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Evaluation of Striped Bass Stocks in Virginia: Monitoring and Tagging Studies, 2010-2014 Annual Report 1 September 2009 - 31 August 2010

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Annual Report

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Preface

This report presents the results of striped bass (*Morone saxatilis*) tagging and monitoring activities in Virginia during the period 1 September 2009 through 31 August 2010. It includes an assessment of the biological characteristics of striped bass taken from the 2010 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, and variable-mesh experimental gill nets. Spawning stock assessment was expanded to include the James River in 1994, utilizing commercial fyke nets and variable-mesh experimental gill nets. An experimental fyke net was established in the James River to assess its potential as a source for tagging striped bass. The use of fyke nets was discontinued after 1997. In conjunction with the monitoring studies, tagging programs have been conducted in the James and Rappahannock rivers since 1987. These studies were established to document the migration and relative contribution of these Chesapeake Bay stocks to the coastal population and to provide a means to estimate annual survival rates (S). With the re-establishment of fall recreational fisheries in 1993, the tagging studies were expanded to include the York River and western Chesapeake Bay to provide a direct estimation of the resultant fishing mortality (F). Commencing in 2005, these estimates of F were estimated from the striped bass tagged during the spring in the Rappahannock River.

Acknowledgments

We are deeply indebted to many people for their participation and/or contributions to the striped bass tagging and spawning stock assessment program. These include: the Anadromous Fishes Program staff; the Environmental and Aquatic Animal Health staff, Drs. Wolfgang Vogelbein and Hamish Small; Fisheries Department students of the Virginia Institute of Marine Science and Amy Then; the cooperating commercial fishermen Ernest George, Joe Hinson, Albert and Stanley Oliff, Paul Somers, Clark Trader, Wayne France, John Wyatt and Glenn Wyatt; William and Mary student volunteers; and Maryland Department of Natural Resources (Md DNR) staff Harry Hornick, Beth Versak and Alexi Sharov.

Executive Summary

New Features: This year we include spatial comparisons of growth, disease prevalence and progression for tagging locations at both the upper and lower Rappahannock River to assess potential differences between resident populations.

I. Assessment of the spawning stocks of striped bass in the Rappahannock and James rivers, Virginia, spring 2010.

Catch Summaries:

1. In the Rappahannock River, 1,048 striped bass were sampled from three commercial pound nets. The samples were predominantly male (78.7%) and in the 5-8 year range (49.3%). Females dominated the older age classes (79.5%). The mean age of the male striped bass was 5.2 years and 10.1 years for females.

2. In experimental anchor gill nets set in the Rappahannock River, 486 striped bass were sampled. The samples were predominantly male (89.9%) and young (99.2%). Females dominated the older age classes (96.3%). The mean age of the male striped bass was 5.3 years and 10.9 years for females.

3. In two experimental anchor gill nets (mile 62) in the James River, 890 striped bass were sampled. The samples were predominantly male (91.2%) and young (98.0% ages 2-4). Females dominated the older age classes (84.8%). The mean age of the male striped bass was 4.5 years and 8.9 years for females.

Spawning Stock Biomass Indexes (SSBI)

4. The Spawning Stock Biomass Index (SSBI) from the Rappahannock River pound nets was 60.6 kg/day for male striped bass and 63.1 kg/day for female striped bass. The male SSBI was the highest in the 1991-2010 time series, nearly 1.6 times higher than the 2009 index. The 2010 female SSBI was 41.2% higher than the 2009 index. The 2010 index was more than double the 20-year average.

5. The SSBI for the Rappahannock River gill nets was 105.8 kg/day for male striped bass and 48.9 kg/day for female striped bass. The male index was 31.8% above the 20-year average and the female index was 25.1% above the 20-year average.

6. The SSBI for the James River gill nets was 145.7 kg/day for male striped bass and 56.4 kg/day for female striped bass. The male was 27.4% above the 17-year average while the female index was near the 17-year average.

Egg Production Potential Indexes (EPPI)

7. An index of potential egg production was derived from estimates of numbers of

oocytes in the ovaries of mature females. The 2010 Egg Production Potential Index (EPPI) for the Rappahannock River pound nets was 9.87 million eggs/day, increasing from the previous year. Older (8+ years) female stripers were responsible for 81.4% of the index.

8. The 2010 EPPI for the Rappahannock River gill nets was 7.20 million eggs/day Older female striped bass were responsible for 79.2% of the index.

9. The 2010 EPPI for the James River gill nets was 8.50 million eggs/day. Older female striped bass were responsible for 57.3% of the index.

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

10. The cumulative catch rate from the Rappahannock River pound nets (34.89 fish/day) was the second highest in the 1991-2010 time series. There was an increase in almost all year classes from the 2009 values. The cumulative catch rates of male (27.50 fish/day) and female (7.40 fish/day) were the third highest in the time series.

11. Year class-specific estimates of annual survival (S) for pound net data varied widely between years. The geometric mean S of the 1983-2002 year classes varied from 0.516-0.826 (mean = 0.673). Mean survival rates for male stripers varied from 0.317-0.659 (mean = 0.485) while mean survival rates of female stripers varied from 0.461-0.675 (mean = 0.627).

12. The cumulative catch rate from Rappahannock River gill nets (48.80 fish/day) was the seventh lowest value in the time series and was more than double the rate in 2009. Cumulative catch rate of male stripers (38.80 fish/day) was the eighth lowest in the time series and was 2.4 times the rate in 2009. The cumulative catch rate of female striped bass (4.90 fish/day) was near the median in the time series, and 31.9% less than the catch rate in 2009.

13. Year class-specific estimates of annual survival for gill net data varied widely between years. The geometric mean S of the 1984-2002 year classes varied from 0.408-0.722 (mean = 0.603). The mean survival rates for male stripers varied from 0.153-0.690 (mean = 0.426). The mean survival rates for female stripers varied from 0.496-0.855 (mean = 0.647).

14. The cumulative catch rate from James River (mile 62) gill nets (89.00 fish/day) was the highest since 2006, 19.9% higher than the rate in 2009. The cumulative catch rate for male striped bass (81.10 fish/day) was the highest since 2006 of the time series and 23.4% higher than the rate in 2009. The cumulative catch rate of female striped bass (7.90 fish/day) was 7.1% lower than the rate in 2009.

15. Year class-specific estimates of annual survival in the James River varied widely between years. The geometric mean S of the 1984-2003 year classes varied from 0.338-0.733 (mean = 0.561). The mean survival rates of male stripers (1988-2003 year classes) varied from 0.286-0.612 (mean = 0.440). The mean survival rates of female stripers (1984-2001 year classes) varied from 0.339-0.859 (mean = 0.652).

Catch rate histories of the 1987-2002 year classes

16. Plots of year class-specific catch rates vs. year in the James and Rappahannock rivers from 1991-2010 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.

17. 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

18. The scales of 190 striped bass were digitally measured and the increments between annuli were used to determine their growth history.

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

20. Striped bass were estimated to reach the minimum legal length for the resident fishery (18 in.) and the coastal fishery (28 in.) at age 3.5 and seven, respectively.

Age determinations using scales and otoliths

21. A total of 193 specimens from 12 size ranges were aged by reading both scales and otoliths. The two ageing methodologies were in agreement in 37.3% of the specimens and within one year 82.4% of the time.

22. 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 ($p < .0005$).

23. A paired t-test of the mean of the age differences produced by the two ageing methodologies found that the mean difference was significantly different from zero ($p < .001$).

24. 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 2009-2010.

1. A total of 2,050 striped bass were tagged and released from pound nets in the Rappahannock River between 5 April and 3 May, 2010. Of this total, 1,567 were between 457-710 mm total length and considered to be predominantly resident striped bass and 483 were considered to be predominantly migrant striped bass.

2. A total of 94 striped bass tagged during spring 2009, were recaptured between 28 April, 2009 and 18 April, 2010, and were used to estimate mortality. In addition, 48 striped bass tagged in previous springs were recaptured during the 2009-2010 recovery interval and were used to complete the input data matrix. Most recaptures (69.1%) were caught within Chesapeake Bay. However, other recaptures came from Massachusetts, New York, New Jersey, Rhode Island, Connecticut, and Delaware.

3. A total of 39 migratory striped bass (>710 mm total length), tagged during spring 2009, were recaptured between 28 April, 2009 and 18 April, 2010, and were used to estimate the mortality. In addition, 43 striped bass tagged in previous springs were recaptured during the recovery interval and were used to complete the input data matrix. Most recaptures (30.0%) came from Chesapeake Bay. Other recaptures came from Massachusetts, New York, New Jersey, Rhode Island, Connecticut, and Delaware.

4. The ASFMC Striped Bass Tagging Subcommittee established a data analysis protocol that involves deriving survival estimates from a suite of nine Seber models using program MARK. The resultant estimates of survival were 0.52 (> 457 mm TL) and 0.59 (>711 mm TL).

5. The MARK survival estimates were used to estimate exploitation rate, fishing mortality and natural mortality using Baranov's catch equation. The estimates of exploitation were 0.07 (>457 mm TL) and 0.10 (>711 mm TL). The estimates of fishing mortality were 0.11 (>457 mm TL) and 0.06 (>711 mm TL).

6. Alternatively, a similar suite of input models similar were used to estimate survival, fishing and natural mortality using an instantaneous rates model. In 2009, an analytical approach that allowed two period of natural mortality was found to fit the data better than if constant natural mortality was used. The estimates of survival were 0.49 (>457 mm TL) and 0.54 (>711 mm TL). The estimates of fishing mortality were 0.09 (>457 mm TL) and 0.11 (>711 mm TL).

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 is a chronic disease caused by species of bacteria in the genus *Mycobacterium*. The disease causes grey granulomatous nodules in internal organs and ulcerous skin lesions externally. Mycobacteriosis in captive fishes is 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 movement, feeding, reproduction and mortality rates associated with the disease are unknown.

3. A total of 3,259 striped bass were tagged, assessed for external disease indication, photographed and released from two pound nets in the upper Rappahannock (n=277) and five pound nets in the lower Rappahannock (n=2,982) River during fall, 2009. Only 24.8% of those tagged were without any external sign of mycobacteriosis.

4. A total of 232 striped bass were tagged, assessed for external disease indication, photographed and released from five pound nets in the lower Rappahannock River during spring, 2010. Only 40.9% of those tagged were without any external sign of mycobacteriosis.

5. A total 188 striped bass tagged during fall, 2009 were recaptured prior to 20 September, 2009. There was a strong prevalence of clean and lightly diseased striped bass in recaptures at large less than seven days.

6. A total of 24 striped bass tagged during spring, 2010 were recaptured prior to 20 September, 2010. Three quarters of these were within seven days of release.

7. The prevalence of uninfected striped bass, as well as severe infection, has decreased from 2007-2009. Light and moderate infections have increased. Also the prevalence of non-infected striped bass decreases to near zero by age five.

8. Based on the recapture and reassessment of 371 tagged striped bass originally assessed as having a light or moderate mycobacterial infection, it was calculated that it take 416 days for the external infection to progress from light to moderate infection and 534 days to progress from moderate to heavy infection.

9. Release assessments show the relative disease prevalence is increasing at a greater rate at the upper Rappahannock. Fish released in the lower Rappahannock River averaged larger recaptured fork lengths than fish from the upper Rappahannock.

When combined with days at liberty, upper Rappahannock fish have a slower growth rate. This may suggest spatial differences affecting disease progression.

10. The return rate for moderate and heavy mycobacteroisis-infected striped 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 63%. Striped bass originally assessed as lightly infected had a less significant decrease in survival from the non-infected striped bass.

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Appendix A. Daily river flows for the Rappahannock River, 30 March – 3 May, 1985-2009.

I. Assessment of the spawning stocks of striped bass in the Rappahannock and James rivers, Virginia, spring, 2010.

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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 2 April – 3 May, 2010. This year, adverse weather conditions prevented setting of the pound nets at the start of the season. Therefore, samples from these pound nets were delayed until 5 April, 2010. Due to the delay, measurements and sex of the striped bass from the net designated for the monitoring sample were recorded and the stripers greater than 18 inches then tagged and released. All undersize stripers and any striped bass of indeterminate sex were brought back to the lab. 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 weights of the striped bass tagged and released rather than brought to the lab were estimated using sex-specific regressions of weight vs. length.

The otolith subsample was the first 10 striped bass of each sex sampled from each of the following size ranges (fork length, in mm): <165, 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 30 March - 3 May mean CPUE (kg/net day) of mature males (age 3 years and older), females (age 4 years and older) and the combined sample (males and females of the specified ages). An alternative index, based on the fecundity potential of the female striped bass sampled, was investigated and the results compared with the index based on mean female biomass.

To determine fecundity, the geometric mean of the egg counts of the gonad subsamples for each ripe female striped bass collected in 2001-2003 was calculated. A non-linear regression was fitted to data of total oocytes versus fork length. The resultant equation was then applied to the fork lengths of all mature (4+ years old) females from the pound net and gill net samples and the Egg Production Potential Index (EPPI) was defined as the mean number of eggs potentially produced per day of fishing effort by the mature female (age 4+) striped bass sampled from 30 March - 3 May.

Estimates of survival (S, the fraction surviving after becoming fully recruited to the stock) were calculated by dividing the catch rate (number/day) of a year class in year a+1 by the catch rate (number/day) of the same year class in year a. If the survival estimate between successive years was >1, the estimate was derived by interpolating to the following year. The geometric mean of S was used to estimate survival over periods exceeding one year (Ricker 1975). Separate estimates of survival were made for male and female striped bass, as well as the sexes combined.

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

Results

Catch Summaries

Rappahannock River:

Pound nets: Striped bass (n= 1,048) were sampled between 5 April - 3 May, 2010 from the pound nets in the Rappahannock River. The number of striped bass sampled was 69% greater than the sample in 2009 (n= 620) and 59% greater than the 18-year average (n=659). Total catches varied from 12-358 striped bass, with the peak catch on 12 April (Table 1). Surface water temperature increased slowly from 15.5 EC on 5 April to 17 EC on 22 April, and then increased to 21 EC on 3 May. River flows were above average at the start of the season, but for the seventh consecutive year, dry weather persisted throughout early April, resulting in lower river flows than had been present in 2001-2003 (Fig 3). Salinities were 0.0-0.1 p.p.t. throughout the sampling season. Catches of female striped bass peaked on 8 and 12 April and were dominated by the pre-2001 year classes. Males made up 78.7% of the total catch, which was near the 18-year average (77.2%). The 2002-2005 year classes (five to eight years old) comprised 49.3% of the total catch. In contrast, in 2009 the 2003-2006 year classes comprised 39.9% of the total catch. Males dominated the 2006-2008 year classes (95.7%) and the 2002-2005 year classes (91.3%), but females dominated the 1992-2001 year classes (79.5%).

Biomass catch rates (g/day) of both male and female striped bass peaked on 12 April (Table 2). The numeric catch rate of males exceeded that of females on every sampling date except 5 April. Unlike 2008, but consistent with most previous years, the biomass catch rates for female striped bass exceeded that for males overall (1.04:1), peaking on 8 April (1.2:1). The mean ages of male striped bass varied from 4.5-5.8 years by sampling date, with the oldest mean age occurring on 8 April. The mean ages of females varied from 7.3-14.0 years by sampling date, which was a much larger range than in 2009 (6.3-9.8 years).

There was a broad peak in abundance of striped bass (mostly male) between 490-630 mm total lengths in the pound net samples (Table 3). This size range accounted for 53.9% of the total sampled. There was a secondary peak in abundance of striped bass between 880-930 mm total lengths. Consistent with previous years, the striped bass from 630-710 mm total length accounted for only 5.1% of the total sample. The total contribution of striped bass greater than 710 mm total length (the minimum total length for the coastal fishery) was 25.6% (vs. 29.0% in 2009).

During the 5 April – 3 May period, the 2005 (29.9%) and 2006 (18.6%) year classes were the most abundant (Table 4). These year classes were 94.1% male. The contribution of males age six and older (the pre-2005 year classes) was 22.4% 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 17.7% of the total aged catch, but was also 80.2% of the total females captured. The catch rate (fish/day) of male striped bass was 27.5, which is 65.7% above the 18-year average (Table 5). The catch rate of female striped bass (7.4 fish/day) was above the 18-year average, and was the highest since 2007. The biomass catch rates (kg/day) of both sexes of striped bass were well above the average of the 18-year time series. The mean age of the male striped bass was above the 18-year average and the highest since 2004. The mean age of the female striped bass was the highest since 2007 and well above the mean value in the time series.

Experimental gill nets: Striped bass (n= 486) were also sampled between 2 April and 3 May, 2010 from two multi-mesh experimental gill nets in the Rappahannock River. The total catch was greater than the total catch in 2009 (n=231) but was still 3.2% below the 18 year average. Total catches peaked on 8 and 12 April (Table 6). Total catches of male striped bass were at the highest on 8 and 12 April. Total catches of female striped bass peaked on 8 April. Males made up 89.9% of the total catch. Males dominated the 2006-2008 year classes (99.2%) and the 2002-2005 year classes (96.3%), but the 1992-2001 year classes were 70.6% female.

Biomass catch rate (g/day) of male striped bass was highest on 8 April (Table 7). In contrast to 2009, the catch rate (fish/day) of males exceeded that of females on every sampling date. The mean ages of male striped bass varied from 4.2-6.5 years by sampling date, with the oldest males being most abundant on 19 April. The biomass catch rate of female striped bass (g/day) peaked sharply on 8 April. The mean ages of females varied from 6.3-13.7 years by sampling date, with the oldest females (age nine and older) being most abundant from 5-12 April.

Unlike 2009, but consistent with previous years, there was a broad peak in the distribution of length frequencies of striped bass in the gill net samples between 490-640 mm TL (Table 8). In previous years, there was also distinct secondary peak of larger striped bass, but this has been less apparent since 2006. Unlike 2008 and 2009, but consistent with previous years, the total contribution of striped bass greater than 840 mm total length from the gill nets (9.5%) was lower than from the pound nets (17.6%). The total contribution of striped bass greater than 710 mm total length was 19.1% in the gill nets.

During the 2 April – 3 May period, the 2005 (27.4%) and 2004 (21.6%) year classes were most abundant (Table 9). These year classes were 97.1% male. The contribution of males age six and older (the pre-2005 year classes) was 36.4% of the total aged catch. These year classes were most vulnerable to commercial and recreational exploitation within Chesapeake Bay. The contribution of females age seven and older, presumably repeat spawners, was 8.4% of the total aged catch but was 81.6% of the total females captured. The catch rate of male striped bass (43.7 fish/day) was the near the median in the 18-year time series and was 3.5% below the average (Table 10). The catch rate of female striped bass (4.9 fish/day) was also near the median in the time series and was 14.0% below the 18-year average. The biomass catch rates (g/day) for male striped bass was the third highest in the time series and was 36.2% above the 18-year average. The biomass catch rate for female striped bass was the sixth highest in the time series and was 30.9% above the 18-year average.

James River:

Experimental gill nets: Striped bass (n= 890) were sampled between 2 April and 3 May, 2010, from two multi-mesh experimental gill nets at mile 62 in the James River. Total catches peaked on 19 April. Young, male striped bass were primarily responsible for the peak catch (Table 11). Catches of female striped bass peaked on 19 and 22 April. Males dominated the 2006-2008 year classes (98.0%) and the 2002-2005 year classes (91.5%), but the 1992-2001 year classes were predominantly female (84.8%).

Biomass catch rates (g/day) of male striped bass peaked on 5 and 19 April, but were high on all but two occasions (Table 12). The catch rates of female striped bass peaked first on 5 and 8 April then again on 19 April. The biomass catch rate of males exceeded that of females on every sampling date except for 3 May (2.6:1 for the season). The mean ages of male striped bass varied from only 4.3-4.9 years by sampling date. The mean ages of females varied from 3.0-12.5 years by sampling date.

There was a peak of striped bass 430- 630 mm total length in the gill net length frequencies (Table 13). This size range accounted for 81.2% of the total striped bass sampled. In contrast to the pound net samples from the Rappahannock River, the striped bass greater than 840 mm total length accounted for 5.2% of the total sampled. The total contribution of striped bass greater than 710 mm total length was 7.1%.

During the 2 April – 3 May period, the 2006 (49.3%) and 2005 (23.3%) year classes were the most abundant in the gill nets (Table 14). These year classes were 96.4% male. The contribution of males age six and older (the pre-2005 year classes) was only 11.9% 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 5.4% of the total aged catch, but represented 59.5% of the total females captured.

The catch rate of male striped bass (81.2 fish/day) was much higher than for 2009, and was 19.8% above the 16-year average (Table 15). However, the catch rate of female striped bass (7.8 fish/day) was lower than for 2009 and was 14.3% below the 16-year average. The biomass catch rate (g/day) of male striped bass was higher than 2009, and was 17.3% above the 16-year average. The biomass catch rate of female striped bass was lower than in 2009, and was slightly below the 16-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 2010 was 60.6 kg/day for male striped bass and 63.1 kg/day for female striped bass. The index for male striped bass was the highest in the 20-year time series, was 1.6 times the index value for 2009, and more than double the 20-year average (Table 16). The magnitude of the index for male striped bass was largely determined by the 2005 (31.1%) and 2004 (16.8%) year classes. The index for female striped bass was 41.2% higher than the 2009 index. It was the third highest in the time series and was also nearly double the 20-year average (Table 16). The magnitude of the index for the females was largely determined by the 1996 and 2000 year classes (21% each).

Experimental gill nets: The Spawning Stock Biomass Index for spring 2010 was 105.8 kg/day for male striped bass and 48.9 kg/day for female striped bass. The index for male striped bass was the fourth highest of the time series, more than double the 2009 index, and was 31.8% above the 20-year average (Table 16). The 2004 and 2005 year classes each contributed 26% of the biomass in the male index. In contrast to the pound net index, the index for female striped bass was 17.0% below the 2009 index, but was still 25.1% above the 20-year average. The 1996 year class contributed 29.1% of the biomass in the female index.

James River:
Experimental gill nets: The Spawning Stock Biomass Index for spring 2010 was 145.7 kg/day for male striped bass and 56.4 kg/day for female striped bass. The male index was near the median in the 17-year time series, 17.4% above the 2009 index, and 27.4% above the 17-year average (Table 17). The 2004-2006 year classes contributed 79.9% of the biomass in the male index. The female index was also near the median in the time series, was 13.2% lower than the 2009 index, and was near the 17-year average. The 1996 and 1997 year classes each accounted for 18% 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 2010 Egg Production Potential Indexes (EPPI, Table 19) for the Rappahannock River were 9.87 (pound nets) and 7.20 (gill nets). The 2010 EPPI for the James River was 8.50. The indexes for both the Rappahannock and James rivers were heavily dependent on the egg production potential of the 1996-2000 year class females (75.4% in the pound nets, 56.2% in the Rappahannock gill nets and 62.6% in the James River gill nets). Previous values for the EPPI for 2001-2009 from the Rappahannock River were 3.992, 1.764, 9.829, 10.55, 6.30, 4.01, 13.792, 8.66 and 6.87 (pound nets) and 4.039, 6.070, 3.724, 8.432, 3.06, 6.27, 9.915, 6.58 and 9.04 (gill nets). Previous values for the EPPI for 2001-2009 from the James River were 5.286, 6.709, 6.037, 4.922, 3.24, 15.1, 8.396, 8.86 and 9.52 respectively (Sadler et al 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008 and 2009). Thus, the EPPI values for the pound nets in the Rappahannock River signaled an improvement in the status of the spawning stock from the 2009 values, while the EPPI value for the gill nets in the Rappahannock and James rivers were below their 2009 values. Modest changes in the methodology (utilizing fully mature ovaries solely rather than ovaries in various states of maturation) in the 2001-2010 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 1991-2010 samples are presented in Tables 20-22. The cumulative annual catch rate of all year classes for 2010 was the second highest in the time series and was 52.0% higher than the cumulative catch rate for 2009 (Tables 20a,b). The increase was the result of higher catch rates for almost all year classes. The catch rate of males was dominated by four through six year olds (2004- 2006 year

classes, Tables 21a,b). These three age classes contributed 72.6% 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 third highest of the time series, and was 10.9% higher than the catch rate in 2009 (Tables 22a,b). The 1996-2000 year classes accounted for 68.9% of the total female catch.

The range of overall ages was unchanged from 1991-2009, 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, then increased to 0.787-0.929 from 2003-2007. The cumulative catch rate dropped to 0.678 in 2008 and 0.593 in 2009, but rebounded to 0.780 in 2010.

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 (1991-2010 of the 1983-2002 year classes (sexes combined) varied from 0.516-0.826 (Tables 23a,b) with an overall mean survival rate of 0.673. 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 (1991-2010) of the 1985-2002 year classes of males varied from 0.317-0.659 (Tables 24a,b) with an overall mean survival rate of 0.485. These year classes have been the major target of the fall recreational and commercial fisheries that reopened in 1993. The geometric mean survival rate (1991-2010) of the 1983-1995 year classes of females varied from 0.461-0.675 (Tables 25a,b) with an overall mean survival rate of 0.627.

Experimental gill nets: Numeric catch rates (fish/day) of individual year classes from 1991-2010 are presented in Tables 26-28. The cumulative annual catch rate (all age classes, sexes combined) for 2010 from the gill nets was the seventh lowest in the time series, but was more than double the rate for 2009 and the highest since 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 significant contributors in 2010, but the increase in the cumulative catch rate was driven by high catches of 2005-2007 year class striped bass. The age of peak abundance was age five for the first time since 2002. 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 eight lowest in the time series, but 2.4 times the catch rate in 2009

(Tables 27 a,b). However, the cumulative catch rate of female striped bass was 31.9% less than the cumulative catch rate for 2009 and near the median of the time series (Tables 28a,b).

The overall age structure from 1991-2010 consisted of 2-12 year old males (Tables 27a,b) and 2-14 year old females (Tables 28a,b). However, in 2010 there were small catches of the 1992-1995 year classes. The proportion of males age six and older (0.43) was less than 2009 (0.48), but consistent with the 2002-2008 values after being 0.03-0.06 from 1997-2001. The proportion of female striped bass age eight and older was also lower than 2009 (0.81) but consistent with the values since 2004. 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 2004-2008.

The cumulative catch rate (all age classes) of male striped bass was the highest value since 2007 (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 2010 cumulative catch (all age classes) rate of female striped bass was lower than in 2009 (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 2005-2010. 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 (1991-2010) of the 1984-2002 year classes (sexes combined) varied from 0.408-0.722 (Tables 29a,b) with an overall mean survival of 0.603. There were widely divergent estimates of annual survival of male and female striped bass. The geometric mean survival rate (1991-2010) of the 1991-2002 year classes of males varied from 0.153-0.690 (Tables 30a,b) with an overall mean survival of 0.426. These year classes have been the major target of the fall recreational and commercial fisheries that reopened in 1993. The geometric mean survival rate (1991-2010) of the 1984-1997 (excluding 1991 and 1996) year classes of females varied from 0.496-0.855 (Tables 31a,b) with an overall mean survival rate of 0.647. 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 1984-2010 are presented in Tables 32-34. The cumulative annual catch rate (all age classes, sexes combined) for 2010 was the highest since 2006, and was 19.9% higher than the catch rate for 2009 (Tables 32a,b). The cumulative catch rate was driven by high catch rates for the four to six year old (2004-2006 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, although small number of 15-17 year old stripers were captured in 2010 (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 had been stable from 1994-2009, consisting of three to 14 year old females (Tables 34a,b). The cumulative proportion of males age six and older was 0.127, and has varied from 0.091-0.191 in 2000-2010 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, increased to 0.864 in 2008 and has since declined to 0.544 in 2010.

The cumulative catch rate of male striped bass mirrored the trends of the combined data with the 2010 catch rate being the highest since 2006, and 23.4% higher than the cumulative catch rate for 2009 (Tables 33a,b). Using the maximum catch rate of the resident males as an indicator, the 1995-1997, 2000 and 2006 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 2010 cumulative catch rate of female striped bass was 7.1% lower than the catch rate in 2009, and was the seventh highest in the 17-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 (1994-2010) of the 1984 -2003 year classes (sexes combined) varied from 0.338-0.733 (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 (1994-2010) of the 1988-2003 year classes of males varied from 0.286-0.612 (Table 36) with an overall mean survival rate of 0.440. These year classes have been the major target of the fall recreational and commercial fisheries that reopened in 1993. The geometric mean survival rate (1994-2010) of the 1984-2001 year classes (except 1999) of females varied from 0.339-0.859 (Table 37) with an overall mean survival rate of 0.652.

Catch Rate Histories of the 1987-2002 Year Classes

The catch rate histories of the 1987-2002 year classes from each sampling gear (sampling on the James River commenced in 1993) are depicted in Figures 4-18. 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 16 year classes) as an indicator of year class strength, the 1987 year class was near the mean for the 1987-2002 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 2010.

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 2010.

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 2010.

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 2010.

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 2010.

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). One male and two female 1992 year class striped bass was captured in the Rappahannock River in 2010.

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). Six female 1993 year class striped bass, four in the Rappahannock River and two in the James River were captured in 2010.

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). Four female 1994 year class striped bass, one in the James River and three in the Rappahannock River, were captured in 2010.

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, all in the Rappahannock River, were captured in 2010.

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). Fifty-one (48 females and three males) 1996 year class striped bass (44 in the Rappahannock and seven in the James) were captured in 2010.

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). Twenty-eight female 1997 year class striped bass (20 in the Rappahannock and eight in the James) were captured in 2010.

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). Twenty-nine (25 females and four males) 1998 year class striped bass (25 in the Rappahannock River and four in the James River) were captured in 2010.

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). Forty-seven (35 females and 12 males) 1999 year class striped bass (41 in the Rappahannock River and six in the James River) were captured in 2010.

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 (Table 40). Sixty-eight (52 females and 16 males) 2000 year class striped bass (60 in the Rappahannock River and eight in the James River) were captured in 2010.

2001 Year class: Peak abundance of male striped bass occurred at age three in the Rappahannock gill nets, age four in the pound nets and age five in the James River gill nets (Figure 18). Peak abundance of female striped bass occurred at age five in the pound nets and James River gill nets, but at six in the Rappahannock River gill nets. The CCA at age eight was the highest since the 1997 year class for all three indexes (Tables 38-40). Sixty (33 females and 27 males) 2001 year class striped bass (50 in the Rappahannock River and 10 in the James River were captured in 2010.

2002 Year class: Peak abundance of male striped bass occurred at age four and age five for the female striped bass in the pound nets and the gill nets in both rivers (Figure 19). The CCA at age eight was near the overall average in the pound nets and James River gill nets, but was the third lowest in the Rappahannock gill nets (Tables 38-40). Sixty-four (49 males and 15 females) 2002 year class striped bass (51 in the Rappahannock River and 13 in the James River) were captured in 2010.

Growth Rate of Striped Bass Derived from Annuli Measurements

The scales of 190 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 145mm 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 193 striped bass from 12 size ranges were aged by reading both their scales and otoliths. Scale and otolith ages from the same specimen were in agreement 37.3% (72/ 193) of the time and within one year 82.4% (159/193) 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 = 19). We tested the hypothesis that the observed age differences were symmetrically distributed about the main table diagonal (Table 42). The hypothesis was rejected ($\chi^2 = 63.54$, 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 2007-2009, but not in 2006.

Differences between the scale and otolith age from the same specimen ranged from zero to four years except for one specimen (Figure 19). The otolith-derived age exceeded the scale age 34.7% of the total examined (55.4% 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 (73.5%). 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) also rejected the hypothesis that these differences were random (X^2 = 9.68, df = 5, p< 0.05). 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=193) determined by reading the otoliths was greater than the mean age determined by reading the scales (by 0.25 years, Table 43). The test results were:

$$\bar{A}ge_{otolith} = 8.91 \qquad \bar{A}ge_{scale} = 8.66$$

$$S_{otolith} = 4.74 \qquad S_{scale} = 4.11$$

$$t = 0.564$$

$$df = 382$$

$$p = .5734$$

Therefore the null hypothesis was rejected.

A paired t-test was also performed on the ages determined for each specimen by the two methodologies. The null hypothesis tested was that the mean of the difference resultant from the two methods was not different from zero. The paired t-test results were highly significant ($t=2.62$, $df=192$, $p<.001$) and the null hypothesis was not 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 ($K_{.05}$):

$$D_{\max} = 0.0984 \qquad K_{.05} = 1.3581$$

$$D_{.05} = 1.3581\sqrt{\frac{193+193}{193^2}} = 0.1383$$

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 is consistent with the 2008 and 2009 results, but 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 2010, persist bad weather delayed efforts by our fishermen to establish their nets (usually done in mid-March) until 5 April (one net). Hence we tagged and released all striped bass greater than 457 mm and used a sex and size-based regression to estimate biomass for our pound net index.

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.

The biological characterization of the spawning stock of striped bass in the Rappahannock River changed dramatically from 1991-2010. 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 2002-2010. 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. Total catches in 2010 were greater than in 2008 and 2009 but much lower than the catches in 2007.

Of note again in the 2010 samples was the relative abundance of 1996 year class (14 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. Also, the 1992 year class, abundant in 2005-2007, but absent from the samples again in 2008 and 2009, were captured again in 2010.

The 2010 value of the Spawning Stock Biomass Index (SSBI) for the Rappahannock River pound nets approximately 50% greater than the SSBI for 2009 and the second highest since 1991. The SSBI for male striped bass captured in the pound nets was more than double the mean of the 1991-2010 time series. The SSBI for female striped bass was 82.4% above the mean of the time series. While the biomass indexes are dominated by the older age classes, there was a notable increase in four to seven year old females compared to recent years.

The 2010 SSBI for the gill nets was also higher than for 2009 and approximately 50% above the mean of the 1991-2010 time series. The male SSBI was more than double that for 2009 and was the fourth highest overall. However, the female SSBI was 17% lower than for 2009 but well over the mean for the 1991-2010 time series.

The 1991-2010 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 2010 was driven by increased catches of 2003-2006 year classes of males, compared to the 2001-2004 year classes that dominated the index in 2009. The female biomass from pound nets showed no reliance upon any age groups, although the exceptionally strong 1996-1998 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.

The 2010 value of the SSBI in the James River was much about 10% higher than in 2009 and nearly 20% above the mean of the 1994-2010 time series. The male index was driven by large catches of the 2003-2006 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 2010, the contribution of 8+ year old females was 81.4% of the total number, 92.9% of the biomass, and 95.2% of the calculated egg potential. It should be noted that our fecundity estimates for individual striped bass are well below those reported by Setzler et al. (1980). Our methodology differs from the previous studies, but the relative contribution in potential egg production of the older females may be underestimated at present.

In our analysis of pound net catch rates, we observed a distinctive bimodal distribution of the striped bass. 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 2004-2010, the second group was expanded to 750-1200 mm as the strong 1996-1998 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 1983-2002 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 0.63 in pound nets and 0.65 in gill nets. The survival estimates of 1985-2002 year class male striped bass were 0.49 in pound nets and 0.43 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 0.65 for female striped bass.

The catch histories of the 1987-2002 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 145 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 2006 year class in fall 2009) and the 28 in. (711 mm) minimum total length for the coastal fishery at age seven.

The ages of striped bass determined by reading both their scales and otoliths were found to differ by as much as eight years (though only for a single specimen). Overall, the age difference determined for the largest, and oldest, specimens was 0-4 years (13-16 years by reading the scale vs. 13-18 years by reading the otolith). The maximum age determined by reading scales has generally remained constant at 16 years since 1991 (although one each of ages 17-19 was aged in 2009); while there has been an annual progression in the maximum age determined by reading otoliths. Agreement between the two ageing methodologies was 37.3% and was slightly less than the results from 2009. When there was disagreement between methodologies, the otolith age was 1.3 times more likely to have been aged older than the respective scale-derived age and 2.8 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, 2007, 2008 and 2009. 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.

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Table 1. Numbers of striped bass in three age categories (year classes 2006-2008, 2002-2005 and 1992-2001) from pound nets in the Rappahannock River, by sampling date, spring, 2010. M = males, F = females.

Date	n	Year Class							
		No age		2006-2008		2002-2005		1992-2001	
		M	F	M	F	M	F	M	F
5 April	12	0	0	1	0	1	3	0	7
8 April	154	4	0	19	2	73	3	7	46
12 April	358	14	1	87	2	146	17	23	68
15 April	115*	8	1	32	3	51	3	3	13
19 April	138	5	0	31	0	73	9	5	15
22 April	68*	1	0	27	0	37	1	1	1
26 April	146	8	0	55	4	66	4	2	7
29 April	33	0	0	8	1	14	5	1	4
3 May	24	2	0	9	0	11	0	0	2
Total	**1,048**	**42**	**2**	**269**	**12**	**472**	**45**	**42**	**163**

*** 1 2005 YC – sex indeterminate**

Table 2. Net-specific summary of catch rates and mean ages of striped bass (n=1,048) in pound nets on the Rappahannock River, spring, 2010. 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
5 April	S454	12	1.0	5.0	2,213.2	49,524.4	5.5	10.8
8 April	S454	154	34.3	17.0	96,746.1	173,792.0	5.8	11.4
12 April	S454	358	67.5	22.0	161,956.7	197,414.2	5.4	10.6
15 April	S473	115	31.3	6.7	62,074.3	51,107.4	4.9	9.0
19 April	S473	138	28.5	6.0	63,016.4	41,296.8	5.2	8.8
22 April	S462	68	22.0	0.7	40,995.8	4,166.9	4.8	14.0
26 April	S462	146	32.8	3.8	58,062.7	20,577.6	4.9	7.3
29 April	S454	33	7.7	3.3	15,142.5	17,905.7	5.2	7.6
3 May	S462	24	5.5	0.5	9,054.1	4,487.6	4.5	10.0
Totals	S454	557	33.2	13.3	82,426.6	121,983.1	5.5	10.7
	S462	164	19.9	1.6	35,586.8	10,251.0	4.7	8.0
	S473	205	29.7	6.3	62,612.6	45,501.3	5.1	8.9
Season		1,048	**27.5**	**7.4**	**60,615.4**	**63,169.0**	**5.2**	**10.1**

Table 3. Length frequencies (TL in mm) of striped bass sampled from the pound nets in the Rappahannock River, spring, 2010.

TL	n	TL	n	TL	n	TL	n	TL	n	TL	n
250-	0	**410-**	12	**570-**	58	**730-**	7	**890-**	13	**1050-**	1
260-	0	**420-**	9	**580-**	49	**740-**	6	**900-**	8	**1060-**	1
270-	1	**430-**	14	**590-**	43	**750-**	7	**910-**	11	**1070-**	1
280-	1	**440-**	14	**600-**	41	**760-**	5	**920-**	11	**1080-**	1
290-	3	**450-**	9	**610-**	39	**770-**	7	**930-**	7	**1090-**	3
300-	0	**460-**	12	**620-**	33	**780-**	10	**940-**	7	**1100-**	3
310-	1	**470-**	27	**630-**	20	**790-**	5	**950-**	11	**1110-**	3
320-	1	**480-**	20	**640-**	7	**800-**	6	**960-**	13	**1120-**	0
330-	2	**490-**	34	**650-**	2	**810-**	7	**970-**	7	**1130-**	1
340-	1	**500-**	39	**660-**	10	**820-**	9	**980-**	5	**1140-**	2
350-	2	**510-**	36	**670-**	4	**830-**	8	**990-**	8	**1150-**	0
360-	7	**520-**	41	**680-**	4	**840-**	4	**1000-**	8	**1160-**	0
370-	7	**530-**	34	**690-**	2	**850-**	8	**1010-**	7	**1170-**	0
380-	3	**540-**	49	**700-**	0	**860-**	7	**1020-**	7	**1180-**	0
390-	5	**550-**	40	**710-**	4	**870-**	4	**1030-**	5	**1190-**	0
400-	7	**560-**	29	**720-**	3	**880-**	12	**1040-**	5	**1200-**	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, 5 April – 3 May, 2010.

Year Class	Sex	n	Fork Length Mean	Fork Length SD	Weight Mean	Weight SD	CPUE F/day	CPUE W/day
2008	male	4	275.8	18.6	260.7	50.7	0.1	34.8
	female	3	284.0	27.0	302.3	97.1	0.1	30.2
2007	male	76	381.2	30.9	738.1	172.6	2.5	1,870.0
	female	3	395.3	20.5	981.1	153.8	0.1	98.1
2006	male	189	461.6	22.3	1,329.7	191.5	6.3	8,377.2
	female	6	480.8	16.9	1,699.6	276.8	0.2	339.9
2005	male	289	526.7	27.1	1,960.4	295.9	9.6	18,884.8
	female	24	531.3	23.6	2,313.0	364.1	0.8	1,850.4
2004	male	121	574.1	23.6	2,520.3	325.5	4.0	10,165.4
	female	6	590.0	29.2	3,231.0	545.2	0.2	646.2
2003	male	41	655.5	50.5	3,756.8	789.7	1.4	5,134.3
	female	5	680.0	44.5	4,687.1	752.0	0.2	781.2
2002	male	21	736.9	43.0	5,182.0	817.2	0.7	3,627.4
	female	10	757.5	21.6	6,228.0	400.9	0.3	2,076.0
2001	male	20	770.6	30.0	5,931.6	692.4	0.7	3,954.4
	female	18	809.7	34.0	7,591.7	849.9	0.6	4,555.0
2000	male	8	758.1	45.5	5,656.4	968.4	0.3	1,508.4
	female	45	856.6	21.0	8,803.2	778.9	1.5	13,204.9
1999	male	7	828.4	40.8	7,201.2	943.2	0.2	1,680.3
	female	26	891.7	27.9	9,878.2	891.1	0.9	8,561.1
1998	male	4	837.3	35.9	7,523.5	904.4	0.1	1,003.1
	female	17	910.9	20.8	10,400.8	1,037.1	0.6	5,893.8
1997	female	16	946.5	22.4	11,704.5	837.7	0.5	6,242.4
1996	male	3	904.7	22.2	9,550.4	643.8	0.1	955.0
	female	31	975.2	39.9	12,627.7	1,611.2	1.0	13,048.7
1995	female	4	1,016.3	41.9	14,519.9	1,753.2	0.1	1,936.0
1994	female	2	1,048.0	32.5	15,850.0	1,312.0	0.1	1,056.7
1993	female	2	1,040.0	4.2	15,354.8	391.4	0.1	1,023.7
1992	female	2	1,075.0	14.1	16,327.8	814.5	0.1	1,088.5
Not	male	42	551.6	96.9	2,443.1	1,689.7	1.4	3,420.4
Aged	female	2	926.0	22.6	11,044.0	677.3	0.1	736.3

Table 5. Summary of the seasonal mean catch rates and ages, by sex, from the pound nets in the Rappahannock River, 30 March – 3 May, 1993-2010. M = male, F = female.

Year	n	CPUE (fish/day)		CPUE (g/day)		Mean age	
		M	F	M	F	M	F
2010	1,048	**27**.5	7.4	60,615.4	63,169.0	5.2	10.1
2009	620	16.2	5.7	38,323.9	44,775.3	5.1	8.5
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	**658.8**	**16.6**	**4.9**	**31,792.5**	**35,714.1**	**4.4**	**8.8**

Table 6. Numbers of striped bass in three age categories (year classes 2006-2008, 2002-2005 and 1992-2001) from gill nets in the Rappahannock River, by sampling date, spring, 2010. M = male, F = female.

