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Evaluation of Striped Bass Stocks in Virginia: Monitoring and Tagging Studies, 2010-2014

Progress Report

Contract Number:	**F-77-R-28**
Project Period:	**1 September 2013 - 31 August 2014**
Principal Investigator:	**John M. Hoenig**

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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 2013 through 31 August 2014. It includes an assessment of the biological characteristics of striped bass taken from the 2014 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. Also included is information on gear selectivity of recreational anglers for striped bass and on impacts of dermal mycobacteriosis on striped bass. 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, from 1991-2014, 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 cooperating commercial fishermen Ernest George, Joe Hinson, Albert and Stanley Oliff, Paul Somers, Clark Trader, Wayne France, John Wyatt and Louis Wyatt; Maryland Department of Natural Resources (Md DNR) Beth Versak and Alexi Sharov.

Executive Summary

New this year: The spawning stock biomass indexes based on the variable-mesh gill nets in both the Rappahannock and James rivers were discontinued and we explored the use of these nets to expand our tagging efforts into the James River and expand and increase the number of striped bass tagged in the Rappahannock River. Compilation of results from 2003-2014 comparison of scale and otolith ageing are presented. An analysis of length-specific selectivity of striped bass by recreational anglers is investigated.

I. Assessment of the spawning stocks of striped bass in the Rappahannock and James rivers, Virginia, spring 2014.

Catch Summaries:

1. In 2014, 221 striped bass were sampled between 14 April and 8 May from the commercial pound nets in the Rappahannock River. The samples were predominantly male (56.1%) but had few fish in the 5-8 year range (7.2%). Females dominated the age nine and older age classes (81.6%). The mean age of the male striped bass was 4.8 years. The mean age of the female striped bass was 11.1 years.

2. During the 14 April – 8 May period, the 2010 and 2011 year classes were the most abundant in the Rappahannock River pound net samples and were 96.1% male. The contribution of age six and older males was only 9.5% of the total aged catch. Age seven and older females, presumably repeat spawners, were 41.2% of the total catch but represented 93.8% of all females caught.

3. The Spawning Stock Biomass Index (SSBI) from the Rappahannock River pound nets was 13.4 kg/day for male striped bass and 56.5 kg/day for female striped bass. The male index was the fourth lowest in the 1991-2014 time series. The 2014 female index was 62.4% higher than the 2013 index and 60.1% above the 24-year average.

4. An index of potential egg production was derived from laboratory estimates of weight- and length-specific numbers of oocytes in the ovaries of mature females. The 2014 Egg Production Potential Index (EPPI, millions of eggs/day) for the Rappahannock River pound nets was 8.70 million eggs/day. This was the sixth highest EPPI of the 2001-2014 time series. Older (8+ years) female stripers were responsible for 75.8% of the index.

5. The cumulative catch rate (all age classes, sexes combined) from the Rappahannock River pound nets (13.00 fish/day) was the 32.6% below the 24-year time series. There was an increase in almost all year classes from the 2013 values. The cumulative catch rate of male striped bass (7.29 fish/day) was the fifth lowest in the time series. The cumulative catch rate of female striped bass (5.72 fish/day) was 17.2% higher than the 24-year average and was 40.2% higher than the rate in 2013.

6. Year class-specific estimates of annual survival (S) for pound net data varied widely between years. The geometric mean S of the 1984-2006 year classes varied from 0.500-0.817 (mean = 0.659). The geometric mean survival rates differed between sexes. Mean survival rates for male stripers (1985-2006 year classes) varied from 0.317-0.665 (mean = 0.478) while mean survival rates of female stripers (1984-2000 year classes) varied from 0.462-0.816 (mean = 0.625).

7. Plots of year class-specific catch rates vs. year in the Rappahannock River from 1991-2014 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.

8. The areas under the catch curves indicate that the 1995, 1996, 1997, and 2003 year classes were the strongest, and the 1990 and 1991 year classes the weakest in the Rappahannock River from 1987.

9. The scales of 218 striped bass were digitally measured and the increments between annuli were used to determine their growth history.

10. On average, striped bass grow about 145 mm fork length in their first year. The growth rate decreases with age to about 45 mm per year by age 10.

11. Striped bass were estimated to reach the minimum legal length for the resident fishery (18 in. total length) at age 3.5 and reach the minimum length for the coastal fishery (28 in. total length) at age eight.

12. A total of 71 specimens from 12 size ranges were aged by reading both scales and otoliths. The mean age of the otolith-aged striped bass was 0.30 years older than from the scale-aged striped bass. The two methodologies agreed on the age of the striped bass on 49.3% of the specimens and within one year 85.9% of the time.

13. 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 ($p<.005$).

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

15. 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 represent an equivalent population.

II. Mortality estimates of striped bass (*Morone saxatilis*) that spawn in the Rappahannock River, Virginia, spring 2013-2014.

1. A total of 614 striped bass were tagged and released from pound nets and gill nets in the Rappahannock and James rivers between 2 April and 15 May, 2014. Of this total, 327 were between 457-710 mm total length and considered to be predominantly resident striped bass and 287 were considered to be predominantly migrant striped bass (>710 mm TL). The median date of resident tag releases was 28 April and the median date for resident migrant tag releases was 21 April.

2. A total of 56 striped bass (>457 mm TL), tagged during springs 1990-2013, were recaptured between 1 January and 31 December, 2013, and were used to estimate mortality. Most recaptures (82.1%) were caught within Chesapeake Bay (51.8% in Virginia, 30.4% in Maryland). Other recaptures came from Massachusetts and New Jersey (5.4% each), Rhode Island (3.6%), Connecticut, and New York (1.8% each).

3. A total of 16 migratory striped bass (>710 mm total length), tagged during springs 1990-2013, were recaptured between 1 January and 31 December, 2013, and were used to estimate the mortality. Most recaptures (37.5%) came from Chesapeake Bay (31.5% in Virginia, 6.3% in Maryland). Other recaptures came from Massachusetts and New Jersey (18.8% each), Rhode Island (12.5%), Connecticut and New York (6.3% each).

4. The ASFMC Striped Bass Tagging Subcommittee established a data analysis protocol that involves deriving survival estimates from a suite of Seber models using program MARK. Nine of these models were applied to the recapture matrix, each reflecting a different parameterization over time. The resultant estimates of survival were 0.45 (> 457 mm TL) and 0.76 (>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 0.06 (>457 mm TL) and 0.04 (>711 mm TL). The estimates of fishing mortality were 0.08 (>457 mm TL) and 0.04 (>711 mm TL).

6. Alternatively, a suite of input models similar to the models used in program MARK were used to estimate survival, fishing and natural mortality using an instantaneous rates model. 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 0.51 (>457 mm TL) and 0.59 (>711 mm TL). The estimates of fishing mortality were 0.05 (>457 mm TL) and 0.05 (>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 in striped bass is a chronic disease caused by various species of bacteria in the genus *Mycobacterium*. The disease appears as grey granulomatous nodules in internal organs and externally as ulcerous skin lesions. Mycobacteriosis in captive fishes is generally thought to be fatal, but this has not been established for wild striped bass.

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

3. A total of 17,999 striped bass were tagged, assessed for external diseases indications, photographed and released from five pound nets in the lower Rappahannock River during falls, 2005-2012. Only 31.1% of the total tagged were without any external sign of mycobacteriosis.

4. A total of 2,303 striped bass were tagged, assessed for external diseases indications, photographed and released from three pound nets in the upper Rappahannock River during falls, 2005-2010. Only 30.9% of the total tagged were without any external sign of mycobacteriosis.

3. A total of 117 striped bass tagged and released in the lower Rappahannock River were recaptured and reported between September 21, 2013 and September 20, 2014. Most recaptures occurred from falls and the Rappahannock River, especially the area immediately around the release sites.

