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

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 2007 through 31 August 2008. It includes an assessment of the biological characteristics of striped bass taken from the 2008 spring spawning run, estimates of annual survival and fishing mortality based on annual spring tagging, and the results of the 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.

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Executive Summary

New Features: This year we include graphic representations of daily river flows for the Rappahannock River during the 30 March – 3 May striped bass spawning stock assessment period for the years 1985-2008. We also make the first estimates of the rate of external disease progression of striped bass infected with mycobacteriosis. In addition, we present our first estimates of an increase in natural mortality of striped bass infected with mycobacteriosis based on the assessment of the external severity of the disease.

I. Assessment of the spawning stocks of striped bass in the Rappahannock and James rivers, Virginia, spring 2008.

Catch Summaries:

1. In 2008, 642 striped bass were sampled between 31 March and 3 May from three commercial pound nets in the Rappahannock River. The samples were predominantly male (87.7%) and young (62.8% ages 1-4). Females dominated the age nine and older age classes (83.9%). The mean age of the male striped bass was 4.2 years. The mean age of the female striped bass was 8.6 years.

2. During the 31 March - 3 May period, the 2004 and 2005 year classes were the most abundant in the Rappahannock River pound net samples and were 97.5% male. The contribution of age six and older males was only 17.9% of the total aged catch. Age seven and older females, presumably repeat spawners, were 9% of the total catch but represented 73.4% of all females caught.

3. In 2008, 263 striped bass were sampled between 31 March and 3 May in two experimental anchor gill nets in the Rappahannock River. The samples were predominantly male (81.4%) and young (31.9% ages 2-4). Females dominated the age nine and older age classes (77.8%). The mean age of the male striped bass was 5.3 years. The mean age of the female striped bass was 10.4 years.

4. During the 31 March - 3 May period, the 2003 and 2004 year classes were the most abundant in the Rappahannock River gill net samples and were 98.4% male. The contribution of age six and older males was only 25.1% of the total catch. Age seven and older females, presumably repeat spawners, were 16.7% of the total catch but were 93.8% of the total females caught.

5. In 2008, 442 striped bass were sampled between 31 March and 3 May in two experimental anchor gill nets (mile 62) in the James River. The samples were predominantly male (84.6%) and young (57.8% ages 2-4). Females dominated the age nine and older age classes (90.7%). The mean age of the male striped bass was 4.6 years. The mean age of the female striped bass was 9.8 years.

6. During the 31 March - 3 May period, the 2004 and 2005 year classes were the most abundant in the James River gill net samples and were 100% male. The contribution of age six and older males was only 11.8% of the total catch. Age seven and older females, presumably repeat spawners, were 13.6% of the total aged catch, but represented 89.6% of all females caught.

Spawning Stock Biomass Indexes (SSBI)

7. The Spawning Stock Biomass Index (SSBI) from the Rappahannock River pound nets was 24.2 kg/day for male striped bass and 15.1 kg/day for female striped bass. The male index was the eighth highest in the 1991-2008 time series. The 2008 index was near the 18-year average. The female index was the fourth lowest in the 1991-2008 time series. The 2008 female index was one sixth the 2007 index and less than one half the 18-year average.

8. The SSBI for the Rappahannock River gill nets was 52.7 kg/day for male striped bass and 42.9 kg/day for female striped bass. The male index was the fifth lowest in the 1991-2008 time series and 34.8% below the 18-year average. The female index was the sixth highest in the 1991-2008 time series and was 17.5% above the 18 -year average.

9. The SSBI for the James River gill nets was 69.3 kg/day for male striped bass and 60.3 kg/day for female striped bass. The male index was near the median in the 1994-2008 time series, and was 37.9% below the 15-year average. The female index was the fifth highest in the 15-year time series and was nearly 7.5% above the 15-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 2008 Egg Production Potential Index (EPPI, millions of eggs/day) for the Rappahannock River pound nets was 8.66 million eggs/day. This was the third highest EPPI of the 2001-2008 time series. Older (8+ years) female stripers were responsible for 72% of the index.

11. The 2008 EPPI for the Rappahannock River gill nets was 6.58 million eggs/day. This was the fourth highest EPPI of the 2001-2008 time series. Older (8+years) female striped bass were responsible for 93.6% of the index.

12. The 2008 EPPI for the James River gill nets was 8.86 million eggs/day. This was the highest EPPI of the 2001-2008 time series. Older (8+ years) female striped bass were responsible for 86.4% 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 (18.35 fish/day) was the eighth lowest in the1991-2008 time series. There was an increase in the 2004 and 2005 year classes from the 2007 values. The cumulative catch rate of male striped bass (16.09 fish/day) was the sixth highest in the time series and was 24.7% lower than the rate in 2007. The cumulative catch rate of female striped bass (2.26 fish/day) was the fifth lowest in the 1991-2008 time series and 77.8% lower than the rate in 2007.

14. Year class-specific estimates of annual survival (S) for pound net data varied widely between years. The geometric mean S of the 1983-1998 year classes varied from 0.516-0.721 (mean = 0.632). The geometric mean survival rates differed between sexes. Mean survival rates for male stripers (1985-2000 year classes) varied from 0.308-0.554 (mean = 0.428) but mean survival rates of female stripers (1983-1995 year classes) varied from 0.461-0.675 (mean = 0.599).

15. The cumulative catch rate (all age classes, sexes combined) from Rappahannock River gill nets (26.30 fish/day) was the second lowest value in the 1991-2008 time series and was less than one third the rate in 2007. Cumulative catch rate of male stripers (21.50 fish/day) was the second lowest in the time series and was less than one third the rate in 2007. The cumulative catch rate of female striped bass (4.80 fish/day) was near the median in the time series, but still a third lower than the catch rate in 2007.

16. Year class-specific estimates of annual survival for gill net data varied widely between years. The geometric mean S of the 1984-2001 year classes varied from 0.408-0.714 (mean = 0.593). The mean survival rates for male stripers (1987-2001) varied from 0.153-0.552 (mean = 0.403). The mean survival rates for female stripers (1984-1995, excluding 1991) varied from 0.496-0.756 (mean = 0.605).

17. The cumulative catch rate (all age classes, sexes combined) from James River (mile 62) gill nets (44.10 fish/day) was the fifth lowest catch rate in the 1994-2008 time series. This is the lowest since 1998. The catch rate was 6.6% lower than the rate in 2007. The cumulative catch rate for male striped bass (37.40 fish/day) was also the lowest since 1998 of the 1994-2008 time series, and was 7.0% lower than the rate in 2007. The cumulative catch rate of female striped bass (6.60 fish/day) was 9.5% lower than the rate in 2007, and was the fifth lowest value in the 1994-2008 time series.

18. Year class-specific estimates of annual survival in the James River varied widely between years. The geometric mean S of the 1984-2000 year classes varied from 0.338-0.699 (mean = 0.561). The mean survival rates of male stripers (1988-2000 year classes) varied from 0.286-0.612 (mean = 0.436). The mean survival rates of female stripers (1984-1998 year classes) varied from 0.339-0.854 (mean = 0.633).

Catch rate histories of the 1987-2000 year classes

19. Plots of year class-specific catch rates vs. year in the James and Rappahannock rivers from 1991-2007 showed a consistent trend of a peak in the abundance of male striped bass around age 4 or 5, 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 1993, 1994, 1996, and 1997 year classes were the strongest, and the 1990 and 1991 year classes the weakest in the Rappahannock River from 1987-2000. In the James River, the 1996, 1997, 1998, and 2000 year classes were the strongest and 1987 and 1988 year classes the weakest.

Growth rate of striped bass derived from annuli measurements

20. The scales of 259 striped bass were digitally measured and the increments between annuli were used to determine their growth history.

21. On average, striped bass grow about 159 mm fork length in their first year. The growth rate decreases with age to about 50 mm per year by age 10.

22. 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 259 specimens from 11 size ranges were aged by reading both scales and otoliths. The mean age of the otolith-aged striped bass was 0.46 years older than from the scale-aged striped bass. The two methodologies agreed on the age of the striped bass on 51.0% of the specimens and within one year 80.9% 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 non-random ($p < .0005$).

26. A paired t-test of the mean of the age differences produced by the two ageing methodologies found that the mean difference were not significantly different from zero ($p < .001$).

27. A Kolmogorov-Smirnov test of the age structures produced by the two ageing methodologies also indicated an 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 and age-eleven 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 2006-2007.

1. A total of 524 striped bass were tagged and released from pound nets in the Rappahannock River between 7 April and 15 May, 2008. Of this total, 448 were between 457-710 mm total length and considered to be predominantly resident striped bass and 76 were considered to be predominantly migrant striped bass (>710 mm TL). The median date of resident tag releases was 28 April, while 24 April was the median date of migrant tag releases.

2. A total of 89 (out of 1,961) striped bass (>457 mm TL), tagged during spring 2007, were recaptured between 19 April, 2007 and 27 April, 2008 (the respective midpoints of the two tag release totals), and were used to estimate mortality. Forty six of these recaptures were harvested (51.7%) and the rest were re-released into the population. In addition, 38 striped bass tagged in previous springs were recaptured during the 2007-2008 recovery interval and were used to complete the input data matrix. Most recaptures (62.8%) were caught within Chesapeake Bay (40.1% in Virginia, 22.6% in Maryland). However, other recaptures came from Massachusetts (13.1%), New York (10.2%), New Jersey (5.1%), Rhode Island (4.4%), Delaware and North Carolina (1.5 % each), and Connecticut and New Hampshire (0.7% each).

3. A total of 44 (out of 840) migratory striped bass (>710 mm total length), tagged during spring 2007, were recaptured between 19 April, 2007 and 24 April, 2008, and were used to estimate the mortality. Twenty six of these recaptures were harvested (59.1%), and the rest were re-released into the population. In addition, 24 striped bass tagged in previous springs were recaptured during the recovery interval and were used to complete the input data matrix. Most recaptures (31.9%) came from Chesapeake Bay (29.2% in Virginia and 2.7% in Maryland), followed by Massachusetts (25.0%). Other recaptures came from New York (19.4%), New Jersey (9.7%), Rhode Island (6.9%), Delaware and North Carolina (2.8% each), and Connecticut (1.4%).

4. The ASFMC Striped Bass Tagging Subcommittee established a data analysis protocol that involves deriving survival estimates from a suite of Seber models. Nine of these models were applied to the recapture matrix, each reflecting a different parameterization over time. However, by decision of the Striped Bass Stock Assessment committee, the analyses were deferred until 2009 for the 2007 and 2008 estimates.

6. After adjusting for tag-induced mortality, reporting rate of recaptured striped bass and hook-and-release mortality, the 2007 estimate of exploitation rate for Virginia was 0.06 and the estimate of fishing mortality was 0.06. However, these estimates were considered to be too low in light of the harvest of over 8,000,000 lbs. of striped bass. It also infers that natural mortality in Chesapeake Bay is increasing.

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 1,584 striped bass were tagged, assessed for external diseases indications, photographed and released from two pound nets in the upper Rappahannock (n=597) and five pound nets in the lower Rappahannock (n=987) River during fall, 2007. Only 37.9% of the total tagged were without any external sign of mycobacteriosis.

4. A total of 169 striped bass were tagged, assessed for external diseases indications, photographed and released from five pound nets in the lower Rappahannock (n=169) River during spring, 2008. Only 40.8% of the total tagged were without any external sign of mycobacteriosis.

5. A total of 127 striped bass tagged during fall, 2007 were recaptured prior to 20 September, 2008. Although 35.1% of the releases were assessed as clean and 10.5% were assessed as heavily infected, the recaptures rates were 37.9% for the clean and 9.8 % for the heavily infected striped bass releases.

6. A total of 47 striped bass tagged during spring, 2008 were recaptured prior to 20 September, 2008. Although 59.1% of the releases were assessed as clean and 22.7% were assessed as heavily infected, the recaptures rates were 40.8% for the clean and 11.2 % for the heavily infected striped bass releases.

7. A total of seven striped bass tagged during fall, 2005 were recaptured prior to 20 September, 2008. While the percentage of moderately and heavily infected striped bass recaptures exceed the percentage of the initial releases during the first year at large, this trend reversed in the second year.

8. A total of four striped bass tagged during spring, 2006 were recaptured prior to 20 September, 2008. The relative proportion of the infection index of the recaptures during year two closely mirrored that of their initial release.

9. It must be assumed that all fish have the same tag recovery rate to estimate survival rates, however, the disease severity may affect the movement of individual striped bass. It is therefore necessary to accumulate sufficient tag returns to estimate the relative survival rates.

10. Based on the recapture and reassessment of 153 tagged striped bass originally assessed as having a light or moderate mycobacterial infection, it was calculated that in take 444 days for the external infection to progress from light to moderate infection and 478 days to progress from moderate to heavy infection.

11. The return rate for moderate and heavy mycobacteroisis-infected striped was was less than the return rate for non-infected striped bass. The slope of the regression line of each category of infection plotted versus the non-infected striped bass produced a line with negative slope, indicating higher instantaneous natural mortality. This implies that the annual survival rates of moderate and heavy infected striped bass are 27 and 23% respectively. Striped bass originally assessed as lightly infected had a less significant decrease in survival from the non-infected striped bass.

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I. Assessment of the spawning stocks of striped bass in the Rappahannock and James rivers, Virginia, spring, 2008.

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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° 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 31 March and 3 May, 2008. Samples (the entire catch of striped bass from each gear) were taken twice-weekly (Monday and Thursday) from among three commercial pound nets (river miles 45, 46 and 47) in the Rappahannock River. Pound nets are fixed commercial gears that have been the historically predominant gear type used in the river and are presumed to be non size-selective in their catches of striped bass. The established protocol (Sadler *et al.* 1999) was to alternate the choice of the net sampled but weather constraints often dictated whether that net could be sampled. In addition, data from pound nets sampled in 1991 and 1992 were included to expand the time series. These samples were consistent in every respect to the 1993-2001 samples with the following exceptions in 1991: two samples (3 and 17 April) came from a pound net at river mile 25 and samples were obtained weekly vs. twice weekly.

In addition to the pound nets, samples were also obtained twice-weekly from variable-mesh experimental anchored gill nets (two at river mile 48 on the Rappahannock River and two at river mile 62 on the James River, Figures 1 and 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 successive rinses in water immediately after extraction. 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 31 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 31 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= 642) were sampled between 31 March and 3 May, 2008 from the pound nets in the Rappahannock River. The number of striped bass sampled was much lower than was sampled in 2007 (n= 1,104) but was near the 16-year average (n=639). Total catches varied from 6-155 striped bass, with peak catches on 21 and 28 April (Table 1). Surface water temperature increased from 11 EC on 31 March to 17 EC on 21 April, decreased gradually to 15 EC on 28 April, and then increased to 21 EC on 5 May. For the fifth consecutive year, dry weather persisted throughout early April, resulting in lower river flows than had been present in 2001-2003. However, there was a pulse of high river flows from 15-20 April, but flows returned to below normal afterward (Fig 3). Salinities prior to 15 April exceeded 0.5 p.p.t., but decreased to 0.1 p.p.t. after 28 April. Catches of female striped bass peaked on 14 April and were

dominated by the pre-2000 year classes. Males made up 87.7% of the total catch, which was well above the 16-year average (79.5%). The 2004-2007 year classes comprised 64.3% of the total catch. In contrast, in 2007 the 2003-2005 year classes comprised 35.1% of the total catch. Males dominated the 2004-2007 year classes (97.5%) and the 2000-2003 year classes (87.3%), but females dominated the 1993-1999 year classes (83.9%).

Biomass catch rates (g/day) of male striped bass peaked on 21 April and again on 28 April, while the catch rate of female striped bass peaked on 14 April (Table 2). The numeric catch rate of males exceeded that of females on every sampling date except on 10 April. Unlike 2007, and most previous years, the biomass catch rates for male striped bass exceeded that for females overall (1.59:1), peaking on 21 April (>5.0:1). The mean ages of male striped bass varied from 2.5-5.0 years by sampling date, with the oldest mean age occurring on 17 April. The mean ages of females varied from 5.8-11.3 years by sampling date, which was a much greater range than in 2007 (9.5-11.1 years) and most previous years.

There was a peak in abundance of striped bass (mostly male) between 420-510 mm total lengths in the pound net samples (Table 3). This size range accounted for 49.2% of the total sampled. Unlike 2007, there was no secondary peak in abundance of striped bass between 850-960 mm total lengths. Consistent with previous years, the striped bass from 630-710 mm total length accounted for only 1.9% 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 14.5% (vs. 41.5% in 2007).

During the 31 March – 3 May period, the 2004 (39.3%) and 2005 (24.0%) year classes were the most abundant (Table 4). These year classes were 97.5% male. The contribution of males age six and older (the pre-2003 year classes) was 17.9% of the total aged catch. These year classes were most vulnerable to commercial and recreational exploitation within Chesapeake Bay. The contribution of females age seven and older, presumably repeat spawners, was only 9.0% of the total aged catch, but was also 73.4% of the total females captured. The catch rate (fish/day) of male striped bass was 16.1, which is near the 16-year average (Table 5). In contrast, the catch rate of female striped bass (2.3 fish/day) was 51.1% below the 16-year average, and was the fifth lowest value in the time series. The biomass catch rates (kg/day) of both sexes of striped bass were well below the average of the 16-year time series. The mean age (31 March – 3 May) of the male striped bass was slightly below the 16-year average. The mean age of the female striped bass was the youngest since 2002 and slightly below the mean value in the time series.

Experimental gill nets: Striped bass (n= 263) were also sampled between 31 March and 3 May, 2008 from two multi-mesh experimental gill nets in the Rappahannock River. The total catch was less than half than the total catch in 2007 (n=743). Total catches peaked on 21 April, due to the large number of three to four year old males (Table 6). Total catches of female striped bass peaked on 17 April. Males made up 81.4% of the total catch. Males dominated the 2004-2007 year classes (100.0%) and the 2000-2003 year classes (95.9%), but the 1993-1999 year classes were 77.8% female.

Biomass catch rate (g/day) of male striped bass was highest on 21 April (Table 7). The catch rate (fish/day) of males exceeded that of females on every sampling date except on 3 and 7 April. The mean ages of male striped bass varied from 3.0-7.7 years by sampling date, with the oldest males being most abundant from 10-17 April. The biomass catch rate of female striped bass (g/day) peaked sharply on 17 April. The mean ages of females varied from 9.5-12.3 years by sampling date, with the oldest females (age nine and older) being most abundant from 31 March - 7 April.

There was a peak in the distribution of length frequencies of striped bass in the gill net samples between 450-550 mm TL (Table 8). In previous years, there was a distinct secondary peak of larger striped bass, but this has been less apparent since 2006. In contrast to 2007, the total contribution of striped bass greater than 840 mm total length from the gill nets (17.7%) was higher than from the pound nets (8.6%). The total contribution of striped bass greater than 710 mm total length was 30.0% in the gill nets.

During the 31 March - 3 May period, the 2003 (24.3%) and 2004 (22.8%) year classes were most abundant (Table 9). These year classes were 98.4% male. The contribution of males age six and older (the pre-2003 year classes) was 25.1% 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 16.7% of the total aged catch but was 93.8% of the total females captured. The catch rate of male striped bass (21.5 fish/day) was the second lowest in the 16-year time series and was 54.5% below the average (Table 10). The catch rate of female striped bass (4.8 fish/day) was the eigth highest in the time series and was 15.8% below the 16-year average. The biomass catch rates (g/day) for male striped bass was the second lowest in the time series and was 33.7% below the 16-year average. The biomass catch rate for female striped bass was the sixth highest in the time series and was 23.3% above the 16-year average.

James River:

Experimental gill nets: Striped bass (n= 442) were sampled between 31 March and 3 May, 2008, 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 catch (Table 11). Catches of female striped bass peaked from 31 March-3 April. Males dominated the 2004-2007 year classes (99.6%) and the 2000-2003 year classes (86.9%), but the 1993-1999 year classes were predominantly female (90.7%).

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Biomass catch rates (g/day) of male striped bass peaked strongly on 3 April, but were high on all but two occasions (Table 12). The catch rates of female striped bass were highest from 31 March-3 April. The biomass catch rate of males exceeded that of females on every sampling date except for 10 and 17 April (1.2:1 for the season). The mean ages of male striped bass varied from 3.6-5.1 years by sampling date. The mean ages of females varied from 6.5-10.7 years by sampling date, but varied from only 9.2-10.7 years from 31 March-24 April.

There was a peak of striped bass 410- 530 mm total length in the gill net length frequencies (Table 13). This size range accounted for 50.2% of the total striped bass sampled. In

contrast to the samples from Rappahannock River, the striped bass greater than 840 mm total length accounted for 12.2% of the total sampled. The total contribution of striped bass greater than 710 mm total length was 17.4%.

During the 31 March - 3 May period, the 2004 (34.8%) and 2005 (22.2%) year classes were the most abundant in the gill nets (Table 14). These year classes were all male. The contribution of males age six and older (the pre-2003 year classes) was only 11.8% 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 only 13.6% of the total aged catch, but represented 89.6% of the total females captured.

The catch rate of male striped bass (37.4 fish/day) was lower than for 2007, and was 43.6% below the 14-year average (Table 15). Likewise, the catch rate of female striped bass was lower than for 2007 and was 26.9% below the 14-year average. The biomass catch rate (g/day) of male striped bass was slightly lower than 2007, and was 44.5% below the average. The biomass catch rate of female striped bass was slightly higher than in 2007, and was near the 14-year average. The mean age of male striped bass has varied from only 4.3-4.9 years by sampling year, while the mean age of female striped bass varied from 6.3-9.8 years.

Spawning Stock Biomass Indexes

Rappahannock River:
Pound nets: The Spawning Stock Biomass Index (SSBI) for spring 2008 was 24.2 kg/day for male striped bass and 15.1 kg/day for female striped bass. The index for male striped bass was the eighth highest in the 18-year time series, but was only half the index value for 2007, and was near the 18-year average (Table 16). The magnitude of the index for male striped bass was largely determined by the 2004 (34.5%) and 2003 (24.5%) year classes. The index for female striped bass was one sixth the 2007 index and less than one half the 18-year average (Table 16). The magnitude of the index for the females was largely determined by the 1996 and1997 year classes (52.2%).

Experimental gill nets: The Spawning Stock Biomass Index for spring 2008 was 52.7 kg/day for male striped bass and 42.9 kg/day for female striped bass. The index for male striped bass was the fifth lowest of the time series, 60.8% below the 2007 index, and was 34.8% below the 18-year average (Table 16). The 2000-2003 year classes contributed 66.1% of the biomass in the male index. The index for female striped bass was 36.9% below the 2007 index, and was 17.5% above the 18-year average. The 1996 and 1997 year classes contributed 49.6% of the biomass in the female index.

James River:
Experimental gill nets: The Spawning Stock Biomass Index for spring 2008 was 69.3 kg/day for male striped bass and 60.3 kg/day for female striped bass. The male index was near the median in the 15-year time series, nearly identical to the 2007 index, and 37.9% below the 15-year average (Table 17). The 2002-2004 year classes contributed 67.3% of the biomass in the

male index. The female index was the fifth highest in the time series, and was 8.8% higher than the 2007 index, and was 7.5% above the 15-year average. The 1996-1998 year classes accounted for 65.4% of the biomass in the female index.

Egg Production Potential Indexes

The number of gonads sampled, especially of the larger females, was insufficient to produce separate length-egg production estimates for each river. The pooled data (2001-2003) produce a fork length-oocyte count relationship as follows:

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

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 2008 Egg Production Potential Indexes (EPPI, Table 19) for the Rappahannock River were 8.66 (pound nets) and 6.58 (gill nets). The 2008 EPPI for the James River was 8.86. The indexes for both the Rappahannock and James rivers were heavily dependent on the egg production potential of the 1996-1998 year class females (75.8% in the pound nets, 75.3% in the Rappahannock gill nets and 65.9% in the James River gill nets). Previous values for the EPPI for 2001-2007 from the Rappahannock River were 3.992, 1.764, 9.829, 10.55, 6.30, 4.01 and 13.792 (pound nets) and 4.039, 6.070, 3.724, 8.432, 3.06, 6.27 and 9.915 (gill nets). Previous values for the EPPI for 2001-2007 from the James River were 5.286, 6.709, 6.037, 4.922, 3.24, 15.1 and 8.396 respectively (Sadler et al 2001, 2002, 2003, 2004, 2005, 2006 and 2007). Thus, the EPPI values for the two gears in the Rappahannock River signaled a reduction in the status of the spawning stock from the record 2007 values, 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 2001-2008 indexes preclude direct comparison with the 1999 and 2000 indexes.

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

Rappahannock River:

Pound nets: Numeric catch rates (fish/day) of individual year classes from the 1991-2008 samples are presented in Tables 20-22. The cumulative annual catch rate of all year classes for 2008 was the eighth lowest in the time series and was 43.5% lower than the cumulative catch rate for 2007 (Tables 20a,b). The decrease was the result of lower catch rates for every year class. The catch rate of males was dominated by three and four year olds (2004 and 2005 year classes, Tables 21a,b). These two age classes contributed 70.8% of the total male 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-1996 year class males were captured. The cumulative catch rate of female stripers was the lowest since 2002 and the fifth lowest of the time series, and was less than one fourth the catch rate in 2007 (Tables 22a,b).

The 1996-1998 year classes accounted for 52.9% of the total female catch. No pre-1996 year class females were captured in 2008.

The range of overall ages was unchanged from 1991-2008, 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, 2006-2008). 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 0.787-0.929 from 2003-2007, but dropped to 0.678 in 2008.

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 (1991-2008) of the 1983-1998 year classes (sexes combined) varied from 0.516-0.721 (Tables 23a,b) with an overall mean survival rate of 0.632. 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 (1991-2008) of the 1985-2000 year classes of males varied from 0.308-0.554 (Tables 24a,b) with an overall mean survival rate of 0.428. These year classes have been the major target of the fall recreational and commercial fisheries that reopened in 1993. The geometric mean survival rate (1991-2008) of the 1983-1995 year classes of females varied from 0.461-0.675 (Tables 25a,b) with an overall mean survival rate of 0.599.

Experimental gill nets: Numeric catch rates (fish/day) of individual years classes from 1991-2008 are presented in Tables 26-28. The cumulative annual catch rate (all age classes, sexes combined) for 2008 from the gill nets was the second lowest (to 1992) in the time series and was less than one third the cumulative catch rate in 2007 (Tables 26a,b). The record high cumulative catch rate in 2007 was driven by the catch rates of the 2003 and 2004 year classes (3 and 4 years of age) of striped bass. These age classes were still represented the peak in the 2008 cumulative catch rate, but were much weaker than in 2007. The age of peak abundance had changed from age five (1992-1996, 2002) to age four (1997, 1998, 2000, 2001, 2003, 2007 and 2008) and age three (1999, 2004 and 2006). The cumulative catch rate of male striped bass was also the second lowest in the time series and was less than one third the catch rate in 2007 (Tables 27 a,b). however, the cumulative catch rate of female striped bass, although a third lower than in 2007, was near the median of the time series (Tables 28a,b).

The overall age structure from 1991-2008 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 (0.32) was

the second highest in the 18-year time series and consistent with the 2002-2007 values after being 0.03-0.06 from 1997-2001. The proportion of female striped bass age eight and older (0.94) was the highest in the time series. 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 0.786-0.835 from 2004-2007.

The cumulative catch rate (all age classes) of male striped bass declined from the record rate in 2007, and was the lowest value since 1992 (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 age classes are the primary target of the recreational and commercial fisheries.

The 2008 cumulative catch (all age classes) rate of female striped bass was much lower than the 2007 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 2005-2008. This bimodal distribution of abundance with age had been noted for the pound net catches, but has generally 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 (1991-2007) of the 1984-2001 year classes (sexes combined) varied from 0.408-0.714 (Tables 29a,b) with an overall mean survival of 0.593. There were widely divergent estimates of annual survival of male and female striped bass. The geometric mean survival rate (1991-2008) of the 1987-2001 year classes of males varied from 0.153-0.552 (Tables 30a,b) with an overall mean survival of 0.403. These year classes have been the major target of the fall recreational and commercial fisheries that reopened in 1993. The geometric mean survival rate (1991-2008) of the 1984-1995 (excluding 1991) year classes of females varied from 0.496-0.756 (Tables 31a,b) with an overall mean survival rate of 0.605. The overall survival estimate of male striped bass was lower than that calculated from the pound nets. The estimate of female survival rates, although slightly greater than the pound net estimate, was based on fewer year classes 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 1984-2008 are presented in Tables 32-34. The cumulative annual catch rate (all age classes, sexes combined) for 2008 was the lowest since 1998, and was a 6.6% lower than the catch rate for 2007 (Tables 32a,b). The cumulative catch rate was driven by high catch rates for the three to five year old (2003-2005 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 11 years by 2005 (Tables 33a,b). The age structure of female striped bass was stable from 1994-2008, consisting of three

to 14 year old females (Tables 34a,b). The cumulative proportion of males age six and older was 0.139, and has varied from 0.091-0.191 in 2000-2008 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 has increased to 0.864 in 2008.

The cumulative catch rate of male striped bass mirrored the trends of the combined data with the 2008 catch rate being the lowest since 1998, and 7.0% lower than the cumulative catch rate for 2007 (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 2008 cumulative catch rate of female striped bass was 9.5% lower than the catch rate in 2007, and was the fifth lowest in the 15-year 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 (1994-2008) of the 1984 -2000 year classes (sexes combined) varied from 0.338-0.699 (Table 35), with an overall mean survival rate of 0.561. There were widely divergent estimates of annual survival of male and female striped bass. The geometric mean survival rate (1994-2008) of the 1988-2000 year classes of males varied from 0.286-0.612 (Table 36) with an overall mean survival rate of 0.436. These year classes have been the major target of the fall recreational and commercial fisheries that reopened in 1993. The geometric mean survival rate (1994-2008) of the 1984-1998 year classes of females varied from 0.339-0.854 (Table 37) with an overall mean survival rate of 0.633.

Catch Rate Histories of the 1987-2000 Year Classes

The catch rate histories of the 1987-1999 year classes from each sampling gear (sampling on the James River commenced in 1993) are depicted in Figures 4-17. 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 4). 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 14 year classes) as an indicator of year class strength, the 1987 year class was near the mean for the 1987-2000 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 2008.

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 male striped bass occurred at age four (Figure 5). However, peak abundance of female striped bass was age nine from the gill nets and age 10 in the pound nets. 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 2008.

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 6). Peak abundance of female striped bass occurred at age 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). No 1989 year class striped bass were captured in 2008.

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 7). 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). No 1990 year class striped bass were captured in 2008.

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 8). 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). No 1991 year class striped bass were captured in 2008.

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 9). 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). No 1992 year class striped bass were captured in 2008.

1993 Year class: Peak abundance of male striped bass occurred at age four in the Rappahannock (both gears) and the James rivers (Figure 10). 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). Two female 1993 year class striped bass, both in the James River, were captured in 2008.

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 11). 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 slightly 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). One female 1994 year class striped bass was captured in the James River in 2008.

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 12). 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 below 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. Five female 1995 year class striped bass (four in the Rappahannock and one in the James) were captured in 2008.

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 13). Peak abundance of female striped bass occurred at age ten in the James River and at age 11 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 the highest of any of the year classes (Table 40). Forty (37 females and three males) 1996 year class striped bass (27 in the Rappahannock and 13 in the James) were captured in 2008.

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 14). Age ten females showed an increase in abundance in the Rappahannock River (both gears) and the James 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). Forty two (37 females and five males) 1997 year class striped bass (29 in the Rappahannock and 13 in the James) were captured in 2008.

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 15). Age nine females showed an increase in abundance verses their abundance in 2006 (at age eight) in both rivers. The CCA was the lowest since the 1992 year class 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). Forty six (39 females and seven males) 1998 year class striped bass (31 in the Rappahannock and 15 in the James) were captured in 2008.

1999 Year class: Peak abundance of male striped bass occurred at age four in the Rappahannock River gill nets and at age five in the pound nets and James River gill nets (Figure 16). The CCA at age eight was less than for the 1998 year class and was the lowest since the 1992 year class in the pound nets (Table 38) and the 1991 year class in the Rappahannock River gill nets (Table 39). The CAA for the James River was the lowest since the 1995 year class (Table 40). Twenty eight (17 females and 11 males) 1999 year class striped bass (19 in the Rappahannock and nine in the James) were captured in 2008.

2000 Year class: Peak abundance of male striped bass occurred at age four for all indexes for both the Rappahannock and the James rivers (Figure 17). The peak abundance of female striped bass was age five in the pound nets and age six from the gill nets in both rivers. For the third successive year class, the CCA at age eight was the lowest since the 1992 year class in the pound nets (Table 38). The CCA for the gill nets was higher than for the 1998 year class but still well below the mean (Table 39). The CCA for the James River was higher than both the 1998 and 1999 year classes and was above the overall mean.

Growth Rate of Striped Bass Derived from Annuli Measurements

The scales of 259 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 143mm 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 10th 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 257 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 51.0% (131/ 257 of the time and within one year 80.9% (208/257) 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 = 18). We tested the hypothesis that the observed age differences were symmetrically distributed about the main table diagonal (Table 42). The hypothesis was rejected ($\chi^2 = 67.56$, p< .0005), indicating non-random differences between the two ageing methodologies. The two ageing methods were also found to be non-random in 2004, 2005 and 2007, but not in 2006.

Differences between the scale and otolith age from the same specimen ranged from zero to five years (Figure 18). The otolith-derived age exceeded the scale age 38.1% of the total examined (77.8% 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 (87.8%). 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 = 42.74, df = 4, p< 0.005). This test has far fewer degrees of freedom than did the previous test of symmetry.

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 from zero. The mean age of the sample (n=259) determined by reading the otoliths was greater than the mean age determined by reading the scales (by 0.46 years, Table 43). The test results were:

$$\bar{A}ge_{otolith} = 8.61 \qquad \bar{A}ge_{scale} = 9.07$$
$$S_{otolith} = 3.26 \qquad S_{scale} = 3.64$$

$$t = 1.528$$
$$df = 508$$
$$p = .1272$$

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=4.65, df=257, p<.001) 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 ($K_{.05}$):

$$D_{\max} = 0.1124 \qquad K_{.05} = 1.3581$$

$$D_{.05} = 1.3581\sqrt{\frac{258+258}{258^2}} = 0.1196$$

The maximum difference did not exceed the test statistic, so the null hypothesis, that the age structures derived by the two ageing methods represent the same population, was accepted. This result differs from the test results for the 2007 age comparisons.

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 2008 the oldest striped bass (1993-1995 year classes) were captured in the gill nets.

The biological characterization of the spawning stock of striped bass in the Rappahannock River changed dramatically from 1991-2008. 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 2002-2008. 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. However, in 2008 the catches of striped bass of all ages were dramatically lower than the catches in 2007. A persistent drought throughout the winter and spring resulted in elevated salinities at the sampling locations and reports from other watermen indicated that spawning activity was located well upriver of their normal location. Most of the females captured in 2008 were spent, indicating that the catches were from stripers exiting the spawning grounds and returning to coastal waters.

Of note again in the 2008 samples was the relative abundance of 1996 year class (12 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. However, the 1992 year class, abundant in 2005-2007, were absent from the samples in 2008.

The 2008 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 near the mean of the 1991-2008 time series. However, the SSBI for female striped bass was less than one half the mean. The decrease in the SSBI was due to decreased numbers across almost every age class when compared to 2007. There was a less dramatic decrease in the SSBI for the Rappahannock River gill nets. Although it was also less than half the index for 2007, it was greater than the indexes for 2005 and 2006 and only 20% below the mean for the 1991-2008 time series.

The 1991-2008 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 2008 was driven by increased catches of 2003-2005 year classes of males, compared to the 1998-2001 year classes that dominated the index in 2007. The female biomass

from pound nets showed no reliance upon any age groups, although the exceptionally strong 1996 and 1997 year classes continue to contribute highly. 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.

In contrast to the Rappahannock River, the 2008 value of the SSBI in the James River were slightly higher than in 2007, but still more than 20% below the mean of the 1994-2008 time series. The male index was driven by large catches of the 2003-2005 year classes while the female index had higher catch rates of the 1996-1998 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 2008, the contribution of 8+ year old females was 72.0% of the total number, 88.6% of the biomass, and 90.3% 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 2004-2008, 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 1983-1995 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 0.60 in pound nets and 0.54 in gill nets. The lower capture rates of larger (older) females in the gill nets resulted in lower estimates. The survival estimates of 1985-1998 year class male striped bass were approximately 0.42 in pound nets and 0.39 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 0.44 for male striped bass and approximately 0.63 for female striped bass.

The catch histories of the 1987-2000 year classes in the Rappahannock River show two distinct patterns. The 1987-1990 year classes had initial peaks of abundance of both sexes at ages four or five and a secondary peak in the abundance of female striped bass after age eight. Subsequent year classes did not have the initial peak in abundance of female striped bass, but only what was the secondary peak of eight to 12 year-olds. Since catches of larger, thus older, striped bass was less consistent in the gill net catches, this pattern was less apparent in that data set. Using the area under the catch curve as an indicator of year class strength, the 1993 and 1996 year classes were the strongest and the 1990 and 1991 year classes were the weakest.

Back-calculation of the growth based on measurements between scale annuli indicated that striped bass grow about 160 mm (fork length) in their first year. Growth averaged 100 mm in their second and third years 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 five years (though only for a single specimen). The age difference determined for the largest, and oldest, specimens was 0-5 years (13-16 years by reading the scale vs 13-21 years by reading the otolith). The maximum age determined by reading scales has generally remained constant at 16 years since 1991 (although one 19 year old was aged in 2007), while there has been an annual progression in the maximum age determined by reading otoliths. Agreement between the two ageing methodologies was 51.0% and was similar to the results from 2007. When there was disagreement between methodologies, the otolith age was 3.5 times more likely to have been aged older than the respective scale-derived age and 7.17 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. This was consistent with the results in 2004, 2005 and 2007. However, test of symmetry and t-test of the means gave contradictory results in 2006. However, the relative contributions of the age classes and their overall mean age were not 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.

Literature Cited

Berggren, T.J. and J.T. Lieberman. 1978. Relative contribution of Hudson, Chesapeake and Roanoke striped bass, *Morone saxatilis*, stocks to the Atlantic coast fishery. U. S. Fish. Bull. 76(2): 335-345.

Barbieri, S.K. and L.R. Barbieri. 1993. A new method of oocyte separation and preservation for fish reproduction studies. U. S. Fish. Bull. 91: 165-170.

Chapoton, R.B. and J.E. Sykes. 1961. Atlantic coast migration of large striped bass as evidenced by fisheries and tagging. Trans. Amer. Fish. Soc. 90(1):13-20.

Dorazio, R.M., K.A. Hattala, C.B. McCollough and J.E. Skjeveland. 1994. Tag recovery estimates of migration of striped bass from spawning areas of the Chesapeake Bay. Trans. Amer. Fish. Soc. 123: 950-963.

Evans, G.T. and J.M. Hoenig. 1998. Testing and viewing symmetry in contingency tables, with application to readers of fish ages. Biometrics 54: 620-629.

Field, J.D. 1997. Atlantic striped bass management: where did we go right? Fisheries 22(7): 6-8.

Frie, R.V. 1982. Measurement of fish scales and back-calculation of body lengths using a digitizing pad and microcomputer. Fisheries 7(5): 5-8.

Grant, G.C. and J.E. Olney. 1991. Distribution of striped bass *Morone saxatilis* (Walbaum) eggs and larvae in major Virginia rivers. U. S. Fish. Bull. 89:187-193.

Hardy, J.D. Jr. 1978. Development of fishes of the mid-Atlantic bight. Vol. III, Aphrederidae through Rachycentridae. U. S. Fish Wildl. Serv. FWS/OBS-78/12.

Hoenig, J.M., M.J. Morgan and C.A. Brown. 1995. Analysing differences between two age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52: 354-368.

Lewis, R.M. 1957. Comparative study of populations of the striped bass. U. S. Fish and Wildlife Service Spec. Rep. Fisheries 204:1-54.

Loesch, J.G., W.H. Kriete, Jr., and S.M. Atran. 1985. Sonic digitizers "go fishing": fish scales reveal age by sound. Sea Tech., February 1985: 3-31.

Mansueti, R.J. 1961. Age, growth, and movements of the striped bass, *Roccus saxatilis*, taken in size selective fishing gear in Maryland. Ches. Sci. 2: 9-36.

McGovern, J.C. and J.E. Olney. 1996. Factors affecting survival of early life stages and subsequent recruitment of striped bass on the Pamunkey River, Virginia. Can. J. Fish. Aquat. Sci. 53: 1713-1726.

Merriman, D. 1937. Notes on the life history of the striped bass (*Roccus lineatus*). Copeia 1:15-36.

Merriman, D. 1941. Studies on the striped bass (*Roccus saxatilis*) of the Atlantic Coast. Fish. Bull. U.S. Fish Wildl. Serv. 50(35):1-77.

Olney, J.E., J.D. Field, and J.C. McGovern. 1991. Striped bass egg mortality, production and female biomass in Virginia rivers, 1980-1989. Trans. Amer. Fish. Soc. 120: 354-367.

Pearson, J.C. 1938. The life history of the striped bass, or rockfish, *Roccus saxatilis* (Walbaum). U. S. Fish. Bull. 49: 825-851.

Raney, E.C. 1957. Subpopulations of the striped bass *Roccus saxatilis* (Walbaum), in tributaries in Chesapeake Bay. U. S. Fish Wildl. Serv., Spec. Sci. Fish. 208: 85-107.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Bd. Can. Bull. 191: 382 p.