		Year Class							
		No age		2006-2008		2002-2005		1992-2001	
Date	n	M	F	M	F	M	F	M	F
2 April	6	0	0	4	0	2	0	0	0
5 April	42	0	0	9	0	26	0	1	6
8 April	189	6	0	45	0	108	4	5	21
12 April	127	1	1	46	0	71	0	5	3
15 April	35	1	0	4	0	27	0	2	1
19 April	20	1	0	4	0	11	1	2	1
22 April	33	0	0	4	0	27	0	0	2
26 April	18	0	0	5	0	9	3	0	1
29 April	9	0	0	0	1	7	0	0	1
3 May	7	1	0	1	0	2	3	0	0
Total	**486**	**10**	**1**	**122**	**1**	**290**	**11**	**15**	**36**

Table 7. Summary of catch rates and mean ages of striped bass (n=486) from the two gill nets in the Rappahannock River, spring 2010. 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
1 April	6	6	0	9,312.6	0.0	4.2	
5 April	42	36	6	99,513.5	84,395.0	5.9	13.7
8 April	189	164	25	383,495.3	269,329.9	5.2	11.7
12 April	127	123	4	279,249.2	52,477.6	5.1	12.7
15 April	35	34	1	92,485.9	8,601.5	5.8	9.0
19 April	20	18	2	69,259.1	10,976.2	6.5	7.5
22 April	33	31	2	70,438.1	19,382.6	5.4	11.5
26 April	18	14	4	27,571.1	25,026.8	4.9	7.8
29 April	9	7	2	18,705.8	9,138.1	5.6	6.5
3 May	7	4	3	8,132.3	9,682.5	5.0	6.3
Season	486	**43.7**	**4.9**	**105,816.3**	**48,901.0**	**5.3**	**10.9**

Table 8. Length frequencies (TL in mm) of striped bass sampled from the experimental gill nets in the Rappahannock River, spring, 2010.

TL	n	TL	n	TL	n	TL	n	TL	n	TL	n
300-	1	**460-**	8	**620-**	19	**780-**	6	**940-**	2	**1100-**	1
310-	2	**470-**	8	**630-**	17	**790-**	0	**950-**	1	**1110-**	0
320-	0	**480-**	6	**640-**	14	**800-**	1	**960-**	2	**1120-**	1
330-	3	**490-**	10	**650-**	7	**810-**	4	**970-**	2	**1130-**	0
340-	3	**500-**	11	**660-**	11	**820-**	3	**980-**	2	**1140-**	1
350-	6	**510-**	16	**670-**	8	**830-**	2	**990-**	3	**1150-**	0
360-	5	**520-**	9	**680-**	7	**840-**	2	**1000-**	2	**1160-**	0
370-	8	**530-**	16	**690-**	4	**850-**	5	**1010-**	0	**1170-**	0
380-	7	**540-**	18	**700-**	5	**860-**	1	**1020-**	3	**1180-**	1
390-	4	**550-**	15	**710-**	9	**870-**	2	**1030-**	0	**1190-**	0
400-	2	**560-**	23	**720-**	7	**880-**	2	**1040-**	1	**1200-**	0
410-	4	**570-**	29	**730-**	5	**890-**	3	**1050-**	2	**1210-**	0
420-	5	**580-**	15	**740-**	5	**900-**	1	**1060-**	2	**1220-**	0
430-	2	**590-**	18	**750-**	2	**910-**	0	**1070-**	1	**1230-**	0
440-	2	**600-**	17	**760-**	2	**920-**	1	**1080-**	1	**1240-**	0
450-	3	**610-**	22	**770-**	1	**930-**	1	**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, 30 March – 3 May, 2010.

Year Class	Sex	n	Fork Length Mean	Fork Length SD	Weight Mean	Weight SD	CPUE F/day	CPUE W/day
2008	male	5	301.0	10.3	370.2	58.4	0.5	185.2
2007	male	49	359.2	28.2	627.6	152.1	4.9	3,075.5
2006	male	68	462.1	23.5	1,315.7	207.3	6.8	8,947.0
	female	1	494.0		1,898.3		0.1	189.8
2005	male	132	530.1	26.1	2,053.3	332.6	13.2	27,103.9
	female	1	545.0		2,690.0		0.1	269.0
2004	male	99	585.5	36.7	2,759.4	531.9	9.9	27,317.9
	female	6	612.8	17.7	3,197.9	343.5	0.6	1,918.8
2003	male	41	650.5	45.6	3,801.2	720.5	4.1	15,584.9
	female	2	619.5	13.4	3,444.5	35.8	0.2	688.9
2002	male	18	711.7	54.4	5,135.9	1,004.0	1.8	9,244.6
	female	2	770.0	7.1	6,944.1	18.4	0.2	1,388.8
2001	male	3	768.3	34.8	5,992.2	822.6	0.3	1,797.7
	female	9	802.0	31.1	7,674.0	824.7	0.9	6,906.6
2000	male	6	806.2	63.1	6,895.6	1,265.2	0.6	4,137.4
	female	1	888.0		9,105.9		0.1	910.6
1999	male	5	819.8	22.4	7,362.8	502.7	0.5	3,681.4
	female	3	889.0	26.2	10,486.0	840.1	0.3	3,145.8
1998	female	4	916.0	27.3	11,423.6	1,618.7	0.4	4,569.5
1997	female	4	930.5	15.4	10,981.5	1.287.7	0.4	4,392.6
1996	female	10	975.5	29.6	14,234.4	1,741.4	1.0	14,234.4
1995	female	1	1,026.0		14,978.4		0.1	1,497.8
1994	female	1	1,104.0		17,333.3		0.1	1,733.3
1993	female	2	1,049.5	65.1	18,004.7	3,371.2	0.2	3,610.0
1992	male	1	1,072.0		18,230.1		0.1	1,823.0
	female	1	1,126.0		21,383.5		0.1	2,138.4
No Age	male	10	598.6	40.8	2,918.0	642.5	1.0	2,918.0
	female	1	950.0		13,067.4		0.1	1,306.7

Table 10. Summary of the season mean (30 March – 3 May) catch rates and mean ages, by sex, from the experimental gill nets in the Rappahannock River, 1993-2010. M = males, F = female.

Year	n	CPUE (fish/day)		CPUE (g/day)		Mean age	
		M	F	M	F	M	F
2010	486	43.7	4.9	105,816.3	48,901.0	5.3	10.9
2009	231	15.9	7.2	47,440.7	58,936.7	5.6	9.7
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	**501.9**	**45.3**	**5.7**	**77,670.0**	**37,343.7**	**4.5**	**8.3**

Table 11. Numbers of striped bass in three age categories (year classes 2006-2008, 2002-2005 and 1992-2001) from gill nets in the James River, by sampling date, spring, 2010. M = male, F = female.

		Year Class							
		No age		2006-2008		2002-2005		1992-2001	
Date	n	M	F	M	F	M	F	M	F
2 April	66	3	0	31	0	27	1	2	2
5 April	131	5	0	57	0	59	0	2	8
8 April	144	3	0	91	2	37	3	1	7
12 April	72	1	0	38	1	26	1	0	5
15 April	90	5	1	50	3	31	0	0	0
19 April	175	5	1	114	0	42	5	1	7
22 April	89	2	0	44	1	27	8	1	6
26 April	59	3	0	35	1	18	2	0	0
29 April	38	0	0	19	1	14	2	0	2
3 May	26	0	0	10	1	8	5	0	2
Total	**890**	**27**	**2**	**489**	**10**	**289**	**27**	**7**	**39**

Table 12. Summary of catch rates and mean ages of striped bass (n=890) from the gill nets in the James River, spring 2010. 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
1 April	66	63	3	143,744.1	26,206.5	4.9	9.7
5 April	131	123	8	262,788.3	105,265.8	4.8	12.5
8 April	144	132	12	219,944.0	105,304.2	4.4	9.4
12 April	72	65	7	113,569.7	66,246.4	4.5	10.3
15 April	90	86	4	152,573.5	3,508.7	4.4	3.0
19 April	175	162	13	249,460.2	100,551.6	4.3	9.1
22 April	89	74	15	127,333.5	83,760.0	4.5	9.1
26 April	59	56	3	101,256.4	5,741.4	4.4	4.7
29 April	38	33	5	57,292.2	38,882.6	4.7	9.2
3 May	26	18	8	28,510.1	32,202.1	4.6	6.4
Season	890	**81.2**	**7.8**	**145,647.2**	**56,766.9**	**4.5**	**8.9**

Table 13. Length frequencies (TL in mm) of striped bass sampled from the experimental gill nets in the James River, spring 2010.

TL	n	TL	n	TL	n	TL	n	TL	n	TL	n
290-	0	450-	32	610-	24	770-	2	930-	0	1090-	0
300-	0	460-	61	620-	12	780-	0	940-	4	1100-	2
310-	1	470-	85	630-	12	790-	1	950-	1	1110-	0
320-	2	480-	67	640-	6	800-	0	960-	3	1120-	0
330-	2	490-	60	650-	9	810-	2	970-	3	1130-	0
340-	1	500-	51	660-	6	820-	0	980-	1	1140-	0
350-	0	510-	52	670-	7	830-	2	990-	1	1150-	0
360-	1	520-	43	680-	4	840-	5	1000-	4	1160-	0
370-	2	530-	42	690-	5	850-	4	1010-	1	1170-	1
380-	2	540-	27	700-	4	860-	0	1020-	1	1180-	1
390-	4	550-	33	710-	0	870-	1	1030-	0	1190-	0
400-	2	560-	23	720-	3	880-	1	1040-	3	1200-	0
410-	5	570-	27	730-	3	890-	2	1050-	1	1210-	0
420-	6	580-	25	740-	1	900-	1	1060-	0	1220-	0
430-	13	590-	21	750-	0	910-	2	1070-	2	1230-	0
440-	28	600-	20	760-	3	920-	1	1080-	0	1240-	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, 1 April – 3 May, 2010.

Year Class	Sex	n	Fork Length Mean	Fork Length SD	Weight Mean	Weight SD	CPUE F/day	CPUE W/day
2008	male	1	287.0		350.1		0.1	35.0
	female	1	299.0		361.9		0.1	36.2
2007	male	57	394.7	31.3	921.8	203.4	5.7	5,254.8
	female	1	387.0		808.0		0.1	80.8
2006	male	431	456.0	22.6	1,364.0	214.9	43.1	58,787.0
	female	8	469.3	20.4	1,539.1	273.2	0.8	1,231.3
2005	male	192	522.5	30.7	2,037.2	369.8	19.2	39,113.3
	female	15	542.1	25.6	2,449.6	386.1	1.5	3,674.4
2004	male	67	575.0	30.9	2,757.5	430.5	6.7	18,475.3
	female	5	611.2	23.4	3,501.3	567.7	0.5	1,750.7
2003	male	20	639.8	33.2	3,764.5	593.4	2.0	7,529.3
	female	4	661.5	20.2	4,635.3	520.1	0.4	1,854.1
2002	male	10	698.6	40.5	4,664.0	755.6	1.0	4,664.0
	female	3	783.7	8.1	6,764.1	526.8	0.3	2,029.2
2001	male	4	734.3	104.9	5,735.9	1,815.5	0.4	2,294.3
	female	6	799.5	22.9	6,858.0	681.4	0.6	4,114.8
2000	male	2	800.5	0.7	7,025.0	101.0	0.2	1,405.0
	female	6	866.2	18.6	9,117.6	1,076.4	0.6	5,470.6
1999	female	6	893.2	21.0	10,274.2	1,282.5	0.6	6,164.5
1998	female	4	928.5	26.7	11,077.9	1,340.9	0.4	4,431.1
1997	female	8	947.0	35.7	12,646.6	1,931.9	0.8	10,117.3
1996	female	7	987.1	42.4	14,382.4	1,965.9	0.7	10,067.7
1994	female	1	1,020.0		15,645.2		0.1	1,564.5
1993	female	2	1,117.0	9.9	19,227.7	229.9	0.2	3,845.5
Not	male	27	548.2	85.8	2,596.7	1,475.1	2.7	7,011.2
Aged	female	2	669.0	444.1	7,062.9	9,095.4	0.2	1,412.6

Table 15. Summary of season mean (30 March – 3 May) catch rates and ages, by sex, from experimental gill nets in the James River, 1995-2010.

Year	mile	n	CPUE (fish/day)		CPUE (g/day)		Mean age	
			M	F	M	F	M	F
2010	62	890	81.2	7.8	145,647.2	56,766.9	4.5	8.9
2009	62	742	65.7	8.5	124,088.4	65,020.8	4.4	9.1
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		715.3	**67.8**	**9.1**	**124,213.1**	**57,132.0**	**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, 30 March – 3 May, 1991 – 2010.

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
2010	825.0	219.0	60.6	63.1	123.7	437.0	49.0	105.8	48.9	154.7
2009	437.0	180.0	38.3	44.7	83.0	159.0	72.0	47.4	58.9	106.3
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	**462.1**	**136.7**	**27.3**	**34.6**	**61.9**	**406.0**	**56.6**	**80.3**	**39.1**	**119.1**

Table 17. Values of the spawning stock biomass index (SSBI) calculated from gill net catches of male and female striped bass in the James River, 30 March – 3 May, 1994-2010. 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**
2010	**62**	817	77	145.65	56.41	202.06
2009	**62**	657	84	124.10	65.00	189.10
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		**590.6**	**82.9**	**114.32**	**56.58**	**170.90**

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

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

Table 19. Total, age-specific, estimated total egg potential (E, in millions of eggs/day) from mature (ages 4 and older) female striped bass, by river and gear type, 30 March – 3 May, 2010. 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	0.045	0.46	1	0.024	0.33	8	0.166	1.95
5	23	0.237	2.40	1	0.033	0.46	15	0.489	5.75
6	6	0.085	0.86	6	0.286	3.97	5	0.237	2.79
7	5	0.111	1.13	2	0.099	1.38	4	0.243	2.86
8	10	0.309	3.13	2	0.195	2.71	3	0.309	3.64
9	18	0.688	6.97	9	1.001	13.91	6	0.659	7.76
10	45	2.046	20.73	1	0.152	2.11	6	0.847	9.97
11	26	1.342	13.60	3	0.460	6.39	6	0.933	10.98
12	17	0.937	9.49	4	0.674	9.37	4	0.703	8.27
13	16	0.995	10.08	4	0.706	9.81	7	1.345	15.83
14	31	2.124	21.52	10	2.053	28.53	7	1.495	17.59
15	4	0.312	3.16	1	0.240	3.33	0	0.000	0.00
16	2	0.171	1.73	1	0.248	3.45	1	0.235	2.77
17	2	0.163	1.69	2	0.517	7.18	2	0.626	7.37
18	2	0.185	1.87	1	0.321	4.46	0	0.000	0.00
n/age	2	0.116	1.18	0	0.188	2.61	1	0.210	2.47
Total	215	**9.870**	100.00	48	**7.197**	100.00	75	**8.497**	100.00

Table 20a. Catch rates (fish/day) of year classes of striped bass (sexes combined) sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2010. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)									
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1998										0.03
1997									0.79	**15.61**
1996								0.19	11.54	**18.13**
1995							0.60	2.15	**11.50**	3.34
1994					0.04	0.51	3.90	**6.33**	2.79	0.11
1993					3.04	3.97	**8.10**	1.48	0.11	0.50
1992			0.12	1.44	**4.80**	2.86	1.25	0.04	0.50	0.50
1991		0.20	0.57	0.48	1.00	**1.63**	0.05	0.52	0.43	0.40
1990	0.42	0.50	1.04	1.33	**2.24**	1.26	0.70	0.70	0.32	0.29
1989	0.33	0.60	3.58	**4.59**	0.68	0.89	0.80	0.78	0.36	0.37
1988	3.58	1.60	**9.54**	2.22	0.60	0.37	1.50	0.89	0.39	0.05
1987	**8.00**	2.75	3.65	1.15	0.68	0.37	1.00	0.89	0.43	0.05
1986	**2.67**	1.15	0.65	0.59	0.40	0.09	1.00	0.22	0.04	0.00
1985	**1.67**	0.30	0.42	0.52	0.08	0.00	0.35	0.15	0.11	0.00
1984	0.50	0.40	**0.58**	0.33	0.28	0.00	0.35	0.07	0.04	0.00
1983	0.25	0.20	**0.46**	0.33	0.08	0.03	0.20	0.00	0.00	0.00
>1983	**0.75**	0.45	0.73	0.33	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.58	0.30	0.38	0.56	0.60	0.32	0.50	0.44	0.54	0.32
Total	**18.75**	**8.45**	**21.72**	**13.87**	**14.52**	**12.30**	**20.30**	**14.85**	**29.89**	**39.70**

Table 20b. Catch rates (fish/day) of year classes of striped bass (sexes combined) sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2010. 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**	**2009**	**2010**
2008										0.23
2007									0.07	2.63
2006								0.17	1.89	**6.50**
2005							0.03	4.40	5.07	**10.43**
2004							2.52	**7.20**	6.93	4.23
2003						7.89	**8.55**	3.26	2.15	1.53
2002					1.83	**6.40**	6.17	0.51	1.22	1.03
2001				3.47	**5.43**	3.17	1.14	0.60	1.22	1.27
2000			0.76	**5.57**	2.77	0.14	1.12	0.57	1.19	1.77
1999	0.07	0.51	3.00	**5.90**	0.71	0.51	1.51	0.29	1.19	1.10
1998	2.74	1.44	3.33	**3.50**	0.77	0.91	1.89	0.43	0.67	0.70
1997	7.49	1.38	0.37	2.23	1.69	0.86	2.68	0.43	0.37	0.53
1996	4.29	0.25	1.83	4.16	1.69	1.17	3.80	0.46	0.70	1.13
1995	0.10	0.68	1.40	2.33	0.94	0.23	0.71	0.00	0.00	0.13
1994	0.58	0.41	1.70	1.67	0.69	0.20	0.71	0.00	0.19	0.07
1993	0.87	0.28	1.43	1.00	0.57	0.20	0.46	0.00	0.00	0.07
1992	0.87	0.19	1.13	1.10	0.29	0.11	0.20	0.00	0.03	0.07
1991	0.81	0.06	0.33	0.17	0.09	0.00	0.00	0.00	0.00	0.00
1990	0.45	0.00	0.27	0.07	0.03	0.00	0.03	0.00	0.00	0.00
1989	0.26	0.00	0.07	0.07	0.03	0.00	0.00	0.00	0.00	0.00
1988	0.10	0.00	0.00	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	0.00	0.00
N/A	0.00	0.00	0.00	0.40	0.49	0.26	0.00	0.00	0.07	1.47
Total	**18.63**	**5.23**	**15.65**	**31.64**	**18.05**	**22.05**	**31.52**	**18.35**	**22.96**	**34.89**

Table 21a. Catch rates (fish/day) of year classes of male striped bass sampled from pound nets in the Rappahannock River, 30 March – 3 May 1991-2010. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)									
	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
1998										0.03
1997									0.79	**15.61**
1996								0.19	11.54	**18.11**
1995							0.55	2.15	**11.46**	3.21
1994					0.04	0.51	3.80	**6.19**	2.68	0.08
1993					2.88	3.83	**7.50**	1.37	0.07	0.26
1992			0.12	1.22	**4.68**	2.66	1.15	0.00	0.36	0.11
1991		0.15	0.54	0.48	0.92	**1.34**	0.05	0.30	0.21	0.05
1990	0.17	0.35	0.96	1.30	**2.00**	0.94	0.35	0.11	0.00	0.03
1989	0.17	0.40	3.46	**3.52**	0.08	0.43	0.55	0.04	0.04	0.03
1988	3.25	0.90	**7.54**	1.11	0.12	0.03	0.20	0.00	0.00	0.00
1987	**6.08**	0.65	1.23	0.22	0.00	0.09	0.00	0.00	0.00	0.00
1986	**2.58**	0.30	0.15	0.11	0.04	0.00	0.00	0.00	0.00	0.00
1985	**0.50**	0.05	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.08	**0.15**	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<1984	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.25	0.10	0.27	0.41	0.44	0.23	0.25	0.33	0.54	0.32
Total	**13.08**	**3.05**	**14.39**	**8.45**	**11.20**	**10.06**	**14.40**	**10.68**	**27.69**	**37.84**

Table 21b. Catch rates (fish/day) of year classes of male striped bass sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2010. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)									
	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
2008										0.13
2007									0.07	**2.53**
2006								0.11	1.78	**6.30**
2005							0.03	4.34	4.48	**9.63**
2004							2.49	**7.03**	5.48	4.03
2003						7.77	**8.46**	3.00	1.70	1.37
2002					1.83	**6.29**	5.83	0.46	1.00	0.70
2001				3.47	**5.40**	2.91	0.97	0.49	0.81	0.67
2000			0.76	**5.47**	2.49	0.09	1.03	0.37	0.48	0.27
1999	0.07	0.44	2.93	**5.67**	0.66	0.20	1.00	0.14	0.19	0.23
1998	2.74	1.38	3.07	**3.37**	0.51	0.57	0.89	0.03	0.07	0.13
1997	7.42	1.25	0.30	1.93	1.00	0.29	0.37	0.06	0.04	0.00
1996	4.03	0.25	1.50	2.23	0.43	0.03	0.29	0.03	0.70	0.10
1995	0.10	0.16	0.56	0.53	0.09	0.00	0.00	0.00	0.00	0.00
1994	0.39	0.03	0.23	0.20	0.09	0.06	0.00	0.00	0.00	0.00
1993	0.16	0.03	0.07	0.10	0.00	0.00	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	0.00	0.00
1991	0.13	0.00	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	0.00	0.00
N/A	0.00	0.00	0.00	0.40	0.46	0.29	0.00	0.00	0.07	1.40
Total	**15.23**	**3.54**	**9.42**	**23.44**	**12.96**	**18.50**	**21.36**	**16.09**	**16.87**	**27.50**

Table 22a. Catch rates (fish/day) of year classes of female striped bass sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2010. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)									
	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
1997										
1996										0.03
1995							0.05	0.00	0.04	0.13
1994							0.10	0.15	0.11	0.03
1993					0.16	0.14	0.60	0.11	0.04	0.24
1992				0.22	0.12	0.20	0.10	0.04	0.14	0.40
1991		0.05	0.04	0.00	0.08	0.29	0.00	0.22	0.21	0.34
1990	0.25	0.15	0.08	0.04	0.24	0.31	0.35	**0.59**	0.32	0.26
1989	0.17	0.20	0.12	**1.07**	0.60	0.46	0.25	0.74	0.32	0.34
1988	0.33	0.70	**2.00**	1.11	0.48	0.34	1.30	0.89	0.39	0.05
1987	1.92	2.10	**2.42**	0.93	0.68	0.29	1.00	0.89	0.43	0.05
1986	**1.08**	0.85	0.50	0.48	0.36	0.09	1.00	0.22	0.04	0.00
1985	**1.17**	0.25	0.39	0.48	0.08	0.00	0.35	0.15	0.11	0.00
1984	0.42	0.25	**0.50**	0.33	0.28	0.00	0.35	0.07	0.04	0.00
1983	0.25	0.20	**0.46**	0.33	0.08	0.03	0.20	0.00	0.00	0.00
>1983	0.58	0.45	**0.73**	0.26	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.25	0.20	0.12	0.15	0.16	0.09	0.25	0.11	0.00	0.00
Total	**6.42**	**5.40**	**7.36**	**5.40**	**3.32**	**2.24**	**5.90**	**4.18**	**2.19**	**1.87**

Table 22b. Catch rates (fish/day) of year classes of female striped bass sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2010. 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**	**2009**	**2010**
2008										0.10
2007										0.10
2006								0.06	0.11	**0.20**
2005							0.00	0.06	0.59	**0.80**
2004							0.03	0.17	**1.44**	0.20
2003						0.11	0.09	0.26	**0.44**	0.17
2002						0.11	**0.34**	0.06	0.22	0.33
2001					0.03	0.26	0.17	0.11	**0.41**	**0.60**
2000				0.10	0.29	0.06	0.09	0.20	0.70	**1.50**
1999		0.06	0.07	0.23	0.06	0.31	0.51	0.14	**1.00**	0.87
1998		0.06	0.27	0.17	0.26	0.34	**1.00**	0.40	0.59	0.57
1997	0.07	0.13	0.07	0.30	0.69	0.57	**2.31**	0.37	0.33	0.53
1996	0.26	0.00	0.37	1.93	1.26	1.14	**3.51**	0.43	0.70	1.03
1995	0.00	0.63	0.80	**1.80**	0.86	0.23	0.71	0.00	0.00	0.13
1994	0.19	0.38	**1.47**	**1.47**	0.60	0.14	0.71	0.00	0.19	0.07
1993	0.71	0.25	**1.37**	0.90	0.54	0.20	0.46	0.00	0.00	0.07
1992	0.68	0.19	**1.13**	1.03	0.29	0.11	0.20	0.00	0.04	0.07
1991	**0.68**	0.06	0.33	0.17	0.09	0.00	0.00	0.00	0.00	0.00
1990	0.45	0.00	0.26	0.07	0.03	0.00	0.03	0.00	0.00	0.00
1989	0.26	0.00	0.07	0.07	0.03	0.00	0.00	0.00	0.00	0.00
1988	0.10	0.00	0.00	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	0.00	0.00
N/A	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.07
Total	**3.40**	**1.79**	**6.24**	**8.24**	**5.09**	**3.58**	**10.16**	**2.26**	**6.67**	**7.40**

Table 23a. Estimated annual and geometric mean survival (S) rates for year classes of striped bass (sexes combined) sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2010.

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, 30 March – 3 May, 1991-2010.

Year	Survival (S)									
Class	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	Mean
2004	-----	------	-----	-----	-----	-----	-----	0.963	0.610	0.766
2003						-----	0.381	0.660	0.712	0.564
2002	-----	-----	-----	-----	-----	0.964	0.445	0.445	0.844	0.634
2001	-----	-----	-----	-----	0.584	0.796	0.796	0.796	0.796	0.748
2000	-----	-----	-----	0.497	0.914	0.914	0.914	0.914	0.914	0.826
1999	-----	-----	-----	0.635	0.635	0.635	0.888	0.888	0.924	0.756
1998	-----	-----	-----	0.814	0.814	0.814	0.718	0.718	0.718	0.764
1997	0.843	0.843	0.843	0.843	0.843	0.843	0.583	0.583	0.583	0.713
1996	0.990	0.990	0.990	0.970	0.970	0.970	0.668	0.668	0.668	0.758
1995	0.914	0.914	0.914	0.403	0.869	0.869	0.568	0.568	0.568	0.665
1994	0.884	0.884	0.982	0.752	0.752	0.752	0.517	0.517	0.368	0.687
1993	0.993	0.993	0.699	0.570	0.898	0.898	0.534	0.534	0.534	0.694
1992	0.983	0.983	0.973	0.264	0.830	0.830	0.705	0.705	0.705	0.740
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	-----	-----	-----	-----	-----	-----	-----	-----	-----	0.610

Table 24a. Estimated annual and geometric mean survival (S) rates for year classes of male striped bass sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2010.

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, 30 March – 3 May, 1991-2010.

Year	Survival (S)									
Class	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	Mean
2004	-----	-----	-----	-----	-----	-----	-----	0.780	0.735	0.757
2003	-----	-----	-----	-----	-----	-----	0.355	0.567	0.806	0.545
2002	-----	-----	-----	-----	-----	0.927	0.414	0.414	0.700	0.577
2001	-----	-----	-----	-----	0.539	0.333	0.914	0.914	0.827	0.659
2000	-----	-----	-----	0.455	0.643	0.643	0.683	0.683	0.563	0.606
1999	-----	-----	-----	0.561	0.561	0.561	0.613	0.613	0.613	0.586
1998	-----	-----	-----	0.642	0.642	0.642	0.527	0.527	0.527	0.582
1997	0.638	0.638	0.638	0.518	0.608	0.608	0.162	0.667	0.000	0.477
1996	0.821	0.821	0.821	0.793	0.793	0.793	0.793	0.793	0.143	0.597
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, 30 March – 3 May, 1991-2010.

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, 30 March – 3 May, 1991-2010.

Year	Survival (S)									
Class	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	Mean
2002	-----	-----	-----	-----	-----	-----	-----	0.804	0.804	0.804
2001	-----	-----	-----	-----	-----	-----	-----	-----		
2000	-----	-----	-----	-----	-----	-----	-----	-----		
1999	-----	-----	-----	-----	-----	-----	-----	-----	0.870	0.870
1998	-----	-----	-----	-----	-----	-----	0.768	0.768	0.966	0.829
1997	-----	-----	-----	-----	-----	-----	0.612	0.612	0.612	0.612
1996	-----	-----	-----	-----	-----	-----	0.665	0.665	0.665	0.665
1995	-----	-----	-----	0.478	0.909	0.909	0.568	0.568	0.568	0.646
1994	-----	-----	0.834	0.834	0.834	0.834	0.517	0.517	0.368	0.647
1993	-----	-----	0.657	0.600	0.906	0.906	0.534	0.534	0.534	0.650
1992	-----	-----	0.912	0.282	0.830	0.830	0.705	0.705	0.705	0.672
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, 30 March – 3 May, 1991-2010. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)									
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
2000										
1999										
1998										1.47
1997									11.70	18.11
1996								0.11	**35.80**	21.26
1995							0.83	**11.67**	10.60	5.79
1994						1.90	29.50	**32.78**	3.20	1.79
1993					4.50	20.00	**83.00**	7.00	0.80	2.00
1992				2.78	7.00	11.40	**14.33**	0.78	1.20	0.63
1991			0.50	2.56	1.88	**5.70**	2.83	1.33	0.50	0.32
1990	0.12	0.56	1.50	**8.22**	7.75	3.50	2.17	0.33	0.10	0.21
1989	1.41	0.78	8.60	**27.56**	4.50	2.50	0.67	0.33	0.20	0.11
1988	9.53	1.89	**25.40**	8.22	2.88	1.50	1.17	0.33	0.20	0.11
1987	**23.65**	5.89	10.40	2.11	1.75	1.60	0.50	0.11	0.10	0.00
1986	**11.18**	3.33	1.60	0.44	1.38	0.30	0.00	0.22	0.00	0.00
1985	**4.12**	1.22	0.40	1.67	0.75	0.20	0.00	0.00	0.20	0.00
1984	**1.64**	0.78	0.40	0.67	0.25	0.00	0.00	0.00	0.00	0.00
1983	0.35	0.11	**1.30**	0.56	0.13	0.00	0.00	0.00	0.00	0.00
>1983	0.47	0.44	0.60	0.22	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.82	0.00	1.10	2.33	1.00	1.20	2.50	2.00	2.50	0.11
Total	**53.29**	**15.00**	**51.80**	**57.34**	**33.77**	**49.80**	**137.50**	**57.00**	**67.10**	**51.91**

Table 26b. Catch rates (fish/day) of year classes of striped bass (sexes combined) sampled from gill nets in the Rappahannock River, 30 March – 3 May, 1991-2010. 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	2009	2010
2008										**0.50**
2007										**4.90**
2006									1.60	**6.90**
2005							1.22	2.40	3.40	**13.30**
2004						0.40	**20.67**	6.00	3.70	10.50
2003					0.40	9.20	**31.11**	6.40	3.80	4.30
2002				4.10	4.00	**8.20**	7.89	2.30	1.80	2.00
2001			2.70	**21.78**	11.80	4.90	6.11	2.20	3.10	1.20
2000		0.50	8.80	**16.22**	6.60	2.80	4.00	1.40	1.60	0.70
1999	0.90	1.10	**16.00**	10.74	2.40	1.10	2.55	0.90	1.10	0.80
1998	9.50	8.80	**12.60**	10.00	1.90	1.90	2.55	1.60	1.40	0.40
1997	**27.00**	10.20	4.60	10.32	1.40	1.60	2.00	1.40	0.20	0.40
1996	17.70	4.60	4.20	7.58	1.30	1.80	2.33	1.10	0.80	1.00
1995	2.10	3.50	1.60	2.74	0.20	0.40	0.22	0.40	0.20	0.10
1994	1.50	1.20	1.30	1.68	0.30	0.80	0.56	0.00	0.20	0.10
1993	1.00	1.00	0.50	0.64	0.10	0.20	0.67	0.00	0.20	0.20
1992	1.10	0.30	0.00	0.42	0.10	0.00	0.56	0.00	0.00	0.20
1991	0.90	0.30	0.00	0.00	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	0.00	0.00
1989	0.10	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00
1988	0.00	0.00	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	0.00	0.00
1985	0.20	0.00	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	0.20	0.00	1.10
Total	**62.40**	**32.30**	**52.50**	**87.06**	**30.90**	**33.50**	**82.55**	**26.30**	**23.10**	**48.80**

Table 27a. Catch rates (fish/day) of year classes of male striped bass sampled from gill nets in the Rappahannock River, 30 March – 3 May, 1991-2010. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)									
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
2000										
1999										
1998										1.47
1997									11.60	18.11
1996								0.11	**35.70**	20.95
1995							0.83	**11.67**	10.60	5.68
1994						1.90	29.50	**32.56**	2.60	1.26
1993					4.50	20.00	**82.67**	6.44	0.60	1.37
1992				2.78	6.88	11.30	**14.00**	0.56	0.90	0.11
1991			0.50	2.56	1.75	**5.60**	2.50	0.67	0.30	0.00
1990	0.12	0.44	1.50	**8.22**	7.00	3.20	1.83	0.22	0.00	0.00
1989	1.29	0.78	8.30	**25.33**	2.63	1.40	0.50	0.00	0.00	0.00
1988	9.41	1.33	**20.30**	4.89	1.13	0.50	0.17	0.00	0.10	0.00
1987	**22.82**	2.78	4.20	0.33	0.13	0.10	0.00	0.00	0.10	0.00
1986	**10.23**	1.22	0.90	0.11	0.00	0.00	0.00	0.00	0.00	0.00
1985	**2.35**	0.11	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00
1984	**0.71**	0.11	0.10	0.11	0.00	0.00	0.00	0.00	0.00	0.00
<1984	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.82	0.00	0.80	1.56	0.88	1.20	2.50	1.78	2.30	0.11
Total	**47.75**	**6.77**	**36.70**	**46.22**	**24.90**	**45.20**	**134.50**	**54.00**	**64.80**	**49.06**

Table 27b. Catch rates (fish/day) of year classes of male striped bass sampled from gill nets in the Rappahannock River, 30 March – 3 May, 1991-2010. 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	2009	2010
2008										**0.50**
2007										4.90
2006									1.60	**6.80**
2005							1.22	2.40	3.20	**13.20**
2004						0.40	**20.67**	6.00	3.40	9.90
2003					0.40	9.20	**31.00**	6.20	3.10	4.10
2002				4.10	4.00	**7.90**	7.11	2.20	1.60	1.80
2001			2.70	**21.78**	11.80	4.60	5.78	2.20	2.10	0.30
2000		0.50	8.80	**16.00**	6.50	2.30	4.00	1.20	0.50	0.10
1999	0.90	1.10	15.90	**10.52**	2.40	1.00	2.11	0.40	0.30	0.50
1998	9.40	8.70	**12.10**	9.68	1.70	0.80	2.11	0.40	0.10	0.00
1997	**27.00**	8.80	4.30	9.68	1.30	0.70	0.89	0.30	0.00	0.00
1996	17.00	3.30	3.80	5.68	0.70	0.60	0.33	0.10	0.00	0.00
1995	1.90	1.40	1.20	0.64	0.10	0.10	0.00	0.00	0.00	0.00
1994	1.30	0.20	0.40	0.32	0.10	0.10	0.00	0.00	0.00	0.00
1993	0.40	0.20	0.00	0.00	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	0.00	0.10
1991	0.00	0.00	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	0.00	0.00
N/A	0.20	0.80	0.10	0.84	0.40	0.20	0.00	0.10	0.00	1.00
Total	**58.10**	**25.00**	**49.30**	**79.24**	**29.40**	**27.90**	**75.22**	**21.50**	**15.90**	**38.80**

Table 28a. Catch rates (fish/day) of year classes of female striped bass sampled from gill nets in the Rappahannock River, 30 March – 3 May, 1991-2010. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	**CPUE (fish/day)**									
	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
2000										
1999										
1998										
1997									0.10	0.00
1996									0.10	0.32
1995									0.00	0.11
1994								0.22	0.60	0.53
1993							0.33	0.56	0.20	0.63
1992					0.25	0.10	0.33	0.22	0.30	0.53
1991					0.13	0.10	0.33	0.67	0.20	0.32
1990		0.11	0.00	0.00	**0.75**	0.30	0.33	0.11	0.10	0.21
1989	0.12	0.00	0.30	**2.22**	1.88	1.10	0.17	0.33	0.20	0.11
1988	0.12	0.56	**5.10**	3.33	1.75	1.00	1.00	0.33	0.10	0.11
1987	0.82	3.11	**6.20**	1.78	1.63	1.50	0.50	0.11	0.00	0.00
1986	0.94	**2.11**	1.70	0.33	1.38	0.30	0.00	0.22	0.00	0.00
1985	**1.76**	1.11	0.40	1.33	0.75	0.20	0.00	0.00	0.20	0.00
1984	**0.94**	0.67	0.30	0.56	0.25	0.00	0.00	0.00	0.00	0.00
1983	0.35	0.11	**1.30**	0.56	0.13	0.00	0.00	0.00	0.00	0.00
>1983	0.47	0.44	**0.50**	0.22	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.00	0.00	0.30	0.78	0.13	0.00	0.00	0.22	0.20	0.00
Total	**5.52**	**8.22**	**16.10**	**11.11**	**9.03**	**4.60**	**3.00**	**3.00**	**2.30**	**2.87**

Table 28b. Catch rates (fish/day) of year classes of female striped bass sampled from gill nets in the Rappahannock River, 30 March – 3 May, 1991-2010. 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	2009	2010
2006										0.10
2005									**0.20**	0.10
2004									0.30	**0.60**
2003							0.11	0.20	**0.70**	0.20
2002						0.30	**0.78**	0.10	0.20	0.20
2001						0.30	0.33	0.00	**1.00**	0.90
2000				0.22	0.10	0.50	0.00	0.20	**1.10**	0.10
1999			0.10	0.22	0.00	0.10	0.44	0.50	**0.80**	0.30
1998	0.10	0.10	0.50	0.32	0.20	1.10	0.44	1.20	**1.30**	0.40
1997	0.00	**1.40**	0.30	0.64	0.10	0.90	1.11	1.10	0.20	0.40
1996	0.70	1.60	0.40	1.90	0.60	1.20	**2.00**	1.00	0.80	1.00
1995	0.20	**2.10**	0.40	**2.10**	0.10	0.30	0.22	0.40	0.20	0.10
1994	0.20	1.00	0.90	**1.36**	0.20	0.70	0.56	0.00	0.20	0.10
1993	0.60	**0.80**	0.50	0.64	0.10	0.20	0.67	0.00	0.20	0.20
1992	**1.10**	0.30	0.00	0.42	0.10	0.00	0.56	0.00	0.00	0.10
1991	**0.90**	0.30	0.00	0.00	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	0.00	0.00
1989	0.10	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00
1988	0.00	0.00	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	0.00	0.00
N/A	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.10
Total	**4.10**	**8.40**	**3.20**	**7.82**	**1.50**	**5.60**	**7.33**	**4.80**	**7.20**	**4.90**

Table 29a. Estimated annual and geometric mean survival (S) rates for year classes of striped bass (sexes combined) sampled from gill nets in the Rappahannock River, 30 March – 3 May, 1991-2010.

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, 30 March – 3 May, 1991-2010.

Year	Survival (S)									
Class	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	Mean
2004	-----	-----	-----	-----	-----	-----	0.798	0.798	0.798	0.798
2003	-----	-----	-----	-----	-----	-----	0.206	0.820	0.820	0.517
2002	-----	-----	-----	-----	-----	0.962	0.292	0.933	0.933	0.703
2001	-----	-----	-----	0.542	0.720	0.720	0.712	0.712	0.387	0.617
2000	-----	-----	-----	0.407	0.407	0.407	0.632	0.632	0.438	0.477
1999	-----	-----	0.671	0.619	0.619	0.619	0.657	0.657	0.727	0.651
1998	-----	-----	0.794	0.634	0.634	0.634	0.627	0.875	0.286	0.611
1997	0.726	0.726	0.726	0.579	0.579	0.579	0.700	0.535	0.535	0.627
1996	0.754	0.754	0.754	0.675	0.675	0.675	0.472	0.953	0.953	0.722
1995	0.777	0.885	0.885	0.618	0.618	0.618	0.618	0.500	0.500	0.672
1994	0.984	0.984	0.984	0.690	0.690	0.700	0.598	0.598	0.500	0.617
1993	0.707	0.923	0.923	0.923	0.923	0.923	0.669	0.669	0.669	0.629
1992	0.894	0.894	0.894	0.894	0.894	0.894	0.710	0.710	0.710	0.720
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, 30 March – 3 May, 1991-2010.

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	0.991
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, 30 March – 3 May, 1991-2010.

Year Class	Survival (S)									
	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	Mean
2004	-----	-----	-----	-----	-----	-----	0.782	0.782	0.782	0.782
2003	-----	-----	-----	-----	-----	-----	0.300	0.813	0.813	0.583
2002	-----	-----	-----	-----	-----	0.900	0.309	0.905	0.905	0.690
2001	-----	-----	-----	0.542	0.700	0.700	0.381	0.955	0.143	0.490
2000	-----	-----	-----	0.406	0.784	0.784	0.300	0.417	0.200	0.429
1999	-----	-----	-----	0.228	0.938	0.938	0.619	0.619	0.619	0.602
1998	-----	-----	0.800	0.602	0.602	0.602	0.190	0.250	0.000	0.409
1997	0.710	0.710	0.710	0.134	0.827	0.827	0.337	0.000	-----	0.498
1996	0.694	0.694	0.694	0.123	0.857	0.550	0.303	0.000	-----	0.501
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	0.991	0.991	0.991	0.991	0.991	0.991	0.991	0.991	0.991	0.684
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, 30 March – 3 May, 1991-2010.

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, 30 March – 3 May, 1991-2010.

Year	Survival (S)									
Class	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	Mean
2003	-----	-----	-----	-----	-----	-----	-----	-----	0.286	0.506
2002	-----	-----	-----	-----	-----	-----	0.635	0.635	0.635	0.635
2001	-----	-----	-----	-----	-----	-----	-----	-----	0.900	0.900
2000	-----	-----	-----	-----	-----	-----	-----	-----	0.091	0.091
1999	-----	-----	-----	-----	-----	-----	-----	-----	0.375	0.375
1998	-----	-----	-----	-----	-----	-----	-----	-----	0.308	0.308
1997	-----	0.955	0.955	0.955	0.955	0.955	0.991	0.603	0.603	0.855
1996	-----	-----	-----	-----	-----	-----	0.794	0.794	0.794	0.794
1995	-----	-----	-----	0.378	0.378	0.733	0.661	0.500	0.500	0.509
1994	-----	-----	-----	0.717	0.717	0.800	0.598	0.598	0.500	0.647
1993	-----	0.965	0.965	0.965	0.965	0.965	0.668	0.668	0.668	0.841
1992	0.894	0.894	0.894	0.894	0.894	0.894	0.563	0.563	0.563	0.766
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, 30 March – 3 May, 1994-2010. 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, 30 March – 3 May, 1994-2010. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)						
	2004	2005	2006	2007	2008	2009	2010
2008							**0.20**
2007						0.30	**5.80**
2006					0.40	14.50	**43.90**
2005				0.11	9.80	**27.90**	20.70
2004			0.50	12.22	15.40	**15.70**	7.20
2003		0.90	**27.60**	12.44	6.80	7.10	**2.40**
2002	0.36	14.70	**37.00**	9.00	2.90	1.30	**1.30**
2001	30.54	27.50	**33.70**	4.66	1.80	1.10	1.00
2000	**48.00**	19.90	9.80	1.33	1.50	1.10	0.80
1999	28.00	7.70	3.90	1.44	0.90	1.50	0.60
1998	11.82	5.10	2.60	1.34	1.50	1.20	0.40
1997	4.08	1.60	2.90	2.00	1.30	0.80	0.80
1996	3.56	1.60	3.90	1.90	1.30	1.40	0.70
1995	1.36	0.60	1.00	0.10	0.10	0.00	0.00
1994	1.00	0.50	1.00	0.10	0.10	0.10	0.10
1993	0.28	0.30	1.10	0.40	0.20	0.20	0.20
1992	0.38	0.10	0.10	0.10	0.00	0.00	0.00
1991	0.00	0.10	0.40	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.40	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.10	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N/A	2.36	1.40	2.40	0.00	0.10	0.00	2.90
Total	**131.74**	**82.00**	**128.30**	**47.24**	**44.10**	**74.20**	**89.00**

Table 33a. Catch rates (fish/day) of year classes of male striped bass sampled from gill nets (mile 62) in the James River, 30 March – 3 May, 1994-2010. 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, 30 March – 3 May, 1994-2010. Maximum catch rate for each year class during the sampling period is in bold type.