5. A total of 2,433 striped bass tagged during fall, 2005-2012 in the lower Rappahannock River were recaptured prior to 20 September, 2014. In addition, a total of 372 striped bass tagged in the upper Rappahannock River were recaptured.

6. A total of 556 striped bass tagged during springs, 2006-2012 were recaptured prior to 20 September, 2014 from both the upper and lower Rappahannock River sites.

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

8. Based on the recapture and reassessment of 597 tagged striped bass originally assessed as having a light or moderate mycobacterial infection, it was calculated to take 407 days for 100% of these striped bass to progress from light to moderate infection and 634 days for 100% progression from moderate to heavy infection.

9. 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 54% and 84% respectively.

IV. Length-specific recreational angling selectivity for striped bass caught in the Chesapeake Bay.

1. Direct estimates of selectivity were obtained from tagged striped bass. The generalized linear modeling approach of Myers and Hoenig (1997) estimates the effects of length, sex, disposition and their interactions on tag return rates.

2. A total of 50,900 tag releases (35,674 MDDNR, 15226 VIMS) were analyzed (46,858 male, 4,042 female). The female striped bass were larger on average.

3. A total of 1,187 of these releases were reported as recaptured by recreational anglers (1,064 male, 123 female).

4. The preferred model (98% weighting), based on minimum QAIC, included experiment, length, sex and disposition with no interaction.

5. Maximum selectivity occurred for striped bass 651-675 mm total length. Selectivity was higher for females and fishers were more likely to release recaptured striped bass rather than harvest them.

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I. Assessment of the spawning stocks of striped bass in the Rappahannock River, Virginia, spring 2014.

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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 from between 14 April – 8 May, 2014. 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 14 April, 2014. In addition, one of the three pound nets normally sampled (net at mile 45) was not set this year. 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 two commercial pound nets (river miles 46 and 47) in the Rappahannock River (Figure 1). 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.

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 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 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 1 April - 2 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 1 April - 2 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 Summary.

Striped bass (n= 221) were sampled between 14 April - 8 May, 2014 from the pound nets in the Rappahannock River. The number of striped bass sampled was only 10.2% lower than the sample in 2013 (n= 246) but 60.3% lower than the 24-year average (n=556.3). Total catches varied from 9-56 striped bass, with the peak catch on 14 April (Table 1). Surface water temperatures were below normal, increasing from 8.8℃ on 28 March to 12.5℃ on 7 April, increased rapidly to 16.2 ℃ on 14 April, then varied from 14.8-18.1℃ from 18 April to 9 May. River flows were well above average at the start of the season and remained at or above average throughout the sampling season, ending with the highest one-day average in our 30 years of records (Figure 2). Salinities were 0.0-0.1 p.p.t. throughout the sampling season. Catches of female striped bass peaked on 14 and 28 April and were dominated by the pre-2005 year classes. Males made up 56.1% of the total catch, which was below the 24-year average (74.5%). The 2006-2009 year classes (five to eight years old) comprised 7.2% of the total catch. This was well below the 2013 samples where the 2005-2008 year classes comprised 30.9% of the total catch. Males dominated the 2010-2012 year classes (96.1%), but females dominated the 2006-2009 year classes (56.3%) the 1996-2005 year classes (81.6%).

Biomass catch rate (g/day) of males peaked on 17 April and female striped bass peaked on 14 and 17 April (Table 2). The numeric catch rate of males exceeded that of females on all but two sampling dates. Unlike 2008, but consistent with most previous years, the biomass catch rates for female striped bass exceeded that for males overall (4.22:1), peaking on 17 April (6.15:1). The mean ages of male striped bass varied from 3.3-7.5 years by sampling date, with the oldest mean age occurring on 14 April. The mean ages of females varied from 10.3-11.3 years by sampling date.

There was a broad peak in abundance of striped bass (mostly male) between 370-490 mm total lengths in the pound net samples (Table 3). This size range accounted for 39.4% of the total sampled. There was a secondary peak in abundance of predominantly female striped bass between 890-990 mm total lengths. Consistent with previous years, the striped bass from 640-

710 mm total length accounted for only 0.9% of the total sample. The total contribution of striped bass greater than 710 mm total length (the minimum total length for the coastal fishery) was 49.8% (vs. 38.6% in 2013).

During the 14 April – 8 May period, the 2010 (20.4%) and 2011 (25.8%) year classes were the most abundant (Table 4). These year classes were 96.1% male. The contribution of males age six and older (the pre-2009 year classes) was 9.5% 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 41.2% of the total aged catch, but was also 93.8% of the total females captured. The catch rate (fish/day) of male striped bass was 7.3, which is 49.0% below the 24-year average (Table 5). The catch rate of female striped bass (5.7 fish/day) was 16.3% above the 24-year average. The biomass catch rates (kg/day) of males were below the average of the 24-year time series, while the rates of females were well above the 24-year average. The mean age of the male striped bass was the ninth highest in the 24-year time series. The mean age of the female striped bass was higher than 2013 and the highest value in the time series.

Spawning Stock Biomass Indexes.

The Spawning Stock Biomass Index (SSBI) for spring 2014 was 13.4 kg/day for male striped bass and 56.5 kg/day for female striped bass. The index for male striped bass was 11.8% below the value for 2013 and the fourth lowest in the 24-year time series (Table 6). The magnitude of the index for male striped bass was largely determined by the 2003-2004 (39.3%) and the 2010-2011 year classes (39.1%). The index for female striped bass was 62.4% higher than the 2013 index. It was the fourth highest in the time series, and 60.1% above the 24-year average (Table 6). The magnitude of the index for the females was largely determined by the 2000-2005 year classes (83.3%).

Egg Production Potential Index.

The number of gonads sampled, especially of the larger females, was insufficient to produce separate length-egg production estimates for both the Rappahannock and James rivers. 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 7).

The 2014 Egg Production Potential Indexes (EPPI, Table 8) for the Rappahannock River was 8.70. The indexes for the Rappahannock River were heavily dependent on the egg production potential of the 2000-2005 year class females (75.8%). Previous values for the EPPI for 2001-2013 from the Rappahannock River were 3.992, 1.764, 9.829, 10.55, 6.30, 4.01, 13.792, 8.66, 6.87, 9.87, 4.85, 5.99 and 5.35 (Sadler et al 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012 and 2013). Thus, the EPPI values for the pound nets in the Rappahannock River signaled a rebound in the status of the spawning stock from the 2011 value. Modest changes in the methodology (utilizing fully mature ovaries solely rather than ovaries in various states of maturation) in the 2001-2013 indexes preclude direct comparison with the 1999 and 2000 indexes.

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

Numeric catch rates (fish/day) of individual year classes from the 1991-2014 samples are presented in Tables 9-11. The cumulative annual catch rate of all year classes for 2014 was 22.2% greater than the cumulative catch rate for 2013 but 32.6% below the 24-year average of 19.30 (Tables 9a,b). The increase was the result of higher catch rates in most of the represented year classes. The catch rate of males was dominated by three through five year olds (2009-2011 year classes, Tables 10a,b). These three age classes contributed 83.0% 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. Only one pre-2000 year class male was captured (1996 year class). The cumulative catch rate of female stripers was 40.2% higher than the catch rate in 2013 and was 17.2% higher than the 24-year average of 4.88 (Tables 11a,b). The 2000-2005 year classes accounted for 79.2% of the total female catch.

The range of overall ages was unchanged from 1991-2014, 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, 2006-2010 and 2014). The catch rate of four and five year olds were near equal in 2003 and 2004 and again in 2011and 2012, but the peak was age three in 2005 and again in 2013. 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. However, the cumulative catch rate dropped to 0.678 in 2008 and 0.593 in 2009, rebounded to 0.733-0.780 from 2010-2013 and increased strongly to .914 in 2014.