Rugolo, L.J., P.W. Jones, R.K. Schaefer, K.S. Knotts, H.T. Hornick and J.L. Markham. 1994. Estimation of Chesapeake Bay-wide exploitation rate and population abundance for the 1993 striped bass stock. Manuscript, Maryland Department of Natural Resources, Annapolis, Md.

Sadler, P.W., R.E. Harris, J. Romine, and J.E. Olney. 1998. Evaluation of striped bass stocks in Virginia: monitoring studies, 1993-1998. Completion Report, Virginia Institute of Marine Science. 99 p.

Sadler, P.W., R.J. Latour, R.E. Harris, and J.E. Olney. 2001. Evaluation of striped bass stocks in Virginia: monitoring and tagging studies, 1999-2003. Annual Report, Virginia Institute of Marine Science: 93 p.

Sadler, P.W., R.J. Latour, R.E. Harris, K.L. Maki and J.E. Olney. 2002. Evaluation of striped bass stocks in Virginia: monitoring and tagging studies, 1999-2003. Annual Report, Virginia Institute of Marine Science: 102 p.

Sadler, P.W., R.J. Latour, R.E. Harris, J.K. J.K. Ellis and J.E. Olney. 2003. Evaluation of striped bass stocks in Virginia: monitoring and tagging studies, 1999-2003. Annual Report, Virginia Institute of Marine Science: 131 p.

Sadler, P.W., J.M. Hoenig, R.E. Harris and B.G. Holloman. 2004. Evaluation of striped bass stocks in Virginia: monitoring and tagging studies, 1999-2004. Annual Report, Virginia Institute of Marine Science: 167 p.

Sadler, P.W., J.M. Hoenig, R.E. Harris and B.G. Holloman. 2005. Evaluation of striped bass stocks in Virginia: monitoring and tagging studies, 2005-2009. Annual Report, Virginia Institute of Marine Science: 199 p.

Sadler, P.W., J.M. Hoenig, R.E. Harris, and B.G. Holloman. 2006. Evaluation of striped bass stocks in Virginia: monitoring and tagging studies, 2005-2009. Annual Report, Virginia Institute of Marine Science: 150 p.

Sadler, P.W., J.M. Hoenig, R.E. Harris, R.J. Wilk and L.M. Goins. 2007. Evaluation of striped bass stocks in Virginia: monitoring and tagging studies, 2005-2009. Annual report, Virginia Institute of Marine Science: 170pp.

Secor, D.H. 1999. Specifying divergent migrations in the concept of stock: the contingent hypothesis. Fisheries research 43: 13-34.

Secor, D.H., T.M. Trice and H.T. Hornick. 1995. Validation of otolith-based ageing and a comparison of oolith and scale-based ageing in mark-recaptured Chesapeake Bay striped bass, *Morone saxatilis.* Fish. Bull. 93:186-190.

Setzler, E.M., W.R. Boyton, K.V. Wood, H.H. Zion, L. Lubbers, N.K. Montford, P. Frere, L. Tucker and J.A. Mihursky. 1980. Synopsis of biological data on striped bass, *Morone saxatilis* (Walbaum). NOAA Tech. Rept. NMFS 433.

Shepherd, G. and H. Lazar (eds). 1998. Source document to Amendment 5 to the Interstate Fishery Management Plan for striped bass. ASMFC Rep. No. 34.

Sokal, R.R. and F.J. Rohlf. 1981. Biometry. W. H. Freeman Co. 859 p.

Van Winkle, W., K.D. Kumar, and D.S. Vaughan. 1988. Relative contributions of Hudson River and Chesapeake Bay striped bass stocks to the Atlantic Coast population. Amer. Fish. Soc. Mono. 4: 255-266.

Welch, T.J., M..J. Van Den Avyle, R.K. Betsill and E.M. Driebe. 1993. Precision and relative accuracy of striped bass age estimates from otoliths, scales, anal fin rays and spines. N. Amer. J. Fish. Mgmt. 13:616-620.

Wischniowski, W. and S. Bobko. 1998. Age and growth laboratory manual. Final report Old Dominion Univ. Center for Quantitive Fisheries Ecology.

Zar, J.H. 1999. Biostatistical Analysis, Fourth Edition. Prentis Hall Press. 663 pp.

Table 1. Numbers of striped bass in three age categories (year classes 2004-2007, 2000-2003 and 1993-1999) from pound nets in the Rappahannock River, by sampling date, spring, 2008. M = males, F = females.

Date	n	Year Class					
		2004-2007		2000-2003		1993-1999	
		M	F	M	F	M	F
31 March	94	60	2	21	2	1	8
3 April	43	30	1	6	3	0	3
7 April	13	7	2	1	2	0	1
10 April	6	2	0	0	0	0	4
14 April	33	10	2	7	4	0	10
17 April	52	16	0	29	5	0	2
21 April	155	119	0	26	1	5	4
24 April	52	29	2	13	2	0	6
28 April	130	81	0	37	2	3	7
1 May	64	49	1	11	1	0	2
Total	**642**	**403**	**10**	**151**	**22**	**9**	**47**

Table 2. Net-specific summary of catch rates and mean ages of striped bass (n=642) in pound nets on the Rappahannock River, spring, 2008. Values in bold are the 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
31 March	S454	94	20.5	3.0	30,937.8	22,170.8	4.1	8.9
3 April	S454	43	12.0	2.3	16,790.7	16,451.9	4.1	8.3
7 April	S462	13	2.0	1.3	2,474.0	4,548.5	3.4	5.8
10 April	S454	6	0.7	1.3	412.8	14,998.1	2.5	11.3
14 April	S462	33	4.3	4.0	7,981.1	26,239.4	4.7	8.6
17 April	S454	52	15.0	2.3	32,757.7	12,255.3	5.0	7.4
21 April	S462	155	37.5	1.3	47,715.3	9,451.6	4.1	10.0
24 April	S454	52	14.0	3.3	21,632.1	20,269.3	4.2	8.7
28 April	S473	130	30.3	2.3	51,467.7	16,208.8	4.5	9.6
1 May	S473	64	20.0	1.3	24,015.1	7,383.9	3.9	8.0
Totals	S454	247	12.9	2.5	21,158.2	17,537.9	4.3	8.7
	S462	201	14.6	2.2	19,390.1	13,413.1	4.1	8.3
	S473	194	25.1	1.8	37,741.4	11,796.4	4.3	9.1
Season		**642**	**16.1**	**2.3**	**23,868.6**	**14,975.4**	**4.2**	**8.6**

Table 3. Length frequencies (TL in mm) of striped bass sampled from the pound nets in the Rappahannock River, spring, 2008.

TL	n	TL	n	TL	n	TL	n	TL	n	TL	n
160-	1	**320-**	1	**480-**	28	**640-**	1	**800-**	4	**960-**	7
170-	0	**330-**	3	**490-**	27	**650-**	4	**810-**	3	**970-**	0
180-	0	**340-**	4	**500-**	29	**660-**	1	**820-**	1	**980-**	3
190-	0	**350-**	4	**510-**	30	**670-**	0	**830-**	3	**990-**	3
200-	0	**360-**	8	**520-**	15	**680-**	1	**840-**	4	**1000-**	2
210-	0	**370-**	8	**530-**	14	**690-**	2	**850-**	3	**1010-**	0
220-	0	**380-**	8	**540-**	22	**700-**	1	**860-**	0	**1020-**	1
230-	1	**390-**	12	**550-**	21	**710-**	2	**870-**	3	**1030-**	0
240-	0	**400-**	13	**560-**	10	**720-**	3	**880-**	2	**1040-**	0
250-	0	**410-**	13	**570-**	8	**730-**	2	**890-**	5	**1050-**	1
260-	1	**420-**	28	**580-**	19	**740-**	0	**900-**	3	**1060-**	0
270-	0	**430-**	34	**590-**	7	**750-**	5	**910-**	4	**1070-**	1
280-	0	**440-**	21	**600-**	10	**760-**	2	**920-**	1	**1080-**	0
290-	1	**450-**	30	**610-**	10	**770-**	3	**930-**	3	**1090-**	0
300-	2	**460-**	45	**620-**	7	**780-**	4	**940-**	5	**1100-**	0
310-	0	**470-**	44	**630-**	0	**790-**	6	**950-**	4	**1110-**	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, 31 March – 3 May, 2008.

Year			Fork Length		Weight		CPUE	
Class	Sex	n	Mean	SD	Mean	SD	F/day	W/day
2007	male	1	151.0		48.9		0.0	1.4
2006	male	4	280.3	29.0	315.7	91.3	0.1	36.1
	female	2	248.5	41.7	217.5	86.1	0.1	12.4
2005	male	152	378.5	30.0	720.1	166.9	4.3	3,127.3
	female	2	375.5	4.9	651.6	11.5	0.1	37.2
2004	male	246	448.0	25.2	1,189.1	229.1	7.1	8,357.7
	female	6	462.5	18.2	1,519.9	240.3	0.2	260.6
2003	male	105	525.2	26.9	1,979.0	341.8	3.0	5,937.0
	female	9	554.7	34.6	2,622.6	408.1	0.3	674.4
2002	male	16	583.9	30.3	2,721.4	568.9	0.5	1,244.1
	female	2	609.5	3.5	3,257.0	300.7	0.1	186.1
2001	male	17	681.9	43.6	4,142.0	655.0	0.5	2,011.8
	female	4	715.3	31.4	4,777.9	1,132.0	0.1	546.0
2000	male	13	740.4	24.6	5,162.7	668.9	0.4	1,917.6
	female	7	773.9	28.6	6,210.3	455.0	0.2	1,242.1
1999	male	5	801.6	22.2	6,042.7	626.9	0.1	863.2
	female	5	803.2	28.6	6,633.3	382.8	0.1	947.6
1998	male	1	745.0		5,273.8		0.0	150.7
	female	14	861.7	27.1	8,266.4	1,397.5	0.4	3,306.6
1997	male	2	788.0	89.1	6,410.0	1,452.0	0.1	366.3
	female	13	893.8	29.9	9,502.6	1,088.7	0.4	3,529.5
1996	male	1	845.0		8,661.8		0.0	247.5
	female	15	921.6	47.4	10,170.9	1,854.5	0.4	4,359.0

Table 5. Summary of the season mean (31 March – 3 May) catch rates and ages, by sex, from the pound nets in the Rappahannock River, 31 March– 3 May, 1993-2008. M = male, F = female.

Year	n	CPUE (fish/day)		CPUE (g/day)		Mean age	
		M	F	M	F	M	F
2008	642	16.1	2.3	23,868.6	14,975.4	4.2	8.6
2007	1,104	21.4	13.2	47,614.4	87,666.9	5.0	10.5
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	53,437.0	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	636.9	15.9	4.7	26,532.9	33,431.8	4.3	8.8

Table 6. Numbers of striped bass in three age categories (year classes 2004-2007, 2000-2003 and 1993-1999) from gill nets in the Rappahannock River, by sampling date, spring, 2008. M = male, F = female.

		Year Class					
		2004-2007		2000-2003		1993-1999	
Date	**n**	**M**	**F**	**M**	**F**	**M**	**F**
31 March	23*	3	0	14	0	2	3
3 April	8	1	0	1	1	0	5
7 April	5	1	0	0	0	0	4
10 April	7	0	0	2	0	1	4
14 April	18	4	0	7	1	1	5
17 April	65	10	0	37	2	4	12
21 April	119	61	0	48	1	4	5
24 April	15**	2	0	8	0	0	4
28 April	1	1	0	0	0	0	0
1 May	2	1	0	1	0	0	0
Total	**263**	**84**	**0**	**118**	**5**	**12**	**42**

***1 male – age unknown**
****1 female – age unknown**

Table 7. Summary of catch rates and mean ages of striped bass (n=263) from the two gill nets in the Rappahannock River, spring 2008. 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
31 March	23	20	3	62,218.6	32,781.7	6.0	12.3
3 April	8	2	6	5,376.2	51,978.8	5.0	10.0
7 April	5	1	4	685.9	38,979.5	3.0	11.5
10 April	7	3	4	14,880.4	34,567.3	7.7	10.5
14 April	18	12	6	35,726.1	49,912.2	5.5	10
17 April	65	51	14	151,921.7	130,631.1	5.9	10.4
21 April	119	113	6	226,772.2	38,481.9	4.8	9.5
24 April	15	10	5	23,215.5	51,276.8	5.2	10.6
28 April	1	1	0	1,165.2		4.0	
1 May	2	2	0	4,587.0		5.5	
Season	**263**	**21.5**	**4.8**	**52,654.9**	**42,860.9**	**5.3**	**10.4**

Table 8. Length frequencies (TL in mm) of striped bass sampled from the experimental nets in the Rappahannock River, spring, 2008.

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

Table 9. Mean fork length (mm), weight (g), standard deviation (SD) and CPUE (number per day; weight per day) of striped bass from gill nets in the Rappahannock River, 31 March – 3 May, 2008.

Year			Fork Length		Weight		CPUE	
Class	Sex	n	Mean	SD	Mean	SD	F/day	W/day
2005	male	24	394.8	18.8	840.1	104.7	2.4	2,016.2
2004	male	60	449.0	23.2	1,209.9	247.6	6.0	7,259.4
2003	male	62	528.5	26.1	2,114.1	330.6	6.2	13,107.4
	female	2	521.5	51.6	2,195.0	600.3	0.2	439.0
2002	male	22	600.7	41.0	3,043.6	653.2	2.2	6,695.9
	female	1	580.0		2,939.7		0.1	294.0
2001	male	22	666.6	41.9	4,023.1	616.0	2.2	8,850.8
2000	male	12	734.3	37.4	5,133.6	706.8	1.2	6,160.3
	female	2	715.5	37.5	5,635.0	839.7	0.2	1,127.0
1999	male	4	815.8	7.5	6,619.2	283.8	0.4	2,647.7
	female	5	814.8	36.6	7,903.8	1,796.9	0.5	3,951.9
1998	male	4	799.5	41.3	6,608.6	560.0	0.4	2,643.4
	female	12	854.3	25.2	7,757.0	1,177.8	1.2	9,308.4
1997	male	3	834.3	52.7	8,107.7	2,187.9	0.3	2,432.3
	female	11	883.8	32.1	9,759.6	1,357.6	1.1	10,735.6
1996	male	1	709.0		5,572.2		0.1	557.2
	female	10	914.2	34.4	10,558.7	1,981.4	1.0	10,558.7
1995	female	4	962.0	17.4	13,154.0	1,667.7	0.4	5,261.6
N/A	male	1	570		2,845.6		0.1	284.6
	female	1	926		11,848.2		0.1	1,184.8

Table 10. Summary of the season mean (31 March – 3 May) catch rates and mean ages, by sex, from the experimental gill nets in the Rappahannock River, 1993-2008. M = males, F = female.

Year	n	CPUE (fish/day)		CPUE (g/day)		Mean age	
		M	F	M	F	M	F
2008	263	21.5	4.8	52,654.9	42,860.9	5.3	10.4
2007	743	75.2	7.3	134,524.0	68,017.7	4.5	11.1
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	13,331.3	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	537.0	47.3	5.7	79,476.5	34,765.9	4.4	8.0

Table 11. Numbers of striped bass in three categories (year class 2004-2007, 2000-2003 and 1993-1999) from gill nets in the James River by sampling date, spring 2008. M = male, F = female.

Date	n	Year Class					
		2004-2007		2000-2003		1993-1999	
		M	F	M	F	M	F
31 March	60	35	0	12	1	1	11
3 April	96*	57	0	24	2	2	10
7 April	45	24	0	12	2	0	7
10 April	30	22	0	5	1	0	2
14 April	63	38	0	15	4	0	6
17 April	10	7	0	1	1	0	1
21 April	50	25	0	18	2	0	5
24 April	49	26	0	12	4	1	6
28 April	26	17	1	6	0	1	1
1 May	12	4	0	8	0	0	0
Total	**441**	**255**	**1**	**113**	**17**	**5**	**49**

***1 male – age unknown**

Table 12. Summary of catch rates and mean ages of striped bass (n=442) from the gill nets in the James River, spring 2008. Values in bold are grand means for each column. M = male, F = female.

Date	n	CPUE (fish/day)		CPUE (g/day)		Mean age	
		M	F	M	F	M	F
31 March	60	48	12	88,224.9	125,219.9	4.2	10.7
3 April	97*	84	13	148,316.0	113,125.6	4.2	10.1
7 April	45	36	9	72,302.1	75,810.3	4.4	9.8
10 April	30	27	3	39,338.5	31,704.9	3.7	10.7
14 April	63	53	10	93,210.5	86,035.0	4.2	9.6
17 April	10	8	2	10,538.1	17,348.0	3.6	9.5
21 April	50	43	7	90,299.0	57,525.6	4.6	9.9
24 April	49	39	10	71,382.6	50,176.0	4.4	9.2
28 April	26	24	2	51,300.4	11,039.8	4.7	6.5
1 May	12	12	0	27,834.0	0	5.1	
Season	**442**	**374**	**68**	**69,274.6**	**56,798.5**	**4.6**	**9.8**

*** 1 male – age unknown**

Table 13. Length frequencies (TL in mm) of striped bass sampled from the experimental gill nets in the James River, spring 2008.

TL	n	TL	n	TL	n	TL	n	TL	n	TL	n
300-	2	**460-**	22	**620-**	12	**780-**	0	**940-**	5	**1100-**	0
310-	0	**470-**	14	**630-**	5	**790-**	5	**950-**	3	**1110-**	0
320-	3	**480-**	25	**640-**	6	**800-**	0	**960-**	2	**1120-**	0
330-	2	**490-**	13	**650-**	2	**810-**	4	**970-**	4	**1130-**	0
340-	0	**500-**	12	**660-**	4	**820-**	4	**980-**	2	**1140-**	0
350-	3	**510-**	10	**670-**	3	**830-**	0	**990-**	1	**1150-**	0
360-	0	**520-**	18	**680-**	1	**840-**	3	**1000-**	1	**1160-**	0
370-	4	**530-**	14	**690-**	4	**850-**	2	**1010-**	1	**1170-**	0
380-	4	**540-**	7	**700-**	1	**860-**	1	**1020-**	3	**1180-**	0
390-	9	**550-**	12	**710-**	3	**870-**	4	**1030-**	0	**1190-**	0
400-	8	**560-**	9	**720-**	1	**880-**	0	**1040-**	0	**1200-**	0
410-	15	**570-**	11	**730-**	3	**890-**	3	**1050-**	0	**1210-**	0
420-	19	**580-**	7	**740-**	0	**900-**	3	**1060-**	3	**1220-**	0
430-	14	**590-**	5	**750-**	2	**910-**	4	**1070-**	0	**1230-**	0
440-	25	**600-**	8	**760-**	1	**920-**	3	**1080-**	0	**1240-**	0
450-	21	**610-**	10	**770-**	0	**930-**	5	**1090-**	1	**1250-**	0

Table 14. Mean fork length (mm), weight (g), standard deviation (SD) and CPUE (number per day; weight per day) of striped bass from gill nets in the James River, 31 March – 3 May, 2008.

Year			Fork Length		Weight		CPUE	
Class	Sex	n	Mean	SD	Mean	SD	F/day	W/day
2006	male	3	291.0	7.0	356.2	19.8	0.3	106.9
	female	1	304.0		405.8		0.1	40.6
2005	male	98	383.8	29.7	892.4	219.4	9.8	8,745.5
2004	male	154	450.3	26.5	1,442.3	282.5	15.4	22,211.0
2003	male	66	536.7	27.2	2,439.9	424.6	6.6	16,103.4
	female	2	555.0	41.0	2,930.7	768.1	0.2	586.2
2002	male	25	588.0	25.7	3,331.0	644.4	2.5	8,327.6
	female	4	624.8	31.4	3,952.2	615.8	0.4	1,580.8
2001	male	15	649.9	47.5	4,327.6	817.2	1.5	6,491.4
	female	3	727.7	25.3	5,429.2	655.4	0.3	1,628.8
2000	male	7	704.0	60.6	4,960.0	935.5	0.7	3,472.0
	female	8	771.6	18.7	7,049.2	717.7	0.8	5,639.4
1999	male	2	809.5	62.9	6,875.8	2,121.2	0.2	1,375.2
	female	7	819.7	24.7	7,937.5	569.5	0.7	5,556.2
1998	male	2	746.5	9.2	6,367.0	203.7	0.2	1,273.4
	female	13	854.5	21.1	8,854.9	596.3	1.3	11,511.4
1997	female	13	883.1	20.8	10,266.1	1,594.8	1.3	13,346.0
1996	male	1	911.0		10,449.0		0.1	1,044.9
	female	12	931.0	32.5	12,114.4	1,436.4	1.2	14,537.2
1995	female	1	940.0		12,233.2		0.1	1,223.3
1994	female	1	1,035.0		15,041.1		0.1	1,504.1
1993	female	2	1,009.5	9.2	15,689.4	184.1	0.2	3,137.8
N/A	male	1	432		1,230.7		0.1	123.1

Table 15. Summary of season mean (31 March – 3 May) catch rates and ages, by sex, from experimental gill nets in the James River, 1995-2008.

Year	mile	n	CPUE (fish/day)		CPUE (g/day)		Mean age	
			M	F	M	F	M	F
2008	62	442**	37.4	6.8	69,274.6	56,798.5	4.3	8.6
2007	62	426*	40.2	7.0	69,725.9	55,447.5	4.5	9.8
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		700.9	67.0	9.3	122,690.9	56,594.6	4.5	7.9

* **1 sex undetermined**
** **1 male – age unknown**

Table 16. Values of the spawning stock biomass index (SSBI) for male and female striped bass, by gear, in the Rappahannock River, 31 March – 3 May, 1991 – 2008.

Year	Pound nets					Gill nets				
	N		SSBI (kg/day)			N		SSBI (kg/day)		
	M	F	M	F	M+F	M	F	M	F	M+F
2008	558.0	77.0	24.2	15.1	39.3	215.0	48.0	52.7	42.9	95.6
2007	747.0	355.0	47.6	87.6	135.2	666.0	66.0	134.1	68.0	202.1
2006	647.0	122.0	25.8	24.7	50.5	275.0	56.0	49.2	39.6	88.8
2005	438.0	177.0	26.4	39.0	65.4	291.0	27.0	55.6	19.9	75.4
2004	703.0	247.0	58.5	65.4	123.9	714.0	74.0	171.9	52.0	223.9
2003	283.0	187.0	22.8	53.6	76.4	467.0	31.0	97.3	20.7	118.0
2002	113.0	57.0	7.1	11.4	18.5	240.0	78.0	53.4	40.7	94.1
2001	470.0	105.0	24.2	27.6	51.8	572.0	41.0	88.6	30.9	119.5
2000	1,436.0	71.0	42.7	14.6	57.3	452.0	27.0	65.3	16.5	81.8
1999	738.0	61.0	30.5	19.8	50.3	532.0	21.0	51.4	13.2	64.6
1998	273.0	113.0	14.8	36.4	51.2	485.0	27.0	81.5	18.5	100.0
1997	277.0	115.0	22.2	49.6	71.7	801.0	18.0	177.8	19.1	197.0
1996	334.0	73.0	14.1	9.3	23.4	433.0	46.0	63.7	30.2	93.9
1995	207.0	76.0	12.4	19.8	32.2	162.0	69.0	43.9	56.7	100.6
1994	195.0	141.0	17.1	30.9	48.0	391.0	100.0	101.6	64.7	166.3
1993	357.0	188.0	31.2	37.5	68.7	361.0	160.0	85.6	74.1	159.6
1992	51.0	100.0	5.4	19.4	24.8	61.0	74.0	15.0	32.2	47.2
1991	153.0	70.0	21.3	21.5	42.8	406.0	47.0	65.0	17.8	83.8
Mean	**443.3**	**129.7**	**24.9**	**32.4**	**57.3**	**418.0**	**56.1**	**80.8**	**36.5**	**117.3**

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, 31 March – 3 May, 1994-2008. The 1994 catch 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).

	River	n		SSBI (kg/day)		
Year	**Mile**	**Male**	**Female**	**Male**	**Female**	**M+F**
2008	**62**	374	67	69.27	60.25	129.52
2007	**62**	361	63	69.70	55.40	125.10
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		**577.8**	**83.3**	**111.57**	**56.04**	**167.61**

Table 18. Predicting 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, 31 March – 3 May, 2008. 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	6	0.119	1.37	0	0.000	0.00	0	0.000	0.00
5	9	0.317	3.66	2	0.058	0.89	2	0.070	0.79
6	2	0.094	1.08	1	0.040	0.61	4	0.204	2.30
7	4	0.311	3.59	0	0.000	0.00	3	0.245	2.77
8	7	0.696	8.03	2	0.156	2.36	8	0.786	8.87
9	5	0.558	6.44	5	0.585	8.89	7	0.832	9.39
10	14	1.948	22.49	12	1.624	24.67	13	1.759	19.85
11	13	2.030	23.43	11	1.659	25.20	13	1.951	22.01
12	15	2.590	29.90	10	1.677	25.47	12	2.130	24.03
13	0	0.000	0.00	4	0.784	11.92	1	0.182	2.06
14	0	0.000	0.00	0	0.000	0.00	1	0.246	2.78
15	0	0.000	0.00	0	0.000	0.00	2	0.456	5.14
Total	75	**8.663**	100.00	47	**6.583**	100.00	66	**8.861**	100.00

Table 20a. Catch rates (fish/day) of year classes of striped bass (sexes combined) sampled from pound nets in the Rappahannock River, 31 March – 3 May, 1991-2008. 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, 31 March - 3 May, 1991-2008. Maximum catch rate for each year class during the sampling period is in bold type.

Year	CPUE (fish/day)							
Class	2001	2002	2003	2004	2005	2006	2007	2008
2006								**0.17**
2005							0.03	**4.40**
2004							2.52	**7.20**
2003						7.89	**8.55**	3.26
2002					1.83	6.40	**6.17**	0.51
2001				3.47	**5.43**	3.17	1.14	0.60
2000			0.76	**5.57**	2.77	0.14	1.12	0.57
1999	0.07	0.51	3.00	**5.90**	0.71	0.51	1.51	0.29
1998	2.74	1.44	3.33	**3.50**	0.77	0.91	1.89	0.43
1997	7.49	1.38	0.37	2.23	1.69	0.86	2.68	0.43
1996	4.29	0.25	1.83	4.16	1.69	1.17	3.80	0.46
1995	0.10	0.68	1.40	2.33	0.94	0.23	0.71	0.00
1994	0.58	0.41	1.70	1.67	0.69	0.20	0.71	0.00
1993	0.87	0.28	1.43	1.00	0.57	0.20	0.46	0.00
1992	0.87	0.19	1.13	1.10	0.29	0.11	0.20	0.00
1991	0.81	0.06	0.33	0.17	0.09	0.00	0.00	0.00
1990	0.45	0.00	0.27	0.07	0.03	0.00	0.03	0.00
1989	0.26	0.00	0.07	0.07	0.03	0.00	0.00	0.00
1988	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.03	0.03	0.00	0.03	0.00	0.00	0.00
N/A	0.00	0.00	0.00	0.40	0.49	0.26	0.00	0.00
Total	**18.63**	**5.23**	**15.65**	**31.64**	**18.05**	**22.05**	**31.52**	**18.35**

Table 21a. Catch rates (fish/day) of year classes of male striped bass sampled from pound nets in the Rappahannock River, 31 March - 3 May, 1991-2008. 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, 31 March - 3 May, 1991-2008. Maximum catch rate for each year class during the sampling period is in bold type.

Year	CPUE (fish/day)							
Class	2001	2002	2003	2004	2005	2006	2007	2008
2006								**0.11**
2005							0.03	**4.34**
2004							2.49	**7.03**
2003						7.77	**8.46**	3.00
2002					1.83	**6.29**	5.83	0.46
2001				3.47	**5.40**	2.91	0.97	0.49
2000			0.76	**5.47**	2.49	0.09	1.03	0.37
1999	0.07	0.44	2.93	**5.67**	0.66	0.20	1.00	0.14
1998	2.74	1.38	3.07	**3.37**	0.51	0.57	0.89	0.03
1997	7.42	1.25	0.30	1.93	1.00	0.29	0.37	0.06
1996	4.03	0.25	1.50	2.23	0.43	0.03	0.29	0.03
1995	0.10	0.16	0.56	0.53	0.09	0.00	0.00	0.00
1994	0.39	0.03	0.23	0.20	0.09	0.06	0.00	0.00
1993	0.16	0.03	0.07	0.10	0.00	0.00	0.00	0.00
1992	0.19	0.00	0.00	0.07	0.00	0.00	0.00	0.00
1991	0.13	0.00	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	0.00	0.00
N/A	0.00	0.00	0.00	0.40	0.46	0.29	0.00	0.00
Total	**15.23**	**3.54**	**9.42**	**23.44**	**12.96**	**18.50**	**21.36**	**16.09**

Table 22a. Catch rates (fish/day) of year classes of female striped bass sampled from pound nets in the Rappahannock River, 31 March - 3 May, 1991-2008. 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, 31 March - 3 May, 1991-2008. Maximum catch rate for each year class during the sampling period is in bold type.

Year	CPUE (fish/day)							
Class	2001	2002	2003	2004	2005	2006	2007	2008
2006								**0.06**
2005							0.00	**0.06**
2004							0.03	**0.17**
2003						0.11	0.09	**0.26**
2002						0.11	**0.34**	0.06
2001					0.03	**0.26**	0.17	0.11
2000				0.10	**0.29**	0.06	0.09	0.20
1999		0.06	0.07	0.23	0.06	0.31	**0.51**	0.14
1998		0.06	0.27	0.17	0.26	0.34	**1.00**	0.40
1997	0.07	0.13	0.07	0.30	0.69	0.57	**2.31**	0.37
1996	0.26	0.00	0.37	1.93	1.26	1.14	**3.51**	0.43
1995	0.00	0.63	0.80	**1.80**	0.86	0.23	0.71	0.00
1994	0.19	0.38	**1.47**	**1.47**	0.60	0.14	0.71	0.00
1993	0.71	0.25	**1.37**	0.90	0.54	0.20	0.46	0.00
1992	0.68	0.19	**1.13**	1.03	0.29	0.11	0.20	0.00
1991	**0.68**	0.06	0.33	0.17	0.09	0.00	0.00	0.00
1990	0.45	0.00	0.26	0.07	0.03	0.00	0.03	0.00
1989	0.26	0.00	0.07	0.07	0.03	0.00	0.00	0.00
1988	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.03	0.03	0.00	0.03	0.00	0.00	0.00
N/A	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
Total	**3.40**	**1.79**	**6.24**	**8.24**	**5.09**	**3.58**	**10.16**	**2.26**

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, 31 March - 3 May, 1991-2008.

Year	Survival (S)									
Class	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01
2001										
2000										
1999										
1998										
1997										0.480
1996										0.237
1995									0.290	0.914
1994								0.441	0.884	0.884
1993							0.183	0.993	0.993	0.993
1992					0.596	0.437	0.983	0.983	0.983	0.983
1991						0.869	0.869	0.869	0.869	0.869
1990					0.563	0.745	0.745	0.863	0.863	0.863
1989				0.440	0.440	0.899	0.975	0.689	0.689	0.703
1988			0.233	0.877	0.877	0.877	0.593	0.438	0.506	0.506
1987	0.456	0.456	0.315	0.954	0.954	0.954	0.890	0.483	0.116	0.903
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, 31 March - 3 May, 1991-2008.

Year Class	Survival (S)							
	01-02	02-03	03-04	04-05	05-06	06-07	07-08	Mean
2002						0.964	0.083	0.283
2001	-----	-----	-----	-----	0.584	0.360	0.526	0.480
2000	-----	-----	-----	0.497	0.636	0.636	0.509	0.566
1999	-----	-----	-----	0.635	0.635	0.635	0.192	0.471
1998	-----	-----	-----	0.814	0.814	0.814	0.228	0.592
1997	0.843	0.843	0.843	0.843	0.843	0.843	0.160	0.638
1996	0.980	0.980	0.980	0.980	0.980	0.980	0.121	0.632
1995	0.914	0.914	0.914	0.403	0.869	0.869	0.000	0.638
1994	0.884	0.884	0.982	0.752	0.752	0.752	0.000	0.693
1993	0.993	0.993	0.699	0.570	0.898	0.898	0.000	0.707
1992	0.983	0.983	0.973	0.264	0.830	0.830	0.000	0.721
1991	0.869	0.638	0.515	0.529	0.000	-----	-----	0.663
1990	0.863	0.775	0.259	0.754	0.754	0.754	0.000	0.654
1989	0.703	0.646	0.646	0.429	0.000	-----	-----	0.584
1988	0.000	-----	-----	-----	-----	-----	-----	0.516
1987	0.903	0.903	0.903	0.903	0.000	-----	-----	0.637
1986	-----	-----	-----	-----	-----	-----	-----	0.621
1985	-----	-----	-----	-----	-----	-----	-----	0.621
1984	-----	-----	-----	-----	-----	-----	-----	0.571
1983	-----	-----	-----	-----	-----	-----	-----	0.620

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, 31 March - 3 May, 1991-2008.

Year	Survival (S)									
Class	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01
2002										
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	0.315	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	0.505	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, 31 March - 3 May, 1991-2008.

Year Class	Survival (S)							
	01-02	02-03	03-04	04-05	05-06	06-07	07-08	Mean
2002	-----	-----	-----	-----	-----	0.927	0.079	0.271
2001	-----	-----	-----	-----	0.539	0.333	0.305	0.380
2000	-----	-----	-----	0.455	0.643	0.643	0.359	0.510
1999	-----	-----	-----	0.561	0.561	0.561	0.140	0.397
1998	-----	-----	-----	0.642	0.642	0.642	0.034	0.308
1997	0.638	0.638	0.638	0.518	0.608	0.608	0.162	0.499
1996	0.821	0.821	0.821	0.193	0.821	0.821	0.103	0.491
1995	0.559	0.559	0.946	0.170	0.000	-----	-----	0.409
1994	0.768	0.768	0.870	0.450	0.667	0.000	-----	0.500
1993	0.855	0.855	0.855	0.000	-----	-----	-----	0.496
1992	0.717	0.717	0.717	0.000	-----	-----	-----	0.554
1991	0.000	-----	-----	-----	-----	-----	-----	0.508
1990	-----	-----	-----	-----	-----	-----	-----	0.353
1989	-----	-----	-----	-----	-----	-----	-----	0.395
1988	-----	-----	-----	-----	-----	-----	-----	0.335
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, 31 March - 3 May, 1991-2008.

Year	Survival (S)									
Class	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01
1999										
1998										
1997										
1996										
1995										
1994										
1993										
1992										
1991										
1990								0.914	0.914	0.914
1989				0.912	0.912	0.912	0.912	0.679	0.679	0.764
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	0.182	0.000	-----
1985	0.743	0.743	0.743	0.900	0.900	0.900	0.429	0.733	0.000	-----
1984			0.915	0.915	0.915	0.915	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, 31 March - 3 May, 1991-2008.

Year Class	Survival (S)							
	01-02	02-03	03-04	04-05	05-06	06-07	07-08	Mean
1999	-----	-----	-----	-----	-----	-----	0.275	0.275
1998	-----	-----	-----	-----	-----	-----	0.400	0.400
1997	-----	-----	-----	-----	-----	-----	0.160	0.160
1996	-----	-----	-----	-----	-----	-----	0.123	0.123
1995	-----	-----	-----	0.478	0.909	0.909	0.000	0.523
1994	-----	-----	0.834	0.834	0.834	0.834	0.000	0.624
1993	-----	-----	0.657	0.600	0.906	0.906	0.000	0.573
1992	-----	-----	0.912	0.282	0.830	0.830	0.000	0.524
1991	0.697	0.697	0.515	0.529	0.000	-----	-----	0.461
1990	0.760	0.760	0.269	0.754	0.754	0.754	0.000	0.649
1989	0.646	0.646	0.646	0.429	0.000	-----	-----	0.655
1988	0.000	-----	-----	-----	-----	-----	-----	0.607
1987	0.902	0.902	0.902	0.902	0.000	-----	-----	0.675
1986	-----	-----	-----	-----	-----	-----	-----	0.646
1985	-----	-----	-----	-----	-----	-----	-----	0.648
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, 31 March - 3 May, 1991-2008. 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, 31 March - 3 May, 1991-2008. Maximum catch rate for each year class during the sampling period is in bold type.

Year	CPUE (fish/day)							
Class	2001	2002	2003	2004	2005	2006	2007	2008
2005							1.22	**2.40**
2004						0.40	**20.67**	6.00
2003					0.40	9.20	**31.11**	6.40
2002				4.10	4.00	**8.20**	7.89	2.30
2001			2.70	**21.78**	11.80	4.90	6.11	2.20
2000		0.50	8.80	**16.22**	6.60	2.80	4.00	1.40
1999	0.90	1.10	16.00	**10.74**	2.40	1.10	2.55	0.90
1998	9.50	8.80	**12.60**	10.00	1.90	1.90	2.55	1.60
1997	**27.00**	10.20	4.60	10.32	1.40	1.60	2.00	1.40
1996	17.70	4.60	4.20	7.58	1.30	1.80	2.33	1.10
1995	2.10	3.50	1.60	2.74	0.20	0.40	0.22	0.40
1994	1.50	1.20	1.30	1.68	0.30	0.80	0.56	0.00
1993	1.00	1.00	0.50	0.64	0.10	0.20	0.67	0.00
1992	1.10	0.30	0.00	0.42	0.10	0.00	0.56	0.00
1991	0.90	0.30	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.10	0.00	0.10	0.00	0.00	0.00	0.00	0.00
1989	0.10	0.00	0.00	0.00	0.00	0.00	0.11	0.00
1988	0.00	0.00	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	0.00	0.00
1985	0.20	0.00	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	0.00	0.20
Total	**62.40**	**32.30**	**52.50**	**87.06**	**30.90**	**33.50**	**82.55**	**26.30**

Table 27a. Catch rates (fish/day) of year classes of male striped bass sampled from gill nets in the Rappahannock River, 31 March - 3 May, 1991-2008. 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, 31 March - 3 May, 1991-2008. Maximum catch rate for each year class during the sampling period is in bold type.

Year	CPUE (fish/day)							
Class	2001	2002	2003	2004	2005	2006	2007	2008
2005							1.22	**2.40**
2004						0.40	**20.67**	6.00
2003					0.40	9.20	**31.00**	6.20
2002				4.10	4.00	**7.90**	7.11	2.20
2001			2.70	**21.78**	11.80	4.60	5.78	2.20
2000		0.50	8.80	**16.00**	6.50	2.30	4.00	1.20
1999	0.90	1.10	15.90	**10.52**	2.40	1.00	2.11	0.40
1998	9.40	8.70	**12.10**	9.68	1.70	0.80	2.11	0.40
1997	**27.00**	8.80	4.30	9.68	1.30	0.70	0.89	0.30
1996	17.00	3.30	3.80	5.68	0.70	0.60	0.33	0.10
1995	1.90	1.40	1.20	0.64	0.10	0.10	0.00	0.00
1994	1.30	0.20	0.40	0.32	0.10	0.10	0.00	0.00
1993	0.40	0.20	0.00	0.00	0.00	0.00	0.00	0.00
1992	0.00	0.00	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	0.00	0.00
1990	0.00	0.00	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	0.00	0.00
N/A	0.20	0.80	0.10	0.84	0.40	0.20	0.00	0.10
Total	**58.10**	**25.00**	**49.30**	**79.24**	**29.40**	**27.90**	**75.22**	**21.50**

Table 28a. Catch rates (fish/day) of year classes of female striped bass sampled from gill nets in the Rappahannock River, 31 March - 3 May, 1991-2008. 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, 31 March - 3 May, 1991-2008. Maximum catch rate for each year class during the sampling period is in bold type.

Year	CPUE (fish/day)							
Class	2001	2002	2003	2004	2005	2006	2007	2008
2003							0.11	**0.20**
2002						0.30	**0.78**	0.10
2001						0.30	**0.33**	0.00
2000				0.22	0.10	**0.50**	0.00	0.20
1999			0.10	0.22	0.00	0.10	0.44	**0.50**
1998	0.10	0.10	0.50	0.32	0.20	1.10	0.44	**1.20**
1997	0.00	**1.40**	0.30	0.64	0.10	0.90	1.11	1.10
1996	0.70	1.60	0.40	1.90	0.60	1.20	**2.00**	1.00
1995	0.20	**2.10**	0.40	**2.10**	0.10	0.30	0.22	0.40
1994	0.20	1.00	0.90	**1.36**	0.20	0.70	0.56	0.00
1993	0.60	**0.80**	0.50	0.64	0.10	0.20	0.67	0.00
1992	**1.10**	0.30	0.00	0.42	0.10	0.00	0.56	0.00
1991	**0.90**	0.30	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.10	0.00	0.10	0.00	0.00	0.00	0.00	0.00
1989	0.10	0.00	0.00	0.00	0.00	0.00	0.11	0.00
1988	0.00	0.00	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	0.00	0.00
N/A	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.10
Total	**4.10**	**8.40**	**3.20**	**7.82**	**1.50**	**5.60**	**7.33**	**4.80**

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, 31 March - 3 May, 1991-2008.

Year	Survival (S)									
Class	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01
2002										
2001										
2000										
1999										
1998										
1997										
1996									0.594	0.833
1995								0.908	0.546	0.777
1994								0.098	0.559	0.984
1993							0.084	0.535	0.535	0.707
1992							0.289	0.289	0.957	0.957
1991						0.496	0.470	0.878	0.878	0.878
1990				0.943	0.452	0.620	0.152	0.798	0.798	0.781
1989				0.163	0.556	0.268	0.495	0.606	0.928	0.928
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	0.929	0.929	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	0.456	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, 31 March - 3 May, 1991-2008.