Year Class	CPUE (fish/day)						
	2004	2005	2006	2007	2008	2009	2010
2008							**0.10**
2007						0.30	**5.70**
2006					0.30	14.40	**43.10**
2005				0.11	9.80	**27.30**	19.20
2004			0.50	12.22	**15.40**	14.30	6.70
2003		0.90	**27.60**	12.33	6.60	6.30	2.00
2002	0.36	14.70	**36.90**	8.33	2.50	1.10	1.00
2001	30.54	27.30	**32.30**	4.33	1.50	0.80	0.40
2000	**47.82**	19.60	8.70	0.89	0.70	0.60	0.20
1999	27.64	7.50	3.50	1.11	0.20	0.40	0.00
1998	10.46	4.90	2.20	0.56	0.20	0.10	0.00
1997	3.90	1.00	1.40	0.22	0.00	0.00	0.00
1996	2.28	1.20	0.60	0.10	0.10	0.10	0.00
1995	0.54	0.10	0.10	0.00	0.00	0.00	0.00
1994	1.00	0.30	0.10	0.00	0.00	0.00	0.00
1993	0.00	0.10	0.00	0.00	0.00	0.00	0.00
1992	0.10	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.10	0.00	0.00	0.00	0.00
1990	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
N/A	2.36	1.40	2.40	0.00	0.10	0.00	2.70
Total	**127.00**	**79.00**	**116.40**	**40.20**	**37.40**	**65.70**	**81.10**

Table 34a. Catch rates (fish/day) of year classes of female striped bass sampled from gill nets (mile 62) in the James River, 30 March – 3 May, 1994-2010. 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, 30 March – 3 May, 1994-2010. 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**	**2009**	**2010**
2008							**0.10**
2007							**0.10**
2006						0.10	**0.80**
2005						**0.60**	**1.50**
2004						**1.40**	0.50
2003				0.11	0.20	**0.80**	0.40
2002			0.10	**0.67**	0.40	0.20	0.30
2001		0.20	**1.40**	0.33	0.30	0.30	0.60
2000	0.18	0.30	**1.10**	0.44	0.80	0.50	0.60
1999	0.18	0.20	0.40	0.33	0.70	**1.10**	0.60
1998	0.36	0.20	0.40	0.78	1.30	1.10	0.40
1997	0.18	0.60	1.50	1.78	1.30	0.80	0.80
1996	1.28	0.40	3.30	1.70	1.20	1.30	0.70
1995	0.82	0.50	0.90	0.10	0.10	0.00	0.00
1994	1.00	0.20	0.90	0.10	0.10	0.10	0.10
1993	0.28	0.20	1.10	0.40	0.20	0.20	0.20
1992	0.28	0.10	0.10	0.10	0.00	0.00	0.00
1991	0.00	0.10	0.30	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.40	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.10	0.10	0.00	0.00	0.00
N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**4.56**	**3.00**	**12.00**	**6.94**	**6.60**	**8.50**	**7.90**

Table 35a. Estimated annual and geometric mean survival (S) rates for year classes of striped bass (sexes combined) sampled from gill nets in the James River, 30 March – 3 May, 1994-2010.

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, 30 March – 3 May, 1994-2010.

Year	Survival (S)						
Class	**04-05**	**05-06**	**06-07**	**07-08**	**08-09**	**09-10**	**Mean**
2003	-----	-----	0.451	0.755	0.755	0.338	0.543
2002	-----	-----	0.243	0.322	0.670	0.670	0.433
2001	-----	-----	0.138	0.386	0.611	0.909	0.414
2000	0.415	0.492	0.391	0.391	0.733	0.727	0.505
1999	0.275	0.506	0.727	0.727	0.727	0.400	0.568
1998	0.431	0.510	0.760	0.760	0.800	0.333	0.584
1997	0.843	0.843	0.690	0.650	0.784	0.784	0.643
1996	0.772	0.772	0.487	0.858	0.858	0.500	0.628
1995	0.857	0.857	0.316	0.316	0.000	-----	0.451
1994	0.974	0.974	0.562	0.562	0.562	0.562	0.648
1993	0.928	0.928	0.364	0.794	0.794	0.794	0.733
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, 30 March – 3 May, 1994-2010.

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, 30 March – 3 May, 1994-2010.

Year Class	Survival (S)						
	04-05	05-06	06-07	07-08	08-09	09-10	Mean
2004	-----	-----	-----	-----	0.929	0.469	0.660
2003	-----	-----	0.447	0.535	0.955	0.317	0.519
2002	-----	-----	0.226	0.300	0.440	0.909	0.406
2001	-----	-----	0.134	0.346	0.533	0.500	0.333
2000	0.410	0.444	0.102	0.787	0.857	0.333	0.401
1999	0.271	0.467	0.317	0.600	0.600	0.000	0.423
1998	0.468	0.449	0.255	0.357	0.500	0.000	0.397
1997	0.599	0.599	0.157	0.000	-----	-----	0.391
1996	0.526	0.500	0.550	0.550	0.550	0.000	0.439
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, 30 March – 3 May, 1994-2010.

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, 30 March – 3 May, 1994-2009.

Year	Survival (S)						
Class	04-05	05-06	06-07	07-08	08-09	09-10	Mean
2003	-----	-----	-----	-----	-----	0.500	0.500
2002	-----	-----	-----	0.597	0.866	0.866	0.765
2001	-----	-----	0.809	0.809	0.809	0.809	0.809
2000	-----	-----	0.852	0.852	0.866	0.866	0.859
1999	-----	-----	-----	-----	-----	0.545	0.545
1998	0.854	0.854	0.854	0.854	0.846	0.384	0.761
1997	0.860	0.860	0.860	0.730	0.784	0.784	0.823
1996	-----	-----	0.515	0.874	0.874	0.538	0.678
1995	0.945	0.945	0.333	0.333	0.000	-----	0.649
1994	0.949	0.949	0.577	0.577	0.577	0.577	0.684
1993	0.844	0.844	0.364	0.794	0.794	0.794	0.769
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 1988-2008 year classes of striped bass from pound nets in the Rappahannock River, 1991-2010.

age	year class										
	1988	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
2		0.2	0.3	0.3	0.7	1.5	0.3	0.3	0.1	0.4	0.0
3	3.6	0.8	1.3	0.8	5.5	5.5	4.2	2.5	11.6	16.0	2.7
4	5.2	4.4	2.6	1.8	8.4	13.6	10.5	14.0	29.8	23.5	4.2
5	14.7	8.9	4.9	3.4	9.6	15.1	13.3	17.3	34.1	24.9	7.5
6	16.9	9.6	6.1	3.5	9.7	15.2	13.4	17.4	34.3	25.3	11.0
7	17.5	10.5	6.8	4.0	10.2	15.7	14.0	18.1	36.1	27.5	11.8
8	17.9	11.3	7.5	4.4	10.7	16.6	14.4	19.5	40.3	29.2	12.7
9	19.4	12.1	7.8	4.8	11.5	16.8	16.1	21.8	42.0	30.1	14.6
10	20.3	12.5	8.1	5.7	11.7	18.3	17.8	22.7	43.2	32.8	15.0
11	20.7	12.8	8.6	5.9	12.9	19.3	18.4	22.9	47.0	33.2	15.7
12	20.7	13.1	8.6	7.0	14.0	19.8	18.6	23.6	47.5	33.5	16.4
13	20.8	13.1	8.9	8.1	14.3	20.0	19.3	23.6	48.2	34.0	
14	20.8	13.2	8.9	8.4	14.4	20.5	19.3	23.6	49.3		
15	20.8	13.2	9.0	8.4	14.6	20.5	19.5	23.7			
16	20.8	13.3	9.0	8.4	14.6	20.5	19.6				
17	20.8	13.3	9.0	8.4	14.6	20.6					
18	20.8	13.3	9.0	8.4	14.7						
19	20.8	13.3	9.0	8.4							
20	20.8	13.3	9.0								
area	**20.8**	**13.3**	**9.0**	**8.4**	**14.7**	**20.6**	**19.5**	**23.7**	**49.3**	**34.0**	**16.4**

Table 38b. Comparison of the area under the catch curve (fish/ day) of the 1988-2008 year classes of striped bass from pound nets in the Rappahannock River, 1991-2010.

age	year class										mean
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	
2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.2	**0.2**
3	0.6	0.8	3.5	1.8	7.9	2.6	4.4	2.0	2.7		**4.0**
4	3.6	6.3	8.9	8.2	16.5	9.8	9.5	8.5			**9.9**
5	9.5	9.1	12.1	14.3	19.8	16.7	19.9				**14.0**
6	10.2	9.2	13.3	14.8	21.9	20.9					**15.0**
7	10.7	10.3	13.9	16.0	23.5						**15.9**
8	12.2	10.9	15.1	17.0							**17.0**
9	12.5	12.1	16.4								**18.1**
10	13.7	13.9									**19.2**
11	14.8										**20.1**
12											**20.6**
13											**21.0**
14											**21.1**
15											**21.2**
16											**21.2**
17											**21.2**
18											**21.2**
19											**21.2**
20											**21.2**
area	**14.8**	**13.9**	**16.4**	**17.0**	**23.5**	**20.9**	**19.9**	**8.5**	**2.7**	**0.2**	**21.2**

Table 39a. Comparison of the area under the catch curve (fish/ day) of the 1988-2008 year classes of striped bass from gill nets in the Rappahannock River, 1991-2010.

age	year class										
	1988	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
2		0.7	0.3	0.3	1.4	2.3	1.0	0.4	0.1	5.9	0.7
3	9.5	1.5	1.8	2.8	8.4	22.3	30.5	12.1	35.9	24.0	10.2
4	11.4	10.1	10.0	4.7	19.8	105.3	63.2	22.7	57.1	51.0	19.0
5	36.8	37.7	17.8	10.4	34.1	112.3	66.4	28.5	74.8	61.2	31.6
6	45.0	42.2	21.3	13.2	34.9	113.1	68.2	30.6	79.4	65.8	41.6
7	47.9	44.7	23.4	14.6	36.1	115.1	69.7	34.1	83.6	76.1	43.5
8	49.4	45.3	23.8	15.1	36.7	116.1	70.9	35.7	91.2	77.5	45.4
9	50.6	45.7	23.9	15.4	37.8	117.1	72.2	38.4	92.5	79.1	47.9
10	50.9	45.9	24.1	16.3	38.1	117.6	73.9	38.6	94.3	81.1	49.5
11	51.1	46.0	24.2	16.6	38.1	118.2	74.2	39.0	96.6	82.5	50.9
12	51.2	46.1	24.2	16.6	38.6	118.3	75.0	39.2	97.7	82.7	51.3
13	51.2	46.1	24.3	16.6	38.7	118.5	75.6	39.6	98.5	83.1	
14	51.2	46.1	24.3	16.6	38.7	119.2	75.6	39.8	99.5		
15	51.2	46.1	24.3	16.6	39.3	119.2	75.8	39.9			
16	51.2	46.1	24.3	16.6	39.3	119.4	75.9				
17	51.2	46.1	24.3	16.6	39.3	119.6					
18	51.2	46.2	24.3	16.6	39.5						
19	51.2	46.2	24.3	16.6							
20	51.2	46.2	24.3								
area	**51.2**	**46.2**	**24.3**	**16.6**	**39.5**	**119.6**	**75.8**	**39.9**	**99.5**	**83.1**	**51.3**

Table 39b. Comparison of the area under the catch curve (fish/ day) of the 1988-2008 year classes of striped bass from gill nets in the Rappahannock River, 1991-2010.

age	year class										mean
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	
2	0.5	0.3	1.4	2.1	0.2	0.2	0.6	0.0	0.0	0.5	**0.9**
3	1.6	9.1	23.1	6.1	9.4	20.9	3.0	1.6	4.9		**13.0**
4	17.6	25.3	34.9	14.3	40.5	26.9	6.4	8.5			**29.5**
5	28.3	31.9	39.8	22.2	46.9	30.6	19.7				**40.1**
6	30.7	34.7	45.9	24.5	50.7	41.1					**43.9**
7	31.8	38.7	48.1	26.3	55.0						**46.8**
8	34.3	40.1	51.2	28.3							**48.6**
9	35.2	41.7	52.4								**49.7**
10	36.3	42.4									**50.6**
11	37.1										**51.3**
12											**51.6**
13											**51.9**
14											**52.0**
15											**52.1**
16											**52.2**
17											**52.2**
18											**52.2**
19											**52.2**
20											**52.2**
area	**37.1**	**42.4**	**52.4**	**28.3**	**55.0**	**41.1**	**19.7**	**8.5**	**4.9**	**0.5**	**52.2**

Table 40a. Comparison of the area under the catch curve (fish/ day) of the 1988-2008 year classes of striped bass from gill nets in the James River, 1994-2010.

age	year class										
	1988	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
2					0.0	0.3	0.1	0.0	0.0	0.1	0.8
3				2.4	4.3	2.0	1.6	1.2	9.1	21.7	14.3
4			12.4	11.4	7.2	6.5	8.7	11.5	82.4	64.1	44.0
5		12.0	23.5	15.9	10.6	11.7	20.4	49.8	115.0	103.4	72.8
6	3.2	21.8	26.6	17.9	13.6	17.8	31.5	58.2	126.0	111.4	84.6
7	5.9	24.4	28.6	19.6	16.5	19.9	34.1	60.8	128.8	115.5	89.7
8	6.9	25.3	29.4	21.8	17.8	21.5	35.2	62.4	132.4	117.1	92.3
9	8.3	26.4	30.8	22.4	18.8	22.4	35.7	63.7	134.0	120.0	93.7
10	9.1	27.6	31.2	23.9	19.7	23.2	36.7	64.3	137.9	122.0	95.2
11	9.5	27.7	31.7	24.1	20.0	23.5	37.2	65.3	139.8	123.3	96.4
12	9.6	27.7	31.8	24.3	20.4	23.8	38.2	65.4	141.1	124.1	96.8
13	9.6	27.7	32.0	24.3	20.5	24.9	38.3	65.5	142.5	124.9	
14	9.6	27.8	32.0	24.4	20.6	25.3	38.4	65.5	143.2		
15	9.6	27.8	32.0	24.8	20.7	25.5	38.5	65.5			
16	9.6	27.8	32.4	24.8	20.7	25.7	38.6				
17	9.6	27.9	32.4	24.8	20.7	25.9					
18	9.6	28.0	32.4	24.8	20.7						
19	9.6	28.0	32.4	24.8							
20	9.6	28.2	32.4								
area	**9.6**	**28.0**	**32.4**	**24.8**	**20.7**	**25.9**	**38.6**	**65.5**	**143.2**	**124.9**	**96.8**

Table 40b. Comparison of the area under the catch curve (fish/ day) of the 1988-2008 year classes of striped bass from gill nets in the James River, 1991-2010.

age	year class										mean
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	
2	0.2	0.2	0.4	0.2	0.5	0.5	0.1	0.2	0.3	0.2	**0.2**
3	4.0	15.7	31.0	14.9	28.1	12.7	9.9	14.7	6.1		**11.9**
4	35.3	63.7	58.5	51.9	40.5	28.1	37.8	58.6			**38.3**
5	63.3	83.6	92.2	60.9	47.3	43.8	58.5				**57.5**
6	71.0	93.4	96.8	63.7	54.4	51.2					**64.4**
7	74.9	94.7	98.6	65.0	56.8						**67.0**
8	76.3	96.2	99.7	66.3							**68.6**
9	77.2	97.3	100.7								**69.8**
10	78.7	98.1									**71.1**
11	79.3										**71.8**
12											**72.2**
13											**72.6**
14											**72.8**
15											**72.9**
16											**73.0**
17											**73.1**
18											**73.1**
19											**73.1**
20											**73.1**
area	**79.3**	**98.1**	**100.7**	**66.3**	**56.8**	**51.2**	**58.5**	**58.6**	**6.1**	**0.2**	**73.1**

Table 41a. Back-calculated length-at-age (FL, in mm) for striped bass sampled from the James and Rappahannock rivers during spring, 2010.

Year Class	n	length-at-age (FL, in mm)							
		1	2	3	4	5	6	7	8
2008	9	160.5							
2007	13	160.3	279.3						
2006	13	161.2	284.1	386.1					
2005	18	150.1	261.2	369.0	454.4				
2004	20	143.5	248.6	357.7	455.1	536.5			
2003	8	130.7	227.2	323.1	416.1	502.2	580.9		
2002	16	146.6	249.3	343.8	431.5	516.7	593.5	657.6	
2001	15	145.7	246.4	344.2	438.5	520.6	599.8	671.0	728.4
2000	11	140.7	240.9	335.7	426.1	505.6	578.2	644.7	709.9
1999	3	135.9	239.7	337.1	430.8	517.4	592.3	657.5	725.8
1998	17	142.8	236.7	335.5	423.4	507.7	586.1	656.7	723.3
1997	21	135.6	236.0	324.8	414.9	497.1	569.2	632.2	691.8
1996	17	136.9	238.6	333.3	425.5	515.9	593.7	662.4	722.6
1995	2	141.0	233.4	323.3	427.9	514.0	584.1	660.1	723.1
1994	4	132.2	226.5	317.9	400.6	481.3	562.3	636.1	702.4
1993	1	138.9	229.4	315.8	381.4	450.1	539.2	593.3	658.9
1992	1	127.1	229.6	324.4	408.7	488.0	561.8	634.1	696.6
1991	1	150.9	247.5	350.4	451.6	534.7	601.0	686.8	745.7
all	190	145.0	249.3	345.7	433.0	512.0	584.8	651.4	711.3

Table 41b. Back-calculated length-at-age (FL, in mm) for striped bass sampled from the James and Rappahannock rivers during spring, 2010.

Year Class	n	length-at-age (FL, in mm)									
		9	10	11	12	13	14	15	16	17	18
2008	9										
2007	13										
2006	13										
2005	18										
2004	20										
2003	8										
2002	16										
2001	15										
2000	11	768.									
1999	3	781.1	824.7								
1998	17	782.5	834.5	874.6							
1997	21	745.3	793.6	839.5	880.1						
1996	17	776.1	826.0	869.7	911.5	946.9					
1995	2	771.0	822.9	870.8	922.1	965.8	999.7				
1994	4	759.2	810.6	859.8	905.5	950.1	992.8	1026.			
1993	1	715.9	771.0	825.1	865.8	903.2	945.9	986.7	1023.		
1992	1	756.8	807.1	854.4	897.6	936.1	978.7	1012.	1053.	1079.	
1991	1	797.5	848.8	890.6	921.5	952.6	992.8	1021.	1057.	1083.	1106.
all	190	767.4	815.4	859.3	898.7	927.9	977.9	1020.	1049.	1072.	1106.

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 bolded 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**	**27**
1	**0**																					
2		**10**	0																			
3		7	**6**	0																		
4			6	**6**	1	1																
5				7	**8**	2	1															
6				1	3	**9**	7	0														
7					1	0	**5**	2	0													
8						0	5	**2**	8	0		1										
9							3	2	**6**	3	1	0	0									
10							1	0	6	**3**	0	0	0	1								
11									0	0	**0**	2	1	0	0							
12										2	1	**5**	0	8	1	0						
13											0	3	**0**	13	1	1	3					
14												0	1	**13**	2	2	0					
15													0	1	**0**	1	0	0				
16														1	1	**1**	0	1	0			
17																0	**0**	1	0	0		
18																	0	**0**	0	0	1	
19																		0	**0**	0	0	1
20																			0	**0**	0	0
21																				0	**0**	0
27																					0	**0**

Note: ages 22-27 omitted for space.

Table 43. Relative contributions of striped bass age classes as determined by ageing specimens (n = 193) by reading both their scales and otoliths.

Age	scale		Otolith	
	n	prop	n	Prop
1	0	0.0000	0	0.0000
2	9	0.0466	16	0.0829
3	13	0.0674	12	0.0622
4	14	0.0725	14	0.0725
5	18	0.0933	13	0.0674
6	20	0.1036	12	0.0622
7	8	0.0415	22	0.1140
8	16	0.0829	6	0.0155
9	15	0.0777	20	0.1036
10	11	0.0570	8	0.0415
11	3	0.0155	2	0.0104
12	17	0.0881	11	0.0570
13	21	0.1088	2	0.0104
14	18	0.0933	37	0.1917
15	2	0.0104	5	0.0259
16	4	0.0207	5	0.0259
17	1	0.0052	3	0.0155
18	1	0.0052	2	0.0104
19	1	0.0052	0	0.0000
20	0	0.0000	0	0.0000
21	0	0.0000	1	0.0052
27	0	0.0000	1	0.0052
	Age = 8.66		Age = 8.91	

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, springs 1991-2010.

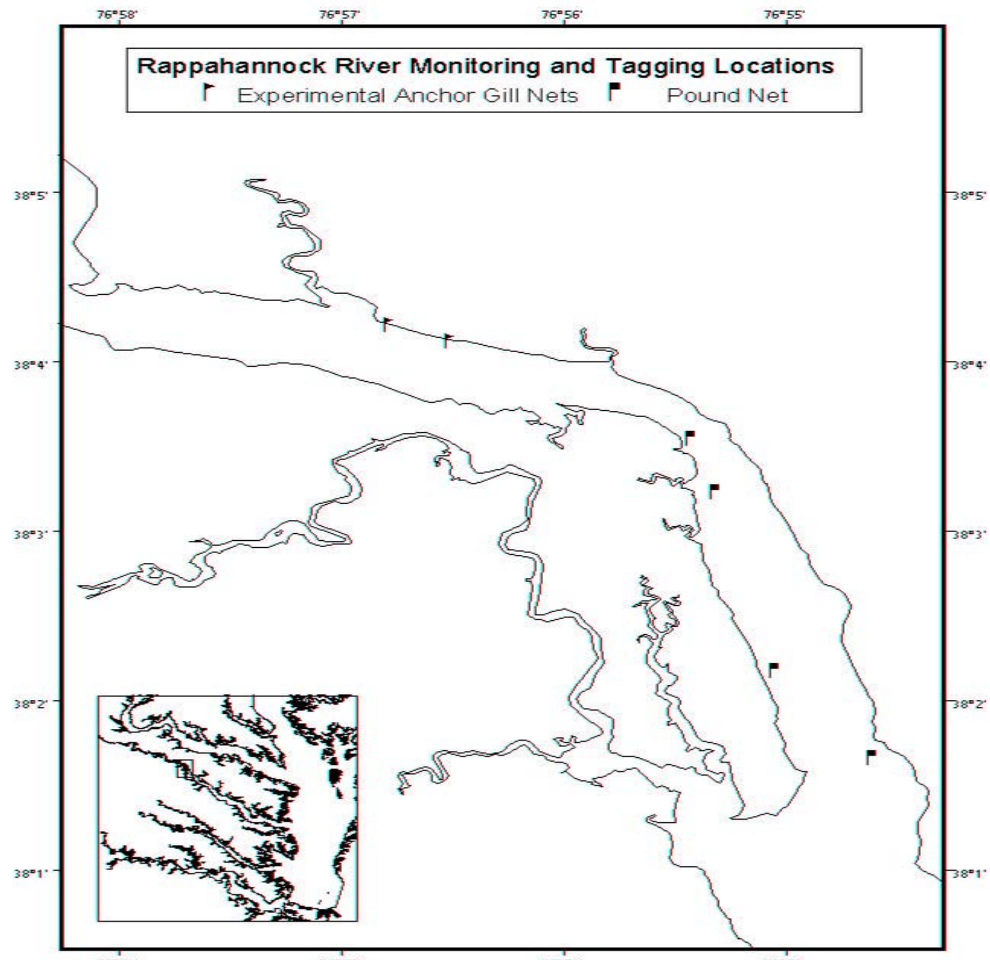


Figure 2. Locations of the experimental anchor gill nets sampled in spring spawning stock assessments of striped bass in the James River, springs 2003-2010.

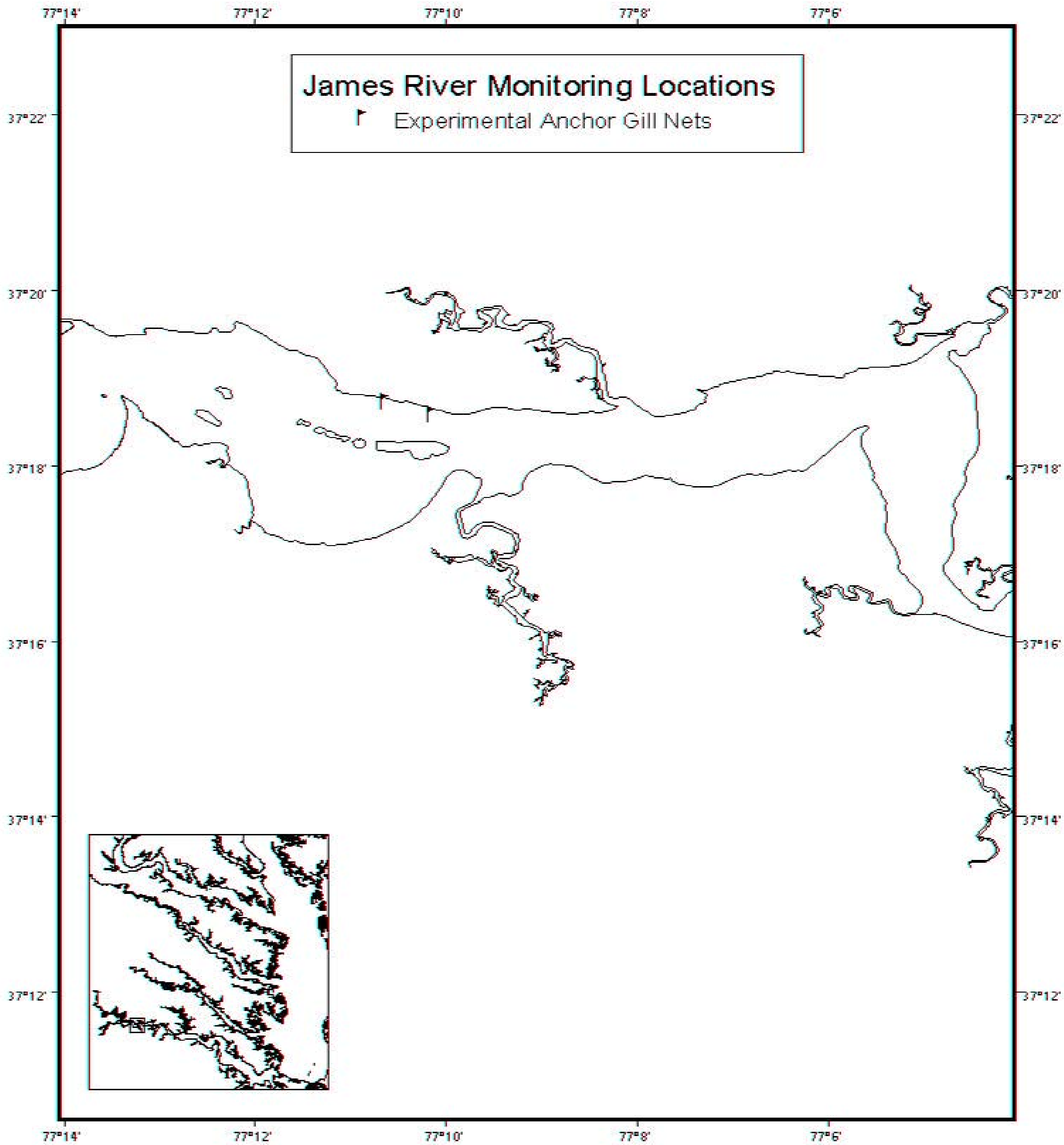


Figure 3. Daily and historic mean river flows (cf/s) for the Rappahannock River during the 30 March – 3May spawning stock assessment period, spring 2010.

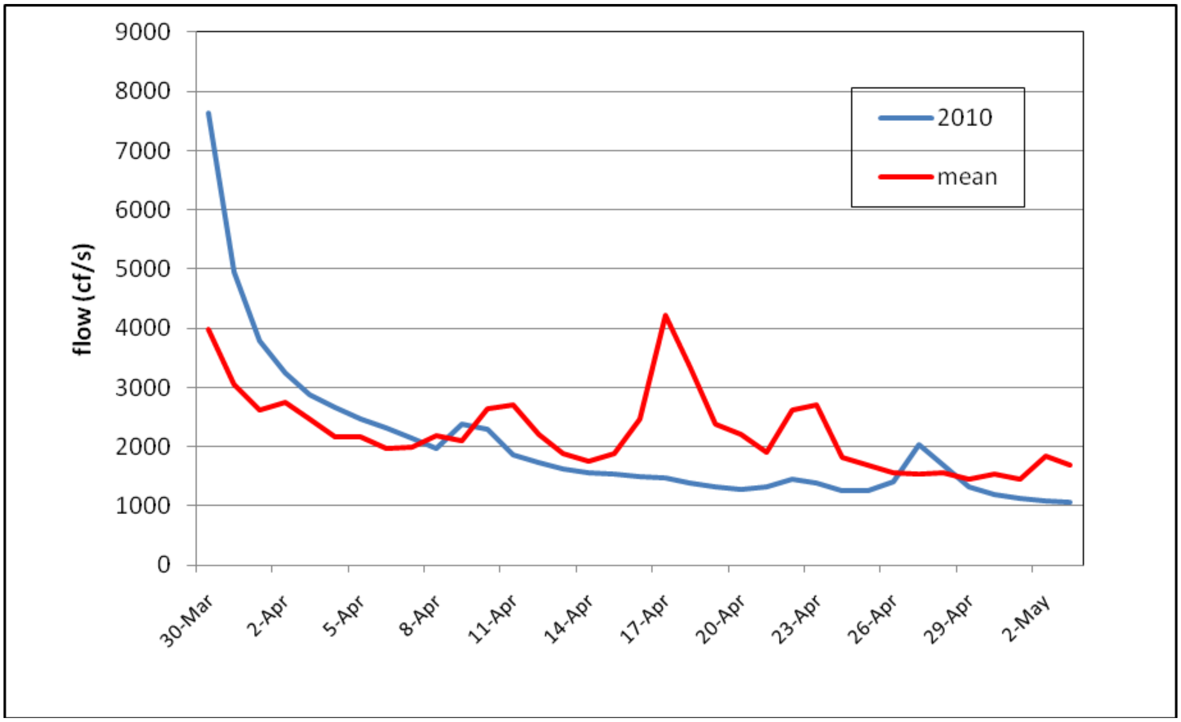


Figure 4. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1987 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1991-2010.

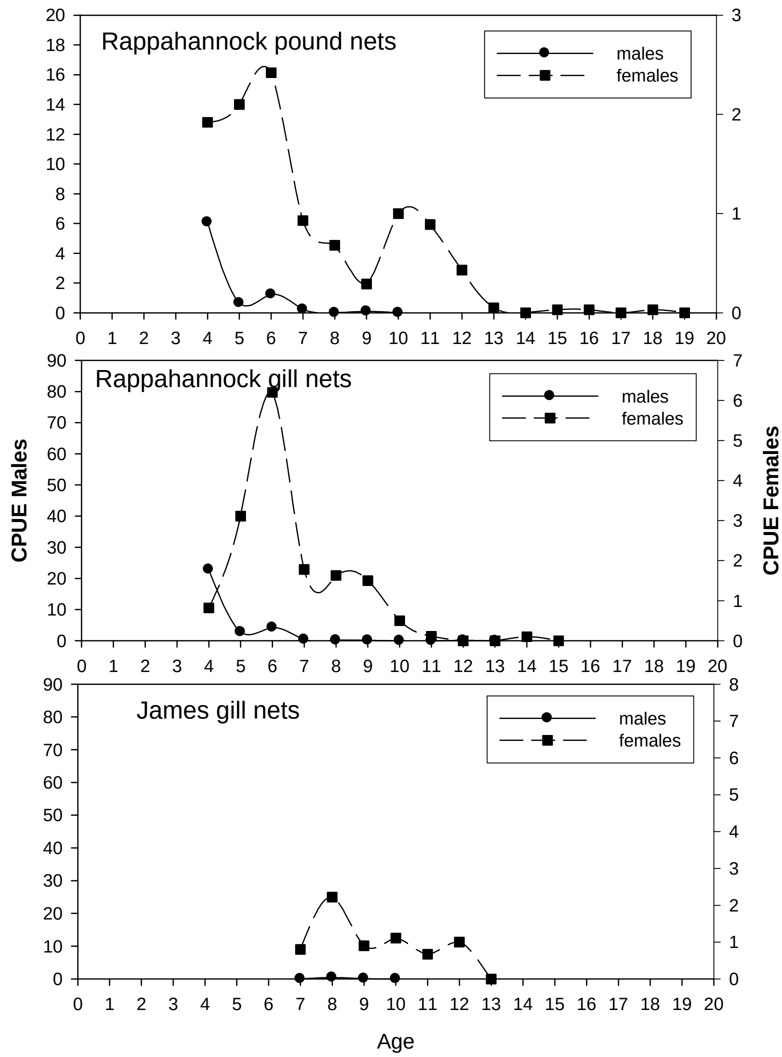


Figure 5. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1988 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1991-2010.

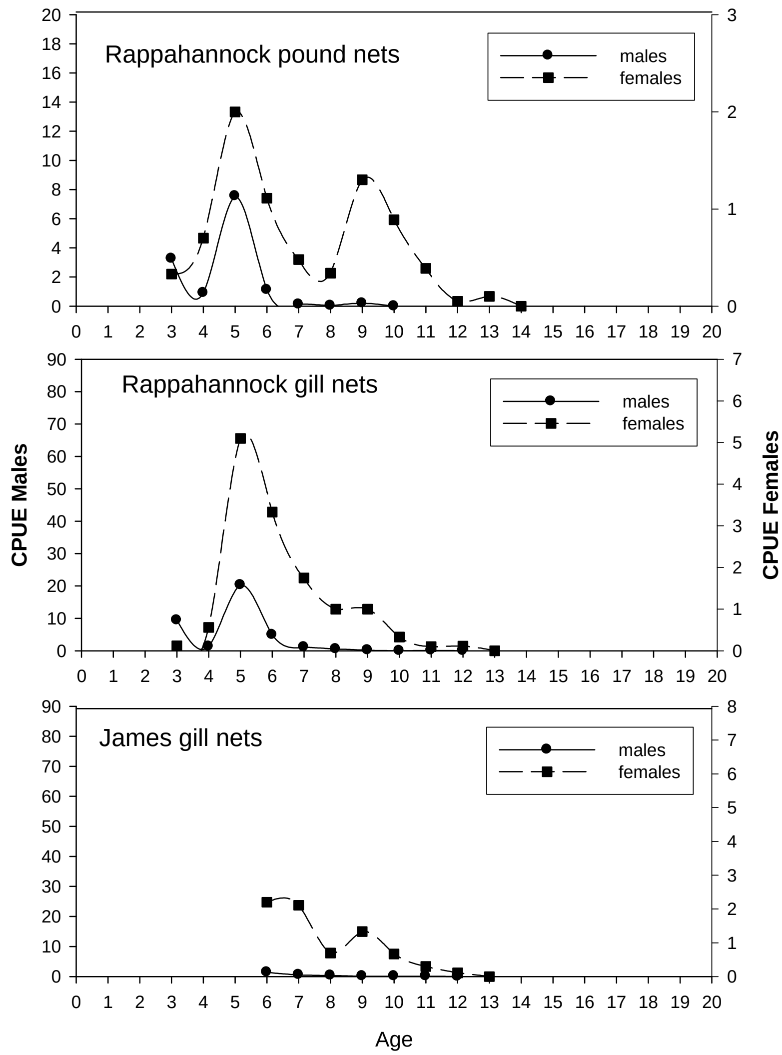


Figure 6. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1989 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1991-2010.

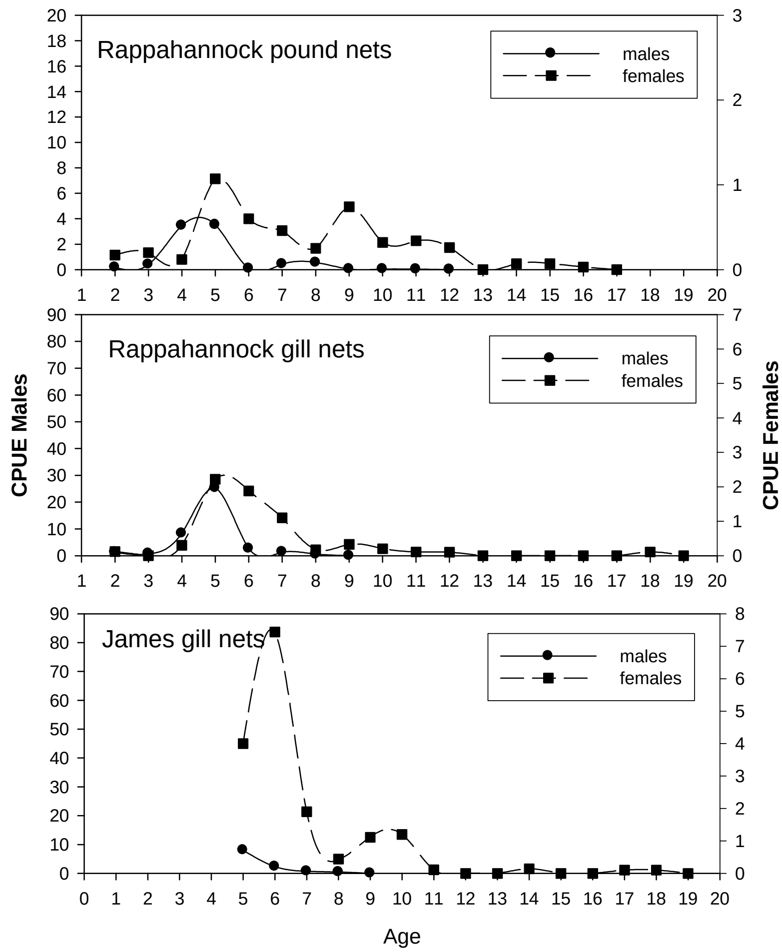


Figure 7. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1990 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1991-2010.

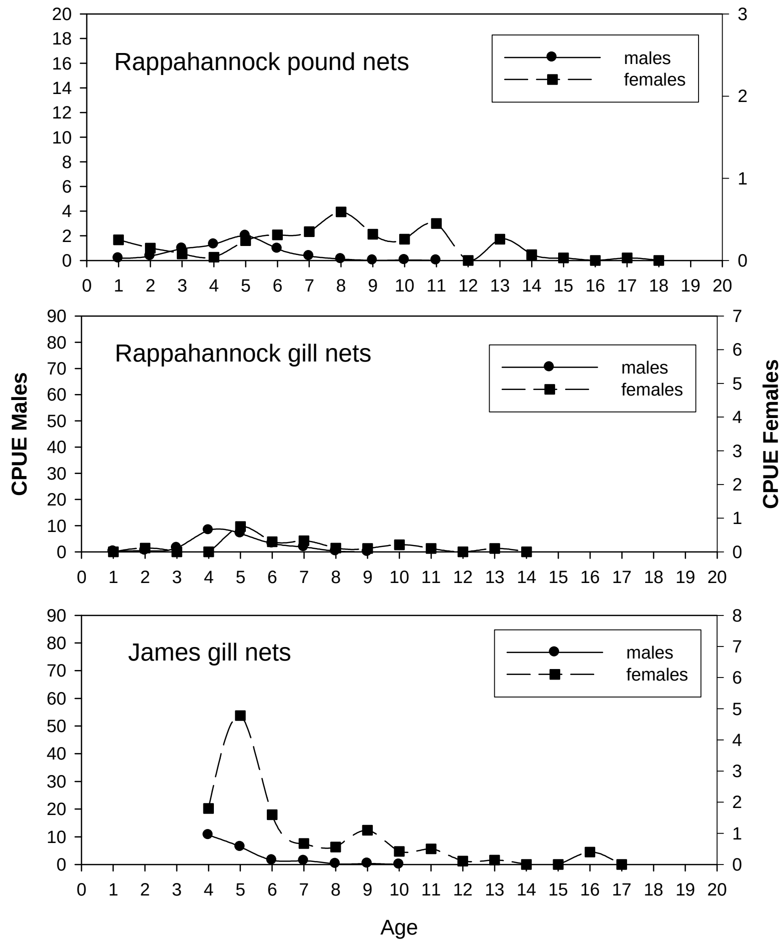


Figure 8. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1991 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1992-2010.

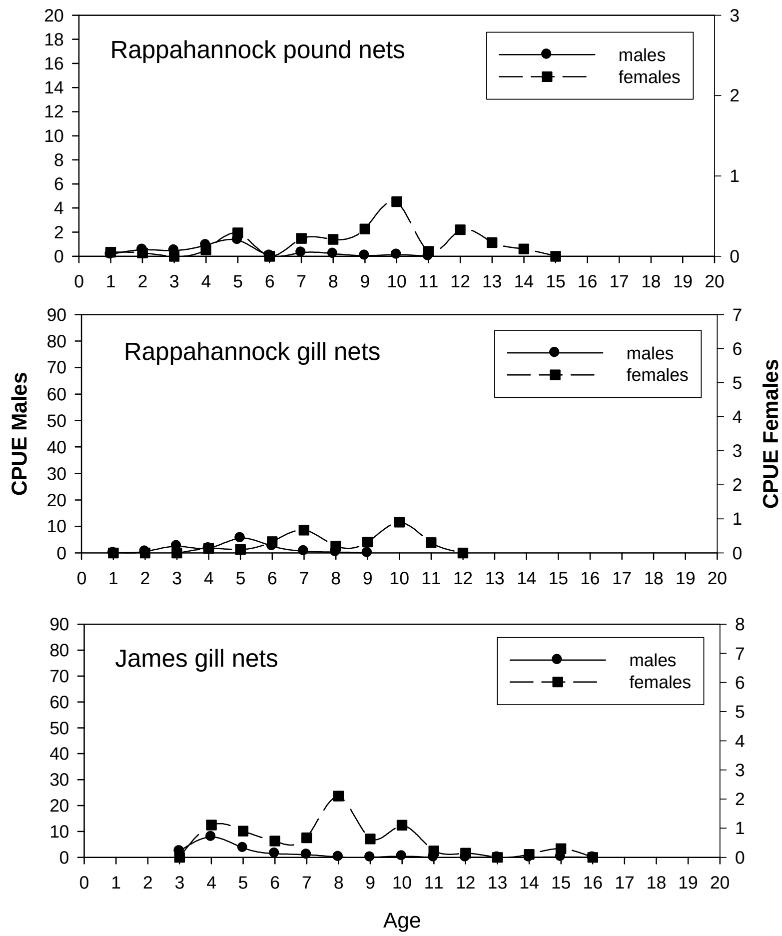


Figure 9. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1992 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1993-2010.