Estimates of annual survival (S) for the individual year classes and their overall geometric means are presented in tables 12-14. While annual survival estimates varied widely among years, due to strong or weak overall catches, the geometric mean survival rates (1991-2014 of the 1984-2006 year classes (sexes combined) varied from 0.500-0.817 (Tables 12a,b) with an overall mean survival rate of 0.659. 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 (1991-2014) of the 1985-2006 year classes of males varied from 0.317-0.665 (Tables 13a,b) with an overall mean survival rate of 0.478. These year classes have been the major target of the fall recreational and commercial fisheries that reopened in 1993. The geometric mean survival rate (1991-2014) of the 1984-2000 year classes of females varied from 0.462-0.816 (Tables 14a,b) with an overall mean survival rate of 0.625.

Catch Rate Histories of the 1987-2004 Year Classes

The catch rate histories of the 1987-2004 year classes are depicted in Figures 3-11. Consistent among the year classes are a peak of male striped bass at age four or five followed by a rapid decline in the catch rate and a secondary peak of mostly female striped bass around age 10. This secondary peak is best defined from the pound net data. In our pound net samples 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.

The area under the catch curves (CCA) was calculated for each year class (sexes combined) from 1989-2010 (Table 15a, b). The relative ranking of the year classes was found not to change after age ten and the these partial CCAs were compared to indicate year class strengths for as many years classes as possible.

1987 Year class: The catch history of the 1987 year class commences at age four from the Rappahannock River. Peak abundance of male striped bass occurred at age four and the peak abundance of female striped bass occurred at age six in the Rappahannock River (Figure 3). Abundances of both sexes declined rapidly with age, although there was a distinctive secondary peak in the abundance of female striped bass captured from the pound nets. No 1987 year class striped bass were captured in 2014.

1988 Year class: The catch history of the 1988 year class commences at age three from the Rappahannock River. Age three was the apparent age of full recruitment and peak abundance of male striped bass occurred at age four (Figure 3). However, peak abundance of female striped bass was 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. No 1988 year class striped bass were captured in 2014.

1989 Year class: Peak abundance of male striped bass occurred at age four (Figure 4). Peak abundance of female striped bass occurred at age five in the Rappahannock River. There was a secondary peak in abundance of female striped bass at age nine in the pound net samples. The

CCA was below the mean and the fourth lowest in among 1989-2004 year classes. No 1989 year class striped bass were captured in 2014.

1990 Year class: Peak abundance of male striped bass occurred at age five in the Rappahannock River (Figure 4). The peak abundance of female striped bass occurred at age eight in the pound net samples. The CCA was the second lowest of the time series in the Rappahannock River. No 1990 year class striped bass were captured in 2014.

1991 Year class: Peak abundance of male striped bass occurred at age five in the Rappahannock River (Figure 5). Peak abundance of female striped bass occurred 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 from the Rappahannock River. No 1991 year class striped bass were captured in 2014.

1992 Year class: Peak abundance of male striped bass occurred at age three in the pound nets in the Rappahannock River (Figure 5). Peak abundance of female striped bass occurred at age 11 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 the 1990 and 1991 year classes, but was well below the mean in the Rappahannock River. No 1992 year class striped bass were captured in 2014.

1993 Year class: Peak abundance of male striped bass occurred at age four in the Rappahannock River (Figure 6). Peak abundance of female striped bass occurred at age 10 in the Rappahannock River. Again, there were relatively few ages five and six female striped bass captured in the Rappahannock River. The CCA was above the mean from the pound net samples in the Rappahannock River. No 1993 year class striped bass were captured in 2014.

1994 Year class: Peak abundance of male striped bass occurred at age four in the Rappahannock River (Figure 6). Peak abundance of female striped bass occurred at age 10 in the Rappahannock River. Again, there were relatively few ages five and six female striped bass captured in the Rappahannock River. The CCA was slightly above the mean from the pound net sample in the Rappahannock River. No 1994 year class striped bass were captured in 2014.

1995 Year class: Peak abundance of male striped bass occurred at age four in the Rappahannock River (Figure 7). Peak abundance of female striped bass occurred at age nine in the Rappahannock River. Again, there were relatively few ages five and six female striped bass captured in the Rappahannock River. The CCA was well above the mean in the Rappahannock River pound nets. 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. No 1995 year class striped bass were captured in 2014.

1996 Year class: Peak abundance of male striped bass occurred at age four in the Rappahannock River (Figure 7). Peak abundance of female striped bass occurred at age 11 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 amongst the year classes from the pound samples in the Rappahannock River. Three (two females and one male) 1996 year class striped bass were captured in 2014.

1997 Year class: Peak abundance of male striped bass occurred at age three in the Rappahannock River (Figure 8). Age ten females showed an increase in abundance in the Rappahannock River. The CCA was the second highest in the Rappahannock River pound nets. One female 1997 year class striped bass was captured in 2014.

1998 Year class: Peak abundance of male striped bass occurred at age six in the Rappahannock River (Figure 8). Age nine females showed an increase in abundance verses their abundance in 2006 (at age eight). The CCA was below average in the Rappahannock River pound nets. Four female 1998 year class striped bass were captured in 2014.

1999 Year class: Peak abundance of male striped bass occurred at age five in the pound nets in the Rappahannock River (Figure 9). The CCA was less than for the 1998 year class and well below the average in the Rappahannock River. No 1999 year class striped bass were captured in 2014.

2000 Year class: Peak abundance of male striped bass occurred at age four in the Rappahannock River (Figure 9). The peak abundance of female striped bass was age five in the pound nets in the Rappahannock River. The CCA almost equal to the 1999 year class and well below the average in the pound nets. Eleven female 2000 year class striped bass were captured in 2014.

2001 Year class: Peak abundance of male striped bass occurred at age four in Rappahannock River (Figure 10). Peak abundance of female striped bass occurred at age five in the Rappahannock River. The CCA was the highest since the 1997 year class and near the average for all year classes Fifteen (13 females and two males) 2001 year class striped bass were captured in 2014.

2002 Year class: Peak abundance of male striped bass occurred at age four in the Rappahannock River (Figure 10). Peak abundance of female striped bass occurred at age five in the Rappahannock River. The CCA was slightly above the average in the pound nets in the Rappahannock River. Nine (eight females and one male) 2002 year class striped bass were captured in 2014.

2003 Year class: Peak abundance of male striped bass occurred at age five in the Rappahannock River (Figure 11). Peak abundance of female striped bass occurred at age nine in the Rappahannock River. The CAA was the third highest overall and the highest since the 1997 year class. Twenty-six (18 females and eight males) 2003 year class striped bass were captured in 2014.

2004 Year class: Peak abundance of male striped bass occurred at age four in the pound nets in the Rappahannock River (Figure 11). Peak abundance of female striped bass occurred at age five in the Rappahannock River. The CAA was well above the average and the fourth highest overall in the Rappahannock River. Twenty-three (17 females and 6 males) 2004 year class striped bass were captured in 2014.

Growth Rate of Striped Bass Derived from Annuli Measurements

The scales of 218 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 16a). The rate of growth was about 100 mm in their second year and decreased gradually with age to about 85 mm in their fifth year and to about 45 mm in their 10th year (Tables16a,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 eight.

Age Determinations using Scales and Otoliths

2014 data

Tests of symmetry: A total of 71 striped bass were aged by reading both their scales and otoliths. Scale and otolith ages from the same specimen were in agreement 49.3% (35/ 71) of the time and within one year 85.9% (61/71) 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 17) 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 ith row and jth column and n_{ji} = the observed frequency in the jth row and ith 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 = 12). We tested the hypothesis that the observed age differences were symmetrically distributed about the main table diagonal (Table 17). The hypothesis was not rejected (X^2 = 18.67, p=.179), indicating random differences between the two ageing methodologies. The two ageing methods were found to be non-random in 2004, 2005 and 2007-2013, but not in 2006.

