51.2	12,990.6	2,397.1	1.1	14,289.6
1992	female	1	994.0		14,986.0		0.1	1,498.6
1991	male	1	880.0		9,236.0		0.1	923.6
	female	3	1,051.7	36.7	17,633.4	1,801.9	0.3	5,290.0
1990	female	4	1,023.5	42.2	15,633.6	2,372.9	0.4	6,126.7
1989	female	1	1,005.0		15,641.1		0.1	1,564.1

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, 1995-2006.

Year	mile	n	CPUE (fish/day)		CPUE (g/day)		Mean age	
			M	F	M	F	M	F
2006	62	1,284	116.4	12.0	213,141.3	99,613.1	4.5	9.6
2005	62	820	79.0	3.0	147,962.7	21,585.9	4.6	8.5
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
Mean		**745.3**	**71.7**	**9.7**	**131,556.0**	**56,673.2**	**4.5**	**7.3**

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, 1991-2006.

	Pound nets					Gill nets				
	N		SSBI (kg/day)			N		SSBI (kg/day)		
Year	M	F	M	F	M+F	M	F	M	F	M+F
2006	647	122	25.8	24.7	50.5	275	56	49.2	39.6	88.8
2005	438	177	26.4	39.0	65.4	291	27	55.6	19.9	75.4
2004	703	247	58.5	65.4	123.9	714	74	171.9	52.0	223.9
2003	283	187	22.8	53.6	76.4	467	31	97.3	20.7	118.0
2002	113	57	7.1	11.4	18.5	240	78	53.4	40.7	94.1
2001	470	105	24.2	27.6	51.8	572	41	88.6	30.9	119.5
2000	1,436	71	42.7	14.6	57.3	452	27	65.3	16.5	81.8
1999	738	61	30.5	19.8	50.3	532	21	51.4	13.2	64.6
1998	273	113	14.8	36.4	51.2	485	27	81.5	18.5	100.0
1997	277	115	22.2	49.6	71.7	801	18	177.8	19.1	197.0
1996	334	73	14.1	9.3	23.4	433	46	63.7	30.2	93.9
1995	207	76	12.4	19.8	32.2	162	69	43.9	56.7	100.6
1994	195	141	17.1	30.9	48.0	391	100	101.6	64.7	166.3
1993	357	188	31.2	37.5	68.7	361	160	85.6	74.1	159.6
1992	51	100	5.4	19.4	24.8	61	74	15.0	32.2	47.2
1991	153	70	21.3	21.5	42.8	406	47	65.0	17.8	83.8
Mean	**417**	**119**	**23.7**	**30.0**	**53.7**	**415**	**56**	**79.2**	**34.2**	**113.4**

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, 1994-2006. 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
2006	**62**	1,159	120	213.14	99.49	312.63
2005	**62**	781	30	147.66	21.59	169.25
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
Mean		**661**	**93**	**127.89**	**60.41**	**188.30**

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

FL	Fecundity	FL	Fecundity	FL	Fecundity	FL	Fecundity
400	0.125	**600**	0.446	**800**	1.099	**1000**	2.212
420	0.146	**620**	0.494	**820**	1.187	**1020**	2.354
440	0.168	**640**	0.546	**840**	1.280	**1040**	2.502
460	0.194	**660**	0.601	**860**	1.378	**1060**	2.656
480	0.221	**680**	0.660	**880**	1.482	**1080**	2.817
500	0.251	**700**	0.723	**900**	1.590	**1100**	2.984
520	0.284	**720**	0.789	**920**	1.703	**1120**	3.157
540	0.320	**740**	0.860	**940**	1.822	**1140**	3.337
560	0.359	**760**	0.935	**960**	1.947	**1160**	3.525
580	0.401	**780**	1.015	**980**	2.077	**1180**	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 2006. 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	4	0.022	0.54	3	0.055	0.88	1	0.021	0.14
5	9	0.076	1.89	3	0.086	1.38	14	0.448	2.96
6	2	0.021	0.51	5	0.244	3.92	11	0.530	3.51
7	11	0.233	5.81	1	0.085	1.36	4	0.264	1.75
8	12	0.306	7.64	11	1.038	16.68	4	0.392	2.59
9	20	0.661	16.51	9	1.046	16.81	15	1.691	11.20
10	40	1.516	37.81	12	1.681	26.99	33	4.525	29.96
11	8	0.351	8.77	3	0.489	7.86	9	1.409	9.33
12	5	0.238	5.95	7	1.208	19.40	9	1.527	10.11
13	7	0.346	8.64	2	0.294	4.72	11	2.118	14.03
14	4	0.238	5.93	0	0.000	0.00	1	0.217	1.44
15	0	0.000	0.00	0	0.000	0.00	3	0.780	5.16
16	0	0.000	0.00	0	0.000	0.00	4	0.956	6.33
17	0	0.000	0.00	0	0.000	0.00	1	0.225	1.49
18	0	0.000	0.00	0	0.000	0.00	0	0.000	0.00
19	0	0.000	0.00	0	0.000	0.00	0	0.000	0.00
20	0	0.000	0.00	0	0.000	0.00	0	0.000	0.00
Total	122	**4.008**	100.00	56	**6.226**	100.00	119	**15.103**	100.00

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, 1991-2006. 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	**15.61**
1996								0.19	11.54	**18.13**
1995							0.60	2.15	**11.50**	3.34
1994					0.04	0.51	3.90	**6.33**	2.79	0.11
1993					3.04	3.97	**8.10**	1.48	0.11	0.50
1992			0.12	1.44	**4.80**	2.86	1.25	0.04	0.50	0.50
1991		0.20	0.57	0.48	1.00	**1.63**	0.05	0.52	0.43	0.40
1990	0.42	0.50	1.04	1.33	**2.24**	1.26	0.70	0.70	0.32	0.29
1989	0.33	0.60	3.58	**4.59**	0.68	0.89	0.80	0.78	0.36	0.37
1988	3.58	1.60	**9.54**	2.22	0.60	0.37	1.50	0.89	0.39	0.05
1987	**8.00**	2.75	3.65	1.15	0.68	0.37	1.00	0.89	0.43	0.05
1986	**2.67**	1.15	0.65	0.59	0.40	0.09	1.00	0.22	0.04	0.00
1985	**1.67**	0.30	0.42	0.52	0.08	0.00	0.35	0.15	0.11	0.00
1984	0.50	0.40	**0.58**	0.33	0.28	0.00	0.35	0.07	0.04	0.00
1983	0.25	0.20	**0.46**	0.33	0.08	0.03	0.20	0.00	0.00	0.00
>1983	**0.75**	0.45	0.73	0.33	0.00	0.00	0.00	0.00	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
Total	**18.75**	**8.45**	**21.72**	**13.87**	**14.52**	**12.30**	**20.30**	**14.85**	**29.89**	**39.70**

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, 1991-2006. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)					
	2001	**2002**	**2003**	**2004**	**2005**	**2006**
2003						**7.89**
2002					1.83	**6.40**
2001				3.47	**5.43**	3.17
2000			0.76	**5.57**	2.77	0.14
1999	0.07	0.51	3.00	**5.90**	0.71	0.51
1998	2.74	1.44	3.33	**3.50**	0.77	0.91
1997	7.49	1.38	0.37	2.23	1.69	0.86
1996	4.29	0.25	1.83	4.16	1.69	1.17
1995	0.10	0.68	1.40	2.33	0.94	0.23
1994	0.58	0.41	1.70	1.67	0.69	0.20
1993	0.87	0.28	1.43	1.00	0.57	0.20
1992	0.87	0.19	1.13	1.10	0.29	0.11
1991	0.81	0.06	0.33	0.17	0.09	0.00
1990	0.45	0.00	0.27	0.07	0.03	0.00
1989	0.26	0.00	0.07	0.07	0.03	0.00
1988	0.10	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.03	0.03	0.00	0.03	0.00
N/A	0.00	0.00	0.00	0.40	0.49	0.26
Total	**18.63**	**5.23**	**15.65**	**31.71**	**17.63**	**22.05**

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, 1991-2006. 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	**15.61**
1996								0.19	11.54	**18.11**
1995							0.55	2.15	**11.46**	3.21
1994					0.04	0.51	3.80	**6.19**	2.68	0.08
1993					2.88	3.83	**7.50**	1.37	0.07	0.26
1992			0.12	1.22	**4.68**	2.66	1.15	0.00	0.36	0.11
1991		0.15	0.54	0.48	0.92	**1.34**	0.05	0.30	0.21	0.05
1990	0.17	0.35	0.96	1.30	**2.00**	0.94	0.35	0.11	0.00	0.03
1989	0.17	0.40	3.46	**3.52**	0.08	0.43	0.55	0.04	0.04	0.03
1988	3.25	0.90	**7.54**	1.11	0.12	0.03	0.20	0.00	0.00	0.00
1987	**6.08**	0.65	1.23	0.22	0.00	0.09	0.00	0.00	0.00	0.00
1986	**2.58**	0.30	0.15	0.11	0.04	0.00	0.00	0.00	0.00	0.00
1985	**0.50**	0.05	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.08	**0.15**	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<1984	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.25	0.10	0.27	0.41	0.44	0.23	0.25	0.33	0.54	0.32
Total	**13.08**	**3.05**	**14.39**	**8.45**	**11.20**	**10.06**	**14.40**	**10.68**	**27.69**	**37.84**

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, 1991-2006. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)					
	2001	**2002**	**2003**	**2004**	**2005**	**2006**
2003						**7.77**
2002					1.83	**6.29**
2001				3.47	**5.40**	2.91
2000			0.76	**5.47**	2.49	0.09
1999	0.07	0.44	2.93	**5.67**	0.66	0.20
1998	2.74	1.38	3.07	**3.37**	0.51	0.57
1997	7.42	1.25	0.30	1.93	1.00	0.29
1996	4.03	0.25	1.50	2.23	0.43	0.03
1995	0.10	0.16	0.56	0.53	0.09	0.00
1994	0.39	0.03	0.23	0.20	0.09	0.06
1993	0.16	0.03	0.07	0.10	0.00	0.00
1992	0.19	0.00	0.00	0.07	0.00	0.00
1991	0.13	0.00	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.00	0.00	0.00	0.40	0.46	0.29
Total	**15.23**	**3.54**	**9.42**	**23.44**	**12.66**	**18.50**

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, 1991-2006. 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	**0.59**	0.32	0.26
1989	0.17	0.20	0.12	**1.07**	0.60	0.46	0.25	0.74	0.32	0.34
1988	0.33	0.70	**2.00**	1.11	0.48	0.34	1.30	0.89	0.39	0.05
1987	1.92	2.10	**2.42**	0.93	0.68	0.29	1.00	0.89	0.43	0.05
1986	**1.08**	0.85	0.50	0.48	0.36	0.09	1.00	0.22	0.04	0.00
1985	**1.17**	0.25	0.39	0.48	0.08	0.00	0.35	0.15	0.11	0.00
1984	0.42	0.25	**0.50**	0.33	0.28	0.00	0.35	0.07	0.04	0.00
1983	0.25	0.20	**0.46**	0.33	0.08	0.03	0.20	0.00	0.00	0.00
>1983	0.58	0.45	**0.73**	0.26	0.00	0.00	0.00	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
Total	**6.42**	**5.40**	**7.36**	**5.40**	**3.32**	**2.24**	**5.90**	**4.18**	**2.19**	**1.87**

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, 1991-2006. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)					
	2001	**2002**	**2003**	**2004**	**2005**	**2006**
2003						**0.11**
2002						**0.11**
2001					0.03	**0.26**
2000				0.10	**0.29**	0.06
1999		0.06	0.07	0.23	0.06	**0.31**
1998		0.06	0.27	0.17	0.26	**0.34**
1997	0.07	0.13	0.07	0.30	**0.69**	0.57
1996	0.26	0.00	0.37	**1.93**	1.26	1.14
1995	0.00	0.63	0.80	**1.80**	0.86	0.23
1994	0.19	0.38	**1.47**	**1.47**	0.60	0.14
1993	0.71	0.25	**1.37**	0.90	0.54	0.20
1992	0.68	0.19	**1.13**	1.03	0.29	0.11
1991	**0.68**	0.06	0.33	0.17	0.09	0.00
1990	0.45	0.00	0.26	0.07	0.03	0.00
1989	0.26	0.00	0.07	0.07	0.03	0.00
1988	0.10	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.03	0.03	0.00	0.03	0.00
N/A	0.00	0.00	0.00	0.00	0.03	0.00
Total	**3.40**	**1.79**	**6.24**	**8.24**	**4.97**	**3.47**

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, 1991-2006.

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	0.556	0.895	0.895	0.895	0.895
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	0.902
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, 1991-2006.

Year Class	Survival (S)					
	01-02	02-03	03-04	04-05	05-06	Mean
2001				------	0.584	0.584
2000			------	0.497	0.051	0.159
1999			------	0.120	0.718	0.294
1998			------	0.510	0.510	0.510
1997	0.668	0.668	0.688	0.758	0.509	0.620
1996	0.990	0.990	0.990	0.406	0.692	0.633
1995	0.914	0.914	0.914	0.403	0.245	0.572
1994	0.884	0.884	0.982	0.413	0.290	0.650
1993	0.993	0.993	0.699	0.570	0.351	0.663
1992	0.983	0.983	0.973	0.264	0.379	0.709
1991	0.638	0.638	0.515	0.529	0.000	0.641
1990	0.775	0.775	0.259	0.429	0.000	0.602
1989	0.519	0.519	0.655	0.655	0.000	0.578
1988	0.000	------	------	------	------	0.516
1987	0.902	0.902	0.902	0.902	0.000	0.668
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, 1991-2006.

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, 1991-2006.

Year Class	Survival (S)					
	01-02	02-03	03-04	04-05	05-06	Mean
2001			------	------	0.539	0.539
2000			------	0.455	0.036	0.128
1999			------	0.116	0.303	0.187
1998			------	0.411	0.411	0.411
1997	0.638	0.638	0.638	0.518	0.290	0.514
1996	0.891	0.891	0.891	0.193	0.070	0.359
1995	0.559	0.559	0.946	0.170	0.000	0.409
1994	0.768	0.768	0.870	0.450	0.667	0.560
1993	0.855	0.855	0.855	0.000	------	0.496
1992	0.716	0.716	0.716	0.000	------	0.554
1991	------	------	------	------	------	0.508
1990	------	------	------	------	------	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, 1991-2006.

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	0.902
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, 1991-2006.

Year Class	Survival (S)					
	01-02	02-03	03-04	04-05	05-06	Mean
1998	------	------	------	------	------	------
1997	------	------	------	------	0.826	0.826
1996	------	------	------	0.653	0.905	0.769
1995	------	------	------	0.477	0.267	0.357
1994	------	------	0.639	0.639	0.233	0.457
1993	------	------	0.657	0.600	0.370	0.526
1992	------	------	0.912	0.282	0.379	0.460
1991	0.697	0.697	0.515	0.529	0.000	0.462
1990	0.760	0.760	0.269	0.429	0.000	0.540
1989	0.519	0.519	0.655	0.655	0.000	0.644
1988	0.000	------	------	-------	-------	0.620
1987	0.902	0.902	0.902	0.902	0.000	0.658
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, 1991-2006. 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	**35.80**	21.26
1995							0.83	**11.67**	10.60	5.79
1994						1.90	29.50	**32.78**	3.20	1.79
1993					4.50	20.00	**83.00**	7.00	0.80	2.00
1992				2.78	7.00	11.40	**14.33**	0.78	1.20	0.63
1991			0.50	2.56	1.88	**5.70**	2.83	1.33	0.50	0.32
1990	0.12	0.56	1.50	**8.22**	7.75	3.50	2.17	0.33	0.10	0.21
1989	1.41	0.78	8.60	**27.56**	4.50	2.50	0.67	0.33	0.20	0.11
1988	9.53	1.89	**25.40**	8.22	2.88	1.50	1.17	0.33	0.20	0.11
1987	**23.65**	5.89	10.40	2.11	1.75	1.60	0.50	0.11	0.10	0.00
1986	**11.18**	3.33	1.60	0.44	1.38	0.30	0.00	0.22	0.00	0.00
1985	**4.12**	1.22	0.40	1.67	0.75	0.20	0.00	0.00	0.20	0.00
1984	**1.64**	0.78	0.40	0.67	0.25	0.00	0.00	0.00	0.00	0.00
1983	0.35	0.11	**1.30**	0.56	0.13	0.00	0.00	0.00	0.00	0.00
>1983	0.47	0.44	0.60	0.22	0.00	0.00	0.00	0.00	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
Total	**53.29**	**15.00**	**51.80**	**57.34**	**33.77**	**49.80**	**137.50**	**57.00**	**67.10**	**51.91**

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, 1991-2006. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)					
	2001	2002	2003	2004	2005	2006
2004						**0.40**
2003					0.40	**9.20**
2002				4.10	4.00	**8.20**
2001			2.70	**21.78**	11.80	4.90
2000		0.50	8.80	**16.22**	6.60	2.80
1999	0.90	1.10	**16.00**	10.74	2.40	1.10
1998	9.50	8.80	**12.60**	10.00	1.90	1.90
1997	**27.00**	10.20	4.60	10.32	1.40	1.60
1996	17.70	4.60	4.20	7.58	1.30	1.80
1995	2.10	3.50	1.60	2.74	0.20	0.40
1994	1.50	1.20	1.30	1.68	0.30	0.80
1993	1.00	1.00	0.50	0.64	0.10	0.20
1992	1.10	0.30	0.00	0.42	0.10	0.00
1991	0.90	0.30	0.00	0.00	0.00	0.00
1990	0.10	0.00	0.10	0.00	0.00	0.00
1989	0.10	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.10	0.00	0.00	0.00	0.00	0.00
1985	0.20	0.00	0.00	0.00	0.00	0.00
N/A	0.20	0.80	0.10	0.84	0.40	0.20
Total	**62.40**	**32.30**	**52.50**	**87.06**	**32.20**	**33.50**

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, 1991-2006. 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	**35.70**	20.95
1995							0.83	**11.67**	10.60	5.68
1994						1.90	29.50	**32.56**	2.60	1.26
1993					4.50	20.00	**82.67**	6.44	0.60	1.37
1992				2.78	6.88	11.30	**14.00**	0.56	0.90	0.11
1991			0.50	2.56	1.75	**5.60**	2.50	0.67	0.30	0.00
1990	0.12	0.44	1.50	**8.22**	7.00	3.20	1.83	0.22	0.00	0.00
1989	1.29	0.78	8.30	**25.33**	2.63	1.40	0.50	0.00	0.00	0.00
1988	9.41	1.33	**20.30**	4.89	1.13	0.50	0.17	0.00	0.10	0.00
1987	**22.82**	2.78	4.20	0.33	0.13	0.10	0.00	0.00	0.10	0.00
1986	**10.23**	1.22	0.90	0.11	0.00	0.00	0.00	0.00	0.00	0.00
1985	**2.35**	0.11	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00
1984	**0.71**	0.11	0.10	0.11	0.00	0.00	0.00	0.00	0.00	0.00
<1984	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.82	0.00	0.80	1.56	0.88	1.20	2.50	1.78	2.30	0.11
Total	**47.75**	**6.77**	**36.70**	**46.22**	**24.90**	**45.20**	**134.50**	**54.00**	**64.80**	**49.06**

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, 1991-2006. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)					
	2001	2002	2003	2004	2005	2006
2004						**0.40**
2003					0.40	**9.20**
2002				4.10	4.00	**7.90**
2001			2.70	**21.78**	11.80	4.60
2000		0.50	8.80	**16.00**	6.50	2.30
1999	0.90	1.10	**15.90**	10.52	2.40	1.00
1998	9.40	8.70	**12.10**	9.68	1.70	0.80
1997	**27.00**	8.80	4.30	9.68	1.30	0.70
1996	17.00	3.30	3.80	5.68	0.70	0.60
1995	1.90	1.40	1.20	0.64	0.10	0.10
1994	1.30	0.20	0.40	0.32	0.10	0.10
1993	0.40	0.20	0.00	0.00	0.00	0.00
1992	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.20	0.80	0.10	0.84	0.40	0.20
Total	**58.10**	**25.00**	**49.30**	**79.24**	**29.50**	**27.90**

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, 1991-2006. 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	**0.75**	0.30	0.33	0.11	0.10	0.21
1989	0.12	0.00	0.30	**2.22**	1.88	1.10	0.17	0.33	0.20	0.11
1988	0.12	0.56	**5.10**	3.33	1.75	1.00	1.00	0.33	0.10	0.11
1987	0.82	3.11	**6.20**	1.78	1.63	1.50	0.50	0.11	0.00	0.00
1986	0.94	**2.11**	1.70	0.33	1.38	0.30	0.00	0.22	0.00	0.00
1985	**1.76**	1.11	0.40	1.33	0.75	0.20	0.00	0.00	0.20	0.00
1984	**0.94**	0.67	0.30	0.56	0.25	0.00	0.00	0.00	0.00	0.00
1983	0.35	0.11	**1.30**	0.56	0.13	0.00	0.00	0.00	0.00	0.00
>1983	0.47	0.44	**0.50**	0.22	0.00	0.00	0.00	0.00	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	**5.52**	**8.22**	**16.10**	**11.11**	**9.03**	**4.60**	**3.00**	**3.00**	**2.30**	**2.87**

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, 1991-2006. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)					
	2001	**2002**	**2003**	**2004**	**2005**	**2006**
2002						**0.30**
2001						**0.30**
2000				0.22	0.10	**0.50**
1999			0.10	**0.22**	0.00	0.10
1998	0.10	0.10	0.50	0.32	0.20	**1.10**
1997	0.00	**1.40**	0.30	0.64	0.10	0.90
1996	0.70	1.60	0.40	**1.90**	0.60	1.20
1995	0.20	2.10	0.40	**2.10**	0.10	0.30
1994	0.20	1.00	0.90	**1.36**	0.20	0.70
1993	0.60	**0.80**	0.50	0.64	0.10	0.20
1992	**1.10**	0.30	0.00	0.42	0.10	0.00
1991	**0.90**	0.30	0.00	0.00	0.00	0.00
1990	0.10	0.00	0.10	0.00	0.00	0.00
1989	0.10	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.10	0.00	0.00	0.00	0.00	0.00
N/A	0.00	0.80	0.00	0.00	0.00	0.00
Total	**4.10**	**8.40**	**3.20**	**7.62**	**2.70**	**5.60**

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, 1991-2006.