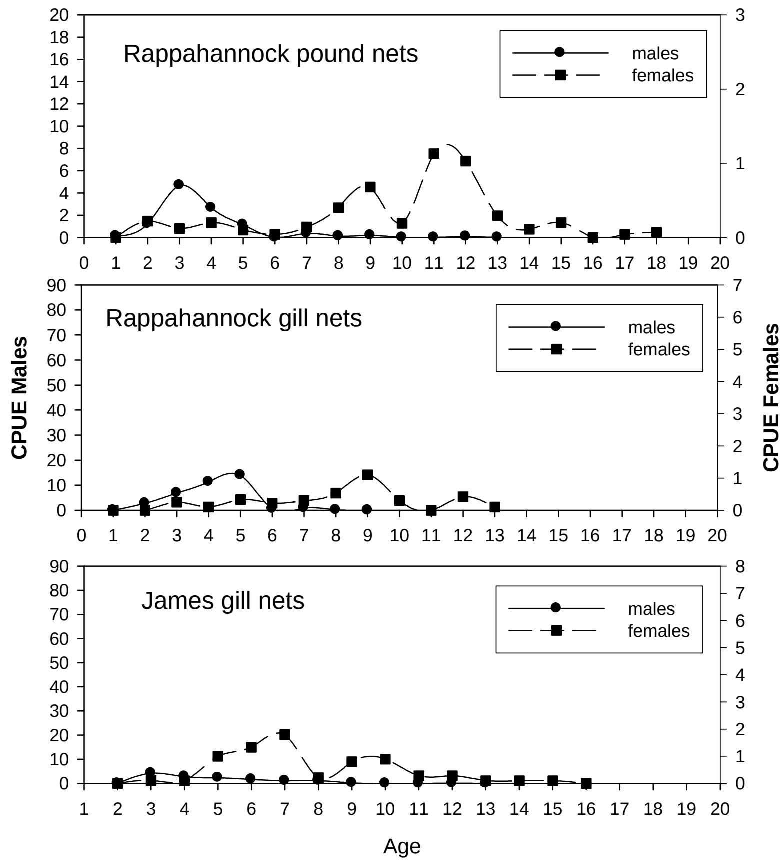


Figure 10. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1993 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1994-2010.

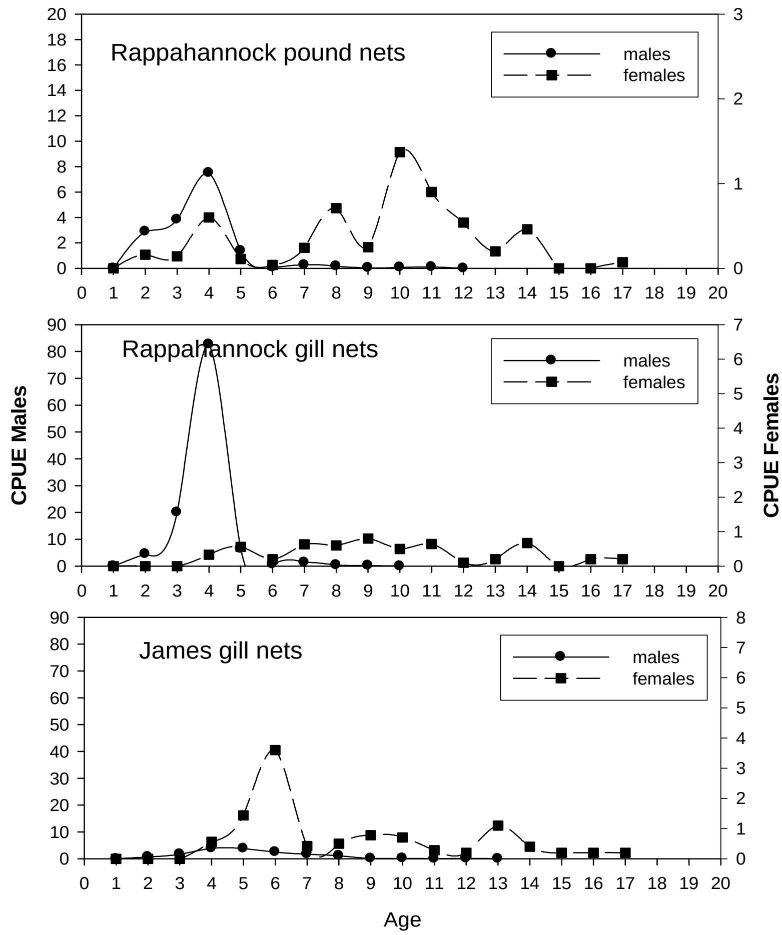


Figure 11. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1994 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1995-2010.

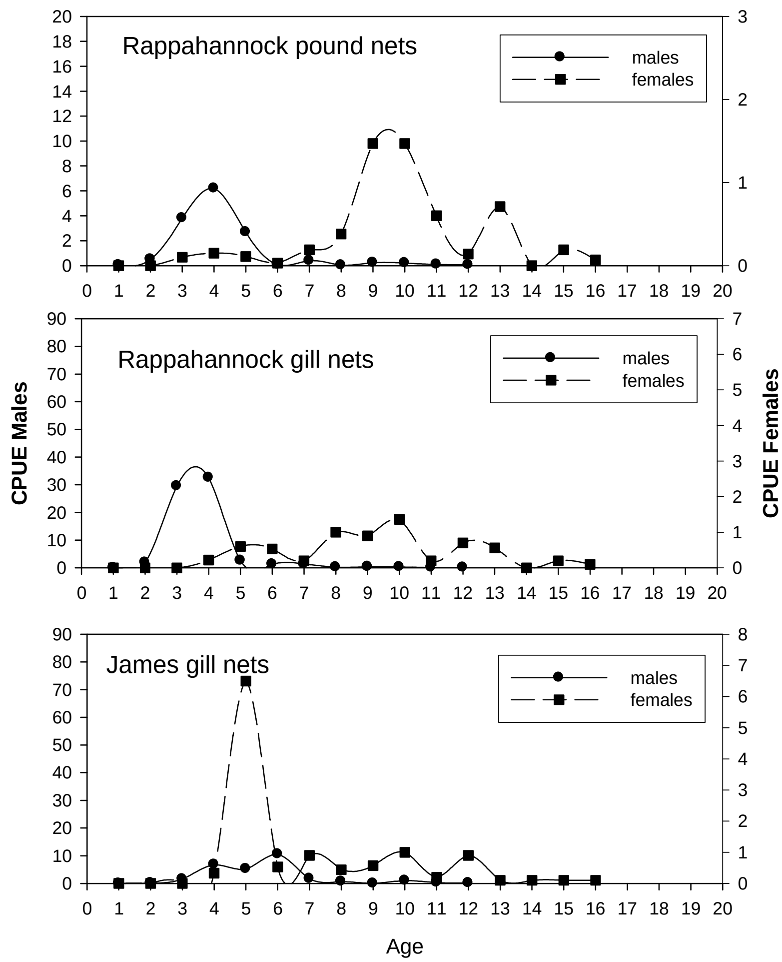


Figure 12. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1995 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1996-2010.

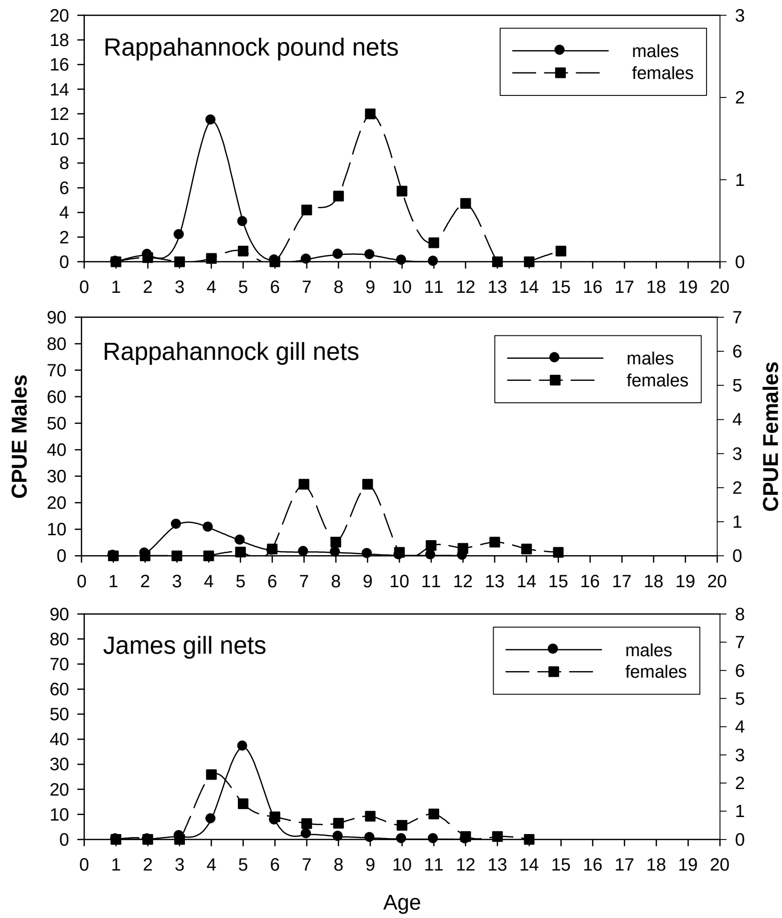


Figure 13. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1996 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1997-2010.

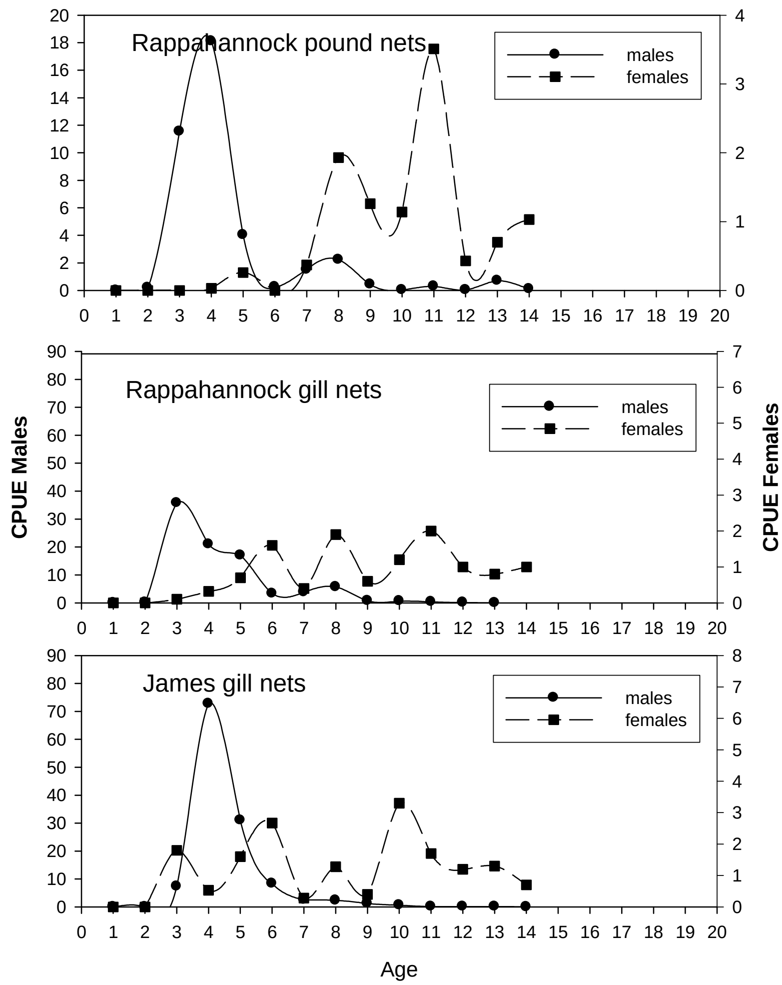


Figure 14. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1997 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1998-2010.

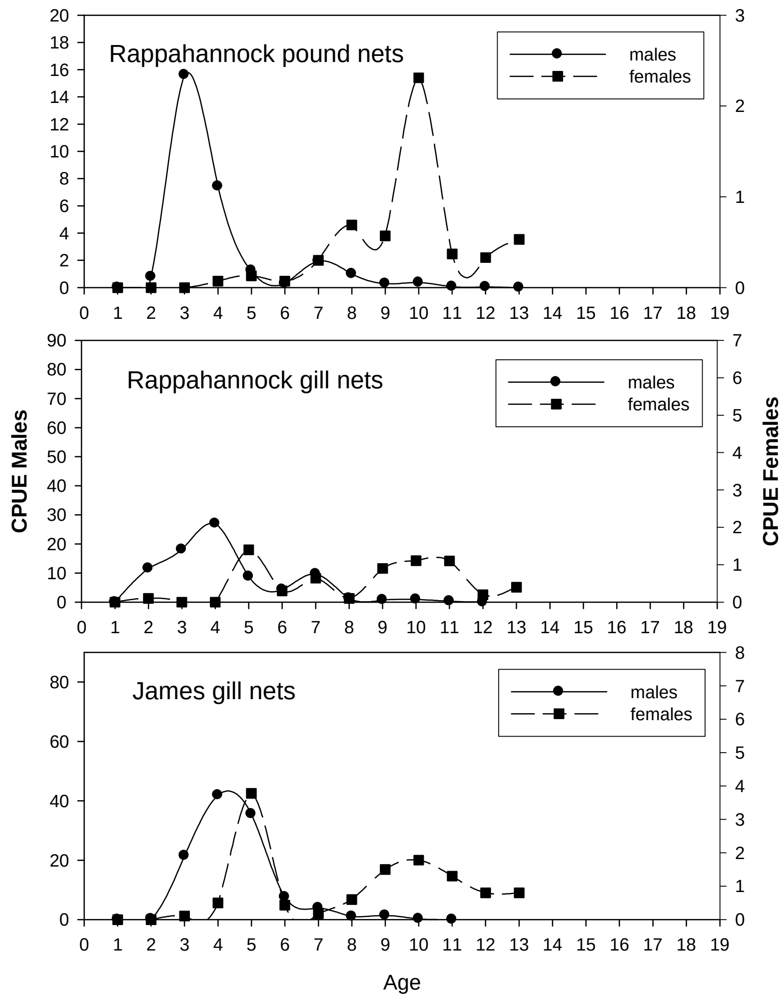


Figure 15. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1998 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 1999-2010.

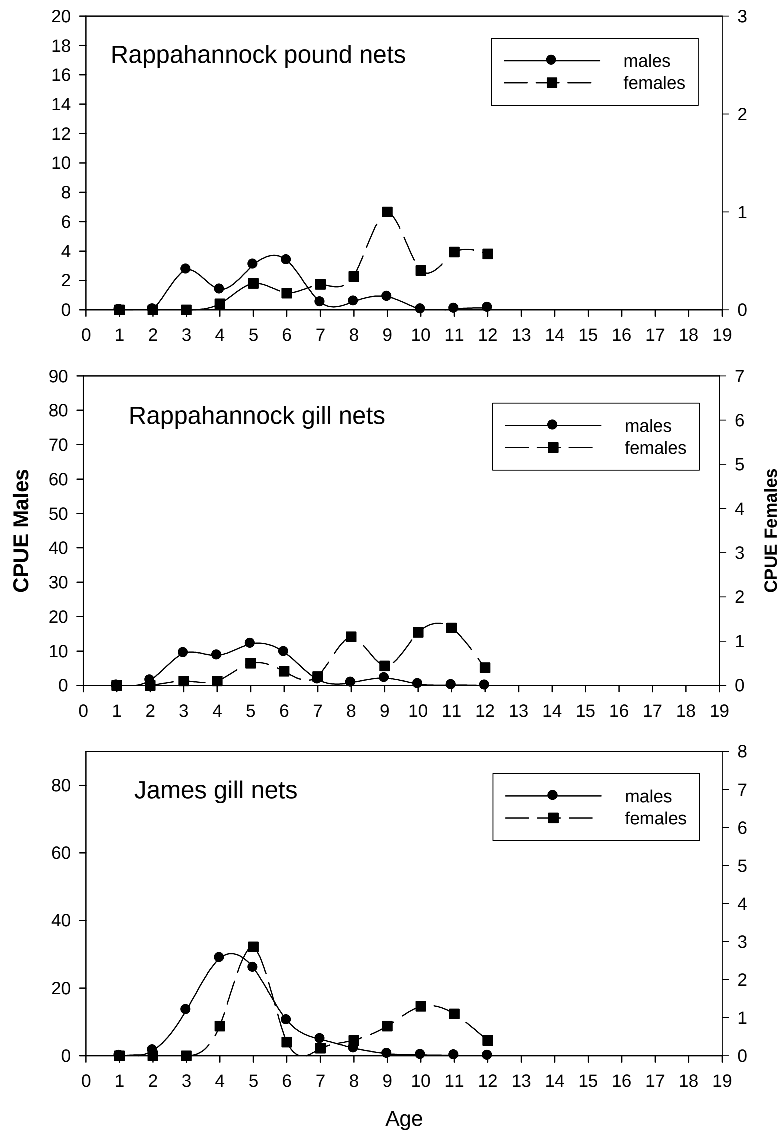


Figure 16. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1999 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 2000-2010.

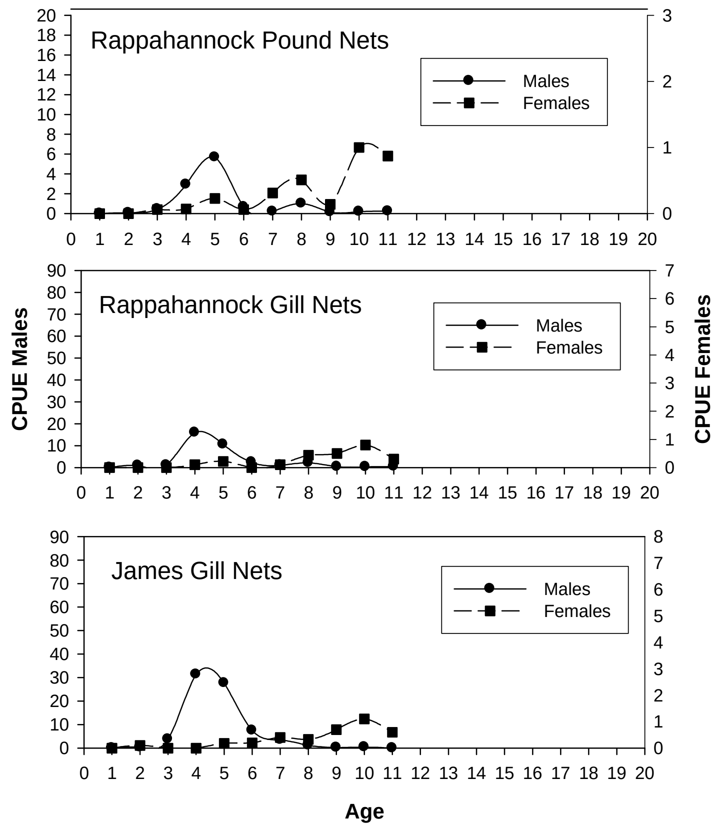


Figure 17. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 2000 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 2001-2010.

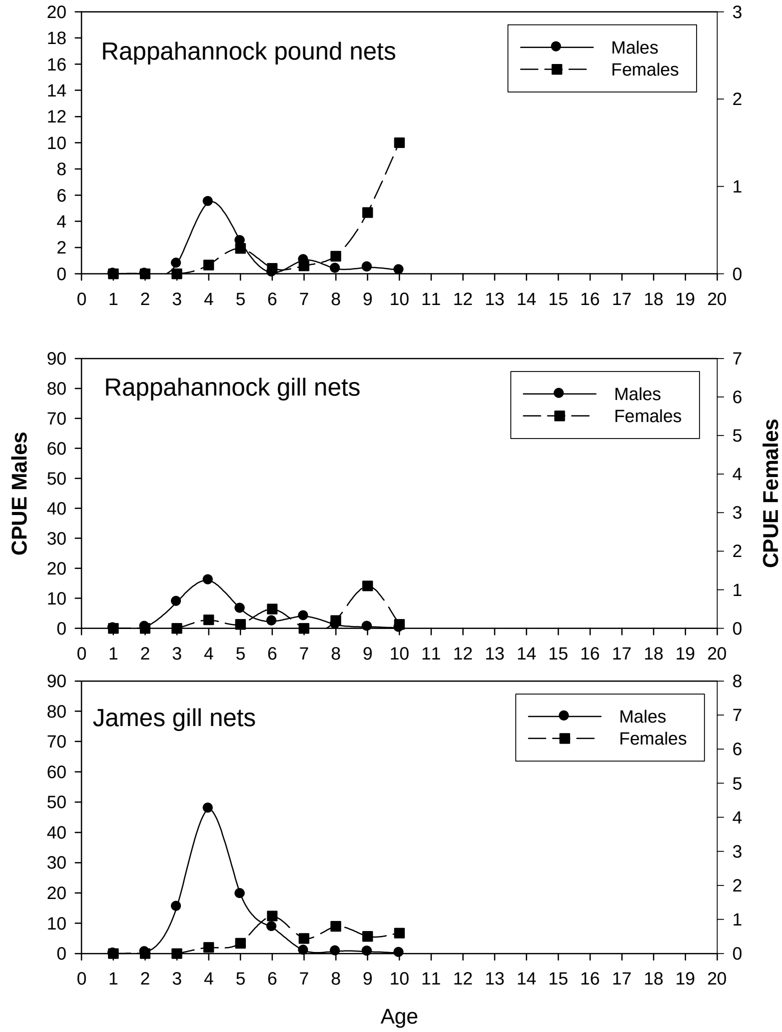


Figure 18. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 2001 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 2001-2010.

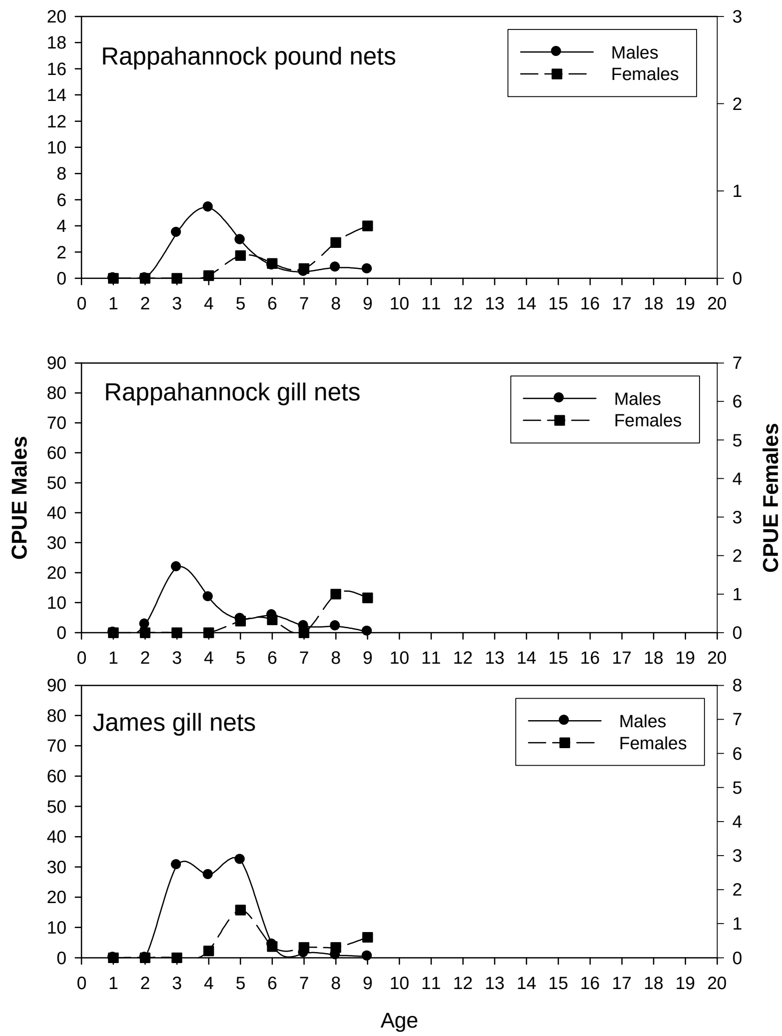


Figure 19. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 2002 year class of striped bass from the Rappahannock (pound nets and experimental gill nets) and James (experimental gill nets) rivers, spring, 2002-2010.

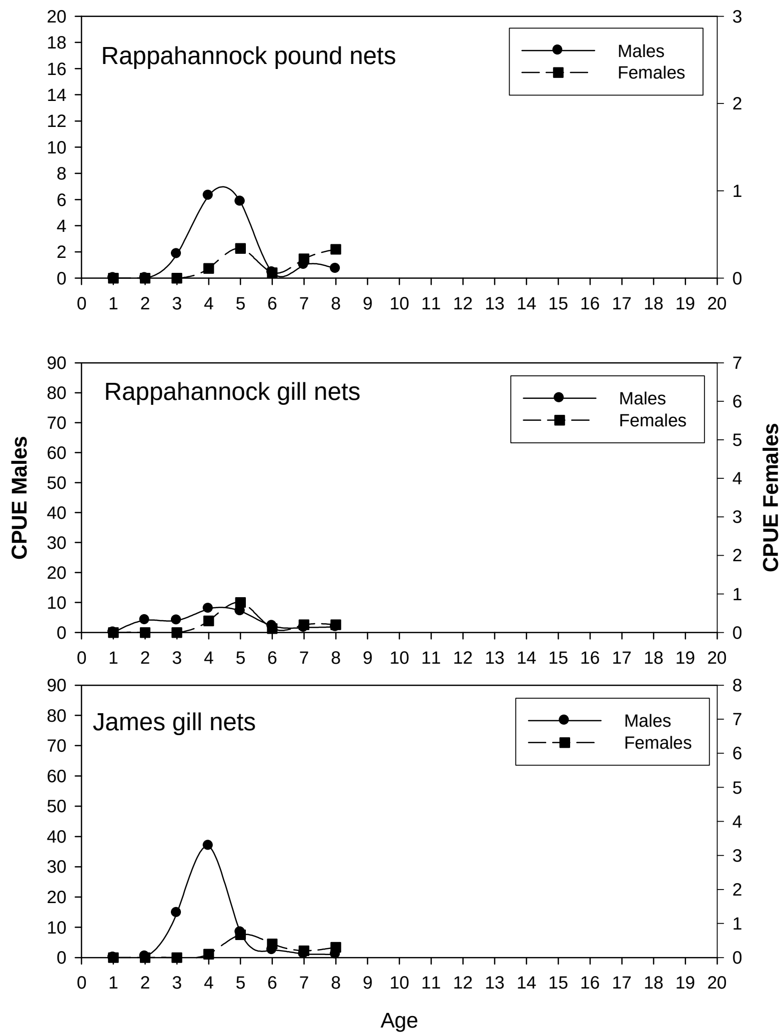
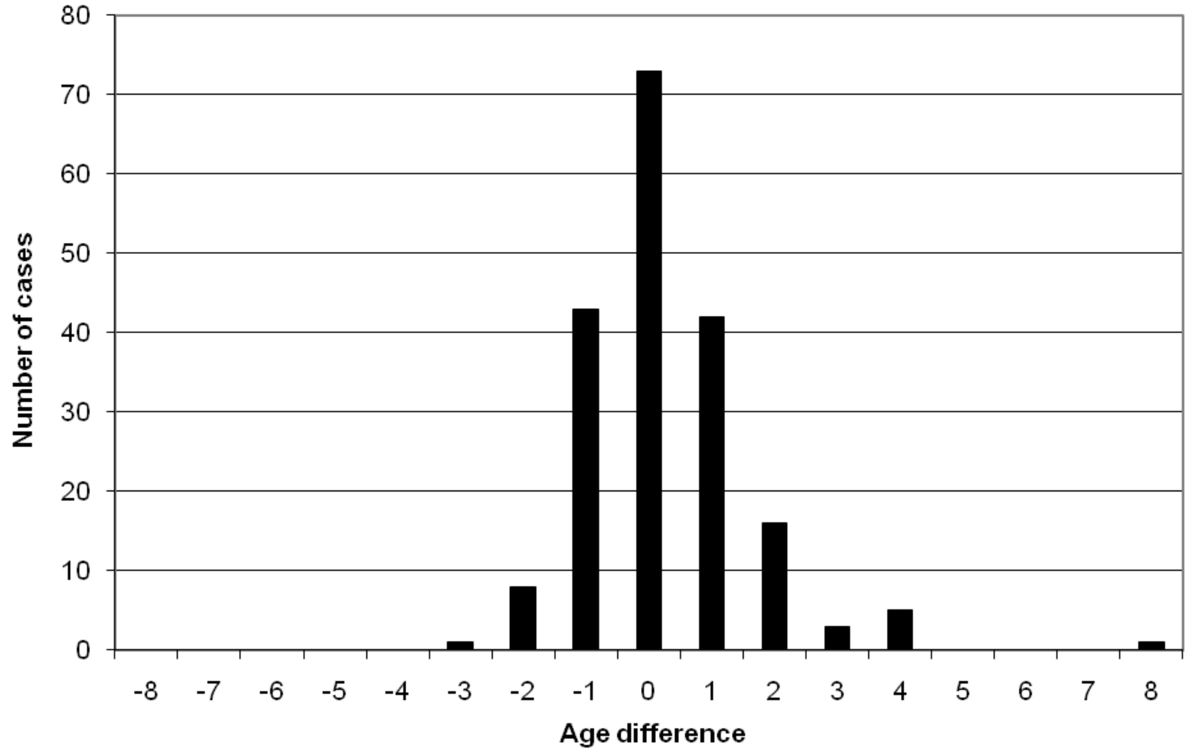


Figure 20. Magnitude of the age differences (otolith = 193) by reading both their scales and otoliths, spring, 2010.



II. Mortality estimates of striped bass (*Morone saxatilis*) that spawn in the Rappahannock River, Virginia, spring, 2009-2010.

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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 coastwide plan. To be in compliance with the plan, coastal states have imposed restrictions on their commercial and recreational striped bass fisheries ranging from combinations of catch quotas, size limits, and time-limited 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 ASMFC 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 ASMFC 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 2010, 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

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

The protocol consists of six steps. First, prior to data analysis, a set of biologically reasonable candidate models is identified. Characteristics of the stock being studied (i.e., Chesapeake Bay, Hudson River, Delaware Bay, etc.) and time are used as factors in determining the parameterizations of the candidate models. These models are then fit to the tagging data (program MARK), 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 2003-2009) 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, 2003-2008 and 2009).
S(v)r(p)	Survival and tag-recovery rates vary over different regulatory periods (v= constant 1990-1994, 1995-1999, 2000-2002, 2003-2007, 2008 and 2009).

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

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 (0.43) 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 methods: This method (defined in the multi-year tagging methods section) allows the estimate of natural mortality to be constant, or to vary by periods. In the 2009 analysis, two scenarios were assessed, based of the ASMFC tagging subcommittee recommendations: constant natural mortality and two periods of differing natural mortality. To determine when to separate the two periods all possible 2 period combinations were tried (1990, 1991-2008; 1990-1991, 1992-2008;…1990-2007,2008) and the minimum qAIC value used as the determinant. The resultant periods were 1990-1997, 1998-2008 for striped bass > 457 mm TL and 1990-2002, 2003-2008 for striped bass > 711 mm TL. These periods were used in the models this year, with the terminal year being 2009. The candidate models for fishing mortality (F), release mortality (F') and natural mortality (M) are:

- F(t) F'(t)M(p) Fishing and release mortalities time-specific; natural mortality constant.
- F(p)F'(t)M(p) Fishing mortality period-specific (1990-1994, 1995-1999, 2000-2002 and 2003-2009); release mortality time-specific; natural mortality constant.
- F(.)F'(t)M(p) Fishing mortality constant; release mortality time-specific; natural mortality constant.
- F(t)F'(p)M(p) Fishing mortality time-specific; release mortality period-specific; natural mortality constant.
- F(t)F'(.)M(p) Fishing mortality time-specific; release and natural mortalities constant.
- F(p)F'(p)M(p) Fishing and release mortalities period-specific; natural mortality constant.
- F(.)F'(.)M(p) Fishing, release and natural mortalities constant.
- F(d)F'(d)M(p) Fishing and release mortalities vary over a different periods (1990-1994, 1995-1999,2000-2002,2003-2008 and 2009); natural mortality constant.
- F(v)F'(v)M(p) Fishing and release mortalities vary over different periods (1990-1994, 1995-1999, 2000-2002, 2003-2007 and 2008-2009); natural mortality constant.

All analytical approaches were applied to striped bass greater than 457 mm total length (minimum legal size) and to striped bass greater than 710 mm TL (coastal migrants).

Results

Spring 2010 Tag Release summary

A total of 2,050 striped bass were tagged and released from the pound nets in the Rappahannock River between 5 April and 3 May, 2010 (Table 1). There were 1,567 resident striped bass (457-710 mm TL) tagged and released. These stripers were predominantly male (93.6%), but the female stripers were larger on average. The median date of these tag releases, to be used as the beginning of the 2009-2010 recapture interval, was 19 April. There were 483 migrant striped bass (>710 mm TL) tagged and released. These stripers were predominantly female (60.2%) and their average size was larger than for the male striped bass. The median date of these tag releases was 15 April. The tag release totals were greater than the release total for 2009, and they were well above the release targets of 700 resident and 300 migratory striped bass.

Mortality Estimates, 2009-2010

Tag recapture summary: A total of 94 striped bass (>457 mm TL) were recaptured between 1 January and 31 December, 2009. The largest source of recaptures (69.1%) was from Chesapeake Bay (43.6% in Virginia, 25.5% in Maryland, Table 2). Other recaptures came from Massachusetts and New York (9.6% each), Rhode Island (4.3%), New Jersey (3.2%), Connecticut and Delaware (2.1% each). There were no recaptures reported from Maine, New Hampshire or North Carolina. The primary peak of recaptures was in May and June, with a secondary peak from October through December. However, there were recaptures in every month of the year.

A total of 39 migratory striped bass (>710 mm total length) were recaptured between 1 January and 31 December, 2009. The largest source (25.6%) of the recaptured tagged striped bass was Chesapeake Bay (15.4% in Virginia and 10.3% in Maryland, Table 3). Other recaptures came from Massachusetts and New York (23.1% each), New Jersey (7.7%), Connecticut and Delaware (5.1%). There were no recaptures reported from Maine, New Hampshire or North Carolina. The peak month for recaptures was in August, but some migrant striped bass were recaptured from every month of the year except January.

ASMFC protocol: Survival estimates were made utilizing the mark-recapture data for the Rappahannock River from 1990-2009. 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 prior to the 2006 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.

Estimates of survival using MARK: Forty-three striped bass (≥ 457 mm TL) tagged in spring 2009 and 48 striped bass tagged in previous springs were harvested during the 2010 recapture interval. These were added to complete the input matrix (Table 4) for annual estimates of survival using program MARK. Likewise, there were seven striped bass (≥ 711 mm TL) tagged in spring 2009 and 31 striped bass tagged in previous springs harvested during the 2010 recapture interval and used to complete the input matrix (Table 5).

The suite of nine models were ranked and weighted by MARK according to their QAIC values. For striped bass ≥ 457 mm TL, the time-specific model received 100% of the weighting (Table 6). The 2009 estimate of survival was 0.500 which became 0.515 when adjusted for release bias (Table 7). The 2009 survival estimate was unchanged from the 2008 estimate. The ranking and weighting among the nine models were much different in striped bass ≥ 711 mm TL with the period model ranked highest (weighted 40.9%) and four models contributing greater than 10% (Table 8). The 2009 estimate of survival was 0.589 (0.595 after bias adjustment) which was marginally higher than the survival estimates for 2003-2008 (Table 9).

Catch equation estimates of mortality and exploitation rates: The MARK estimates of survival were used to estimate exploitation rate (U) as well as instantaneous (Z), annual (A), fishing (F) and natural (M) mortalities. The 2009 estimates for striped bass ≥ 457 mm TL were 0.66 (Z), 0.49 (A), 0.07 (U), 0.10 (F) and 0.57 (M, Table 10). The estimates of U and F have declined steadily since 2001 while the estimate of M has fluctuated, but remained well above the assumed value of 0.15 since 2004. The 2009 estimates for striped bass ≥ 711 mm TL were 0.52 (Z), 0.41 (A), 0.05 (U), 0.06 (F) and 0.46 (M, Table 11). The estimates of F and U have declined since 2003, but the M estimate, while lower than the value for the smaller striped bass, has also exceeded the 0.15 value since 2004.

Instantaneous rates model estimates of survival, fishing and natural mortality: The results of the iterative running of two natural mortality period scenarios resulted in the adoption of 1990-1997 and 1998-2009 M periods for striped bass ≥ 457 mm TL and 1990-2003 and 2004-2008 M periods for striped bass ≥ 711 mm TL.

Twenty-six striped bass (≥ 457 mm TL) tagged in spring 2009 were harvested and an additional 14 were released with the tag streamers cut off during the 2009-2010 recapture interval. In addition, there were 31 striped bass harvested and five striped bass released with their streamers cut off that were tagged in previous springs. These were added to their respective input matrixes (Tables 12a,b) for estimating survival and mortality parameters using the instantaneous rates model. Likewise there were five harvested and one released striped bass (≥ 711 mm TL) from striped bass tagged in spring 2009 and 19 harvested and three released striped bass tagged in previous springs during the 2009-2010 recapture interval used to complete their respective instantaneous rate model input matrixes (Tables 13a, b).

The time-specific F, period F' model received the highest weighting in the 2009 constant M IRCR analysis for striped bass greater than 457 mm TL. However, when these 1M suite of models were run in addition to the same models with two M periods, none of the one M models received any weight. The model was included in addition to the full 2M suite of models for the 2010 analysis, but again received zero weighting (Table 14). The four period model was the highest weighted model (0.537), followed by the Vic variation (0.296) and minor contributions from the Des variation model and the time-specific F, period-based F' model (0.167 combined).

The IRCR estimate of survival for 2009 was 0.492 (Table 15). The 2009 estimate of natural mortality was 0.617 respectively, while the 2009 estimate of fishing mortality was 0.090. Consistent with the 2008 results, the two M IRCR analysis gave lower estimates of survival and higher natural mortality estimates than if constant natural mortality is assumed. The natural mortality estimates from both analyses are much higher than the 0.15 value assumed in the MARK analysis.

The same four models combined for 100% of the weighting for the IRCR analysis for striped bass ≥ 711 mm TL (Table 16). Again, the time-specific 1M model received zero weight. However the Vic variation period model received the strongest weighting (0.459) followed by the period model (0.361) and the Des variation period model (0.174), while the time-specific F, period-based F' model was only minimally weighted (0.006).

The IRCR estimate of survival was 0.536 respectively (Table 17). The 2009 estimate of natural mortality was 0.509 while the estimate of fishing mortality was 0.113. Again the estimates of natural mortality were much higher than the 0.15 assumed in the MARK analysis.

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

The program MARK survival estimates for 2009 were 0.515 for striped bass greater than 18 inches (457 mm) total length and 0.589 for striped bass greater than 28 inches (711 mm) total length (migratory). The survival estimate for striped bass greater than 18 inches was equal to the estimate for 2008, but had varied widely and without apparent temporal direction. Likewise, the 2009 survival estimate for striped bass greater than 28 inches was almost equal to the 2008 estimate and has shone a gradual decrease since 2000.

The resultant estimates of fishing mortality exceeded the 0.30 limit endorsed by the ASMFC. In 2006 the final period in the period-based models was redefined and partitioned into two periods. Since this redefinition the estimates of fishing mortality started exceeding the threshold value of 0.30 endorsed by the ASMFC. Prior to 2004, the models that assume constant survival and/or reporting rate and the models that partition the time series into two periods (1990-1994 and 1995-2004) were found to best fit the data and contributed most heavily to the analysis (0.62 in 2003). These are the models that use the fewest parameters to produce the estimates of survival and fishing mortality. However, since 2004 the regulatory-based reporting rate models were the most heavily weighted. Since 2007, specialized variants of the regulatory models, creating a separate period for the final (d model) or each of the final two (v model) years were added to the suite of models and consistently receive high weighting. However, these new models haven’t been fully evaluated and the results are contrary to the other analytical methods. Furthermore, this analysis assumes a constant value of 0.15 for natural mortality and there is increasing evidence that natural mortality has increased and may greatly exceed this value which would result in an over estimation of fishing mortality.

The catch equation method uses the survival estimates from the MARK analysis, but rather than assume a value of natural mortality, it partitions mortality into both its natural and fishing components. This methodology produced 2009 estimates of fishing mortality of 0.10 (>18 inches) and 0.06 (>28 inches), well below the ASMFC threshold. It also produced estimates of natural mortality well above 0.15 in both size groups.

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.

Starting last year, the protocol was modified to allow for an increase in natural mortality in recent years and these models were found to better fit the data. The estimates of fishing mortality were 0.09 (>18 inches) and 0.11 (>28 inches). It also estimated the natural mortality has greatly increased in the recent years.

A number of studies in recent years have indicated a development of mycobacteriosis, a bacterial disease in Chesapeake Bay striped bass beginning around 1997 (Vogelbein et al 1999). The disease is believed to have spread significantly thereafter. It has been suggested that mycobacteriosis might lead to an increase in striped bass mortality (Jiang et al 2007, Guathier et al 2008 and Hoenig et al 2009). Kahn and Crecco (2006) analyzed MD and VA spring tagging data for two groups of fish (fish $\geq$ 18 inches TL and fish $\geq$ 28 inches TL) using Program MARK and the catch equation. They reported high natural mortality rates similar to those estimated in the present analysis and suggested that their high estimates of natural mortality were related to mycobacteriosis. However, as mentioned above, the natural mortality could be overestimated if migration out of the Bay is not accounted for partially or completely.

A significant advantage of the catch equation method and the IRCR model is the ability to estimate natural mortality in addition to fishing mortality, either through the use of external model results (the catch equation uses survival estimates from Program MARK) or internally (IRCR model). As reported above, estimated values of natural mortality from both methods were substantially higher than the life-history-based fixed level of natural mortality traditionally used in the analyses (0.15 $year^{-1}$). A significant increase in natural mortality of striped bass in Chesapeake Bay may have a considerable effect on population dynamics and serious implications for management. An obvious effect of an increase in M is a faster decay of individual cohort size (increase in the catch curve slope) and overall decline of population abundance. A significant decline in population size should in turn affect fish availability and lead to a decline in CPUE and total harvest. However, the Bay landings reached record harvest values in 2006 and declined only slightly thereafter.

This lack of agreement between model results and observed fishery data suggests a need for careful evaluation of the tagging analysis assumptions (full mixing and equal probability of marked fish to be recovered) and interpretation of the results. What is currently interpreted in the model as total mortality can be more generally described as a rate of disappearance, where disappearance includes total mortality and emigration. Striped bass emigrate from Chesapeake Bay as they age and if the fish are moving to areas that are not fished or very lightly fished (for example, the EEZ) the probability of tagged fish being recovered becomes extremely low. In this case, the decline in the number of recovered tags is interpreted in the model as a decline in survival and increase in natural mortality. A simulation analysis is recommended to investigate the ability of the instantaneous rates model to differentiate natural mortality from emigration to areas with different or no fishing activity/tag returns.

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Table 1. Summary data of striped bass tagged and released from pound nets in the Rappahannock River, spring 2010.

Date	N	457-710 mm TL						> 711 mm TL			
		Males		Females		Unknown		Males		Females	
		n	$\overline{TL}$	n	$\overline{TL}$		$\overline{TL}$		$\overline{TL}$		$\overline{TL}$
5 Apr	12	2	577.5	1	667.0	0		0		9	959.4
8 Apr	144	72	580.2	3	593.0	0		25	780.7	44	979.2
12 Apr	397	242	560.9	19	582.8	0		53	812.0	83	946.2
15 Apr	314	218	560.0	21	563.0	0		35	793.0	40	942.3
19 Apr	391	272	548.0	26	588.7	0		41	827.4	52	917.3
22 Apr	301	251	550.1	7	570.3	0		17	818.2	26	941.7
26 Apr	431	360	546.2	18	579.4	0		21	818.7	32	897.4
3 May	60	50	544.7	5	592.0	0		0		5	835.6

Table 2. Location of striped bass (≥ 457 mm TL), recaptured in 2009, that were originally tagged and released in the Rappahannock River during springs 1988-2009.