Differences between the scale and otolith age (up to age 21) from the same specimen ranged from zero to five years (Figure 12). The otolith-derived age exceeded the scale age 32.4% of the total examined (63.9% 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 (80.0%). Another test of symmetry that compared the negative and positive differences of the same magnitude (i.e. -4 and 4, -3 and 3, etc., Evans and Hoenig, 1998) rejected the hypothesis that these differences were random (X^2 = 8.08, df = 3, 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=71) determined by reading the otoliths was greater than the mean age determined by reading the scales (by 0.30 years, Table 18). The test results were:

$$\overline{Age}_{otolith}= 7.24 \qquad \overline{Age}_{scale}= 6.94$$

$$S_{otolith}= 3.17 \qquad S_{scale}= 3.84$$

df = 141
p = .560

Therefore the null hypothesis was not rejected.

A paired t-test was also performed on the ages determined for each specimen by the two methodologies. The null hypothesis tested was that the mean of the difference resultant from the two methods was not different from zero. The paired t-test results were not significant (df= 140, p= .019) and the null hypothesis was rejected.

Kolmogorov-Smirnov test: To determine whether the distribution of age classes that resulted from the two ageing methodologies were representative of the same population, a Kolmogorov-Smirnov test was performed on the relative proportion that each assigned age class contributed to the total sample (Table 18). This compares the maximum difference in the relative proportions that an age class contributes to the test statistic ($K_{.05}$):

$$D_{max}= 0.1061 \qquad K_{.05}= 1.3581$$

$$D_{.05}= K_{.05}\sqrt{\frac{(71)+(71)}{(71)^2}}=0.2279$$

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 2008-2013 results, but differs from the test results for the 2007 age comparisons.

2003-2014 data

A total of 2,815 were aged by reading both their scales and otoliths. The mean age from the scale pairs from each otolith age varied by less than 0.5 years for ages 2-11 (Table 19), but diverged steadily thereafter (Figure 13).

Tests of symmetry: The scale and otolith ages from the same specimen were in agreement 42.7% (1203/2815) of the time and within one year 82.3% 2316/2815) of the time. A chi-square test was performed to test the hypothesis that an m x m contingency table (Table 19) consisting of two classifications of a sample into categories is symmetric about the main diagonal.

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 = 50). We tested the hypothesis that the observed age differences were symmetrically distributed about the main table diagonal (Table 19). The hypothesis was rejected (X^2 = 346.65, p<.005), indicating non-random differences between the two ageing methodologies.

Differences between the scale and otolith age from the same specimen ranged from zero to eigth years (Figure 14). The otolith-derived age exceeded the scale age 34.2% of the total examined (59.7% 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 (79.1%). Another test of symmetry that compared the negative and positive differences of the same magnitude (i.e. -4 and 4, -3 and 3, etc., Evans and Hoenig, 1998) rejected the hypothesis that these differences were random (X^2 = 182.2, df = 6, p< 0.005). This test has far fewer degrees of freedom than did the previous test of symmetry.

T-tests: Next, t-tests of the resultant means of the two ageing methods were performed. A two-tailed t-test was made to test the null hypothesis that the mean ages determined by the two methods were not different from zero. The mean age of the sample (n=2815) determined by reading the otoliths was greater than the mean age determined by reading the scales (by 0.30 years, Table 20). The test results were:

$$\overline{Age}_{otolith} = 8.52 \qquad \overline{Age}_{scale} = 8.78$$

$$S_{otolith} = 3.37 \qquad S_{scale} = 3.70$$

$$df = 5629$$

$$p = .004$$

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 significant (df= 5628, p< .001) and the null hypothesis was rejected.

Kolmogorov-Smirnov test: To determine whether the distribution of age classes that resulted from the two ageing methodologies were representative of the same population, a Kolmogorov-Smirnov test was performed on the relative proportion that each assigned age class contributed to the total sample (Table 21). This compares the maximum difference in the relative proportions that an age class contributes to the test statistic ($K_{.05}$):

$$D_{max} = 0.1061 \qquad K_{.05} = 1.3581$$

$$D_{.05} = K_{.05}\sqrt{\frac{(2815)+(2815)}{(2815)^2}} = 0.0362$$

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.

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 2011- 2014, persistent, bad weather delayed efforts by our fishermen to establish their first net (usually done in mid-March) until 14 April (one net) and precluded setting the third net at mile 45. 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. This year the sampling season was further complicated by severe flooding on 29-30 April damaged all the pound nets in the Rappahannock River and prevented any sampling from occurring on 30 April – 4 May.

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.

The biological characterization of the spawning stock of striped bass in the Rappahannock River changed dramatically from 1991-2014. 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 2002-2014. 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. Due to the late start to the sampling and the interruption due to flooding, total catches were lower in 2014 than in 2013, but the catch rates and biomass estimates were higher.

Of note again in the 2014 samples was the relative abundance of 1996 year class (18 year old) male and female stripers. This year class has been above-average in abundance since recruiting to the gears at age three, which indicates that it is a very strong year class. However, the 1993 year class, abundant in 2005-2007 and captured again in 2010-2013 was absent in the 2014 samples.

The 2014 value of the Spawning Stock Biomass Index (SSBI) for the Rappahannock River pound nets was approximately 40% higher than the SSBI for 2013 and approximately 14% above the mean. However, the SSBI for male striped bass captured in the pound nets was 12% below the index for 2013 and nearly 50% below the mean of the 1991-2014 time series. The SSBI for female striped bass was approximately 62% higher than the 2013 value and 60% above the mean of the time series. Both the male and female components of the SSBI were dominated by 10+ year-old striped bass

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 2014, the contribution of 8+ year old females was 94.8% of the total number (there were very few four to eight year old females caught in 2014), 99.0% of the biomass, and 99.1% 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 2004-2014, 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, then four to five years since 2003. Changes in the annual catch rates by year class in the Rappahannock River indicated that strong year classes occurred in 1988, 1989, 1996, 1997 and 2003, and weak year classes occurred in 1990,1991and 2002. 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.

The time series allows estimates of the instantaneous rates of survival of the year classes using catch curves, especially for the 1983-2006 year classes that were captured for four or five years subsequent to their peak in abundance at age four or five. The survival estimate of female striped bass of the 1984-2000 year classes in the Rappahannock River was 0.625. The survival estimate of 1984-2006 year class male striped bass was 0.478. The higher 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.

The catch histories of the 1987-2004 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, 1996, 1997 and 2003 year classes were the strongest and the 1990, 1991 and 2002 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 2009 year class in fall 2012) and the 28 in. (711 mm) minimum total length for the coastal fishery at age eight.

Since 2003 we have aged 2,861 striped bass using both scales and otoliths from the same specimen. The ages were found to differ by as much as eight years (only twice). Generally, the age difference determined for the largest, and oldest, specimens was 0-5 years (14-19 years by reading the scale vs. 14-21 years by reading the otolith). The maximum age determined by reading scales has generally remained constant at 17 years since 1991 (although one 20 year-old was aged in 2005 and in 2011); while there has been an annual progression in the maximum age determined by reading otoliths. Agreement between the two ageing methodologies was 42.8% and varied annually from 33.7% to 51.2%. When there was disagreement between methodologies, the otolith age was 1.5 times more likely to have been aged older than the respective scale-derived age. When the age difference was two years or greater, the otolith age was 3.8 times more likely to be the older age. The differences were found not to be statistically non-random and different from zero. 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 2010-2012, 2006-2009 and 1996-2005) from pound nets in the Rappahannock River, by sampling date, spring, 2014. M = males, F = females.