Year	Survival (S)							
Class	01-02	02-03	03-04	04-05	05-06	06-07	07-08	Mean
2002	-----	-----	-----	-----	-----	0.962	0.292	0.530
2001	-----	-----	-----	0.542	0.720	0.720	0.360	0.564
2000	-----	-----	-----	0.407	0.778	0.778	0.350	0.542
1999	-----	-----	-----	0.619	0.619	0.619	0.353	0.538
1998	-----	-----	0.794	0.634	0.634	0.634	0.627	0.662
1997	0.726	0.726	0.726	0.579	0.579	0.579	0.700	0.655
1996	0.754	0.754	0.754	0.675	0.675	0.675	0.472	0.679
1995	0.777	0.885	0.885	0.618	0.618	0.618	0.618	0.714
1994	0.984	0.984	0.984	0.690	0.690	0.700	0.000	0.625
1993	0.707	0.923	0.923	0.923	0.923	0.923	0.000	0.616
1992	0.894	0.894	0.894	0.894	0.894	0.894	0.000	0.676
1991	0.333	0.000	-----	-----	-----	-----	-----	0.527
1990	0.781	0.781	0.000	-----	-----	-----	-----	0.579
1989	0.928	0.928	0.928	0.928	0.928	0.928	0.000	0.644
1988	-----	-----	-----	-----	-----	-----	-----	0.408
1987	0.000	-----	-----	-----	-----	-----	-----	0.569
1986	-----	-----	-----	-----	-----	-----	-----	0.529
1985	0.000	-----	-----	-----	-----	-----	-----	0.659
1984	-----	-----	-----	-----	-----	-----	-----	0.493
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, 31 March - 3 May, 1991-2008.

Year	Survival (S)									
Class	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01
2002										
2001										
2000										
1999										
1998										
1997										
1996									0.567	0.811
1995								0.908	0.536	0.335
1994								0.080	0.707	0.707
1993							0.078	0.461	0.461	0.292
1992							0.254	0.254	0.122	0.000
1991						0.446	0.268	0.448	0.000	-----
1990				0.852	0.457	0.572	0.120	0.000	-----	-----
1989				0.104	0.532	0.357	0.000	-----	-----	-----
1988			0.241	0.231	0.442	0.340	0.767	0.767	0.000	-----
1987	0.429	0.429	0.079	0.394	0.769	0.000	-----	-----	-----	-----
1986	0.119	0.738	0.122	0.000	-----	-----	-----	-----	-----	-----
1985	0.520	0.520	0.520	0.000	-----	-----	-----	-----	-----	-----
1984	0.537	0.537	0.537	0.000	-----	-----	-----	-----	-----	-----
1983	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

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, 31 March - 3 May, 1991-2008.

Year Class	Survival (S)							
	01-02	02-03	03-04	04-05	05-06	06-07	07-08	Mean
2002	-----	-----	-----	-----	-----	0.900	0.309	0.527
2001	-----	-----	-----	0.542	0.670	0.670	0.381	0.552
2000	-----	-----	-----	0.406	0.784	0.784	0.300	0.523
1999	-----	-----	-----	0.228	0.938	0.938	0.190	0.442
1998	-----	-----	0.800	0.602	0.602	0.602	0.190	0.506
1997	0.710	0.710	0.710	0.134	0.827	0.827	0.337	0.525
1996	0.694	0.694	0.694	0.123	0.857	0.550	0.303	0.518
1995	0.737	0.857	0.533	0.395	0.395	0.000	-----	0.496
1994	0.555	0.555	0.800	0.565	0.565	0.000	-----	0.477
1993	0.500	0.000	-----	-----	-----	-----	-----	0.283
1992	-----	-----	-----	-----	-----	-----	-----	0.153
1991	-----	-----	-----	-----	-----	-----	-----	0.276
1990	-----	-----	-----	-----	-----	-----	-----	0.369
1989	-----	-----	-----	-----	-----	-----	-----	0.231
1988	-----	-----	-----	-----	-----	-----	-----	0.373
1987	-----	-----	-----	-----	-----	-----	-----	0.326
1986	-----	-----	-----	-----	-----	-----	-----	0.215
1985	-----	-----	-----	-----	-----	-----	-----	0.369
1984	-----	-----	-----	-----	-----	-----	-----	0.380
1983	-----	-----	-----	-----	-----	-----	-----	-----

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, 31 March - 3 May, 1991-2008.

Year	Survival (S)									
Class	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01
2002										
2001										
2000										
1999										
1998										
1997										
1996										
1995										
1994										
1993										
1992										
1991										
1990					0.663	0.663	0.860	0.860	0.860	0.476
1989				0.847	0.585	0.548	0.548	0.606	0.928	0.928
1988			0.653	0.526	0.756	0.756	0.330	0.577	0.577	0.000
1987			0.287	0.916	0.920	0.333	0.220	0.969	0.969	0.969
1986		0.806	0.901	0.901	0.217	0.856	0.856	0.000	-----	-----
1985	0.911	0.911	0.911	0.567	0.719	0.719	0.719	0.719	0.000	-----
1984	0.713	0.914	0.914	0.446	0.000	-----	-----	-----	-----	-----
1983			0.430	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, 31 March - 3 May, 1991-2008.

Year	Survival (S)							
Class	01-02	02-03	03-04	04-05	05-06	06-07	07-08	Mean
2002	-----	-----	-----	-----	-----	-----	0.128	0.128
2001	-----	-----	-----	-----	-----	-----	0.000	0.000
2000	-----	-----	-----	-----	-----	0.632	0.632	0.632
1999	-----	-----	-----	-----	-----	-----	-----	-----
1998	-----	-----	-----	-----	-----	-----	-----	-----
1997	-----	0.955	0.955	0.955	0.955	0.955	0.991	0.961
1996	-----	-----	-----	-----	-----	-----	0.500	0.500
1995	-----	-----	-----	0.378	0.378	0.733	0.661	0.513
1994	-----	-----	-----	0.717	0.717	0.800	0.000	0.518
1993	-----	0.965	0.965	0.965	0.965	0.965	0.000	0.756
1992	0.894	0.894	0.894	0.894	0.894	0.894	0.000	0.729
1991	0.333	0.000	-----	-----	-----	-----	-----	0.155
1990	0.000	-----	-----	-----	-----	-----	-----	0.595
1989	0.928	0.928	0.928	0.928	0.928	0.928	0.000	0.730
1988	-----	-----	-----	-----	-----	-----	-----	0.501
1987	0.000	-----	-----	-----	-----	-----	-----	0.496
1986	-----	-----	-----	-----	-----	-----	-----	0.605
1985	-----	-----	-----	-----	-----	-----	-----	0.660
1984	-----	-----	-----	-----	-----	-----	-----	0.555
1983	-----	-----	-----	-----	-----	-----	-----	0.207

Table 32a. Catch rates (fish/day) of year classes of striped bass (sexes combined) sampled from gill nets (mile 62) in the James River, 31 March - 3 May, 1994-2008. 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 (mile 62) in the James River, 31 March - 3 May, 1994-2008. Maximum catch rate for each year class during the sampling period is in bold type.

Year	CPUE (fish/day)				
Class	2004	2005	2006	2007	2008
2006					**0.40**
2005				0.11	**9.80**
2004			0.50	12.22	**15.40**
2003		0.90	**27.60**	12.44	6.80
2002	0.36	14.70	**37.00**	9.00	2.90
2001	30.54	27.50	**33.70**	4.66	1.80
2000	**48.00**	19.90	9.80	1.33	1.50
1999	28.00	7.70	3.90	1.44	0.90
1998	11.82	5.10	2.60	1.34	1.50
1997	4.08	1.60	2.90	2.00	1.30
1996	3.56	1.60	3.90	1.90	1.30
1995	1.36	0.60	1.00	0.10	0.10
1994	1.00	0.50	1.00	0.10	0.10
1993	0.28	0.30	1.10	0.40	0.20
1992	0.38	0.10	0.10	0.10	0.00
1991	0.00	0.10	0.40	0.00	0.00
1990	0.00	0.00	0.40	0.00	0.00
1989	0.00	0.00	0.00	0.10	0.00
1988	0.00	0.00	0.00	0.00	0.00
N/A	2.36	1.40	2.40	0.00	0.10
Total	**131.74**	**82.00**	**128.30**	**47.24**	**44.10**

Table 33a. Catch rates (fish/day) of year classes of male striped bass sampled from gill nets (mile 62) in the James River, 31 March - 3 May, 1994-2008. 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 (mile 62) in the James River, 31 March - 3 May, 1994-2008. Maximum catch rate for each year class during the sampling period is in bold type.

Year	CPUE (fish/day)				
Class	2004	2005	2006	2007	2008
2006					**0.30**
2005				0.11	**9.80**
2004			0.50	12.22	**15.40**
2003		0.90	**27.60**	12.33	6.60
2002	0.36	14.70	**36.90**	8.33	2.50
2001	30.54	27.30	**32.30**	4.33	1.50
2000	**47.82**	19.60	8.70	0.89	0.70
1999	27.64	7.50	3.50	1.11	0.20
1998	10.46	4.90	2.20	0.56	0.20
1997	3.90	1.00	1.40	0.22	0.00
1996	2.28	1.20	0.60	0.10	0.10
1995	0.54	0.10	0.10	0.00	0.00
1994	1.00	0.30	0.10	0.00	0.00
1993	0.00	0.10	0.00	0.00	0.00
1992	0.10	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.10	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.00
N/A	2.36	1.40	2.40	0.00	0.10
Total	**127.00**	**79.00**	**116.40**	**40.20**	**37.40**

Table 34a. Catch rates (fish/day) of year classes of female striped bass sampled from gill nets (mile 62) in the James River, 31 March - 3 May, 1994-2008. 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 (mile 62) in the James River, 31 March - 3 May, 1994-2008. Maximum catch rate for each year class during the sampling period is in bold type.

Year	CPUE (fish/day)				
Class	2004	2005	2006	2007	2008
2003				**0.11**	0.20
2002			0.10	**0.67**	0.40
2001		0.20	**1.40**	0.33	0.30
2000	0.18	0.30	**1.10**	0.44	0.80
1999	0.18	0.20	0.40	0.33	**0.70**
1998	0.36	0.20	0.40	0.78	1.30
1997	0.18	0.60	1.50	1.78	1.30
1996	1.28	0.40	3.30	1.70	1.20
1995	0.82	0.50	0.90	0.10	0.10
1994	1.00	0.20	0.90	0.10	0.10
1993	0.28	0.20	1.10	0.40	0.20
1992	0.28	0.10	0.10	0.10	0.00
1991	0.00	0.10	0.30	0.00	0.00
1990	0.00	0.00	0.40	0.00	0.00
1989	0.00	0.00	0.10	0.10	0.00
1988	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.00
N/A	0.00	0.00	0.00	0.00	0.00
Total	**4.56**	**3.00**	**12.00**	**6.94**	**6.60**

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, 31 March - 3 May, 1994-2008.

Year	Survival (S)									
Class	94-95	95-96	96-97	97-98	98-99	99-00	00-01	01-02	02-03	03-04
2003										
2002										
2001										
2000										
1999										0.895
1998									0.973	0.410
1997								0.928	0.203	0.510
1996							0.445	0.337	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	0.919
1988	0.834	0.734	0.734	0.542	0.513	0.275	0.000	-----	-----	-----
1987		0.645	0.645	0.949	0.949	0.000	-----	-----	-----	-----
1986		0.449	0.413	0.953	0.953	0.000	-----	-----	-----	-----
1985		0.246	0.733	0.500	0.909	0.000	-----	-----	-----	-----
1984	0.650	0.256	0.550	0.000	-----	-----	-----	-----	-----	-----

Table 35b. Estimated annual and geometric mean survival (S) rates for year classes of striped bass (sexes combined) sampled from gill nets in the James River, 31 March - 3 May, 1994-2008.

Year Class	Survival (S)				
	04-05	05-06	06-07	07-08	Mean
2003	-----	-----	0.451	0.547	0.497
2002	-----	-----	0.243	0.322	0.280
2001	-----	-----	0.138	0.386	0.231
2000	0.415	0.492	0.391	0.391	0.420
1999	0.275	0.506	0.369	0.625	0.492
1998	0.431	0.510	0.760	0.760	0.608
1997	0.843	0.843	0.690	0.650	0.608
1996	0.772	0.772	0.487	0.684	0.604
1995	0.857	0.857	0.316	0.316	0.475
1994	0.974	0.974	0.316	0.316	0.591
1993	0.928	0.928	0.364	0.500	0.684
1992	0.641	0.641	0.641	0.000	0.667
1991	0.768	0.768	0.000	-----	0.677
1990	0.956	0.956	0.000	-----	0.699
1989	0.919	0.919	0.919	0.000	0.648
1988	-----	-----	-----	-----	0.491
1987	-----	-----	-----	-----	0.593
1986	-----	-----	-----	-----	0.508
1985	-----	-----	-----	-----	0.440
1984	-----	-----	-----		0.338

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, 31 March - 3 May, 1994-2008.

Year	Survival (S)									
Class	94-95	95-96	96-97	97-98	98-99	99-00	00-01	01-02	02-03	03-04
2003										
2002										
2001										
2000										
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	0.838	0.838	0.838
1993				0.972	0.661	0.672	0.655	0.357	0.357	0.845
1992		0.664	0.832	0.717	0.833	0.833	0.172	0.794	0.794	0.794
1991		0.456	0.400	0.694	0.736	0.736	0.736	0.758	0.758	0.758
1990	0.597	0.237	0.887	0.475	0.475	0.000	-----	-----	-----	-----
1989	0.291	0.300	0.629	0.000	-----	-----	-----	-----	-----	-----
1988	0.400	0.536	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, 31 March - 3 May, 1994-2008.

Year	Survival (S)				
Class	04-05	05-06	06-07	07-08	Mean
2003	-----	-----	0.447	0.535	0.489
2002	-----	-----	0.226	0.300	0.260
2001	-----	-----	0.134	0.346	0.215
2000	0.410	0.444	0.102	0.787	0.348
1999	0.271	0.467	0.317	0.180	0.363
1998	0.468	0.449	0.255	0.357	0.437
1997	0.599	0.599	0.157	0.000	0.391
1996	0.526	0.500	0.167	0.408	0.392
1995	0.430	0.430	0.000	-----	0.326
1994	0.300	0.333	0.000	-----	0.434
1993	0.845	0.000	-----	-----	0.566
1992	0.000	-----	-----	-----	0.612
1991	0.758	0.758	0.000	-----	0.610
1990	-----	-----	-----	-----	0.417
1989	-----	-----	-----	-----	0.286
1988	-----	-----	-----	-----	0.481
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, 31 March - 3 May, 1994-2008.

Year	Survival (S)									
Class	94-95	95-96	96-97	97-98	98-99	99-00	00-01	01-02	02-03	03-04
2002										
2001										
2000										
1999										
1998										0.854
1997									0.860	0.860
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	0.561	0.561
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	0.919
1988	0.959	0.794	0.794	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		0.246	0.733	0.500	0.909	0.000	-----	-----	-----	-----
1984	0.650	0.258	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, 31 March - 3 May, 1994-2008.

Year Class	Survival (S)				
	04-05	05-06	06-07	07-08	Mean
2002	-----	-----	-----	0.597	0.597
2001	-----	-----	0.236	0.909	0.463
2000	-----	-----	0.852	0.852	0.852
1999	-----	-----	-----	-----	-----
1998	0.854	0.854	0.854	0.854	0.854
1997	0.860	0.860	0.860	0.730	0.837
1996	-----	-----	0.515	0.706	0.603
1995	0.945	0.945	0.333	0.333	0.705
1994	0.949	0.949	0.333	0.333	0.711
1993	0.844	0.844	0.364	0.500	0.725
1992	0.709	0.709	0.709	0.000	0.603
1991	0.771	0.771	0.000	-----	0.638
1990	0.956	0.956	0.000	-----	0.729
1989	0.919	0.919	0.919	0.000	0.653
1988	-----	-----	-----	-----	0.520
1987	-----	-----	-----	-----	0.617
1986	-----	-----	-----	-----	0.515
1985	-----	-----	-----	-----	0.440
1984	-----	-----	-----	-----	0.339
1983	-----	-----	-----	-----	0.189
1982	-----	-----	-----	-----	0.245

Table 38a. Comparison of the area under the catch curve (fish/ day) of the 1987-2006 year classes of striped bass from pound nets in the Rappahannock River, 1991-2008.

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	47.0	
12	18.9	20.7	13.1	8.6	7.0	14.0	19.8	18.6	23.6	47.5	
13	19.0	20.8	13.1	8.9	8.1	14.3	20.0	19.3	23.6		
14	19.0	20.8	13.2	8.9	8.4	14.4	20.5	19.3			
15	19.0	20.8	13.2	9.0	8.4	14.6	20.5				
16	19.0	20.8	13.3	9.0	8.4	14.6					
17	19.0	20.8	13.3	9.0	8.4						
18	19.1	20.8	13.3	9.0							
19	19.1	20.8	13.3								
20	19.1	20.8									
area	**19.1**	**20.8**	**13.3**	**9.0**	**8.4**	**14.6**	**20.5**	**19.3**	**23.6**	**47.5**	

Table 38b. Comparison of the area under the catch curve (fish/ day) of the 1987-2006 year classes of striped bass from pound nets in the Rappahannock River, 1991-2008.

age	year class										mean
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	
2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	**0.2**
3	16.0	2.7	0.6	0.8	3.5	1.8	7.9	2.6	4.4		**4.2**
4	23.5	4.2	3.6	6.3	8.9	8.2	16.5	9.8			**10.1**
5	24.9	7.5	9.5	9.1	12.1	14.3	19.8				**13.6**
6	25.3	11.0	10.2	9.2	13.3	14.8					**14.5**
7	27.5	11.8	10.7	10.3	13.9						**15.4**
8	29.2	12.7	12.2	10.9							**16.4**
9	30.1	14.6	12.5								**17.4**
10	32.8	15.0									**18.4**
11	33.2										**19.2**
12											**19.8**
13											**20.1**
14											**20.2**
15											**20.2**
16											**20.2**
17											**20.2**
18											**20.2**
19											**20.2**
20											**20.2**
area	**33.2**	**15.0**	**12.5**	**10.9**	**13.9**	**14.8**	**19.8**	**9.8**	**4.4**	**0.1**	**20.2**

Table 39a. Comparison of the area under the catch curve (fish/ day) of the 1987-2006 year classes of striped bass from gill nets in the Rappahannock River, 1991-2008.

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	96.6	
12	46.1	51.2	46.1	24.2	16.6	38.6	118.3	75.0	39.2	97.7	
13	46.1	51.2	46.1	24.3	16.6	38.7	118.5	75.6	39.6		
14	46.2	51.2	46.1	24.3	16.6	38.7	119.2	75.6			
15	46.2	51.2	46.1	24.3	16.6	39.3	119.2				
16	46.2	51.2	46.1	24.3	16.6	39.3					
17	46.2	51.2	46.1	24.3	16.6						
18	46.2	51.2	46.2	24.3							
19	46.2	51.2	46.2								
20	46.2	51.2									
area	**46.2**	**51.2**	**46.2**	**24.3**	**16.6**	**39.3**	**119.2**	**75.6**	**39.6**	**97.7**	

Table 39b. Comparison of the area under the catch curve (fish/ day) of the 1987-2006 year classes of striped bass from gill nets in the Rappahannock River, 1991-2008.

age	year class										mean
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	
2	5.9	0.7	0.5	0.3	1.4	2.1	0.2	0.2	0.6	0.0	**1.0**
3	24.0	10.2	1.6	9.1	23.1	6.1	9.4	20.9	3.0		**13.0**
4	51.0	19.0	17.6	25.3	34.9	14.3	40.5	26.9			**31.7**
5	61.2	31.6	28.3	31.9	39.8	22.2	46.9				**42.9**
6	65.8	41.6	30.7	34.7	45.9	24.5					**47.1**
7	76.1	43.5	31.8	38.7	48.1						**50.0**
8	77.5	45.4	34.3	40.1							**51.7**
9	79.1	47.9	35.2								**52.9**
10	81.1	49.5									**53.8**
11	82.5										**54.3**
12											**54.6**
13											**54.8**
14											**54.9**
15											**55.0**
16											**55.0**
17											**55.0**
18											**55.0**
19											**55.0**
20											**55.0**
area	**82.5**	**49.5**	**35.2**	**40.1**	**48.1**	**24.5**	**46.5**	**26.9**	**3.0**	**0.0**	**55.0**

Table 40a. Comparison of the area under the catch curve (fish/ day) of the 1987-2006 year classes of striped bass from gill nets in the James River, 1994-2008.

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	139.8	
12	7.3	9.6	27.7	31.8	24.3	20.4	23.8	38.2	65.4	141.1	
13	7.3	9.6	27.7	32.0	24.3	20.5	24.9	38.3	65.5		
14	7.3	9.6	27.8	32.0	24.4	20.6	25.3	38.4			
15	7.3	9.6	27.8	32.0	24.8	20.7	25.5				
16	7.3	9.6	27.8	32.4	24.8	20.7					
17	7.3	9.6	27.9	32.4	24.8						
18	7.3	9.6	28.0	32.4							
19	7.3	9.6	28.0								
20	7.3	9.6									
area	**7.3**	**9.6**	**28.0**	**32.4**	**24.8**	**20.7**	**25.5**	**38.4**	**65.5**	**141.1**	

Table 40b. Comparison of the area under the catch curve (fish/ day) of the 1987-2006 year classes of striped bass from gill nets in the James River, 1991-2008.

age	year class										mean
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	
2	0.1	0.8	0.2	0.2	0.4	0.2	0.5	0.5	0.1	0.2	**0.2**
3	21.7	14.3	4.0	15.7	31.0	14.9	28.1	12.7	9.9		**12.1**
4	64.1	44.0	35.3	63.7	58.5	51.9	40.5	28.1			**36.4**
5	103.4	72.8	63.3	83.6	92.2	60.9	47.3				**55.9**
6	111.4	84.6	71.0	93.4	96.8	63.7					**63.0**
7	115.5	89.7	74.9	94.7	98.6						**65.7**
8	117.1	92.3	76.3	96.2							**67.3**
9	120.0	93.7	77.2								**68.5**
10	122.0	95.2									**69.7**
11	123.3										**70.4**
12											**70.9**
13											**71.1**
14											**71.2**
15											**71.3**
16											**71.3**
17											**71.3**
18											**71.3**
19											**71.3**
20											**71.3**
area	**123.3**	**95.2**	**77.2**	**96.2**	**98.6**	**63.7**	**47.3**	**28.1**	**9.9**	**0.2**	**71.3**

Table 41a. Back-calculated length-at-age (FL, in mm) for striped bass sampled from the James and Rappahannock rivers during spring, 2008.

Year Class	n	length-at-age (FL, in mm)							
		1	2	3	4	5	6	7	8
2006	6	151.4							
2005	14	159.0	276.1						
2004	17	155.6	273.4	377.7					
2003	27	148.6	263.6	377.8	476.4				
2002	16	141.6	263.9	380.7	485.9	572.8			
2001	19	144.3	252.2	363.8	471.1	570.5	648.4		
2000	16	138.0	240.7	345.2	445.8	545.5	631.4	698.4	
1999	24	137.8	236.3	337.5	437.3	528.1	613.8	689.4	751.8
1998	34	142.1	238.1	332.7	429.6	524.3	610.0	689.0	758.4
1997	35	137.2	230.4	326.0	415.7	504.6	584.4	660.6	731.0
1996	46	138.8	232.7	327.0	413.3	499.6	578.0	650.7	720.1
1995	3	143.0	233.3	322.2	428.2	506.0	580.7	644.8	708.3
1994	1	146.3	245.2	337.3	413.2	486.7	570.4	626.7	697.3
all	258	143.1	246.0	345.9	439.3	525.1	602.5	671.4	736.8

Table 41b. Back-calculated length-at-age (FL, in mm) for striped bass sampled from the James and Rappahannock rivers during spring, 2008.

Year Class	n	length-at-age (FL, in mm)							
		9	10	11	12	13	14	15	16
2006	6								
2005	14								
2004	17								
2003	27								
2002	16								
2001	19								
2000	16								
1999	24								
1998	34	810.9							
1997	35	796.1	847.6						
1996	46	783.7	839.9	887.6					
1995	3	770.4	827.7	880.1	935.4				
1994	1	756.9	826.4	892.3	948.9	995.3			
all	258	794.6	842.4	887.2	938.7	995.3			

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

S	Otolith Age																					
A	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
1	**1**																					
2		**5**																				
3		1	**11**		2																	
4				**8**	6																	
5				6	**27**	0	2															
6					2	**2**	4	1														
7						1	**13**	3														
8							2	**6**	5	2		1										
9								4	**4**	4	2	3										
10								3	0	**7**	3	18										
11									2	4	**3**	18	4		1							
12										1	0	**43**	10	1	1							
13												2	**1**	2	1	1						
14														**0**	0	1		1				
15															**0**	0						
16																**0**					1	
17																	**0**					
18																		**0**				
19																			**0**			
20																				**0**		
21																					**0**	
22																						**0**

Table 43. Relative contributions of striped bass age classes as determined by ageing specimens (n = 259) by reading both their scales and otoliths.

Age	scale		Otolith	
	n	prop	n	Prop
1	1	0.0039	1	0.0039
2	5	0.0194	6	0.0233
3	14	0.0543	11	0.0426
4	14	0.0543	14	0.0543
5	35	0.1357	37	0.1434
6	9	0.0349	3	0.0116
7	17	0.0659	21	0.0814
8	16	0.0620	17	0.0659
9	17	0.0659	11	0.0426
10	31	0.1202	18	0.0698
11	32	0.1240	8	0.0310
12	56	0.2171	85	0.3295
13	7	0.0271	16	0.0620
14	3	0.0116	3	0.0116
15	0	0.0000	3	0.0116
16	1	0.0039	2	0.0078
17	0	0.0000	0	0.0000
18	0	0.0000	1	0.0039
19	0	0.0000	0	0.0000
20	0	0.0000	0	0.0000
21	0	0.0000	1	0.0039
	$\mathcal{A}ge$ = 8.61		$\mathcal{A}ge$ = 9.07	

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, 1991-2008.

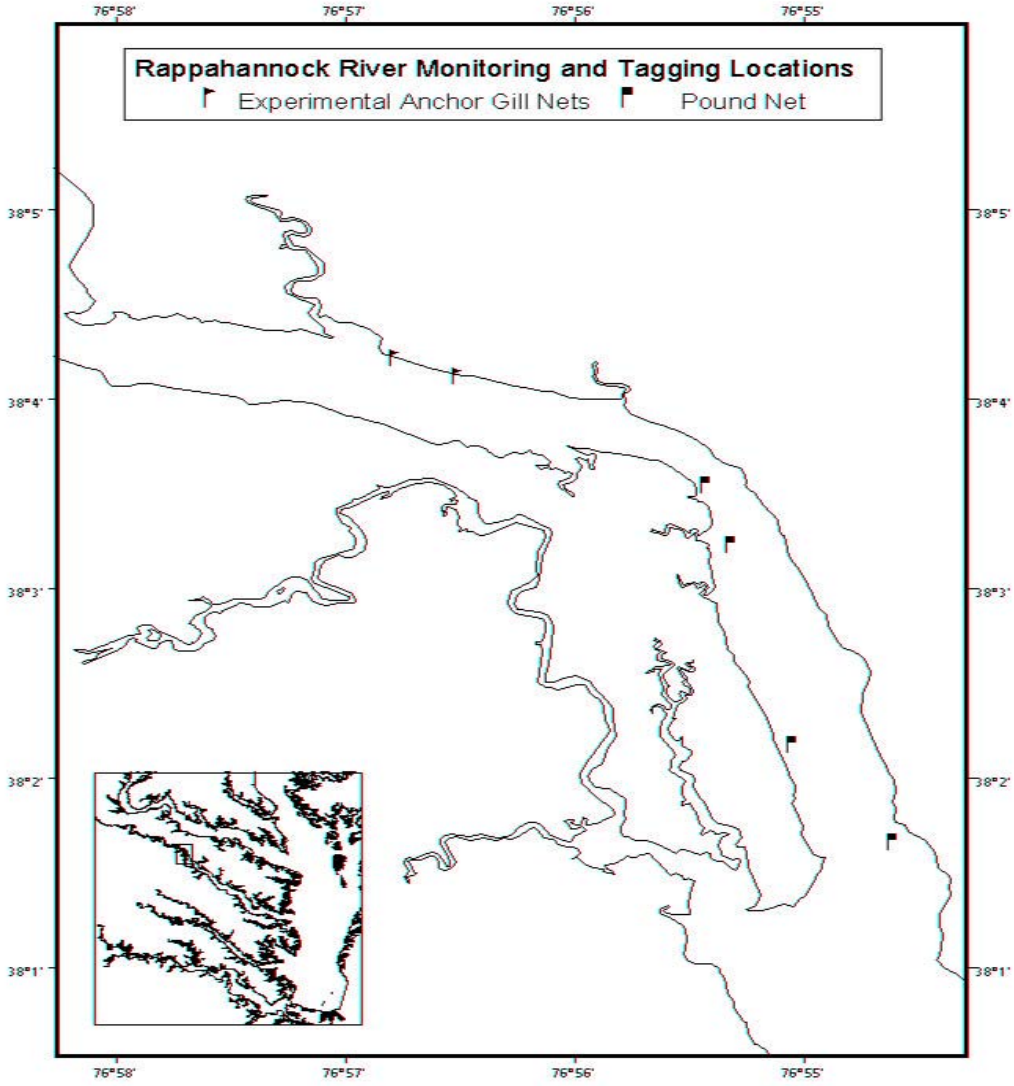


Figure 2. Locations of the experimental anchor gill nets sampled in spring spawning stock assessments of striped bass in the James River, springs 2003-2008.

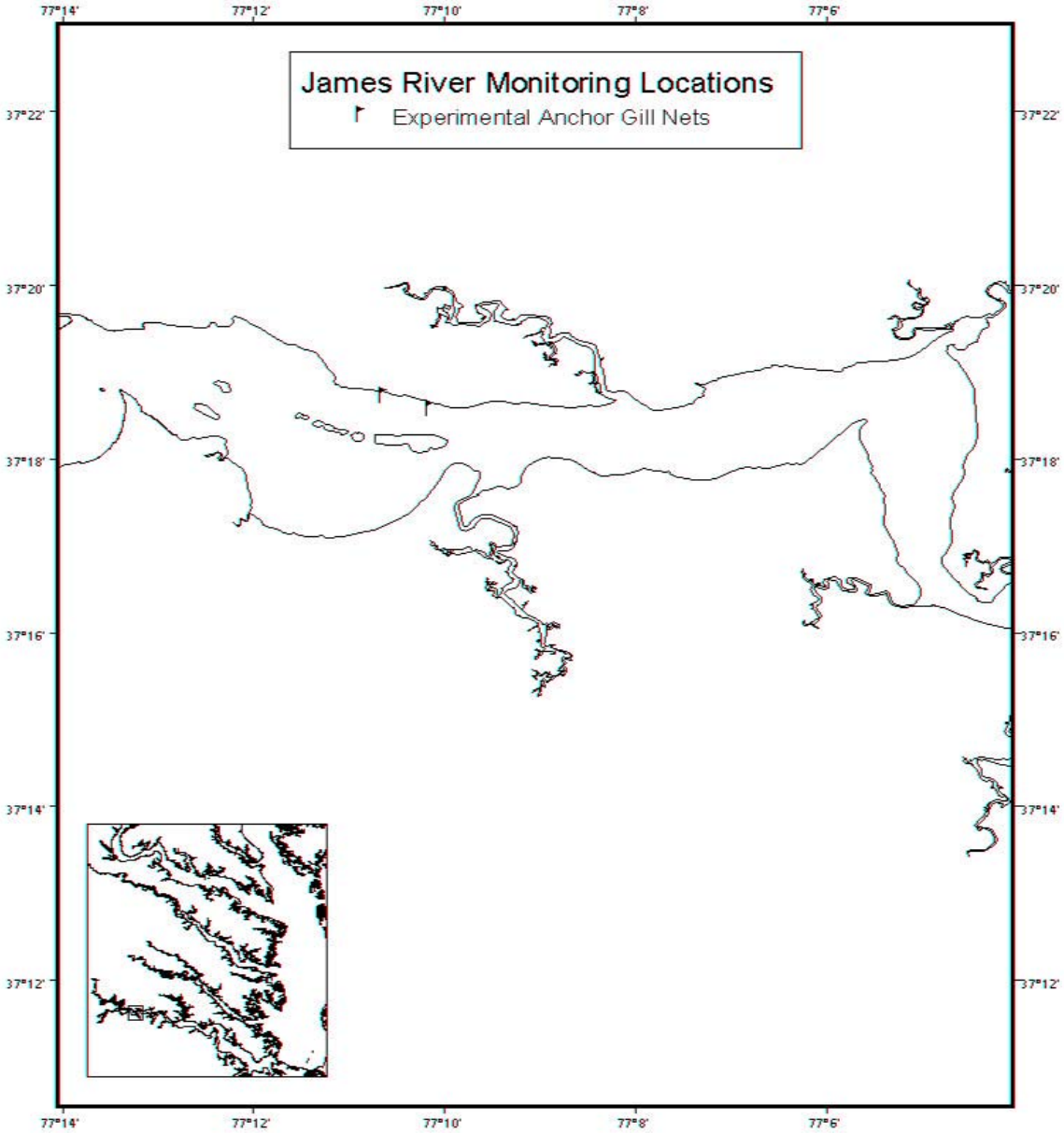


Figure 3. Daily and historic mean river flows (cf/s) for the Rappahannock River during the 30 March-3 May spawning stock assessment period, spring 2008.

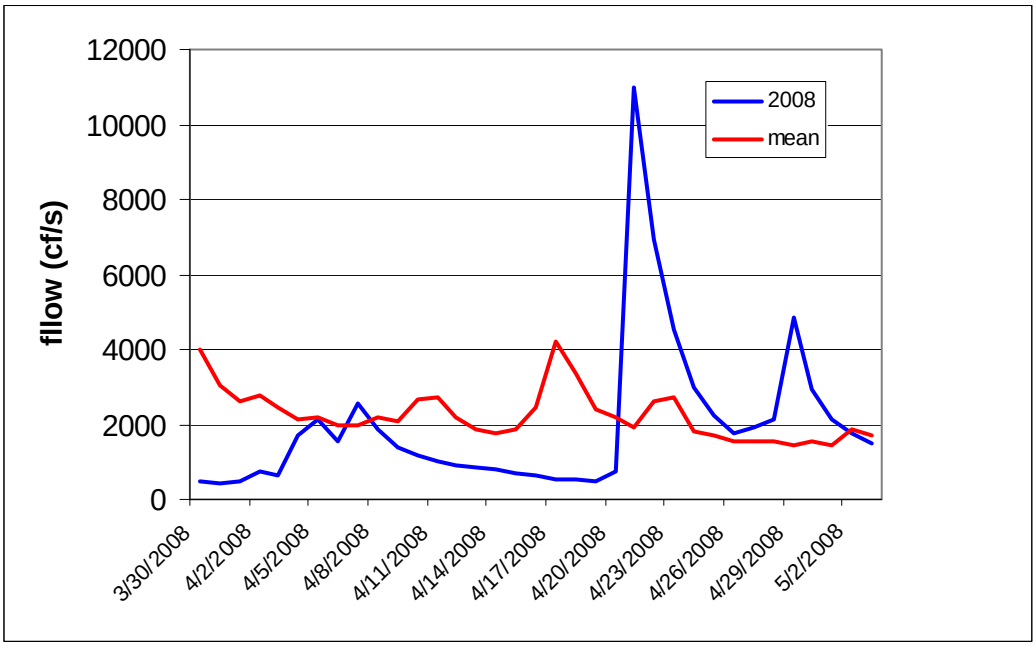


Figure 4. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1987 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1991-2008.

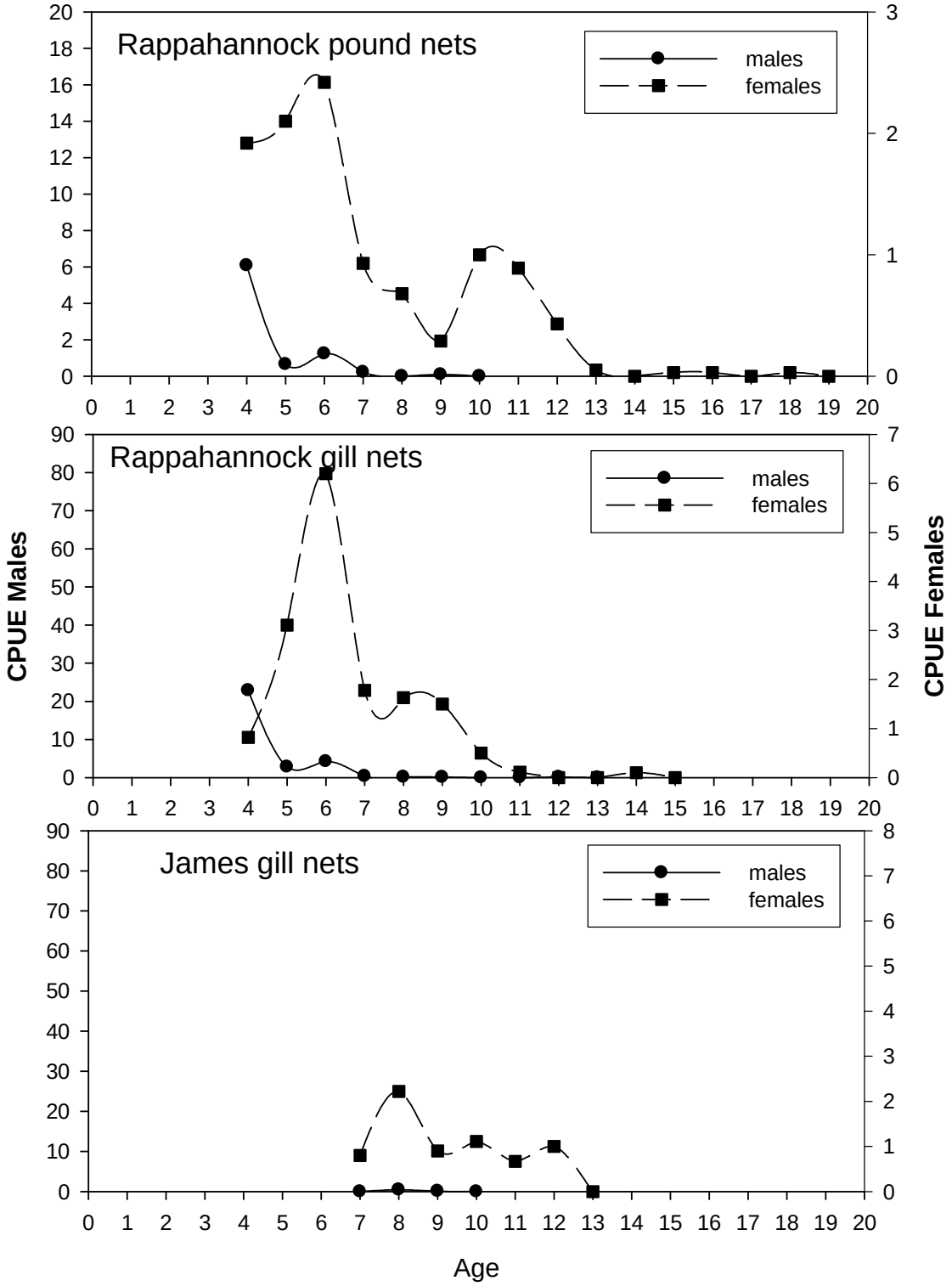


Figure 5. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1988 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1991-2008.