State	Month												total
	J	F	M	A	M	J	J	A	S	O	N	D	
New Hampshire	0	0	0	0	0	0	0	0	0	0	0	0	0
Massachusetts	0	0	0	0	0	1	3	5	0	0	0	0	9
Rhode Island	0	0	0	0	0	2	0	2	0	0	0	0	4
Connecticut	0	0	0	0	0	0	0	0	2	0	0	0	2
New York	0	0	0	0	1	1	0	3	0	3	1	0	9
New Jersey	0	0	0	0	0	1	0	0	0	0	2	0	3
Delaware	0	0	0	0	1	1	0	0	0	0	0	0	2
Maryland	0	0	1	1	8	2	4	3	0	2	3	0	24
Virginia	3	1	3	1	5	6	0	0	2	5	6	9	41
North Carolina	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	3	1	4	2	15	14	7	13	4	10	12	9	94

Table 3. Location of striped bass (≥ 711 mm TL), recaptured in 2009, that were originally tagged and released in the Rappahannock River during springs 1988-2009.

State	Month												total
	J	F	M	A	M	J	J	A	S	O	N	D	
Massachusetts	0	0	0	0	0	1	3	5	0	0	0	0	9
Rhode Island	0	0	0	0	0	2	0	2	0	0	0	0	4
Connecticut	0	0	0	0	0	0	0	0	2	0	0	0	2
New York	0	0	0	0	1	1	0	3	0	3	1	0	9
New Jersey	0	0	0	0	0	1	0	0	0	0	2	0	3
Delaware	0	0	0	0	1	1	0	0	0	0	0	0	2
Maryland	0	0	0	1	2	0	0	0	0	0	1	0	4
Virginia	0	1	3	0	0	0	0	0	0	0	0	2	6
North Carolina	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	1	3	1	4	6	3	10	2	3	4	2	39

Table 4. Input recapture matrix for program MARK: from striped bass (>457 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2009.

Release		Recapture year																			
	Year	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
1,464	1990	162	64	47	25	12	10	3	2	3	1	1	0	0	1	0	0	0	0	0	0
2,481	1991		167	81	53	29	6	5	2	2	4	1	0	0	1	0	0	0	0	0	0
130	1992			14	8	6	5	1	1	1	1	0	0	0	0	0	0	0	0	0	0
621	1993				50	37	17	8	9	0	0	1	0	0	0	0	0	0	0	0	0
195	1994					13	10	5	4	4	0	0	0	0	0	0	0	0	0	0	0
698	1995						55	30	20	5	4	2	3	0	1	0	1	0	0	0	0
376	1996							21	18	7	3	1	1	1	0	0	1	0	0	0	0
712	1997								47	26	14	3	0	1	2	1	0	0	0	0	0
784	1998									55	26	2	3	3	1	0	0	0	0	0	0
853	1999										66	23	9	5	3	0	0	0	0	0	0
1,765	2000											122	51	23	16	6	5	1	1	0	0
797	2001												61	23	16	7	2	2	2	0	0
315	2002													20	8	15	1	1	2	1	0
852	2003														58	37	9	4	5	3	2
1,477	2004															80	21	13	7	4	2
921	2005																44	26	10	2	5
668	2006																	49	11	6	6
1,961	2007																		117	50	24
523	2008																			30	9
867	2009																				43

Table 5. Input recapture matrix for program MARK: from striped bass (>710 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2009.

Release		Recapture year																			
	Year	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
301	1990	26	9	15	2	4	6	1	0	2	1	1	0	0	1	0	0	0	0	0	0
390	1991		41	24	16	11	3	2	2	1	2	0	0	0	1	0	0	0	0	0	0
40	1992			4	3	2	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0
212	1993				22	18	7	4	7	0	0	1	0	0	0	0	0	0	0	0	0
123	1994					9	7	5	1	2	0	0	0	0	0	0	0	0	0	0	0
210	1995						29	11	8	3	3	2	3	0	1	0	1	0	0	0	0
67	1996							1	3	1	0	0	1	0	0	0	0	0	0	0	0
212	1997								15	13	8	3	0	1	2	1	0	0	0	0	0
158	1998									24	13	2	3	2	0	0	0	0	0	0	0
162	1999										17	6	2	3	2	0	0	0	0	0	0
365	2000											28	19	14	9	4	3	0	1	0	0
269	2001												19	14	4	6	2	1	1	0	0
122	2002													10	6	7	1	0	2	1	0
400	2003														35	24	7	1	3	3	2
686	2004															39	12	13	5	4	2
284	2005																16	11	8	1	4
175	2006																	13	4	4	3
840	2007																		55	30	18
75	2008																			6	2
242	2009																				7

Table 6. Performance statistics (>457 mm TL), based on quasi-likelihood Akaike Information Criterions (QAIC), used to assess the Seber (1970) models utilized in the ASMFC analysis protocol. Model notations: S (f) and r (f) indicate that survival (S) and tag-reporting rate (r) are functions (f) of the factors within the parenthesis; constant parameters across time (.); parameters constant from 1990-1994, 1995-1999, 2000-2002, and 2003-2009 (p); parameters vary in 2009 (d), otherwise the same as p; parameters vary in 2008 and 2009 (v), otherwise the same as p; and parameters are time-specific (t).

Model	$QAIC_c$	Δ $QAIC_c$	$QAIC_c$ weight	number of parameters
S(t)r(t)	15,368.01	0.00	1.00000	39
S(p)r(t)	15,401.60	33.59	0.00000	24
S(p)r(p)	15,404.53	36.51	0.00000	8
S(.)r(t)	15,404.87	36.86	0.00000	21
S(v)r(p)	15,405.42	37.41	0.00000	9
S(d)r(p)	15,406.07	38.06	0.00000	9
S(t)r(p)	15,406.92	38.91	0.00000	24
S(.)r(p)	15,410.08	42.87	0.00000	5
S(.)r(.)	15,492.16	124.15	0.00000	2

Table 7. Seber (1970) model estimates of unadjusted survival ($\hat{S}$) rates and adjusted rates of survival ($\hat{S}_{adj}$) and fishing mortality ($\hat{F}$) of striped bass (> 457 mm TL) derived from the proportion of recaptures released alive (P_l) in the Rappahannock River, 1990-2009.

Year	$\hat{S}$	SE ($\hat{S}$)	P_l	Bias	$\hat{S}_{adj}$	$\hat{F}$	95% CI $\hat{F}$
1990	0.816	0.082	0.481	-0.143	0.952	-0.101	-0.23, 0.20
1991	0.276	0.049	0.524	-0.082	0.301	1.051	0.73, 1.42
1992	0.805	0.156	0.408	-0.142	0.938	-0.086	-0.27, 0.69
1993	0.604	0.124	0.456	-0.105	0.675	0.243	-0.05, 0.77
1994	0.568	0.120	0.381	-0.087	0.623	0.324	0.01, 0.85
1995	0.684	0.128	0.262	-0.054	0.723	0.174	-0.07, 0.70
1996	0.639	0.126	0.274	-0.040	0.666	0.257	-0.01, 0.78
1997	0.567	0.101	0.330	-0.057	0.601	0.359	0.08, 0.79
1998	0.413	0.075	0.362	-0.059	0.439	0.673	0.36, 1.07
1999	0.367	0.061	0.286	-0.059	0.391	0.790	0.50, 1.14
2000	0.427	0.061	0.436	-0.074	0.461	0.624	0.37, 0.93
2001	0.462	0.091	0.367	-0.068	0.495	0.553	0.23, 1.00
2002	0.620	0.122	0.368	-0.063	0.661	0.263	-0.02, 0.78
2003	0.813	0.129	0.271	-0.049	0.855	0.007	-0.16, 0.60
2004	0.347	0.063	0.281	-0.038	0.361	0.869	0.55, 1.25
2005	0.460	0.087	0.280	-0.032	0.476	0.593	0.28, 1.03
2006	0.463	0.085	0.358	-0.058	0.491	0.561	0.26, 0.98
2007	0.527	0.112	0.305	-0.045	0.553	0.443	0.12, 0.96
2008	0.501	0.141	0.208	-0.027	0.515	0.514	0.11, 1.21
2009	0.500	0.039	0.231	-0.029	0.515	0.514	0.37, 0.68

Table 8. Performance statistics (>710 mm TL), based on quasi-likelihood Akaike Information Criterions (QAIC), used to assess the Seber (1970) models utilized in the ASMFC analysis protocol. Model notations: S (f) and r (f) indicate that survival (S) and tag-reporting rate (r) are functions (f) of the factors within the parenthesis; constant parameters across time (.); parameters constant from 1990-1994, 1995-1999, 2000-2002, and 2003-2009 (p); parameters vary in 2009 (d), otherwise the same as p; parameters vary in 2008 and 2009 (v), otherwise the same as p; and parameters are time-specific (t).

Model	$QAIC_c$	Δ $QAIC_c$	$QAIC_c$ weight	number of parameters
S(p)r(p)	7,177.00	0.00	0.40875	8
S(v)r(p)	7,178.25	1.25	0.21879	9
S(d)r(p)	7,178.46	1.46	0.19670	9
S(.)r(p)	7,178.92	1.93	0.15606	5
S(.)r(t)	7,183.44	6.45	0.01627	21
S(t)r(t)	7,187.72	10.73	0.00191	39
S(p)r(t)	7,188.64	11.64	0.00121	24
S(t)r(p)	7,191.39	14.40	0.00031	24
S(.)r(.)	7,229.83	52.84	0.00000	2

Table 9. Seber (1970) model estimates (SBTC) of unadjusted survival ($\hat{S}$) rates and adjusted rates of survival ($\hat{S}_{adj}$) and fishing mortality ($\hat{F}$) of striped bass (> 710 mm TL) derived from the proportion of recaptures released alive (P_l) in the Rappahannock River, 1990-2009.

Year	$\hat{S}$	SE ($\hat{S}$)	P_l	Bias	$\hat{S}_{\text{adj}}$	$\hat{F}$	95% CI	
1990	0.626	0.023	0.577	-0.127	0.717	0.182	0.11,	0.27
1991	0.627	0.023	0.560	-0.131	0.721	0.177	0.10,	0.26
1992	0.627	0.023	0.535	-0.172	0.757	0.128	0.05,	0.22
1993	0.627	0.023	0.349	-0.093	0.691	0.219	0.14,	0.31
1994	0.626	0.023	0.318	-0.070	0.674	0.245	0.17,	0.33
1995	0.588	0.025	0.204	-0.079	0.639	0.298	0.21,	0.40
1996	0.588	0.025	0.125	-0.016	0.597	0.366	0.28,	0.46
1997	0.588	0.025	0.167	-0.036	0.610	0.345	0.26,	0.46
1998	0.588	0.025	0.217	-0.084	0.643	0.292	0.20,	0.40
1999	0.588	0.025	0.200	-0.057	0.623	0.324	0.24,	0.42
2000	0.662	0.033	0.349	-0.072	0.713	0.188	0.07,	0.33
2001	0.661	0.033	0.298	-0.053	0.698	0.210	0.10,	0.36
2002	0.661	0.033	0.295	-0.079	0.718	0.181	0.07,	0.33
2003	0.568	0.023	0.246	-0.058	0.604	0.355	0.25,	0.48
2004	0.567	0.023	0.321	-0.050	0.597	0.365	0.28,	0.49
2005	0.568	0.023	0.238	-0.035	0.588	0.381	0.28,	0.49
2006	0.568	0.023	0.282	-0.045	0.595	0.370	0.27,	0.48
2007	0.568	0.023	0.231	-0.039	0.591	0.376	0.28,	0.49
2008	0.579	0.031	0.163	-0.024	0.594	0.371	0.23,	0.54
2009	0.589	0.041	0.105	-0.009	0.595	0.370	0.45,	0.58

Table 10. Estimates of total mortality (Z), annual mortality (A), exploitation (U), fishing mortality (F) and natural mortality (M) from striped bass (> 457 mm TL) tagged and released in the Rappahannock River, springs, 1990-2009.

Year	Z	A	U	F	M
1990	0.05	0.05	0.17	0.17	-0.13
1992	1.20	0.70	0.14	0.24	0.96
1992	0.06	0.06	0.31	0.32	-0.26
1993	0.39	0.33	0.23	0.28	0.11
1994	0.47	0.38	0.25	0.31	0.16
1995	0.32	0.28	0.19	0.22	0.10
1996	0.41	0.33	0.15	0.18	0.22
1997	0.51	0.40	0.20	0.26	0.25
1998	0.82	0.56	0.15	0.22	0.60
1999	0.94	0.61	0.13	0.20	0.74
2000	0.77	0.54	0.14	0.20	0.57
2001	0.70	0.51	0.18	0.25	0.45
2002	0.41	0.34	0.19	0.23	0.18
2003	0.16	0.15	0.19	0.21	-0.04
2004	1.02	0.64	0.12	0.19	0.83
2005	0.74	0.52	0.14	0.20	0.54
2006	0.71	0.51	0.15	0.21	0.50
2007	0.59	0.45	0.14	0.19	0.41
2008	0.66	0.49	0.10	0.14	0.53
2009	0.66	0.49	0.07	0.10	0.57

Table 11. Estimates of total mortality (Z), annual mortality (A), exploitation (U), fishing mortality (F) and natural mortality (M) from striped bass (> 710 mm TL) tagged and released in the Rappahannock River, springs, 1990-2009.

Year	Z	A	U	F	M
1990	0.33	0.28	0.25	0.30	0.03
1992	0.33	0.28	0.37	0.43	-0.11
1992	0.28	0.24	0.37	0.42	-0.15
1993	0.37	0.31	0.37	0.44	-0.07
1994	0.40	0.33	0.26	0.31	0.08
1995	0.45	0.36	0.41	0.51	-0.06
1996	0.52	0.40	0.18	0.23	0.29
1997	0.49	0.39	0.38	0.48	0.01
1998	0.44	0.36	0.46	0.57	-0.13
1999	0.47	0.38	0.28	0.35	0.12
2000	0.34	0.29	0.28	0.33	0.01
2001	0.36	0.30	0.24	0.29	0.07
2002	0.33	0.28	0.35	0.41	-0.08
2003	0.50	0.40	0.27	0.34	0.16
2004	0.52	0.40	0.16	0.20	0.31
2005	0.53	0.41	0.24	0.31	0.22
2006	0.52	0.41	0.25	0.32	0.20
2007	0.53	0.41	0.19	0.24	0.28
2008	0.52	0.41	0.19	0.24	0.28
2009	0.52	0.41	0.05	0.06	0.46

Table 12a. Input recapture matrix for IRCR analysis: from striped bass (>457 mm TL) tagged and released in the Rappahannock River, springs 1990-2009. Harvested recaptures only.

Release		Recapture year																			
	Year	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
1,433	1990	21	20	24	10	8	9	2	0	0	1	1	0	0	1	0	0	0	0	0	0
2,457	1991		48	38	22	14	3	1	2	1	4	0	0	0	1	0	0	0	0	0	0
128	1992			7	4	1	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0
617	1993				18	17	12	5	4	1	0	0	0	0	0	0	0	0	0	0	0
193	1994					6	7	4	1	2	0	0	0	0	0	0	0	0	0	0	0
674	1995						24	12	9	4	1	1	2	0	1	0	0	0	0	0	0
374	1996							3	10	3	2	1	1	1	0	0	1	0	0	0	0
703	1997								26	17	10	2	0	1	1	1	0	0	0	0	0
777	1998									28	16	1	3	1	0	0	0	0	0	0	0
844	1999										30	7	4	2	2	0	0	0	0	0	0
1,736	2000											44	23	11	7	4	5	1	1	0	0
784	2001												32	14	5	7	1	0	0	0	0
310	2002													10	4	6	1	1	1	1	0
839	2003														32	20	5	3	3	2	1
1,470	2004															45	14	8	4	3	1
916	2005																27	17	6	1	4
662	2006																	27	4	5	5
1,952	2007																		64	34	16
523	2008																			17	4
865	2009																				26

Table 12b. Input recapture matrix for IRCR analysis: from striped bass (>457 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2009. Recaptures released with streamers cut off only.

Release		Recapture year																			
	Year	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
1,433	1990	60	22	15	8	1	1	0	1	2	0	0	0	0	0	0	0	0	0	0	0
2,457	1991		86	26	18	10	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
128	1992			4	3	3	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
617	1993				26	16	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0
193	1994					5	1	0	2	1	0	0	0	0	0	0	0	0	0	0	0
674	1995						14	7	7	1	0	0	0	0	0	0	0	0	0	0	0
374	1996							9	5	3	0	0	0	0	0	0	0	0	0	0	0
703	1997								9	6	2	0	0	0	0	0	0	0	0	0	0
777	1998									21	5	0	0	1	1	0	0	0	0	0	0
844	1999										19	7	1	2	0	0	0	0	0	0	0
1,736	2000											40	18	6	3	0	0	0	0	0	0
784	2001												17	6	3	0	0	0	1	0	0
310	2002													6	3	2	0	0	1	0	0
839	2003														11	9	2	1	1	0	0
1,470	2004															20	5	5	1	0	1
916	2005																12	8	2	1	0
662	2006																	16	5	1	1
1,952	2007																		31	7	1
523	2008																			7	2
865	2009																				14

Table 13a. Input recapture matrix for IRCR analysis: from striped bass (>710 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2009. Harvested recaptures only.

Release		Recapture year																			
	Year	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
297	1990	10	1	6	1	3	5	1	0	0	1	1	0	0	1	0	0	0	0	0	0
386	1991		19	10	12	9	2	1	2	0	2	0	0	0	1	0	0	0	0	0	0
40	1992			2	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
209	1993				11	11	5	2	3	0	0	0	0	0	0	0	0	0	0	0	0
123	1994					4	4	4	1	0	0	0	0	0	0	0	0	0	0	0	0
205	1995						18	6	5	2	1	1	2	0	1	0	0	0	0	0	0
67	1996							0	3	1	0	0	1	0	0	0	0	0	0	0	0
210	1997								11	12	6	2	0	1	1	1	0	0	0	0	0
156	1998									16	9	1	3	1	0	0	0	0	0	0	0
159	1999										13	2	1	2	1	0	0	0	0	0	0
362	2000											13	11	6	5	3	3	0	1	0	0
268	2001												9	8	2	6	1	0	0	0	0
122	2002													7	3	5	1	0	1	1	0
392	2003														23	13	3	1	2	2	1
680	2004															21	8	8	3	3	1
281	2005																12	7	5	1	3
175	2006																	10	3	3	2
835	2007																		33	22	11
75	2008																			5	1
241	2009																				5

Table 13b. Input recapture matrix for IRCR analysis: from striped bass (>710 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2009. Recaptures released with streamers cut off only.

Release		**Recapture year**																			
	Year	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**
297	**1990**	14	6	7	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
386	**1991**		19	10	4	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	**1992**			2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
209	**1993**				10	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
123	**1994**					4	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
205	**1995**						5	2	2	1	0	0	0	0	0	0	0	0	0	0	0
67	**1996**							1	0	0	0	0	0	0	0	0	0	0	0	0	0
210	**1997**								2	1	1	0	0	0	0	0	0	0	0	0	0
156	**1998**									6	3	0	0	1	0	0	0	0	0	0	0
159	**1999**										2	1	0	1	0	0	0	0	0	0	0
362	**2000**											9	6	4	2	0	0	0	0	0	0
268	**2001**												7	4	2	0	0	0	1	0	0
122	**2002**													2	2	0	0	0	1	0	0
392	**2003**														8	6	2	0	0	0	0
680	**2004**															11	2	5	1	0	1
281	**2005**																3	4	1	0	0
175	**2006**																	2	1	1	1
835	**2007**																		11	5	1
75	**2008**																			0	0
241	**2009**																				1

Table 14. Model Akaike weighting results (striped bass ≥ 457 mm TL) for the1M (constant) and 2M IRCR analyses. Model notations: Fishing mortality (F), release mortality (F') and natural mortality (M), annual estimates (t) and period estimates (4p- 1990-1994, 1995-1999, 2000-2002 and 2003-2009; d- 1990-1994, 1995-1999, 2000-2002, 2003-2008 and 2009; v- 1990-1994, 1995-1999, 2000-2002, 2003-2007 and 2008-2009).

2M (1990-1997, 1998-2009)	
model	**weight**
F(t), F'(t), 1M	0.000
F(t), F'(t), 2M	0.000
F(4p),F'(t), 2M	0.000
F(.), F'(t), 2M	0.000
F(t), F'(4p), 2M	0.071
F(t), F'(.), 2M	0.000
F(4p), F'(4p), 2M	0.537
F(.), F'(.), 2M	0.000
F(d), F'(d), 2M	0.096
F(v), F'(v), 2M	0.296

Table 15. Parameter estimates of survival (S), natural mortality (M), fishing mortality (F) and its standard error (SE) for striped bass ≥ 457 mm TL from the IRCR analyses (2M), 1990-2009.

Year	2M (1990-1997, 1998-2009)			
	S	M	F	SE
1990	0.621	0.390	0.079	0.007
1991	0.620	0.390	0.080	0.007
1992	0.618	0.390	0.084	0.008
1993	0.619	0.390	0.083	0.008
1994	0.618	0.390	0.085	0.008
1995	0.605	0.390	0.109	0.011
1996	0.607	0.390	0.104	0.011
1997	0.606	0.390	0.108	0.011
1998	0.483	0.617	0.106	0.010
1999	0.483	0.617	0.108	0.011
2000	0.499	0.617	0.075	0.009
2001	0.498	0.617	0.077	0.009
2002	0.498	0.617	0.077	0.009
2003	0.491	0.617	0.091	0.008
2004	0.491	0.617	0.091	0.008
2005	0.492	0.617	0.089	0.010
2006	0.491	0.617	0.091	0.008
2007	0.492	0.617	0.090	0.007
2008	0.492	0.617	0.091	0.009
2009	0.492	0.617	0.090	0.010

Table 16. Model Akaike weighting results (striped bass ≥ 711 mm TL) for the1M (constant) and 2M IRCR analyses. Model notations: Fishing mortality (F), release mortality (F') and natural mortality (M), annual estimates (t) and period estimates (4p- 1990-1994, 1995-1999, 2000-2002 and 2003-2009; d- 1990-1994, 1995-1999, 2000-2002, 2003-2007 and 2008; v- 1990-1994, 1995-1999, 2000-2002, 2003-2007 and 2008-2009).

2M (1990-2003,2004-2008)	
model	**weight**
F(t), F'(t), 1M	0.000
F(t), F'(t), 2M	0.000
F(4p),F'(t), 2M	0.000
F(.), F'(t), 2M	0.000
F(t), F'(4p), 2M	0.006
F(t), F'(.), 2M	0.000
F(4p), F'(4p), 2M	0.361
F(.), F'(.), 2M	0.000
F(d), F'(d), 2M	0.174
F(v), F'(v), 2M	0.459

Table 17. Parameter estimates of survival (S), natural mortality (M), fishing mortality (F) and its standard error (SE) for striped bass ≥ 711 mm TL from the IRCR analyses (2M), 1990-2009.

Year	2M (1990-2003, 2004-2009)			
	S	M	F	SE
1990	0.665	0.256	0.143	0.023
1991	0.665	0.256	0.143	0.018
1992	0.665	0.256	0.143	0.023
1993	0.665	0.256	0.143	0.024
1994	0.665	0.256	0.143	0.030
1995	0.618	0.256	0.222	0.033
1996	0.618	0.256	0.222	0.029
1997	0.618	0.256	0.222	0.030
1998	0.618	0.256	0.222	0.033
1999	0.617	0.256	0.222	0.037
2000	0.687	0.256	0.115	0.018
2001	0.687	0.256	0.115	0.019
2002	0.687	0.256	0.115	0.021
2003	0.693	0.256	0.109	0.018
2004	0.538	0.509	0.108	0.013
2005	0.538	0.509	0.108	0.012
2006	0.538	0.509	0.108	0.015
2007	0.538	0.509	0.108	0.012
2008	0.535	0.509	0.115	0.019
2009	0.536	0.509	0.113	0.019

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 conditions 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 the loss of prey through recent declines in menhaden stocks (starvation), overcrowding, and loss of summer thermal refuges as a result of hypoxia and high water 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. One recently named species, *M. shottsi*, has been observed in splenic tissues of infected striped bass at a prevelance of 50 to 70% greater than other *Mycobacterium* species (Rhodes et al. 2004, Gauthier et al. 2003). 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. (2007) 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 three pound nets in the upper Rappahannock River (river miles 45-47) 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 EOS 30D 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,

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

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/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 $t = 1, 2, \ldots$ 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 examination of recaptured fish 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 2009: A total of 3,259 striped bass were tagged, assessed for external disease indications, photographed and released from three pound nets in the upper Rappahannock (n = 277) and five pound nets in the lower Rappahannock (n = 2,982) River during fall, 2009 (Table 2). The striped bass tagged upriver were mostly 430-530 mm in fork length, giving a slightly wider range than the previous year (Figure 3). An increase of disease prevalence with size is observed in the upriver fish, with all fish above 570 mm displaying some external signs of the disease. There was slightly higher range in size at the lower river nets, peaking from 440-540 mm (Figure 4). The striped bass tagged in the lower Rappahannock River also showed a slight discernable trend in prevalence of infection with size. Combined, only 24.8% (814/3,278) of the total that were tagged were without any external sign of mycobacteriosis. This is a decrease from last fall when 30.6% of the releases were clean. The lightly-infected group (46.0%) had the highest prevalence, while 9.0% were heavily infected. The striped bass tagged upriver had a higher prevalence of infected striped bass (84.8% vs.64.3%). The prevalence of infection in the upper Rappahannock River striped bass were the highest recorded to date (71.9% in 2008, 61.6% in 2007, 52.9% in 2006 and 74.8% in 2005). In contrast the prevalence of infection from striped bass tagged in the lower Rappahannock River has decreased over the same time interval (74.3% in 2008, 62.3% in 2007, 69.7% in 2006 and 77.9% in 2005).

Spring 2010: A total of 232 striped bass were tagged, assessed, photographed and released from the pound nets in the lower Rappahannock River during May, 2010 (Table 3). The striped bass tagged in the lower Rappahannock River were similar in size to the 2009 fall releases (Figure 5). Similarly to the fall 2009 releases, fish released in the spring of 2010 showed a trend towards an increasing prevalence of infection with size; however some larger fish still maintained a clean external appearance. Although greater than for the fall releases, only 40.9% (95/232) of the total that were tagged were without any external sign of mycobacteriosis. The lightly-infected group was 35.8% of the releases, while 12.9% were heavily infected. The prevalence of heavily infected striped bass increased slightly from 2009, which is consistent to the increasing trend observed since spring 2006 (7.8%).

Tag Recapture Summary

Current year:

Fall 2009 releases: A total of 188 striped bass tagged during fall 2009 were recaptured prior to 20 September, 2010(Table 4). The overall recapture rate was 0.058 (0.050 from the lower Rappahannock river releases and 0.144 from the upper Rappahannock releases). The incidence of immediate (< 7 days) recapture was greater from the lower Rappahannock River releases (0.030 vs. 0.011) making the recapture rate beyond the initial 7 days much higher for the upper Rappahannock River released bass (0.134 vs. 0.020). In contrast to the results from the fall 2008 releases, the relative prevalence of each of the disease index severity classifications in the recaptures was similar to the prevalence of the releases (e.g. 0.261 vs. 0.244 clean, and 0.202 vs. 0.203 moderate). Further examination of the disease prevalence in the immediate (less than 7 days at large) recaptures shows that 53%, 37%, and 38% of the light, moderate, and heavily diseased recaptures occurred within 7 days compared to 55% of the clean recaptures. Previous recapture summaries have shown a higher prevalence of moderate and severe infections within the immediate recaptures, suggesting that disease may impact a fish’s ability to move. However, with this year’s immediate recaptures having greater occurrences of clean and lightly diseased fish, other factors (i.e. tagging induced mortality, decreased foraging activity) may be influencing the more heavily infected fish making them less likely to be recaptured immediately after tagging

Striped bass tagged in the lower Rappahannock River were recaptured throughout the Virginia and Maryland portions of Chesapeake Bay, the Potomac and Rappahannock River, and the Atlantic Ocean while those tagged from the upper Rappahannock River were recaptured only in Virginia portion of Chesapeake Bay and in the Rappahannock River (Table 5).

Spring 2010 releases A total of 24 striped bass tagged during spring 2010 were recaptured prior to 20 September 2010 (Table 6). Three quarters (75%) of the recaptures were within seven days of release. This accounted for 84% of the clean recaptures, 66% of the lightly infects, 33% of moderate and 100% of the heavily infected. Recaptures from the spring 2010 tag releases were recaptured throughout the Virginia portions of Chesapeake Bay and the released area of the Rappahannock (Table 7). No obvious differences exist in the movements of the different disease classifications.

Fall 2005-Spring 2009 releases:

Fall 2005 releases: No additional striped bass tagged during fall 2005 was recaptured between 21 September, 2009 and 20 September, 2010.

Spring 2006 releases: No additional recaptures of bass tagged and released in the spring of 2006 occurred between 21 September 2009 and 20 September 2010.

Fall 2006 releases: A total of 6 striped bass tagged and released fall 2006 were recaptured between 21 September, 2009 and 20 September, 2010 (year four at large, Table 8). New recaptures from the fall 2006 releases were released as clean (n=4), lightly diseased (n=1) or severely infected (n=1). Recaptures occurred at the release site, the Rappahannock River, Maryland and Virginia portions of the Bay, and the Atlantic Ocean (Table 9).

Spring 2007 releases: A total of 1 striped bass tagged in spring 2007 were recaptured between 21 September, 2009 and September 20, 2010 (2.5 years at large, Table 10). This occurred in the fall of 2009 and in the lower Rappahannock River (Table 11). There were no new recaptures of clean, moderately, or heavily infected striped bass released in spring 2007.

Fall 2007 releases: A total of 15 striped bass tagged during fall 2007 were recaptured prior to between 21 September, 2009 and 20 September, 2010 (their third year at large, Table 12). The majority of the recaptures came from light and moderately diseased fish with 3 recaptures coming from clean fish and 0 recaptures of heavily diseased fish. Most recaptures occurred in the release area and in the Rappahannock River with isolated recaptures occurring in the upper and lower portions of the Bay as well as in the Potomac River (Table 13).

Spring 2008 releases: A total of 3 striped bass tagged during spring 2008 were recaptured between 21 September 2009 and 20 September, 2010 (1.5-2.5 years at large, Table 14). Of these 1 was released in clean condition and 2 were released in lightly diseased condition. No moderately or heavily diseased fish were recaptured. All of the recaptures occurred in the release area and Rappahannock River (Table 15).

Fall 2008 releases: A total of 116 striped bass tagged during fall 2008 were recaptured between 21 September 2009 and 20 September, 2010 (second year at large, Table 16). Of these, 48 were released clean condition and 45 in lightly diseased condition. Numbers for more severely impacted released were smaller with 14 being released with moderate infections, 6 with heavy infection and 3 with other classifications. The majority were recaptured in the release area (n=64), with smaller numbers throughout the Rappahannock River (n=14), the upper (n=10) and lower (n=13) portions of the Maryland Chesapeake Bay, upper (n=11) and lower (n=2) Virginia portions of the Chesapeake Bay, and the Potomac River (n=2, Table 17)

Spring 2009 releases: A total of 13 striped bass tagged during spring 2009 were recaptured between 21 September, 2009 and 20 September, 2010 (0.5-1.5 years at large, Table 18). The majority of the recaptures came from clean fish (n=9), with 2 coming from lightly diseased and 1 each from moderately and heavily diseased fish. Equal numbers were caught at the release site and the Rappahannock River (4 each), with two more in the upper bay portion of Maryland and one additional each in the lower portion of the Chesapeake Bay in Maryland, and the upper and lower portions of Virginia

Disease progression in Rappahannock River Striped Bass, 2005-2009

Release assessments: The relative prevalence of outwardly uninfected (clean) striped bass had been increasing in the lower and upper Rappahannock River between 2005 and 2007. In 2008 both sites experienced significant reductions in the relative prevalence of clean bass. From 2007 to 2008 the relative prevalence of clean bass had dropped about 10% at the upriver site and about 7% at the down river site. The relative prevalence of heavily infected striped bass at both sites increased from 2007 to 2008 which is expected given that there was an increase in the relative prevalence of lightly infected striped bass at both sites between 2006 and 2007. At the lower site, the relative prevalence of lightly diseased bass increased between 2007 and 2008 while the upper site remained stable. From 2008 to 2009 river wide prevalence of clean bass dropped again about 6%, with a drop of 5% at the mouth and 12% upriver. This is a drop in relative prevalence of 13% since 2007. Lightly diseased prevalence increased at both sites in 2009, with a river wide increase of 3% (2.7% downriver and 5.7% upriver). Moderately diseased prevalence also increased over 5% throughout the river in 2009, compared with only a 2% increase in 2008, while heavily infected disease prevalence actually decreased by 2%. While fish from both sites saw a decline this year in clean fish, the trend was more noticeable in the upper site and greater increases in disease prevalence are observed at the upper river when compared to the lower river sites between 2008 and 2009. Based on previous trends, the increased relative prevalence of lightly diseased bass predicts an increase in the relative prevalence of moderate and heavily diseased bass in the following year.

The relative prevalence of clean striped bass in the sample decreased rapidly to near zero by age five in the 2002 through 2004 year classes of striped bass from both locations in the Rappahannock River (Figures 6 through 8). The 2003 and 2004 year class have not shown as sharp a decline in the relative prevalence of the clean fish as the 2002 year class; however, trends in relative prevalence at age of all year classes suggest several things:

1) Bass are infected by the disease at young ages as heavily diseased fish are being observed by age three.
2) Bass continue to become infected with the disease as they age (There appears to be no reduction in susceptibility to infection with age).
3) Relative prevalence of more severe conditions is increasing with age.

Estimates of disease progression

A total of 579 tagged striped bass have been recaptured and returned to VIMS for necropsy and disease reassessment from fall 2005 to present. This represents 3.73% of the total tagged striped bass released. Estimates of disease progression rate could be obtained for fish released as either lightly or moderately diseased. No disease progression rate estimates could be obtained from fish released as clean because of uncertainty around whether the fish was truly disease free or simply not expressing outward signs of the disease. Likewise no estimates could be obtained for fish released in a heavily diseased state as there is no higher stage to progress to in the classification system.

There were 227 recaptures originally assessed as light and 94 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:

$$Y = .00240\ (x) - .03581$$

which yields an estimate of 100% progression to the moderate condition at 416 days (SE = 35 days). Likewise the plot of the progression in the disease of striped bass originally assessed as moderate (Figure 10) was described by:

$$Y = .00187\ (x) - .03797$$

Which yields an estimate of 100% progression to severe at 534 days (SE=143 days).

While it is impossible to obtain direct estimates of progression rate for fish released "clean" exploration of the data shows the trend that nearly all (> 95%) fish released clean in the fall of 2005 - 2009, and subsequently recaptured have progressed to a classifiable disease condition within one year at large (Figure 11). While this is alarming questions still remain over whether this is a true indication of the incidence rate of the disease or an artifact created by the capturing and tagging process.

Spatial comparisons

Of the 579 tagged striped bass that have been recaptured and returned to VIMS for necropsy and disease reassessment, 108 were released in the upper Rappahannock, and 471 in the lower. Given the differences in physical attributes between these sites, there may be differences in the resident bass populations, including disease progression and severity. Release assessments (see prior section) of tagged fish in both portions of the river, combined with information on disease progression and growth obtained from necropsy, can provide further insight into the differences.

Fish released in the lower Rappahannock River tended to have larger recaptured fork lengths than fish from the upper Rappahannock (Figure 12, Table 20). Of fish that were released clean and recaptured as heavily diseased, the mean fork length at the lower Rappahannock was 538.6 mm compared with 475.3 mm at the upper river locations. Though fish released at the lower site tended to be larger than the fish released at the upper Rappahanock (mean = 490.1 mm vs 452.9 mm, respectively), the change in fork length was greater at the lower Rappahannock. Recaptures indicate that changes in fork lengths for fish released clean at the lower Rappahanock were 20.1 mm for lightly infected, 35.7 mm for moderate, and 48.5 for severe. The change in fork lengths as the disease progresses in the upper Rappahannock was 23.2 mm for light, 19.1 mm for moderate and 22.4 for severe. Similar results are seen in fork length measurements for fish releases lightly and moderately infected as the disease progresses.

Additionally, days at liberty varies between the two sites. The variation between the changes in fork length could be attributed to longer days at liberty for fish tagged at the lower site, however on average days at liberty is greater at the upriver site (Figure 13). Fish released at the upriver site assessed as clean, had a mean days at liberty of 110 for clean recaptures, 291.3 for light, 438 for moderate, and 438.3 for severe. In contrast, fish for the downriver site had a mean days at liberty of 106 for clean recaptures, 183.1 for light, 361 for moderate, and 318 for severe. Again, trends continued for light and moderate releases. Extrapolating from both days at liberty and recaptured fork lengths based on disease progression, we can get a growth per day and again see that this is less for the upriver site than for the lower (Table 20). Also from this assessment we can see, in rare cases, that a diseased fish may display a negative disease progression upon its recapture. Though occurrences of this are seldom, the growth per day of these individuals tends to be much smaller than those of fish which have progressed, suggesting that some diseased fish may allocate energy to fighting the infection rather than to somatic growth.

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 14A-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 14A-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 .62 and .39, respectively (Table 21, Figures 14A and B). This implies annual survival rates for fish in disease conditions 3 and 2 that are 53% with a 95% confidence interval of (36% , 77%) and 68% with 95% confidence interval of (49% , 91%), 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 .45; the estimated ratio of survival rates is 63%, 95% confidence interval equal to (39% , 79%) (Table 21, Figure 14D).

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 14C). The estimated difference in instantaneous natural mortality rates is 0.11and the ratio of survival rates is 89%, 95% confidence interval of (72%, 112%) (Table 21).

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 3 (relative to clean fish) is highly statistically significant ($p = 0.001$). The estimate for condition 2 is very similar and the p-value (0.012) is also statistically significant. Combining conditions 2 and 3 to boost sample sizes gives a significant result ($p = .007$) close to the estimate for condition 2 alone. This likely reflects the greater sample size for fish in condition 2 (200 fish) versus the sample size for condition 3 (149 fish). The estimated slope for condition 1 fish indicates a relative survival rate that is four fifths that of clean fish and higher than that of fish in category 2-3. This is a reasonable result. However, the slope is not statistically significant ($p = .33$) so that the possibility that condition 1 fish have the same mortality rate as clean fish cannot be ruled out at this time. The past year of tag returns dramatically improved our ability to estimate the relative mortality rate of condition 1 fish versus clean fish and if the present trend continues statistically significant estimates will be available for all disease conditions after one additional year of tag returns.

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 11.6% of releases), and of tagged carcasses (3.73%), 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. However, our tag returns are of the same ratio as the tag releases, indicating 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 as well as other behaviors from fish without signs of the disease. Fortunately, we are able to obtain detailed recapture locations from almost all fish, which can be used to further examine spatial differences and movement of diseased vs. clean fish. Finally, there is some preliminary indication of spatial differences impacting disease prevalence when examining the data from the upper and lower sites individually, suggesting the disease prevalence is increasing more rapidly at the upper river sites and also has a more drastic effect on growth when in comparison to the lower river.

The prevalence of heavily-infected striped bass, which increased from fall 2007 to fall 2008 (10.3% and 11.1% respectively), decreased to 9.5 % in fall 2009, and the proportion of the striped bass examined as non-infected fell from 30.6%, to 24.4% . This is a decrease in prevalence of clean fish of 13.5% over a two year period. Increases of 7.8% and 6.9% were observed in light and moderate disease prevalence, respectively. 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. Some severely infected fish have been recaptured well over a year later while lightly and moderately infected fish have persisted with the disease for over two years on some occasions. Additionally the necropsies performed on returned carcasses include incidences of healing individual pigmented foci and ulcers. The slow progression and presence of healing fish may indicate that the progression in wild striped bass is slower than what has been observed in aquaculture. However the increased prevalence of diseased fish and a greater likelihood of progression over time do indicate that the disease is progressive. 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 current estimate of disease stage progression is 416 days for lightly infected fish to progress to moderately infected and 534 days for moderately infected to progress to severely infected. These estimates will be refined as more recaptures are returned to VIMS for reassessment; however the time to progression for both of these estimates has decreased since the 2008 model.

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 slightly more than one half the survival rate of fish tagged without outward signs of disease. Fish with early signs of the disease appear to have slightly reduced survival relative to fish without signs of the disease. The estimated relative survival for lightly (early stage) infected fish is not statistically different at the alpha =.05 level from the "clean" fish. 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.

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

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

Table 2. Tag release totals and mycobacteria infection index, by date, of striped bass in the upper and lower Rappahannock River sites, fall, 2009

	release		infection index				
Date	**Area**	**n**	**clean**	**light**	**moderate**	**heavy**	**other**
2 October	Lower	108	27	49	19	13	0
5 October	Upper	36	2	17	10	7	0
9 October	Lower	78	15	39	15	9	0
12 October	Upper	27	2	12	7	6	0
13 October	Lower	433	77	204	117	35	0
16 October	Lower	239	60	114	51	14	0
20 October	Lower	385	83	195	79	28	0
21 October	Upper	114	19	45	32	17	1
23 October	Lower	260	65	112	57	26	0
26 October	Upper	54	12	29	9	4	0
28 October	Lower	333	87	156	62	28	0
29 October	Upper	46	7	21	11	7	0
30 October	Lower	285	75	122	56	32	0
4 November	Lower	292	88	137	45	22	0
9 November	Lower	369	132	157	50	30	0
16 November	Lower	200	44	99	40	17	0
totals	Upper	277	42	124	69	41	1
	Lower	2982	753	1384	591	254	0
	Both	3259	795	1508	660	295	1

Table 3. Tag release totals and mycobacteria infection index, by date, of striped bass in the upper and lower Rappahannock River sites, spring, 2010.

Date	release area	n	infection index				
			clean	light	moderate	heavy	other
8 May	Lower	53	31	28	14	11	1
12 May	Lower	41	24	21	5	8	0
15 May	Lower	13	42	29	12	5	0
19 May	Lower	11	10	16	2	3	0
22 May	Lower	22	20	16	7	4	0
29 May	Lower	29	4	12	3	3	1
4 June	Lower	63	5	5	3	2	0
Totals	Lower	232	136	127	46	36	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, 2009.

Date	release area	n	infection index				
			clean	light	moderate	heavy	other
0-7 days	upper	3	1	1	1	0	0
	lower	88	26	40	13	9	0
Fall 2009 (>7 days)	upper	7	0	2	1	4	0
	lower	25	8	10	5	2	0
Winter 2009	upper	3	1	2	0	0	0
	lower	10	3	3	3	1	0
Spring 2010	upper	13	2	4	4	3	0
	lower	16	5	5	4	2	0
Summer 2010	upper	14	0	7	4	3	0
	lower	9	3	3	3	0	0
totals	upper	40	4	16	10	10	0
	lower	148	45	61	28	14	0
	both	188	49	77	38	24	0

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, 2009.

recapture area	**release area**	**n**	**infection index**				
			clean	**light**	**moderate**	**heavy**	**other**
release area	upper	26	3	11	6	6	0
	lower	110	36	44	16	14	0
Rappahannock River	upper	12	2	3	4	3	0
	lower	5	2	1	2	0	0
upper Bay (Md)	upper	0	0	0	0	0	0
	lower	5	1	2	2	0	0
lower Bay (Md)	upper	1	0	0	0	1	0
	lower	5	2	1	2	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	12	2	8	2	0	0
lower Bay (Va)	upper	1	0	1	0	0	0
	lower	10	2	4	3	1	0
Atlantic Ocean	upper	1	0	1	0	0	0
	lower	0	0	0	0	0	0
totals	upper	41	5	16	10	10	0
	lower	147	45	60	27	15	0
	both	188	50	76	37	25	0

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, 2010.