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	0.500
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, 1991-2006.

Year Class	Survival (S)					
	01-02	02-03	03-04	04-05	05-06	Mean
2001	------	------	------	0.542	0.415	0.474
2000	------	------	------	0.407	0.424	0.415
1999	------	------	0.671	0.223	0.458	0.409
1998	------	------	0.794	0.436	0.436	0.532
1997	0.726	0.726	0.726	0.394	0.394	0.569
1996	0.754	0.754	0.754	0.487	0.487	0.652
1995	0.777	0.884	0.884	0.382	0.382	0.656
1994	0.984	0.984	0.984	0.690	0.690	0.629
1993	0.862	0.862	0.862	0.559	0.559	0.512
1992	0.725	0.725	0.725	0.238	0.000	0.508
1991	0.333	0.000	------	------	------	0.528
1990	0.781	0.781	0.000	------	------	0.579
1989	0.000	------	------	------	------	0.418
1988	------	------	------	------	------	0.408
1987	0.000	------	------	------	------	0.570
1986	------	------	------	------	------	0.529
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, 1991-2006.

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							0.080	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, 1991-2006.

Year Class	Survival (S)					
	01-02	02-03	03-04	04-05	05-06	Mean
2002	------	------	------	------	------	-----
2001	------	------	------	0.542	0.390	0.460
2000	------	------	------	0.406	0.354	0.379
1999	------	------	0.662	0.228	0.417	0.398
1998	------	------	0.800	0.176	0.471	0.405
1997	0.710	0.710	0.710	0.134	0.538	0.481
1996	0.694	0.694	0.694	0.123	0.857	0.558
1995	0.737	0.857	0.533	0.395	0.395	0.552
1994	0.555	0.555	0.800	0.559	0.559	0.485
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, 1991-2006.

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	0.574	0.574	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, 1991-2006.

Year Class	Survival (S)					
	01-02	02-03	03-04	04-05	05-06	Mean
2000				------	------	------
1999				0.674	0.674	0.674
1998	------	------	------	------	------	------
1997		0.895	0.895	0.895	0.895	0.895
1996	------	------	------	0.795	0.795	0.795
1995	------	------	------	0.378	0.378	0.378
1994	------	------	------	0.717	0.717	0.717
1993	------	0.894	0.894	0.559	0.559	0.707
1992	0.725	0.725	0.725	0.238	0.000	0.447
1991	0.333	0.000	------	------	------	0.155
1990	0.781	0.781	0.000	------	------	0.669
1989	0.000	------	------	------	------	0.550
1988	------	------	------	------	------	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, 1994-2006. 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	**31.29**
1998							1.58	13.50	**29.67**	28.86
1997						0.20	21.58	**42.40**	39.33	8.00
1996						9.10	**73.26**	32.60	11.00	2.86
1995					1.22	10.30	**38.32**	8.40	2.56	1.57
1994			0.10	1.55	7.11	**11.70**	11.05	2.60	1.11	0.57
1993		0.67	1.70	4.44	5.22	**6.10**	2.10	1.60	0.89	0.86
1992		**4.33**	2.90	3.33	3.00	2.90	1.37	1.00	0.89	0.28
1991	2.40	**9.00**	4.50	2.00	1.67	2.20	0.63	1.50	0.22	0.14
1990	**12.40**	11.11	3.10	2.00	0.78	1.40	0.42	0.50	0.11	0.14
1989	**12.00**	9.78	2.60	0.89	1.11	1.20	0.11	0.00	0.00	0.14
1988	**3.20**	2.67	1.00	1.44	0.78	0.40	0.11	0.00	0.00	0.00
1987	0.80	**2.67**	1.00	1.11	0.67	1.00	0.00	0.00	0.00	0.00
1986	0.80	**1.78**	0.80	0.33	0.11	0.30	0.00	0.00	0.00	0.00
1985	0.80	**1.22**	0.30	0.22	0.11	0.10	0.00	0.00	0.00	0.00
1984	**1.20**	0.78	0.20	0.11	0.00	0.00	0.00	0.00	0.00	0.00
>1984	**1.20**	0.56	0.00	0.00	0.00	0.00	0.00	0.00	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
Total	**35.60**	**46.56**	**18.40**	**17.78**	**22.11**	**48.20**	**151.27**	**105.00**	**91.56**	**91.28**

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, 1994-2006. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)		
	2004	2005	2006
2004			**0.50**
2003		0.90	**27.60**
2002	0.36	14.70	**37.00**
2001	30.54	27.50	**33.70**
2000	**48.00**	19.90	9.80
1999	28.00	7.70	3.90
1998	11.82	5.10	2.60
1997	4.08	1.60	2.90
1996	3.56	1.60	3.90
1995	1.36	0.60	1.00
1994	1.00	0.50	1.00
1993	0.28	0.30	1.10
1992	0.38	0.10	0.10
1991	0.00	0.10	0.40
1990	0.00	0.00	0.40
1989	0.00	0.00	0.00
1988	0.00	0.00	0.00
1987	0.00	0.00	0.00
N/A	2.36	1.40	2.40
Total	**131.56**	**82.00**	**128.30**

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, 1994-2006. 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	**31.29**
1998							1.58	13.50	**28.89**	26.00
1997						0.20	21.47	**41.90**	35.56	7.57
1996						7.30	**72.74**	31.00	8.33	2.57
1995					1.22	8.00	**37.05**	7.60	2.00	1.00
1994			0.10	1.56	6.78	5.20	**10.53**	1.70	0.67	0.00
1993		0.67	1.70	**3.89**	3.78	2.50	1.68	1.10	0.11	0.14
1992		**4.22**	2.80	2.33	1.67	1.10	1.16	0.20	0.00	0.00
1991	2.40	**7.89**	3.60	1.44	1.00	0.10	0.00	0.40	0.00	0.00
1990	**10.60**	6.33	1.50	1.33	0.22	0.30	0.00	0.00	0.00	0.00
1989	**8.00**	2.33	0.70	0.44	0.00	0.00	0.00	0.00	0.00	0.00
1988	**1.40**	0.56	0.30	0.11	0.11	0.10	0.00	0.00	0.00	0.00
1987	0.00	**0.44**	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1986	0.00	**0.11**	0.00	0.00	0.00	0.00	0.00	0.00	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
Total	**23.20**	**24.00**	**10.90**	**11.11**	**14.89**	**25.30**	**146.95**	**98.10**	**81.33**	**85.14**

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, 1994-2006. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)		
	2004	2005	2006
2004			**0.50**
2003		0.90	**27.60**
2002	0.36	14.70	**36.90**
2001	30.54	27.30	**32.30**
2000	**47.82**	19.60	8.70
1999	27.64	7.50	3.50
1998	10.46	4.90	2.20
1997	3.90	1.00	1.40
1996	2.28	1.20	0.60
1995	0.54	0.10	0.10
1994	1.00	0.30	0.10
1993	0.00	0.10	0.00
1992	0.10	0.00	0.00
1991	0.00	0.00	0.10
1990	0.00	0.00	0.00
1989	0.00	0.00	0.00
1988	0.00	0.00	0.00
N/A	2.36	1.40	2.40
Total	**127.00**	**79.00**	**116.40**

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, 1994-2006. 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	**2.86**
1997							0.11	0.50	**3.78**	0.43
1996						1.80	0.53	1.60	2.67	0.28
1995						**2.30**	1.26	0.80	0.56	0.57
1994					0.33	**6.50**	0.53	0.90	0.44	0.57
1993				0.56	1.44	**3.60**	0.42	0.50	0.78	0.71
1992		0.11	0.10	1.00	1.33	**1.80**	0.21	0.80	0.89	0.28
1991		1.11	0.90	0.56	0.67	**2.10**	0.63	1.10	0.22	0.14
1990	1.80	**4.78**	1.60	0.67	0.56	1.10	0.42	0.50	0.11	0.14
1989	4.00	**7.44**	1.90	0.44	1.11	1.20	0.11	0.00	0.00	0.14
1988	**2.20**	2.11	0.70	1.33	0.67	0.30	0.11	0.00	0.00	0.00
1987	0.80	**2.22**	0.90	1.11	0.67	1.00	0.00	0.00	0.00	0.00
1986	0.80	**1.67**	0.80	0.33	0.11	0.30	0.00	0.00	0.00	0.00
1985	0.40	**1.22**	0.30	0.22	0.11	0.10	0.00	0.00	0.00	0.00
1984	**1.20**	0.78	0.20	0.11	0.00	0.00	0.00	0.00	0.00	0.00
1983	**0.80**	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1982	**0.40**	0.22	0.00	0.00	0.00	0.00	0.00	0.00	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	**12.40**	**22.56**	**7.50**	**6.67**	**7.22**	**22.90**	**4.33**	**6.90**	**10.22**	**6.14**

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, 1994-2006. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)		
	2004	**2005**	**2006**
2002			**0.10**
2001		0.20	**1.40**
2000	0.18	0.30	**1.10**
1999	0.18	0.20	**0.40**
1998	0.36	0.20	0.40
1997	0.18	0.60	1.50
1996	1.28	0.40	**3.30**
1995	0.82	0.50	0.90
1994	1.00	0.20	0.90
1993	0.28	0.20	1.10
1992	0.28	0.10	0.10
1991	0.00	0.10	0.30
1990	0.00	0.00	0.40
1989	0.00	0.00	0.10
1988	0.00	0.00	0.00
1987	0.00	0.00	0.00
1986	0.00	0.00	0.00
N/A	0.00	0.00	0.00
Total	**4.56**	**3.00**	**12.00**

Table 35a. 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, 1994-2006.

Year Class	Survival (S)									
	94-95	95-96	96-97	97-98	98-99	99-00	00-01	01-02	02-03	03-04
1999										0.970
1998									0.973	0.410
1997								0.928	0.203	0.510
1996							0.445	0.751	0.772	0.772
1995							0.219	0.305	0.613	0.866
1994						0.944	0.235	0.427	0.974	0.974
1993						0.344	0.762	0.928	0.928	0.928
1992		0.877	0.877	0.901	0.967	0.472	0.730	0.890	0.653	0.653
1991		0.500	0.788	0.788	0.788	0.826	0.826	0.768	0.768	0.768
1990	0.896	0.279	0.645	0.837	0.837	0.598	0.598	0.956	0.956	0.956
1989	0.815	0.266	0.773	0.773	0.773	0.584	0.584	0.584	0.584	0.000
1988				0.834	0.734	0.734	0.542	0.513	0.275	0.000
1987					------	0.645	0.645	0.948	0.948	0.000
1986					------	0.449	0.413	0.953	0.953	0.000
1985					------	0.245	0.733	0.500	0.909	0.000
1984							0.650	0.256	0.550	0.000
1983									0.413	0.000
1982									0.555	0.000

Table 35b. Estimated annual and geometric mean survival (S) rates for year classes of striped bass (sexes combined) sampled from gill nets (mile 62) in the James River, 30 March - 3 May, 1994-2006.

Year Class	Survival (S)		
	04-05	05-06	Mean
2001	------	------	------
2000	0.415	0.492	0.452
1999	0.275	0.506	0.499
1998	0.431	0.510	0.544
1997	0.843	0.843	0.585
1996	0.772	0.772	0.613
1995	0.857	0.857	0.544
1994	0.975	0.974	0.703
1993	0.928	0.928	0.783
1992	0.513	0.513	0.710
1991	0.768	0.768	0.754
1990	0.956	0.956	0.758
1989	------	------	0.551
1988	------	------	0.491
1987	------	------	0.593
1986	------	------	0.508
1985	------	------	0.440
1984	------	------	0.347

Table 36a. 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, 1994-2006.

Year Class	Survival (S)									
	94-95	95-96	96-97	97-98	98-99	99-00	00-01	01-02	02-03	03-04
1999										0.883
1998									0.900	0.402
1997								0.849	0.213	0.515
1996							0.426	0.269	0.309	0.887
1995							0.205	0.263	0.500	0.540
1994							0.161	0.843	0.843	0.843
1993				0.971	0.662	0.672	0.655	0.357	0.357	0.591
1992		0.663	0.833	0.717	0.833	0.833	0.172	0.794	0.794	0.794
1991				0.456	0.401	0.694	0.737	0.737	0.758	0.758
1990					0.597	0.237	0.887	0.474	0.474	0.000
1989							0.292	0.300	0.629	0.000
1988					0.400	0.535	0.606	0.606	0.909	0.000
1987									0.227	0.000
1986										0.000

Table 36b. 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, 1994-2006.

Year Class	Survival (S)		
	04-05	05-06	Mean
2001	------	------	------
2000	0.406	0.444	0.425
1999	0.228	0.467	0.455
1998	0.176	0.449	0.411
1997	0.599	0.599	0.507
1996	0.123	0.500	0.353
1995	0.430	0.430	0.373
1994	0.313	0.333	0.463
1993	------	------	0.495
1992	------	------	0.562
1991	0.758	0.758	0.672
1990	------	------	0.417
1989	------	------	0.286
1988	------	------	0.482
1987	------	------	0.108
1986	------	------	0.000

Table 37a. 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, 1994-2006.

Year Class	Survival (S)									
	94-95	95-96	96-97	97-98	98-99	99-00	00-01	01-02	02-03	03-04
1999										------
1998										0.519
1997									0.794	0.794
1996									------	------
1995						0.548	0.945	0.945	0.945	0.945
1994						0.688	0.688	0.688	0.688	0.688
1993						0.844	0.844	0.844	0.844	0.844
1992						0.791	0.791	0.791	0.315	0.709
1991						0.724	0.724	0.771	0.771	0.771
1990		0.335	0.883	0.883	0.883	0.674	0.674	0.956	0.956	0.956
1989		0.255	0.858	0.858	0.858	0.584	0.584	0.584	0.584	0.894
1988				0.960	0.795	0.795	0.504	0.448	0.367	0.000
1987					------	0.707	0.707	0.949	0.949	0.000
1986					------	0.479	0.413	0.953	0.953	0.000
1985					------	0.245	0.733	0.500	0.909	0.000
1984							0.650	0.286	0.550	0.000
1983									0.413	0.000
1982									0.550	0.000

Table 37b. 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, 1994-2006.

Year Class	Survival (S)		
	04-05	05-06	Mean
1999	------	------	------
1998	0.519	0.519	0.519
1997	0.794	0.794	0.794
1996	------	------	------
1995	0.945	0.945	0.945
1994	0.949	0.949	0.754
1993	0.844	0.844	0.844
1992	0.709	0.709	0.662
1991	0.771	0.771	0.757
1990	0.956	0.956	0.798
1989	0.894	0.894	0.676
1988	------	------	0.520
1987	------	------	0.617
1986	------	------	0.515
1985	------	------	0.440
1984	------	------	0.347
1983	------	------	0.180
1982	------	------	0.245

Table 38a. Comparison of the area under the catch curve (fish/ day) of the 1987-2004 year classes of striped bass from pound nets in the Rappahannock River, 1991-2006.

age	year class										
	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	
2			0.2	0.3	0.3	0.7	1.5	0.3	0.3	0.1	
3		3.6	0.8	1.3	0.8	5.5	5.5	4.2	2.5	11.6	
4	8.0	5.2	4.4	2.6	1.8	8.4	13.6	10.5	14.0	29.8	
5	10.8	14.7	8.9	4.9	3.4	9.6	15.1	13.3	17.3	34.1	
6	14.4	16.9	9.6	6.1	3.5	9.7	15.2	13.4	17.4	34.3	
7	15.6	17.5	10.5	6.8	4.0	10.2	15.7	14.0	18.1	36.1	
8	16.2	17.9	11.3	7.5	4.4	10.7	16.6	14.4	19.5	40.3	
9	16.6	19.4	12.1	7.8	4.8	11.5	16.8	16.1	21.8	42.0	
10	17.6	20.3	12.5	8.1	5.7	11.7	18.3	17.8	22.7	43.2	
11	18.5	20.7	12.8	8.6	5.9	12.9	19.3	18.4	22.9		
12	18.9	20.7	13.1	8.6	7.0	14.0	19.8	18.6			
13	19.0	20.8	13.1	8.9	8.1	14.3	20.0				
14	19.0	20.8	13.2	8.9	8.4	14.4					
15	19.0	20.8	13.2	9.0	8.4						
16	19.0	20.8	13.3	9.0							
17	19.0	20.8	13.3								
18	19.1	20.8									
19	19.1										
20											
area	**19.1**	**20.8**	**13.3**	**9.0**	**8.4**	**14.4**	**20.0**	**18.6**	**22.9**	**43.2**	

Table 38b. Comparison of the area under the catch curve (fish/ day) of the 1987-2004 year classes of striped bass from pound nets in the Rappahannock River, 1991-2006.

age	year class										mean
	1997	1998	1999	2000	2001	2002	2003	2004			
2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.1			0.3
3	16.0	2.7	0.6	0.8	3.5	1.8	7.9				4.4
4	23.5	4.2	3.6	6.3	8.9	8.2					10.1
5	24.9	7.5	9.5	9.1	12.1						13.7
6	25.3	11.0	10.2	9.2							14.6
7	27.5	11.8	10.7								15.5
8	29.2	12.7									16.5
9	30.1										17.5
10											18.4
11											19.0
12											19.5
13											19.9
14											20.0
15											20.0
16											20.0
17											20.0
18											20.0
19											
20											
area	30.1	12.7	10.7	9.2	12.1	8.2	7.9	0.1			20.0

Table 39a. Comparison of the area under the catch curve (fish/ day) of the 1987-2004 year classes of striped bass from gill nets in the Rappahannock River, 1991-2006.