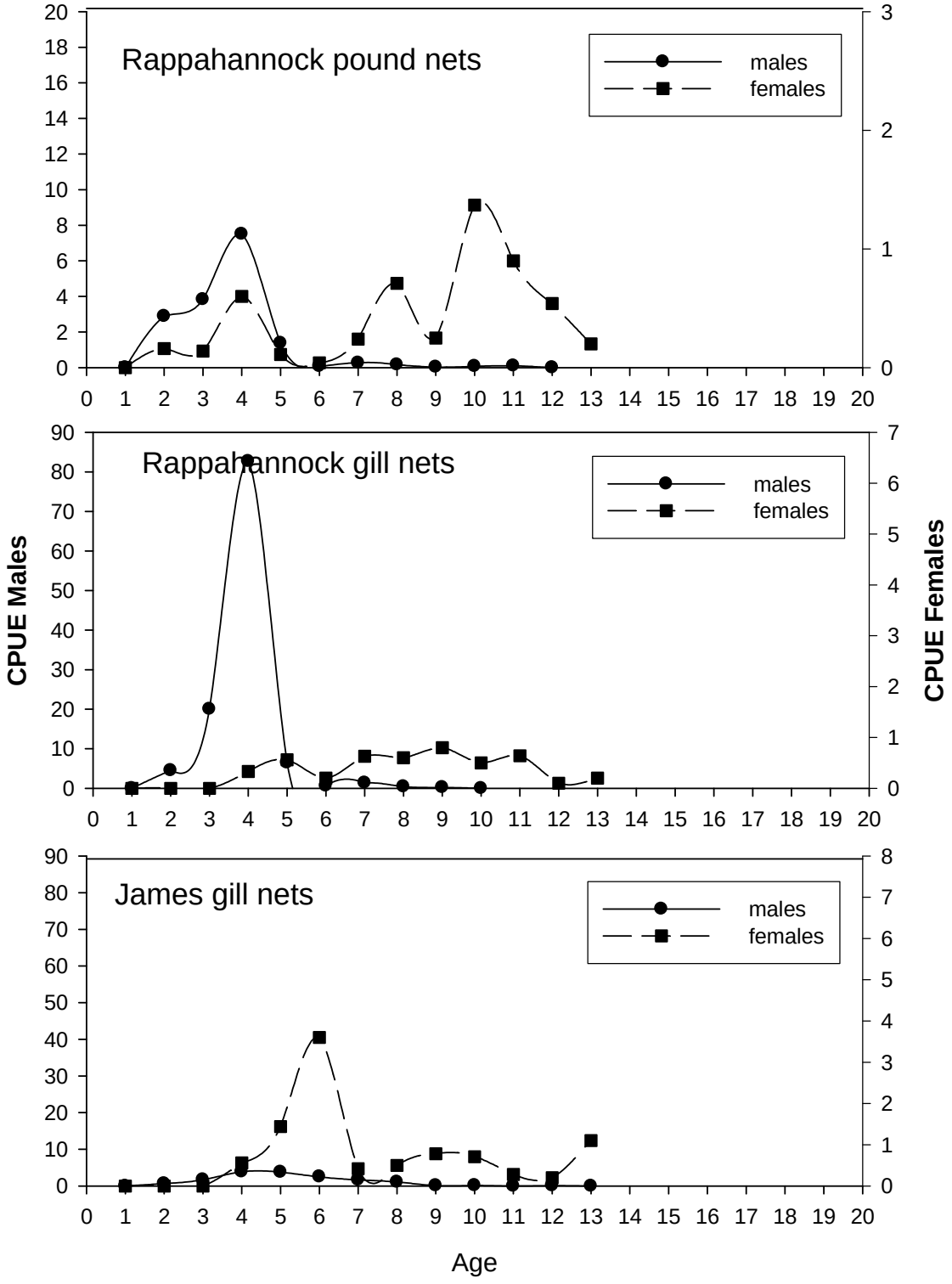


Figure 6. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1989 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1991-2008.

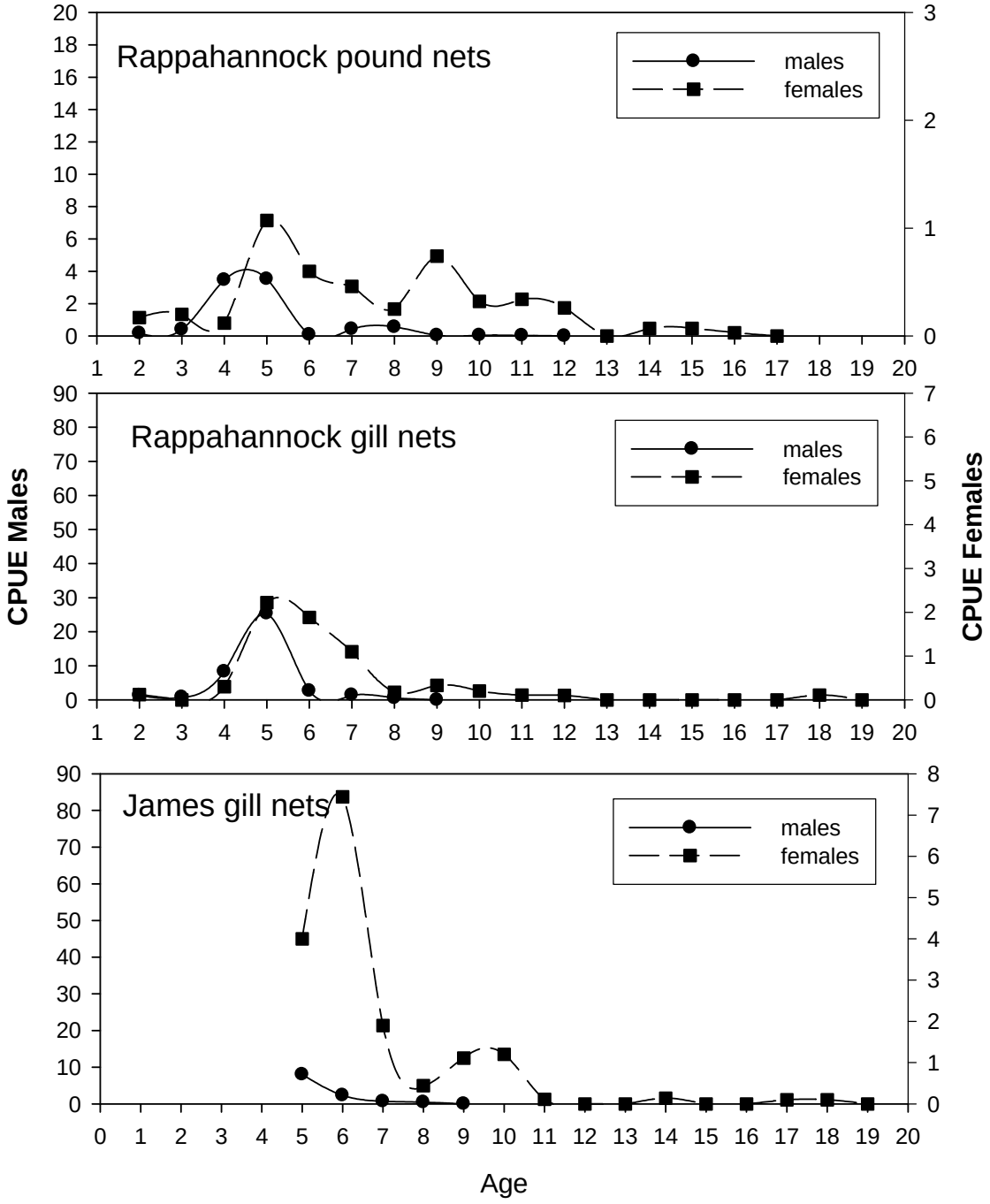


Figure 7. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1990 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1991-2008.

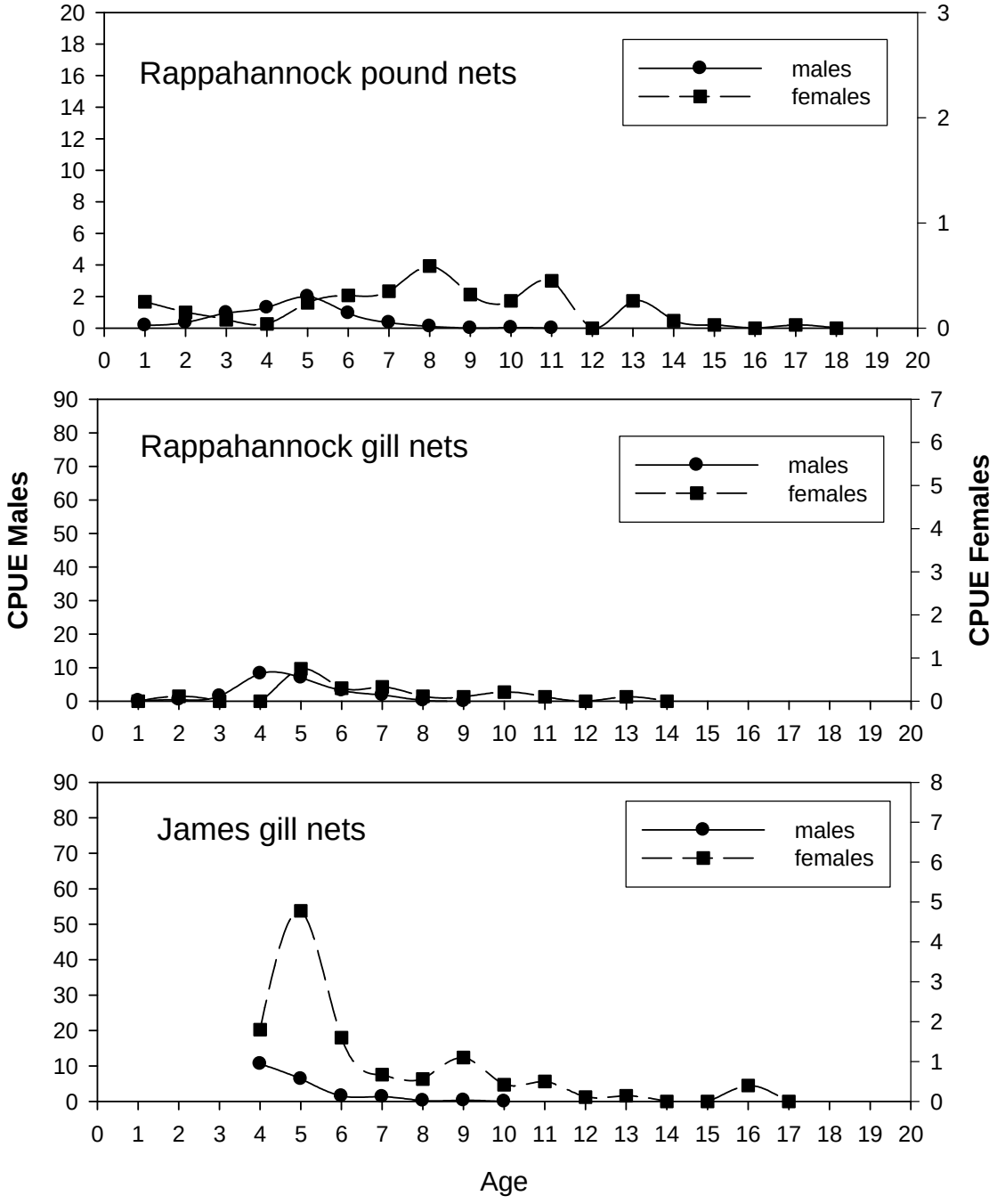


Figure 8. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1991 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1992-2008.

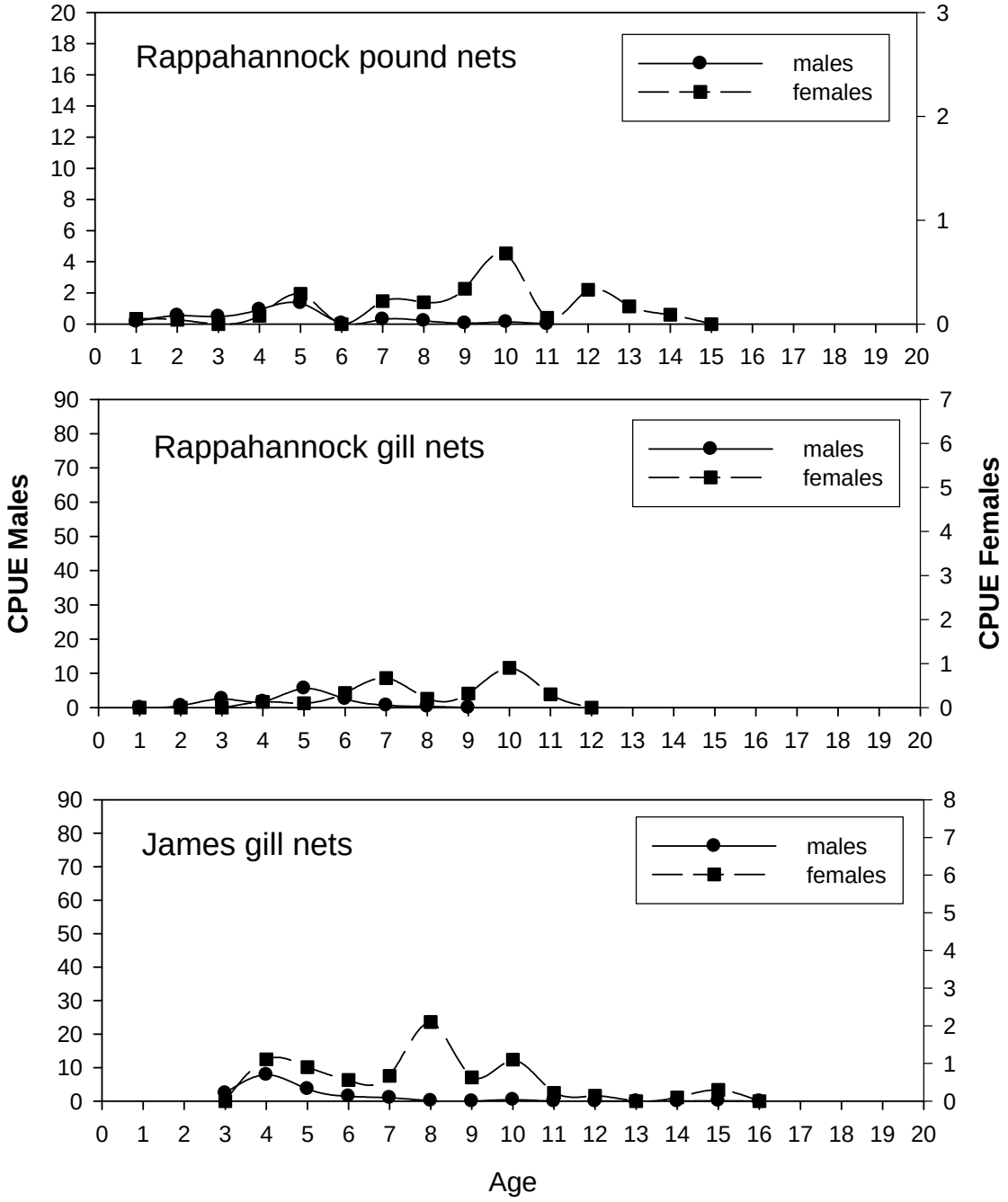


Figure 9. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1992 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1993-2008.

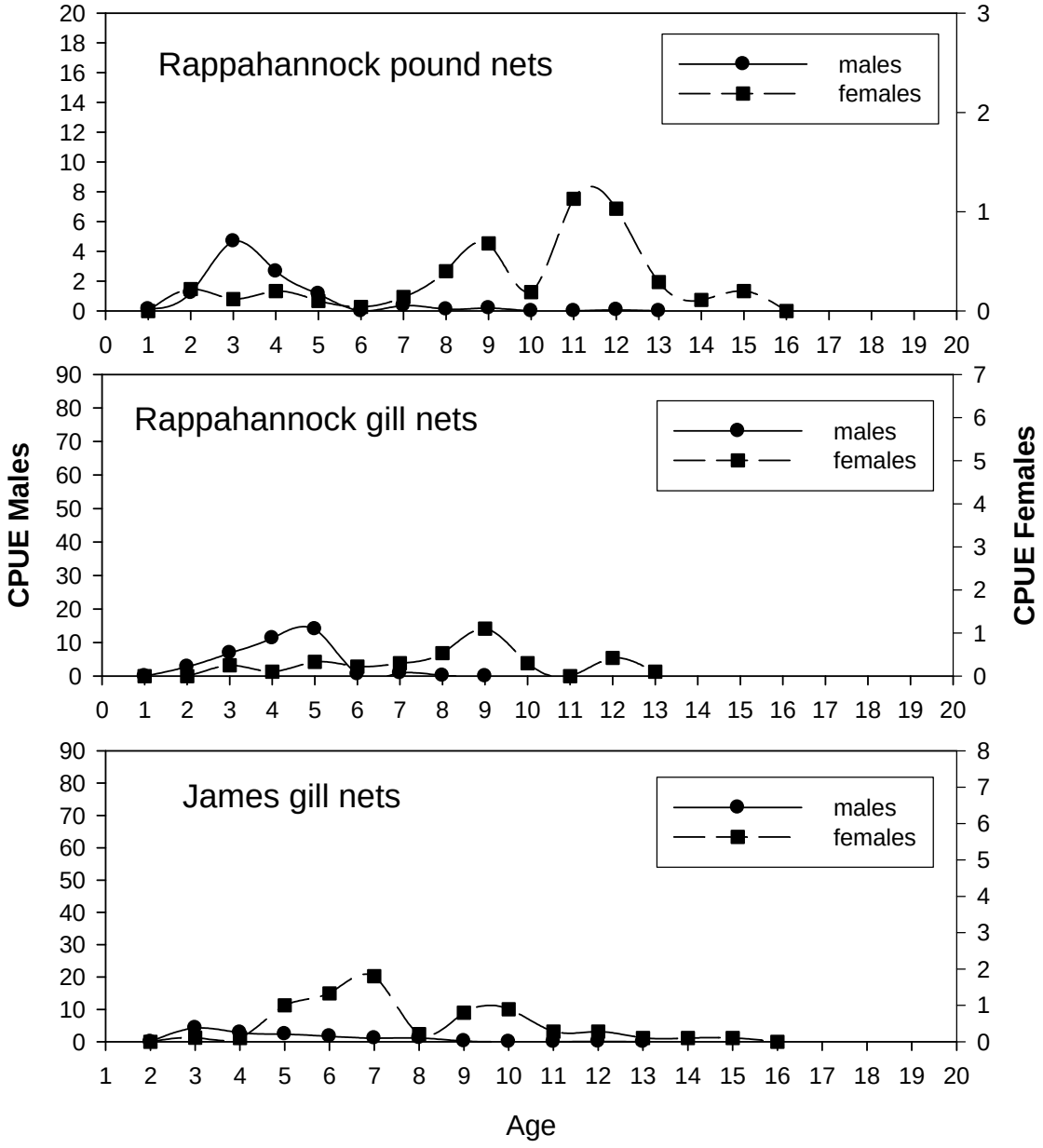


Figure 10. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1993 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1994-2008.

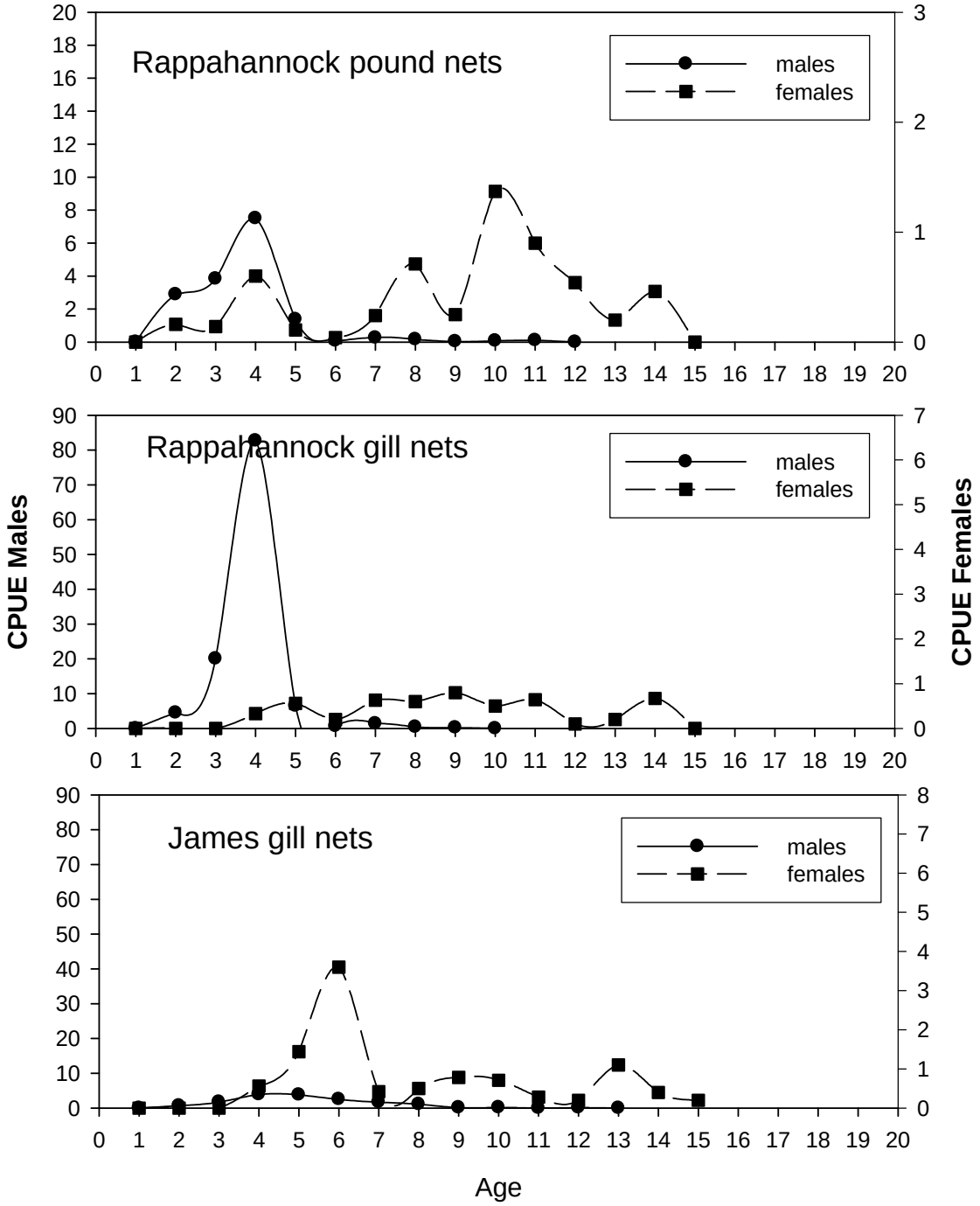


Figure 11. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1994 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1995-2008.

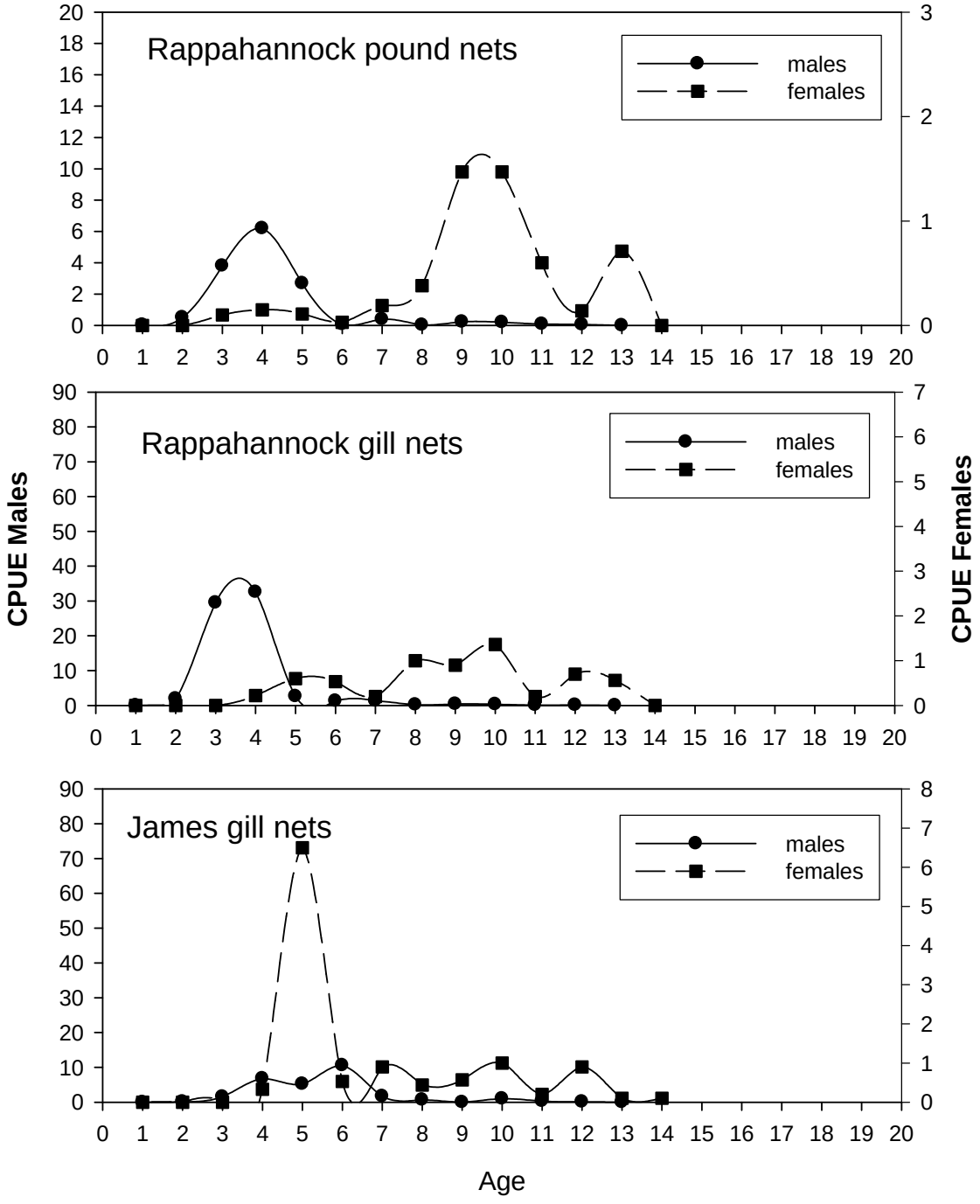


Figure 12. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1995 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1996-2008.

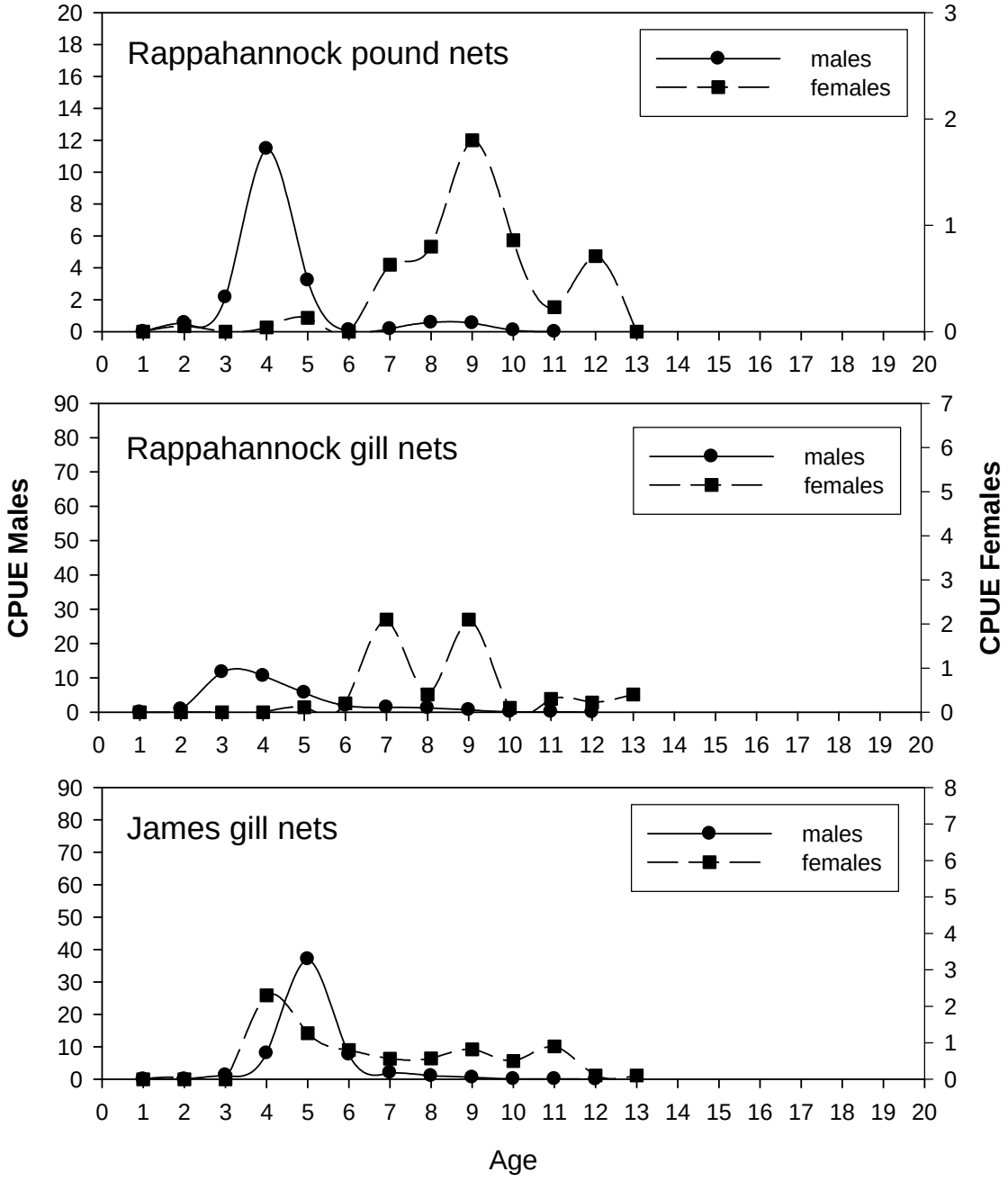


Figure 13. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1996 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1997-2008.

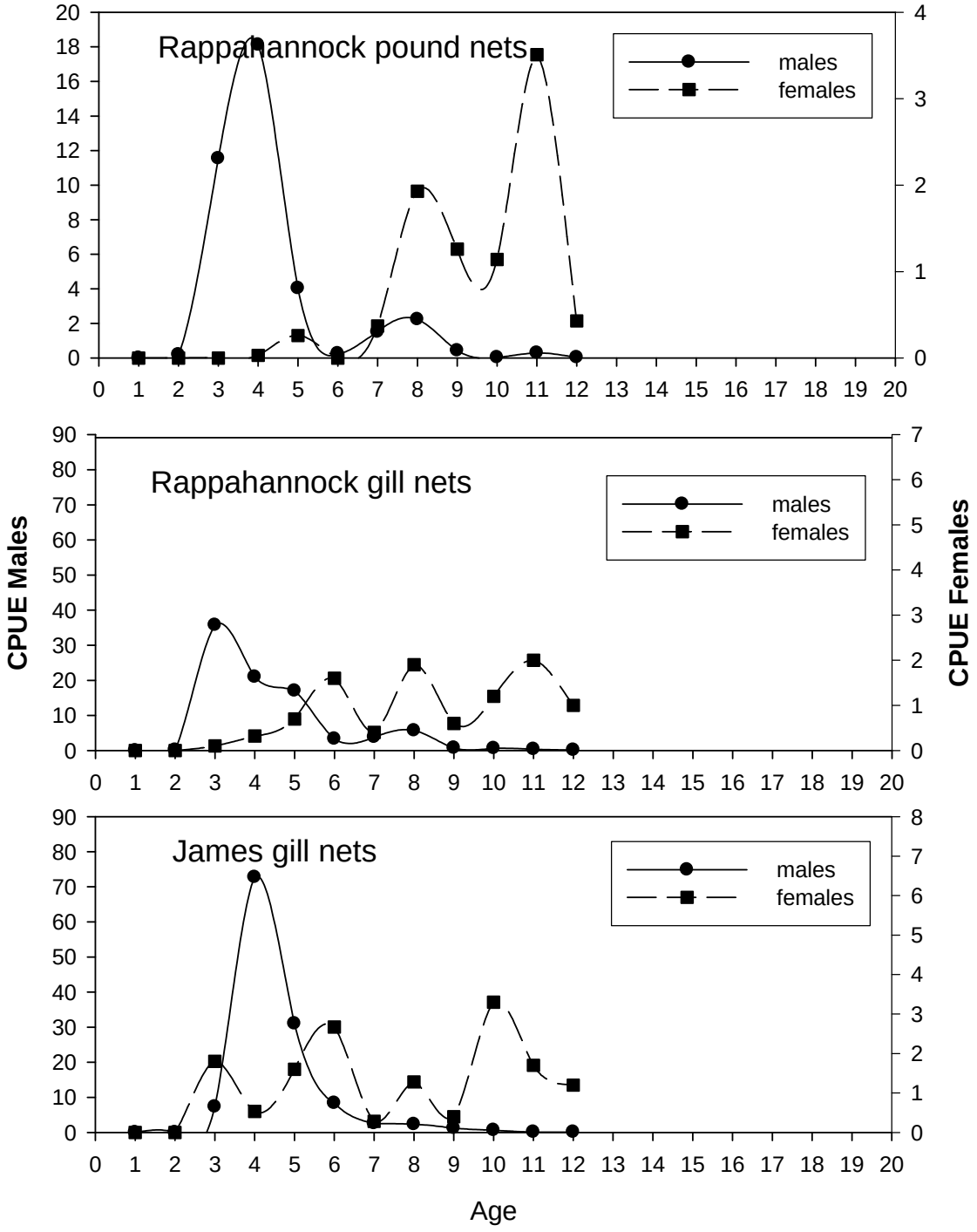


Figure 14. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1997 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1998-2008.

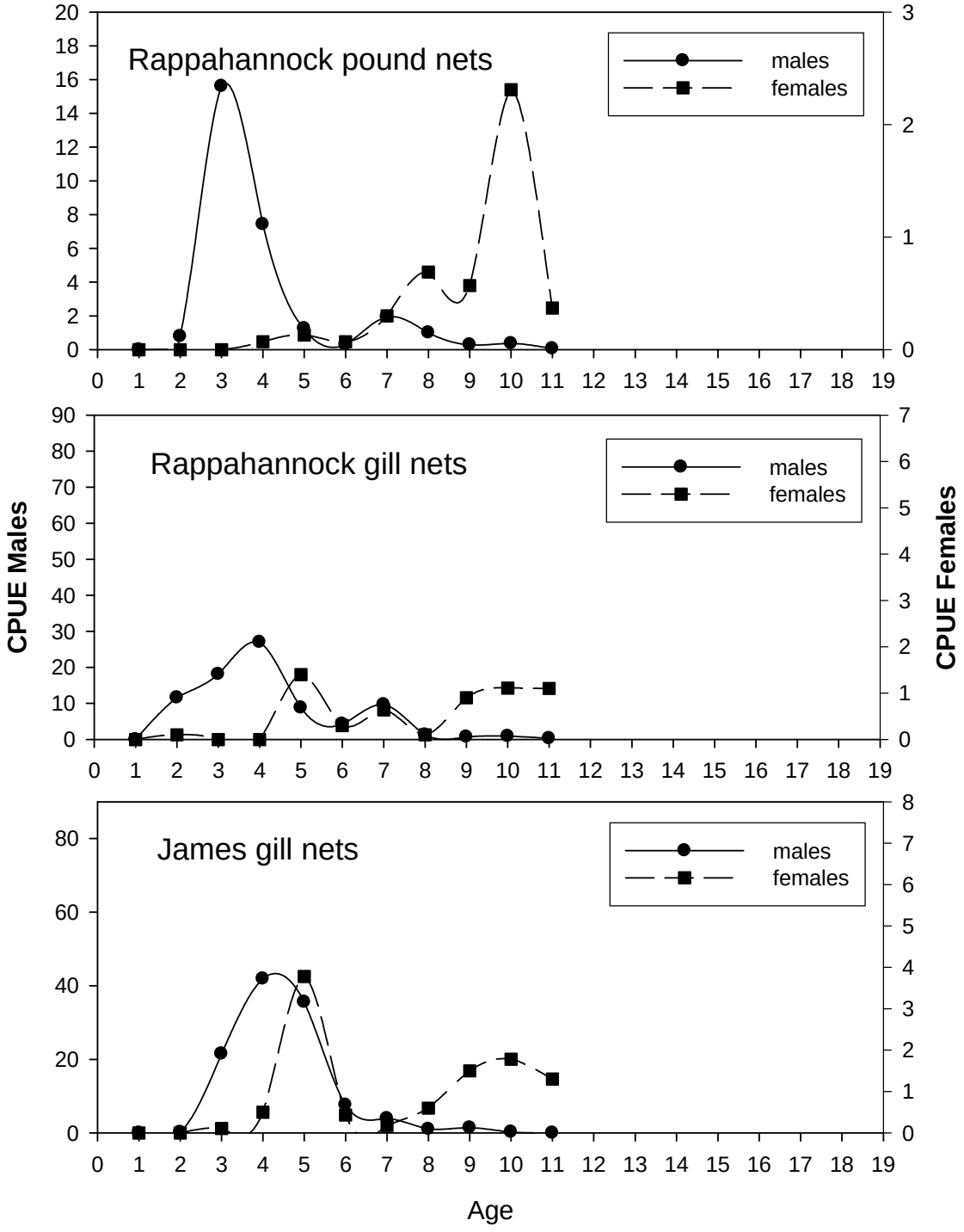


Figure 15. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1998 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1999-2008.

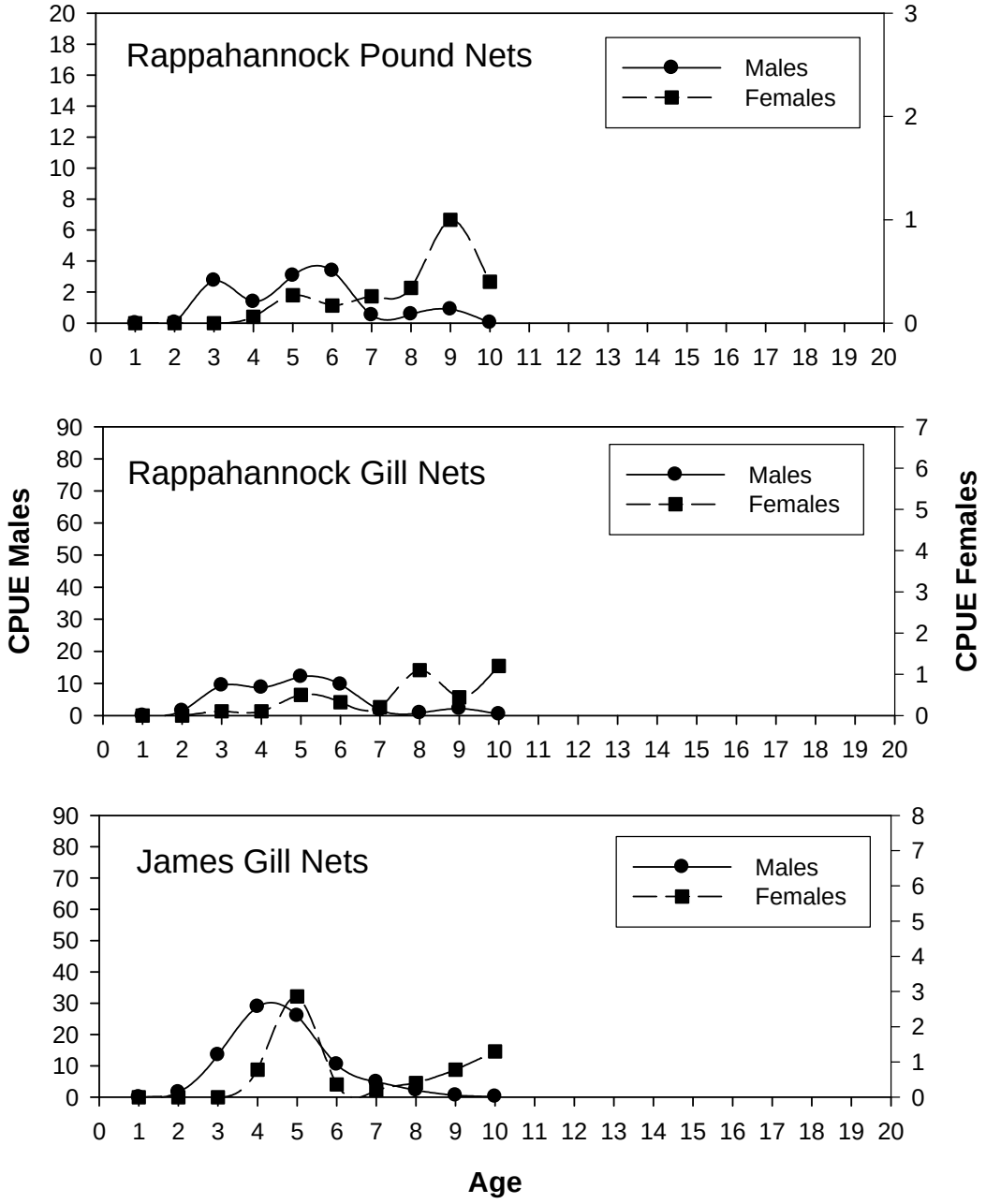


Figure 16. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1999 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 2000-2008.