Date	n	Year Class							
		No age		2010-2012		2006-2009		1996-2005	
		M	F	M	F	M	F	M	F
14 April	56	0	0	5	3	5	3	9	31
17 April	33	0	0	16	1	2	0	1	13
21 April	27	0	0	19	0	0	1	1	6
28 April	46	0	0	21	0	0	3	4	18
5 May	50	0	0	33	0	0	2	4	11
8 May	9	0	0	4	0	0	0	0	5
Total	**221**	**0**	**0**	**98**	**4**	**7**	**9**	**19**	**84**

Table 2. Net-specific summary of catch rates and mean ages of striped bass (n=221) in pound nets on the Rappahannock River, spring, 2014. 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
14 April	S462	56	6.3	12.3	24,544.5	127,533.2	7.5	11.1
17 April	S462	33	19.0	14.0	23,649.9	145,394.7	4.0	11.3
21 April	S462	27	5.0	1.8	4,679.4	14,743.3	3.6	10.3
28 April	S462	46	8.3	7.0	17,613.2	65,897.9	5.0	11.0
5 May	S462	50	12.3	4.3	18,516.0	42,461.5	4.4	11.2
8 May	S462	9	1.3	1.7	1,041.6	16,204.7	3.3	11.2
Totals	S462	221	7.3	5.7	13,383.1	56,509.4	4.8	11.1
	S473	0						
Season		221	**7.3**	**5.7**	**13,383.1**	**56,509.4**	**4.8**	**11.1**

Table 3. Length frequencies (TL in mm) of striped bass sampled from the pound nets in the Rappahannock River, spring, 2014.

TL	n	TL	n	TL	n	TL	n	TL	n	TL	n
280-	0	**440-**	7	**600-**	1	**760-**	0	**920-**	8	**1080-**	1
290-	0	**450-**	6	**610-**	0	**770-**	0	**930-**	3	**1090-**	2
300-	0	**460-**	6	**620-**	0	**780-**	0	**940-**	7	**1100-**	0
310-	0	**470-**	5	**630-**	0	**790-**	0	**950-**	5	**1110-**	0
320-	0	**480-**	10	**640-**	0	**800-**	1	**960-**	4	**1120-**	0
330-	1	**490-**	5	**650-**	0	**810-**	2	**970-**	8	**1130-**	0
340-	4	**500-**	2	**660-**	1	**820-**	5	**980-**	2	**1140-**	0
350-	3	**510-**	2	**670-**	0	**830-**	5	**990-**	6	**1150-**	1
360-	2	**520-**	3	**680-**	1	**840-**	4	**1000-**	4	**1160-**	0
370-	6	**530-**	0	**690-**	0	**850-**	2	**1010-**	4	**1170-**	0
380-	4	**540-**	0	**700-**	0	**860-**	1	**1020-**	2	**1180-**	0
390-	8	**550-**	1	**710-**	0	**870-**	3	**1030-**	2	**1190-**	0
400-	5	**560-**	1	**720-**	0	**880-**	3	**1040-**	3	**1200-**	0
410-	13	**570-**	2	**730-**	3	**890-**	4	**1050-**	3	**1210-**	0
420-	7	**580-**	0	**740-**	2	**900-**	6	**1060-**	0	**1220-**	0
430-	5	**590-**	0	**750-**	0	**910-**	2	**1070-**	1	**1230-**	1

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, spring 2014.

Year Class	Sex	n	Fork Length		Weight		CPUE	
			Mean	SD	Mean	SD	F/day	W/day
2011	male	56	360.0	26.3	648.4	134.9	3.5	2,135.8
	female	1	385.0		889.4		0.1	52.3
2010	male	42	437.6	23.8	1,091.6	176.5	2.5	2,696.9
	female	3	466.3	40.1	1,305.2	430.4	0.2	230.3
2009	male	5	496.2	24.5	1,578.5	296.9	0.3	464.3
	female	2	547.5	24.7	2,467.6	321.5	0.1	290.3
2008		0					0.0	0.0
2007	male	1	615.0		3,406.2		0.1	200.4
2006	male	1	641.0		3,455.1		0.1	203.2
	female	7	744.4	40.8	6,021.3	908.2	0.4	2,479.4
2005	male	1	700.0		4,516.4		0.1	265.7
	female	10	799.4	23.4	7,362.6	625.1	0.6	4,330.9
2004	male	6	765.0	38.0	5,953.8	829.1	0.4	2,101.3
	female	17	866.4	18.7	9,276.6	577.4	1.0	9,276.6
2003	male	8	795.4	49.8	6,731.0	1,217.3	0.5	3,167.5
	female	18	896.0	26.2	10,238.1	856.2	1.1	10,841.1
2002	male	1	880.0		9,059.9		0.1	532.9
	female	8	911.0	32.0	10,749.9	1,089.3	0.5	5,058.8
2001	male	2	843.0	18.4	7,955.9	527.5	0.1	936.0
	female	13	948.2	26.1	12,056.8	962.4	0.8	9,219.9
2000	female	11	968.7	40.7	12,857.1	1,564.6	0.6	8,319.3
1999		0					0.0	0.0
1998	female	4	989.3	47.8	13,664.8	1,831.5	0.2	3,215.5
1997	female	1	1,093.0		18,144.0		0.1	1,067.3
1996	male	1	953.0		11,545.2		0.1	679.1
	female	2	1,086.0	116.0	18,087.6	5,505.0	0.1	2,127.9
Not	male	0						
Aged	female	0						

Table 5. Summary of the seasonal mean catch rates and ages, by sex, from the pound nets in the Rappahannock River, springs 1991-2014. M = male, F = female.

Year	n	CPUE (fish/day)		CPUE (g/day)		Mean age	
		M	F	M	F	M	F
2014	221	7.3	5.7	13,383.2	56,509.4	4.8	11.1
2013	246	6.6	4.1	15,256.1	34,875.3	5.1	10.1
2012	437	12.9	3.4	32,356.6	38,137.1	5.5	9.9
2011	215	5.5	3.5	17,031.8	27,563.8	6.0	9.5
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
1992	151	3.1	5.4	5,400.0	19,400.0	4.5	6.1
1991	223	13.1	6.6	21,300.0	42,800.0	4.0	5.0
Mean	**556.3**	**14.3**	**4.9**	**26,174.7**	**35,922.5**	**4.5**	**8.7**

Table 6. 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 – 2014.

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
2014	124.0	96.0	13.4	56.5	69.9					
2013	151.0	94.0	15.2	34.8	50.0	246.0	125.0	62.8	104.8	167.6
2012	320.0	116.0	32.3	38.1	70.4	169.0	69.0	48.4	51.8	100.2
2011	130.0	83.0	17.0	27.6	44.6	127.0	62.0	36.8	52.2	89.0
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	**415.3**	**130.2**	**26.0**	**35.3**	**61.3**	**376.6**	**60.3**	**76.3**	**42.4**	**118.7**

Table 7. 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 8. Total, age-specific, estimated total egg potential (E, in millions of eggs/day) from mature (ages 4 and older) female striped bass from the Rappahannock River, spring 2014. The Egg Production Potential Indexes (millions of eggs/day) are in bold.