age	year class										
	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	
3		9.5	1.5	1.8	2.8	8.4	22.3	30.5	12.1	35.9	
4	23.7	11.4	10.1	10.0	4.7	19.8	105.3	63.2	22.7	57.1	
5	29.5	36.8	37.7	17.8	10.4	34.1	112.3	66.4	28.5	74.8	
6	39.9	45.0	42.2	21.3	13.2	34.9	113.1	68.2	30.6	79.4	
7	42.1	47.9	44.7	23.4	14.6	36.1	115.1	69.7	34.1	83.6	
8	43.8	49.4	45.3	23.8	15.1	36.7	116.1	70.9	35.7	91.2	
9	45.4	50.6	45.7	23.9	15.4	37.8	117.1	72.2	38.4	92.5	
10	45.9	50.9	45.9	24.1	16.3	38.1	117.6	73.9	38.6	94.3	
11	46.0	51.1	46.0	24.2	16.6	38.1	118.2	74.2	39.0		
12	46.1	51.2	46.1	24.2	16.6	38.6	118.3	75.0			
13	46.1	51.2	46.1	24.3	16.6	38.7	118.5				
14	46.2	51.2	46.1	24.3	16.6	38.7					
15	46.2	51.2	46.1	24.3	16.6						
16	46.2	51.2	46.1	24.3							
17	46.2	51.2	46.1								
18	46.2	51.2									
19	46.2										
20											
area	**46.2**	**51.2**	**46.1**	**24.3**	**16.6**	**38.7**	**118.5**	**75.0**	**39.0**	**94.3**	

Table 39b. Comparison of the area under the catch curve (fish/ day) of the 1987-2004 year classes of striped bass from gill nets in the Rappahannock River, 1991-2006.

age	year class										mean
	1997	1998	1999	2000	2001	2002	2003	2004			
2	5.9	0.7	0.5	0.3	1.4	2.1	0.2	0.4			**1.1**
3	24.0	10.2	1.6	9.1	23.1	6.1	9.4				**13.0**
4	51.0	19.0	17.6	25.3	34.9	14.3					**31.1**
5	61.2	31.6	28.3	31.9	39.8						**42.1**
6	65.8	41.6	30.7	34.7							**46.3**
7	76.1	43.5	31.8								**49.1**
8	77.5	45.4									**50.7**
9	79.1										**51.8**
10											**52.5**
11											**52.7**
12											**52.9**
13											**53.0**
14											**53.0**
15											**53.0**
16											**53.0**
17											**53.0**
18											**53.0**
19											
20											
area	**79.1**	**45.4**	**31.8**	**34.7**	**39.8**	**14.3**	**9.4**	**0.4**			**53.0**

Table 40a. Comparison of the area under the catch curve (fish/ day) of the 1987-2004 year classes of striped bass from gill nets in the James River, 1994-2006.

age	year class										
	1987	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	
2						0.0	0.3	0.1	0.0	0.0	
3					2.4	4.3	2.0	1.6	1.2	9.1	
4				12.4	11.4	7.2	6.5	8.7	11.5	82.4	
5			12.0	23.5	15.9	10.6	11.7	20.4	49.8	115.0	
6		3.2	21.8	26.6	17.9	13.6	17.8	31.5	58.2	126.0	
7	0.8	5.9	24.4	28.6	19.6	16.5	19.9	34.1	60.8	128.8	
8	3.5	6.9	25.3	29.4	21.8	17.8	21.5	35.2	62.4	132.4	
9	4.5	8.3	26.4	30.8	22.4	18.8	22.4	35.7	63.7	134.0	
10	5.6	9.1	27.6	31.2	23.9	19.7	23.2	36.7	64.3	137.9	
11	6.3	9.5	27.7	31.7	24.1	20.0	23.5	37.2	65.3		
12	7.3	9.6	27.7	31.8	24.3	20.4	23.8	38.2			
13	7.3	9.6	27.7	32.0	24.3	20.5	24.9				
14	7.3	9.6	27.8	32.0	24.4	20.6					
15	7.3	9.6	27.8	32.0	24.8						
16	7.3	9.6	27.8	32.4							
17	7.3	9.6	27.9								
18	7.3	9.6									
19	7.3										
20											
area	**7.3**	**9.6**	**27.9**	**32.4**	**24.8**	**20.6**	**24.9**	**38.2**	**65.3**	**137.9**	

Table 40b. Comparison of the area under the catch curve (fish/ day) of the 1987-2004 year classes of striped bass from gill nets in the James River, 1991-2006.

age	year class										mean
	1997	1998	1999	2000	2001	2002	2003	2004			
2	0.1	0.8	0.2	0.2	0.4	0.2	0.5	0.5			**0.3**
3	21.7	14.3	4.0	15.7	31.0	14.9	28.1				**11.6**
4	64.1	44.0	35.3	63.7	58.5	51.9					**37.6**
5	103.4	72.8	63.3	83.6	92.2						**58.3**
6	111.4	84.6	71.0	93.4							**65.6**
7	115.5	89.7	74.9								**68.4**
8	117.1	92.3									**70.2**
9	120.0										**71.4**
10											**72.5**
11											**72.9**
12											**73.3**
13											**73.5**
14											**73.6**
15											**73.7**
16											**73.8**
17											**73.8**
18											**73.8**
19											
20											
area	**120.0**	**92.3**	**74.9**	**93.4**	**92.2**	**51.9**	**28.1**	**0.5**			**73.8**

Table 41a. Back-calculated length-at-age (FL, in mm) for striped bass sampled from the James and Rappahannock rivers during spring, 2006.

Year Class	n	length-at-age (FL, in mm)							
		1	2	3	4	5	6	7	8
2004	1	171.4							
2003	16	162.1	283.5						
2002	17	151.6	273.7	373.6					
2001	28	145.1	264.0	372.1	467.6				
2000	14	139.8	255.8	370.0	470.5	551.7			
1999	23	142.4	252.4	366.6	469.9	560.4	633.2		
1998	27	141.8	248.9	352.9	458.1	552.7	636.2	705.4	
1997	34	141.1	245.6	346.8	440.7	533.6	618.0	693.8	753.9
1996	68	140.1	240.7	335.2	431.1	520.0	606.0	686.4	757.6
1995	25	137.8	238.4	332.6	426.8	517.9	600.0	677.5	750.0
1994	15	136.7	232.3	318.7	407.8	491.7	570.8	648.7	721.9
1993	11	132.8	227.1	314.9	398.2	476.0	550.3	624.0	692.2
1992	3	133.5	220.9	304.6	394.3	487.0	556.4	624.1	690.9
1991	2	126.8	215.8	295.9	375.4	464.8	541.3	616.1	678.1
1990	0								
1989	2	125.8	197.6	255.2	328.6	421.1	489.7	555.1	623.7
all	286	142.2	248.5	346.0	440.1	526.0	606.2	679.4	743.9

Table 41b. Back-calculated length-at-age (FL, in mm) for striped bass sampled from the James and Rappahannock rivers during spring, 2006.

Year Class	n	length-at-age (FL, in mm)							
		9	10	11	12	13	14	15	16
2004	1								
2003	16								
2002	17								
2001	28								
2000	14								
1999	23								
1998	27								
1997	34								
1996	68	816.5							
1995	25	816.4	867.5						
1994	15	788.0	846.7	894.2					
1993	11	758.0	821.2	874.0	921.6				
1992	3	758.6	823.4	881.7	933.6	969.7			
1991	2	736.7	797.3	864.0	918.7	961.5	1006.0		
1990	0								
1989	2	681.2	735.5	792.9	847.2	903.0	947.7	997.2	1037.1
all	286	803.2	844.1	878.4	915.0	948.3	976.8	997.2	1037.1

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

SA	Otolith age																			
	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
2	**0**	0																		
3	0	**16**	0	1																
4		6	**3**	6																
5			4	**20**	4															
6				5	**7**	1	1													
7				0	7	**6**	5	0	3											
8						2	**6**	2	14	1										
9							3	**2**	20	3	1	1								
10							1	0	**44**	6	2	3								
11								0	23	**6**	4	6	0							
12									5	6	**3**	6	1							
13									4	1	0	**4**	2	2	1					
14										1	1	2	**2**	0	1					
15											0	1	1	**0**	1	1				
16												0	0	0	**0**	0				
17												0	1	0	2	**0**				
18															1	0	**0**			
19															0	0		**0**		
20																			**0**	
21																				**0**

Table 43. Relative contributions of striped bass age classes as determined by ageing specimens (n = 296) by reading both their scales and ooliths.

Age	scale		otolith	
	n	prop.	n	.prop
2	0	.0000	0	.0000
3	17	.0574	22	.0743
4	15	.0507	7	.0236
5	28	.0946	32	.1081
6	15	.0507	18	.0608
7	21	.0709	9	.0304
8	25	.0845	16	.0541
9	30	.1014	4	.0135
10	56	.1892	113	.3818
11	39	.1318	24	.0811
12	21	.0709	11	.0372
13	14	.0473	23	.0777
14	7	.0236	7	.0236
15	4	.0135	2	.0068
16	0	.0000	7	.0236
17	3	.0101	1	.0034
18	1	.0034	0	.0000
19	0	.0000	0	.0000
20	0	.0000	0	.0000
21	0	.0000	0	.0000
22	0	.0000	0	.0000
	$\overline{Age} = 8.81$		$\overline{Age} = 9.02$	

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, 1991-2006.

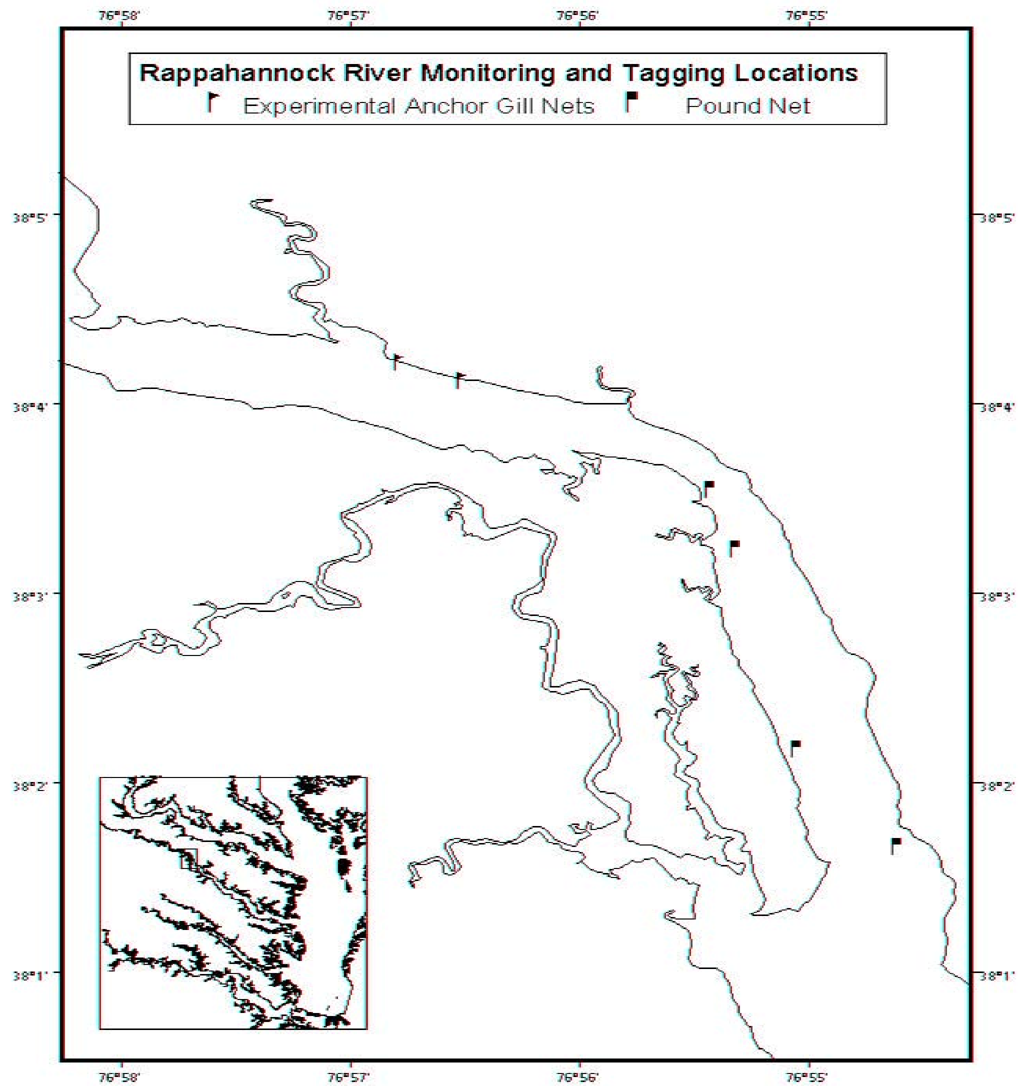


Figure 2. Locations of the experimental anchor gill nets sampled in spring spawning stock assessments of striped bass in the James River, springs 2003-2006.

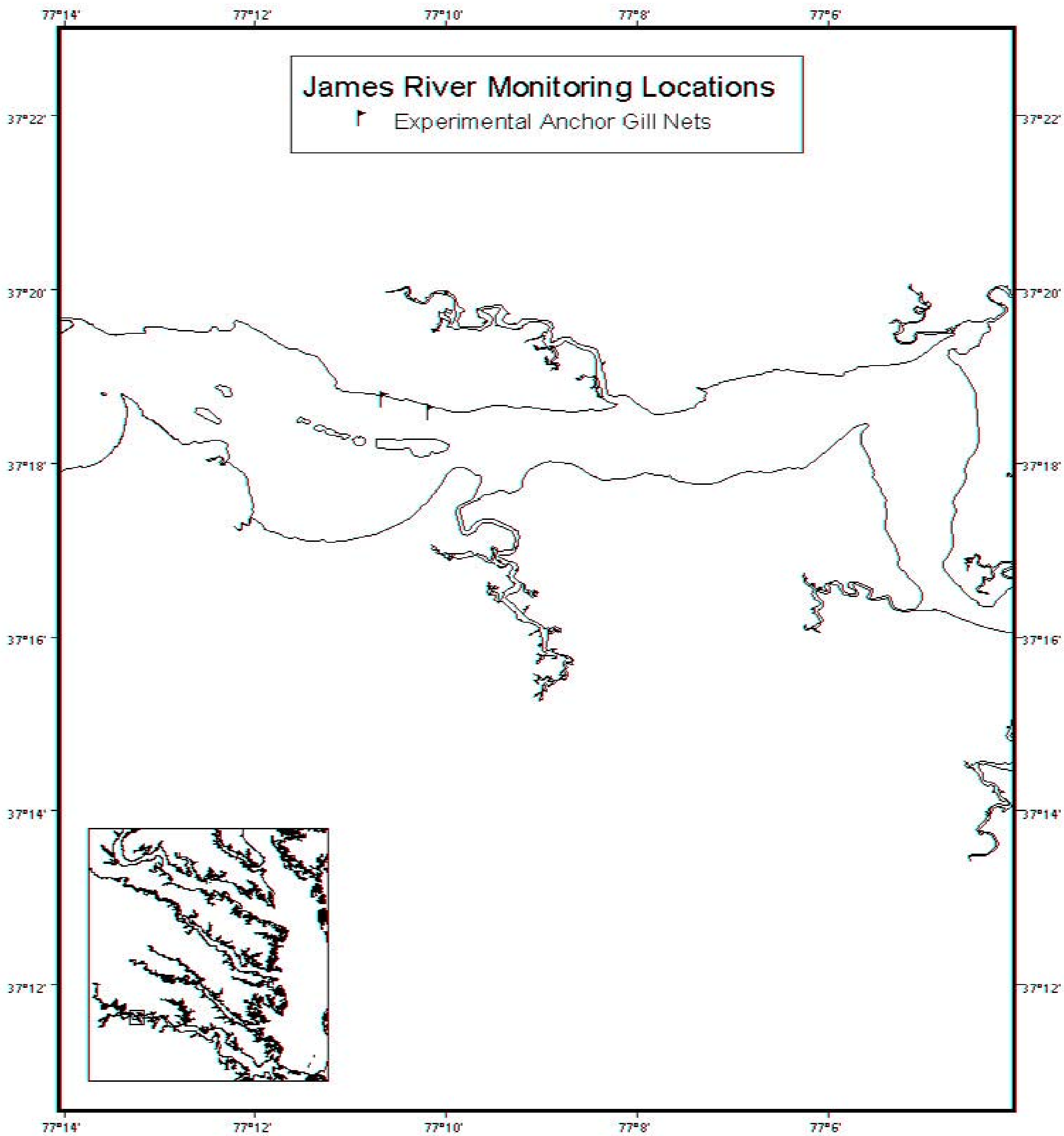


Figure 3. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1987 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1991-2006.

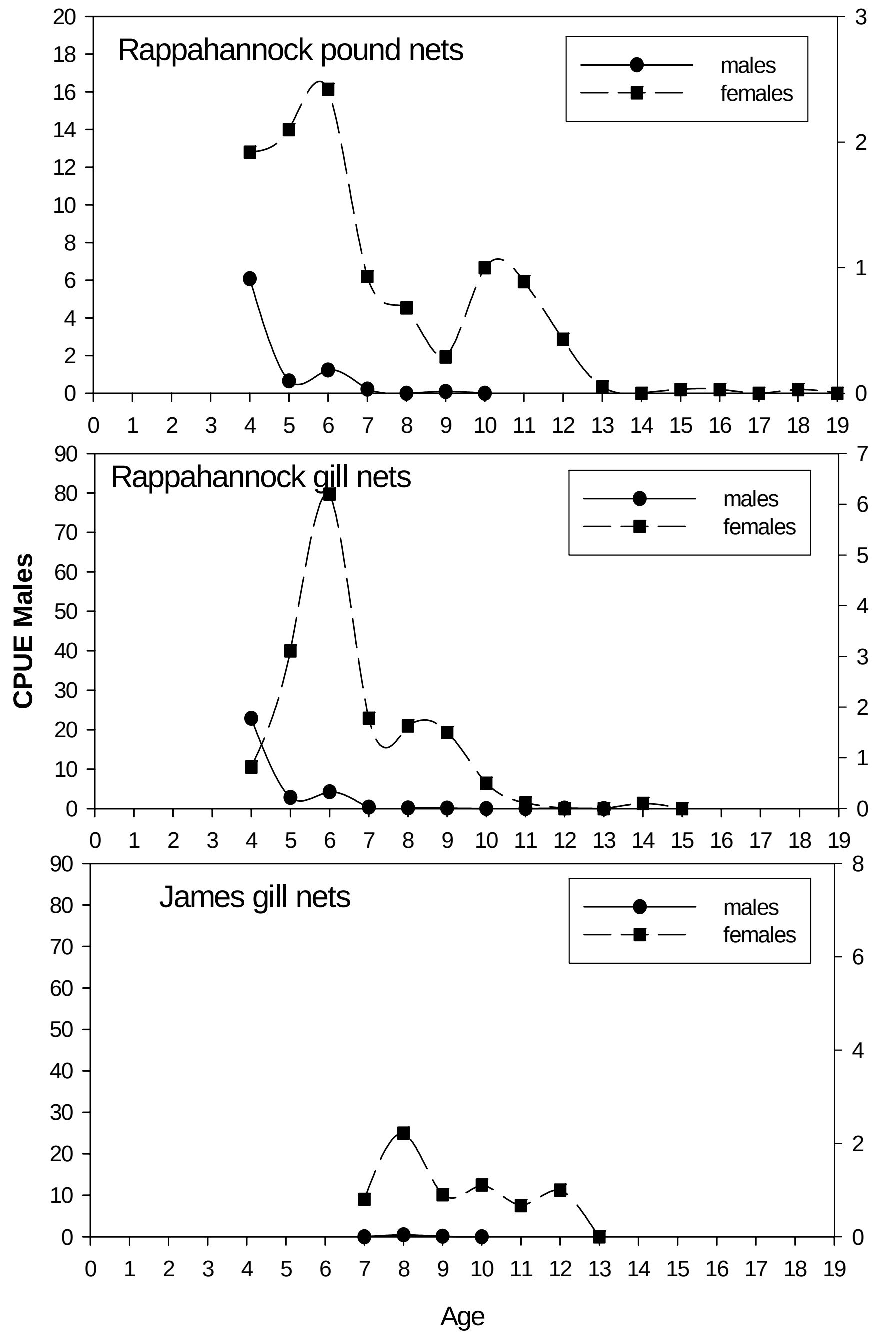


Figure 4. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1988 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1991-2006.