Date	release area	N	infection index				
			clean	light	moderate	heavy	other
0-7 days	lower	18	11	4	1	2	0
Spring 2010 (>7days)	lower	2	0	1	1	0	0
Summer 2010	lower	4	2	1	1	0	0
totals	Lower	24	13	6	3	2	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, 2010.

recapture area	release area	n	infection index: clean	light	moderate	heavy	Other
release area	lower	22	12	6	2	2	0
Rappahannock River	lower	0	0	0	0	0	0
upper Bay (Md)	lower	0	0	0	0	0	0
lower Bay (Md)	lower	0	0	0	0	0	0
Potomac River	lower	0	0	0	0	0	0
upper Bay (Va)	lower	1	0	0	1	0	0
lower Bay (Va)	lower	1	1	0	0	0	0
totals	lower	24	13	6	3	2	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, 2006 and recaptured from fall 2009 through summer 2010.

	release		infection index				
Date	**area**	**n**	**clean**	**light**	**moderate**	**heavy**	**other**
Fall 2009	upper	2	2	0	0	0	0
	lower	2	2	0	0	0	0
Winter 2009	upper	0	0	0	0	0	0
	lower	1	0	1	0	0	0
Spring 2010	upper	0	0	0	0	0	0
	lower	1	0	0	0	1	0
Summer 2010	upper	0	0	0	0	0	0
	lower	0	0	0	0	0	0
totals	upper	2	2	0	0	0	0
	lower	4	2	1	0	1	0
	both	6	4	1	0	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, 2006 and recaptured from fall 2009 through summer 2010.

recapture area	release area	n	infection index				
			clean	light	moderate	heavy	other
release area	upper	1	1	0	0	0	0
	lower	1	1	0	0	0	0
Rappahannock River	upper	1	1	0	0	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	1	0	0	0	1	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	0	0	0	0	0	0
	lower	1	1	0	0	0	0
Atlantic Ocean	upper	0	0	0	0	0	0
	lower	1	0	1	0	0	0
totals	upper	2	2	0	0	0	0
	lower	4	2	1	0	1	0
	both	6	4	1	0	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, 2007 and recaptured from fall 2009 through summer 2010.

Date	release area	n	infection index				
			clean	light	moderate	heavy	other
Fall 2009	upper	0	0	0	0	0	0
	lower	1	0	1	0	0	0
Winter 2009	upper	0	0	0	0	0	0
	lower	0	0	0	0	0	0
Spring 2010	upper	0	0	0	0	0	0
	lower	0	0	0	0	0	0
Summer 2010	upper	0	0	0	0	0	0
	lower	0	0	0	0	0	0
totals	upper	0	0	0	0	0	0
	lower	1	0	1	0	0	0
	both	1	0	1	0	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, 2007 and recaptured from fall 2009 through summer 2010.

recapture area	**release area**	**n**	**infection index**				
			clean	**light**	**moderate**	**heavy**	**other**
release area	upper	0	0	0	0	0	0
	lower	0	0	0	0	0	0
Rappahannock River	upper	0	0	0	0	0	0
	lower	1	0	1	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	0	0	0	0	0	0
	lower	0	0	0	0	0	0
totals	upper	0	0	0	0	0	0
	lower	1	0	1	0	0	0
	both	1	0	1	0	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, 2007 and recaptured from fall 2009 through summer 2010.

Date	release area	n	infection index				
			Clean	light	moderate	heavy	other
Fall 2009	upper	3	1	0	2	0	0
	lower	5	2	1	2	0	0
Winter 2009	upper	2	0	2	0	0	0
	lower	0	0	0	0	0	0
Spring 2010	upper	1	0	0	1	0	0
	lower	1	0	1	0	0	0
Summer 2010	upper	2	0	2	0	0	0
	lower	1	0	0	1	0	0
totals	upper	8	1	4	3	0	0
	lower	7	2	2	3	0	0
	both	15	3	6	6	0	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, 2007 and recaptured from fall 2009 through summer 2010.

recapture area	release area	N	infection index				
			Clean	Light	Moderate	Heavy	other
release area	upper	3	0	2	1	0	0
	lower	3	1	1	1	0	0
Rappahannock River	upper	3	1	2	0	0	0
	lower	2	1	1	0	0	0
upper Bay (Md)	upper	0	0	0	0	0	0
	lower	1	0	0	1	0	0
lower Bay (Md)	upper	1	0	0	1	0	0
	lower	0	0	0	0	0	0
Potomac River	upper	0	0	0	0	0	0
	lower	1	0	0	1	0	0
upper Bay (Va)	upper	1	0	0	1	0	0
	lower	0	0	0	0	0	0
lower Bay (Va)	upper	0	0	0	0	0	0
	lower	0	0	0	0	0	0
totals	upper	8	1	4	3	0	0
	lower	7	2	2	3	0	0
	both	15	3	6	6	0	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, 2008 and recaptured from fall 2009 through summer 2010.

	release		infection index				
Date	**area**	**n**	**clean**	**light**	**moderate**	**heavy**	**other**
Fall 2009	upper	0	0	0	0	0	0
	lower	0	0	0	0	0	0
Winter 2009	upper	0	0	0	0	0	0
	lower	0	0	0	0	0	0
Spring 2010	upper	0	0	0	0	0	0
	lower	2	1	1	0	0	0
Summer 2010	upper	0	0	0	0	0	0
	lower	1	0	1	0	0	0
totals	upper	0	0	0	0	0	0
	lower	3	1	2	0	0	0
	both	3	1	2	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, 2008 and recaptured from fall 2009 through summer 2010

recapture area	release area	n	infection index				
			clean	light	moderate	heavy	other
release area	upper	0	0	0	0	0	0
	lower	2	1	1	0	0	0
Rappahannock River	upper	0	0	0	0	0	0
	lower	1	0	1	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	0	0	0	0	0	0
	lower	0	0	0	0	0	0
totals	upper	0	0	0	0	0	0
	lower	3	1	2	0	0	0
	both	3	1	2	0	0	0

Table 16. 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, 2008 and recaptured from fall 2009 through summer 2010.

Date	release area	n	infection index				
			clean	light	moderate	heavy	other
Fall 2009	upper	3	1	1	1	0	0
	lower	80	33	32	9	5	1
Winter 2009	upper	1	0	0	0	0	1
	lower	8	3	5	0	0	0
Spring 2010	upper	3	1	2	0	0	0
	lower	8	5	3	0	0	0
Summer 2010	upper	7	2	1	2	1	1
	lower	6	3	1	2	0	0
totals	upper	14	4	4	3	1	2
	lower	102	44	41	11	5	1
	both	116	48	45	14	6	3

Table 17. 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, 2008 and recaptured from fall 2009 through summer 2010

recapture area	release area	n	infection index				
			clean	light	moderate	heavy	other
release area	upper	9	3	2	3	0	1
	lower	55	24	22	6	3	0
Rappahannock River	upper	4	1	1	0	1	1
	lower	10	5	4	0	1	0
upper Bay (Md)	upper	1	0	1	0	0	0
	lower	9	2	5	2	0	0
lower Bay (Md)	upper	0	0	0	0	0	0
	lower	13	6	5	2	0	0
Potomac River	upper	0	0	0	0	0	0
	lower	2	0	1	1	0	0
upper Bay (Va)	upper	0	0	0	0	0	0
	lower	11	6	3	0	1	1
lower Bay (Va)	upper	0	0	0	0	0	0
	lower	2	1	1	0	0	0
totals	upper	14	4	4	3	1	2
	lower	102	44	41	11	5	1
	both	116	48	45	14	6	3

Table 18. 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, 2009 and recaptured from fall 2009 through summer 2010.

	release		infection index				
Date	**area**	**n**	**clean**	**light**	**moderate**	**heavy**	**other**
Fall 2009	upper	0	0	0	0	0	0
	lower	10	6	1	0	1	0
Winter 2009	upper	0	0	0	0	0	0
	lower	1	1	0	0	0	0
Spring 2010	upper	0	0	0	0	0	0
	lower	3	2	0	1	0	0
Summer 2010	upper	0	0	0	0	0	0
	lower	0	0	1	0	0	0
totals	upper	0	0	0	0	0	0
	lower	13	9	2	1	1	0
	both	13	9	2	1	1	0

Table 19. 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, 2009 and recaptured from fall 2009 through summer 2010

recapture area	release area	n	infection index: clean	light	moderate	heavy	other
release area	upper	0	0	0	0	0	0
	lower	4	4	0	0	0	0
Rappahannock River	upper	0	0	0	0	0	0
	lower	4	3	0	0	1	0
upper Bay (Md)	upper	0	0	0	0	0	0
	lower	2	2	0	0	0	0
lower Bay (Md)	upper	0	0	0	0	0	0
	lower	1	0	0	1	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	1	0	0	0
lower Bay (Va)	upper	0	0	0	0	0	0
	lower	1	0	1	0	0	0
totals	upper	0	0	0	0	0	0
	lower	13	9	2	1	1	0
	both	13	9	2	1	1	0

Table 20. Spatial necropsy summary of growth and days at liberty, by mycobacteria infection index and release area, of striped bass tagged and released in the upper and lower Rappahannock River sites through summer 2010.

Release site and disease	Recaptured disease	Mean recaptured Fork Length (mm)	change in Fork Length	Mean days at Liberty	Growth per Day
Upper clean	clean	460.6	7.68	110	0.069818
	Light	476.1	23.18	291.3	0.079574
	Moderate	472	19.08	438	0.043562
	Severe	475.3	22.38	438.3	0.051061
Lower clean	clean	488.48	-1.62	106	-0.01528
	Light	510.1	20	183.1	0.10923
	Moderate	525.82	35.72	361	0.098947
	Severe	538.61	48.51	318	0.152547
Upper Light	Light	516.86	27.14	268.4	0.101118
	Moderate	504.35	14.63	342.8	0.042678
	Severe	512.25	22.53	523.5	0.043037
Lower Light	clean	493.66	-7.65	138.5	-0.05523
	Light	515.43	14.12	138.6	0.101876
	Moderate	522.1	20.79	328	0.063384
	Severe	528.4	27.09	382.8	0.070768
Upper Moderate MModerate	Moderate	485.85	14.13	260.62	0.054217
	Severe	482.71	10.99	421.71	0.026061
Lower Moderate Release	Light	528.16	24.36	125.33	0.194367
	Moderate	519.11	15.31	133.5	0.114682
	Severe	510.54	6.74	232	0.029052

Table 21. 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)
heavy vs. clean	-0.62	0.19	0.001	0.53
moderate vs. clean	-0.39	0.15	0.012	0.68
light vs. clean	-0.11	0.11	0.33	0.89
moderate + heavy vs. clean	-0.45	0.16	0.007	0.63

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).

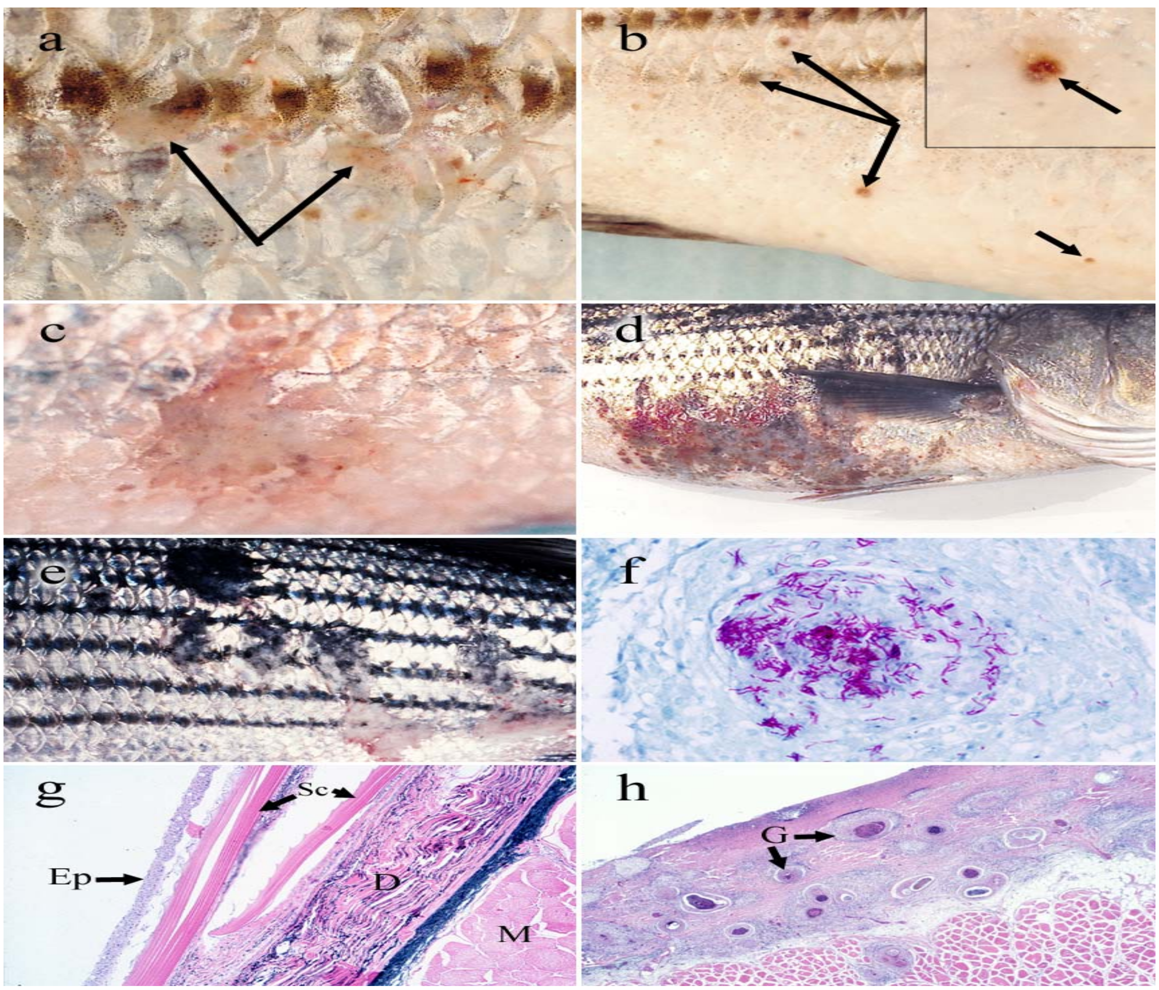


Figure 3. a) Size distribution (fork length in mm), by infection index, of striped bass tag releases from the upper Rappahannock River, fall 2009. b) Relative proportion of each infection index, by fork length, of the tag releases.

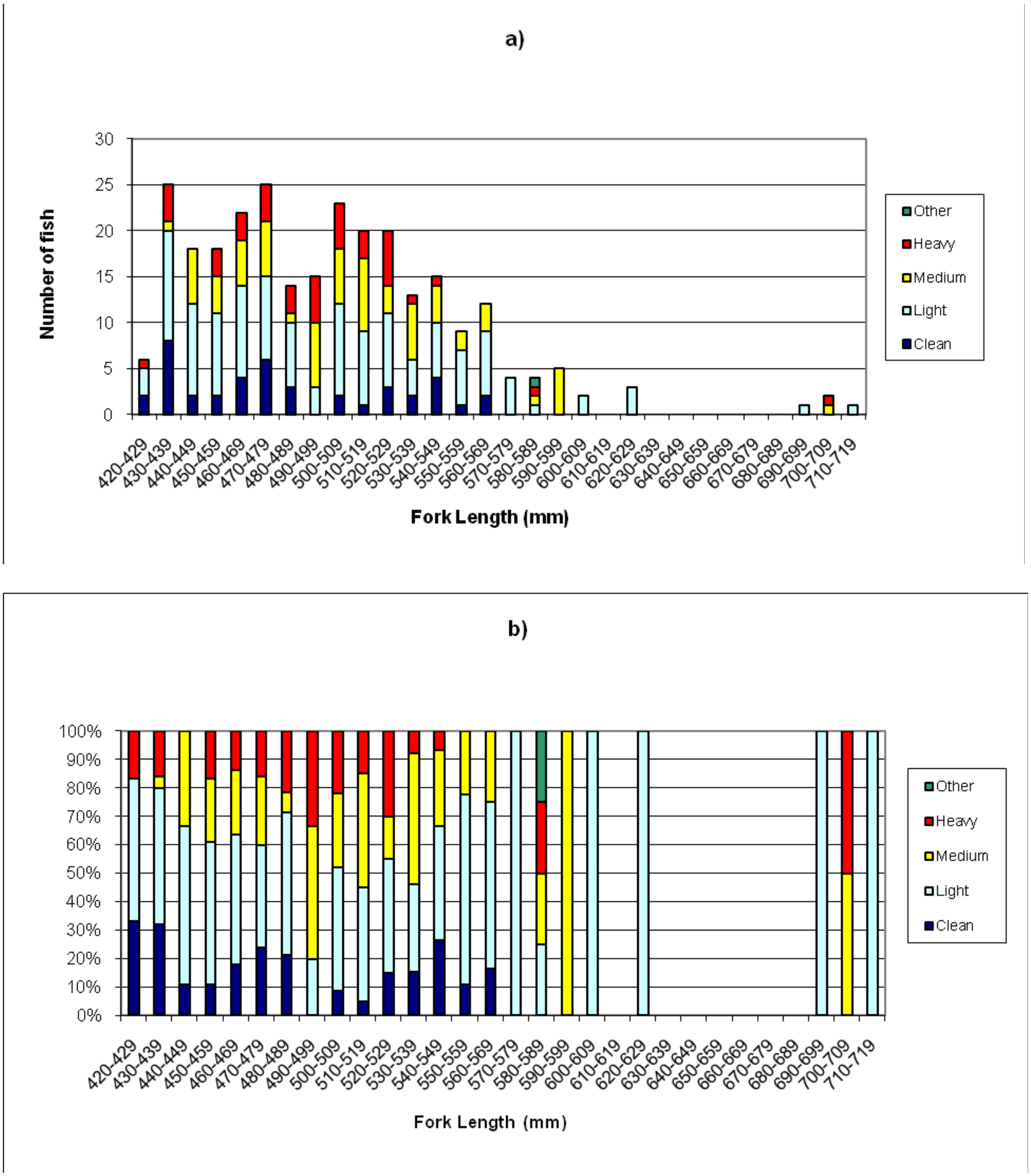
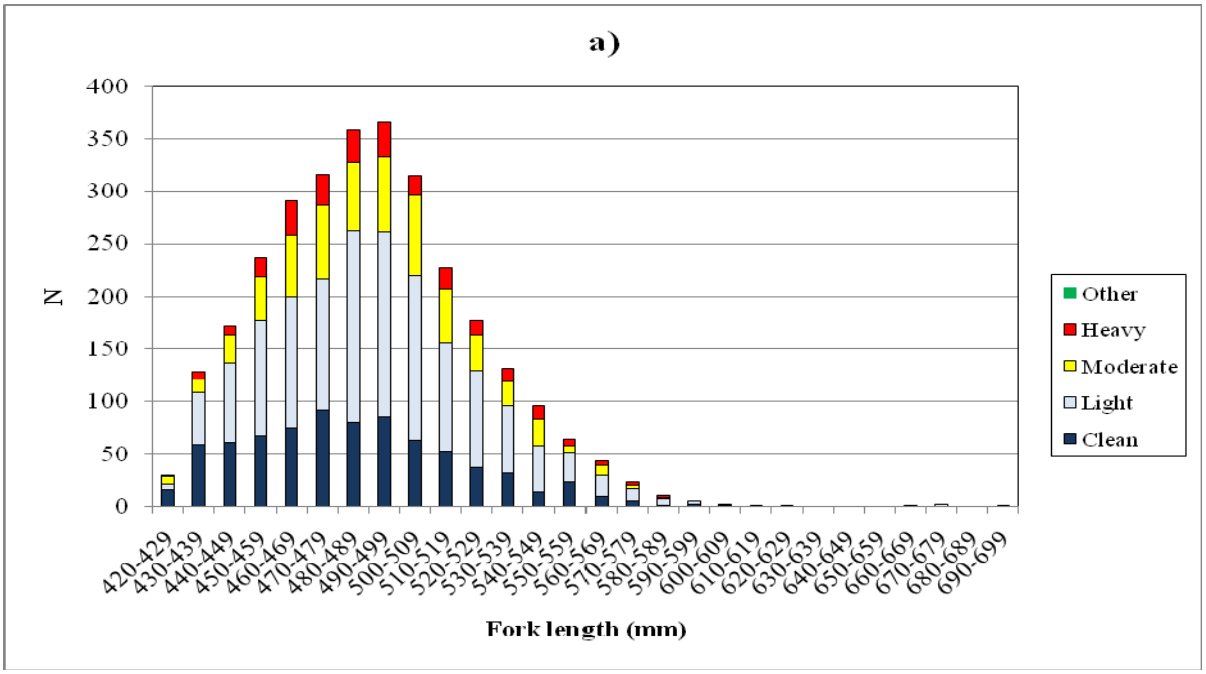


Figure 4. a) Size distribution (fork length in mm), by infection index, of striped bass tag releases from the lower Rappahannock River, fall 2009. b) Relative proportion of each infection index, by fork length, of the tag releases.



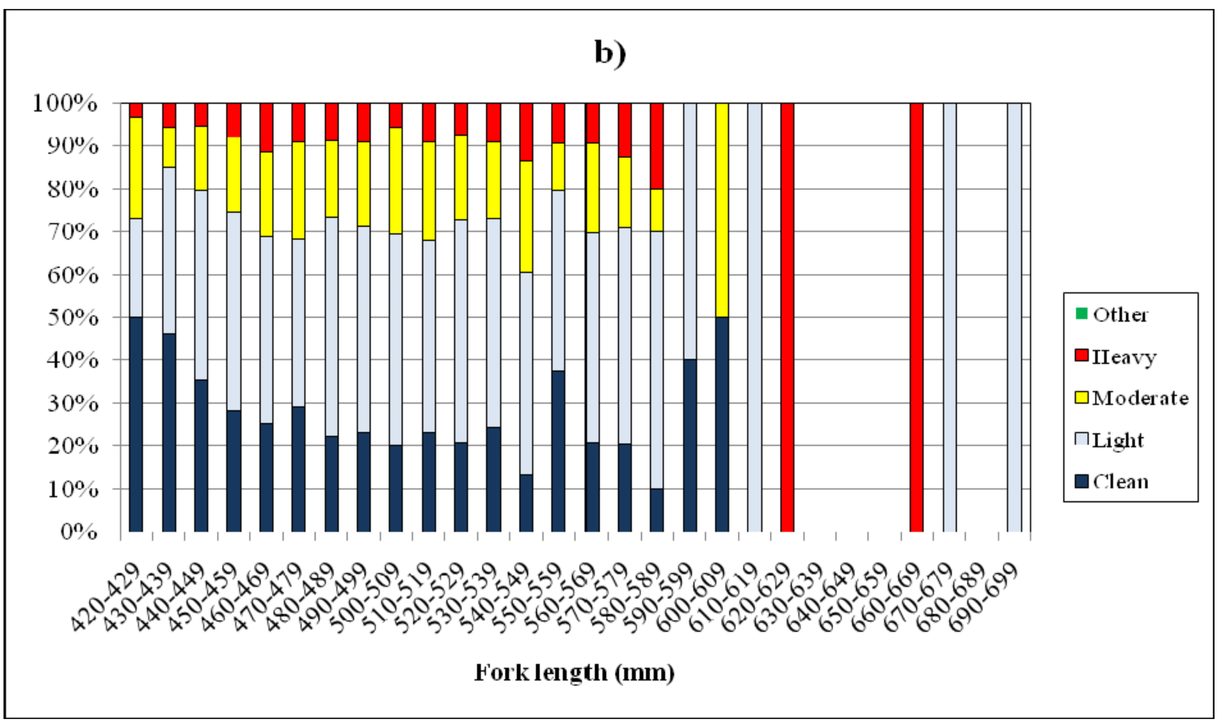
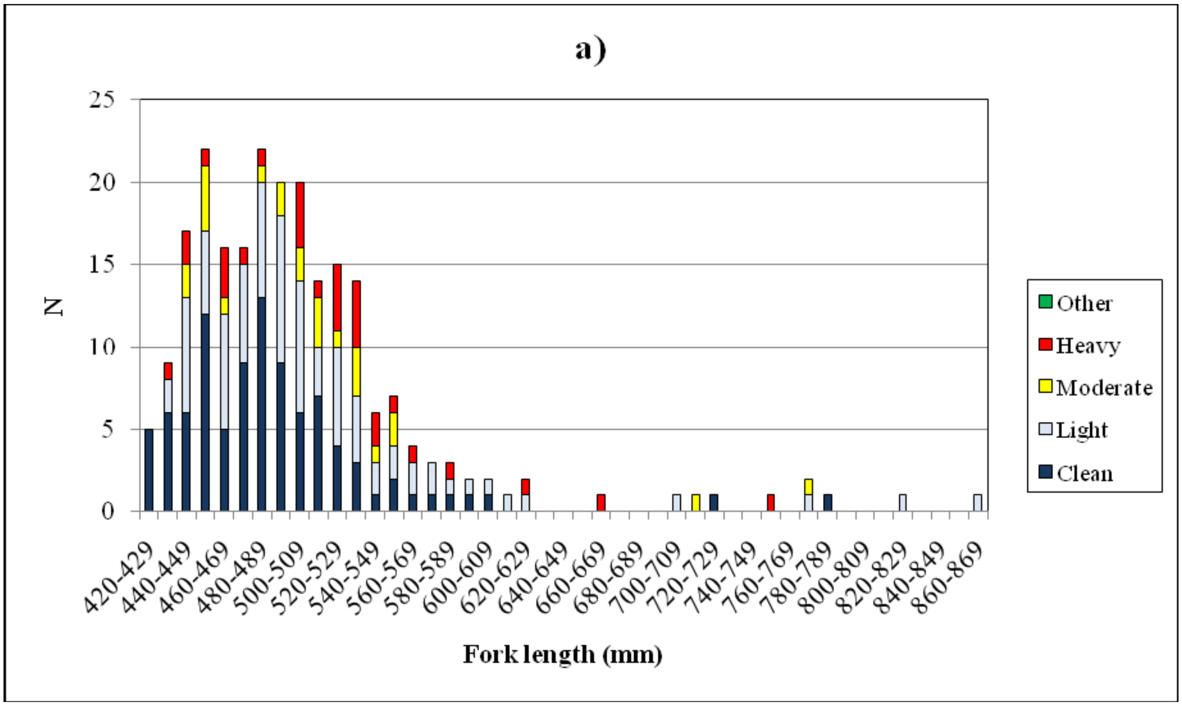


Figure 5. a) Size distribution (fork length in mm), by infection index, of striped bass tag releases from the lower Rappahannock River, spring 2010. b) Relative proportion of each infection index, by fork length, of the tag releases.



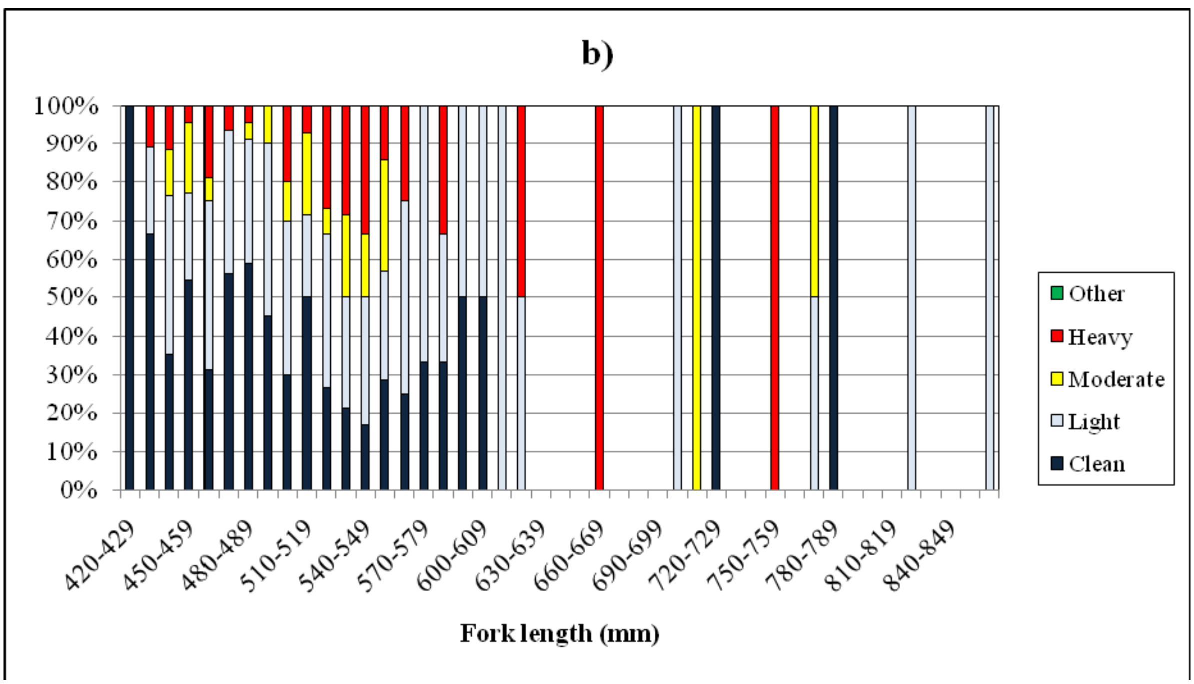


Figure 6. Progression in the mycobacteriosis skin severity index, with age, of the 2002 year class of striped bass in the lower Rappahannock River, falls 2005-2009.

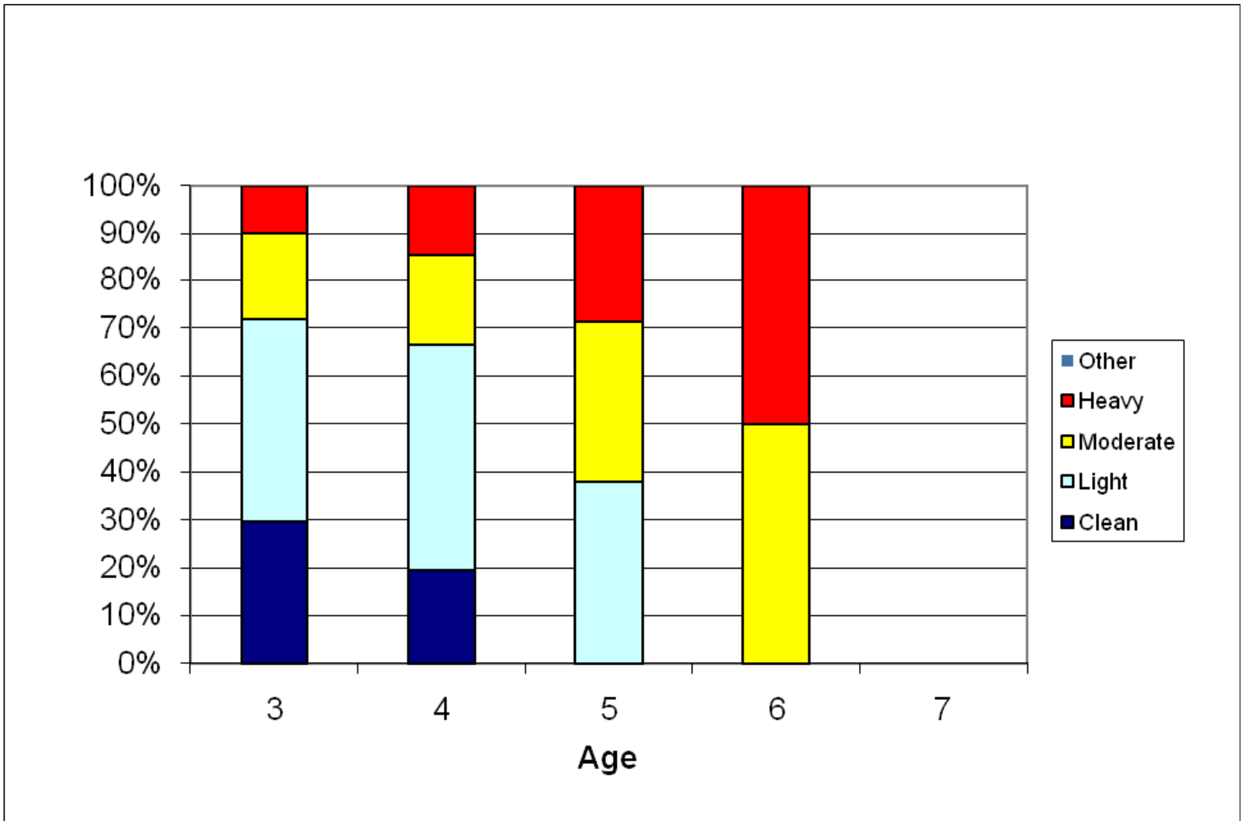


Figure 7. Progression in the mycobacteriosis skin severity index, with age, of the 2003 year class of striped bass in the lower Rappahannock River, falls 2006 - 2009.

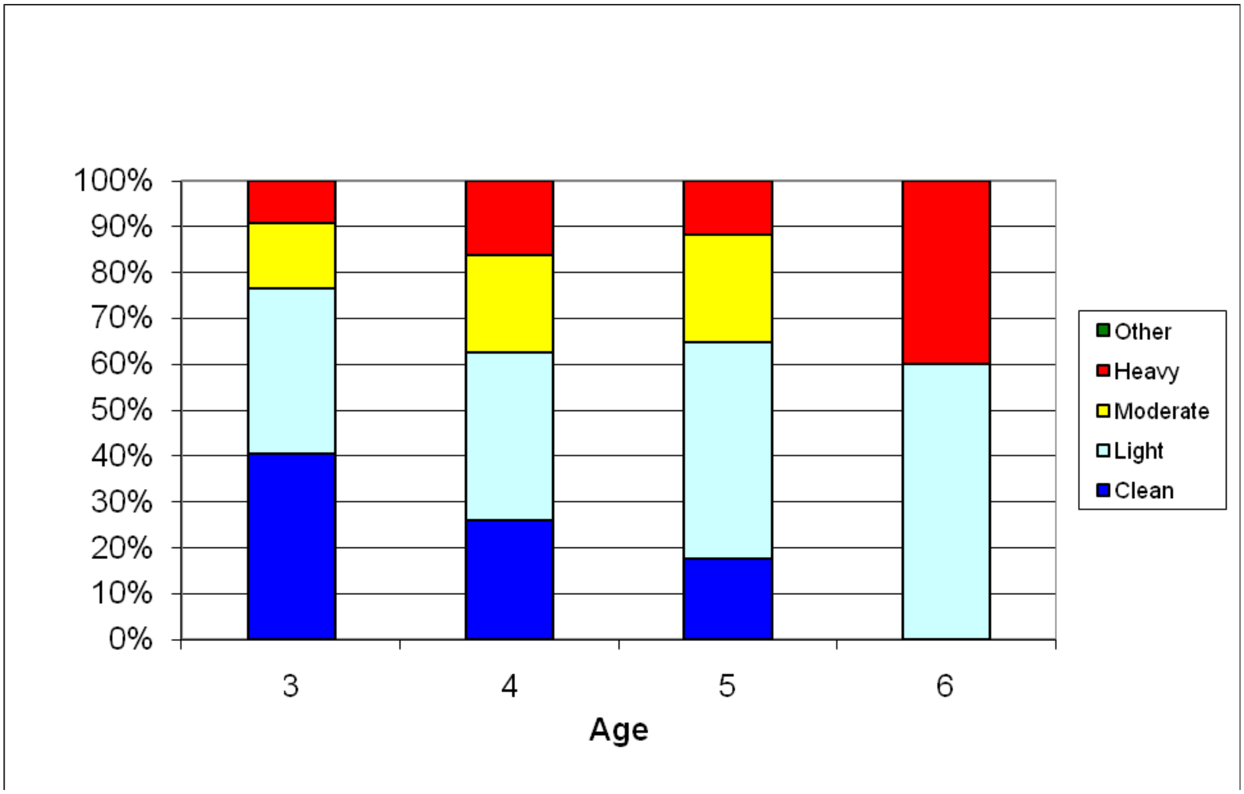


Figure 8. Progression in the mycobacteriosis skin severity index, with age, of the 2004 year class of striped bass in the lower Rappahannock River, falls 2007 - 2009.

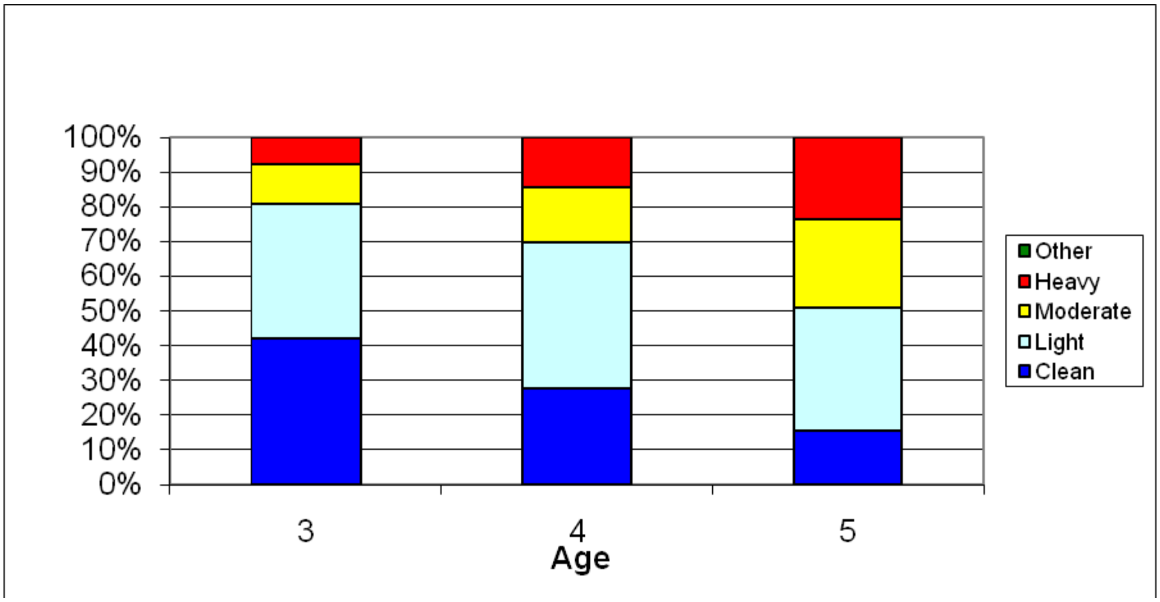


Figure 9. Progression of mycobacteriosis from lightly diseased at time of release to moderately diseased versus time-at-large for striped bass tagged and released in the Rappahannock River, fall 2005 to present (combined). Numbers next to the data points indicate number of recaptures.

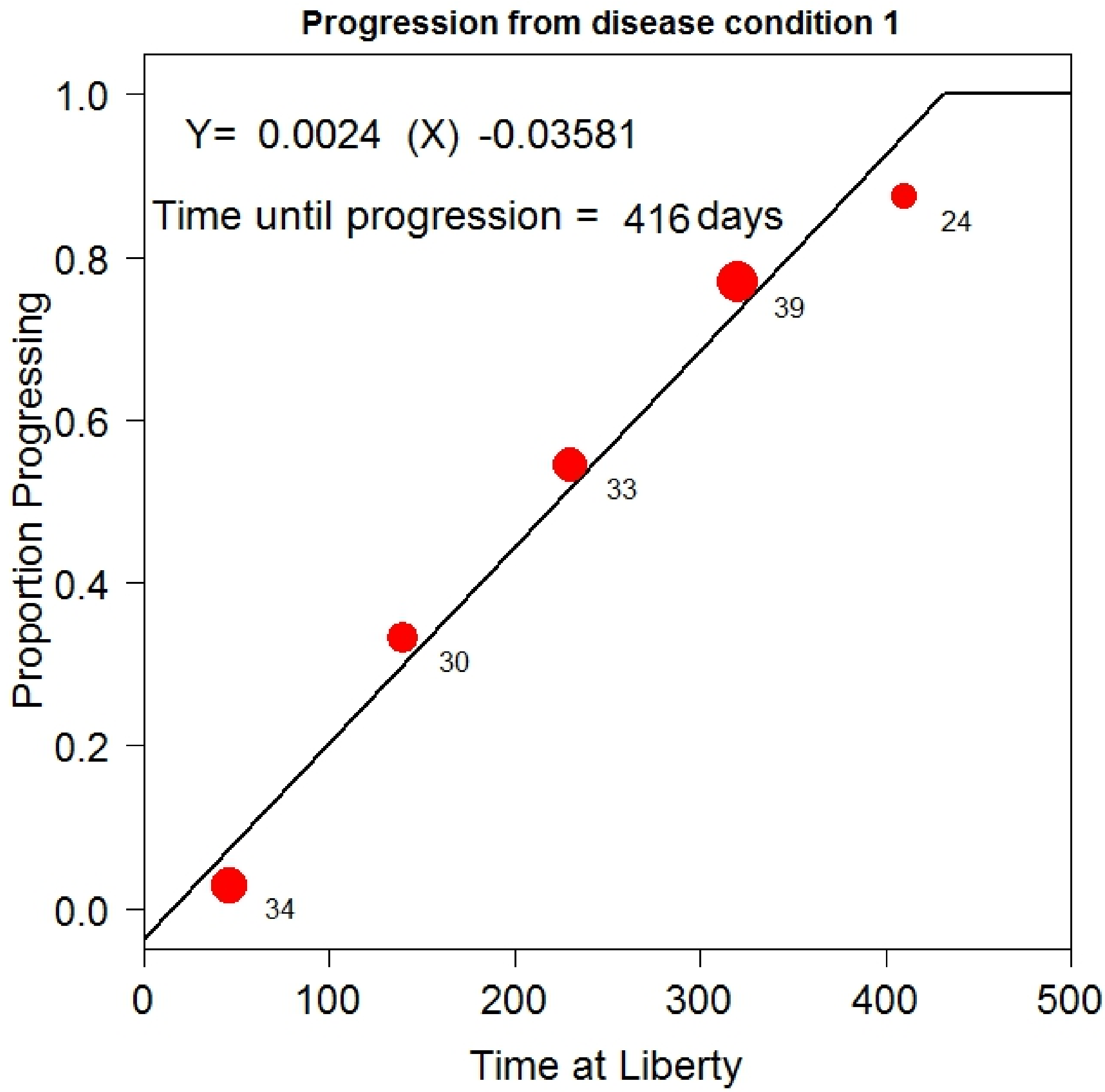


Figure 10. Progression of mycobacteriosis from moderately diseased at time of release to severely diseased versus time-at-large for striped bass tagged and released in the Rappahannock River, fall 2005 to present (combined). Numbers next to the data points indicate number of recaptures.