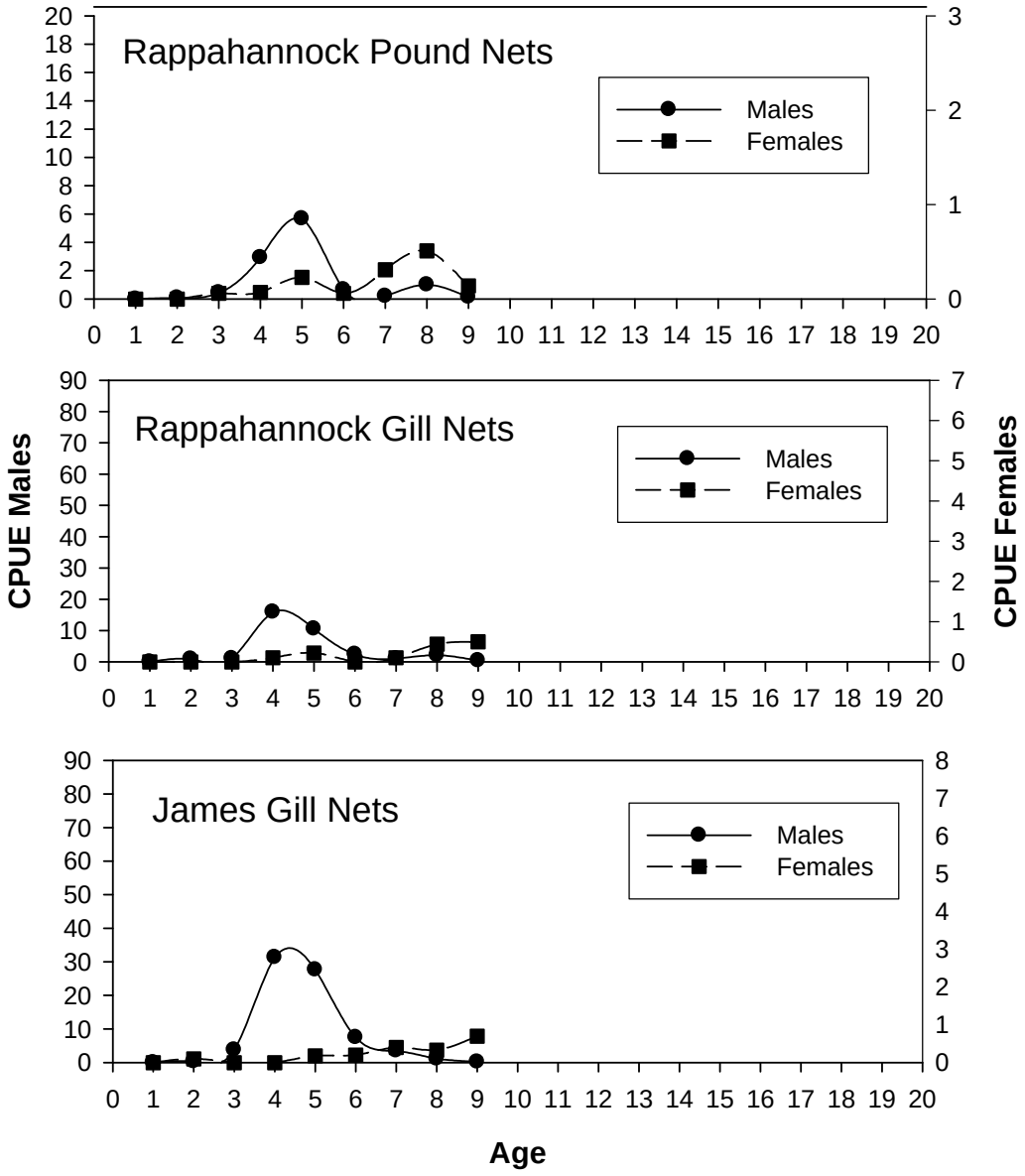


Figure 17. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 2000 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 2001-2008.

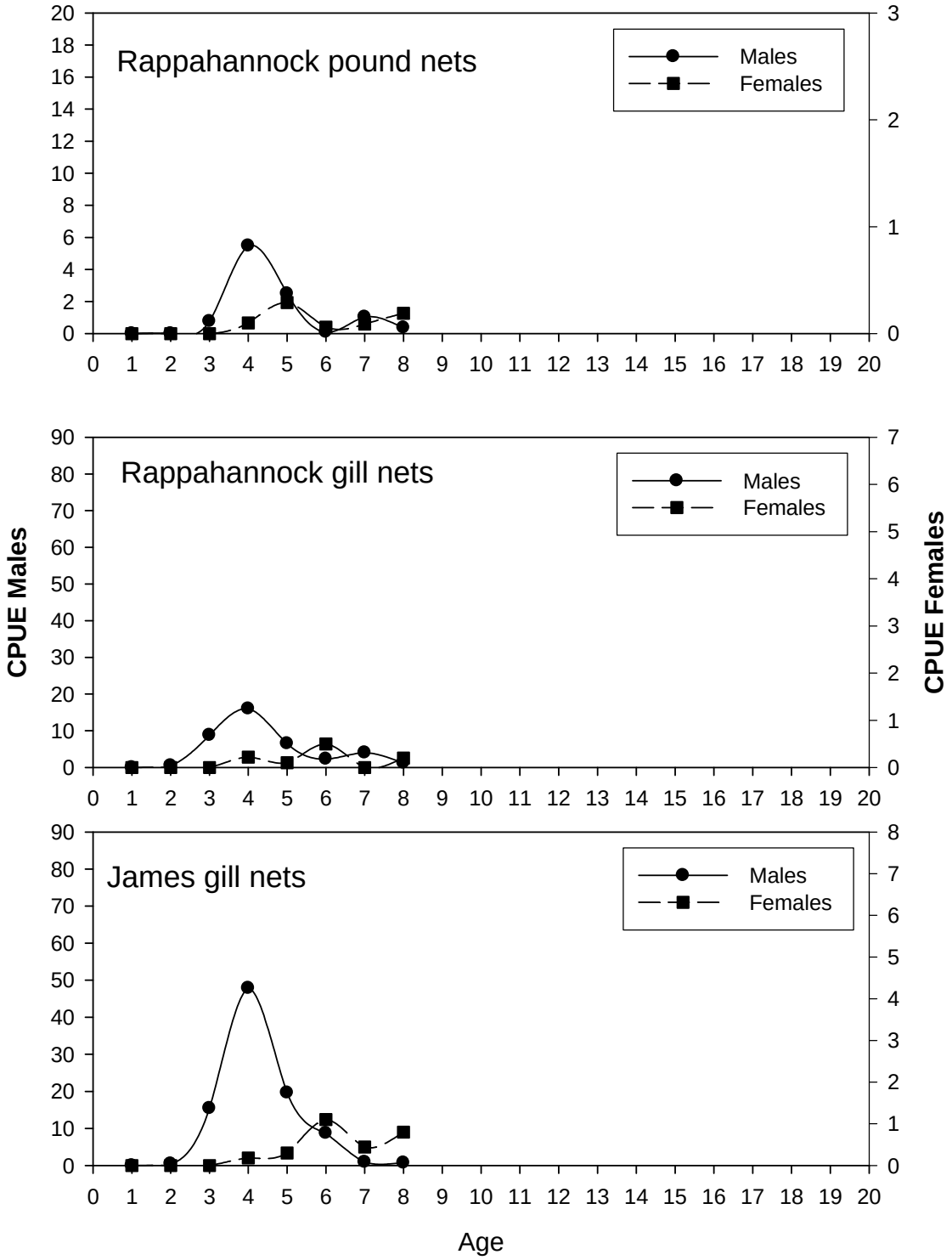
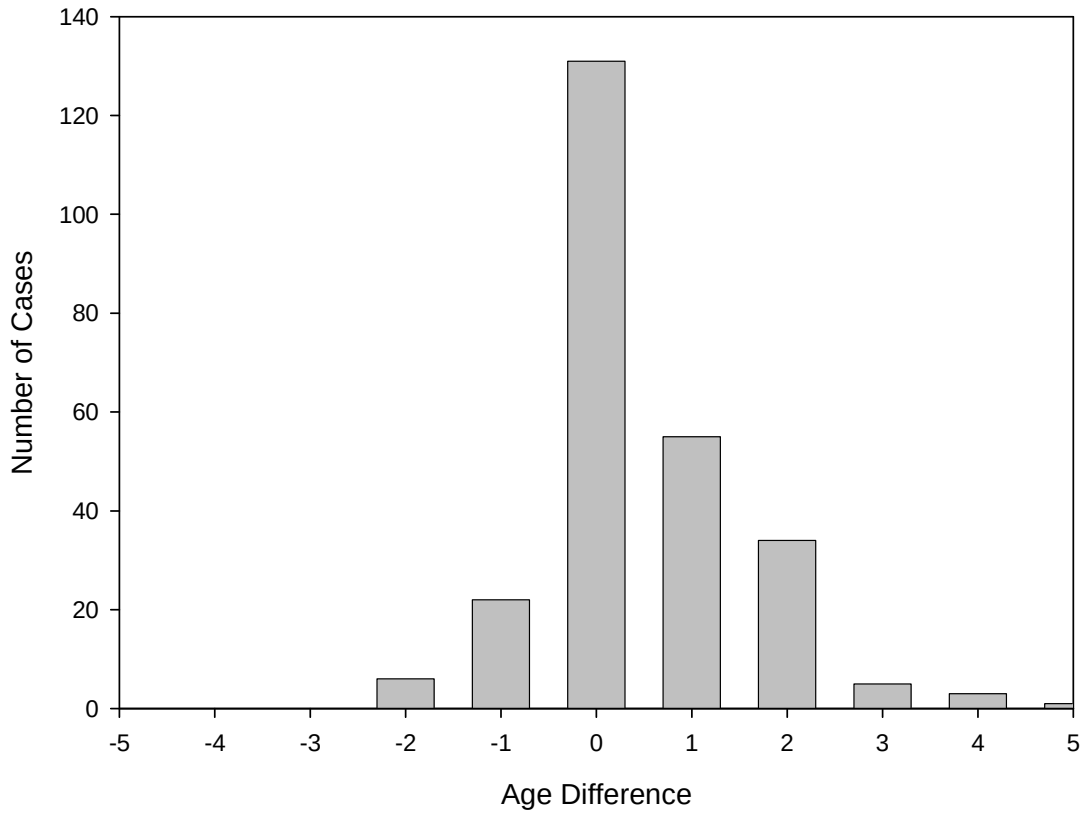


Figure 18. Magnitude of the age differences (otolith = 259) by reading both their scales and otoliths, spring, 2008.



II. Mortality estimates of striped bass (*Morone saxatilis*) that spawn in the Rappahannock River, Virginia, spring, 2007-2008.

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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. For the 2006 estimates the updated version of MARK (version 4.3) replaced the version used in previous years (version 4.2).

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 2008, 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: The ASFMC 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). For the 2006 analysis, the last regulatory period (2000-present in previous years), was redefined as two periods (2000-2002 and 2003-present) to reflect the adoption of the latest amendment to the Federal Management Plan (FMP). 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)r(t)	Survival rates vary by regulatory periods (p=constant 1990-1994, 1995-1999, 2000-2002 and 2003-2007) and tag-recovery rates are time-specific.
S(p)r(p)	Survival and tag-recovery rates vary by regulatory period.
S(.)r(p)	Survival rate is constant and tag-recovery rates vary by regulatory periods.

S(t)r(p)	Survival rates are time-specific and tag-recovery varies by regulatory periods.
S(d)r(p)	Survival and tag-recovery rates vary over different regulatory periods (d= constant 1990-1994, 1995-1999, 2000-2002, 2003-2005 and 2007).
S(v)r(p)	Survival and tag-recovery rates vary over different regulatory periods (v= constant 1990-1994, 1995-1999, 2000-2002, 2003-2004, 2005 and 2007).

The following models were eliminated from the analyses in 2007 after an evaluation by the Tagging Subcommittee found that they were not producing meaningful results:

S(Tp)r(Tp)	Survival and tag-recovery rates have linear trends within regulatory periods.
S(Tp)r(p)	Survival rates have a linear trend within regulatory periods and tag-recovery rates vary by regulatory period.
S(Tp)r(t)	Survival rates have a linear trend within regulatory periods and tag-recovery rates are time-specific.
S(p_1)r(p_1)	Survival and tag-recovery rates vary over regulatory periods (p_1 = constant 1990-1992, 1993-1994 and 1995-2007).

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 of resident striped bass

Exploitation rate (R/M) method: Estimates of the exploitation rate (μ) are calculated by the recapture rate adjusted for the reporting rate:

$$\mu = (R_k + R_r * 0.08) / (\lambda M)$$

where R_k is the number or recaptures kept with tags, R_r is the number of fish released with tags, 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).

Catch equation method: Fishing and natural mortality can be estimated from the tagging data using the above described relationship between exploitation rate, fishing mortality and natural mortality. This can be rewritten as:

$$F = \mu / (S-1) * \ln(S)$$

Survival (S) is estimated from the tagging data using the MARK models used with the estimate of μ to determine F.

Instantaneous rates method: This method (defined in the multi-year tagging methods section) allows the estimate of natural mortality to be constant, or to vary by periods. Three scenarios were analyzed, based of the ASMFC tagging subcommittee recommendations: Constant natural mortality, two periods of differing natural mortality (1988-1997 and1998-2007) and three periods (1988-1996, 1998-2000 and 2001-2007).

Results

Spring 2008 Tag Release summary

A total of 524 striped bass were tagged and released from the pound nets in the Rappahannock River between 7 April and 15 May, 2008 (Table 1). There were 448 resident striped bass (457-711 mm TL) tagged and released. These stripers were predominantly male (96.0%), but the female stripers were larger on average. The median date of these tag releases, to be used as the beginning of the 2007-2008 recapture interval, was 28 April. There were 76 migrant striped bass (>710 mm TL) tagged and released. These stripers were predominantly female (64.5%) and their average size was larger than for the male striped bass. The median date

of these tag releases was 24 April. It should be noted that the tag release totals were less than one half the release total for 2007 and were well below the release targets of 700 resident and 300 migratory striped bass.

Mortality Estimates, 2007-2008

Tag recapture summary: A total of 89 (out of 1,961) striped bass (>457 mm TL), tagged during spring 2007, were recaptured between 19 April, 2007, and 27 April, 2008 (the respective midpoints of the two tag release totals), and were used to estimate mortality. Forty six of these recaptures were harvested (51.7%) and the rest were re-released into the population (Table 2). The proportion of tagged striped bass recaptured from 1991-2007 in their first year after release varied from 0.045 (89/1,961 in 2007) to 0.111 (162/1.464, in 1990). Since 1997, the initial recapture rates have only varied from 0.045-0.077. In addition, 38 (19 harvested) striped bass tagged in previous springs were recaptured during the 2007-2008 recovery interval and were used to complete the input data matrix. The largest source of recaptures (62.8%) in the 2007-2008 recovery interval was Chesapeake Bay (40.1% in Virginia, 22.6% in Maryland, Table 3). Other recaptures came from Massachusetts (13.1%), New York (10.2%), New Jersey (5.1%), Rhode Island (4.4%), Delaware and North Carolina (1.5 % each), and Connecticut and New Hampshire (0.7% each). There were no recaptures from Maine. The primary peak of recaptures was in April through July, with a secondary peak from October through December. However, there were recaptures in every month of the year.

A total of 44 (out of 840) migratory striped bass (>710 mm total length), tagged during spring 2007, were recaptured between 19 April, 2007, and 24 April, 2008 (the 2007-2008 recovery interval) and were used to estimate the mortality of this sub-group. Twenty six of these recaptures were harvested (59.1%), and the rest were re-released into the population (Table 4). The proportion of tagged striped bass recaptured from 1991-2008 in their first year after release varied from 0.015 (1/67) to 0.152 (24/158). In addition, 24 striped bass tagged in previous springs were recaptured during the recovery interval and were used to complete the input data matrix. The largest source (31.9%) of the recaptured tagged striped bass was Chesapeake Bay (29.2% in Virginia and 2.7% in Maryland, Table 5), followed by Massachusetts (25.0%). Other recaptures came from New York (19.4%), New Jersey (9.7%), Rhode Island (6.9%), Delaware and North Carolina (2.8% each) and Connecticut (1.4%). The peak months for recaptures were June and July, but some migrant striped bass were recaptured from every month of the year except March.

ASMFC protocol: Survival estimates were made utilizing the mark-recapture data for the Rappahannock River from 1990-2007. The suite of Seber (1970) models consisted of nine 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. Models that allowed trends within periods and Virginia-specific models for the transition from a partial to an open fishery were eliminated for

the 2007 analyses after the ASMFC tagging subcommittee determined that they only poorly evaluated the data and carried no weight in the model averaging for multiple years.

There were no survival estimates made for 2007. A peer-review of the methodologies used for striped bass stock assessment was scheduled and the analyses were deferred to 2008. Any changes in the protocol will be adopted by then and estimates of Survival will then be presented for 2007 and 2008.

Estimates of Exploitation and Fishing Mortality of resident striped bass

Tag recapture summary: There were 44 recaptures (of 1,078 tagged) of resident striped bass (males, 457-711 mm TL) recaptured within Chesapeake Bay between 1 April, 2007 and 31 March, 2008 (Table 6). An additional 11 recaptures from striped bass tagged during springs 1990-2006 were recaptured. Twenty four of these recaptures were harvested (43.6%). This was a much lower fraction than was harvested in 2007 (81.8%). These data were provided to Maryland Department of Natural Resources to produce separate (Virginia and Maryland) and combined estimates of F.

MARK method: There was a vacancy at the USFWS office responsible for providing the recapture data that was not filled in time to provide the input matrix for the MARK analysis. Estimates for 2007 and 2008 will be presented in the 2009 report.

Catch equation method: The S estimates from the MARK analysis are required to complete this methodology. The estimate for 2007 and 2008 will be presented in the next report.

R/M method: There was no estimate for 2007, pending re-evaluation of the methodology. From 1988-2006, the estimates of F ranged from 0.00-0.18 (Table 7). It should be noted that the 1992 value resulted from a very low release total (31) and is suspect. The range for all other years is 0.00-0.09. Natural mortality is assumed to be 0.15 in this analytical approach.

Instantaneous rates method: The three approaches (constant M, two separate and three separate periods of constant M) all produced estimates of F that ranged from 0.00-0.10 (Table 7) but produced quite different estimates of M. The constant M approach produced an intermediate, averaged estimate of 0.60. The two periods approach produced M estimates that rose from 0.35 prior to 1997 and 0.90 thereafter. However, the three periods approach produced post-1997 estimates that rose to 0.99 from 1997-2000, but then fell back to 0.82 thereafter.

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)r(t), S(t)r(p), 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

A peer-review of the management strategies and analytical protocols for striped bass was conducted during 2008. To allow preparation for this review, all analyses scheduled for 2008 (the 2007 estimates of survival and exploitation rates) were deferred for one year. In addition, a vacancy at the USFWS office tasked with the management and dissemination of the release and recapture data to the various agencies, including VIMS, was left unfilled until August, 2008. Thus, it was impossible to even calculate preliminary estimates of these parameters to include for this report cycle. The 2009 report will include updated protocols and the appropriate estimates for the years 2007 and 2008.

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 in 2007 suggested that the models would 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 peer-review made a recommendation to emphasize the instantaneous rates approach for 2008. However, the estimates of fishing mortality for the resident striped bass stocks in Maryland and Virginia gave results that were very low and suspect (Sharov personal communication) despite a Bay-wide harvest of 8,432,214 lbs of striped bass. If the exploitation and fishing mortality rates are correct as estimated, then natural mortality must be increasing yearly. A bacterial infection (mycobacteriosis) has been identified in striped bass and may be a

significant source of increased non-fishing mortality in resident striped bass. This issue is addressed in the third chapter of this report.

Literature Cited

Akaike, H. 1973. Information theory as an extension of the maximum likelihood principle. In Second International Symposium on Information Theory. Edited by B. N. Petrov and F. Csaki. Budapest. Academiai Kiado.

Akaike, H. 1985. Prediction and entropy. In A Celebration of Statistics. Edited by A.C. Atkinson and S.E. Fienberg. New York: Springer.

Beverton, R.J.H., and S.J. Holt. 1959. A review of the lifespans and mortality rates of fish in nature, and their relation to growth and other physiological characteristics. Ciba Found. Colloq. Ageing 5:142-177.

Brownie, C., D.R. Anderson, K.P. Burhnam, and D.R. Robson. 1985. Statistical inference from band recovery data: a handbook, 2nd ed., U.S. Fish and Wildl. Serv. Resour. Publ. No. 156.

Buckland, S.T., K.P. Burnham, and N.H. Augustin. 1997. Model selection: an integral part of inference. Biometrics 53:603-618.

Burnham, K.P. and D.R. Anderson. 1992. Data-based selection of an appropriate biological model: The key to modern data analysis. In Wildlife 2001: Populations. Edited by D.R. McCullough and R.H. Barrett. London: Elsevier Science Publishers.

Burnham, K.P. and D.R. Anderson. 1998. Model selection and inference: a practical information theoretical approach. Springer-Verlag, New York.

Burnham, K.P., G.C. White, and D.R. Anderson. 1995. Model selection strategy in the analysis of capture-recapture data. Biometrics 51:888-898.

Dunning, D.J., Q.E. Ross, J.F. Waldman, and M.T. Mattson. 1987. Tag retention by, and tagging mortality of, Hudson River striped bass. N. Am J. Fish. Manage. 7:535-538.

Field, J.D. 1997. Atlantic striped bass management: where did we go right? Fisheries 22(7):6-8.

Gamble, M. et al. 2003. Striped bass tagging report for 2002. Revised summary of U.S.F.W.S. cooperative tagging program results. Report No. SB Tag 2003-1. 35pp.

Gunderson, D.R., and P.H. Dygert. 1988. Reproductive effort as a predictor of natural mortality rate. J. Cons. int. Explor. Mer 44:200-209.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. 81:898-903.

Hoenig, J.M., N.J. Barrowman, W.S. Hearn, and K.H. Pollock. 1998a. Multiyear tagging studies incorporating fishing effort data. Can. J. Fish. Aquat. Sci. 55:1466-1476.

Hoenig, J.M., N.J. Barrowman, K.H. Pollock, E.N. Brooks, W.S. Hearn and T. Polacheck. 1998b. Models for Tagging Data that Allow for Incomplete Mixing of Newly Tagged Animals. Can. J. Fish. Aquat. Sci. 55:1477-1483.

Latour, R.J., K.H. Pollock, C.A. Wenner, and J.M. Hoenig. 2001a. Estimates of fishing and natural mortality for red drum (*Sciaenops ocellatus*) in South Carolina waters. N. Am. J.Fish. Manage. 21: 733-744.

Latour, R.J., J.M. Hoenig, J.E. Olney, and K.H. Pollock. 2001b. Diagnostics for multi-year tagging models with application to Atlantic striped bass (*Morone saxatilis*). Can. J. Fish. Aquat. Sci. 5: 1716-1726.

Latour, R.J., J.M. Hoenig and K.H. Pollock. 2001c. Properties of the residuals from two tag-recovery models. Fish. Bull. In review.

Latour, R.J., J.M. Hoenig and K.H. Pollock. 2002. Properties of the residuals from two tag-recovery models. Fish. Bull. In press.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. Int. Explor. Mer. 39(2):175-192.

Ricker, W.E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations.Bull. Fish. Res. Board Can. No 191.

Roff, D.A. 1984. The evolution of life history parameters in teleosts. Can. J. Fish. Aquat. Sci. 41:989-1000.

Sadler, P.W., R.J. Latour, R.E. Harris, and J.E. Olney. 2001. Evaluation of striped bass stocks in Virginia: monitoring and tagging studies, 1999-2003. Annual Report, Virginia Institute of Marine Science: 93 p.

Seber, G.A.F. 1970. Estimating time-specific survival and reporting rates for adult birds from band returns. Biometrika, 57: 313-318.

Sharov, A. and P.W. Jones. 2003. Estimation of the fishing mortality rate of resident striped bass in the Chesapeake Bay using spring tagging data. Report to the Atlantic States Marine Fisheries Stock Assessment Committee. 9pp.

Smith, D.R., K.P. Burnham, D.M. Kahn, X. He, C.J. Goshorn, K.A. Hattala, and A.W. Kahnle. 2000. Bias in survival estimates from tag-recovery models where catch-and-release is common, with an example from Atlantic striped bass (Morone saxatilis). Can. J. Fish. Aquat. Sci. 57:886-897.

Weaver, J.E., R.B. Fairbanks and C. M. Wooley. 1986. Interstate management of Atlantic coastal migratory striped bass. MRFSS 11: 71-85.

White, G.C. 1983. Numerical estimation of survival rates from band-recovery and biotelemetry data. J. Wildl. Manage. 47:716-728.

White, G.C. and K. P. Burnham. 1999. Program MARKBsurvival estimation from populations of marked animals. Bird Study 46:120-138.

Wooley, C.M., N.C. Parker, B.M. Florence and R.W. Miller. 1990. Striped bass restoration along the Atlantic Coast: a multistate and federal cooperative hatchery and tagging program.

Table 1. Summary data of striped bass tagged and released from pound nets in the Rappahannock River, spring 2008.

Date	Total	457 - 711 mm TL				>711 mm TL			
		males		females		males		females	
	Tagged	n	*TL*	n	*TL*	n	*TL*	n	*TL*
7 April	6	2	495.0	1	585.0	1	776.0	2	846.5
11 April	3	1	520.0	0		0		2	957.5
14 April	15	6	529.8	0		1	798.0	8	968.8
17 April	41	29	535.3	1	522.0	2	764.0	9	985.3
21 April	96	84	512.6	3	570.3	4	827.0	5	876.2
24 April	62	43	526.4	3	568.3	6	839.6	10	923.1
28 April	87	78	528.6	3	583.0	5	789.8	1	886.0
1 May	115	98	522.1	3	563.0	7	810.9	7	919.7
5 May	96	86	517.9	5	577.6	1	727.0	4	921.8
15 May	3	3	510.7	0		0		0	
Total	524	430	521.8	18	602.7	27	807.4	49	915.3

Table 2. Recapture matrix of striped bass (>457 mm TL) that were released in the Rappahannock River, springs 1990-2007. The second (bottom) number is the number of those recaptures that were harvested.

		Recaptures																	
Year	**n**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**
1990		162	64	47	25	12	10	3	2	3	1	1	0	0	1	0	0	0	0
	1,464	21	20	24	10	8	9	2	0	0	1	1			1				
1991			167	81	53	29	6	5	2	2	4	1	0	0	1	0	0	0	0
	2,481		48	38	22	14	3	1	2	1	4	0			1				
1992				14	8	6	5	1	1	1	1	0	0	0	0	0	0	0	0
	130			7	4	1	3	0	0	0	1								
1993					50	37	17	8	9	2	0	1	0	0	0	0	0	0	0
	621				18	17	12	5	4	1		0							
1994						13	10	5	4	4	0	0	0	0	0	0	0	0	0
	195					6	7	4	1	2									
1995							55	30	20	5	4	2	3	0	1	0	1	0	0
	698						24	12	9	4	1	1	2		1		0		
1996								21	18	7	3	1	1	1	0	0	1	0	0
	376							3	10	3	2	1	1	1			1		
1997									47	26	14	3	0	1	2	1	0	0	0
	712								26	17	10	2		1	1	1			
1998										55	26	2	3	3	1	0	0	0	0
	784									28	16	1	3	1	0				
1999											66	23	9	5	3	0	0	0	0
	853										30	7	4	2	2				
2000												122	51	23	16	6	5	1	1
	1,765											44	23	11	7	4	5	1	1
2001													61	23	16	7	2	2	2
	797												32	14	5	7	1	0	0
2002														20	8	15	1	1	2
	315													10	4	6	1	1	1
2003															58	37	9	4	5
	852														32	20	5	3	3
2004																80	21	13	7
	1,477															45	14	8	4
2005																	42	26	10
	921																27	17	6
2006																		48	11
	668																	27	4
2007																			89
	1,961																		46

Table 3. Location of striped bass (> 457 mm TL), recaptured in 2008, that were originally tagged and released in the Rappahannock River during springs 1990-2007.

State	Month												total
	J	F	M	A	M	J	J	A	S	O	N	D	
New Hampshire	0	0	0	0	0	1	0	0	0	0	0	0	1
Massachusetts	0	0	0	0	0	2	9	3	4	0	0	0	18
Rhode Island	0	0	0	0	0	3	2	0	1	0	0	0	6
Connecticut	0	0	0	0	0	1	0	0	0	0	0	0	1
New York	0	0	0	0	2	2	1	1	4	3	1	0	14
New Jersey	0	0	0	0	0	3	0	0	0	0	4	0	7
Delaware	0	0	0	0	0	1	0	0	0	0	1	0	2
Maryland	0	0	0	0	2	10	8	5	3	0	3	0	31
Virginia	3	0	1	13	8	6	1	0	2	5	2	14	55
North Carolina	1	1	0	0	0	0	0	0	0	0	0	0	2
Total	4	1	1	13	12	29	21	9	14	8	11	14	137

Table 4. Recapture matrix of striped bass (>710 mm TL) that were released in the Rappahannock River, springs 1990-2007. The second (bottom) number is the number of those recaptures that were harvested.

		Recaptures																	
Year	**n**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**
1990		26	9	15	2	4	6	1	0	2	1	1	0	0	1	0	0	0	0
	301	10	1	6	1	3	5	1		0	1	1			1				
1991			41	24	16	11	3	2	2	1	2	0	0	0	1	0	0	0	0
	390		19	10	12	9	2	1	2	0	2				1				
1992				4	3	2	2	0	0	0	1	0	0	0	0	0	0	0	0
	40			2	1	1	1				1								
1993					22	18	7	4	7	0	0	1	0	0	0	0	0	0	0
	212				11	11	5	2	3			0							
1994						9	7	5	1	2	0	0	0	0	0	0	0	0	0
	123					4	4	4	1	0									
1995							29	11	8	3	3	2	3	0	1	0	1	0	0
	210						18	6	5	2	1	1	2		1		0		
1996								1	3	1	0	0	1	0	0	0	0	0	0
	67							0	3	1			1						
1997									15	13	8	3	0	1	2	1	0	0	0
	212								11	12	6	2		1	1	1			
1998										24	13	2	3	2	0	0	0	0	0
	158									16	9	1	3	1					
1999											17	6	2	3	2	0	0	0	0
	162										13	2	1	2	1				
2000												28	19	14	9	4	3	0	1
	365											13	11	6	5	3	3		1
2001													19	14	4	6	2	1	1
	269												9	8	2	6	1	0	0
2002														10	6	7	1	0	2
	122													7	3	5	1		1
2003															35	24	7	1	3
	400														23	13	3	1	2
2004																39	12	13	5
	686															21	8	8	3
2005																	16	11	8
	284																12	7	5
2006																		12	4
	175																	10	3
2007																			44
	840																		26

Table 5. Location of striped bass (> 710 mm TL), recaptured in 2008, that were originally tagged and released in the Rappahannock River during springs 1988-2007.

State	Month												total
	J	F	M	A	M	J	J	A	S	O	N	D	
Massachusetts	0	0	0	0	0	2	9	3	4	0	0	0	18
Rhode Island	0	0	0	0	0	2	2	0	1	0	0	0	5
Connecticut	0	0	0	0	1	0	0	0	0	0	0	0	1
New York	0	0	0	0	2	2	1	1	4	3	1	0	14
New Jersey	0	0	0	0	0	3	0	0	0	0	4	0	7
Delaware	0	0	0	0	0	1	0	0	0	0	1	0	2
Maryland	0	0	0	0	0	2	0	0	0	0	0	0	2
Virginia	2	0	0	5	1	2	0	0	0	1	1	9	21
North Carolina	1	1	0	0	0	0	0	0	0	0	0	0	2
Total	3	1	0	5	4	14	12	4	9	4	7	9	72

Table 6. Recapture matrix of male striped bass (457-710 mm TL) that were released in the Rappahannock River, springs 1990-2007. 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	06	07
1990	189	20 1	7 1	2 0	1 0	0	1 1	0	0	0	0	0	0	0	0	0	0	0	0
1991	107		18 3	6 5	2 0	1 0	1 0	0	0	0	0	0	0	0	0	0	0	0	0
1992	31			4 3	0	2 0	1 1	0	0	0	0	0	0	0	0	0	0	0	0
1993	166				12 2	8 3	3 3	1 1	1 0	1 0	0	0	0	0	0	0	0	0	0
1994	38					1 0	3 3	0	0	0	0	0	0	0	0	0	0	0	0
1995	361						37 6	10 5	10 3	2 2	0	0	0	0	0	0	0	0	0
1996	258							20 2	12 6	4 2	3 2	0	0	0	0	0	0	0	0
1997	458								27 12	9 5	4 3	0	0	0	0	0	0	0	0
1998	601									26 11	12 7	0	0	1 0	1 0	0	0	0	0
1999	666										48 16	15 4	6 3	2 0	1 1	0	0	0	0
2000	1352											113 29	30 12	7 5	7 2	1 0	1 1	0	0
2001	496												50 22	8 6	9 1	0	0	1 0	1 0
2002	189													12 3	2 1	7 1	0	1 1	0
2003	443														24 8	11 7	2 2	2 2	1 1
2004	757															38 22	6 5	0	1 1
2005	597																26 14	15 10	2 1
2006	461																	33 14	6 1
2007	1,078																		44 20

Table 7. Estimates of fishing mortality (F) and natural mortality (M) of the catch equation, exploitation rate (R/M, where M is the number of marked striped bass), and instantaneous rate (IRCR) analytical approaches (there are no 2007 estimates for F for the catch equation and R/M methods pending committee action).

Year	IRCR constant M		IRCR 2 period M		IRCR 3 period M		Catch Equation		R/M assumed M	
	F	M	F	M	F	M	F	M	F	M
1988	0.01	0.60	0.01	0.35	0.01	0.35			0.01	0.15
1989	0.00	0.60	0.00	0.35	0.00	0.35			0.00	0.15
1990	0.06	0.60	0.04	0.35	0.04	0.35	0.06	1.36	0.01	0.15
1991	0.06	0.60	0.04	0.35	0.04	0.35	0.18	0.52	0.06	0.15
1992	0.18	0.60	0.10	0.35	0.10	0.35	0.26	0.18	0.18	0.15
1993	0.06	0.60	0.04	0.35	0.04	0.35	0.10	0.00	0.02	0.15
1994	0.05	0.60	0.03	0.35	0.03	0.35	0.21	0.87	0.00	0.15
1995	0.09	0.60	0.06	0.35	0.06	0.35	0.12	0.74	0.03	0.15
1996	0.04	0.60	0.03	0.35	0.03	0.35	0.08	0.00	0.02	0.15
1997	0.07	0.60	0.07	0.90	0.07	0.99	0.11	0.73	0.05	0.15
1998	0.05	0.60	0.06	0.90	0.06	0.99	0.10	1.45	0.03	0.15
1999	0.06	0.60	0.07	0.90	0.08	0.99	0.11	1.21	0.04	0.15
2000	0.04	0.60	0.05	0.90	0.05	0.99	0.11	1.17	0.04	0.15
2001	0.06	0.60	0.09	0.90	0.09	0.82	0.15	0.79	0.09	0.15
2002	0.04	0.60	0.06	0.90	0.06	0.82	0.07	0.29	0.03	0.15
2003	0.03	0.60	0.05	0.90	0.05	0.82	0.09	0.45	0.04	0.15
2004	0.06	0.60	0.08	0.90	0.07	0.82	0.13	1.71	0.05	0.15
2005	0.04	0.60	0.06	0.90	0.06	0.82	0.11	0.96	0.04	0.15
2006	0.06	0.60	0.09	0.90	0.08	0.82	0.16	2.84	0.06	0.15
2007	0.05	0.60	0.07	0.90	0.06	0.82				

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 used force-of-infection models to examine the epizootiology of mycobacteriosis in Chesapeake Bay striped bass from 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 (Gauthier et al. 2008).

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 Canon 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 3 discrete lesion categories:

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 and H) 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:

Disease progression:

The duration of the stages (i.e., the time it takes to progress from one condition to the next) can be estimated from tagging data if it is assumed that transitions are asynchronous across the population. This means that at the time of tagging, a fish can be anywhere in the time interval it takes to progress from one stage to the next. The methodology is analogous to that used to estimate intermolt periods in crustaceans and insects (Willoughby and Hurley 1987, Restrepo and Hoenig 1988, Hoenig and Restrepo 1989, Millar and Hoenig 1997). In the crustacean molt models, the data consist of size at

tagging, time at liberty, and size at recapture. If the size at recapture is greater than the size at tagging then the animal has molted. Thus, the data reduce to time at liberty and an indicator of whether the animal molted. In the case of striped bass with dermal mycobacteriosis, the data consist of condition class at tagging, time at liberty, and condition class at recapture. Thus, the data reduce to time at liberty and an indicator of whether the animal has progressed to the next disease condition class.

The simplest model to handle this situation was developed by Munro (1974, 1983). The recaptures are tabulated by time period, say by month. Then, under the assumptions that:

1) the duration of a stage (condition class) is a constant, g

2) at the time of tagging the time elapsed since the animal entered the condition class is a uniform random variable over the interval 0 to g

3) the probability of recapture does not vary by condition class

the proportion of animals, p_t, making the transition to a higher condition class at time t is a linear function of the time at liberty, t, up until g units of time have passed, and is 1.0 for $t > g$. That is,

$$p_t = \begin{cases} \dfrac{t}{g}, & 0 \le t < g \\ 1.0, & t > g \end{cases}.$$

Thus, a plot of the proportion of recaptures in a time interval that show a transition to a higher condition class should describe a linear relationship with time up until the proportion reaches 100%; the slope of the regression line estimates $1/g$. The stage duration, g, is estimated by

$$g = 1/\text{slope} .$$

The categories for disease progression are defined as:

Clean:	no external sign of infection (condition 0)
Light:	PF1 and/or U1 on at least one side (condition 1)
Moderate:	PF2 and/or U2 on at least one side (condition 2)
Heavy:	PF3 and/or U3,4 on at least one side (condition 3)
Other:	all H, but without any PF or U (condition 4)

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.

The Munro method is generally robust (Restrepo and Hoenig 1988) but it is inefficient because a) it requires recaptures to be binned into time intervals rather than using exact times of recapture, and b) it does not use the information from animals at liberty for a long period of time. Hoenig and Restrepo (1989) developed a likelihood approach to estimating the stage duration but their model is based on the assumption that there is no individual variability in stage duration. This assumption can cause a serious positive bias in estimates of stage duration. Millar and Hoenig (1997) generalized the approach of Hoenig and Restrepo to allow for individual variability in stage duration.

Mortality estimates:

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

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

(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 (Hoenig et al. 1990, Hueter *et al*. 2006).

Here, we develop a logistic model of relative survival as a linear model because this approach is intuitive and provides a graphical means to see how the model performs. Better estimates can be obtained using the method of maximum likelihood (e.g., by fitting a generalized linear model) and these will be presented in the future.

Suppose the survival rate of "clean" fish is S_o and the survival rate of fish in disease condition x is S_x. We tag and release some fish in each category and the ratio of fish in condition x to condition 0 is R in the releases. We then obtain recaptures at time t, for t = 1, 2, … Under the assumption of the model, the ratio among the recaptures at time t, R_t, should be

$$R_t = R\left(\frac{S_x}{S_o}\right)^t$$

Taking natural logarithms of both sides leads to the linear model

$$\log_e(R_t) = \log_e(R) + t \cdot \log_e\left(\frac{S_x}{S_o}\right)$$

where $\log_e(R)$ is the y-axis intercept and $\log_e(S_x/S_o)$ is the slope. Thus, exponentiating the estimated slope provides an estimate of the relative survival (ratio of survival rates). Also, letting the survival rate of fish in disease category x be expressed as $S_x = \exp(-Z_x)$ and $S_o = \exp(-Z_o)$, we have

$$\text{slope} = \log_e\left(\frac{\exp(-Z_x)}{\exp(-Z_o)}\right) = Z_o - Z_x$$

which is the difference in the instantaneous total mortality rates. Assuming both groups of fish experience the same fishing mortality, we have

$$\text{slope} = M_o - M_x$$

where M_o is the natural mortality rate of "clean" fish and M_x is the natural mortality rate of fish in disease condition x. That is, the slope estimates how much additional natural mortality is caused by mycobacteriosis.

In theory, the intercept of the linear regression line can estimate the initial ratio of fish in the two condition categories. However, if there is differential stress or mortality

associated with the tagging process then an artificial situation can be created where the ratio changes substantially over the first few days after release and then stabilizes and is then subject to just differential mortality associated with the disease (and not the tagging process). Thus, it may be necessary to disregard the initial ratio at the time of tagging and the recaptures over the first few days of recapture.

In the work plan, it was proposed that relative survival be expressed by the odds ratio approach. It should be noted that the odds ratio approach is a special case of the logistic regression described above in which observations are obtained at just two points in time. That is, the data for intermediate time steps is not used.

In subsequent reports, because tagged fish will be released at two times (one year apart), it should 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 2007: A total of 1,584 striped bass were tagged, assessed for external disease indications, photographed and released from two pound nets in the upper Rappahannock (n = 597) and five pound nets in the lower Rappahannock (n = 987) River during fall, 2007 (Table 2). The striped bass tagged upriver were mostly 430-480 mm in fork length (Figure 3). There was a trend towards a higher prevalence of infection with size. There was a broader range in size at the lower river nets, peaking from 440-520 mm (Figure 4).

The striped bass tagged in the lower Rappahannock River also showed a trend of an increasing prevalence of infection with size. Combined, only 37.9% (600/1,584) of the total that were tagged were without any external sign of mycobacteriosis. The lightly-infected group (38.4%) had the highest prevalence, while 9.8% were heavily infected. The striped bass tagged upriver had a slightly lower prevalence of infected striped bass (61.6% vs.62.3%). These prevalences were different than was found in 2006 (52.9% and 69.7%), but were lower than was found in the 2005 tag releases (74.8% vs. 77.9%).

Spring 2008: A total of 169 striped bass were tagged, assessed, photographed and released from the pound nets in the lower Rappahannock River during late spring, 2008 (Table 3). The striped bass tagged in the upper Rappahannock River were similar in size to the fall releases there (Figure 5) and showed the same trend towards an increasing prevalence of infection with size. Although greater than for the fall releases, only 40.8% (69/169) of the total that were tagged were without any external sign of mycobacteriosis. The lightly-infected group was 38.5% of the releases, while 11.2% were heavily infected. Interestingly, the prevalence of non-infected striped bass was less than in 2006, but the prevalence of heavily infected striped bass has increased each year since 2005.