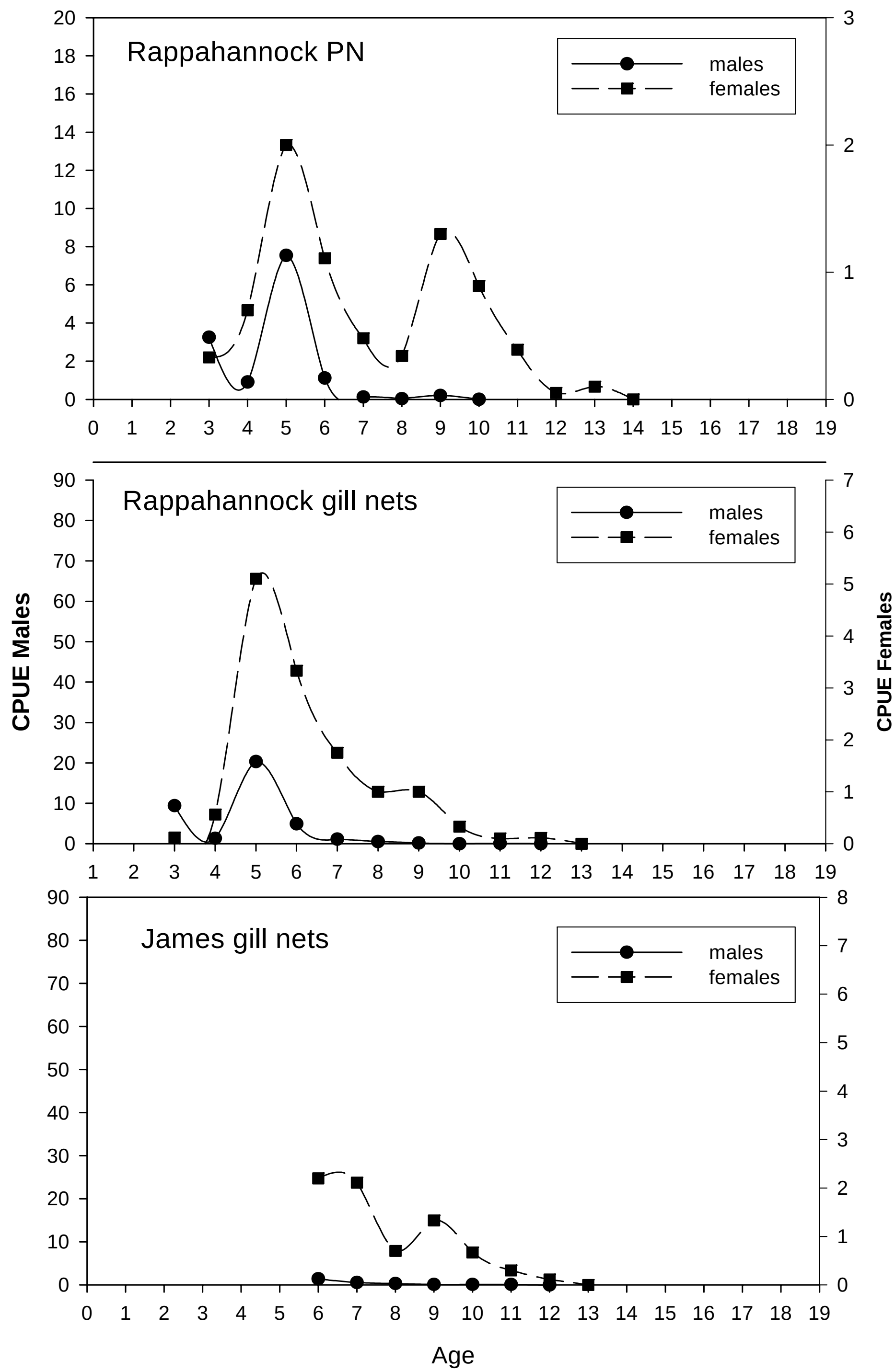


Figure 5. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1989 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1991-2006.

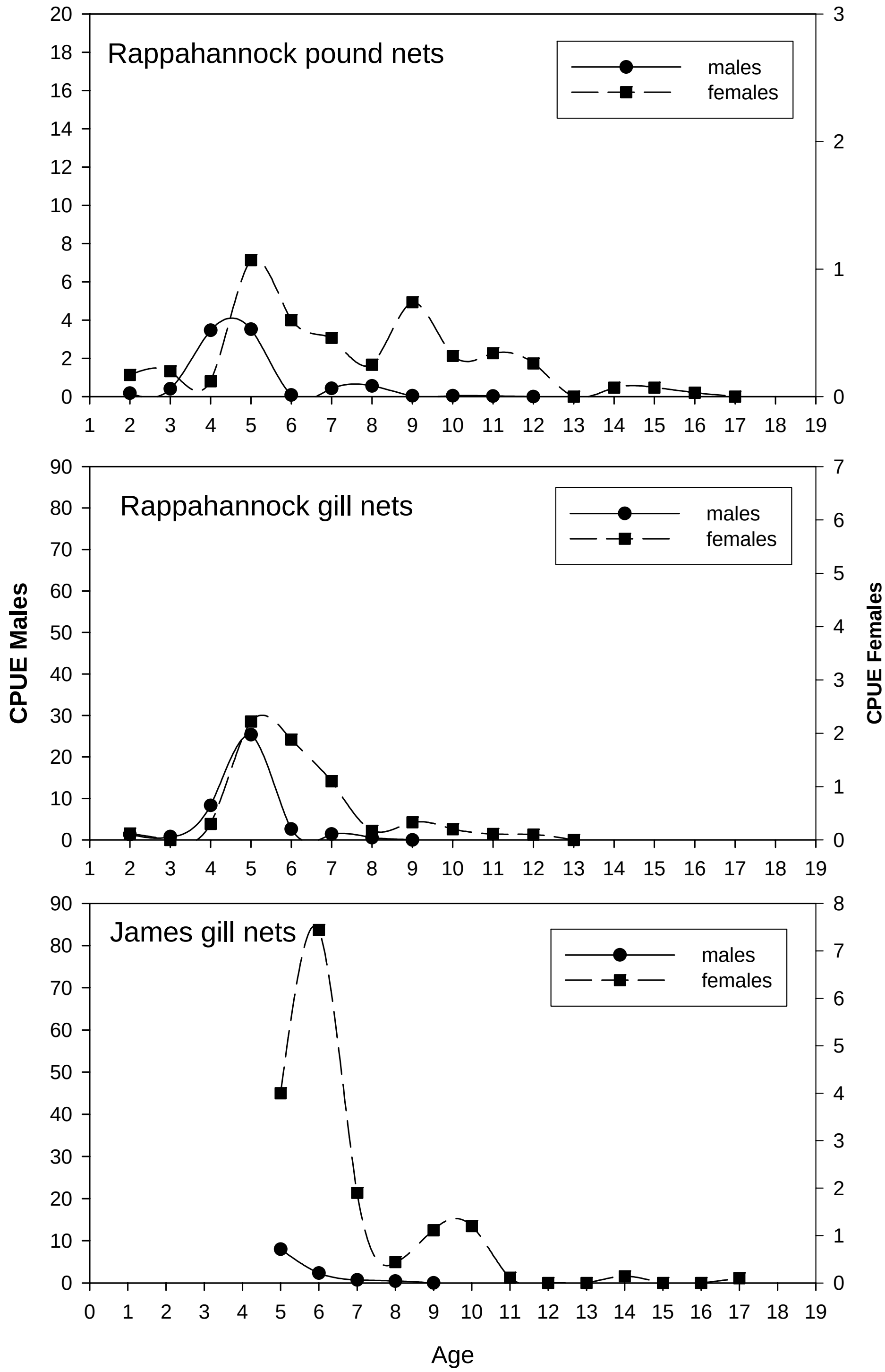


Figure 6. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1990 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1991-2006.

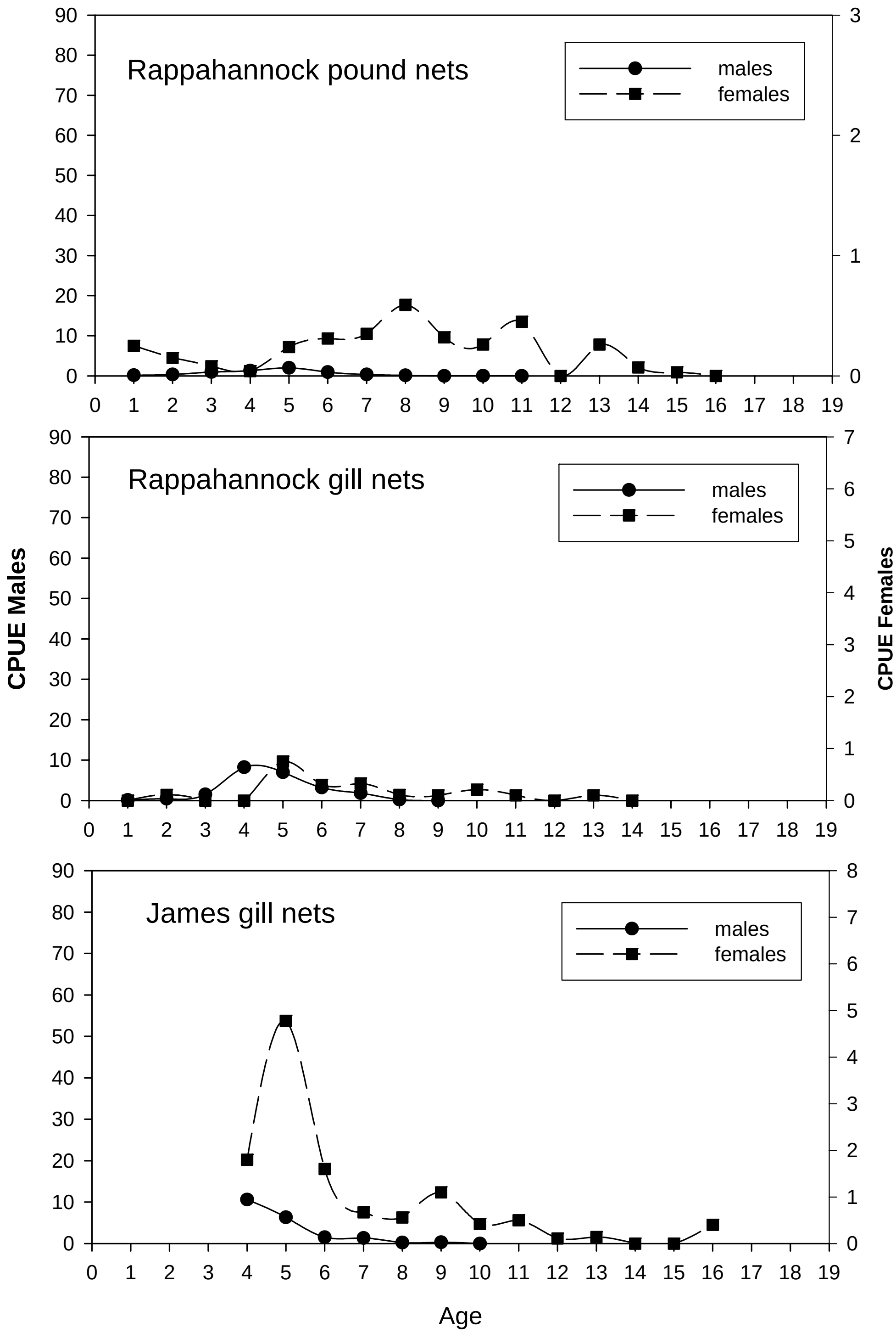


Figure 7. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1991 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1992-2006.

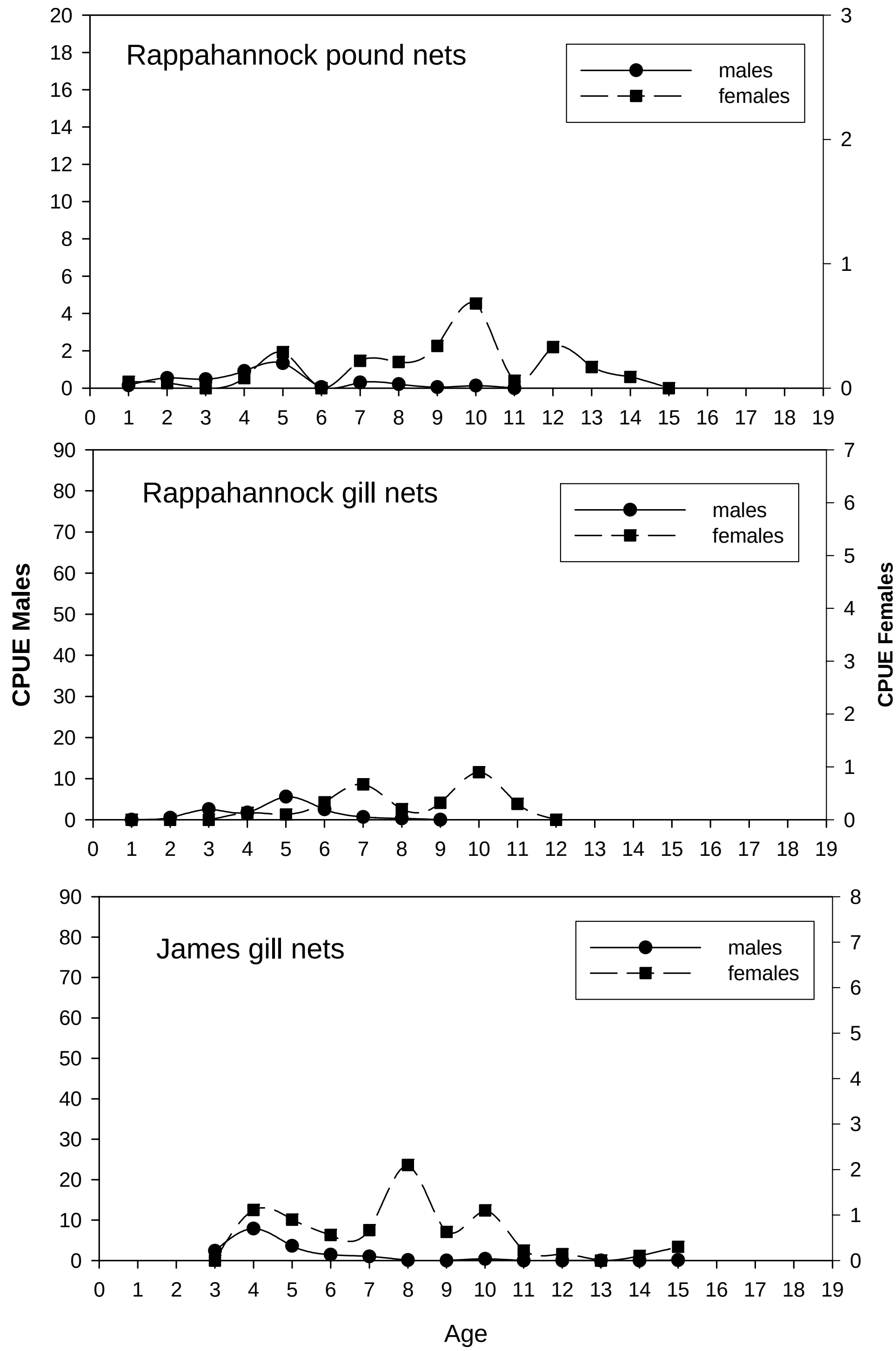


Figure 8. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1992 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1993-2006.

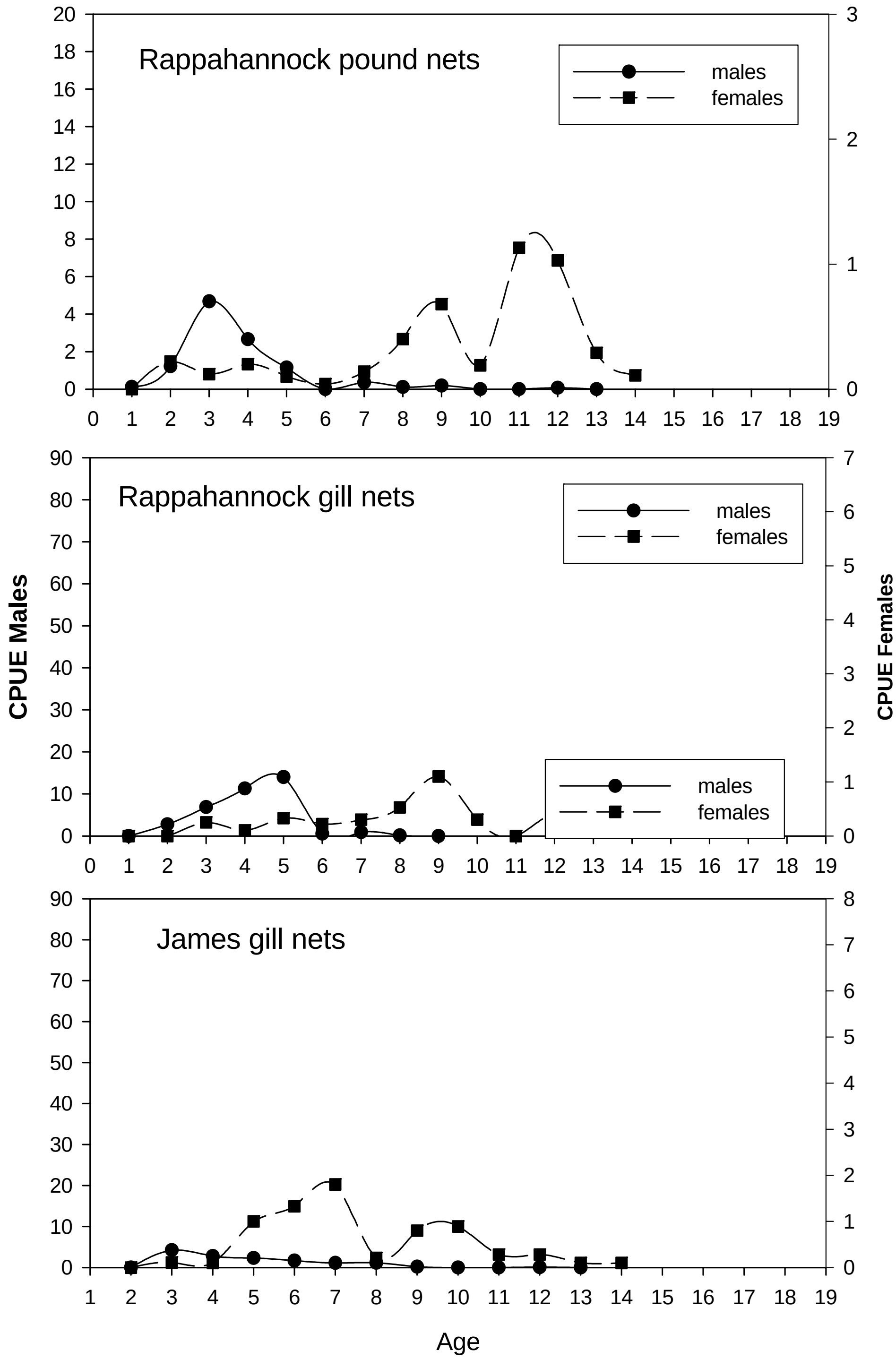


Figure 9. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1993 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1994-2006.