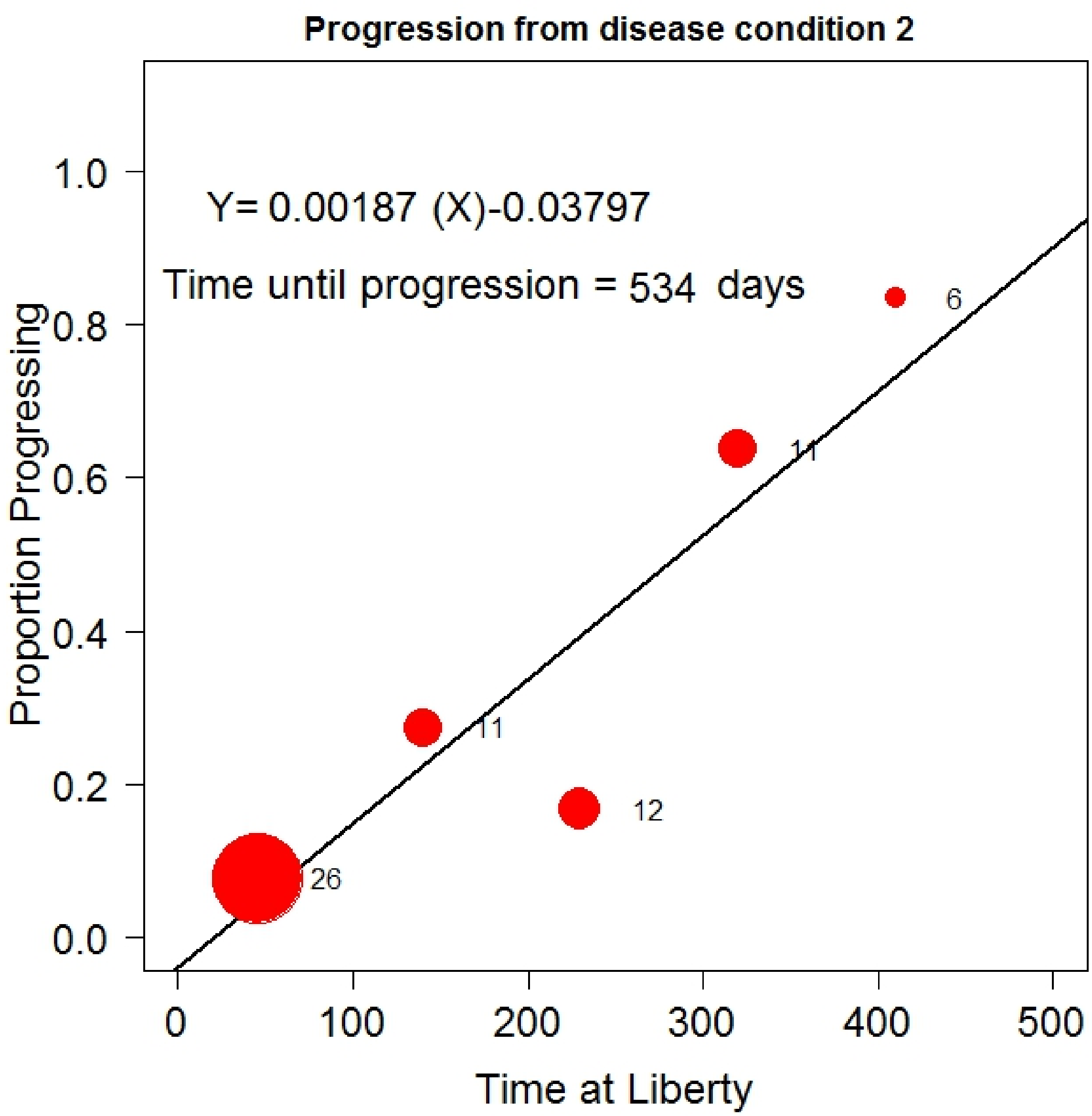


Figure 11. Progression of pigmented foci (PF) of uninfected striped bass based on reassessment of recaptured striped bass originally tagged and released in the Rappahannock River, falls 2005-2009.

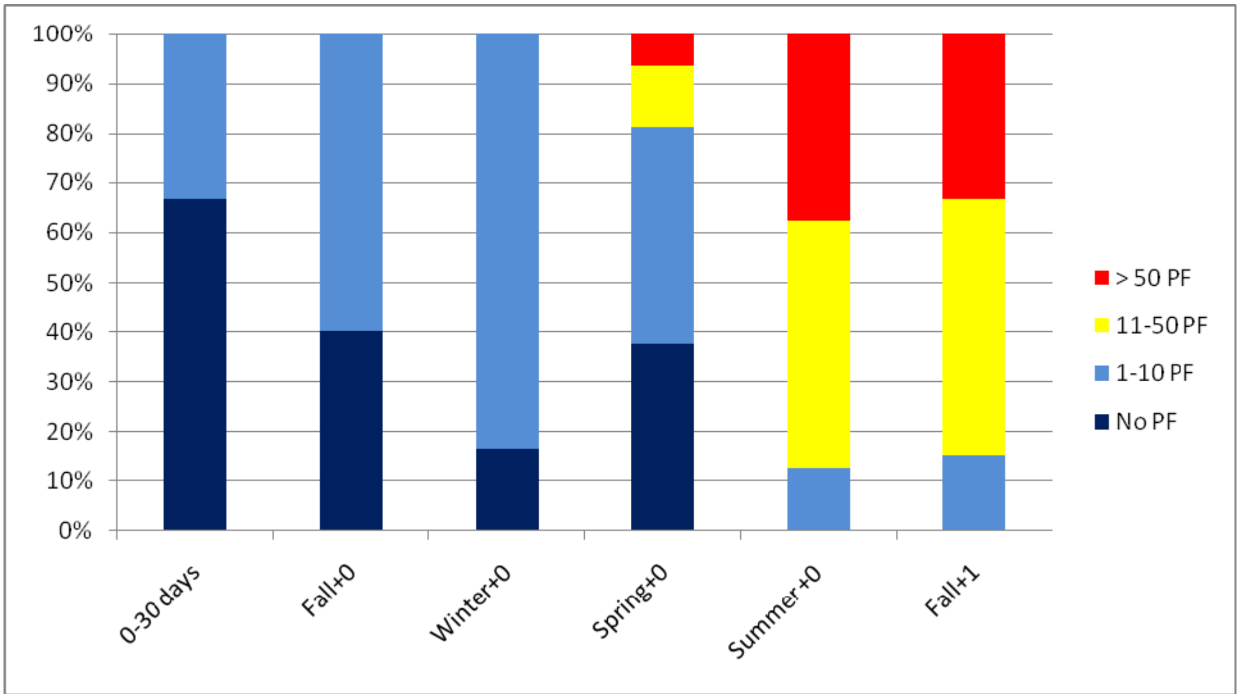


Figure 12. Mean recaptured fork length of fish tagged at the upper and lower locations of the Rapphannock River, broken down by site and release disease condition. A) Original disease assessment of clean. B) Original disease assessment of light. Note the presence of fish "healing" or displaying negative disease progression C) Original disease assessment of Moderate, again with some fish displaying negative disease progression.

Figure 12a.

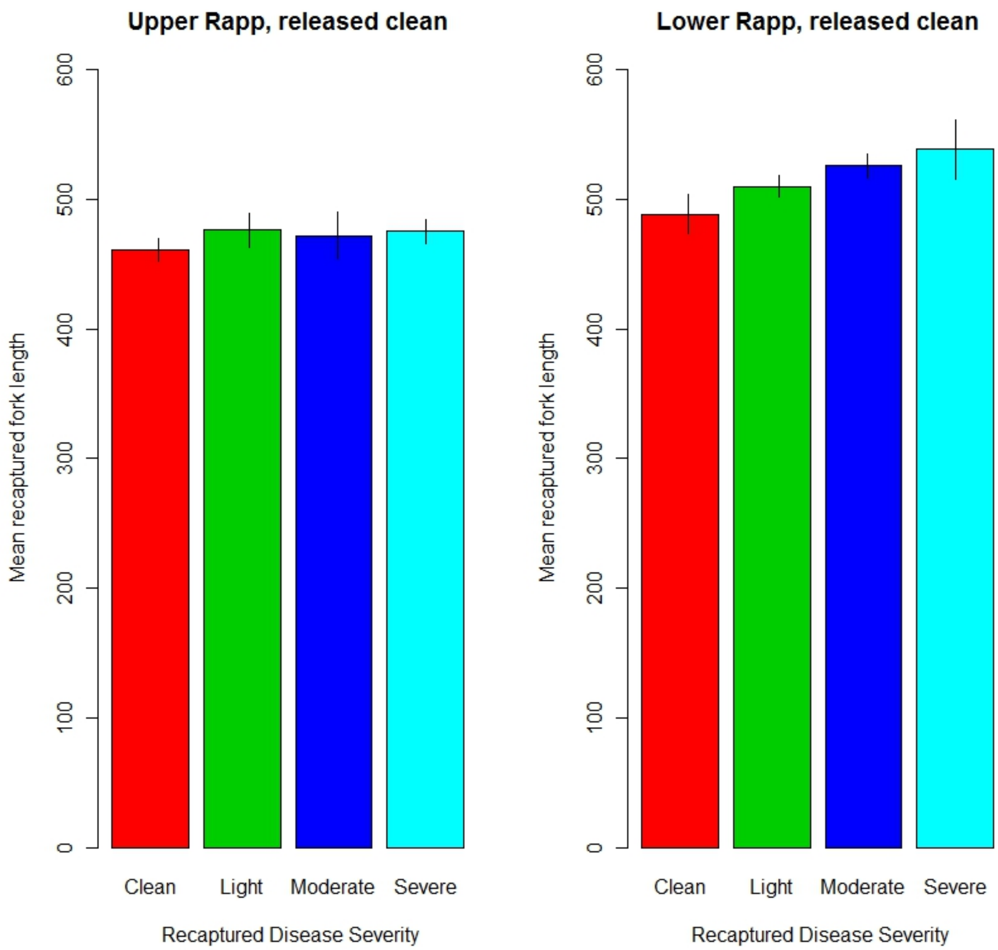


Figure 12b.

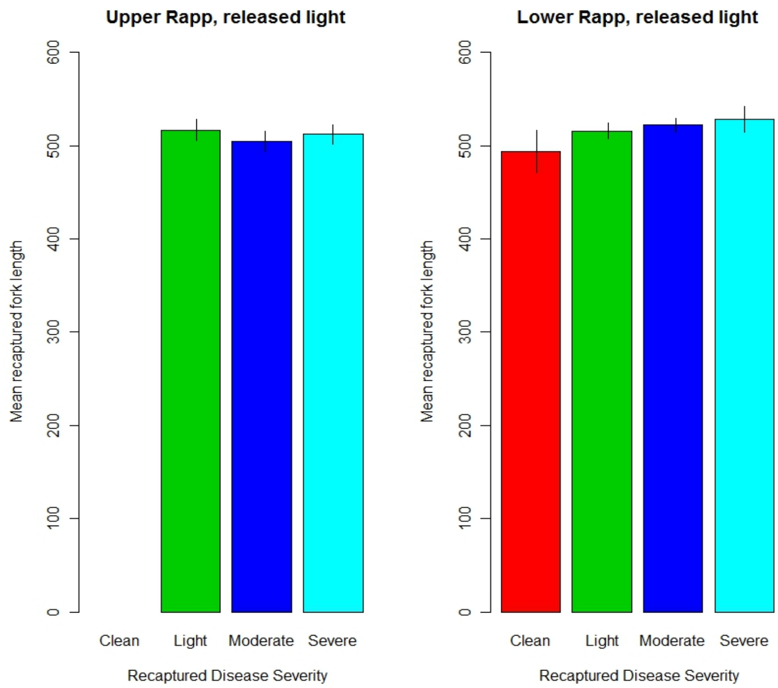


Figure 12c.

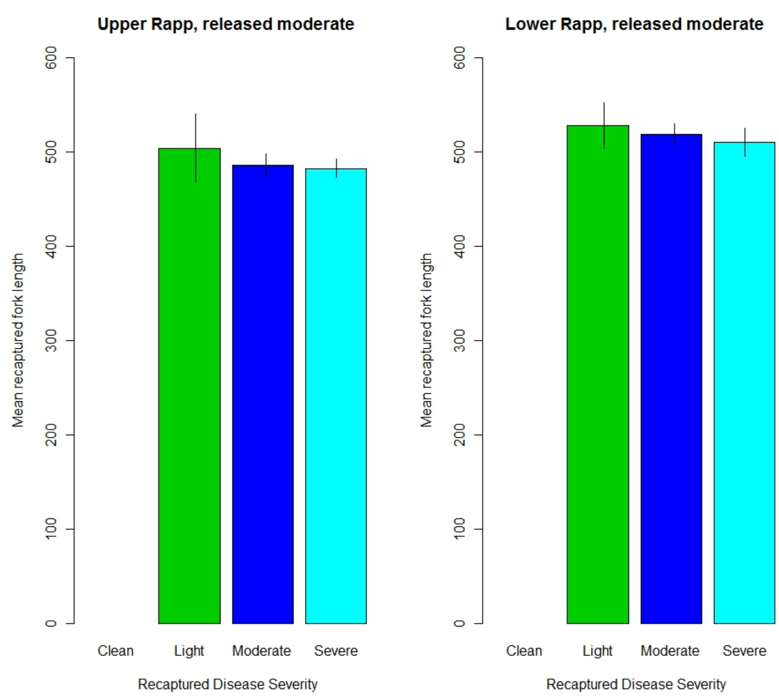


Figure 13. Boxplot of days at liberty by disease progression based site and release disease assessment. A) Fish released as clean with no external signs of the disease. B) Fish with an original assessment of light, note the presence of fish "healing" or displaying negative disease progression. C) Fish released with a disease assessment of moderate, again with some fish displaying negative disease progression.

Figure 13a.

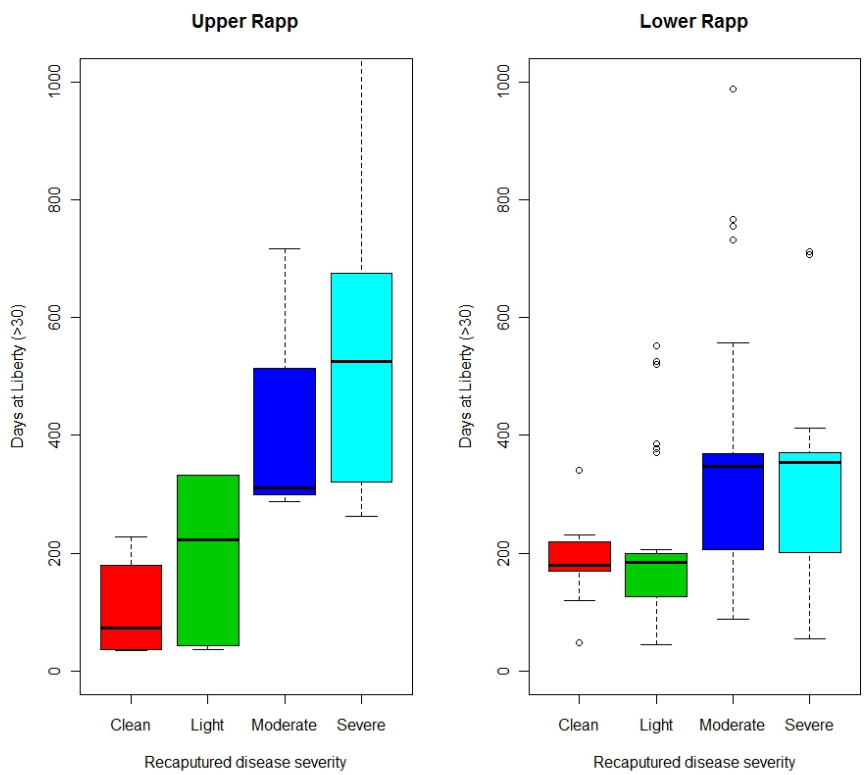


Figure 13b.

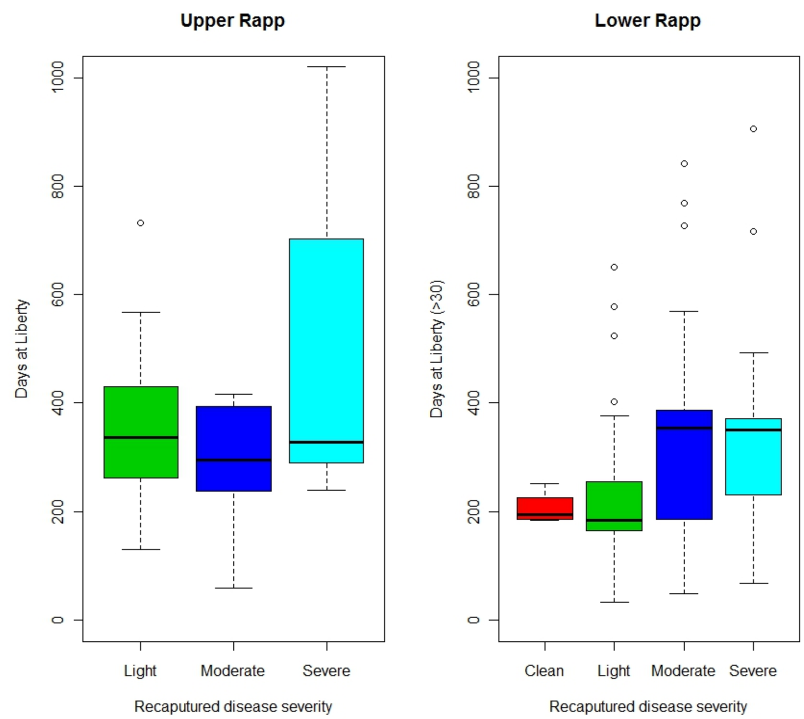


Figure 13c.

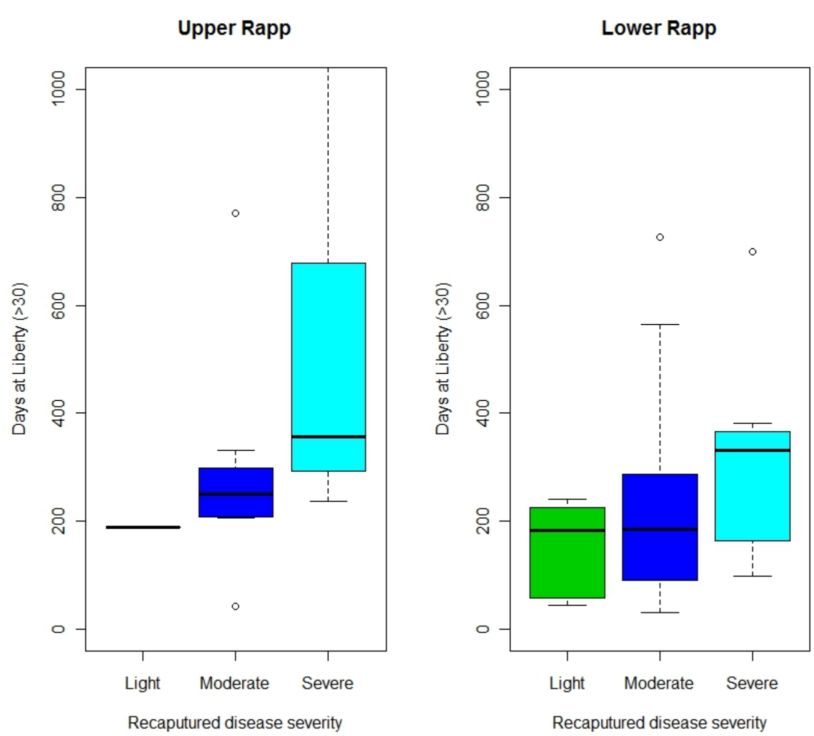
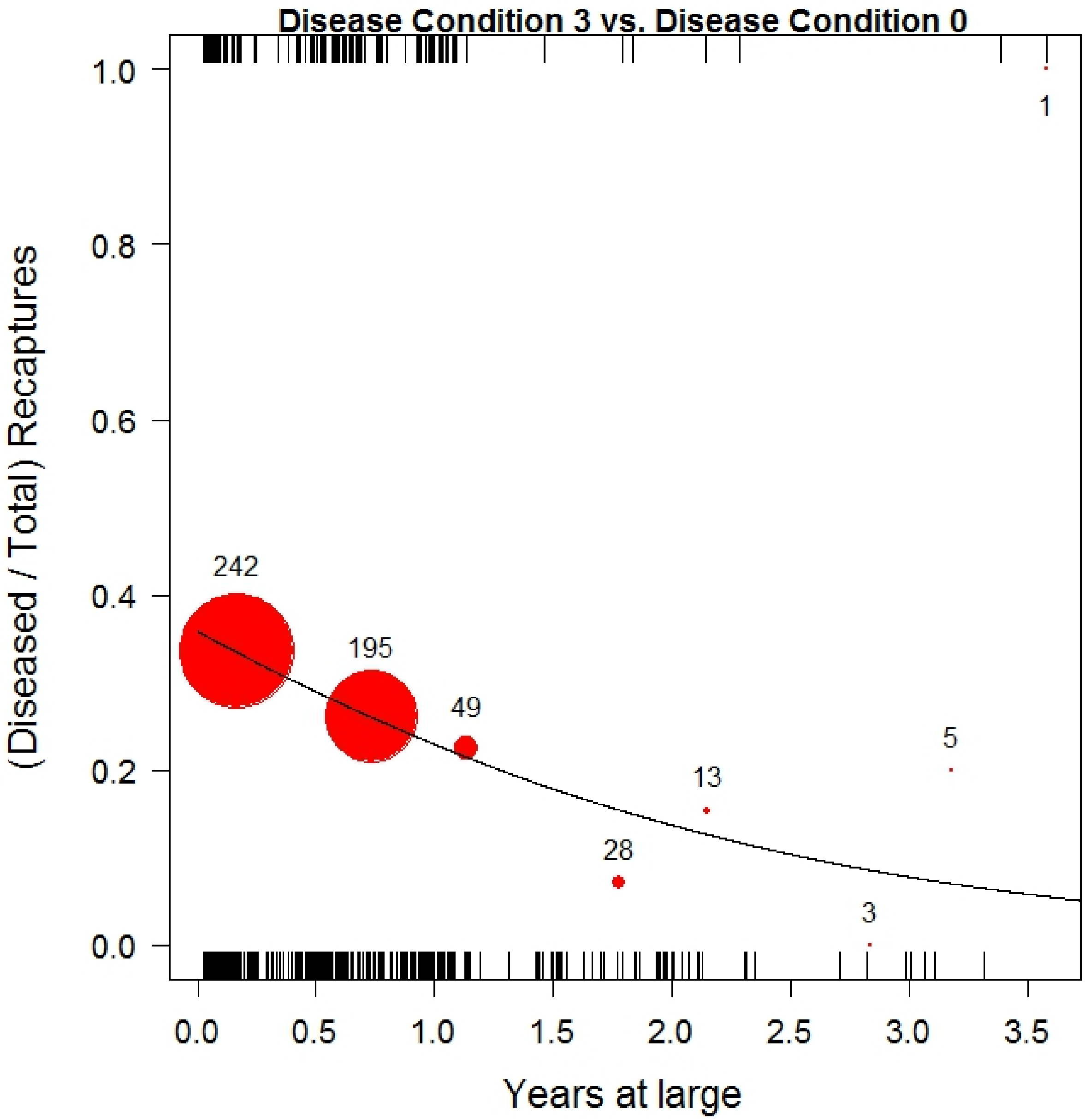


Figure 14. Logarithm of the ratio of returns of fish tagged in disease condition *x* and disease condition 0 (fish in condition 0 are “clean”, showing no signs of the disease) as a function of time at liberty. Numbers next to the data points are the number of tag returns. The slope of the weighted regression 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 = -0.62. The exponentiated slope, which is an estimate of the relative survival rate, is 0.53 indicating that fish in condition 3 have 53% of the survival rate of clean fish. B) Condition 2 versus condition 0. Estimated slope = -0.39. The exponentiated slope, which is an estimate of the relative survival rate, is 0.69. C) Condition 1 versus condition 0. Estimated slope = -0.11. The exponentiated slope, which is an estimate of the relative survival rate, is 0.89. D) Conditions 2 and 3 combined versus condition 0. Estimated slope = -0.45. The exponentiated slope, which is an estimate of the relative survival rate, is 0.63.

Figure 14a.



Disease Condition 3 vs. Disease Condition 0
(Diseased / Total) Recaptures
Years at large
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
242
195
49
28
13
3
5
1

Figure 14b.

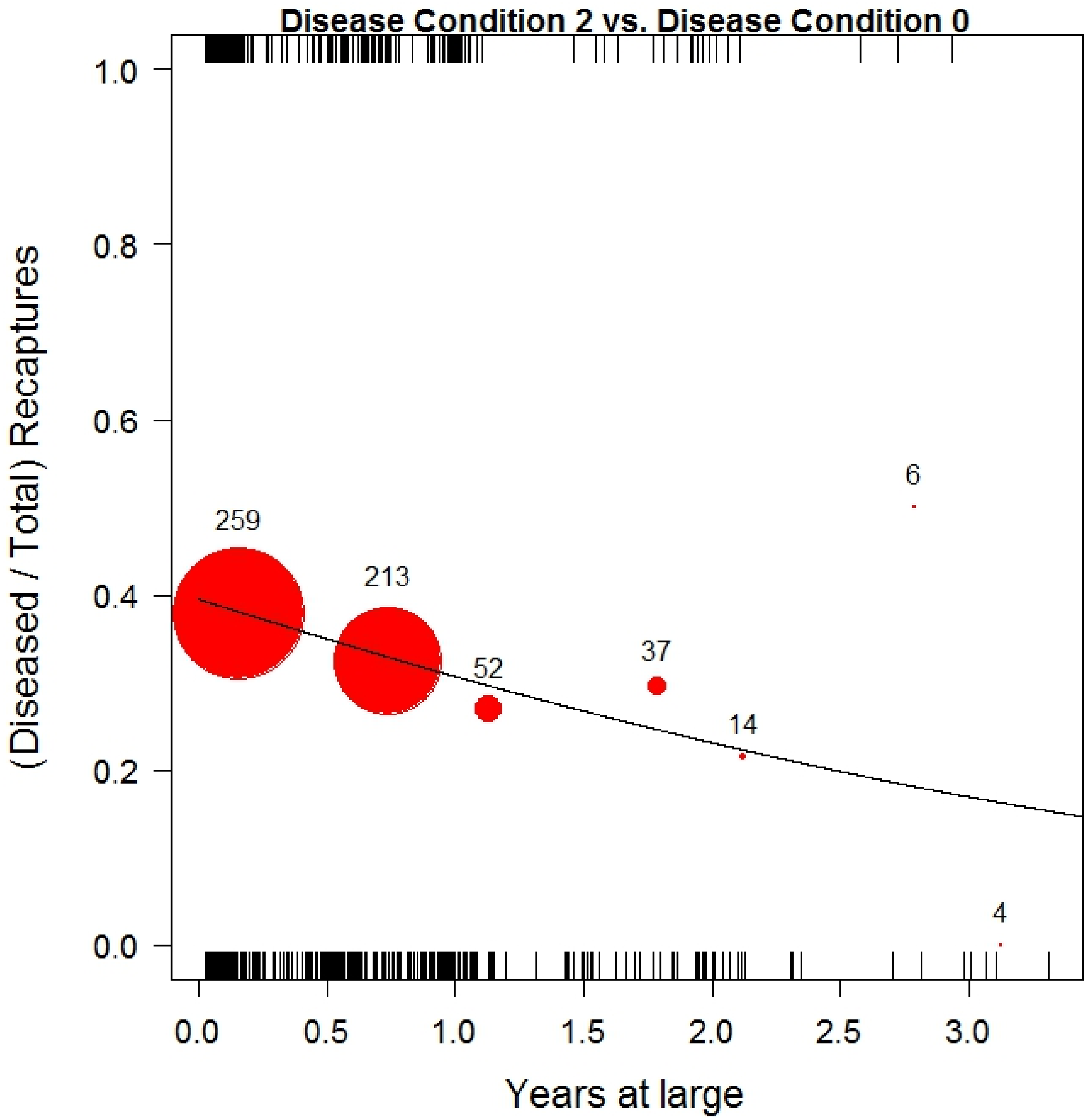
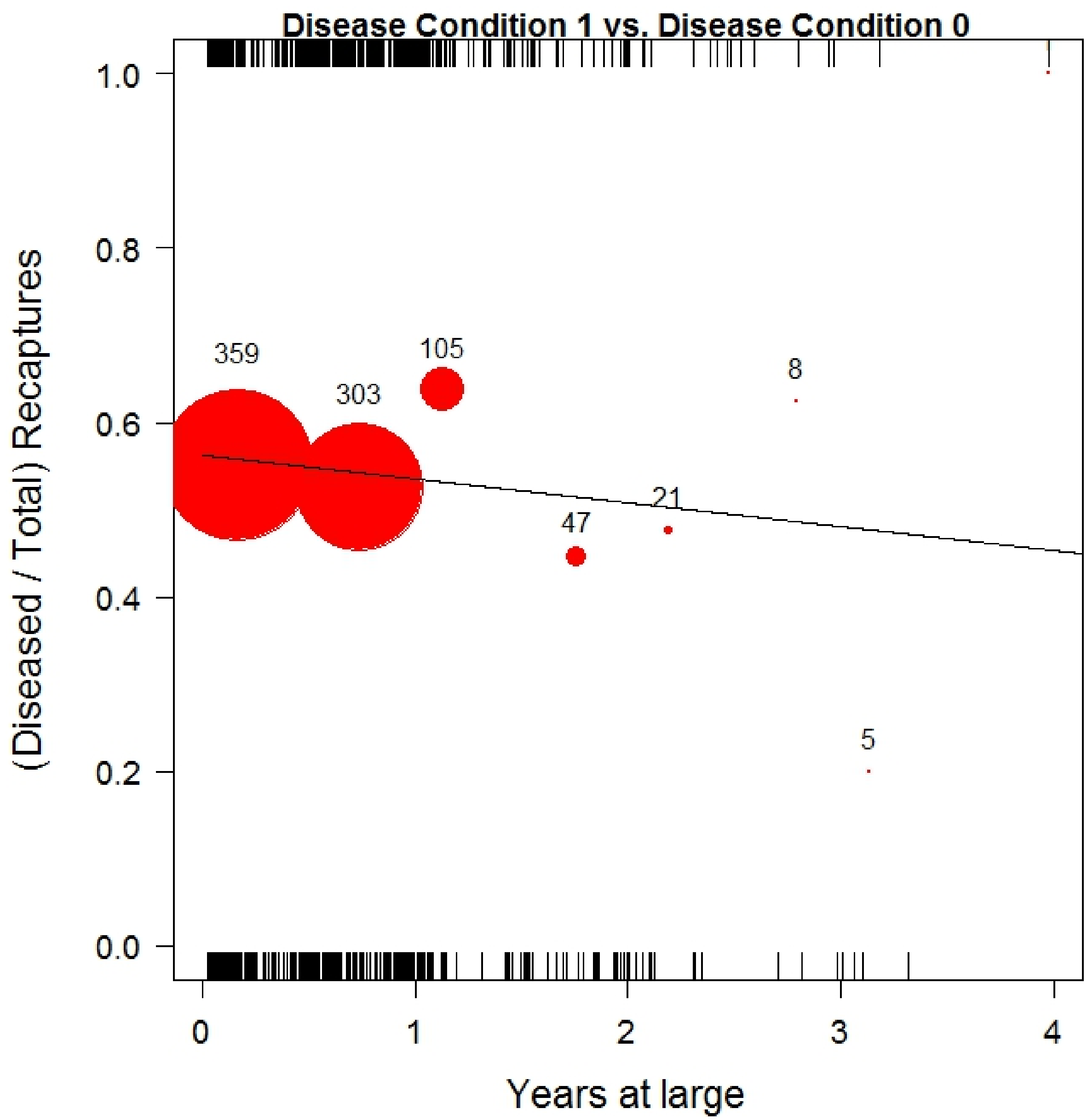
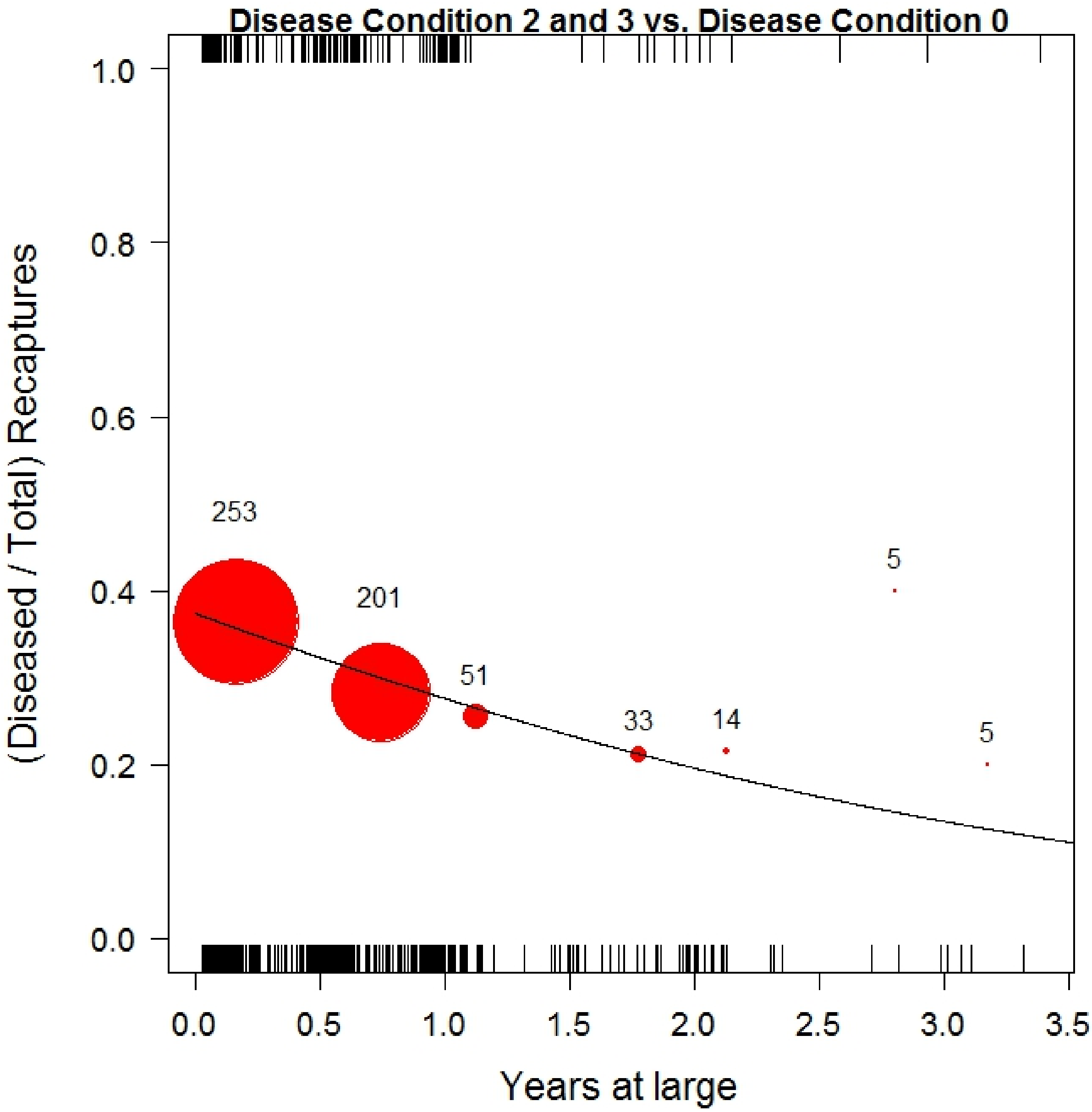

Disease Condition 2 vs. Disease Condition 0
(Diseased / Total) Recaptures
1.0
0.8
0.6
0.4
0.2
0.0
259
213
52
37
14
6
4
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Years at large

Figure 14c.



Disease Condition 1 vs. Disease Condition 0
1.0
0.8
0.6
0.4
0.2
0.0
(Diseased / Total) Recaptures
359
303
105
8
21
47
5
0
1
2
3
4
Years at large

Figure 14d.

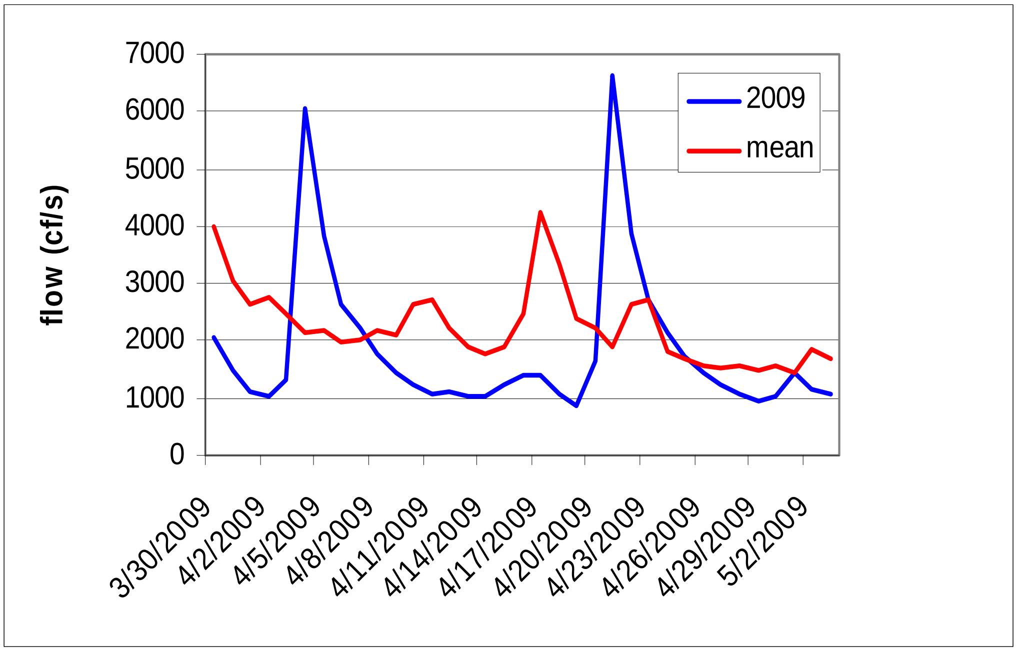


Disease Condition 2 and 3 vs. Disease Condition 0
(Diseased / Total) Recaptures
1.0
0.8
0.6
0.4
0.2
0.0
253
201
51
33
14
5
5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Years at large

Appendix A. Daily flow rates of the Rappahannock River,
30 March – 3 May, 1985-2009.

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 2008-2009.



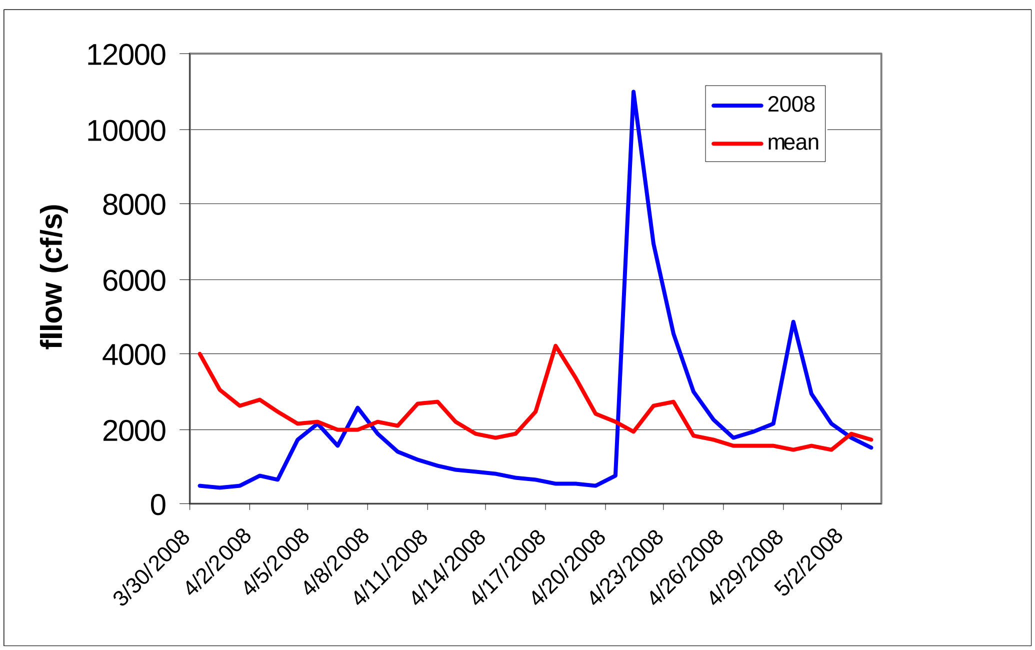
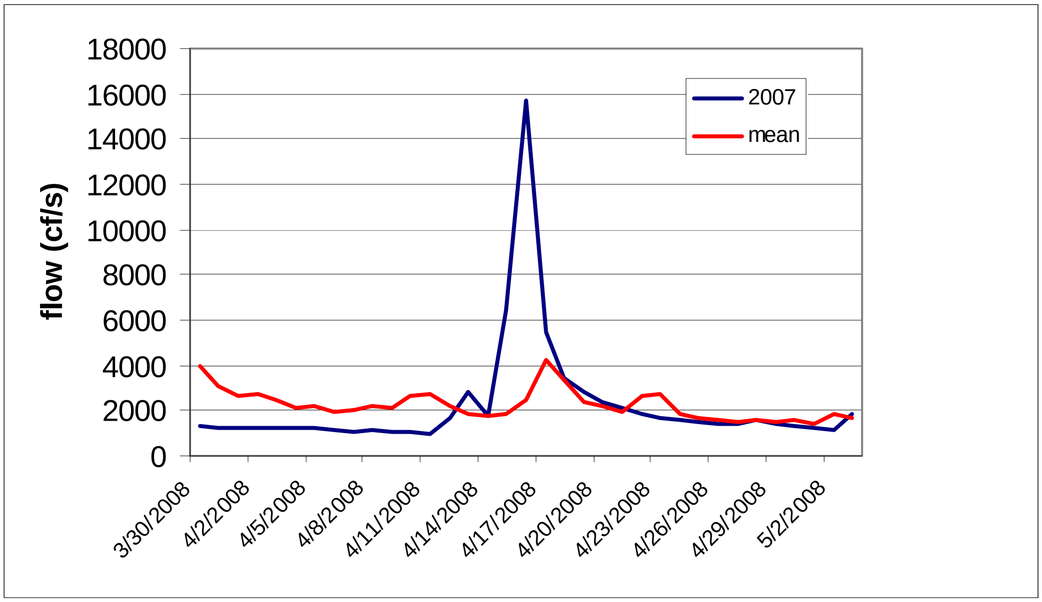


Figure 2. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2006-2007.