Tag Recapture Summary

Current year:

Fall 2007 releases: A total of 127 striped bass tagged during fall 2007 were recaptured prior to 20 September, 2008 (Table 4). The overall recapture rate was 0.080 (0.085 from the lower Rappahannock river releases and 0.072 from the upper Rappahannock releases). However, the incidence of immediate (< 7 days) recapture was much greater from the lower Rappahannock River releases (0.0487 vs. 0.017) so that the Recapture rate beyond the initial 7 days was higher from the upper Rappahannock River (0.055 vs. 0.039). In contrast to the results from the falls 2005 and 2006 releases, the relative prevalence of each of the disease index severity classifications was similar to the prevalence of the releases (e.g. 0.351 vs. 0.379 clean, and 0.105 vs. 0.098 heavy). The immediate recaptures from the fall 2005 and 2006 releases had a much higher prevalence of the heavy classification and a lower prevalence of the clean than did the releases (Sadler et al. 2007).

Striped bass tagged in the lower Rappahannock River were recaptured throughout the Virginia and Maryland portions of Chesapeake Bay while those tagged from the upper Rappahannock River were recaptured only in Virginia portion of Chesapeake Bay and in the Potomac River (Table 5). The recaptured clean and moderately infected striped bass appeared to have a greater range than did the heavily infected releases. However, since there were fewer total releases of the heavily infected striped bass, there were fewer subsequent recaptures (a total of five outside of the release area) upon which to compare with the other classifications.

Spring 2008 releases: A total of 47 striped bass tagged during spring 2008 were recaptured prior to 20 September 2008 (Table 6). Almost one half (46.8%) of the recaptures were within seven days of release within the release area. The prevalence of

both the clean and heavy index classifications of the immediate recaptures were greater than the respective release prevalences (0.591 vs. 0.408 for clean and 0.227 vs. 0.112 for heavy).

Recaptures from the spring 2008 tag releases were recaptured throughout both the Maryland and Virginia portions of Chesapeake Bay (Table 7). As noted for the fall 2007 releases, the recaptured clean and moderately infected striped bass appeared to have a greater range than did the heavily infected releases.

Fall 2005-Spring 2007 releases:
Fall 2005 releases: A total of seven striped bass tagged during fall 2005 were recaptured between 21 September, 2007 and 20 September, 2008, their third year at large (Table 8). These recaptures were mostly from uninfected releases, but there was one recapture of a heavily infected release, indicating that at least some of these releases survive through a third year at large. These few recaptures were mostly (71.4%) from the release area and within the rest of the Rappahannock River, the remaining recaptures were from the lower Virginia Chesapeake Bay (Table 9).

Spring 2006 releases: A total of four striped bass tagged and released during spring 2006 were recaptured between 20 September, 2007 and 21 September, 2008 (1.5-2.5 years at large, Table 10). These recaptures were comprised of clean and moderate releases, but there were no recaptures of heavy releases. These recaptures were split between the Rappahannock River and the Virginia portions of Chesapeake Bay (Table 11).

Fall 2006 releases: A total of 52 striped bass tagged and released during fall 2006 were recaptured between 21 September, 2007 and 20 September, 2008 (year two at large, Table 12). Most of these recaptures (59.6%) were in the subsequent fall of their release with a consistent, low, incidence of recapture thereafter. Both the prevalences of the clean (0.423) and the heavy (0.135) recaptures exceeded the prevalences of their releases (0.324 and 0.107 respectively).

Even after being at large for one full year, 50.0% were recaptured back within their release area and another 11.5% were recaptured within the Rappahannock River (Table 13). The rate of recapture in year two was similar from both the upper Rappahannock (1.8%) and the lower Rappahannock releases (1.4%). There were recaptures of each disease index classification from every portion of both the Maryland and Virginia portions of Chesapeake Bay, including the Potomac River (Table 13).

Spring 2007 releases: A total of 19 striped bass tagged in spring 2007 were recaptured between 21 September, 2007 and September 20, 2008 (0.5-1.5 years at large, Table 14). While most of the recaptures (63.2%) were caught the following fall, there was a second peak (26.3%) the next spring. Again, most recaptures (68.4%) were caught in the area of release and the Rappahannock River (10.5%), but there was one recapture reported from each section of Chesapeake Bay except for the upper Maryland portion of Chesapeake Bay (Table 15). There were no recaptures of either moderately or heavily infected striped bass released in spring 2007.

Disease progression in Rappahannock River Striped Bass, 2005-2007

Release assessments: The prevalence of outwardly uninfected (clean) striped bass was higher in the upper Rappahannock River three year-old striped bass (40-52%) than in the lower river (30-42%, Figure 6) from the fall 2005-2007 tag releases. The prevalence of heavily infected striped bass was 5-10% from both locations. Age three striped bass are the youngest age fully recruited to the pound nets and are also the youngest age that meets the 457 mm total length minimum for legal recreational and commercial harvest.

The prevalence of clean striped bass decreased rapidly to near zero by age five in the 2002 year class striped bass from both locations in the Rappahannock River (Figure 7). The prevalence of lightly infected striped bass remained fairly constant, but the prevalence of the heavily infected striped bass increased from 8-10% at age three to 28% (lower Rappahannock River)-48% (upper Rappahannock River) by age five. The 2002 year class is the only one to progress through all three ages to date.

Recapture assessments: A total of 374 tagged striped bass have been recaptured and returned to VIMS for necropsy and disease reassessment from fall 2005 to present. This represents 4.4% of the total tagged striped bass released. These reassessments of the recaptures show a strong progression in the number of pigmented foci over the course of a year at large in striped bass that were originally assessed as being without any pigmented foci when released from falls 2005-2007 (Figure 8). Pigmented foci appeared within the first 30 days at large and by the following fall less than 5% remained without any pigmented foci and most had progressed to more than 10 pigmented foci.

There was a similar progression in the number of pigmented foci in recaptured striped bass originally released with less than 10 PFs (lightly infected) during falls 2005-2007. The progression to the moderate classification (11-50 PFs) occurred within the first 30 days at large and by the following fall almost 70% had progressed to the moderate and heavy classifications (Figure 8). However, there were incidences of regression (healing) of some pigmented foci, even resulting in total remission (clean reassessment) during the winter (one of three recaptures) and spring (three of 45 recaptures). However, the trend toward a progression in the total number of pigmented foci throughout the first year at large was stronger (zero out of 46 recaptures reassessed as clean in the summer and following fall).

Estimates of disease progression

There were 94 recaptures originally assessed as light and 59 recaptures originally assessed as moderate that were returned to VIMS and had their external disease status reassessed. The plot of the progression in the disease of the striped bass originally released in the light condition with time at large (grouped by season, Figure 9) was described by:

$$Y = .00212\ (x) - .006226$$

which yields an estimate of 100% progression to the moderate condition at 444 days (SE = 72 days). Likewise the plot of the progression in the disease of striped bass originally assessed as moderate (Figure 10) was described by:

$$Y = .00209 (x) - .03122$$

Which yields an estimate of 100% progression to severe at 478 days (SE=176 days).

Estimation of survival rates and relative survival rates

Logistic model

The rate of return of tags from diseased fish is clearly lower than that for "clean" fish (showing no overt signs of disease). If the rate of return were equal for the two groups, a plot of the ratio of returns (or the log of the ratio) versus time would be a horizontal line. But, it can be seen in Figures 11A-D that the slope is negative indicating that diseased fish are not surviving as well as clean fish or that diseased fish are less catchable than clean fish. The slope of the regression lines in Figures 11A-D provide estimates of the difference in instantaneous natural mortality rates, i.e., of the additional mortality caused by mycobacteriosis. Estimates of the ratio of annual survival rates can be obtained by exponentiating the slope of the regression line. In computing the linear regression lines, the initial tagging ratio and the recaptures during the first seven days at liberty have not been used because of concerns that they represent an artificial situation associated with the stress of tagging (see methods section for an explanation).

Fish in disease conditions 3 and 2 have estimated elevations of natural mortality rate M above that of clean fish of 1.31 and 1.49, respectively (Table 19, Figures 11A and B). This implies annual survival rates for fish in disease conditions 3 and 2 that are 27 and 23 %, respectively, of the survival of clean fish. Because the results for disease conditions 2 and 3 are similar, we combined the data from these two disease categories to boost sample sizes and increase precision. The result is an estimated difference in M between fish in conditions 2 and 3 and fish that are clean of 1.46; the estimated ratio of survival rates is 0.23 (Table 19, Figure 11D).

Fish in disease condition 1 appear to have an elevated mortality rate relative to clean fish but not as high a mortality rate as fish in disease conditions 2 and 3 (Figure 11C). The estimated difference in instantaneous natural mortality rates is 0.71 and the ratio of survival rates is 0.49 (Table 19).

The estimated impacts of the disease are not very precise but provide a compelling indication that the disease has population impacts. The estimates of the

increase in mortality for fish in condition 2 (relative to clean fish) is highly statistically significant ($p = 0.01$). The estimate for condition 3 is very similar and the p-value (0.10) is low though not statistically significant. Combining conditions 2 and 3 to boost sample sizes gives a significant result close to the estimate for condition 2 alone. This likely reflects the greater sample size for fish in condition 2 (254 fish) versus the sample size for condition 3 (219 fish). The estimated slope for condition 1 fish indicates a survival rate that is half that of clean fish and twice that of fish in category 2-3. This is a reasonable result. However, the slope is not statistically significant so that the possibility that condition 1 fish have the same mortality rate as clean fish cannot be ruled out at this time.

Discussion

The results so far establish some important points. First, we continue to obtain excellent cooperation from commercial and sport fishers so that our rate of return of tags (about 12.4% of releases), and of tagged carcasses(4.4%), 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.

The prevalence of heavily-infected striped bass, which remained stable from fall 2005 to fall 2006 (11.7% and 10.8% respectively), fell to 7.8 % in fall 2007, and the proportion of the striped bass examined as non-infected rose from 25 to 38%. We have recapture information from striped bass released as heavily-infected more than one year after their release, so the disease is not 100% fatal within this time frame. However, the necropsies performed on returned carcasses do indicate that the disease is progressive, and include incidences of healing individual pigmented foci and ulcers. We have determined that the majority of striped bass will progress in disease severity on an annual basis and that very few resident (fall) striped bass remain outwardly uninfected by age five. Our first estimate of disease stage progression was 444 days for lightly infected fish to progress to moderately infected and 478 days for moderately infected to progress to severely infected. Thus mycobacteriosis is an extremely slowly progressing disease. These estimates will be refined as more recaptures are returned to VIMS for reassessment.

The lower prevalence of mycobacterial infections in the larger, migrant striped bass indicates that the resident population is most at risk. Since the resident striped bass form the basis of both the recreational and commercial fisheries in Virginia, the results of this study will be increasingly important.

This project has provided a direct measurement of disease-associated mortality by stage of the disease. Moderately and heavily infected fish appear to have one quarter the survival rate of fish tagged without outward signs of disease. Fish with early signs of the disease appear to have half the survival of fish without signs of the disease. The standard error for the estimate for lighly (early stage) infected fish is not statistically different from zero mortality associated with the disease. As further tagging results are obtained the standard error can be expected to be reduced. It should be noted that the fish tagged without outward signs of disease are a mixture of uninfected fish and infected fish that are not yet showing signs of the disease. Thus, a comparison of the two groups underestimates the disease-associated mortality because some fish in the “clean” group may already be experiencing disease-related mortality.

Literature Cited

Brownie, C., D.R. Anderson, K.P. Burhnam, and D.R. Robson. 1985. Statistical inference from band recovery data: a handbook, 2nd ed., U.S. Fish and Wildl. Serv. Resour. Publ. No. 156.

Bruno DW, J Griffiths, CG Mitchell, BP Wood, ZJ Fletcher, FA Drobniewski, and TS Hastings. 1998. Pathology attributed to *Mycobacteria chelonae* infection among farmed and laboratory - infected Atlantic salmon (*Salmo salar*). Dis Aquat Org. 33:101-109

Cardinal JL. 2001. Mycobacteriosis in striped bass, *Morone saxatilis*, from Virginia waters of Chesapeake Bay. Master's Thesis. School of Marine Science, Virginia Institute of Marine Science. Pp.83.

Colorni A. 1992. A systemic mycobacteriosis in the European sea bass *Dicentrarchus labrax* cultured in Eilat (Red Sea). Bamidgeh – Isr J Aquacult 44:75-81

Crecco, V. 2003. Methods of estimating fishing (F) and natural (M) mortality rates from total mortality (Z) and exploitation (u) rates for striped bass. Final Report. Connecticut Marine Fisheries Division. 40 pp.

Garrison, LP, JS Link and G White. 2004. A multispecies modeling approach to evaluate interactions between Atlantic menhaden and its predators. Abstract: 60th Annual Northeast Fish and Wildlife Conference. 25-28 April, 2004. Ocean City, Maryland.

Gauthier, DT, RJ Latour, DM Heisey, CF Bonzak, J Gartland, EJ Burge and WK Vogelbein. 2008. Mycobacteriosis-associated mortality in wild striped bass (*Morone saxatilis*) from Chesapeake Bay, USA. Ecol. Appl. 18: 1718-1727.

Hartman, KJ 2004. Increases in coastal striped bass predatory demand and implications of declines in Atlantic menhaden populations. Abstract: 60th Annual Northeast Fish and Wildlife Conference. 25-28 April, 2004. Ocean City, Maryland.

Hoenig JM, NJ Barrowman, WS Hearn, and KH Pollock. 1998. Multiyear Tagging Studies Incorporating Fishing Effort Data. Can. J. Fish. Aquat. *Sci*. 55:1466-1476.

Hoenig JM, NJ Barrowman, KH Pollock, EN Brooks, WS Hearn and T Polacheck. 1998. Models for Tagging Data that Allow for Incomplete Mixing of Newly Tagged Animals. Can. J. Fish. Aquat. Sci. 55:1477-1483.

Hoenig JM, P Pepin, and WD Lawing. 1990. Estimating Relative Survival Rate for Two Groups of Larval Fishes from Field Data: Do Older Larvae Survive Better than Young? Fish. Bull. 88:485-491.

Hoenig, J.M. and V.R. Restrepo. 1989. Estimating the Intermolt Periods in Asynchronously Molting Crustacean Populations. Biometrics 45:71-82.

Hueter, R.E., C.A. Manire, J. Tyminski, J.M. Hoenig and D.A. Hepworth. 2006. Assessing Mortality of Released or Discarded Fish Using a Logistic Model of Relative Survival Derived from Tagging Data. Trans. Am. Fish. Soc. 135:500-508.

Jacobs JM, HL Rogers, WF Van Heukelem, B Coakley, C Gieseker and M Matsche. 2004. Nutritional health of Chesapeake Bay striped bass *Morone saxatilis* in relation to disease. Abstract: 60th Annual Northeast Fish and Wildlife Conference. 25-28 April, 2004. Ocean City, Maryland.

Kahn, DM. 2004. Tag-recapture data from Chesapeake Bay resident striped bass indicate that survival has declined. Abstract: 60th Annual Northeast Fish and Wildlife Conference. 25-28 April, 2004. Ocean City, Maryland.

May, EB, V Pernell Lewis, AM Overton, J Jacobs and L Alade. 2004. Potential impacts of mycobacteriosis in striped bass on Chesapeake and Atlantic coastal stocks. Abstract: 60th Annual Northeast Fish and Wildlife Conference. 25-28 April, 2004. Ocean City, Maryland.

Millar, R.B. and J.M. Hoenig. 1997. A Generalized Model for Estimating Intermolt Periods of Asynchronously Molting Insects and Crustacea from Field or Laboratory Data. J. Agric., Biol. & Environ. Statistics 2(4):1-14.

Munro, J.L. 1974. The biology, ecology and bionomics of spiny lobsters (Palinuridae), spider crabs (Majiidae) and other crustacean resources. Part VI *in* J. L. Munro, ed. The biology, ecology, exploitation and management of Caribbean reef fishes: Scientific Report of the ODA/UWI Fisheries Ecology Research Project 1969-1973: University of the West Indies, Jamaica. Research Reports from the Zoology Department Number 3, University of the West Indies, Kingston. 57 pp.

Nigrelli RF and H Vogel. 1963. Spontaneous tuberculosis in fish and other coldblooded vertebrates with special reference to *Mycobacterium fortuitum* from fish and human lesions. Zoologica 48:131-144.

Restrepo, V.R. and J.M. Hoenig. 1988. Munro's Method for Estimating Intermolt Periods of Tropical Decapods is Robust. Bull. Mar. Sci. 42:488-492.

Rhodes MW, H Kator, S Kotob, P van Berkum, I Kaattari, WK Vogelbein, F Quinn, MM Floyd, WR Butler and CA Ottinger. 2003. *Mycobacterium shottsii* sp. nov., a slow growing species isolated from Chesapeake Bay striped bass (*Morone saxatilis*). Int. J. Syst. Evol. Micro. 53:1-5.

Rhodes MW, H Kator, S Kotob, P van Berkum, I Kaattari, WK Vogelbein, F Quinn, MM Floyd, WR Butler, CA Ottinger. 2002. *Mycobacterium shottsii* sp. nov., a slow growing species isolated from Chesapeake Bay striped bass, (*Morone saxatilis*). Int. J. System. Environ. Microbiol. 53:421-424.

Rhodes, MW, H Kator, I Kaattari, D Gauthier, WK Vogelbein, & C Ottinger. 2004. Isolation and characterization of *Mycobacterium* spp. from striped bass, *Morone saxatilis*, from the Chesapeake Bay. Dis. Aquat. Org. 61:41-51.

Rosner, B. 1990. Fundamentals of Biostatistics, 3rd edition. PWS-Kent Publishing Company, Boston.

Uphoff, JH Jr. 2004. Striped bass and Atlantic menhaden: Is there a predator-prey imbalance in Chesapeake Bay? Abstract: 60th Annual Northeast Fish and Wildlife Conference. 25-28 April, 2004. Ocean City, Maryland.

Sadler, P.W., J.M. Hoenig, R.E. Harris, R.J. Wilk and L.M. Goins. 2007. Evaluation of striped bass stocks in Virginia: monitoring and tagging studies, 2005-2009. Annual report, Virginia Institute of Marine Science: 170pp.

Vogelbein WK, DE Zwerner, H Kator, MW Rhodes and J Cardinal. 1999. Mycobacteriosis of striped bass from Chesapeake Bay. pages 53-58. In J.E. Olney (ed.), *Research on Recreational Fishes and Fisheries*, VIMS Spec. Sci. Rept. 139, 82 pp.

Vogelbein WK, DT Gauthier, MW Rhodes, H Kator, R Latour, C Bonzek and C Ottinger. 2004. Mycobacteriosis in striped bass (*Morone saxatilis*) from Chesapeake Bay. Abstract: 60th Annual Northeast Fish and Wildlife Conference. 25-28 April, 2004. Ocean City, Maryland.

Willoughby, L.G. and M.A. Hurley. 1987. “Echo” moulting used to estimate moulting periodicity of mayflies (Ephemeroptera) and stoneflies (Plecoptera) in nature. Aquatic Insects 9:221-227.

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, 2007.

Date	release area	n	infection index				
			clean	light	moderate	heavy	other
1 October	upper	40	23	13	4	1	0
4 October	upper	95	36	41	11	6	1
5 October	lower	70	15	33	11	10	1
8 October	upper	82	39	23	13	6	1
15 October	upper	131	60	49	13	9	0
18 October	upper	85	31	35	8	10	1
22 October	lower	249	89	105	33	22	0
25 October	upper	66	15	33	8	10	0
12 November	lower	245	108	83	32	20	2
13 November	upper	98	26	39	14	19	0
20 November	lower	217	89	77	33	16	2
28 November	lower	89	34	35	13	7	0
30 November	lower	23	6	10	3	4	0
5 December	lower	72	26	25	9	12	0
7 December	lower	13	2	5	4	2	0
10 December	lower	9	2	3	2	2	0
totals	upper	597	229	233	71	61	3
	lower	987	371	376	140	95	5
	both	1,584	600	609	221	156	8

Table 3. Tag release totals and mycobacteria infection index, by date, of striped bass in the upper and lower Rappahannock River sites, spring, 2008.

Date	release area	n	infection index				
			clean	light	moderate	heavy	other
16 May	lower	27	12	8	5	2	0
19 May	lower	38	19	11	1	7	0
22 May	lower	21	6	12	2	1	0
27 May	lower	47	20	18	1	6	2
29 May	lower	21	9	8	3	1	0
2 June	lower	15	3	8	2	2	0
totals	lower	169	69	65	14	19	2

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, 2007.

Date	release area	n	infection index				
			clean	light	moderate	heavy	other
0-7 days	upper	10	1	8	0	1	0
	lower	46	18	15	7	5	1
Fall 2007 (>7 days)	upper	12	3	5	3	1	0
	lower	10	1	3	5	1	0
Winter 2008	upper	2	1	1	0	0	0
	lower	8	1	4	2	1	0
Spring 2008	upper	6	2	2	1	1	0
	lower	15	3	9	1	2	0
Summer 2008	upper	13	2	6	2	3	0
	lower	5	2	1	0	2	0
totals	upper	43	9	22	6	6	0
	lower	84	25	32	15	11	1
	both	127	34	54	21	17	1

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, 2007.

recapture area	release area	n	infection index				
			clean	light	moderate	heavy	other
release area	upper	29	5	16	5	3	0
	lower	63	21	22	12	9	1
Rappahannock River	upper	8	2	3	1	2	0
	lower	2	1	1	0	0	0
upper Bay (Md)	upper	0	0	0	0	0	0
	lower	1	1	0	0	0	0
lower Bay (Md)	upper	0	0	0	0	0	0
	lower	6	1	3	1	1	0
Potomac River	upper	2	0	2	0	0	0
	lower	3	0	1	1	1	0
upper Bay (Va)	upper	2	1	0	0	1	0
	lower	3	1	2	0	0	0
lower Bay (Va)	upper	2	1	1	0	0	0
	lower	6	1	4	1	0	0
totals	upper	43	9	22	6	6	0
	lower	84	25	32	15	11	1
	both	127	34	54	21	17	1

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, 2008.

Date	release area	n	infection index				
			clean	light	moderate	heavy	other
0-7 days	lower	22	13	3	1	5	0
Spring 2008 (>7days)	lower	17	5	6	0	6	0
Summer 2008	lower	8	3	3	0	2	0
totals	lower	47	21	12	1	13	0

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, 2008.

recapture area	release area	n	infection index				
			clean	light	moderate	heavy	other
release area	lower	38	18	8	1	11	0
Rappahannock River	lower	1	0	0	1	0	0
upper Bay (Md)	lower	1	1	0	0	0	0
lower Bay (Md)	lower	1	0	1	0	0	0
Potomac River	lower	2	1	1	0	0	0
upper Bay (Va)	lower	1	1	0	0	0	0
lower Bay (Va)	lower	2	0	0	0	2	0
totals	lower	46	21	10	2	13	0

Table 8. 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 and recaptured from fall 2007 through summer 2008.

Date	release area	n	infection index				
			clean	light	moderate	heavy	other
Fall 2007	upper	2	1	1	0	0	0
	lower	1	1	0	0	0	0
Winter 2008	upper	2	1	0	0	1	0
	lower	1	1	0	0	0	0
Spring 2008	upper	0	0	0	0	0	0
	lower	0	0	0	0	0	0
Summer 2008	upper	1	0	0	1	0	0
	lower	0	0	0	0	0	0
totals	upper	5	2	1	1	1	0
	lower	2	2	0	0	0	0
	both	7	4	1	1	1	0

Table 9. 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 and recaptured from fall 2007 through summer 2008.

recapture area	release area	n	infection index				
			clean	light	moderate	heavy	other
release area	upper	2	0	1	1	0	0
	lower	1	1	0	0	0	0
Rappahannock River	upper	2	1	0	0	1	0
	lower	0	0	0	0	0	0
upper Bay (Md)	upper	0	0	0	0	0	0
	lower	0	0	0	0	0	0
lower Bay (Md)	upper	0	0	0	0	0	0
	lower	0	0	0	0	0	0
Potomac River	upper	0	0	0	0	0	0
	lower	0	0	0	0	0	0
upper Bay (Va)	upper	0	0	0	0	0	0
	lower	0	0	0	0	0	0
lower Bay (Va)	upper	1	1	0	0	0	0
	lower	1	1	0	0	0	0
totals	upper	5	2	1	1	1	0
	lower	2	2	0	0	0	0
	both	7	4	1	1	1	0

Table 10. 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 and recaptured from fall 2007 through summer 2008.

Date	release area	n	infection index				
			clean	light	moderate	heavy	other
Fall 2007	upper	0	0	0	0	0	0
	lower	2	1	0	1	0	0
Winter 2008	upper	0	0	0	0	0	0
	lower	1	1	0	0	0	0
Spring 2008	upper	1	0	0	1	0	0
	lower	0	0	0	0	0	0
Summer 2008	upper	0	0	0	0	0	0
	lower	0	0	0	0	0	0
totals	upper	1	0	0	1	0	0
	lower	3	2	0	1	0	0
	both	4	2	0	2	0	0

Table 11. 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 and recaptured from fall 2007 through summer 2008.

recapture area	release area	n	infection index				
			clean	light	moderate	heavy	other
release area	upper	0	0	0	0	0	0
	lower	1	1	0	0	0	0
Rappahannock River	upper	1	0	0	1	0	0
	lower	0	0	0	0	0	0
upper Bay (Md)	upper	0	0	0	0	0	0
	lower	0	0	0	0	0	0
lower Bay (Md)	upper	0	0	0	0	0	0
	lower	0	0	0	0	0	0
Potomac River	upper	0	0	0	0	0	0
	lower	0	0	0	0	0	0
upper Bay (Va)	upper	0	0	0	0	0	0
	lower	1	0	0	1	0	0
lower Bay (Va)	upper	0	0	0	0	0	0
	lower	1	1	0	0	0	0
totals	upper	1	0	0	1	0	0
	lower	3	2	0	1	0	0
	both	4	2	0	2	0	0

Table 12. 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, 2006 and recaptured from fall 2007 through summer 2008.

Date	release area	n	infection index				
			Clean	light	moderate	heavy	other
Fall 2007	upper	3	0	3	0	0	0
	lower	0	14	7	3	4	0
Winter 2008	upper	2	0	2	0	0	0
	lower	1	1	1	0	0	0
Spring 2008	upper	0	0	0	0	0	0
	lower	8	3	4	0	1	0
Summer 2008	upper	2	1	0	0	1	0
	lower	6	3	2	1	1	0
totals	upper	7	1	5	0	1	0
	lower	45	21	14	4	6	0
	both	52	22	19	4	7	0

Table 13. 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, 2006 and recaptured from fall 2007 through summer 2008.

recapture area	release area	N	infection index				
			Clean	Light	Moderate	Heavy	other
release area	upper	3	0	2	0	1	0
	lower	13	7	3	2	1	0
Rappahannock River	upper	3	1	2	0	0	0
	lower	3	2	1	0	0	0
upper Bay (Md)	upper	0	0	0	0	0	0
	lower	5	3	0	1	1	0
lower Bay (Md)	upper	0	0	0	0	0	0
	lower	7	3	3	0	1	0
Potomac River	upper	0	0	0	0	0	0
	lower	5	2	2	0	1	0
upper Bay (Va)	upper	0	0	0	0	0	0
	lower	7	3	3	0	1	0
lower Bay (Va)	upper	1	0	1	0	0	0
	lower	5	1	2	1	1	0
totals	upper	7	1	5	0	1	0
	lower	45	21	14	4	6	0
	both	52	22	19	4	7	0

Table 14. 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, 2007 and recaptured from fall 2007 through summer 2008.

Date	release area	n	infection index				
			clean	light	moderate	heavy	other
Fall 2007	upper	0	0	0	0	0	0
	lower	0	6	6	0	0	0
Winter 2008	upper	0	0	0	0	0	0
	lower	0	2	0	0	0	0
Spring 2008	upper	0	0	0	0	0	0
	lower	0	3	2	0	0	0
Summer 2008	upper	0	0	0	0	0	0
	lower	0	0	0	0	0	0
totals	upper	0	0	0	0	0	0
	lower	19	11	8	0	0	0
	both	19	11	8	0	0	0

Table 15. 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, 2007 and recaptured from fall 2007 through summer 2008.

recapture area	release area	n	infection index				
			clean	light	moderate	heavy	other
release area	upper	0	0	0	0	0	0
	lower	0	7	6	0	0	0
Rappahannock River	upper	0	0	0	0	0	0
	lower	0	2	0	0	0	0
upper Bay (Md)	upper	0	0	0	0	0	0
	lower	0	0	0	0	0	0
lower Bay (Md)	upper	0	0	0	0	0	0
	lower	0	0	1	0	0	0
Potomac River	upper	0	0	0	0	0	0
	lower	0	1	0	0	0	0
upper Bay (Va)	upper	0	0	0	0	0	0
	lower	0	0	1	0	0	0
lower Bay (Va)	upper	0	0	0	0	0	0
	lower	0	1	0	0	0	0
totals	upper	0	0	0	0	0	0
	lower	19	10	8	0	0	0
	both	19	10	8	0	0	0

Table 16. Recapture summary, by release assessment and season, of striped bass tagged and released in the upper and lower Rappahannock River sites during fall 2007 and spring 2008.

	Release Assessment	n	Recaptures										
			0-7 days					Fall 2007	Winter 2008	Spring 2008	Summ 2008	Fall 2008	Sum
Fall 2007	Clean	600	19					4	2	5	4	0	34
	Light	436	23					8	5	11	7	0	54
	Moderate	143	7					8	2	2	2	0	21
	Heavy	123	6					2	1	3	5	0	17
	Other	13	1					0	0	0	0	0	1
	No Assess.	2	0					0	0	0	0	0	0
Spring 2008	Clean	69	13							5	3	0	21
	Light	65	3							6	3	0	12
	Moderate	14	1							0	0	0	1
	Heavy	19	5							6	2	0	13
	Other	2	0							0	0	0	0
	No Assess.	0	0							0	0	0	0
Total	Fall 2007	1,584	56					22	10	21	18	0	127
	Spring 2008	169	22							17	8	0	47
	Both	1,753	78					22	10	38	26	0	174

Table 17. Recapture summary, by release assessment and season, of striped bass tagged and released in the upper and lower Rappahannock River sites during fall 2006 and spring 2007.

	Release Assessment	n	Recaptures										
			0-7 days	Fall 2006	Winter 2007	Spring 2007	Summ 2007	Fall 2007	Winter 2008	Spring 2008	Summ 2008	Fall 2008	Sum
Fall 2006	Clean	1,194	30	33	12	30	7	15	1	3	4	0	135
	Light	1,477	44	37	6	28	17	12	2	4	1	0	151
	Moderate	604	24	20	7	7	7	4	0	0	1	0	70
	Heavy	399	24	22	2	13	5	4	0	1	2	0	73
	Other	37	1	1	0	1	1	0	0	0	0	0	4
	No Assess.	2	0	0	0	0	0	0	0	0	0	0	0
Spring 2007	Clean	307	15	-----	-----	6	6	6	2	3	0	0	38
	Light	203	14	-----	-----	17	6	5	0	2	0	0	44
	Moderate	72	3	-----	-----	10	7	0	0	0	0	0	20
	Heavy	62	4	-----	-----	4	2	0	0	0	0	0	10
	Other	10	2	-----	-----	1	1	0	0	0	0	0	4
	No Assess.	2	0	-----	-----	0	0	0	0	0	0	0	0
Total	Fall 2006	3,713	123	113	27	79	37	35	3	8	8	0	433
	Spring 2007	656	38	-----	-----	38	22	11	2	5	0	0	116
	Both	4,372	161	113	27	117	59	46	5	13	8	0	549

Table 18. Recapture summary, by release assessment and season, of striped bass tagged and released in the upper and lower Rappahannock River sites during fall 2005 and spring 2006.

	Release Assess-ment	n	Recaptures											
			0-7 days	Fall 2005	Winter 2006	Spring 2006	Sum 2006	Fall 2006	Winter 2007	Spring 2007	Sum 2007	Fall 2007	Year 2008	Sum
Fall 2005	Clean	465	17	3	1	3	3	5	0	0	1	2	2	37
	Light	761	42	8	4	5	7	16	1	2	0	1	0	86
	Mod.	363	18	7	1	6	0	3	0	1	1	0	1	38
	Heavy	212	16	6	1	3	0	3	1	0	0	0	1	31
	Other	13	1	0	0	0	0	0	0	0	0	0	0	1
	No Ass.	2	1	0	0	0	0	0	0	0	0	0	0	1
Spring 2006	Clean	191	6	-----	-----	6	6	14	2	4	0	1	0	39
	Light	264	17	-----	-----	13	6	16	3	6	1	0	1	63
	Mod.	70	4	-----	-----	6	2	6	0	2	0	1	1	22
	Heavy	39	2	-----	-----	2	0	2	0	2	0	0	0	8
	Other	5	0	-----	-----	0	0	0	0	1	0	0	0	1
	No Ass.	1	0	-----	-----	0	0	0	0	0	0	0	0	0
Total	Fall	1,816	95	24	7	17	10	27	2	3	2	3	4	194
	Spring	570	29	-----	-----	27	14	38	5	15	1	2	2	133
	Both	2,386	114	24	7	44	24	65	7	18	3	5	6	327

Table 19. Estimates of mortality associated with mycobacterial disease and estimated relative survival rates. The slope of the regression line of log(ratio of recaptures) versus time estimates the difference in natural mortality rate (M for clean fish - M for diseased fish). The exponentiated slope estimates the ratio of finite (annual) survival rates (S for diseased fish/ S for clean fish).

Comparison	slope	S.E.	P-value	exp (slope)	adjusted r^2
heavy vs. clean	-1.31	0.69	0.10	0.27	0.22
moderate vs. clean	-1.49	0.47	0.01	0.23	0.45
light vs. clean	-0.71	0.44	0.14	0.49	0.14
moderate + heavy vs. clean	-1.46	0.46	0.01	0.23	0.45

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).

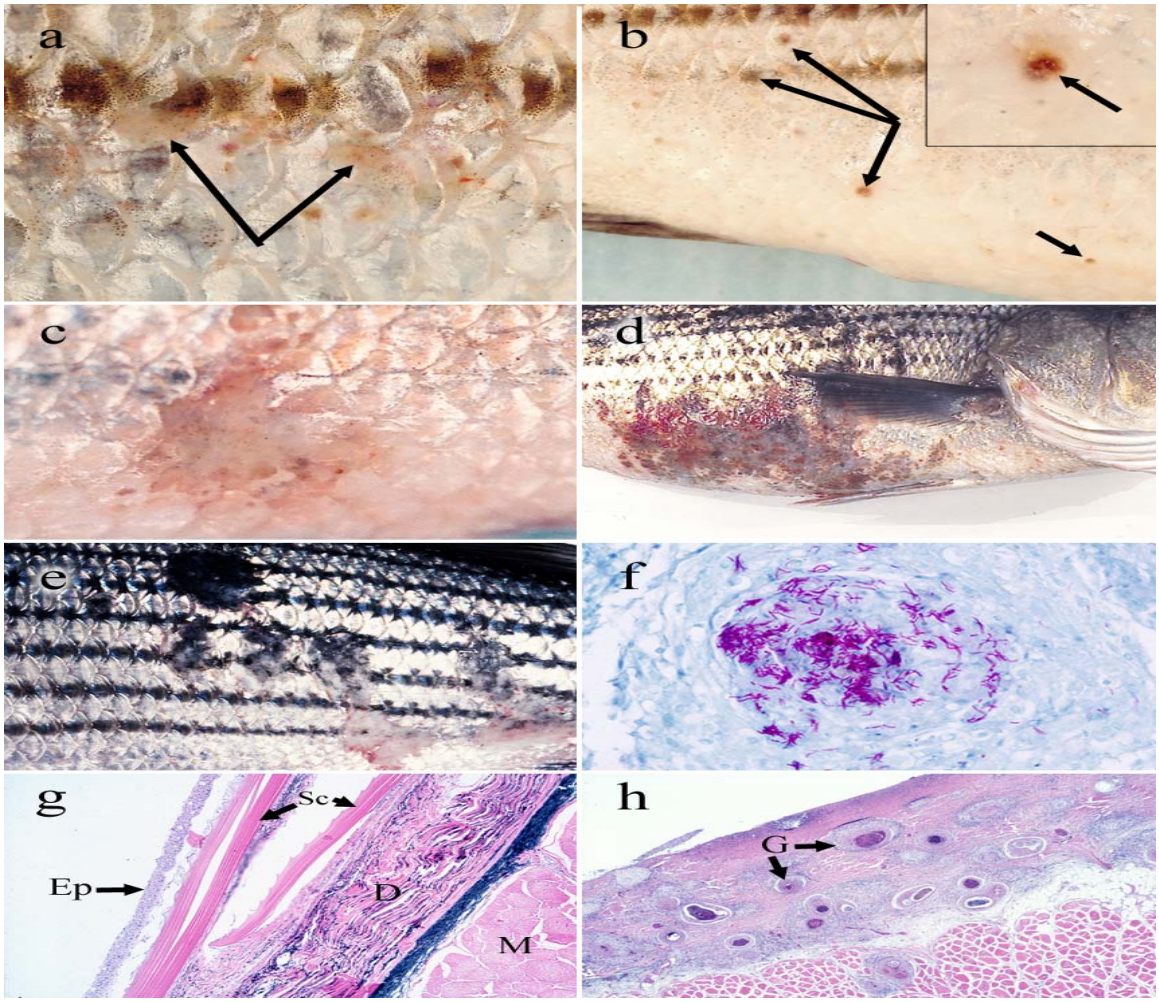
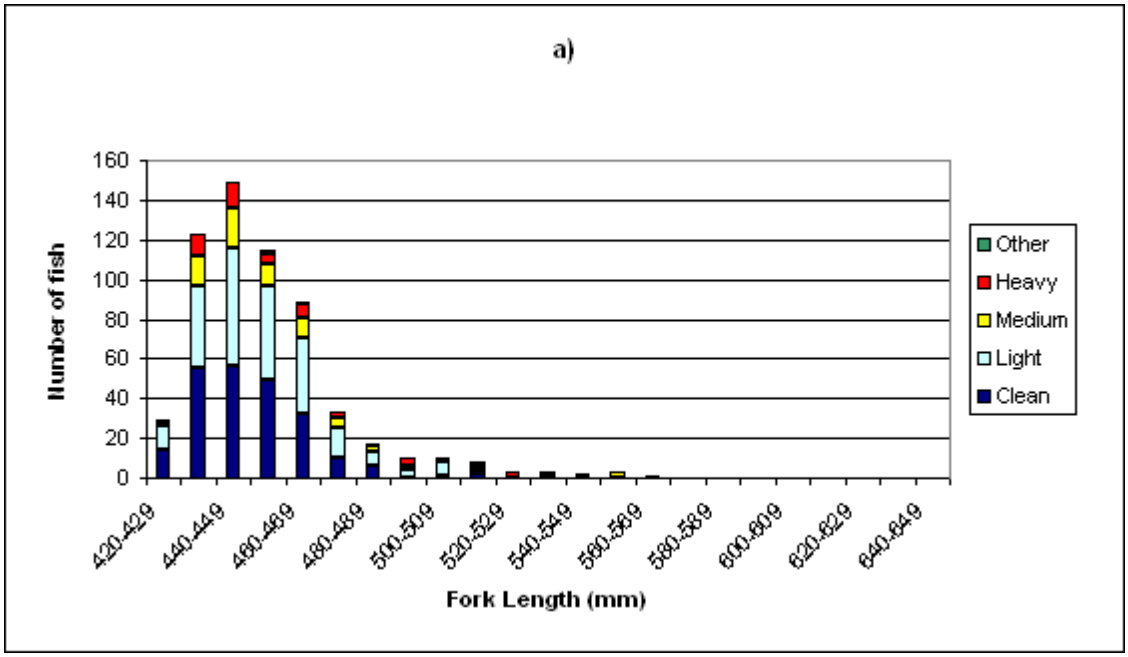


Figure 3. a) Size distribution (fork length in mm), by infection index, of striped bass tag releases from the upper Rappahannock River, fall 2007. b) Relative proportion of each infection index, by fork length, of the tag releases.