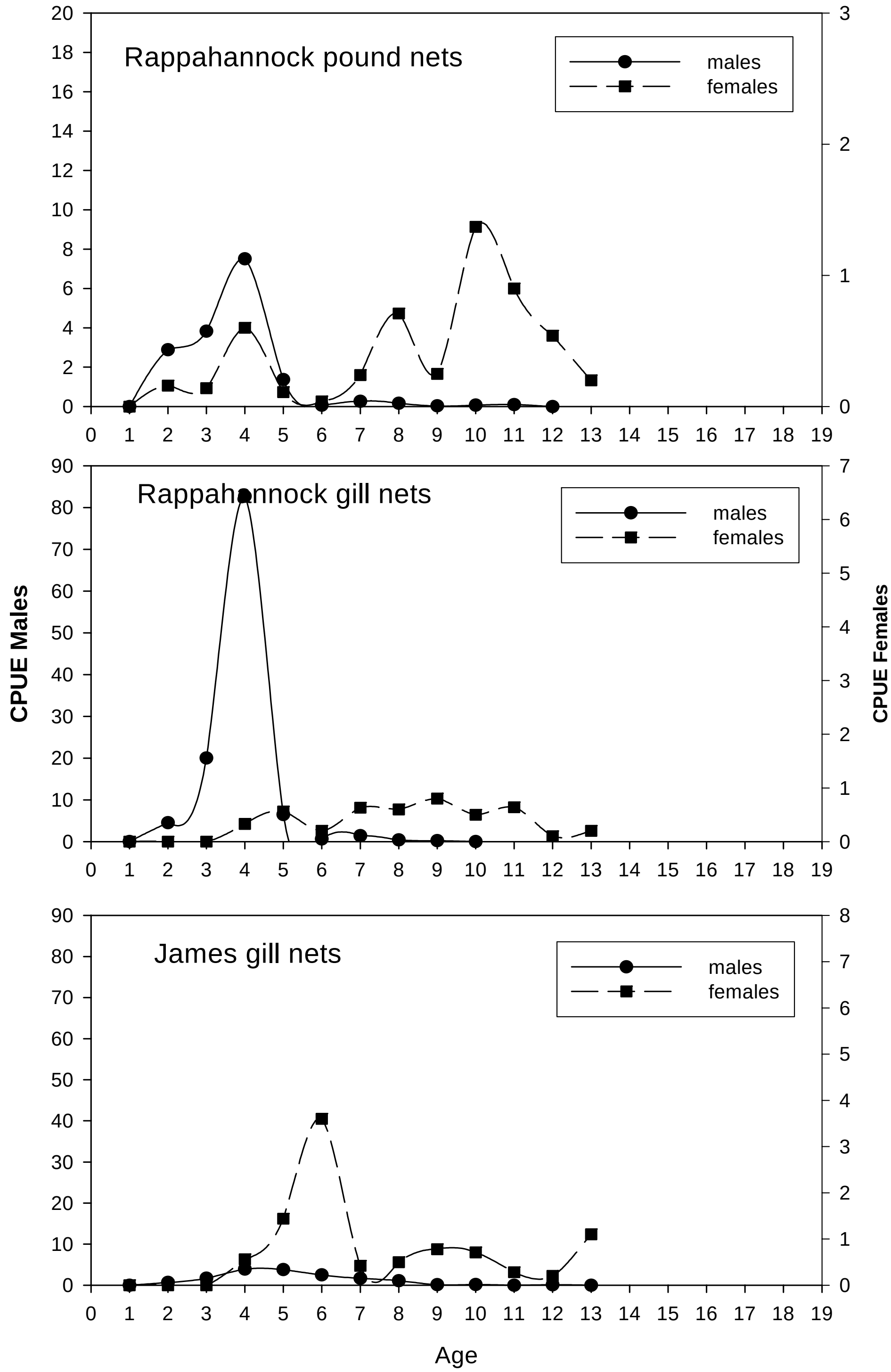


Figure 10. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1994 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1995-2006.

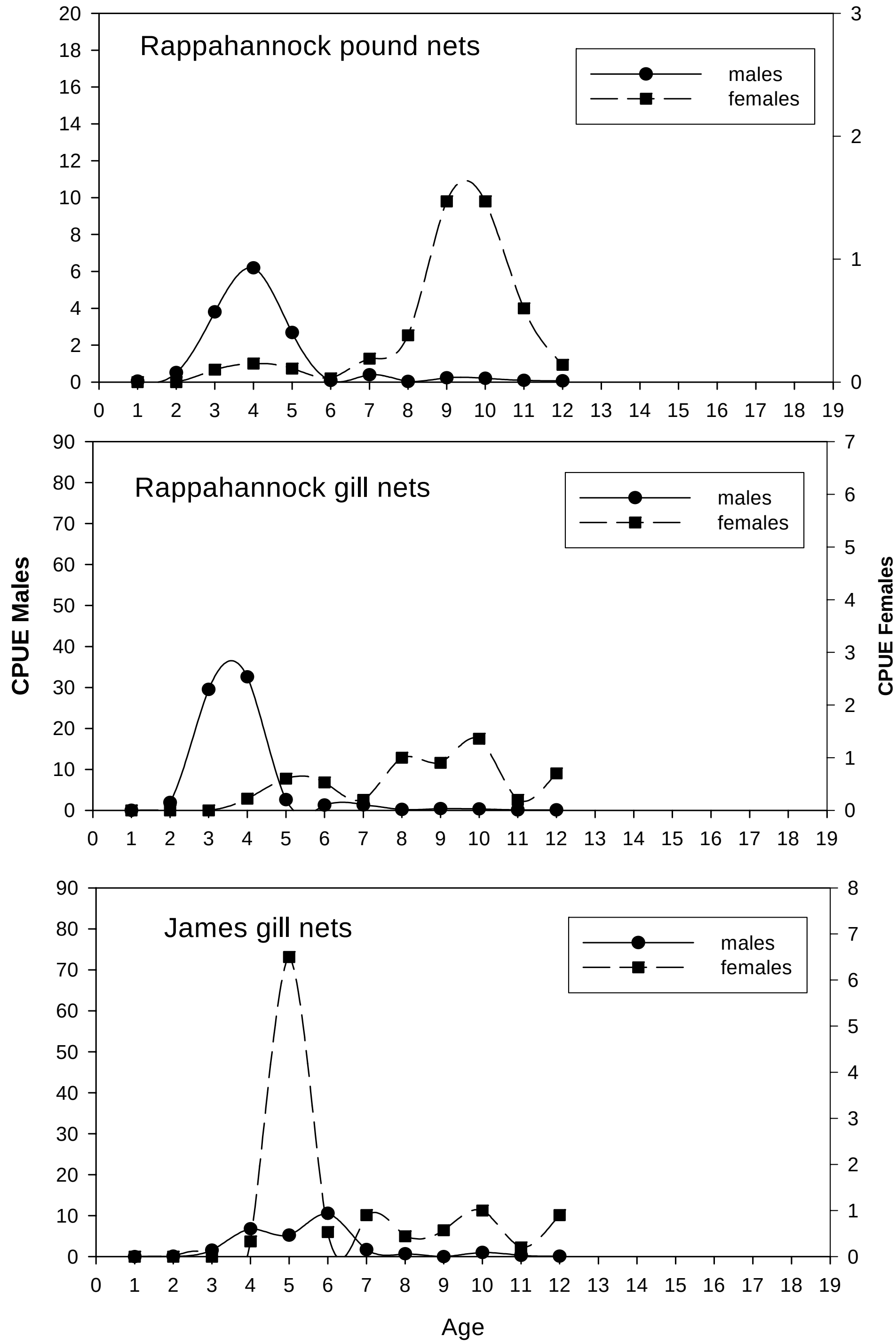


Figure 11. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1995 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1996-2006.

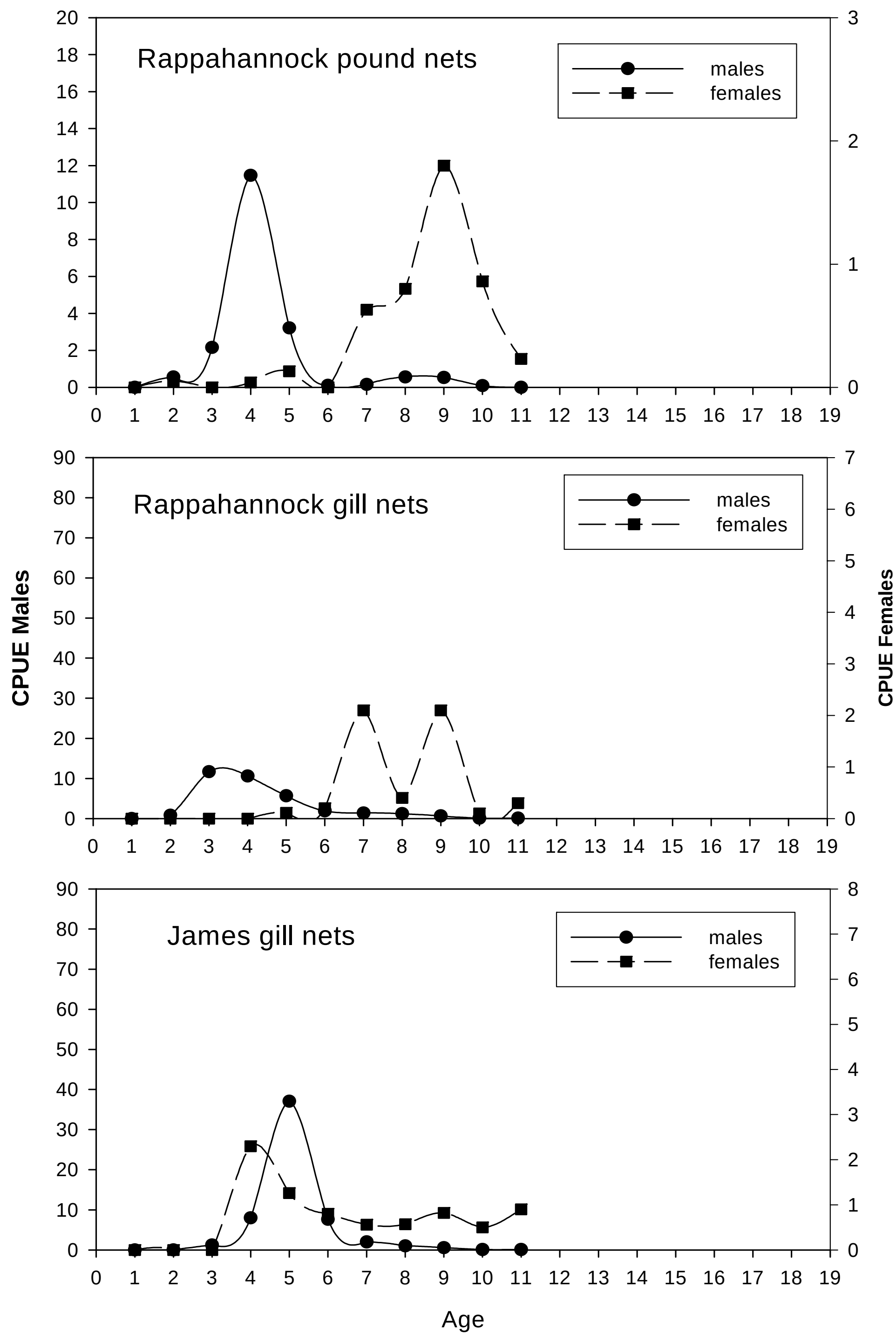


Figure 12. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1996 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1997-2006.

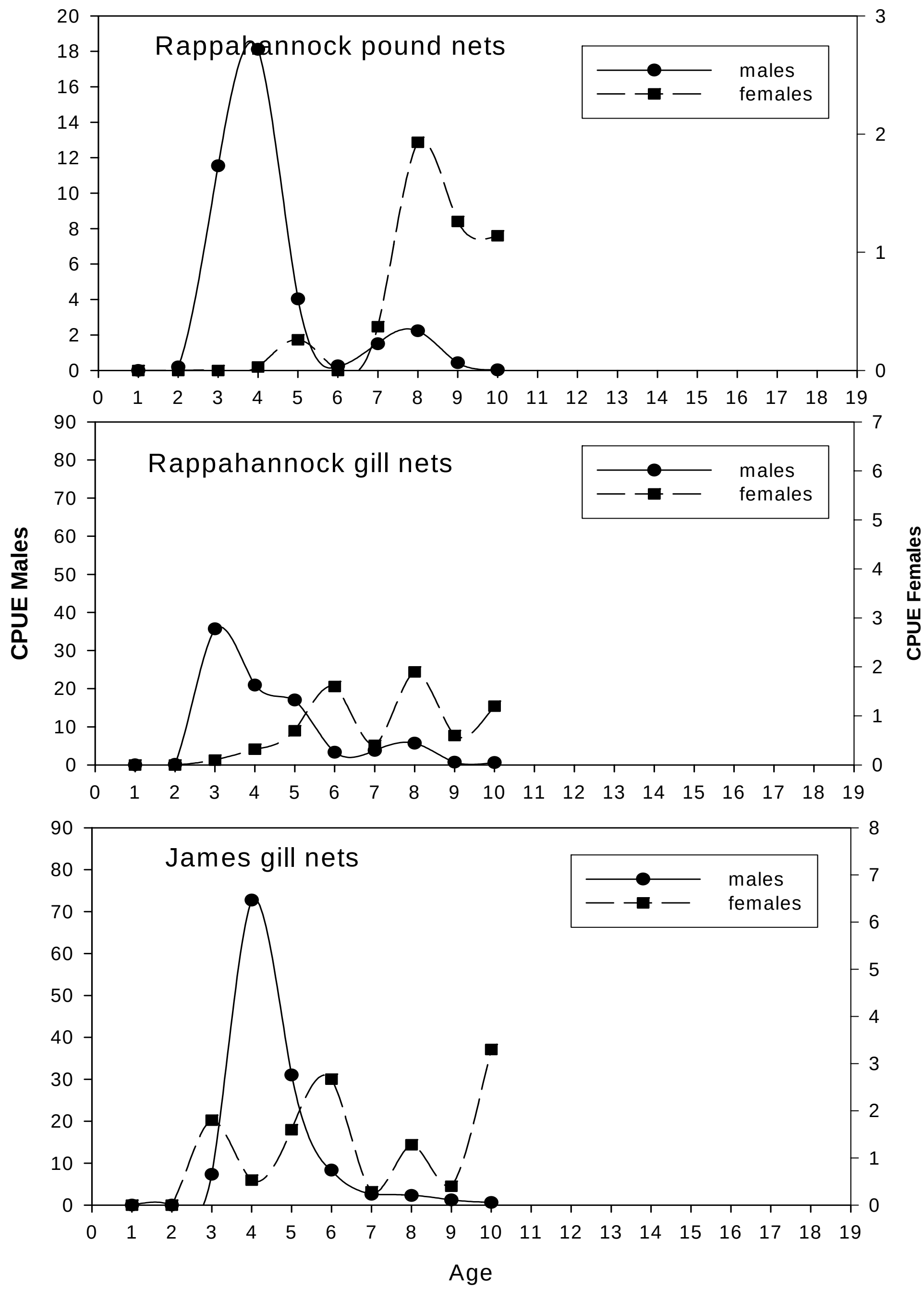


Figure 13. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1997 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1998-2006.

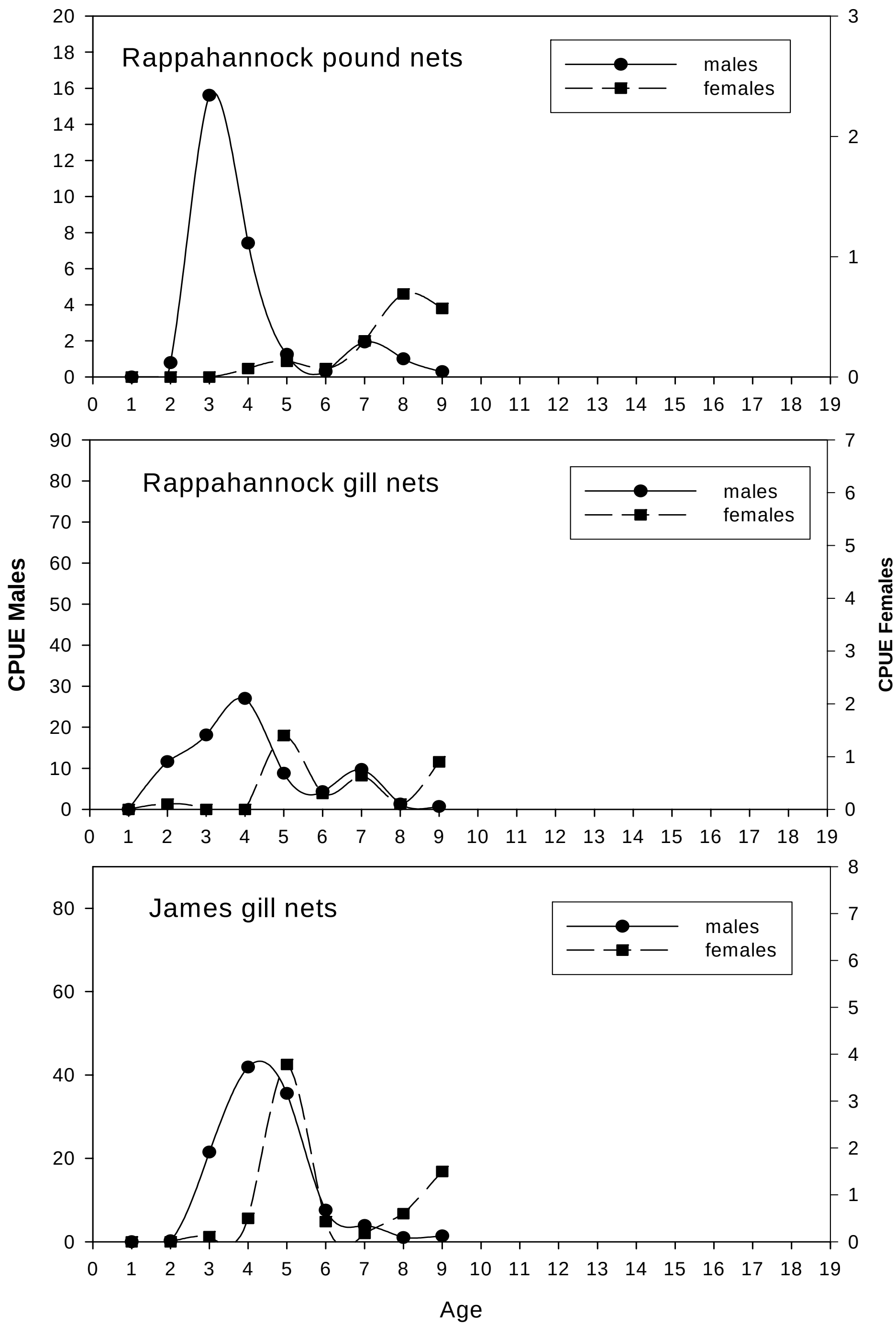


Figure 14. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1998 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1999-2006.