Age	n	E	%
4	3	0.036	0.41
5	2	0.039	0.45
6	0	0.000	0.00
7	0	0.000	0.00
8	7	0.364	4.18
9	10	0.646	7.42
10	17	1.413	16.24
11	18	1.664	19.12
12	8	0.780	8.96
13	13	1.435	16.49
14	11	1.303	14.97
15	0	0.000	0.00
16	4	0.506	5.81
17	1	0.172	1.98
18	2	0.344	3.95
19	0	0.000	0.00
20	0	0.000	0.00
n/age	0	0.000	0.00
Total	96	**8.702**	100.00

Table 9a. Catch rates (fish/day) of year classes of striped bass (sexes combined) sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2014. 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**	**2001**	**2002**	**2003**
2000													0.76
1999											0.07	0.51	3.00
1998										0.03	2.74	1.44	3.33
1997									0.79	**15.61**	7.49	1.38	0.37
1996								0.19	11.54	**18.13**	4.29	0.25	1.83
1995							0.60	2.15	**11.50**	3.34	0.10	0.68	1.40
1994					0.04	0.51	3.90	**6.33**	2.79	0.11	0.58	0.41	1.70
1993					3.04	3.97	**8.10**	1.48	0.11	0.50	0.87	0.28	1.43
1992			0.12	1.44	**4.80**	2.86	1.25	0.04	0.50	0.50	0.87	0.19	1.13
1991		0.20	0.57	0.48	1.00	**1.63**	0.05	0.52	0.43	0.40	0.81	0.06	0.33
1990	0.42	0.50	1.04	1.33	**2.24**	1.26	0.70	0.70	0.32	0.29	0.45	0.00	0.27
1989	0.33	0.60	3.58	**4.59**	0.68	0.89	0.80	0.78	0.36	0.37	0.26	0.00	0.07
1988	3.58	1.60	**9.54**	2.22	0.60	0.37	1.50	0.89	0.39	0.05	0.10	0.00	0.00
1987	**8.00**	2.75	3.65	1.15	0.68	0.37	1.00	0.89	0.43	0.05	0.00	0.03	0.03
1986	**2.67**	1.15	0.65	0.59	0.40	0.09	1.00	0.22	0.04	0.00	0.00	0.00	0.00
1985	**1.67**	0.30	0.42	0.52	0.08	0.00	0.35	0.15	0.11	0.00	0.00	0.00	0.00
1984	0.50	0.40	**0.58**	0.33	0.28	0.00	0.35	0.07	0.04	0.00	0.00	0.00	0.00
1983	0.25	0.20	**0.46**	0.33	0.08	0.03	0.20	0.00	0.00	0.00	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	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	0.00	0.00	0.00
Total	**18.75**	**8.45**	**21.72**	**13.87**	**14.52**	**12.30**	**20.30**	**14.85**	**29.89**	**39.70**	**18.63**	**5.23**	**15.65**

Table 9b. Catch rates (fish/day) of year classes of striped bass (sexes combined) sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2014. 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**	**2011**	**2012**	**2013**	**2014**
2011											**3.35**
2010										1.65	**2.65**
2009								0.08	1.40	**1.74**	0.41
2008							0.23	0.46	**3.20**	1.91	0.00
2007						0.07	2.63	1.08	**3.80**	0.83	0.06
2006					0.17	1.89	**6.50**	1.38	2.12	0.30	0.47
2005				0.03	4.40	5.07	**10.43**	0.96	1.04	0.26	0.65
2004				2.52	**7.20**	6.93	4.23	0.79	0.92	0.30	1.35
2003			7.89	**8.55**	3.26	2.15	1.53	0.88	1.28	1.13	1.53
2002		1.83	**6.40**	6.17	0.51	1.22	1.03	0.96	0.84	0.39	0.53
2001	3.47	**5.43**	3.17	1.14	0.60	1.22	1.27	1.04	0.96	0.87	0.88
2000	**5.57**	2.77	0.14	1.12	0.57	1.19	1.77	0.63	0.44	0.48	0.65
1999	**5.90**	0.71	0.51	1.51	0.29	1.19	1.10	0.25	0.28	0.13	0.00
1998	**3.50**	0.77	0.91	1.89	0.43	0.67	0.70	0.04	0.32	0.13	0.24
1997	2.23	1.69	0.86	2.68	0.43	0.37	0.53	0.17	0.20	0.04	0.06
1996	4.16	1.69	1.17	3.80	0.46	0.70	1.13	0.08	0.20	0.22	0.18
1995	2.33	0.94	0.23	0.71	0.00	0.00	0.13	0.04	0.00	0.00	0.00
1994	1.67	0.69	0.20	0.71	0.00	0.19	0.07	0.00	0.00	0.00	0.00
1993	1.00	0.57	0.20	0.46	0.00	0.00	0.07	0.08	0.00	0.09	0.00
1992	1.10	0.29	0.11	0.20	0.00	0.03	0.07	0.00	0.00	0.00	0.00
1991	0.17	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.07	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	0.07	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.40	0.49	0.26	0.00	0.00	0.07	1.47	0.04	0.44	0.17	0.00
Total	**31.64**	**18.05**	**22.05**	**31.52**	**18.35**	**22.96**	**34.89**	**8.88**	**17.44**	**10.64**	**13.00**

Table 10a. Catch rates (fish/day) of year classes of male striped bass sampled from pound nets in the Rappahannock River, 30 March – 3 May 1991-2014. 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**	**2001**	**2002**	**2003**
2000													0.76
1999											0.07	0.44	2.93
1998										0.03	2.74	1.38	3.07
1997									0.79	**15.61**	7.42	1.25	0.30
1996								0.19	11.54	**18.11**	4.03	0.16	1.50
1995							0.55	2.15	**11.46**	3.21	0.10	0.03	0.56
1994					0.04	0.51	3.80	**6.19**	2.68	0.08	0.39	0.03	0.23
1993					2.88	3.83	**7.50**	1.37	0.07	0.26	0.16	0.00	0.07
1992			0.12	1.22	**4.68**	2.66	1.15	0.00	0.36	0.11	0.19	0.00	0.00
1991		0.15	0.54	0.48	0.92	**1.34**	0.05	0.30	0.21	0.05	0.13	0.00	0.00
1990	0.17	0.35	0.96	1.30	**2.00**	0.94	0.35	0.11	0.00	0.03	0.00	0.00	0.00
1989	0.17	0.40	3.46	**3.52**	0.08	0.43	0.55	0.04	0.04	0.03	0.00	0.00	0.00
1988	3.25	0.90	**7.54**	1.11	0.12	0.03	0.20	0.00	0.00	0.00	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	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	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	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	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	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	0.00	0.00	0.00
Total	**13.08**	**3.05**	**14.39**	**8.45**	**11.20**	**10.06**	**14.40**	**10.68**	**27.69**	**37.84**	**15.23**	**3.54**	**9.42**

Table 10b. Catch rates (fish/day) of year classes of male striped bass sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2014. 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**	**2011**	**2012**	**2013**	**2014**
2011											**3.29**
2010										1.65	**2.47**
2009									**1.40**	1.39	0.29
2008							0.13	0.46	**3.20**	1.43	0.00
2007						0.07	2.53	1.04	**3.36**	0.70	0.06
2006					0.11	1.78	**6.30**	1.00	1.60	0.17	0.06
2005				0.03	4.34	4.48	**9.63**	0.67	0.96	0.09	0.06
2004				2.49	**7.03**	5.48	4.03	0.67	0.68	0.13	0.35
2003			7.77	**8.46**	3.00	1.70	1.37	0.63	0.56	0.39	0.47
2002		1.83	**6.29**	5.83	0.46	1.00	0.70	0.50	0.32	0.09	0.06
2001	3.47	**5.40**	2.91	0.97	0.49	0.81	0.67	0.25	0.08	0.22	0.12
2000	**5.47**	2.49	0.09	1.03	0.37	0.48	0.27	0.17	0.08	0.13	0.00
1999	**5.67**	0.66	0.20	1.00	0.14	0.19	0.23	0.00	0.08	0.00	0.00
1998	**3.37**	0.51	0.57	0.89	0.03	0.07	0.13	0.00	0.08	0.00	0.00
1997	1.93	1.00	0.29	0.37	0.06	0.04	0.00	0.00	0.00	0.00	0.00
1996	2.23	0.43	0.03	0.29	0.03	0.70	0.10	0.00	0.00	0.00	0.06
1995	0.53	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994	0.20	0.09	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1992	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.40	0.46	0.29	0.00	0.00	0.07	1.40	0.04	0.44	0.17	0.00
Total	**23.44**	**12.96**	**18.50**	**21.36**	**16.09**	**16.87**	**27.50**	**5.43**	**12.80**	**6.56**	**7.29**