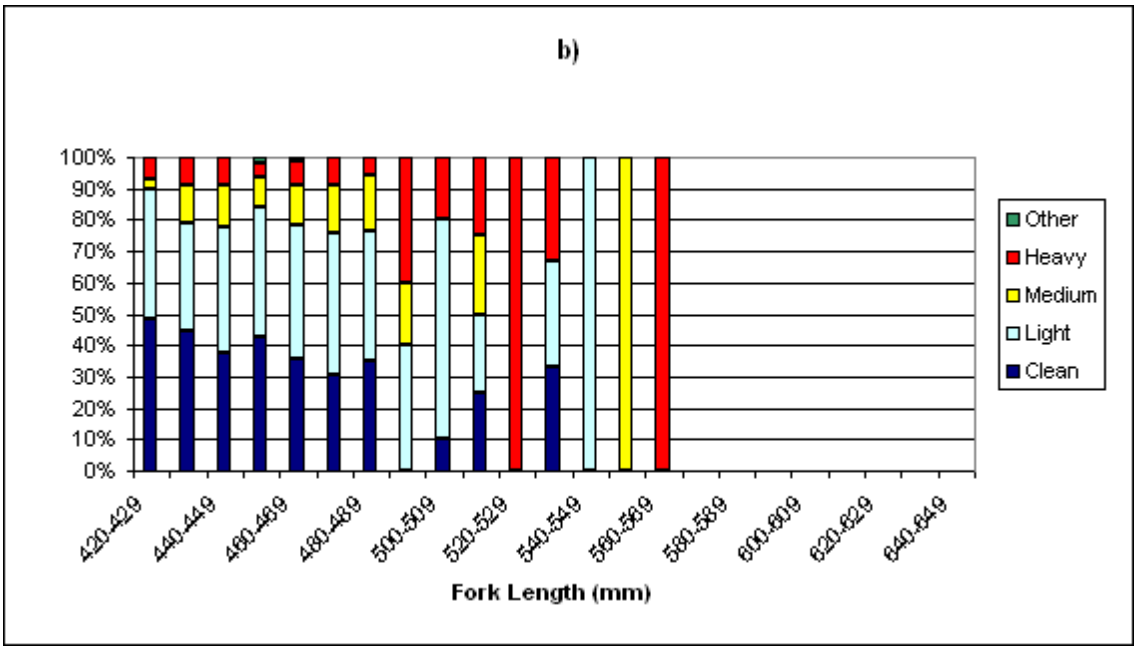
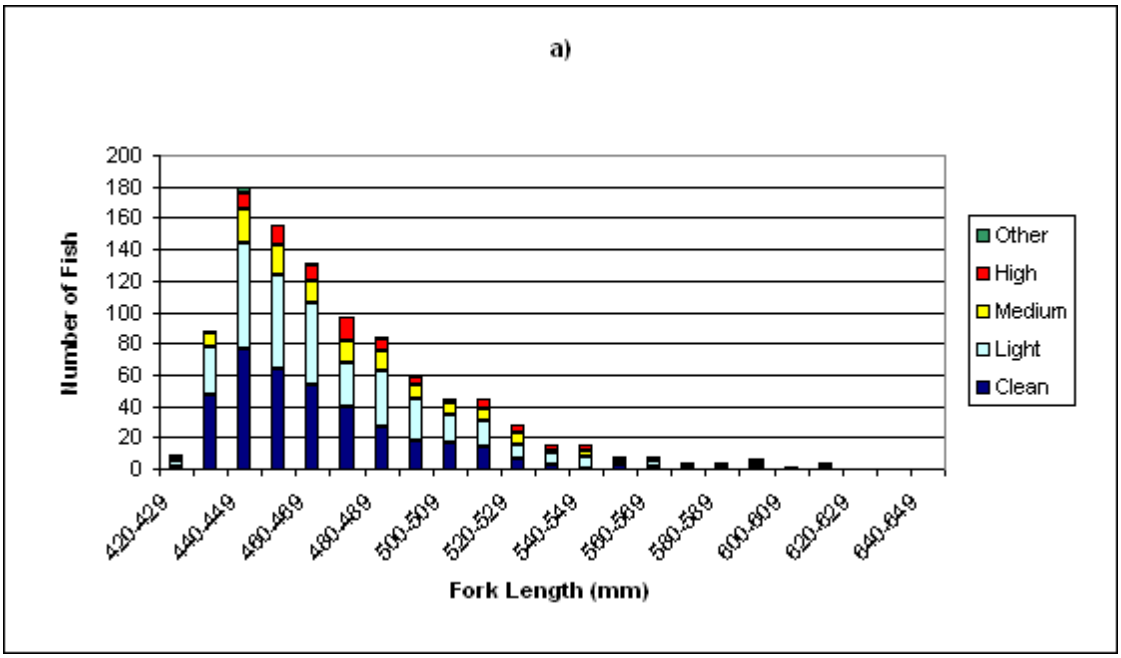


Figure 4. a) Size distribution (fork length in mm), by infection index, of striped bass tag releases from the lower Rappahannock River, fall 2007. b) Relative proportion of each infection index, by fork length, of the tag releases.



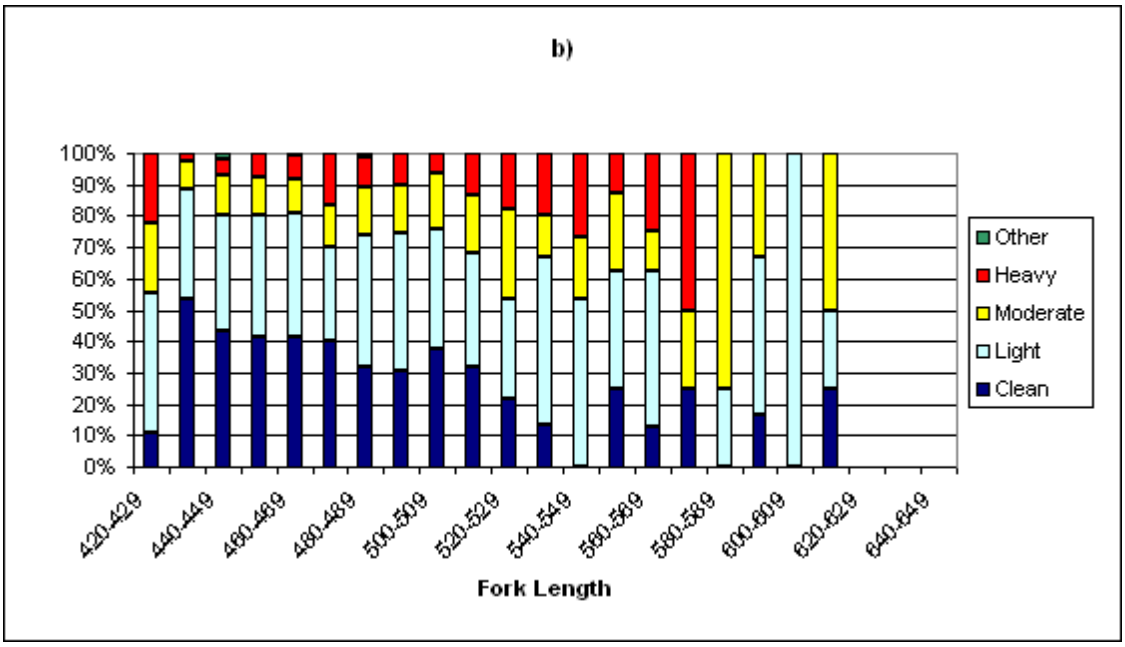
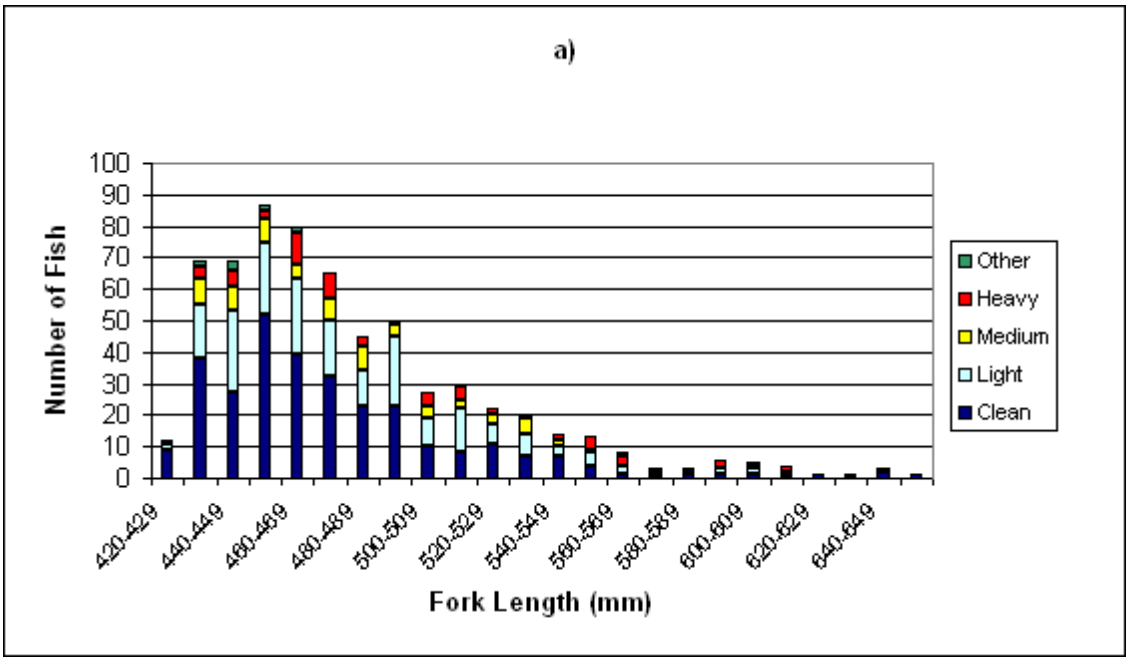


Figure 5. a) Size distribution (fork length in mm), by infection index, of striped bass tag releases from the lower Rappahannock River, spring 2008. b) Relative proportion of each infection index, by fork length, of the tag releases.



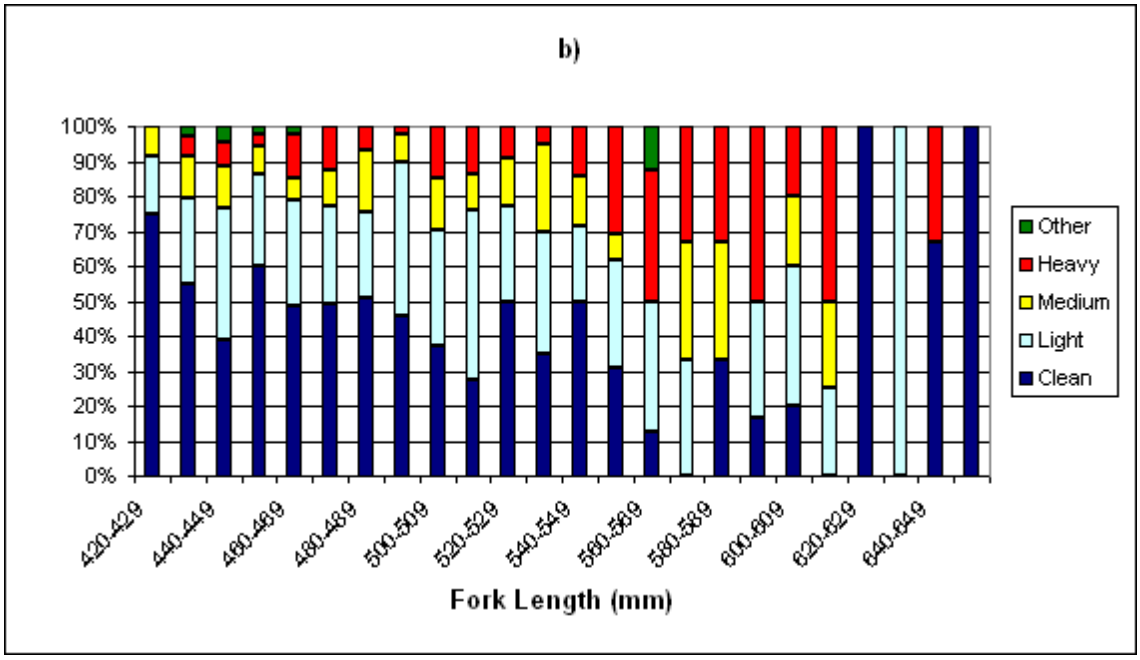


Figure 6. Breakdown of the mycobacteriosis disease index of age three striped bass from the lower Rappahannock River, falls 2005-2007.

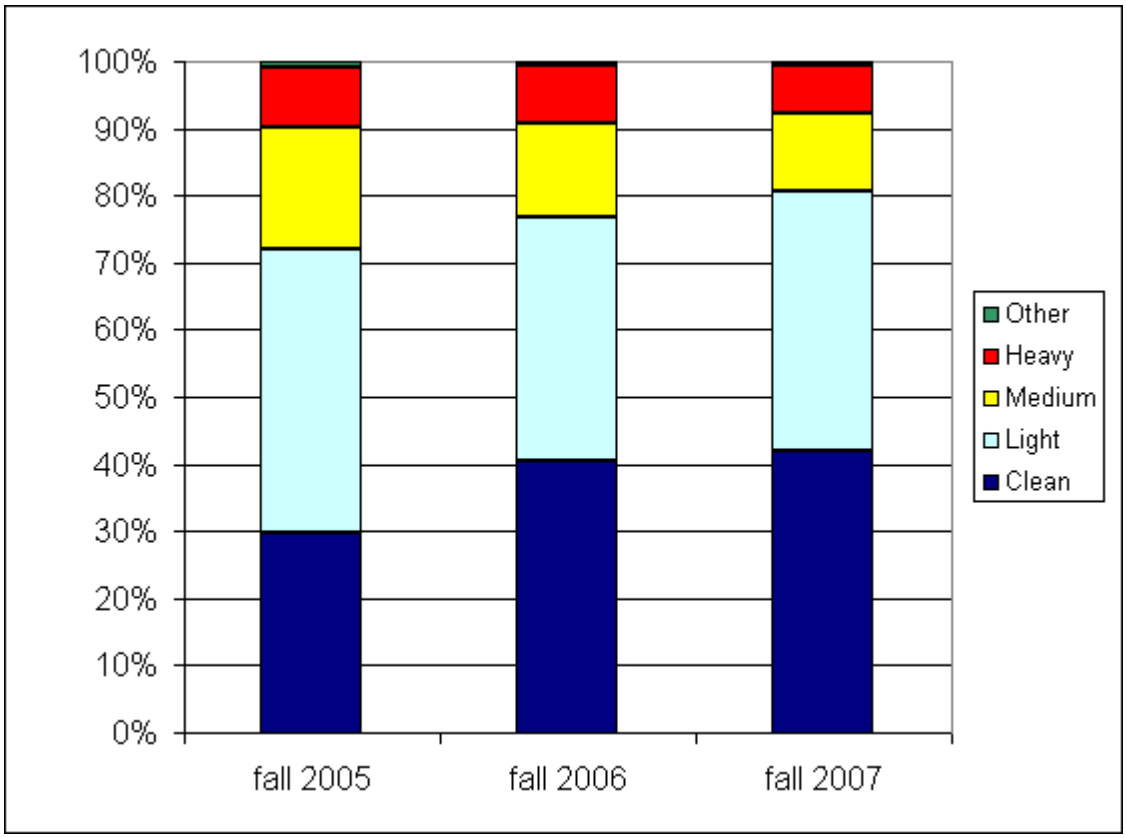


Figure 7. Progression in the mycobacteriosis skin severity index, with age, of the 2002 year class of striped bass in the lower Rappahannock River, falls 2005-2007.

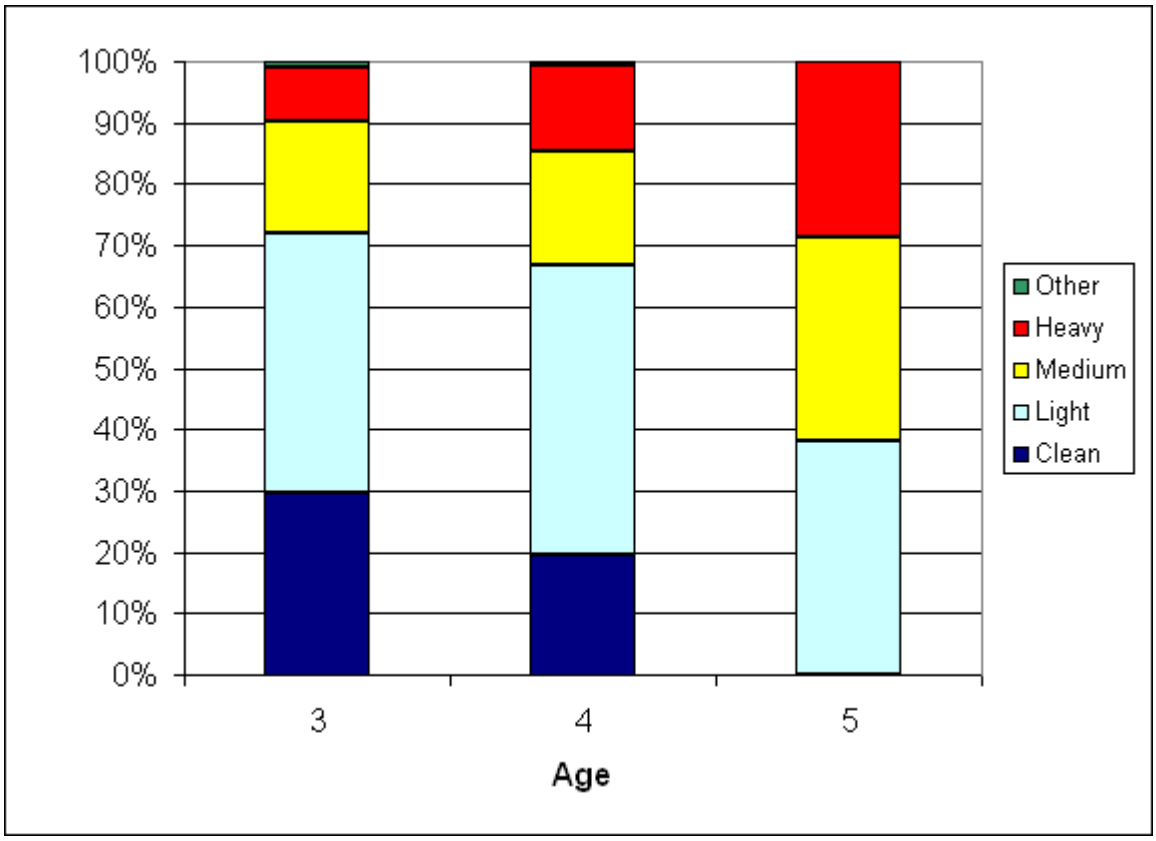


Figure 8. Progression of pigmented foci (PF) of uninfected striped bass based on reassessment of recaptured striped bass originally tagged and released in the Rappahannock River, falls 2005-2007.

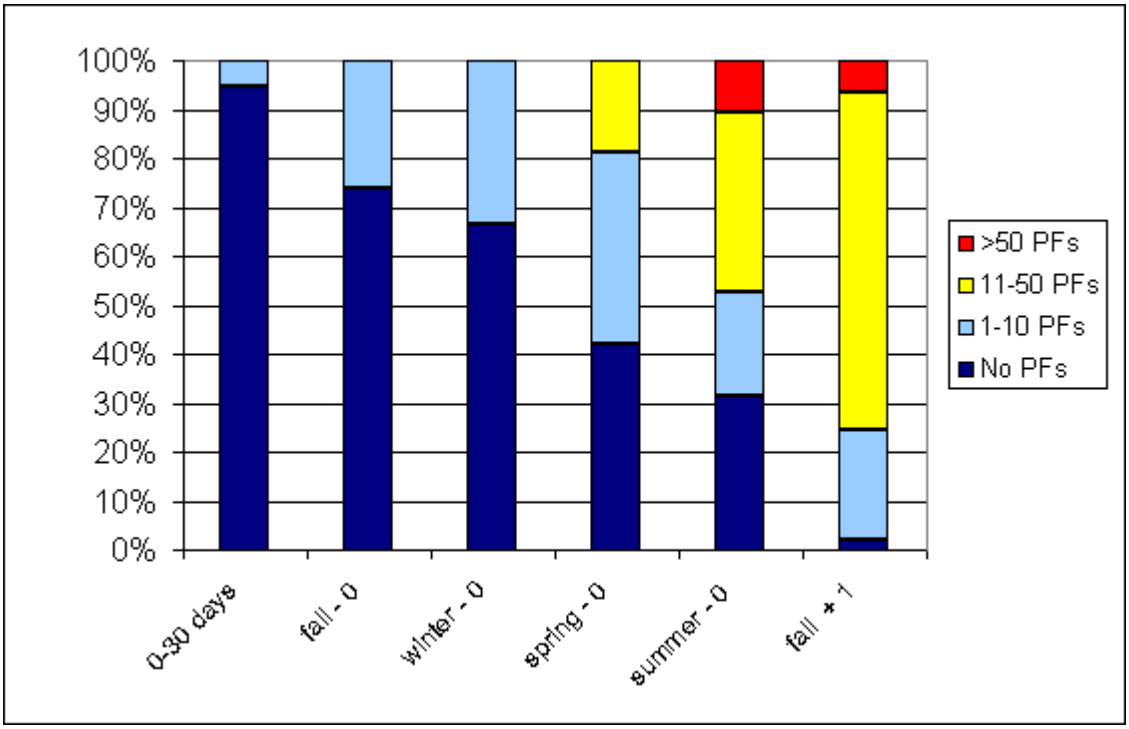


Figure 9. Progression of mycobacteriosis from lightly diseased at time of release to moderately diseased versus time-at-large for striped bass tagged and released in the Rappahannock River, fall 2005 to present (combined). Numbers next to the data points indicate number of recaptures.

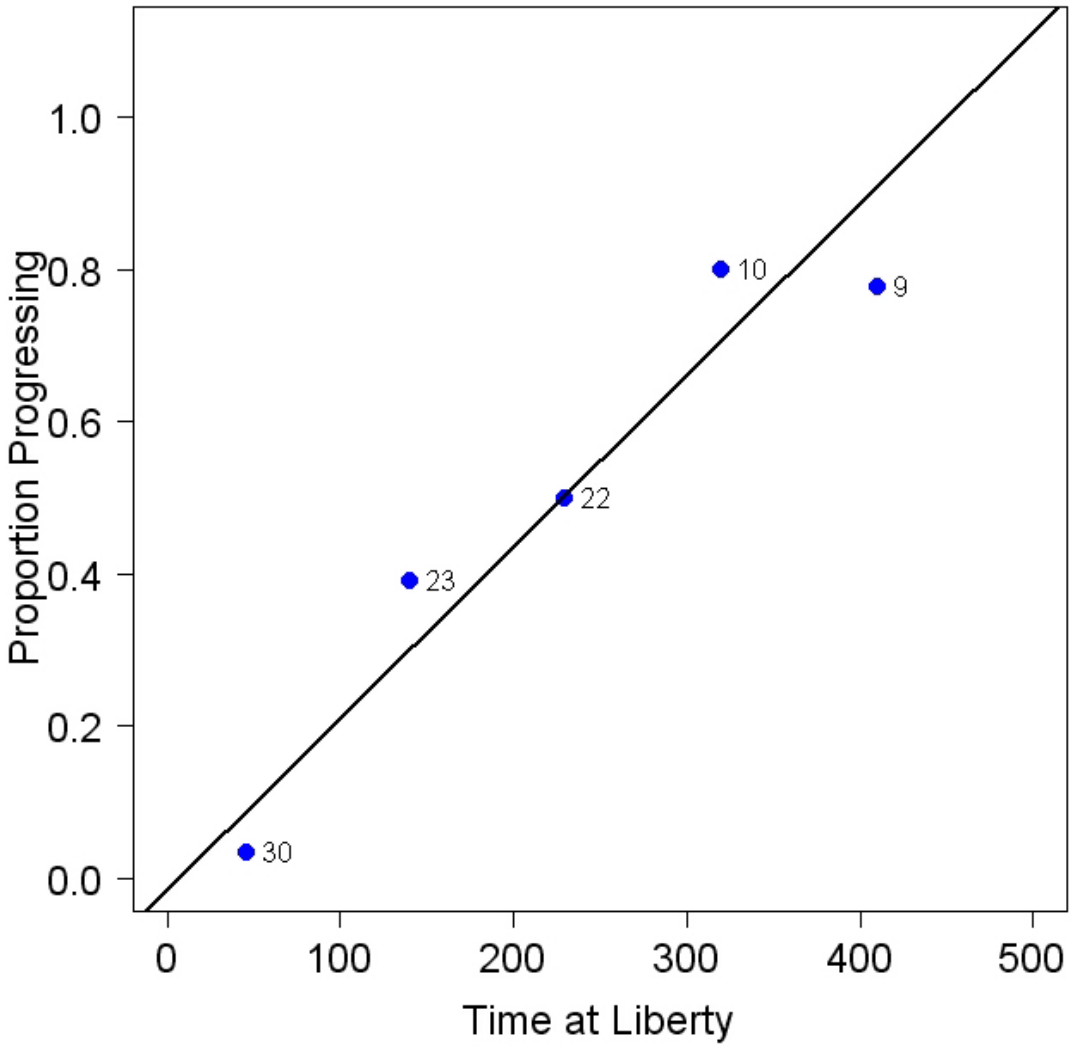


Figure 10. Progression of mycobacteriosis from moderately diseased at time of release to severely diseased versus time-at-large for striped bass tagged and released in the Rappahannock River, fall 2005 to present (combined). Numbers next to the data points indicate number of recaptures.

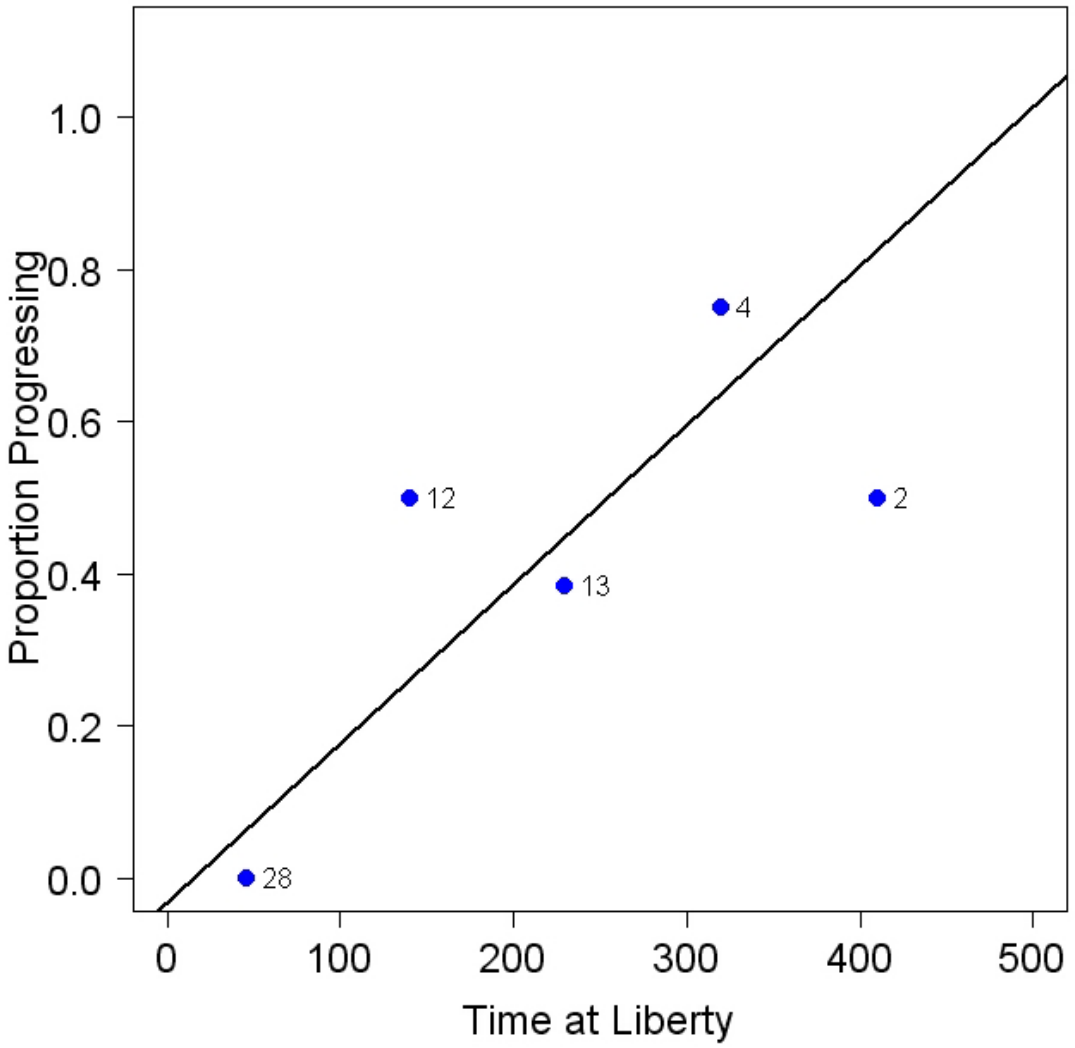
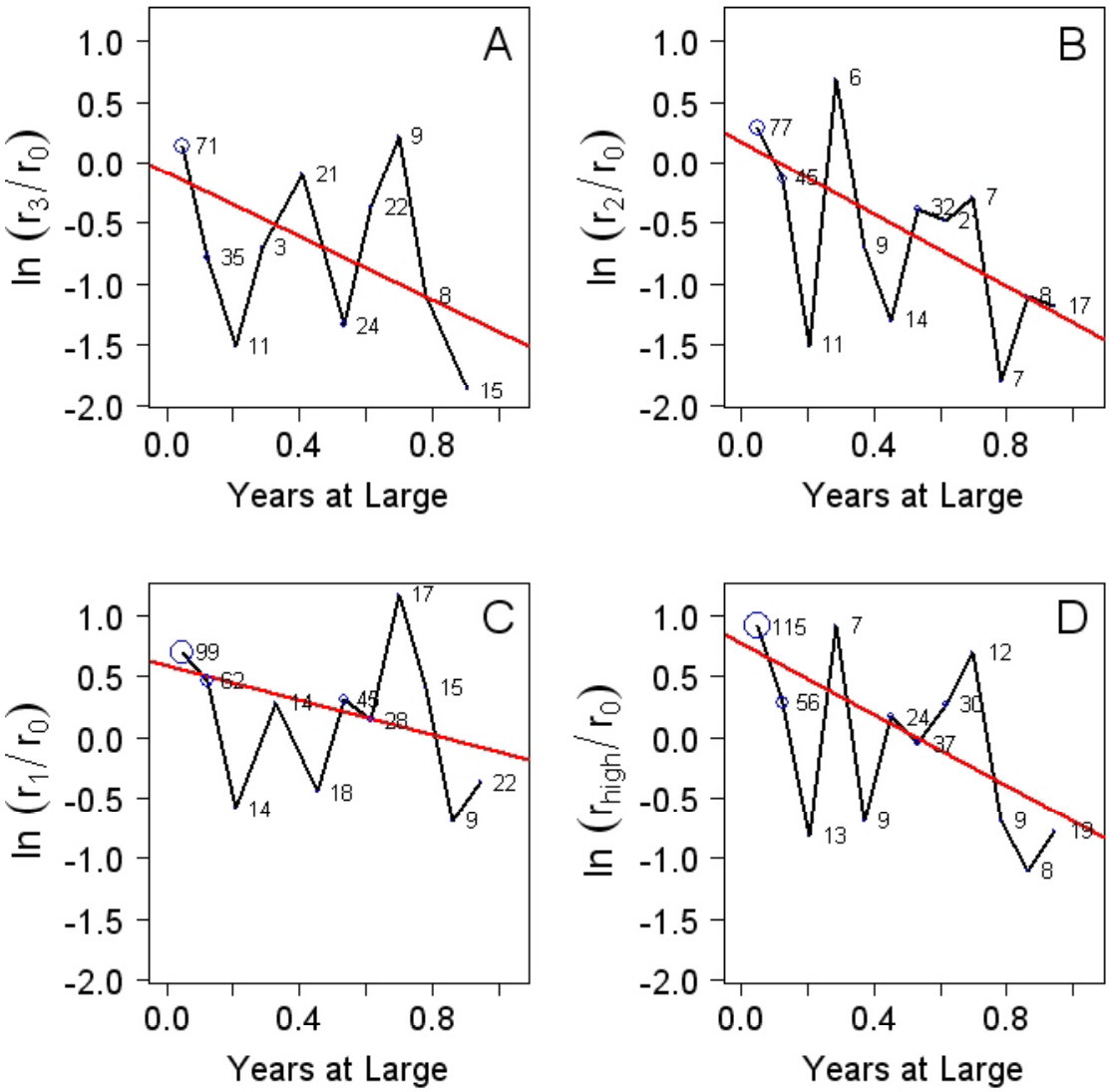


Figure 11. Logarithm of the ratio of returns of fish tagged in disease condition *x* and disease condition 0 (fish in condition 0 are "clean", showing no signs of the disease) as a function of time at liberty. Numbers next to the data points are the number of tag returns. The slope of the weighted regression estimates the difference in instantaneous total mortality rates, $Z_o - Z_x$, which is equivalent to the difference in instantaneous natural mortality rates (because the F component of Z is assumed to be the same for both groups of fish). A) Condition 3 versus condition 0. Estimated slope = -1.31. The exponentiated slope, which is an estimate of the relative survival rate, is 0.27 indicating that fish in condition 3 have 27% of the survival rate of clean fish. B) Condition 2 versus condition 0. Estimated slope = -1.49. The exponentiated slope, which is an estimate of the relative survival rate, is 0.23. C) Condition 1 versus condition 0. Estimated slope = -0.71. The exponentiated slope, which is an estimate of the relative survival rate, is 0.49. D) Conditions 2 and 3 combined versus condition 0. Estimated slope = -1.46. The exponentiated slope, which is an estimate of the relative survival rate, is 0.23.


A
B
C
D
ln (r3/r0)
ln (r2/r0)
ln (r1/r0)
ln (rhigh/r0)
Years at Large
Years at Large
Years at Large
Years at Large
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
0.0
0.4
0.8
71
35
11
3
21
24
22
9
8
15
77
45
11
6
9
14
32
2
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14
14
18
45
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115
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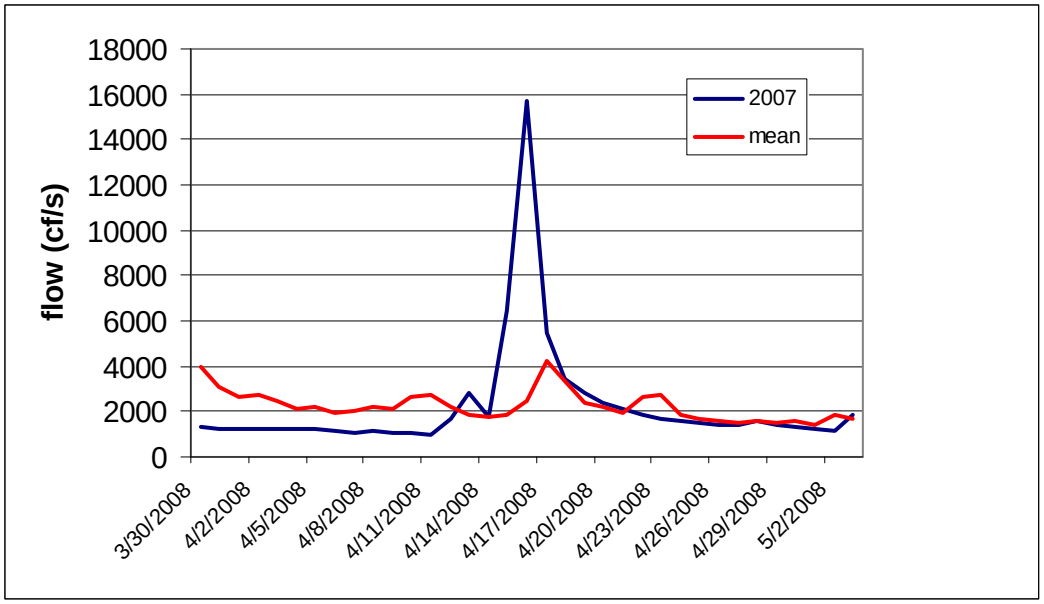
8
19

Appendix A. Daily flow rates of the Rappahannock River, 30 March – 3 May, 1985-2007.

Striped Bass Assessment and Monitoring Program
Department of Fisheries Science
School of Marine Science
Virginia Institute of Marine Science
The College of William and Mary
Gloucester Point, VA. 23062-1346

Figure 1. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2006-2007.



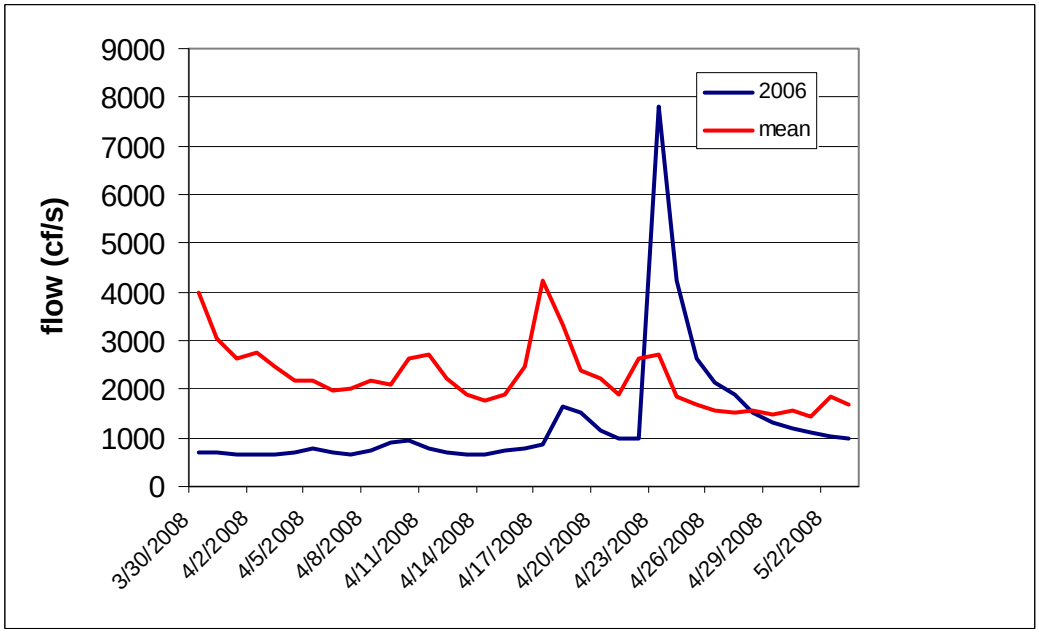
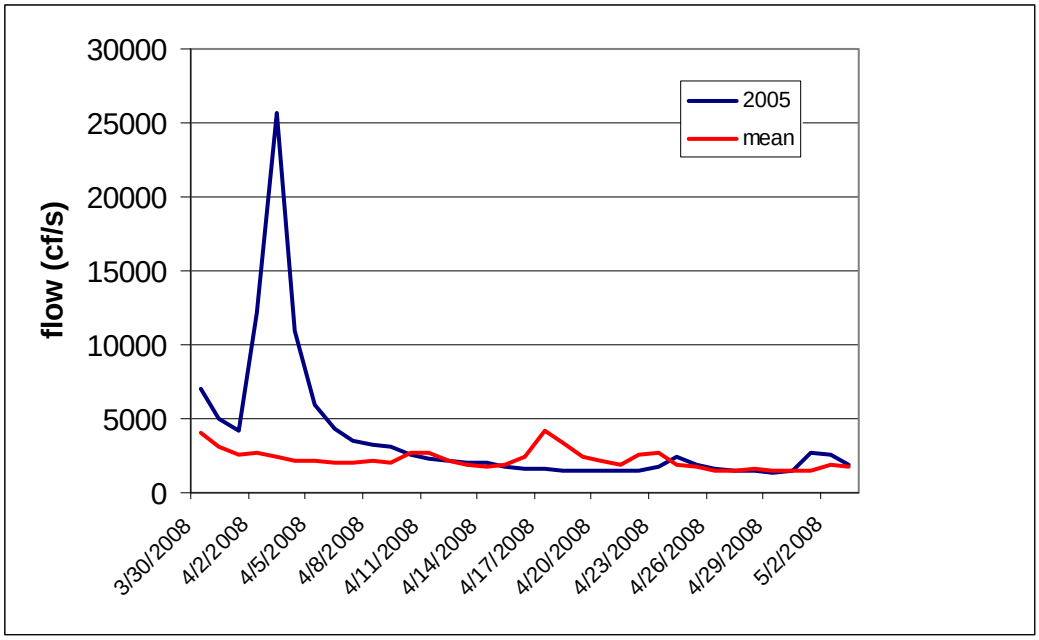


Figure 2. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2004-2005.



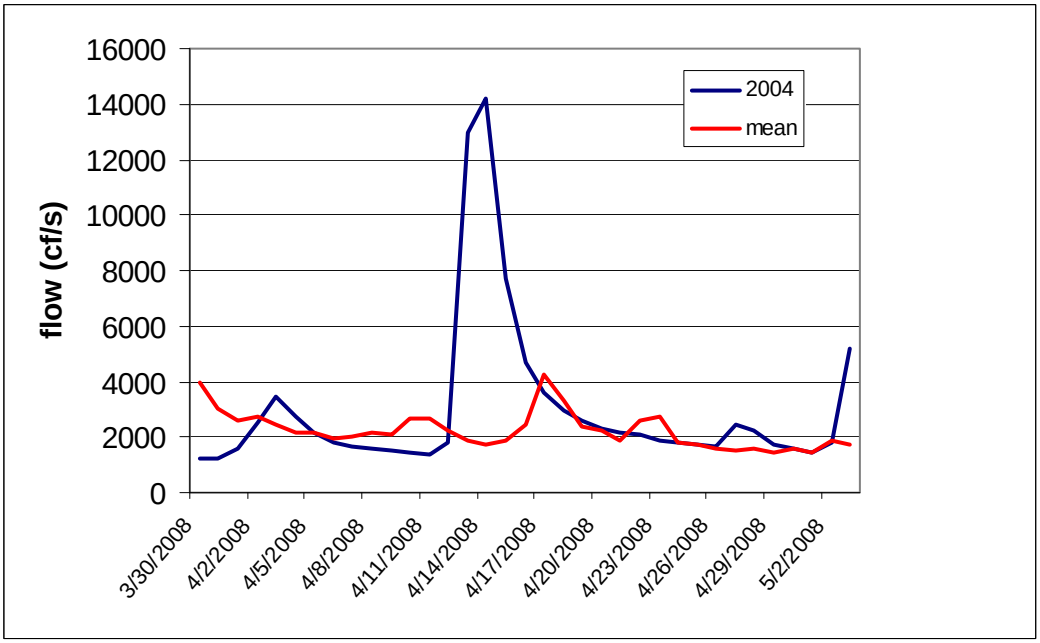
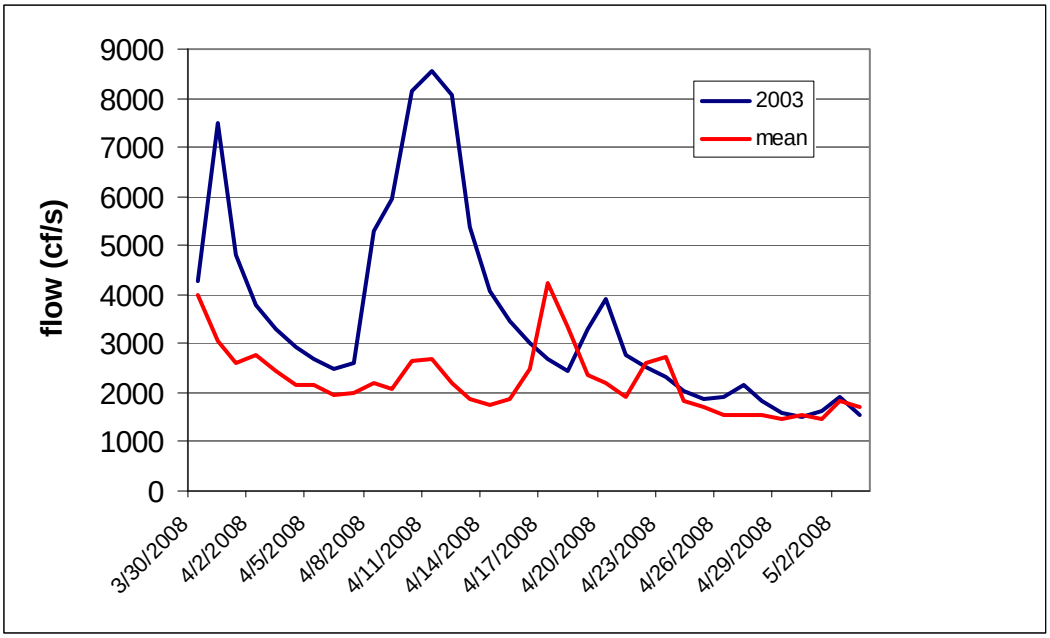


Figure 3. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2002-2003.