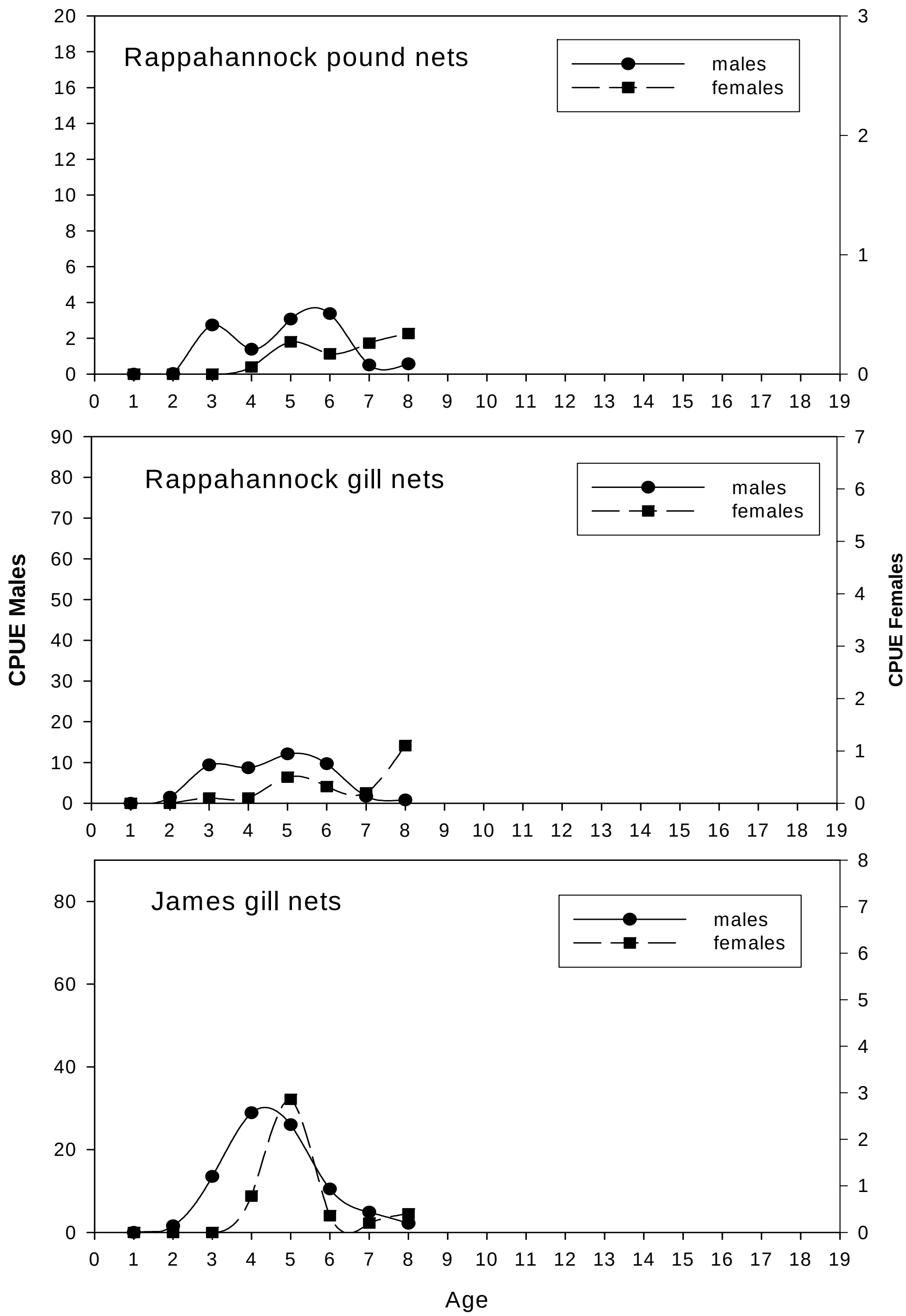
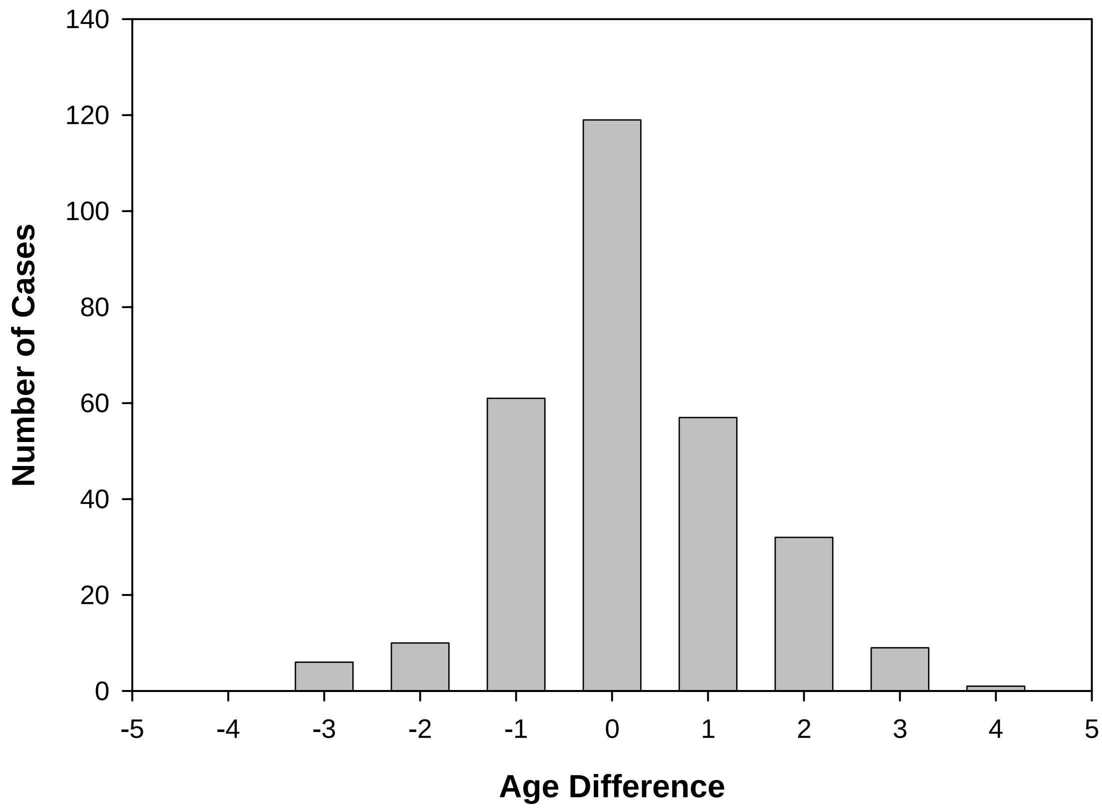


Figure 15. Magnitude of the age differences (otolith age – scale age) resulting from ageing specimens of striped bass (n=294) by reading both their scales and otoliths, spring, 2006.



II. Mortality estimates of striped bass (*Morone saxatilis*) that spawn in the Rappahannock River, Virginia, spring, 2005-2006

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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.

This section is an update to material provided by Sadler et al. (2001). They 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

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

where r_{ij} is the number of tags recovered in year *j* that were released in year *i* (note, $J \exists I$). 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 recovery data over time for each year's batch of tagged fish can be assumed 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

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

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 fishing and natural mortality, which are often of interest to fisheries managers. Estimates of S can be converted to the instantaneous total mortality rate via the equation (Ricker 1975)

$$Z = -\log_e(S) \qquad (3)$$

and, if information about the instantaneous natural mortality rate is available, estimates of the instantaneous fishing mortality 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

$$E(R) = \begin{bmatrix} N_1\phi\lambda u_1(F_1,M) & N_1\phi\lambda u_2(F_2,M)e^{-(F_1+M)} & \cdots & N_1\phi\lambda u_J(F_J,M)e^{-(\sum_{k=1}^{J-1} F_k+(J-1)M)} \\ - & N_2\phi\lambda u_2(F_2,M) & \cdots & N_2\phi\lambda u_J(F_J,M)e^{-(\sum_{k=2}^{J-1} F_k+(J-2)M)} \\ \vdots & \vdots & \ddots & \vdots \\ - & - & - & N_I\phi\lambda u_J(F_J,M) \end{bmatrix} \quad (4)$$

where ϕ is the probability of surviving being tagged and retaining the tag in the short-term, λ is the tag-reporting rate, and $u_k(F_k,M)$ is the exploitation rate in year k which, as mentioned above, depends on whether the fishery is Type I or Type II. For striped bass, a Type II (continuous) fishery is assumed. Note that ϕ and λ are considered constant over time.

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 $\varphi\lambda$. 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 handling mortality 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 (e.g., Beverton and Holt 1959; Pauly 1980; Hoenig 1983; Roff 1984; Gunderson and Dygert 1988), then these models can be used to estimate F and $\varphi\lambda$.

In either case, the auxiliary information needed (i.e., $\varphi\lambda$ or M) can often be difficult to obtain in practice, and since F, M and $\varphi\lambda$ are related functionally in the models, the reliability of the parameters being estimated is directly related to the accuracy of the estimated auxiliary parameter (Latour et al. 2001a).

Materials and Methods

Capture and Tagging Protocol

Each year from 1991 to 2006, 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.

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 pound net. 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: TheASFMC 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 1995-2005) 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, 1995-2004 and 2005).

S(p_3)r(p_1) Survival and tag-recovery rates vary over different regulatory periods (p_3 = constant 1990-1994, 1995-2003, 2004 and 2005).

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 1995-2005).

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 if tag recoveries for re-released fish are treated as if the fish were killed. 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 $Z = F + M$ and 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.

Estimates of Exploitation and Fishing mortality Rates

A refinement of the MARK protocol used a data matrix consisting of males only between 457 and 711 mm total length and their recaptures. This was used in conjunction with Maryland DNR to estimate the fishing mortality and exploitation rate for resident Chesapeake Bay striped bass. This protocol replaces the estimates made in previous years by a multiple tag-release and recapture protocol during summers and falls from 1995-2004 (Sharov and Jones 2003). Estimates of the exploitation rate (µ) are calculated by the recapture rate adjusted for the reporting rate:

$$\mu = R / (\lambda M)$$

where R is the number or recaptures, λ is the reporting rate (0.64) and M is the number of tagged striped bass released. The exploitation rate is then used to calculate the estimate of fishing mortality (F) by solving the following equation for *F*:

$$\mu = F / (F + M) * (1 - \exp(-M - F))$$

where natural mortality (M) is assumed to be 0.15. Other adjustments are made for tag-induced mortality (0.013) and hook-and-release mortality (0.08)

Results

Spring 2006 Tag Release summary

A total of 669 striped bass were tagged and released from the pound nets in the Rappahannock River between 27 March and 4 May, 2006 (Table 1). There were 494 resident striped bass (457-710 mm TL) tagged and released. These stripers were predominantly male (93.7%), but the female stripers were larger on average. The median date of these tag releases, to be used as the beginning of the 2005-2006 recapture interval, was 24 April. There were 175 migrant striped bass (>710 mm TL) tagged and released. These stripers were predominantly female (76.6%) and their average size was larger than for the male striped bass. The median date of these tag releases was 13 April.

Mortality Estimates, 2005-2006

Tag recapture summary: A total of 42 (out of 921) striped bass (>458 mm TL), tagged during spring 2005, were recaptured between 28 April, 2005, and 23 April, 2006 (the respective midpoints of the two tag release totals), and were used to estimate mortality. Twenty seven of these recaptures were harvested (64.3%) and the rest were re-released into the population (Table 2). The proportion of tagged striped bass recaptured from 1991-2006 in their first year after release varied from 0.055 (80/1,447) to 0.111 (162/1.464). Since 1997, the initial recapture rates have only varied from 0.055-0.077. In addition, 40 striped bass tagged in previous springs were recaptured during the 2005-2006 recovery interval and were used to complete the input data matrix. The largest source of recaptures (62.1%) in the 2005-2006 recovery interval was Chesapeake Bay (38.9% in Virginia, 23.2% in Maryland, Table 3). Other recaptures came from Massachusetts (16.8%), New Jersey (6.3%), Rhode Island, New York, Delaware and North Carolina (3.2 % each), Maine and Connecticut (1.1% each). The primary peak of recaptures was in April through August, but recaptures occurred in every month except February.

A total of 16 (out of 284) migratory striped bass (>710 mm total length), tagged during spring 2005, were recaptured between 28 April, 2005, and 12 April, 2006 (the 2005-2006 recovery interval) and were used to estimate the mortality of this sub-group. Twelve of these recaptures were harvested (75.0%), and the rest were re-released into the population (Table 4). The proportion of tagged striped bass recaptured from 1991-2006 in their first year after release varied from 0.015 (1/67) 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. The largest source (36.2%) of the recaptured tagged striped bass was Chesapeake Bay (34.0% in Virginia, 2.1% in Maryland, Table 5). Other recaptures came from Massachusetts (27.7%), Rhode Island, New York, New Jersey, Delaware and North Carolina (6.4%), Maine and Connecticut (2.1%). The peak month for recaptures was July, but some migrant striped bass were recaptured from every month except February and October.

ASMFC protocol: Survival estimates were made utilizing the mark-recapture data for the Rappahannock River from 1990-2005. 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 and the previous results over time had spikes in survival (S) that were not possible (i.e. > 1.0). The 2003 *F* estimate was high (0.62), but this was likely over-estimated due to linear monotonic trend models (Welsh personal comm.). In 2005, as in 2004, the S(t) R(t) was the only model to fit the data (Table 6). The 2005 *F* estimate was 0.20, the *S* estimate was 0.68, and none of the annual *S* estimates exceeded 1.0 (Table 7).

Survival estimates were obtained for striped bass greater than 710 mm (28") total length. Of the 13 proposed models, only two, the S(p_2)r(p_1) and the S(p_3)r(p_1) had ΔAICc values less than 7.0 (Table 8). A ΔAICc of 7.0 receives a weighting of 0.01 and is used as the threshold for inclusion in the analysis. In contrast, in the 2004 analysis, eight models fit this criterium. Models that reflected trends in the parameterizations tended to not fit the data well. The ranking of the models, except for the constant survival and reporting model, 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 0.606-0.785 over the time series (Table 9). The 2005 survival estimate was the highest in the time series. Otherwise, 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 0.062-0.335 and only infrequently, and by slight margins, exceeded the transitional and full fisheries target values.

Estimates of Exploitation and Fishing Mortality

There were 26 recaptures (of 597 tagged) of resident striped bass (males, 457-711 mm TL) recaptured within Chesapeake Bay between 28 April, 2005 and 23 April, 2006. An additional nine recaptures from striped bass tagged during springs 1990-2004 were recaptured. Twenty five of these recaptures were harvested (71.4%). These were input into the MARK input matrix (Table 10). The 13 MARK results of the 13 models gave 100% of the weight to the S(t)r(t) model (Table 11). This gave an estimate of F for 2005 of 0.2 (Table 12). These results were provided to Maryland DNR to compare with the estimates that resulted from their analysis.

In the Maryland model, the number of releases of males, 458-711 mm TL, during spring 2005 was 589 after adjusting for tag-induced mortality. The adjusted number of recreational recoveries within Chesapeake Bay was 32 (20 recaptures/0.64 reporting rate). This produced an exploitation rate (μ) of 0.054. This produced an estimate of fishing mortality (F) of 0.06 for Virginia and 0.14 for Chesapeake Bay (Virginia, Potomac River and Maryland combined). Non-harvest mortality is assumed to be 0.10 to produce a final F of 0.24.

Model Evaluations

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 “never 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. six 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 2005-2006 was 0.785. The survival estimate for 2005 is the highest in the time series and has incrementally increased every year since 1995. The estimate of fishing mortality for 2004-2005 was 0.062, the lowest in the time series. The estimates of fishing mortality from 1990-2004 varied from 0.115-0.335 and exceeded the ASMFC threshold of 0.30 only in 1996 and 1997. Prior to 2004, the models that assume constant survival and/or reporting rate and the models that partition the time series into two periods (1990-1994 and 1995-2004) were found to best fit the data and contributed most heavily to the analysis (0.62 in 2003). These are the models that use the fewest parameters to produce the estimates of survival and fishing mortality. However, in 2004 and 2005 the regulatory-based reporting rate models were the most heavily weighted.

Our analyses of the resident striped bass are problematic. The 2004-2005 estimates of survival (0.507) and fishing mortality (0.491) 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 (0.99996 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 of the trend model to the data in the original analysis, we have little confidence in the result. We intend to investigate the problems in the analyses and their causes 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, and they can be used to obtain estimates of current mortality rates. 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 (Sadler, et al. 2004).

The estimate of the exploitation rate for Chesapeake Bay in Virginia was 0.05 and the corresponding fishing mortality was 0.06. When combined with the Maryland and Potomac River data, the bay-wide value was 0.14. When non-harvest mortality is considered the estimate for 2005 is 0.24. This is below the target of 0.27 set by the ASMFC.

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Table 1. Summary data of striped bass tagged and released from pound nets in the Rappahannock River, spring 2006.

Date	total tagged	457 - 710 mm TL				> 710 mm TL			
		Males		females		males		females	
		n	$\overline{TL}$	n	$\overline{TL}$	n	$\overline{TL}$	n	$\overline{TL}$
27 March	121	78	530.1	13	639.5	8	801.8	22	861.4
3 April	62	33	512.4	8	555.6	7	822.6	14	873.5
6 April	24	11	542.6	1	587.0	1	838.0	11	910.2
10 April	39	30	508.8	0		1	913.0	8	913.6
13 April	74	42	514.2	2	532.5	5	813.0	25	919.4
17 April	21	6	498.5	1	541.0	0		14	893.5
20 April	12	6	507.7	1	564.0	2	832.5	3	945.7
24 April	176	147	502.6	0		9	806.6	20	900.1
27 April	56	50	512.0	1	584.0	1	845.0	4	904.5
1 May	76	60	507.1	4	545.3	7	819.9	5	930.6
4 May	8	0		0		0		8	884.3
Total	669	463	511.9	31	589.7	41	817.0	134	896.9

Table 2. Recapture matrix of striped bass (>457 mm TL) that were released in the Rappahannock River, springs 1990-2005. The second (bottom) number is the number of those recaptures that were harvested.

Year	n	recaptures															
		90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
1990	1,464	162 21	64 20	47 24	25 10	12 8	10 9	3 2	2 0	3 0	1 1	1 1	0	0	1 0	0	0
1991	2,481		167 48	81 38	53 22	29 14	6 3	5 1	2 2	2 1	4 4	1 0	0	0	1 1	0	0
1992	130			14 7	8 4	6 1	5 3	1 0	1 0	1 0	1 1	0	1 0	0	0	0	0
1993	621				50 18	37 17	17 12	8 5	9 4	2 1	0	1 0	0	0	0	0	0
1994	195					13 6	10 7	5 4	4 1	4 2	0	0	0	0	0	0	0
1995	698						55 24	30 12	20 9	5 4	4 1	2 1	3 2	0	1 1	0	1 0
1996	376							21 3	18 10	7 3	3 2	1 1	1 1	1 1	0	0	1 1
1997	712								47 26	26 17	14 10	3 2	0	1 1	2 1	1 1	0
1998	784									55 28	26 16	2 1	3 3	3 1	1 0	0	0
1999	853										66 30	23 7	9 4	5 2	3 2	0	0
2000	1,765											122 44	51 23	23 11	16 7	6 4	5 5
2001	797												61 32	23 14	16 5	7 7	2 1
2002	315													20 10	8 4	15 6	1 1
2003	852														58 32	37 20	9 5
2004	1,447															80 45	21 14
2005	669																42 27

Table 3. Location of striped bass (> 457 mm TL), recaptured in 2006, that were originally tagged and released in the Rappahannock River during springs 1988-2005 and used for mortality analysis.

State	Month												total
	J	F	M	A	M	J	J	A	S	O	N	D	
Maine	0	0	0	0	0	0	1	0	0	0	0	0	1
Massachusetts	0	0	0	0	1	4	7	3	1	0	0	0	16
Rhode Island	0	0	0	0	0	0	0	2	1	0	0	0	3
Connecticut	0	0	0	0	0	0	0	1	0	0	0	0	1
New York	0	0	0	0	0	1	1	0	1	0	0	0	3
New Jersey	0	0	0	0	1	1	0	0	0	0	1	3	6
Delaware	0	0	0	0	0	1	1	0	0	0	1	0	3
Maryland	0	0	0	0	3	3	8	4	3	1	0	0	22
Virginia	1	0	4	11	8	7	1	0	0	1	2	2	37
North Carolina	3	0	0	0	0	0	0	0	0	0	0	0	3
Total	4	0	4	11	13	17	19	10	6	2	4	5	95

Table 4. Recapture matrix of striped bass (>710 mm TL) that were released in the Rappahannock River, springs 1990-2005. The second (bottom) number is the number of those recaptures that were harvested.