Table 11a. Catch rates (fish/day) of year classes of female striped bass sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2014. 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	2001	2002	2003
1999												0.06	0.07
1998												0.06	0.27
1997											0.07	0.13	0.07
1996										0.03	0.26	0.00	0.37
1995							0.05	0.00	0.04	0.13	0.00	0.63	0.80
1994							0.10	0.15	0.11	0.03	0.19	0.38	**1.47**
1993					0.16	0.14	0.60	0.11	0.04	0.24	0.71	0.25	**1.37**
1992				0.22	0.12	0.20	0.10	0.04	0.14	0.40	0.68	0.19	**1.13**
1991		0.05	0.04	0.00	0.08	0.29	0.00	0.22	0.21	0.34	**0.68**	0.06	0.33
1990	0.25	0.15	0.08	0.04	0.24	0.31	0.35	**0.59**	0.32	0.26	0.45	0.00	0.26
1989	0.17	0.20	0.12	**1.07**	0.60	0.46	0.25	0.74	0.32	0.34	0.26	0.00	0.07
1988	0.33	0.70	**2.00**	1.11	0.48	0.34	1.30	0.89	0.39	0.05	0.10	0.00	0.00
1987	1.92	2.10	**2.42**	0.93	0.68	0.29	1.00	0.89	0.43	0.05	0.00	0.03	0.03
1986	**1.08**	0.85	0.50	0.48	0.36	0.09	1.00	0.22	0.04	0.00	0.00	0.00	0.00
1985	**1.17**	0.25	0.39	0.48	0.08	0.00	0.35	0.15	0.11	0.00	0.00	0.00	0.00
1984	0.42	0.25	**0.50**	0.33	0.28	0.00	0.35	0.07	0.04	0.00	0.00	0.00	0.00
>1983	0.83	0.65	**1.19**	0.59	0.08	0.03	0.20	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	0.00	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**	**3.40**	**1.79**	**6.24**

Table 11b. Catch rates (fish/day) of year classes of female striped bass sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2014. 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**	**2011**	**2012**	**2013**	**2014**
2011											**0.06**
2010											**0.18**
2009								0.00	0.04	**0.35**	0.12
2008							0.10	0.00	0.00	**0.48**	0.00
2007							0.10	0.04	**0.44**	0.13	0.00
2006					0.06	0.11	0.20	0.38	**0.52**	0.13	0.41
2005				0.00	0.06	0.59	**0.80**	0.29	0.08	0.17	0.59
2004				0.03	0.17	**1.44**	0.20	0.13	0.24	0.17	1.00
2003			0.11	0.09	0.26	0.44	0.17	0.25	0.72	0.74	**1.06**
2002			0.11	0.34	0.06	0.22	0.33	0.46	**0.52**	0.30	0.47
2001		0.03	0.26	0.17	0.11	0.41	0.60	0.79	**0.88**	0.65	0.76
2000	0.10	0.29	0.06	0.09	0.20	0.70	**1.50**	0.46	0.36	0.35	0.65
1999	0.23	0.06	0.31	0.51	0.14	**1.00**	0.87	0.25	0.20	0.13	0.00
1998	0.17	0.26	0.34	**1.00**	0.40	0.59	0.57	0.04	0.24	0.13	0.24
1997	0.30	0.69	0.57	**2.31**	0.37	0.33	0.53	0.17	0.20	0.04	0.06
1996	1.93	1.26	1.14	**3.51**	0.43	0.70	1.03	0.08	0.20	0.22	0.12
1995	**1.80**	0.86	0.23	0.71	0.00	0.00	0.13	0.04	0.00	0.00	0.00
1994	**1.47**	0.60	0.14	0.71	0.00	0.19	0.07	0.00	0.00	0.00	0.00
1993	0.90	0.54	0.20	0.46	0.00	0.00	0.07	0.08	0.00	0.09	0.00
1992	1.03	0.29	0.11	0.20	0.00	0.04	0.07	0.00	0.00	0.00	0.00
1991	0.17	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.07	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	0.07	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.00	0.03	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00
Total	**8.24**	**5.09**	**3.58**	**10.16**	**2.26**	**6.67**	**7.40**	**3.46**	**4.64**	**4.08**	**5.72**

Table 12a. 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, 1991-2014.

	Year Class											
	1984	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**
91-92		.678	.431	.675								
92-93		.678	.972	.675								
93-94	.881	.678	.972	.315	.233							
94-95	.881	.876	.972	.955	.878	.440						
95-96	.881	.876	.972	.955	.878	.440	.563		.596			
96-97	.881	.876	.972	.955	.878	.899	.745	.868	.437			
97-98	.200	.429	.220	.890	.593	.975	.745	.869	.983	.183		
98-99	.571	.733	.182	.483	.438	.689	.863	.869	.983	.993	.441	
99-00	.000	.000	.000	.116	.506	.689	.863	.869	.983	.993	.884	.290
00-01				.903	.506	.703	.863	.869	.983	.993	.884	.914
01-02				.903	.000	.646	.775	.638	.983	.993	.884	.914
02-03				.903		.646	.775	.638	.983	.993	.884	.914
03-04				.903		.646	.259	.515	.894	.699	.982	.914
04-05				.903		.429	.754	.529	.264	.570	.752	.403
05-06				.000		.000	.754	.000	.830	.898	.752	.869
06-07							.754		.830	.898	.752	.869
07-08							.000		.705	.762	.517	.568
08-09									.705	.762	.517	.568
09-10									.705	.762	.368	.568
10-11									.000	.762	.000	.308
11-12										.762		.000
12-13										.762		
13-14										.000		
mean	**.571**	**.621**	**.581**	**.668**	**.517**	**.579**	**.647**	**.641**	**.714**	**.726**	**.638**	**.594**

Table 12b. 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, 1991-2014.

	Year Class												
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
91-92													
92-93													
93-94													
94-95													
95-96													
96-97													
97-98													
98-99													
99-00													
00-01	.237	.480											
01-02	.990	.842											
02-03	.990	.842											
03-04	.990	.842											
04-05	.970	.842	.814	.635	.497								
05-06	.970	.842	.814	.635	.914	.584							
06-07	.970	.842	.814	.635	.914	.796	.964						
07-08	.667	.583	.718	.888	.914	.796	.445	.381					
08-09	.667	.583	.718	.888	.914	.796	.445	.660	.963				
09-10	.667	.583	.718	.924	.914	.796	.844	.935	.610				
10-11	.580	.614	.676	.505	.778	.819	.932	.934	.752	.316	.571		
11-12	.580	.614	.676	.505	.778	.923	.875	.934	.752	.316	.571		
12-13	.580	.548	.866	.464	.778	.957	.794	.934	.752	.791	.471	.218	.597
13-14	.818	.548	.866	.000	.778	.957	.794	.934	.752	.791	.471	.072	.000
mean	**.719**	**.672**	**.765**	**.584**	**.806**	**.817**	**.732**	**.782**	**.757**	**.500**	**.519**	**.125**	**.486**

Table 13a. 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, 1991-2014.