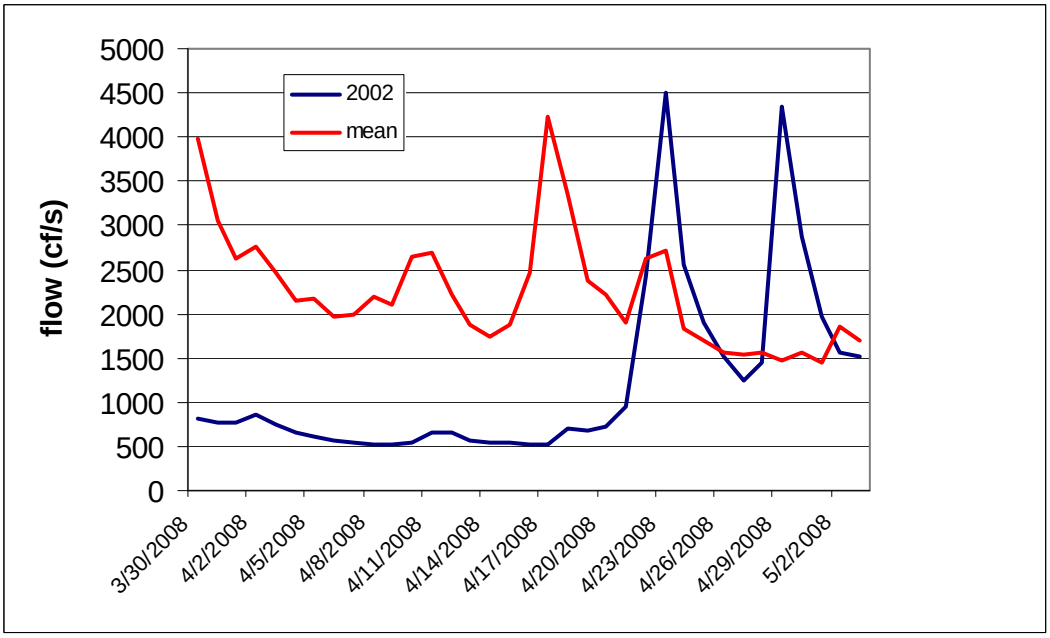
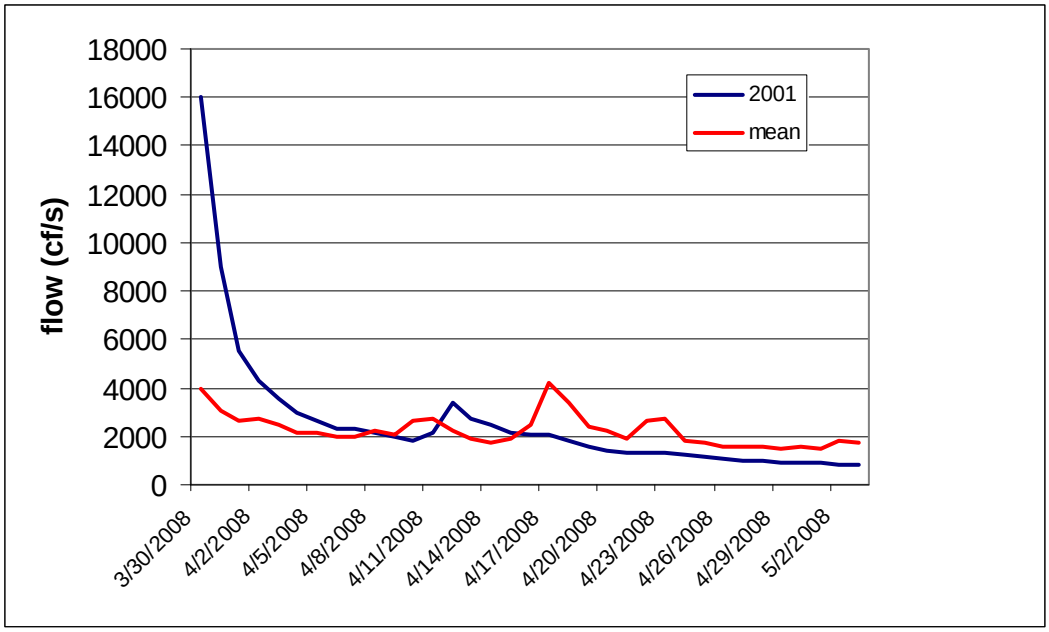


Figure 4. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2000-2001.



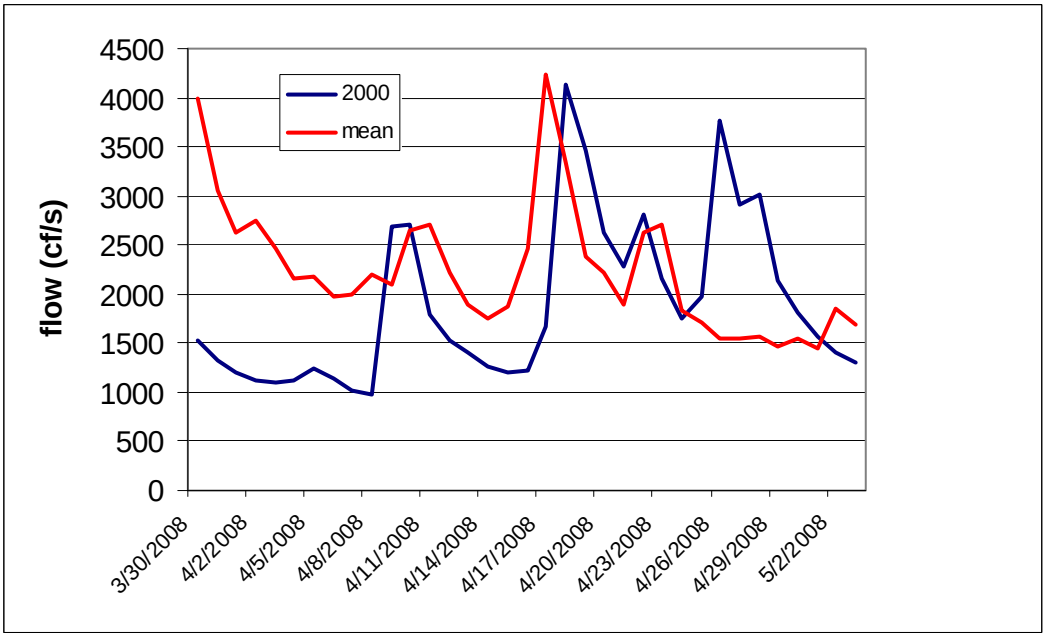
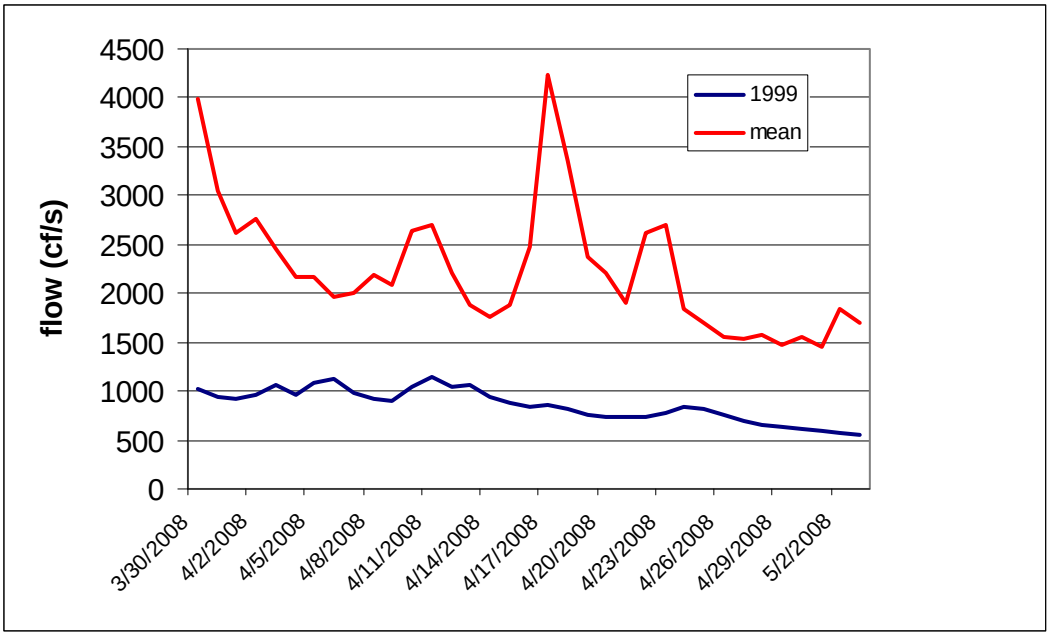


Figure 5. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1998-1999.



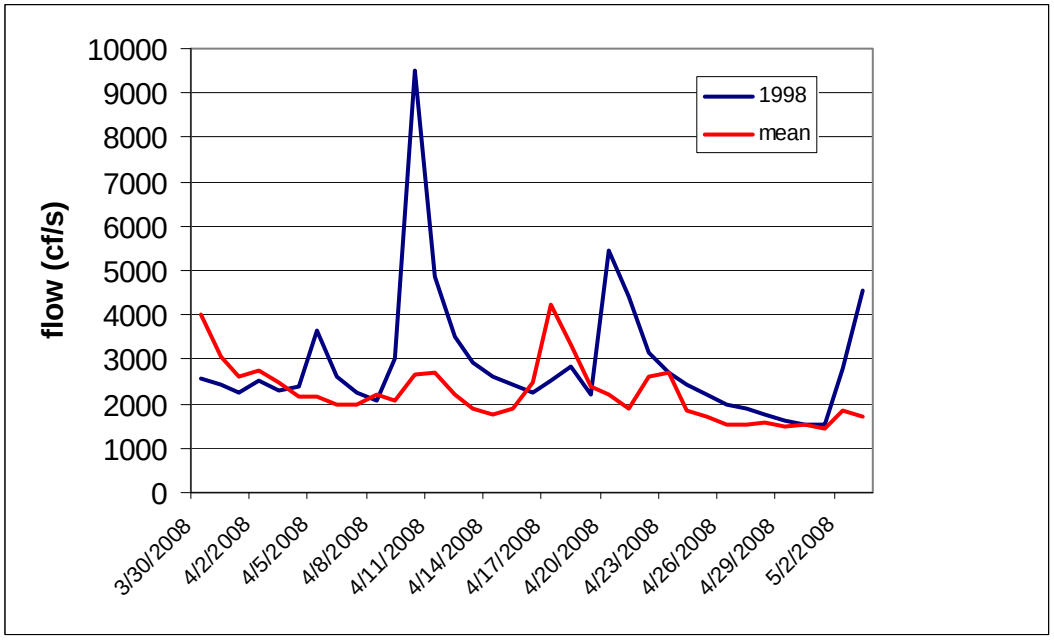
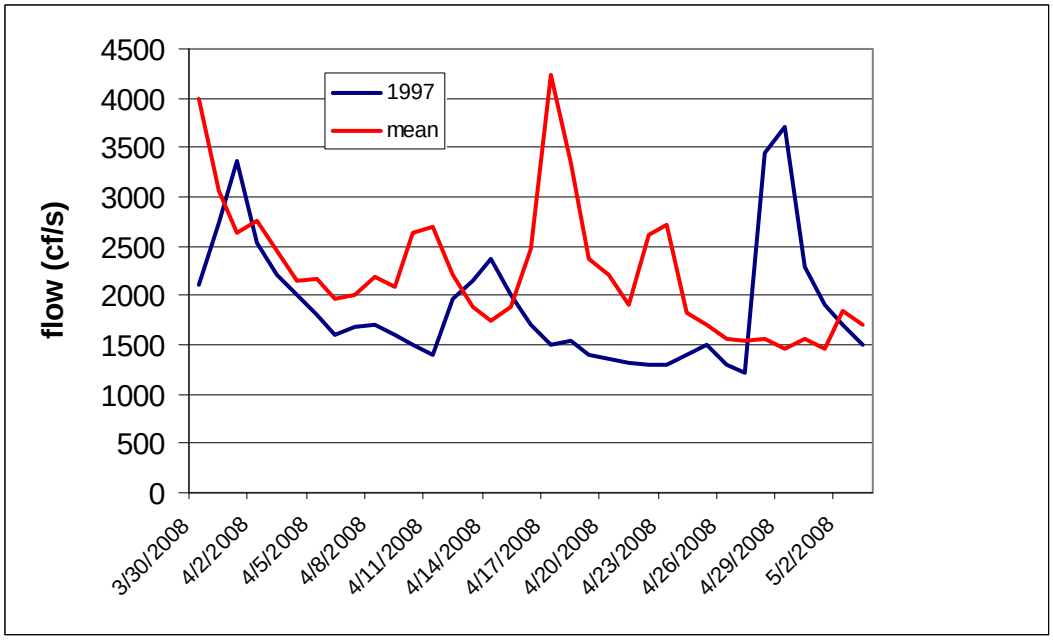


Figure 6. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1996-1997.



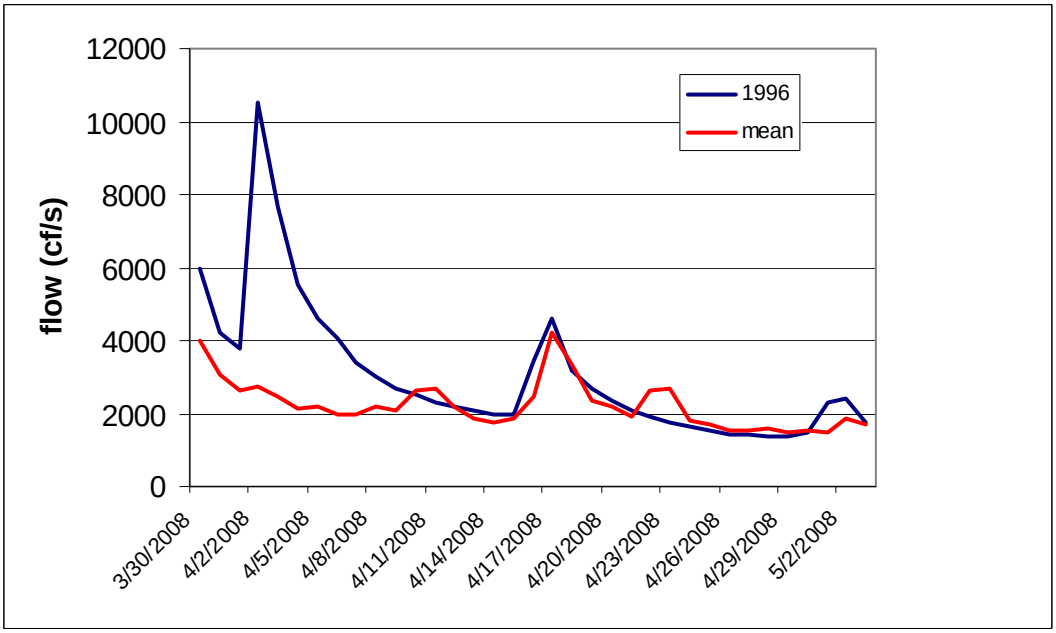
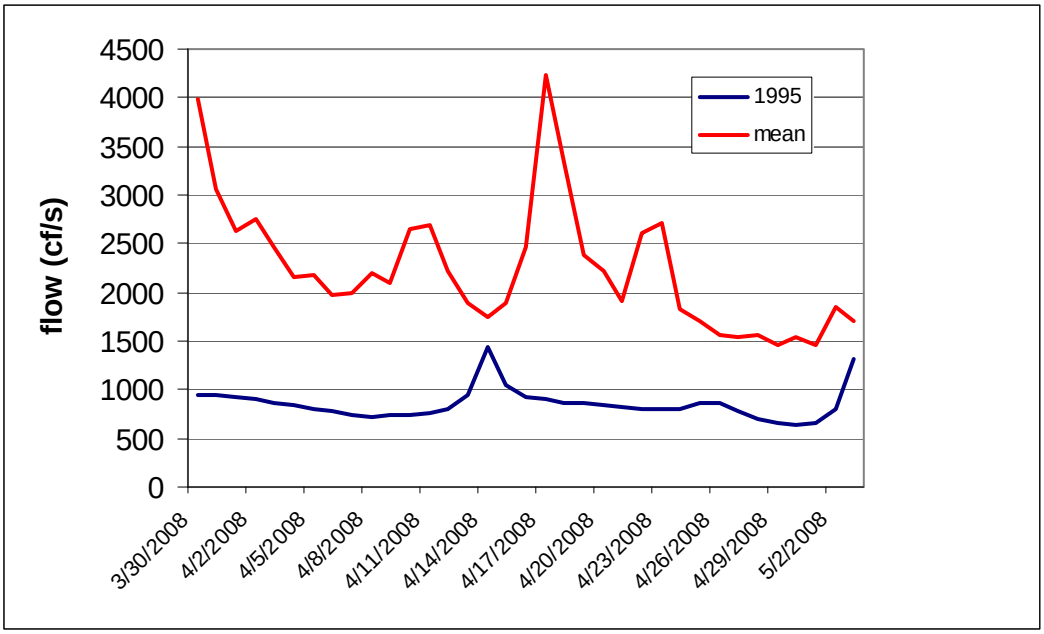


Figure 7. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1994-1995.



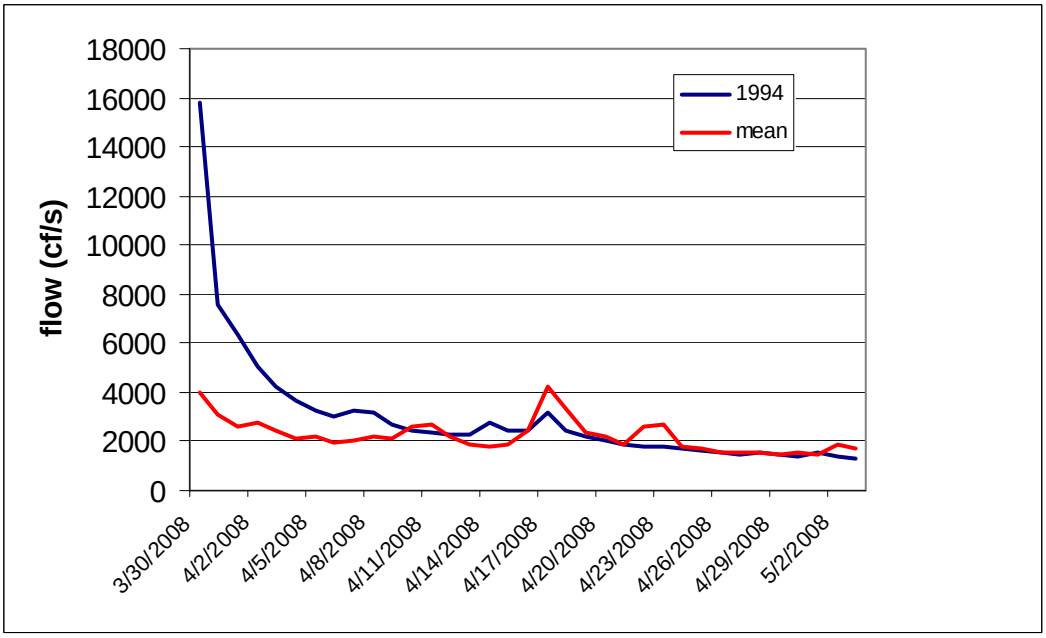
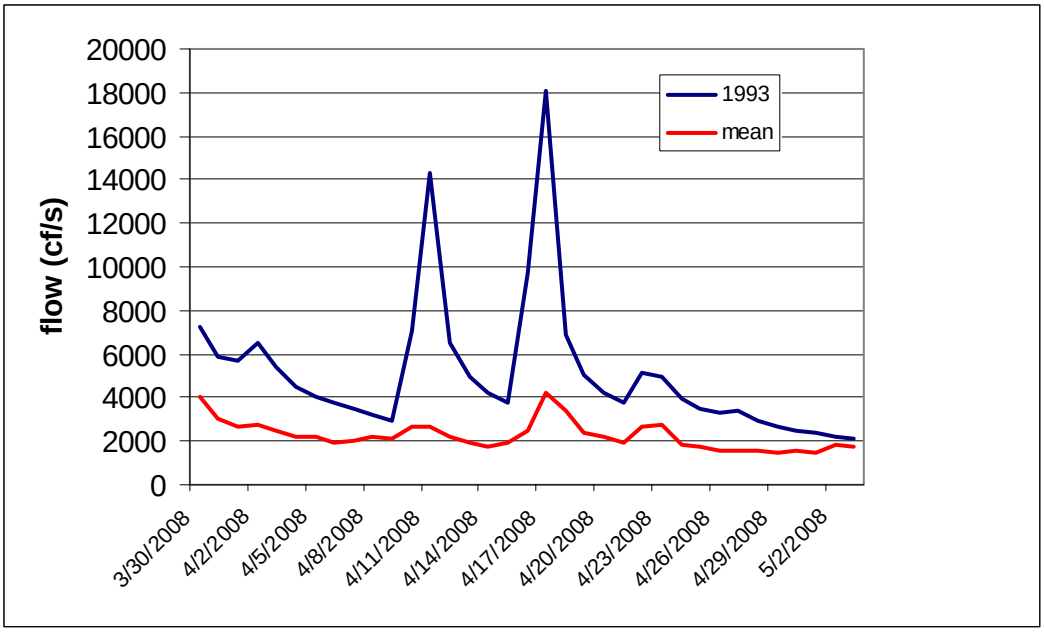


Figure 8. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1992-1993.



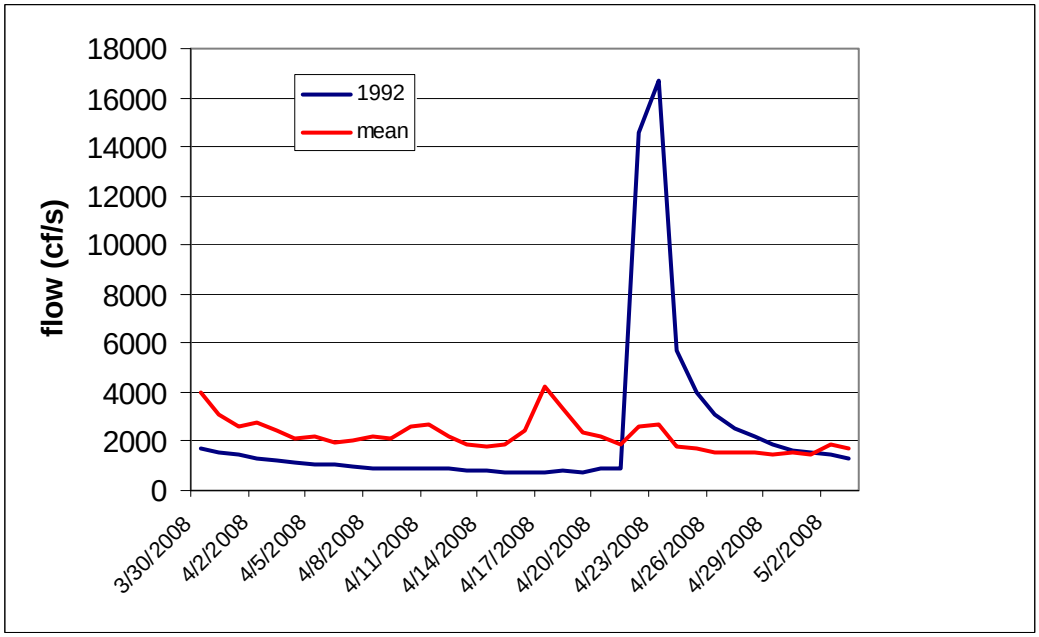
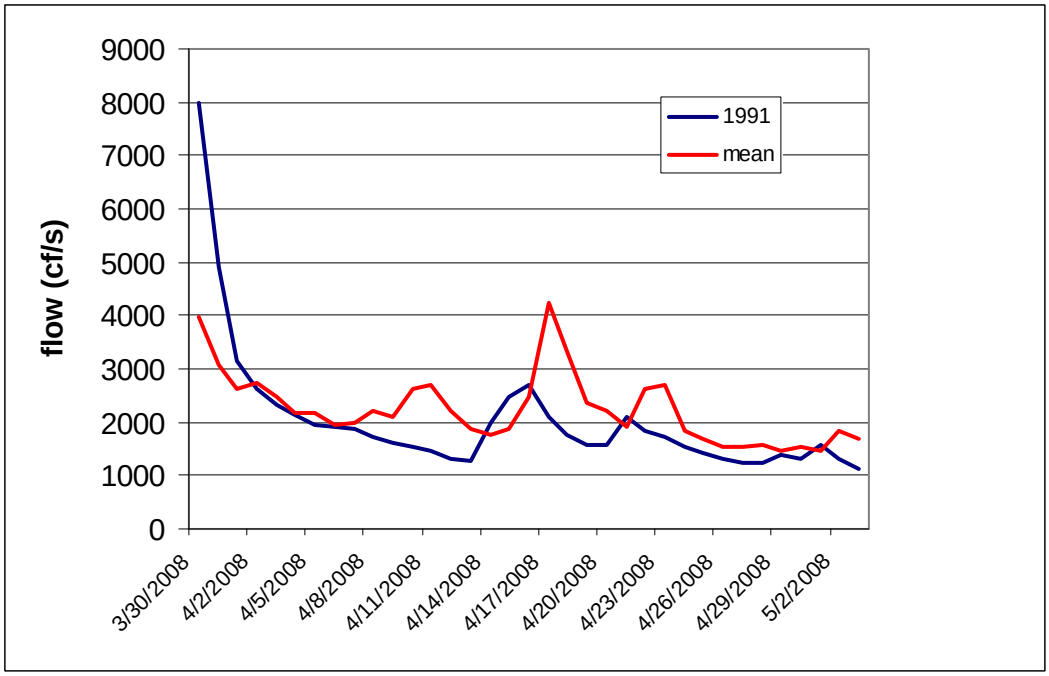


Figure 9. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1990-1991.



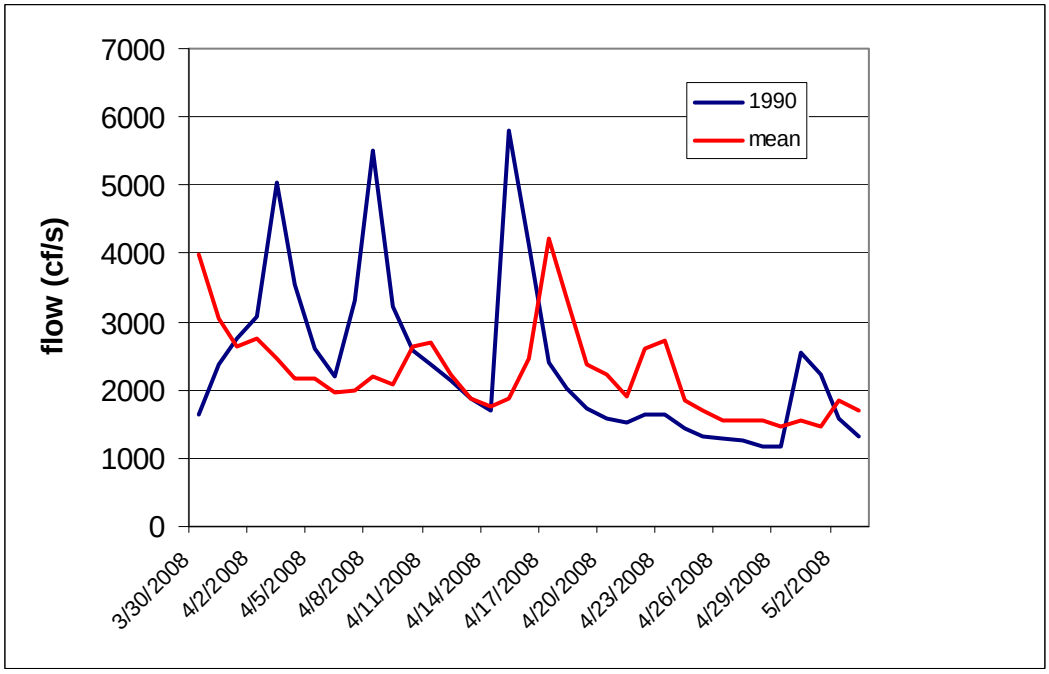
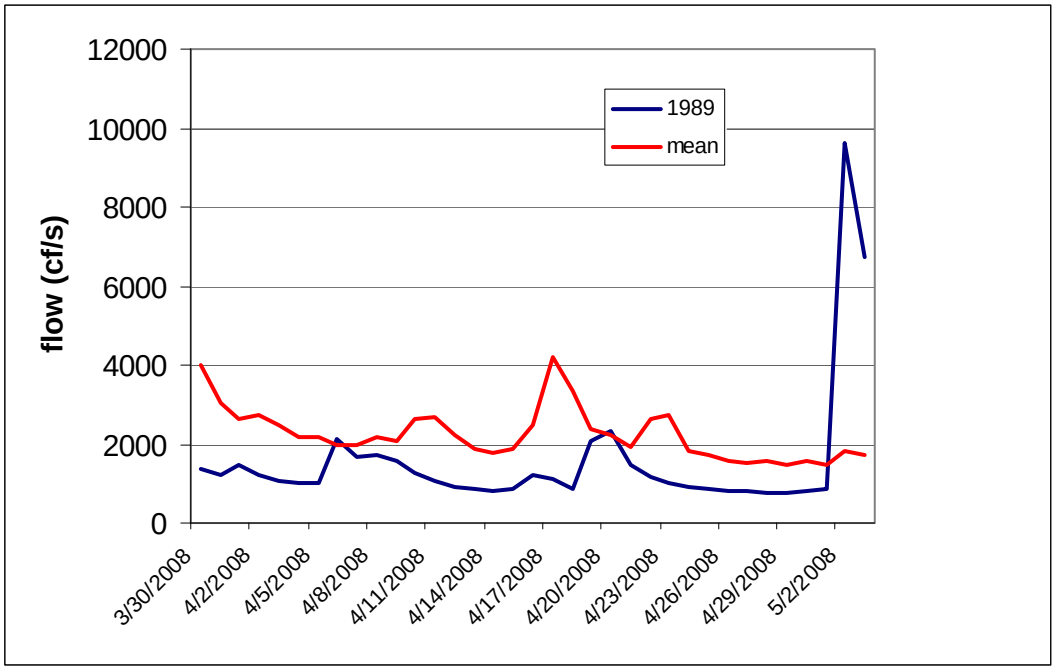


Figure 10. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1988-1989.



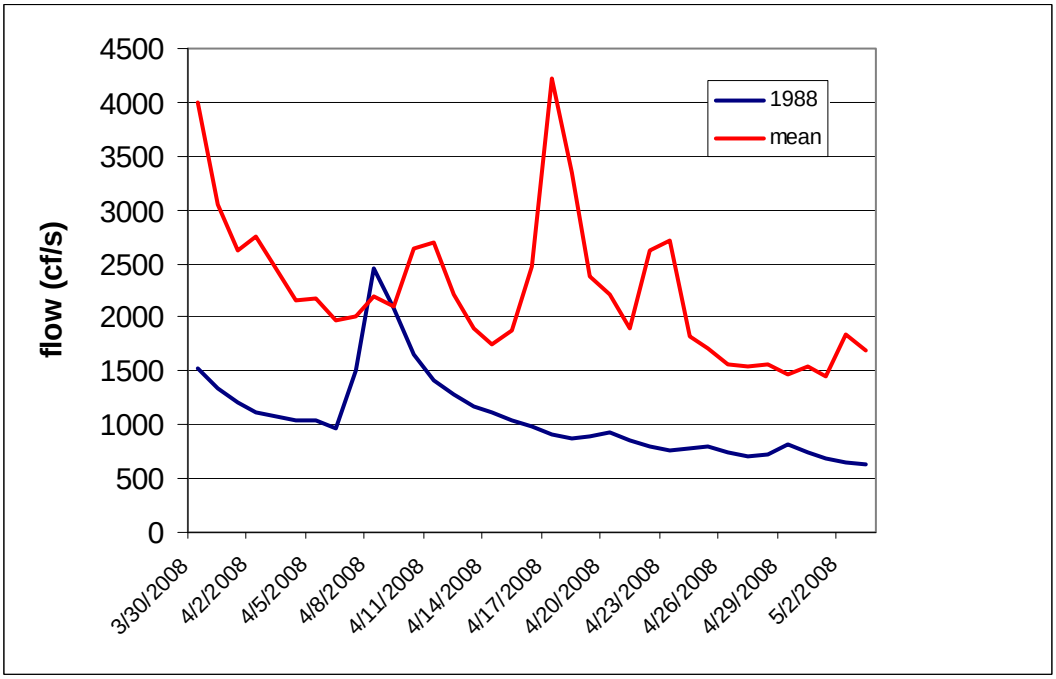
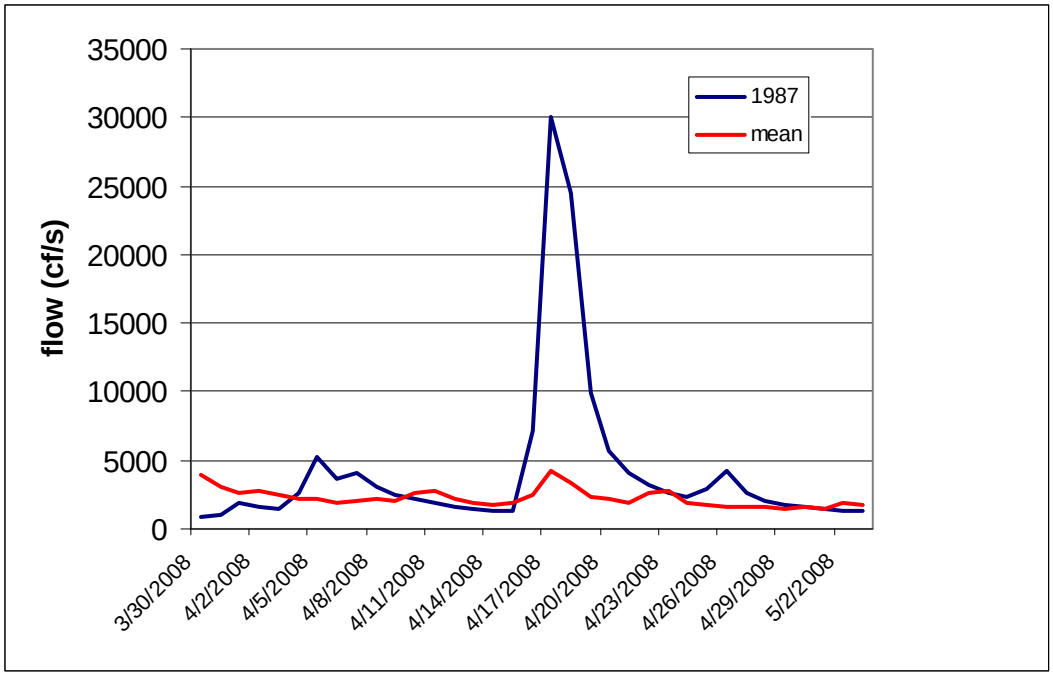


Figure 11. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1986-1987.



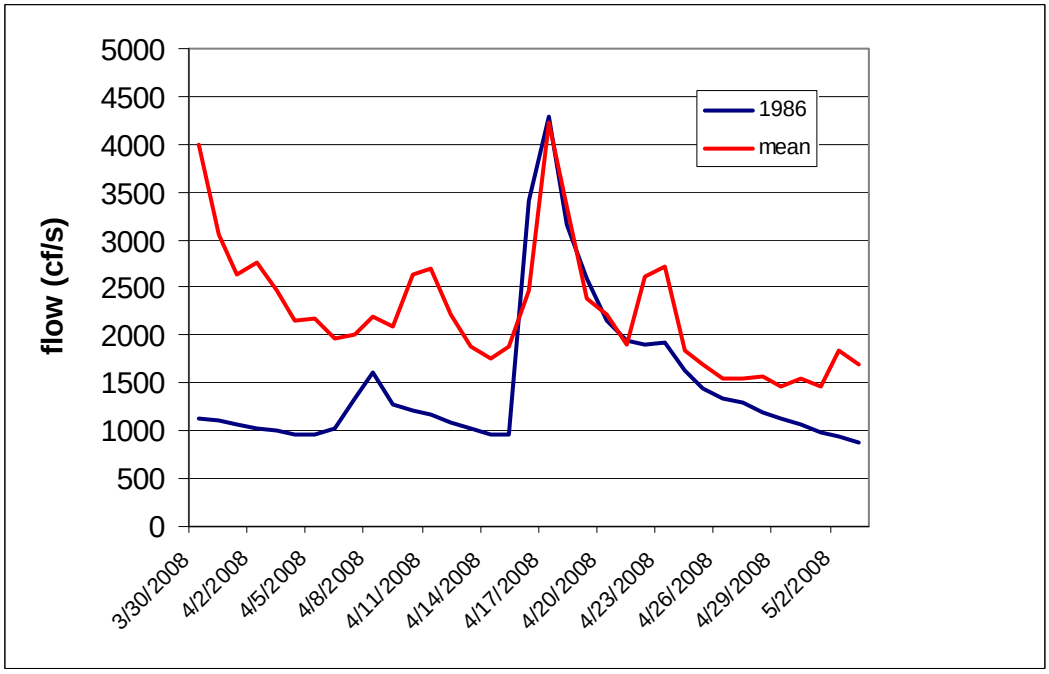
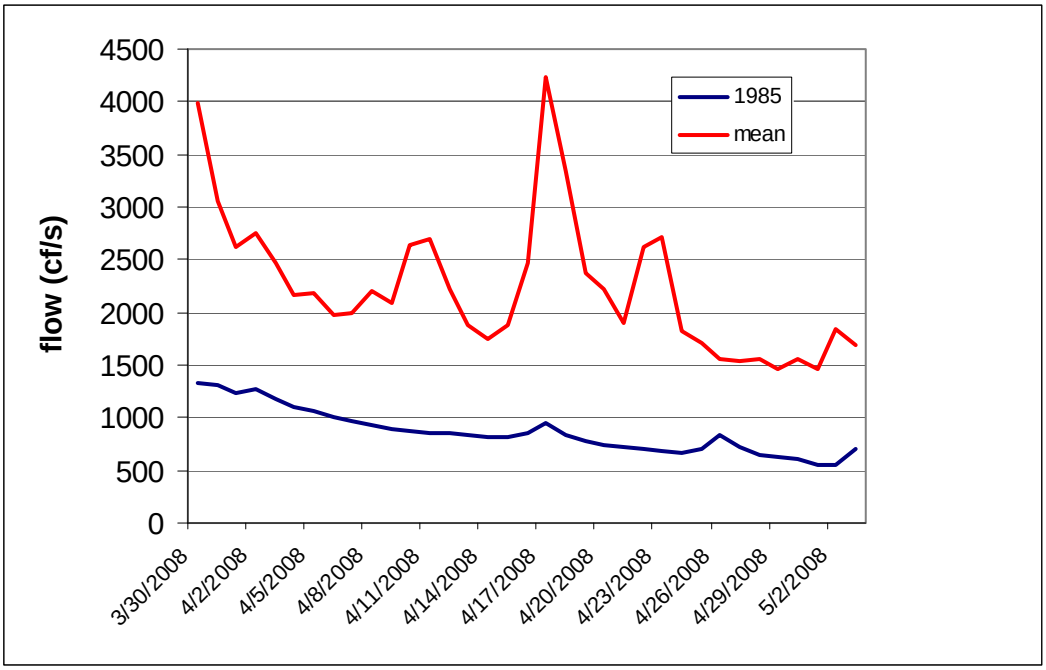



Figure 12. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, spring 1985.