Year	n	recaptures															
		90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
1990	301	26 10	9 2	15 6	2 1	4 3	6 5	1 1	0	2 0	1 1	1 1	0	0	1 1	0	0
1991	390		41 19	24 10	16 12	11 9	3 2	2 1	2 2	1 0	2 2	0	0	0	1 1	0	0
1992	40			4 2	3 1	2 1	2 1	0	0	0	1 1	0	0	0	0	0	0
1993	212				22 11	18 11	7 5	4 2	7 3	0	0	1 0	0	0	0	0	0
1994	123					9 4	7 4	5 4	1 1	2 0	0	0	0	0	0	0	0
1995	210						29 18	11 6	8 5	3 2	3 1	2 1	3 2	0	1 1	0	1 0
1996	67							1 0	3 3	1 1	0	0	1 1	0	0	0	0
1997	212								15 11	13 12	8 6	3 2	0	1 1	2 1	1 1	0
1998	158									24 16	13 9	2 1	3 3	2 1	0	0	0
1999	162										17 13	6 2	2 1	3 2	2 1	0	0
2000	365											28 13	19 11	14 6	9 5	4 3	3 3
2001	269												19 9	14 8	4 2	6 6	2 1
2002	122													10 7	6 3	7 5	1 1
2003	400														35 23	24 13	7 3
2004	686															39 21	12 8
2005	284																16 12

Table 5. Location of striped bass (> 710 mm TL), recaptured in 2006, that were originally tagged and released in the Rappahannock River during springs 1988-2005 and used for mortality analysis.

State	Month												total
	J	F	M	A	M	J	J	A	S	O	N	D	
Maine	0	0	0	0	0	0	1	0	0	0	0	0	1
Massachusetts	0	0	0	0	1	1	7	3	1	0	0	0	13
Rhode Island	0	0	0	0	0	0	0	2	1	0	0	0	3
Connecticut	0	0	0	0	0	0	0	1	0	0	0	0	1
New York	0	0	0	0	0	1	1	0	1	0	0	0	3
New Jersey	0	0	0	0	1	1	0	0	0	0	1	0	3
Delaware	0	0	0	0	0	1	1	0	0	0	1	0	3
Maryland	0	0	0	0	0	0	0	0	1	0	0	0	1
Virginia	1	0	2	7	1	2	0	0	0	0	1	2	16
North Carolina	3	0	0	0	0	0	0	0	0	0	0	0	3
Total	4	0	2	7	3	6	10	6	4	0	3	2	47

Table 6. Performance statistics (>457 mm TL), based on quasi-likelihood Akaike Information Criterions (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 1995-2005 (p_1); parameters vary in 2005 (p_2), otherwise the same as p_1 ; parameters vary in 2004 and 2005 (p_3), otherwise the same as p_1 ; parameters constant from 1990-1992, 1993-1994 and 1995-2005 (p_4); assumption of linear trends from 1990-1994 and 1995-2005 (Tp_1); and parameters are time-specific (t).

Model	$QAIC_c$	$\Delta QAIC_c$	$QAIC_c$ weight	number of parameters
S(t)r(t)	9550.62	0.00	0.99577	31
S(p_2)r(p_1)	9562.43	11.81	0.00271	6
S(p_3)r(p_1)	9563.89	13.27	0.00131	7
S(.)r(t)	9569.18	18.56	0.00009	17
S(p_1)r(t)	9570.07	19.45	0.00006	19
S(.)r(p_1)	9571.62	21.01	0.00003	4
S(p_1)r(p_1)	9572.14	21.52	0.00002	6
S(t)r(p_1)	9573.59	22.97	0.00001	19
S(p_4)r(p_4)	9579.06	28.46	0.00000	6
S(.)r(.)	9608.77	58.15	0.00000	2
S(Tp_1)r(t)	10659.01	1108.40	0.00000	16
S(Tp_1)r(Tp_1)	10665.69	1115.08	0.00000	6
S(Tp_1)r(p_1)	10665.69	1115.08	0.00000	6

Table 7. 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 TL) derived from the proportion of recaptures released alive (P_l) in the Rappahannock River, 1990-2005.

Year	$\hat{S}$	SE ($\hat{S}$)	P_l	bias	$\hat{S}_{adj}$	$\hat{F}$	95%CI $\hat{F}$
1990	0.815	0.094	0.481	-0.143	0.952	-0.101	-0.24, 0.27
1991	0.277	0.056	0.524	-0.082	0.301	1.051	0.68, 1.47
1992	0.803	0.177	0.408	-0.142	0.938	-0.084	-0.28, 0.86
1993	0.604	0.141	0.456	-0.105	0.673	0.243	-0.07, 0.86
1994	0.568	0.136	0.381	-0.087	0.624	0.316	-0.01, 0.94
1995	0.683	0.146	0.262	-0.054	0.724	0.177	-0.09, 0.80
1996	0.639	0.143	0.274	-0.039	0.668	0.263	-0.04, 0.88
1997	0.566	0.115	0.330	-0.058	0.595	0.363	0.06, 0.86
1998	0.414	0.085	0.362	-0.060	0.438	0.674	0.33, 1.13
1999	0.371	0.071	0.286	-0.060	0.393	0.776	0.45, 1.19
2000	0.436	0.071	0.436	-0.074	0.466	0.602	0.32, 0.96
2001	0.474	0.110	0.367	-0.069	0.508	0.533	0.16, 1.07
2002	0.614	0.147	0.368	-0.064	0.652	0.279	-0.04, 0.92
2003	0.789	0.162	0.271	-0.048	0.827	0.044	-0.16, 0.83
2004	0.323	0.096	0.281	-0.042	0.343	0.927	0.44, 1.60
2005	0.679	0.058	0.280	-0.034	0.697	0.202	0.07, 0.40

Table 8. Performance statistics (>710 mm TL), based on quasi-likelihood Akaike Information Criterions (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 1995-2005 (p_1); parameters vary in 2005 (p_2), otherwise the same as p_1; parameters vary in 2004 and 2005 (p_3), otherwise the same as p_1; parameters constant from 1990-1992, 1993-1994 and 1995-2005 (p_4); assumption of linear trends from 1990-1994 and 1995-2005 (Tp_1); and parameters are time-specific (t).

Model	$QAIC_c$	$\Delta QAIC_c$	$QAIC_c$ **weight**	**number of parameters**
S(p_2)r(p_1)	4651.19	0.00	0.70426	6
S(p_3)r(p_1)	4653.07	1.87	0.27520	7
S(.)r(p_1)	4658.85	7.66	0.01532	4
S(p_1)r(p_1)	4662.05	10.86	0.00308	6
S(.)r(t)	4663.46	12.27	0.00152	17
S(p_1)r(t)	4666.08	14.89	0.00041	19
S(t)r(p_1)	4668.49	17.28	0.00012	19
S(t)r(t)	4670.00	18.81	0.00006	31
S(p_4)r(p_4)	4672.79	21.60	0.00001	6
S(.)r(.)	4675.32	24.13	0.00000	2
S(Tp_1)r(p_1)	4943.58	292.39	0.00000	6
S(Tp_1)r(Tp_1)	4943.58	292.39	0.00000	6
S(Tp_1)r(t)	4946.42	295.23	0.00000	16

Table 9. 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 (> 710 mm TL) derived from the proportion of recaptures released alive (P_l) in the Rappahannock River, 1990-2005.

Year	$\hat{S}$	SE ($\hat{S}$)	P_l	bias	$\hat{S}_{adj}$	$\hat{F}$	95%CI
1990	0.626	0.026	0.577	-0.127	0.724	0.179	0.10, 0.27
1991	0.627	0.026	0.560	-0.131	0.720	0.176	0.10, 0.27
1992	0.627	0.026	0.535	-0.172	0.763	0.125	0.05, 0.22
1993	0.627	0.026	0.349	-0.093	0.694	0.221	0.14, 0.31
1994	0.627	0.026	0.318	-0.070	0.673	0.240	0.17, 0.33
1995	0.619	0.021	0.204	-0.078	0.671	0.252	0.18, 0.32
1996	0.619	0.021	0.125	-0.016	0.626	0.312	0.25, 0.39
1997	0.619	0.021	0.167	-0.037	0.636	0.294	0.23, 0.36
1998	0.619	0.021	0.217	-0.086	0.678	0.243	0.18, 0.31
1999	0.619	0.021	0.200	-0.057	0.658	0.274	0.21, 0.34
2000	0.619	0.021	0.348	-0.072	0.668	0.255	0.19, 0.33
2001	0.619	0.021	0.298	-0.052	0.651	0.277	0.21, 0.35
2002	0.619	0.021	0.295	-0.077	0.666	0.246	0.19, 0.32
2003	0.619	0.021	0.246	-0.057	0.658	0.268	0.21, 0.34
2004	0.624	0.031	0.321	-0.057	0.656	0.266	0.18, 0.38
2005	0.785	0.045	0.238	-0.043	0.810	0.062	-0.03, 0.19

Table 10. Recapture matrix of male striped bass (457-710 mm TL) that were released in the Rappahannock River, springs 1990-2005. The second (bottom) number is the number of those recaptures that were harvested.

Year	n	recaptures															
		90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
1990	189	20 11	7 4	2 1	1 0	0	0	0	0	0	0	0	0	0	0	0	0
1991	107		18 8	6 6	2 0	1 0	1 0	0	0	0	0	0	0	0	0	0	0
1992	31			4 3	0	2 1	1 0	0	0	0	0	0	0	0	0	0	0
1993	166				12 6	8 4	3 3	1 1	1 1	1 0	0	0	0	0	0	0	0
1994	38					1 0	3 3	0	0	0	0	0	0	0	0	0	0
1995	361						37 10	10 9	10 6	2 2	0	0	0	0	0	0	0
1996	258							20 13	12 6	4 3	3 3	0	0	0	0	0	0
1997	458								27 16	9 6	4 3	0	0	0	0	0	0
1998	601									26 13	12 8	0	0	1 0	1 0	0	0
1999	666										48 32	15 6	6 5	2 1	1 1	0	0
2000	1,352											113 73	30 15	7 6	7 6	1 1	1 1
2001	496												50 35	8 6	9 3	0	0
2002	189													12 3	2 1	7 6	0
2003	443														24 18	11 9	2 2
2004	757															38 28	6 5
2005	597																26 17

Table 11. Performance statistics (males 457-710 mm TL), based on quasi-likelihood Akaike Information Criterions (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 1995-2005 (p_1); parameters vary in 2005 (p_2), otherwise the same as p_1; parameters vary in 2004 and 2005 (p_3), otherwise the same as p_1; parameters constant from 1990-1992, 1993-1994 and 1995-2005 (p_4); assumption of linear trends from 1990-1994 and 1995-2005 (Tp_1); and parameters are time-specific (t).

Model	$QAIC_c$	$\Delta QAIC_c$	$QAIC_c$ **weight**	**number of parameters**
S(t)r(t)	9288.06	0.00	1.00000	31
S(t)r(p_1 **)**	9339.24	51.18	0.00000	19
S(p_1 **)r(t)**	9344.51	56.45	0.00000	19
S(.)r(t)	9346.04	57.98	0.00000	17
S(p_2 **)r(** p_1 **)**	9363.42	75.36	0.00000	6
S(p_3 **)r(** p_1 **)**	9364.70	76.64	0.00000	7
S(p_4 **)r(** p_4 **)**	9377.88	89.82	0.00000	6
S(p_1 **)r(** p_1 **)**	9388.23	100.73	0.00000	6
S(.)r(p_1 **)**	9395.28	107.22	0.00000	4
S(.)r(.)	9428.56	140.50	0.00000	2
S(Tp_1 **)r(**t**)**	10620.96	1332.90	0.00000	16
S(Tp_1 **)r(** p_1 **)**	10665.90	1377.84	0.00000	6
S(Tp_1 **)r(** Tp_1 **)**	10665.90	1377.84	0.00000	6

Table 12. 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 (males 457-710 mm TL) derived from the proportion of recaptures released alive (P_l) in the Rappahannock River, 1990-2005.

Year	$\hat{S}$	**SE (** $\hat{S}$ **)**	P_l	**bias**	$\hat{S}_{adj}$	$\hat{F}$	**95%CI** $\hat{F}$
1990	0.222	0.058	0.481	-0.143	0.952	-0.101	-0.24, 0.27
1991	0.277	0.056	0.524	-0.082	0.301	1.051	0.68, 1.47
1992	0.803	0.177	0.408	-0.142	0.938	-0.084	-0.28, 0.86
1993	0.604	0.141	0.456	-0.105	0.673	0.243	-0.07, 0.86
1994	0.568	0.136	0.381	-0.087	0.624	0.316	-0.01, 0.94
1995	0.683	0.146	0.262	-0.054	0.724	0.177	-0.09, 0.80
1996	0.639	0.143	0.274	-0.039	0.668	0.263	-0.04, 0.88
1997	0.566	0.115	0.330	-0.058	0.595	0.363	0.06, 0.86
1998	0.414	0.085	0.362	-0.060	0.438	0.674	0.33, 1.13
1999	0.371	0.071	0.286	-0.060	0.393	0.776	0.45, 1.19
2000	0.436	0.071	0.436	-0.074	0.466	0.602	0.32, 0.96
2001	0.474	0.110	0.367	-0.069	0.508	0.533	0.16, 1.07
2002	0.614	0.147	0.368	-0.064	0.652	0.279	-0.04, 0.92
2003	0.789	0.162	0.271	-0.048	0.827	0.044	-0.16, 0.83
2004	0.323	0.096	0.281	-0.042	0.343	0.927	0.44, 1.60
2005	0.679	0.058	0.280	-0.034	0.697	0.202	0.07, 0.40

III. The role of Mycobacteriosis in elevated Natural Mortality of Chesapeake Bay striped bass: disease progression and developing better models for stock assessment and management.

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Introduction

During the late 1990s concern emerged among recreational and commercial fishermen about perceived declining condition in striped bass (*Morone saxatilis*). Emaciation and ulcerative skin lesions were commonly reported and associated with a bacterial disease called mycobacteriosis. The disease is now epizootic throughout the Bay with more than 70% of striped bass in some tributaries affected. Several hypotheses have been presented to explain this emerging problem. These include stress associated with loss of food forage base due to recent declines in menhaden stocks (starvation), overcrowding, and loss of summer thermal refuges as a result of hypoxia and high temperature. Recent tag-recapture analyses indicate that striped bass survival has declined significantly (~20%) over the last 10 to 15 years. This troubling decline is attributable to an increase in natural mortality and corresponds roughly with the Bay-wide outbreak of mycobacteriosis in striped bass. Current fishery management strategies do not account for changes in natural mortality over time, especially during infectious disease epizootics. Thus, the overall aim of the current study is to determine the contribution of mycobacteriosis to natural mortality in the striped bass, and thus the potential for adverse impacts by the disease on the stock.

Mycobacteriosis in fish is a chronic disease caused by various species of bacteria in the genus *Mycobacterium*. Mycobacterial disease occurs in a wide range of species of fish worldwide and is an important problem in aquacultural operations. The disease appears as grey granulomatous nodules in internal organs, especially the spleen and kidney (Figure 1b), and can also manifest itself as ulcerous skin lesions (Figure 1a). Fish with ulcerous dermal lesions in the wild sometimes have an extremely emaciated appearance.

Mycobacteriosis was first reported from Chesapeake Bay striped bass in 1997 (Vogelbein et al. 1999; Rhodes et al. 2002, 2003, 2004). Since then, the disease has spread throughout the Bay and the prevalence has risen to as high as 70 – 80% (Cardinal 2001; Vogelbein et al. 1999; this project, unpublished observations). Several species of *Mycobacterium* have been isolated from Chesapeake Bay striped bass, including several new species, but it is not yet clear which species are involved in disease processes. Indeed, there may be more than one pathogenic species.

Mycobacteria are slow-growing, aerobic bacteria common in terrestrial and aquatic habitats. Most are saprophytes, but certain species infect both endo- and poikilothermic animals. Mycobacterial infections are common in wild and captive fish stocks world-wide. Mycobacteriosis in fishes is a chronic, systemic disease that can result in degradation of body condition and ultimately in death (Colorni 1992). Clinical signs are nonspecific and may include scale loss, skin ulceration, emaciation, exophthalmia, pigmentation changes and spinal defects (Nigrelli & Vogel 1963; Bruno et al. 1998). Granulomatous inflammation, a host cellular response comprised largely of phagocytic cells of the immune system called macrophages, is a characteristic of the disease. In an attempt to sequester, kill and degrade mycobacteria, these macrophages encapsulate bacteria, forming nodular structures called granulomas. Skin ulceration in most fishes is uncommon and usually represents the endstage of the disease process, as captive fish with skin lesions generally do not recover and die quickly. Hence, the presence of skin lesions is particularly alarming, as it may indicate that the fish are progressing from chronic, covert infection to active, lethal disease.

The impact of the disease on the population ecology of striped bass is poorly understood. Fundamental questions, such as mode of transmission, duration of disease stages, effects of disease on fish movements, feeding and reproduction, and mortality rates associated with disease, remain unanswered. Nonetheless, there are indications the disease may be having a significant impact on Chesapeake striped bass populations. Jiang et al. (in press) analyzed striped bass tagging data from Maryland and found a significant increase in natural mortality rate at about the time when mycobacteriosis was first being detected in Chesapeake Bay striped bass. A similar analysis of Rappahannock River, Virginia, striped bass tagging data from this project also reveals an increase in natural mortality rate in recent years (see Table 1): natural mortality rate for fish age 2 and above was estimated to increase from $M = .231$ during the period 1990 – 1996 to $M=.407$ during the period 1997-2004. In addition, R. Latour and D. Gauthier (VIMS, pers. com.) used force-of-infection models to examine the epizootiology of mycobacteriosis in Chesapeake Bay striped bass between 2003-2005. The results of this analysis indicated that the probability a disease negative fish becomes disease positive depends on age; the inclusion of sex and season as covariates significantly improved model fit; and that there is evidence of disease associated mortality.

Mycobacteriosis in fishes is generally thought to be fatal, but this has not been established for wild striped bass. Three possible distinct disease outcomes in the case of striped bass are: 1) death, 2) recovery or reversion to a non-disease state, or 3) movement of infected fish to another location. Because of the uncertainty about the fate of the infected fish, the impact of the disease on striped bass populations is unknown. If mycobacteriosis in striped bass is ultimately fatal, the potential for significant impacts on the productivity and the quality of the Atlantic coastal migratory stock is high. Researchers, fisheries managers and commercial and recreational fishermen are therefore becoming gravely concerned. At a recent symposium entitled "*Management Issues of the Restored Stock of Striped Bass in the Chesapeake Bay: Diseases, Nutrition, Forage Base and Survival*", Kahn (2004) reported that both Maryland and Virginia striped bass tag-recaptures have declined in recent years. This suggests that survival has declined significantly, from 60-70% in the early-mid 1990's to 40-50% during the late 1990's and early 2000's. Kahn (2004) and Crecco (2003) both concluded that the 20% decline in striped bass survival was not caused by fishing mortality, but rather, by an increase in natural mortality. These analyses, however, are predicated on the assumption that tag reporting rate has not changed over time. No data are currently available to evaluate this assumption. Hypotheses presented at the Symposium to explain the decline in striped bass survival included the possible role of mycobacteriosis (May et al., 2004; Vogelbein et al., 2004). However, Jacobs et al. (2004) found that decline in striped bass nutritional status during the fall was independent of disease. Uphoff (2004) reported that abundance of forage-sized menhaden, a primary food source of striped bass, declined to near historic lows during the mid 1990's. Similar studies indicated that as the striped bass population has increased during the 1990's, predatory demand increased coincident with a decline in menhaden populations (Hartman, 2004; Garrison et al., 2004).

Striped bass are presently managed by attempting to control fishing mortality. Fishing mortality is determined in three ways, and each method uses a value for natural mortality rate based on the assumption that natural mortality does not change over time. (This is done because of the difficulty in estimating natural mortality rate). If natural mortality has increased over time, and if these increases have not been quantified, then estimates of fishing mortality will be too high (when they are obtained from a Virtual Population Analysis or from a Brownie-type tagging model). Thus, there is the real potential of restricting the fishery because the fishing mortality appears too high when the actual situation is that the natural mortality has risen. This is not just of theoretical concern – for the last several years the Atlantic States Marine Fisheries Commission's Striped Bass Technical Committee and Subcommittees have struggled with the problem that the total mortality rate appears to have gone up despite the fact that the fishing regulations have been stable. But information on whether diseases may be elevating the natural mortality rate is scarce and largely circumstantial (indirect) or anecdotal. To date, no one has quantified the effects of the disease on striped bass survival rate. Indeed, to our knowledge, quantitative estimates of infectious disease impacts on population dynamics have not been incorporated in the management plan of any marine finfish species.