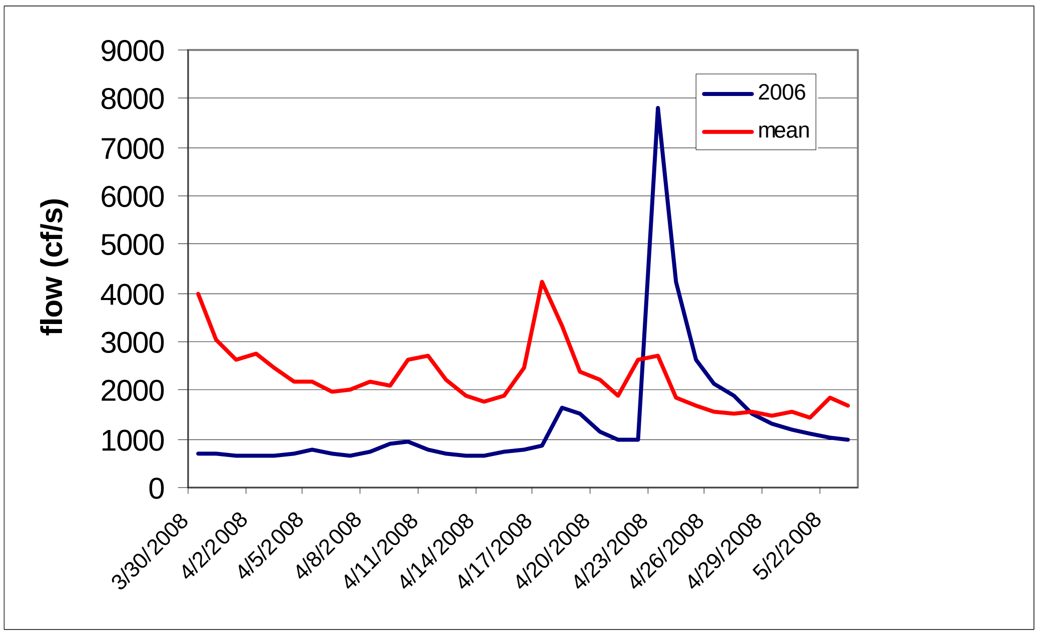
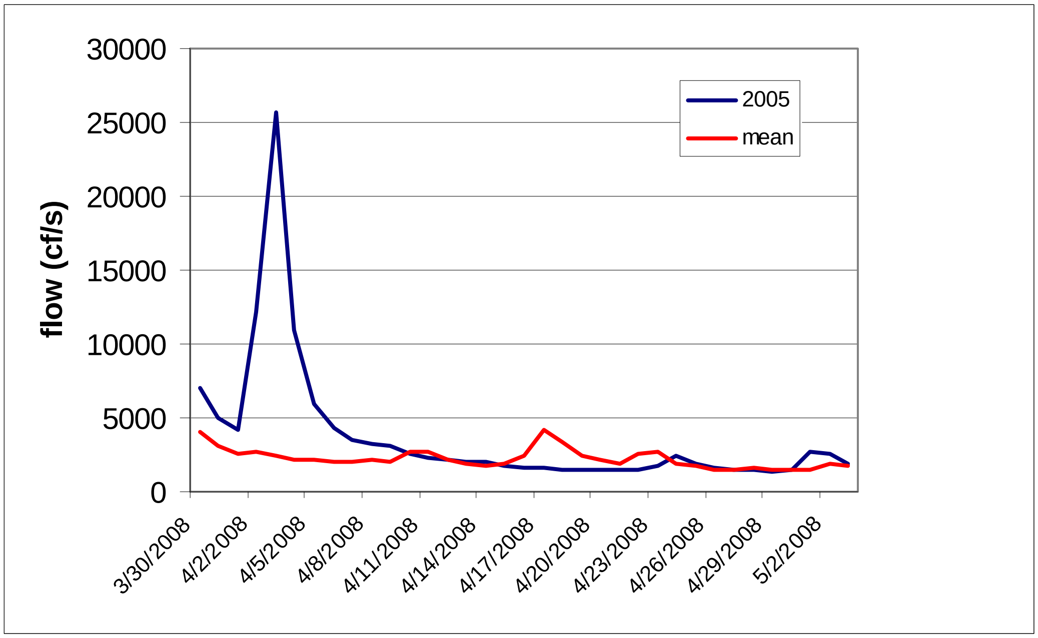


Figure 3. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2004-2005.



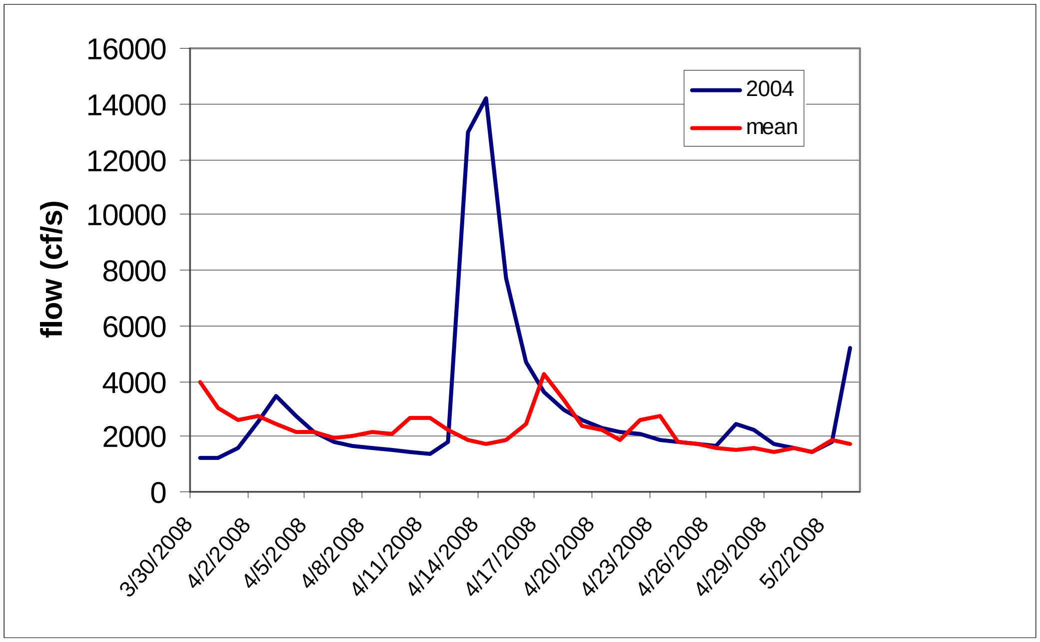
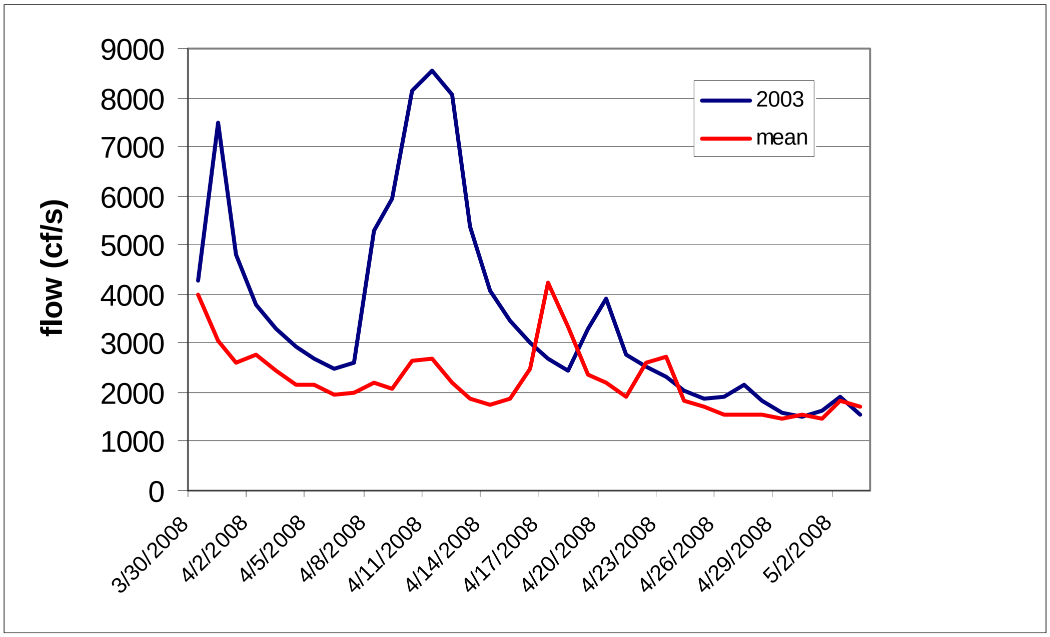


Figure 4. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2002-2003.



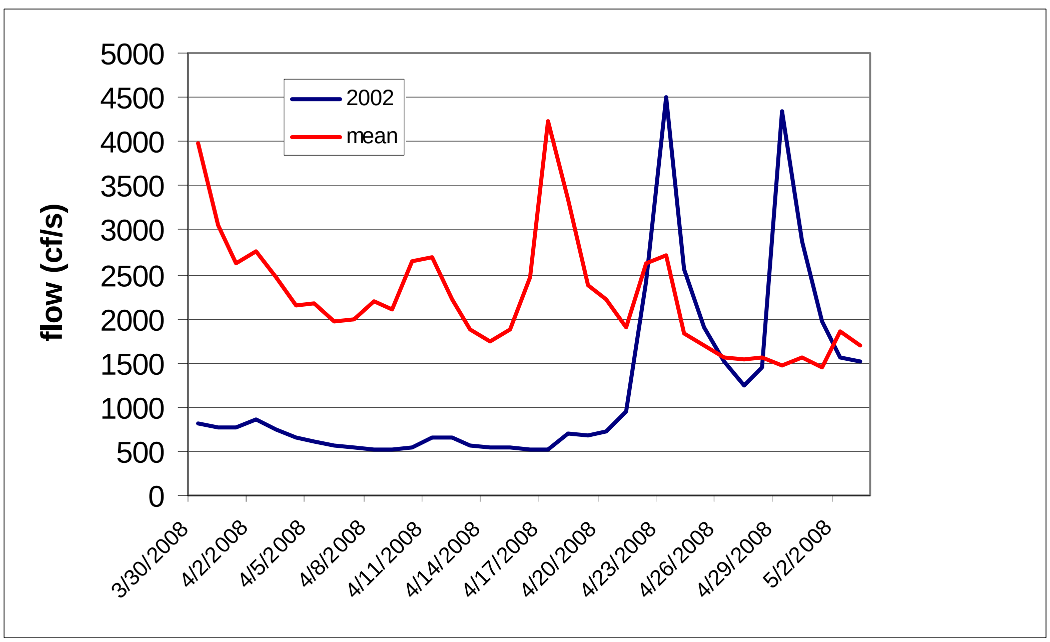
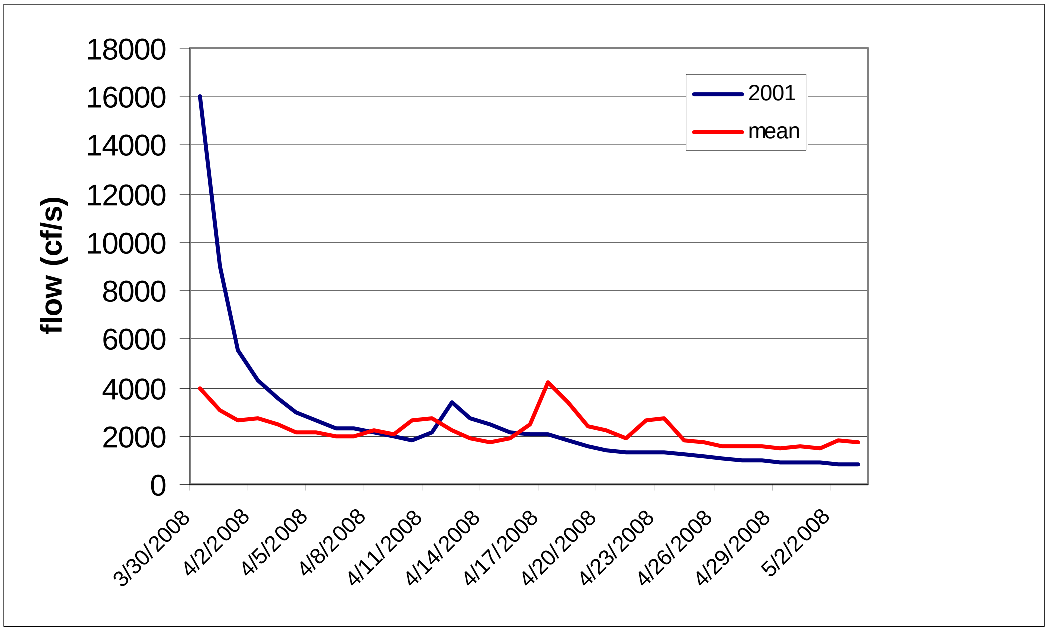


Figure 5. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2000-2001.



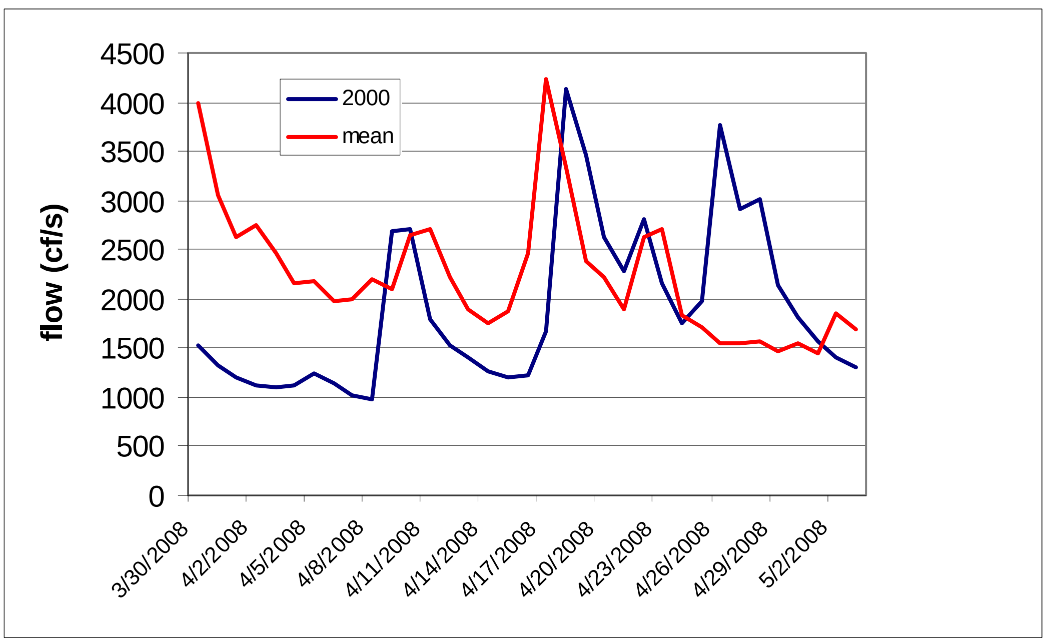
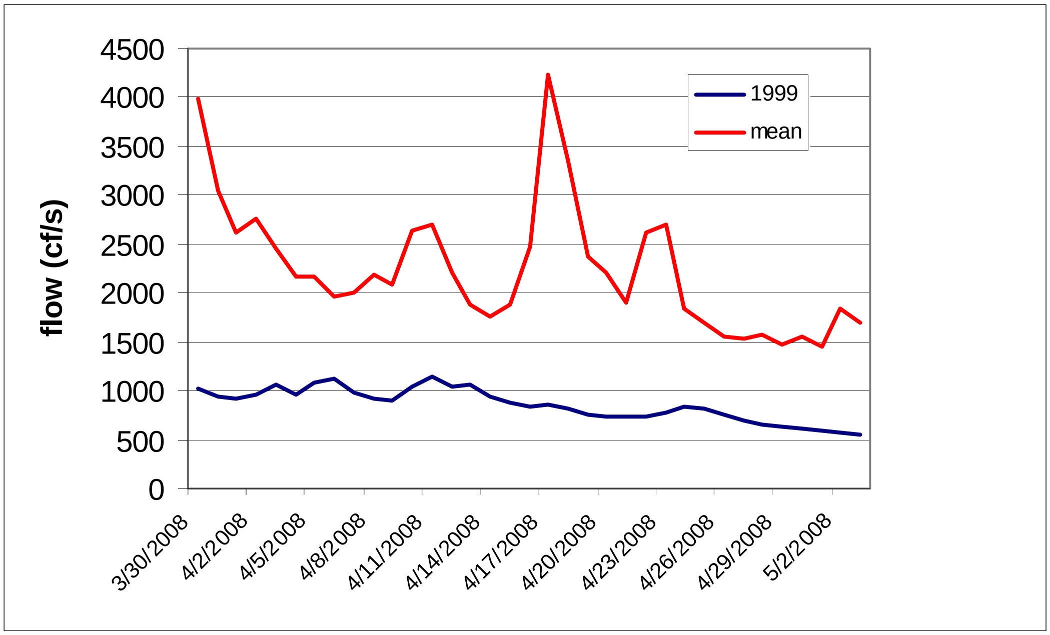


Figure 6. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1998-1999.



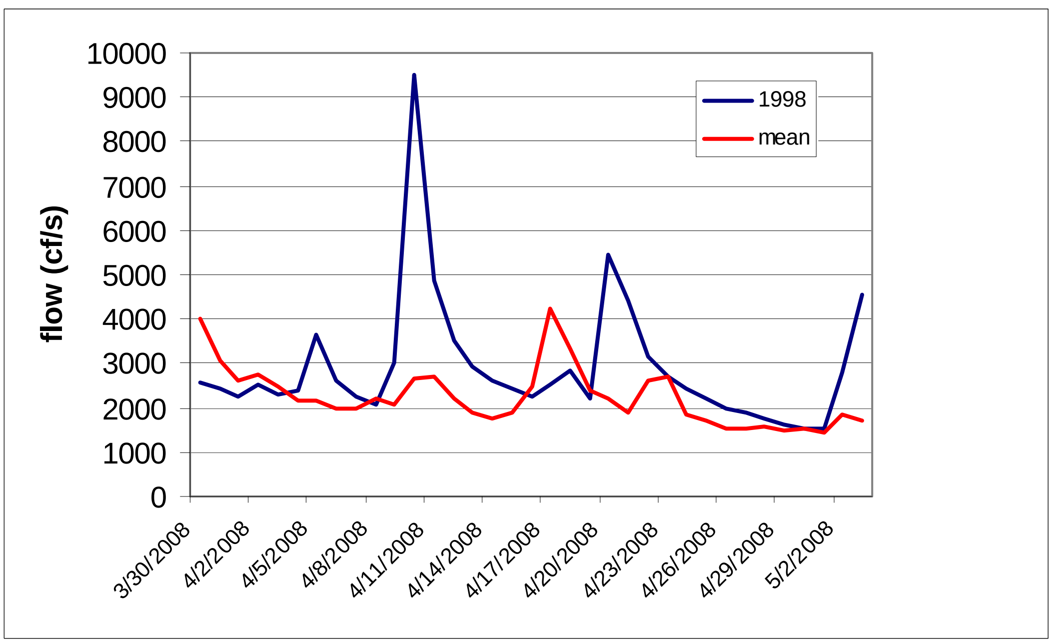
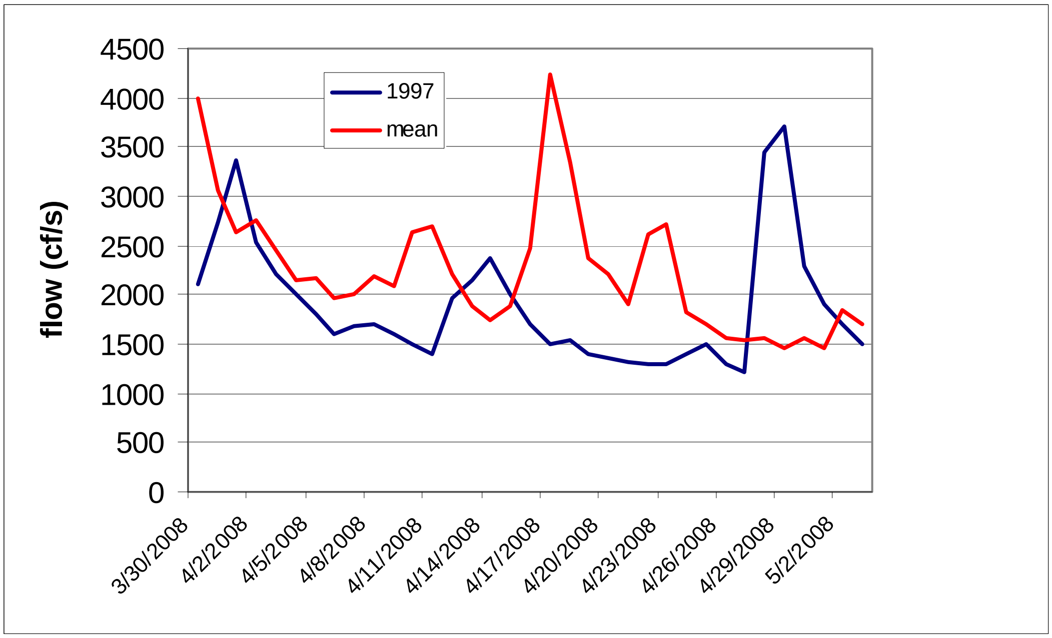


Figure 7. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1996-1997.



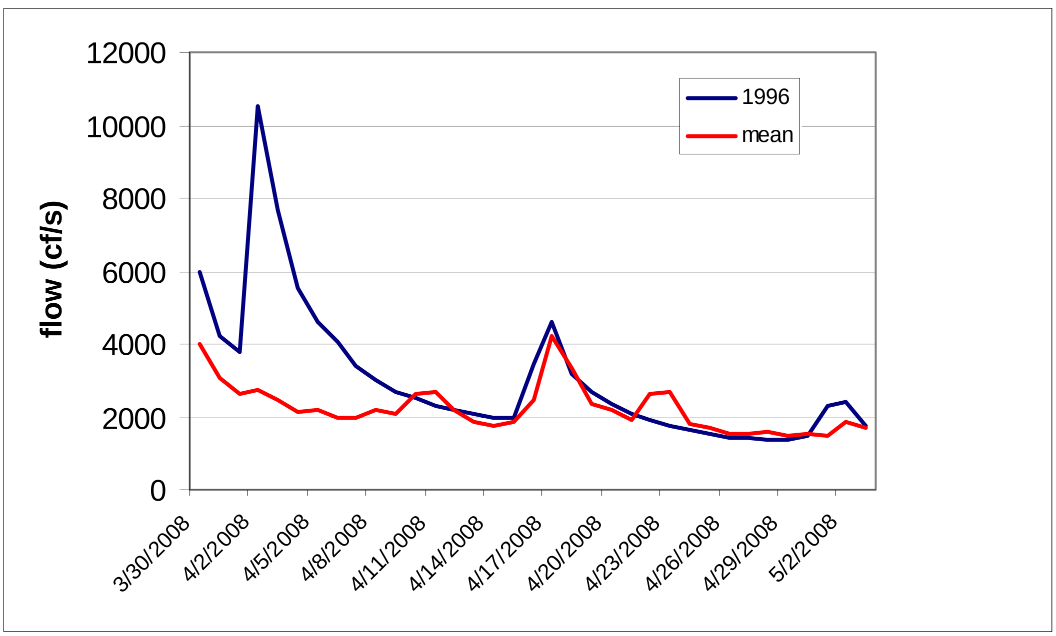
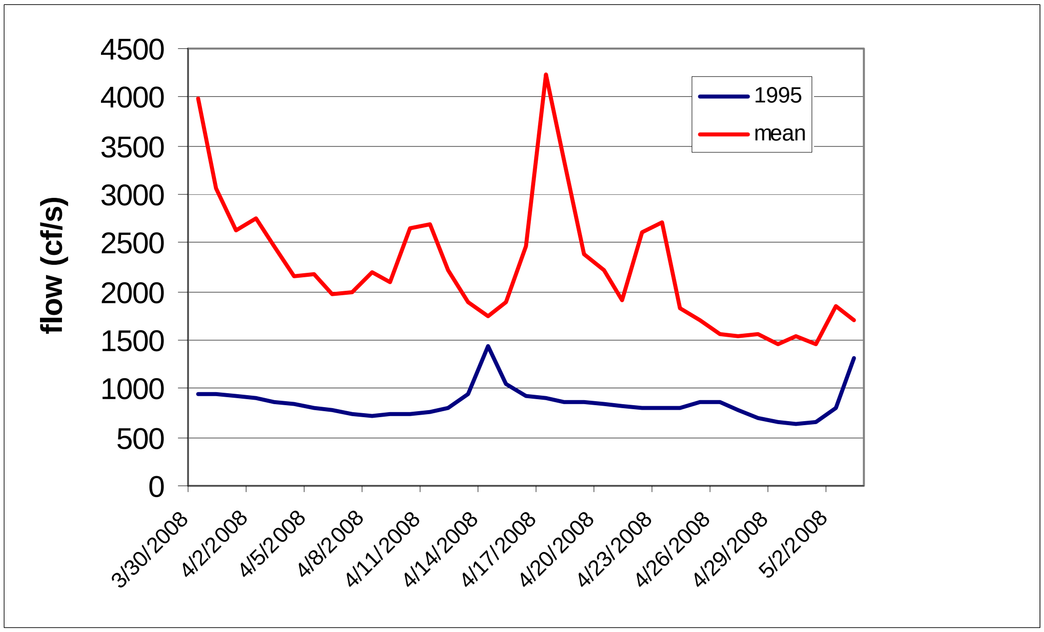


Figure 8. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1994-1995.



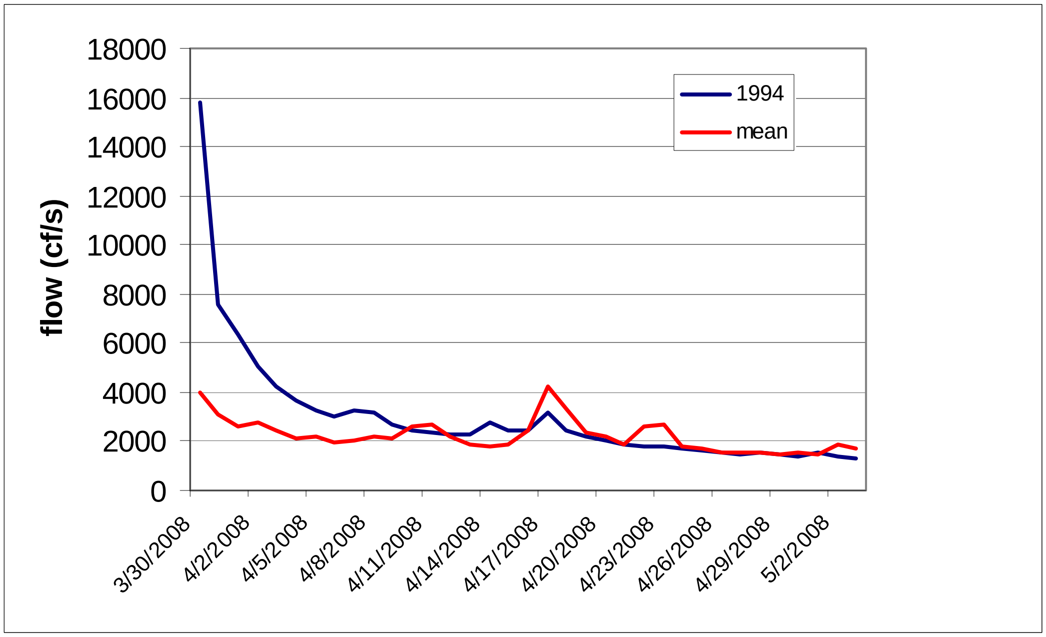
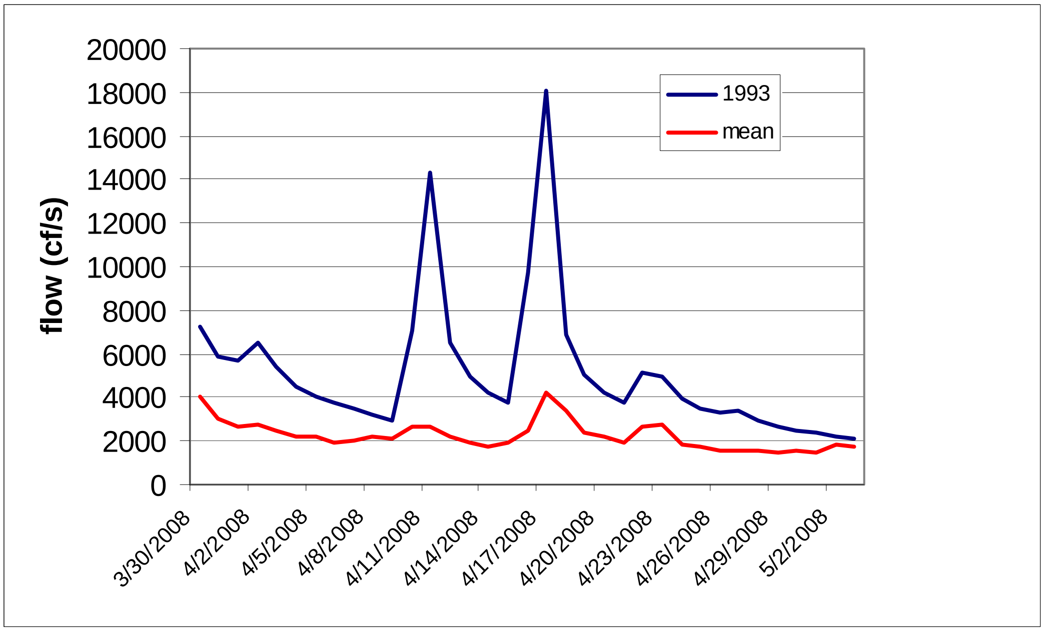


Figure 9. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1992-1993.



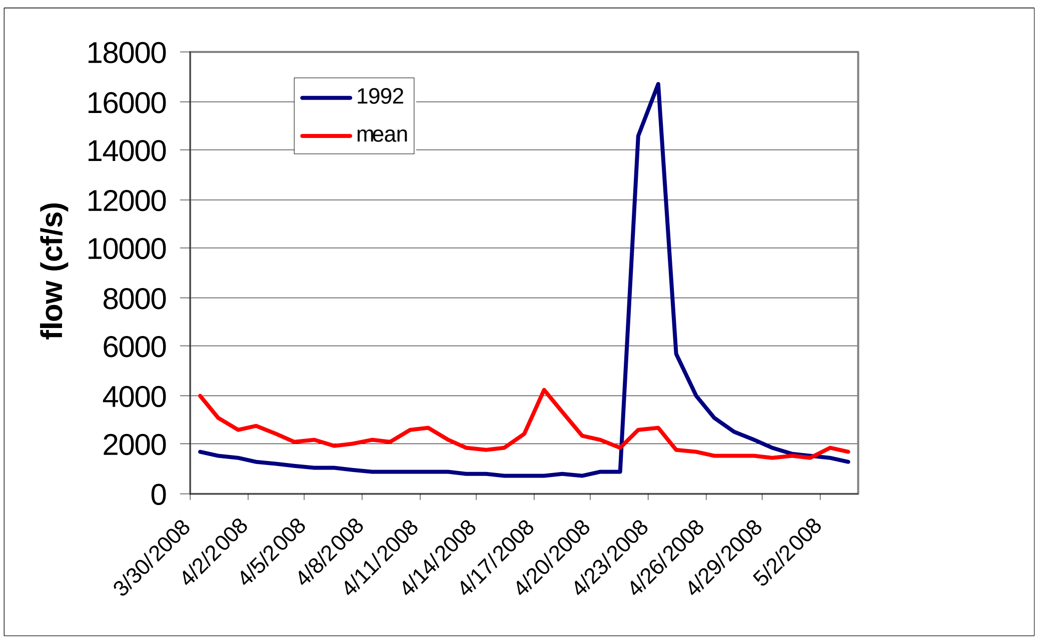
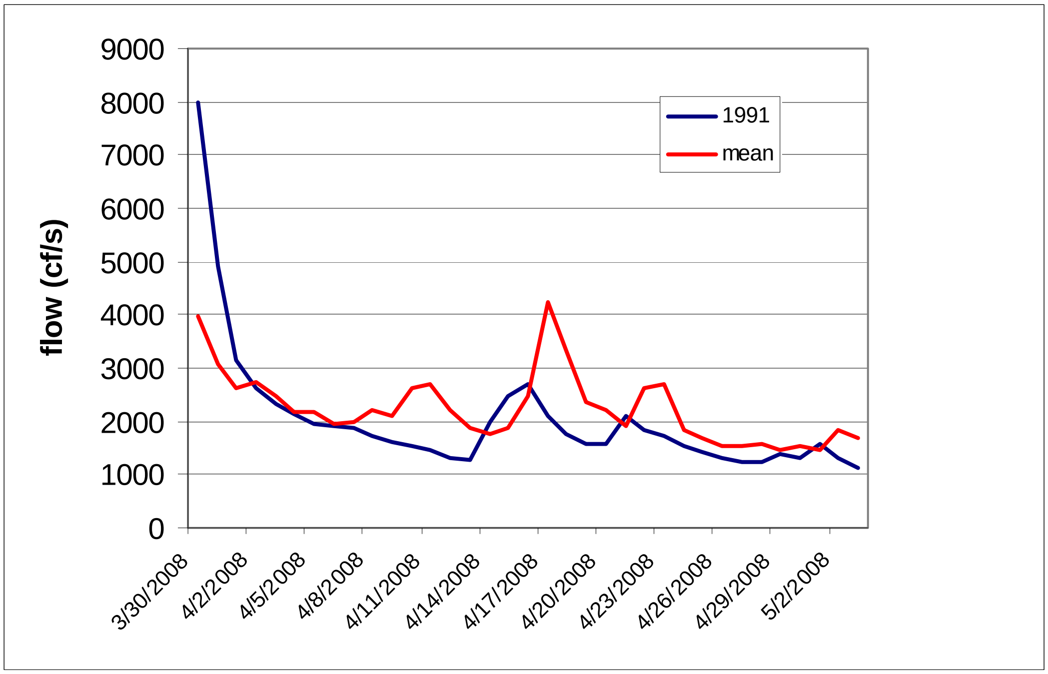


Figure 10. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1990-1991.



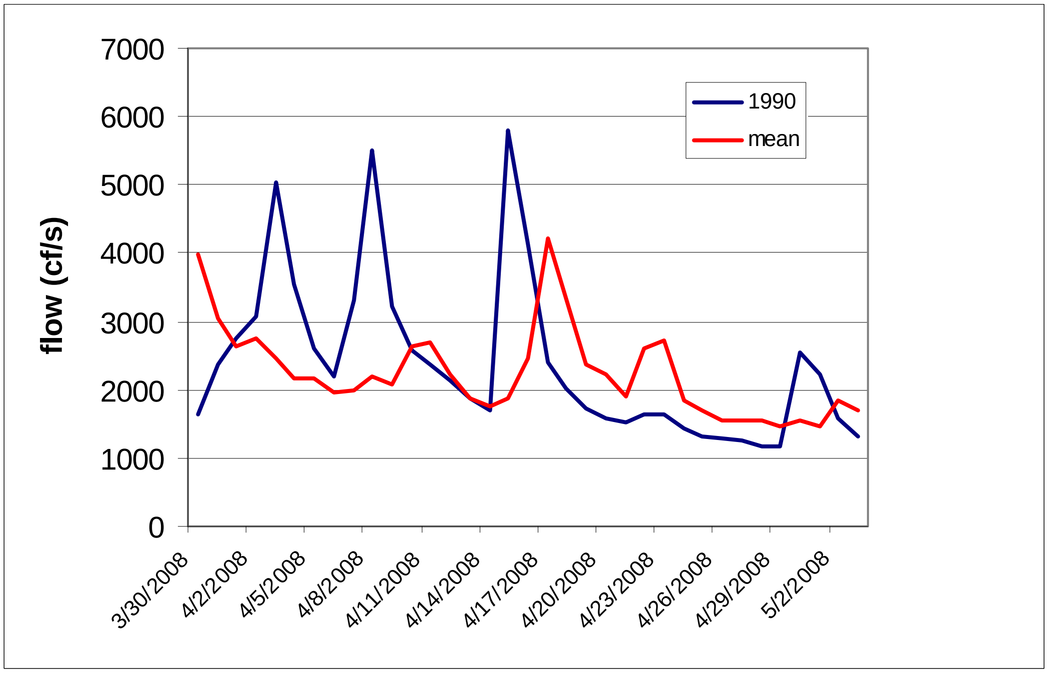
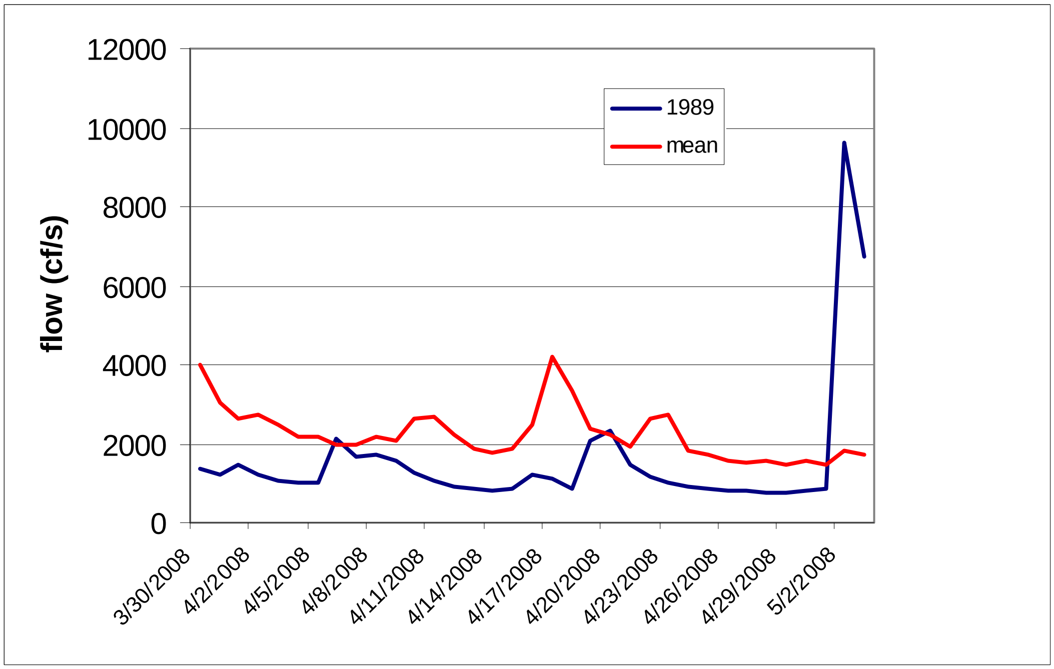


Figure 11. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1988-1989.



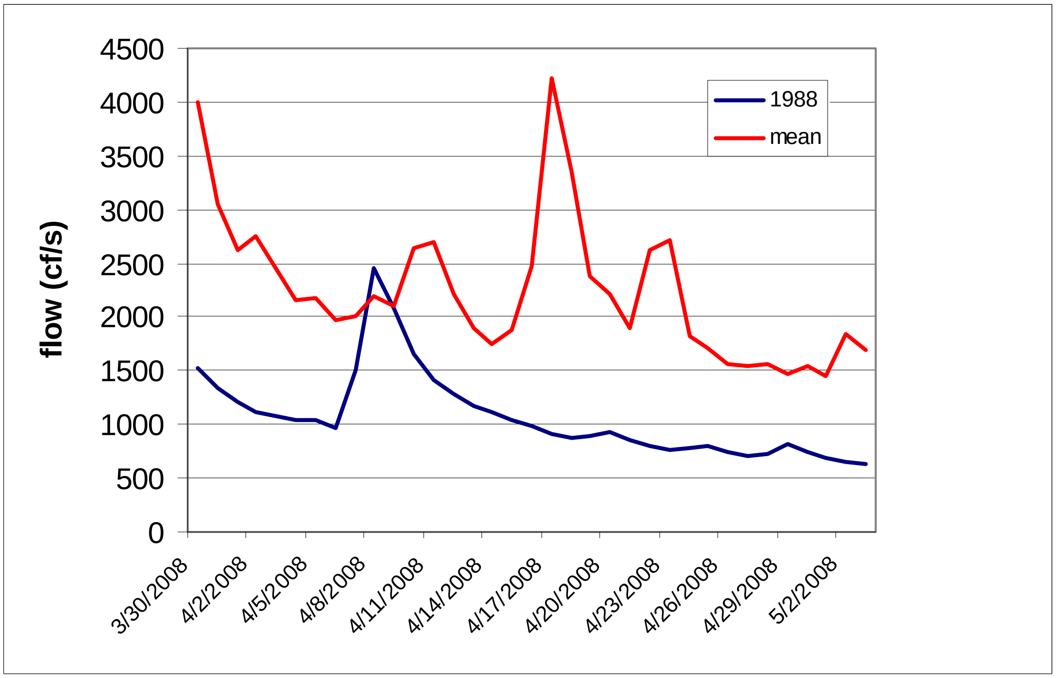
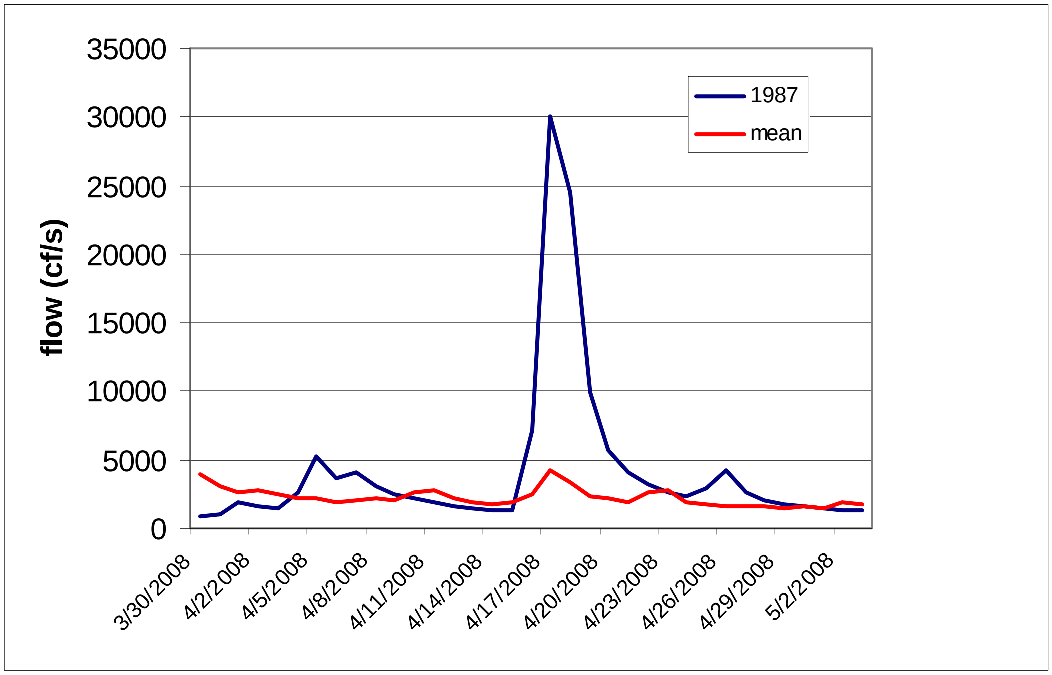


Figure 12. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1986-1987.



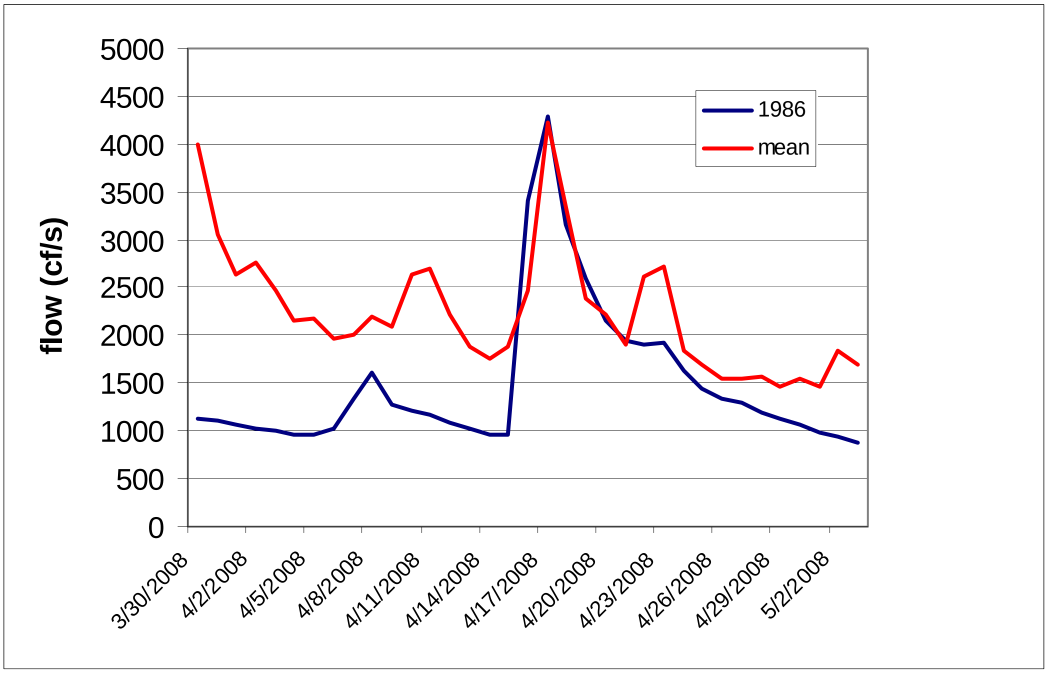


Figure 13. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, spring 1985.