Materials and Methods

Capture and Tagging Protocol

Striped bass for tagging were obtained from two pound nets in the upper Rappahannock River (river miles 45 and 46) and from five pound nets in the lower Rappahannock River (river miles 0-3). The pound net is a fixed trap that is presumed to be non-size selective in its catch of striped bass, and has been historically used by commercial fishermen in the Rappahannock River.

All captured striped bass were removed from each pound net and placed into a floating holding pocket (1.2m x 2.4m x 1.2m deep, with 25.4mm mesh and a capacity of approximately 200 fish) anchored adjacent to the pound net. 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. These tags are identical to the tags issued by the U. S. Fish and Wildlife Service except that they are lime green in color and have REWARD and a VIMS phone number imprinted into them. The rewards offered were $5 for recapture information and $20 for donating the entire specimen, on ice, to VIMS personnel.

Mycobacteriosis Assessment

Each tagged striped bass is given a complete external disease assessment and is photographed with a digital Cannon 30 camera. Overview and close-up photos are made for each side to document the initial assessment and to provide a basis for comparison when project personnel obtain recaptured striped bass. We identify 4 discrete lesion categories:

SD: Scale Damage: Includes one or more of the following features. (Fig. 2a)

- Loss of a single or multiple adjacent scales without significant erosion of underlying tissue. Hemorrhage or discoloration may be apparent
- Hemorrhagic foci underlying intact, scaled skin
- Scales which are present, but appear incomplete or eroded along a margin. Hemorrhage present or absent.

PF: Pigmented focus: ~1mm^2 pale to dark brown focus (Fig. 2b)

U: Ulceration: Loss of multiple adjacent scales with erosion/excavation of underlying tissue. Hemorrhage present or absent. Pigmentation present or absent. (Fig. 2c,d)

- scale damage or extensive loss
- range of severity: single small ulcers to multi-focal, coalescing ulcers occupying large portions of the body.

H: Putative Healing: Hyper-pigmented, (may not be apparent in ventral lesions). Scales present, but incomplete or abnormally organized. (Fig. 2e)

Within the categories U and PF we assign a severity number from 1 to 3 (PF) or 4 (U) according to the number of pigmented foci or the number and/or size of lesions.

A skin pathology diagnostic allows distinction between diseased and healthy fish in the context of the tagging program. By this approach, the impacts of the disease will be evaluated through differential tag return rates. Survival rates of fish with pathognomonic skin pathology will be compared to survival rates of fish without skin pathology. In addition, survival rates of fish with visceral lesions (as predicted by the diagnostic) will be compared to survival rates of fish without visceral lesions. This will provide better estimates of components of natural mortality (M) and provide inputs for future multi-species modeling efforts.

Analytical Approach:

If mycobacteriosis has no impact on the fate of fish, and if tag return rate is not affected by the presence of lesions, then we would expect to recover equal proportions of tags from fish with and without external lesions. In contrast, if externally ulcerous fish have higher mortality, we might expect to see a lower tag return rate in this group. (We discuss the necessary assumptions below.) Thus, we may estimate the impact of the lesions in terms of the relative survival (or relative risk) or in terms of the odds ratio. The results of the tagging experiment can be displayed in a 2x2 contingency table, as follows:

	recovered	not recovered
lesions	*a*	*b*
no lesions	*c*	*d*

The relative survival (with lesions : without lesions) is computed as

$$relative\ survival = \frac{a/(a+b)}{c/(c+d)} = \frac{a(c+d)}{c(a+b)}$$

Thus, if 8% of the tags are recovered from fish with lesions while 16% are recovered from fish without external lesions, the relative survival is 0.5, i.e., fish with external lesions survive half as well as fish without. The odds ratio is computed as

$$odds\ ratio = ad/(bc)$$

(see, e.g., Rosner 1990). The odds of obtaining a tag return from a fish with lesions is a/b; the odds ratio is simply the ratio of the odds for the two groups (fish with and without external lesions). Thus, odds ratio = $(a/b)/(c/d) = ad/bc$. The odds ratio can take on values between 0 and infinity. In the above example, the odds ratio would be 0.46. A value less than one indicates that fish with lesions have lower survival than fish without lesions. It is of interest to examine whether the ratio of survival changes over time. If the ratio of survival is constant over time, then a plot of log(ratio of recaptures) will be a linear function of time at liberty with slope equal to the difference in instantaneous mortality rates (i.e., exp(slope) estimates the ratio of survival rates). Note, that for this analysis to be valid, it is necessary to assume that the *ratio* of tag reporting rates for the two groups remains constant over time but *not* that the reporting rates for the two groups are equal nor that the rates are unchanging. Departures from a linear relationship indicate that the ratio of survival rates or the ratio of reporting rates is changing over time (or both are changing). This model is a logistic model; consequently, standard methods are available for fitting and examining the model (see, e.g., Hoenig et al. 1990).

These analyses can be further refined by sub-dividing the group that has external lesions into categories that reflect the relative progression in severity (infection index). These categories are:

Clean:	no external sign of infection.
Light:	PF1 and/or U1 on at least one side
Moderate:	PF2 and/or U2 on at least one side
Heavy:	PF3 and/or U3 or 4 on at least one side
Other:	all SD and or H, but without any PF or U

Relative return rates and spatial differentiation refine our knowledge of the effects of the disease on striped bass stocks. Comparison of the disease index (and accompanying photos) with the infection index of recaptures returned to VIMS provides a measure of disease progression (or remission) of these striped bass.

In subsequent reports, because tagged fish will be released at two times (one year apart), it will also be possible to fit Brownie tagging models (Brownie et al. 1985) or instantaneous rates models (Hoenig et al. 1998a,b) to the data. These models allow one to estimate annual survival rate. Thus, one can compare the survival of fish tagged with and without external signs of mycobacteriosis. Two assumptions of the model are worth noting. First, tag reporting rate need not be 100%, need not be known, and need not be constant over time. However, previously tagged and newly tagged fish are assumed to have the same reporting rate. This assumption may be violated if, for example, disease severity increases in a tagged cohort over time. In this case previously tagged fish may look less appealing than newly tagged fish, thus affecting reporting rate differentially. Second, the Brownie models are based on the assumption that the population is homogeneous, i.e., that all animals have the same probability of survival. To the extent that survival is a function of the severity of the disease, there may be some heterogeneity within the defined categories of those with and without external signs of disease. Biases that may arise due to failures of these assumptions will be studied by sensitivity analysis. Information on disease progression from the holding studies and from examination of recaptured fish from the pound nets, and information on disease prevalence from periodic examination of samples from the pound net, will be used to guide the sensitivity analyses.

There are other potential problems to this analysis. If ulcerous fish exhibit different movement patterns than fish that do not have the skin disease, this could influence disease dynamics. This will be tested by gathering information on the location of recaptures and evaluating the spatial distribution of recaptures for the two groups of fish.

Results

Tag Release Summary

Fall 2005: A total of 1,816 striped bass were tagged, assessed for external disease indications, photographed and released from two pound nets in the upper Rappahannock (n = 250) and five pound nets in the lower Rappahannock (n = 1,566) River during fall, 2005 (Table 2). Only 22.5% (409/1816) of the total that were tagged were without any external sign of mycobacteriosis. The lightly-infected group (41.8%) had the highest prevalence, while 11.6% were heavily infected. The striped bass tagged upriver had a slightly lower prevalence of infected striped bass (74.8% vs. 77.9%).

Spring 2006: A total of 570 striped bass were tagged, assessed, photographed and released from the pound net in the upper (n = 68) and lower (n = 502) Rappahannock River during late spring, 2006 (Table 3). Although greater than for the fall releases, only 31.8% (181/570) of the total that were tagged were without any external sign of mycobacteriosis. The lightly-infected group was again prevalent (46.1%), while 6.3% were heavily infected. The prevalence of clean striped bass was nearly equal between the upriver and downriver, however, heavily-infected striped bass were only encountered at the downriver nets.

Tag Recapture Summary

Fall 2005 releases: A total of 150 striped bass tagged during fall 2005 were recaptured prior to 20 September, 2006 (Table 4). Most (65.3%) of these stripers were recaptured within 7 days of release, usually from the same or nearby pound net from which they were released. These recaptured stripers had a somewhat different disease index distribution than did the releases. While 22.5% of the releases were clean, only 18.4% of the immediate recaptures were. Also, 11.6% of the releases were heavily infected while 21.4% of the immediate recaptures were. By the end of summer, 2006, 16.0% of the recaptures were clean while 17.3% were assessed as heavy. Overall, 8.2% of the striped bass tagged from the lower Rappahannock River pound nets and 8.8% of the striped bass tagged from the upper Rappahannock River pound nets were recaptured by the end of summer, 2006. Striped bass tagged from the lower Rappahannock River pound nets were recaptured throughout both the Virginia and Maryland portions of the Chesapeake Bay (Table 5), while the striped bass tagged from the upper Rappahannock River pound nets (much fewer in number) were recaptured only within the Virginia portion of Chesapeake Bay.

Spring 2006 releases: A total of 65 striped bass tagged and released during spring 2006 were recaptured prior to 20 September 2006 (Table 6). The incidence of immediate recapture (47.7%), although lower than for the fall 2005 releases, was still the largest category of temporal recapture. Although 31.8% of the spring releases were assessed as clean, only 16.1% on the immediate recaptures were. However, 6.3% of the spring releases were heavily infected and 6.5% of the immediate recaptures were. By 20 September, 24.6% of the recaptures were clean and 6.2% of the recaptures were heavily infected. Recaptures of striped bass released from the lower Rappahannock River pound nets occurred in all sections of Chesapeake Bay (Virginia and Maryland, Table 7). Interestingly, there were more recaptures from Maryland waters than from within Virginia (excluding the immediate release area).

Discussion

The results so far establish some important points. First, we are obtaining excellent cooperation from commercial and sport fishers so that our rate of return of tags, and of tagged carcasses, is encouraging. Second, if diseased fish are less able to withstand the stress of capture and tagging than lightly diseased or non-diseased fish, then we could have an artifact of tagging whereby an appreciable fraction of the diseased fish experience an abnormal mortality associated with the tagging process. The fact that we did not obtain more tag returns from fish without signs of disease than from diseased fish indicates that this is not a problem. In fact, we obtained slightly higher tag return rates from diseased fish than from fish without signs of disease. Third, it is possible that diseased fish may differ in their ability to swim and migrate from fish without signs of the disease. Thus, it will be necessary to investigate the spatial pattern of the tag returns by disease category. Fortunately, we are able to obtain detailed recapture locations from almost all fish.

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Table 1. Parameter estimates and standard errors (SE) from fitting two models to the Virginia striped bass spring tagging data (age 2 and greater). In model (a), estimates are obtained for year-specific fishing mortality rates for killed fish in year xx, Fk(xx), for fishing mortality associated with released fish experiencing hooking mortality, Fr(xx), and for natural mortality rate in two time periods (1990-1996 and 1997-2004). In model (b), the same parameters are estimated but, in addition, the tag reporting rates for kept (lambdaK) and released (lambdaR) fish are estimated instead of being fixed at 0.43.

	(a)		(b)	
parameter	estimate	SE	estimate	SE
Fk(90)	0.122	0.023	0.182	0.057
Fk(91)	0.165	0.021	0.259	0.067
Fk(92)	0.236	0.032	0.360	0.091
Fk(93)	0.227	0.032	0.347	0.086
Fk(94)	0.263	0.043	0.428	0.107
Fk(95)	0.274	0.042	0.469	0.116
Fk(96)	0.195	0.035	0.416	0.111
Fk(97)	0.199	0.039	0.370	0.105
Fk(98)	0.306	0.058	0.645	0.179
Fk(99)	0.240	0.034	0.578	0.163
Fk(00)	0.114	0.023	0.196	0.065
Fk(01)	0.111	0.024	0.145	0.047
Fk(02)	0.252	0.057	0.286	0.084
Fr(90)	0.135	0.025	0.159	0.145
Fr(91)	0.153	0.020	0.184	0.164
Fr(92)	0.166	0.027	0.193	0.172
Fr(93)	0.209	0.031	0.241	0.218
Fr(94)	0.199	0.037	0.246	0.237
Fr(95)	0.073	0.020	0.097	0.095
Fr(96)	0.083	0.022	0.127	0.117
Fr(97)	0.101	0.027	0.137	0.125
Fr(98)	0.076	0.027	0.113	0.106
Fr(99)	0.103	0.022	0.165	0.153
Fr(00)	0.055	0.016	0.076	0.073
Fr(01)	0.064	0.018	0.069	0.065
Fr(02)	0.114	0.035	0.107	0.098
Fk(03)	0.427	0.140	0.362	0.129
Fr(03)	0.242	0.088	0.168	0.164
Fk(04)	0.924	0.556	0.684	0.329
Fr(04)	0.449	0.276	0.245	0.280
M90-96	0.231	0.019	0.083	0.177
M97-04	0.407	0.037	0.168	0.125
lambdaK	0.430	0.000	0.250	0.057
lambdaR	0.430	0.000	0.347	0.312

Table 2. Tag release totals and mycobacteria infection index, by date, of striped bass in the upper and lower Rappahannock River sites, fall, 2005.

Date	release area	n	infection index				
			clean	light	moderate	heavy	other
26 September	upper	66	13	22	22	7	2
29 September	upper	59	15	28	8	4	4
3 October	upper	4	0	0	0	0	4
5 October	lower	116	13	32	37	29	5
6 October	upper	17	2	7	7	1	0
10 October	upper	25	4	15	3	3	0
12 October	lower	168	26	63	43	28	8
13 October	upper	7	1	4	1	1	0
19 October	lower	168	1	95	60	3	9
20 October	upper	4	1	3	0	0	0
24 October	upper	26	13	9	1	2	1
26 October	lower	348	62	168	80	22	16
27 October	upper	22	5	9	3	4	1
31 October	upper	14	5	7	2	0	0
2 November	lower	289	78	115	26	49	21
3 November	upper	6	4	1	0	1	0
9 November	lower	250	96	84	36	29	5
16 November	lower	215	70	92	31	22	0
30 November	lower	12	0	5	2	5	0
totals	upper	250	63	105	47	23	12
	lower	1566	346	654	315	187	64
	both	1816	409	759	362	210	76

Table 3. Tag release totals and mycobacteria infection index, by date, of striped bass in the upper and lower Rappahannock River sites, spring, 2006.

Date	release area	n	infection index				
			clean	light	moderate	heavy	other
3 May	lower	139	57	54	12	12	4
4 May	upper	68	21	32	9	0	6
5 May	lower	100	40	46	8	4	2
9 May	lower	138	22	81	20	13	2
12 May	lower	72	22	27	15	6	2
19 May	lower	53	19	23	8	2	1
totals	upper	68	21	32	9	0	6
	lower	502	160	231	63	37	11
	both	570	181	263	72	37	17

Table 4. Seasonal recapture summary, by mycobacteria infection index and release area, of striped bass tagged and released in the upper and lower Rappahannock River sites during fall, 2005.

Date	release area	n	infection index				
			clean	light	moderate	heavy	other
0-7 days	upper	7	1	5	0	1	0
	lower	87	14	36	18	17	2
Fall 2005 (>7days)	upper	8	1	3	2	2	0
	lower	16	2	6	4	4	0
Winter 2006	upper	3	0	2	0	1	0
	lower	3	0	1	1	0	1
Spring 2006	upper	4	2	1	1	0	0
	lower	15	1	5	6	3	0
Summer 2006	upper	3	2	1	0	0	0
	lower	6	1	5	0	0	0
totals	upper	25	6	12	3	4	0
	lower	127	18	53	29	24	3
	both	152	24	65	32	28	3

Table 5. Spatial recapture summary, by mycobacteria infection index and release area, of striped bass tagged and released in the upper and lower Rappahannock River sites during fall, 2005 (note: 2 striped bass were recaptured outside Chesapeake Bay).

recapture area	release area	n	infection index				
			clean	light	moderate	heavy	other
release area	upper	12	1	5	2	3	1
	lower	86	17	30	19	18	2
Rappahannock River	upper	7	3	2	1	1	0
	lower	2	0	2	0	0	0
upper Bay (Md)	upper	1	0	1	0	0	0
	lower	4	0	2	1	0	1
lower Bay (Md)	upper	0	0	0	0	0	0
	lower	7	1	5	0	1	0
Potomac River	upper	0	0	0	0	0	0
	lower	5	1	1	2	1	0
upper Bay (Va)	upper	1	0	1	0	0	0
	lower	19	0	11	6	2	0
lower Bay (Va)	upper	1	0	1	0	0	0
	lower	5	1	1	3	0	0
totals	upper	22	4	10	3	4	1
	lower	128	20	52	31	22	3
	both	150	24	62	34	26	4

Table 6. Seasonal recapture summary, by mycobacteria infection index and release area, of striped bass tagged and released in the upper and lower Rappahannock River sites during spring, 2006.

Date	release area	n	infection index				
			clean	light	moderate	heavy	other
0-7 days	upper	0	0	0	0	0	0
	lower	31	5	18	5	2	1
Spring 2006 (>7days)	upper	3	2	1	0	0	0
	lower	19	4	8	5	2	0
Summer 2006	upper	1	1	0	0	0	0
	lower	13	5	5	3	0	0
totals	upper	4	3	1	0	0	0
	lower	63	14	31	13	4	1
	both	67	18	32	13	4	1

Table 7. Spatial recapture summary, by mycobacteria infection index and release area, of striped bass tagged and released in the upper and lower Rappahannock River sites during spring, 2006.

recapture area	release area	n	infection index				
			clean	light	moderate	heavy	other
release area	upper	1	0	1	0	0	0
	lower	43	7	22	10	3	1
Rappahannock River	upper	2	2	0	0	0	0
	lower	3	0	2	1	0	0
upper Bay (Md)	upper	0	0	0	0	0	0
	lower	4	1	3	0	0	0
lower Bay (Md)	upper	1	1	0	0	0	0
	lower	6	1	2	2	1	0
Potomac River	upper	0	0	0	0	0	0
	lower	4	2	0	2	0	0
upper Bay (Va)	upper	0	0	0	0	0	0
	lower	1	1	0	0	0	0
lower Bay (Va)	upper	1	0	0	0	0	0
	lower	2	1	1	0	0	0
totals	upper	4	3	1	0	0	0
	lower	63	13	30	15	4	1
	both	67	16	31	15	4	1

Figure 1. Gross clinical signs of mycobacteriosis in Chesapeake Bay striped bass. A) severe ulcerative dermatitis. Note shallow, rough textured hemorrhagic and hyper-pigmented (dorsal lesions) ulcers. B) Multi-focal pale gray nodules within the spleen.

Figure 2. A spectrum of gross skin lesions attributable to mycobacteriosis in the striped bass, *Morone saxatilis.* a) mild scale damage and scale loss (arrows). b) pigmented foci (arrows). Inset: higher magnification of a pigmented focus showing pin-point erosion through an overlying scale (arrow). c) early ulceration exhibiting focal loss of scales, mild pin-point multifocal pigmentation and underlying exposed dermis. d) large advanced shallow roughly textured ulceration exhibiting hyper-pigmentation and hemorrhage. e) late stage healing lesion exhibiting hyper-pigmentation, reformation of scales and re-epithelialization and closure of the ulcer. f) Ziehl Neelsen stain of a histologic section of a skin lesion exhibiting granulomatous inflammation and acid-fast rod-shaped mycobacteria (staining red). g) histologic section showing normal healthy skin composed of epidermis (Ep), scales (Sc), dermis (D) and underlying skeletal muscle. h) histologic section through a skin ulcer showing loss of epidermis and scales and extensive granuloma formation (G).