	Year Class											
	1984	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**
91-92		.100	.116	.450								
92-93	.533	.894	.500	.450								
93-94	.000	.894	.733	.179	.147							
94-95		.000	.364	.640	.565	.539						
95-96			.000	.640	.565	.539	.470		.568			
96-97				.000	.565	.539	.372	.473	.432			
97-98					.000	.270	.314	.473	.560	.183		
98-99						.270	.522	.700	.560	.436	.433	
99-00						.750	.522	.787	.726	.436	.381	.280
00-01						.000	.000	.787	.726	.615	.381	.559
01-02								.000	.000	.855	.768	.559
02-03										.855	.768	.559
03-04										.855	.870	.946
04-05										.000	.450	.170
05-06											.667	.000
06-07											.000	
07-08												
08-09												
09-10												
10-11												
11-12												
12-13												
13-14												
mean	**.238**	**.409**	**.317**	**.372**	**.345**	**.395**	**.353**	**.508**	**.490**	**.496**	**.501**	**.409**

Table 13b. 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, 1991-2014.

	Year Class												
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
91-92													
92-93													
93-94													
94-95													
95-96													
96--97													
97-98													
98-99													
99-00													
00-01	.223	.475											
01-02	.821	.639											
02-03	.821	.639											
03-04	.821	.639											
04-05	.793	.518	.642	.561	.455								
05-06	.793	.608	.642	.561	.643	.539							
06-07	.793	.608	.642	.561	.643	.333	.927						
07-08	.793	.162	.527	.613	.683	.914	.414	.355					
08-09	.793	.667	.527	.613	.683	.914	.414	.567	.780				
09-10	.143	.000	.527	.613	.563	.827	.700	.806	.735				
10-11	.880		.784	.590	.630	.373	.714	.460	.411	.316	.504		
11-12	.880		.784	.590	.874	.938	.640	.889	.411	.316	.504		
12-13	.880		.000	.000	.874	.938	.281	.916	.717	.094	.106	.208	.447
13-14	.880				.000	.545	.667	.916	.717	.667	.353	.086	.000
mean	**.665**	**.477**	**.545**	**.508**	**.584**	**.655**	**.559**	**.662**	**.607**	**.281**	**.312**	**.133**	**.203**

Table 14a. 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, 1991-2014.

	Year Class											
	1984	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**
91-92		.743	.987									
92-93		.743	.987									
93-94	.915	.743	.987	.802	.898							
94-95	.915	.900	.987	.802	.898	.912						
95-96	.915	.900	.987	.802	.898	.912						
96-97	.915	.900	.987	.802	.898	.912						
97-98	.200	.429	.220	.890	.685	.912						
98-99	.571	.733	.182	.483	.438	.678	.914					
99-00	.000	.000	.000	.093	.506	.678	.914					
00-01				.903	.506	.765	.914					
01-02				.903	.000	.646	.760	.697				
02-03				.903		.646	.760	.697				
03-04				.903		.646	.269	.515	.912	.657	.834	
04-05				.903		.429	.754	.529	.282	.600	.834	.478
05-06				.000		.000	.754	.000	.830	.923	.834	.909
06-07							.754		.830	.923	.834	.909
07-08							.000		.705	.762	.517	.568
08-09									.705	.762	.517	.568
09-10									.705	.762	.368	.568
10-11									.000	.762	.000	.000
11-12										.762		
12-13										.762		
13-14										.000		
mean	**.587**	**.649**	**.646**	**.673**	**.607**	**.655**	**.649**	**.462**	**.589**	**.676**	**.563**	**.542**

Table 14b. 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, 1991-2014.

	Year Class											
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
91-92												
92-93												
93-94												
94-95												
95-96												
96-97												
97-98												
98-99												
99-00												
00-01												
01-02												
02-03												
03-04												
04-05												
05-06												
06-07												
07-08	.665	.612	.768									
08-09	.665	.612	.768									
09-10	.665	.612	.966	.870					.930			
10-11	.598	.614	.806	.287	.811				.930	.927		
11-12	.598	.614	.806	.800	.811				.930	.927		
12-13	.598	.548	.806	.650	.811	.929	.951		.930	.927	.888	.295
13-14	.545	.548	.806	.000	.811	.929	.951		.930	.927	.888	.000
mean	**.618**	**.594**	**.816**	**.482**	**.811**	**.929**	**.951**		**.930**	**.927**	**.888**	**.138**

Table 15a. Comparison of the area under the catch curve (fish/ day) of the 1989-2010 year classes of striped bass from pound nets in the Rappahannock River, 1991-2014.

age	year class										
	1989	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
2	0.2	0.3	0.3	0.7	1.5	0.3	0.3	0.1	0.4	0.0	0.0
3	0.8	1.3	0.8	5.5	5.5	4.2	2.5	11.6	16.0	2.7	0.6
4	4.4	2.6	1.8	8.4	13.6	10.5	14.0	29.8	23.5	4.2	3.6
5	8.9	4.9	3.4	9.6	15.1	13.3	17.3	34.1	24.9	7.5	9.5
6	9.6	6.1	3.5	9.7	15.2	13.4	17.4	34.3	25.3	11.0	10.2
7	10.5	6.8	4.0	10.2	15.7	14.0	18.1	36.1	27.5	11.8	10.7
8	11.3	7.5	4.4	10.7	16.6	14.4	19.5	40.3	29.2	12.7	12.2
9	12.1	7.8	4.8	11.5	16.8	16.1	21.8	42.0	30.1	14.6	12.5
10	12.5	8.1	5.7	11.7	18.3	17.8	22.7	43.2	32.8	15.0	13.7
11	12.8	8.6	5.9	12.9	19.3	18.4	22.9	47.0	33.2	15.7	14.8
12	13.1	8.6	7.0	14.0	19.8	18.6	23.6	47.5	33.5	16.4	15.1
13	13.1	8.9	8.1	14.3	20.0	19.3	23.6	48.2	34.0	16.4	15.4
14	13.2	8.9	8.4	14.4	20.5	19.3	23.6	49.3	34.2	16.7	15.5
15	13.2	9.0	8.4	14.6	20.5	19.5	23.7	49.4	34.4	16.8	15.5
16	13.3	9.0	8.4	14.6	20.5	19.6	23.7	49.6	34.4	17.0	
17	13.3	9.0	8.4	14.6	20.6	19.6	23.7	49.8	34.5		
18	13.3	9.0	8.4	14.7	20.7	19.6	23.7	50.0			
19	13.3	9.0	8.4	14.7	20.7	19.6	23.7				
20	13.3	9.0	8.4	14.7	20.8	19.6					
area	**13.3**	**9.0**	**8.4**	**14.7**	**20.8**	**19.6**	**23.7**	**50.0**	**34.5**	**17.0**	**15.5**

Table 15b. Comparison of the area under the catch curve (fish/ day) of the 1989-2010 year classes of striped bass from pound nets in the Rappahannock River, 1991-2014.

age	**year class**											**mean**
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	
2	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.2	0.1	0.0	**0.2**
3	0.8	3.5	1.8	7.9	2.6	4.4	2.0	2.7	0.7	1.5	1.7	**3.7**
4	6.3	8.9	8.2	16.5	9.8	9.5	8.5	3.8	3.9	3.2	4.3	**8.9**
5	9.1	12.1	14.3	19.8	16.7	19.9	9.9	7.6	5.8	3.6		**12.3**
6	9.2	13.3	14.8	21.9	20.9	20.9	12.0	8.4	5.8			**13.3**
7	10.3	13.9	16.0	23.5	21.7	21.9	12.3	8.5				**14.2**
8	10.9	15.1	17.0	24.4	22.6	22.2	12.8					**15.3**
9	12.1	16.4	18.0	25.7	22.9	22.8						**16.3**
10	13.9	17.5	18.8	26.8	24.3							**17.4**
11	14.6	18.5	19.2	28.3								**18.3**
12	15.0	19.4	19.7									**19.0**
13	15.5	20.3										**19.4**
14	16.1											**19.7**
15												**19.8**
16												**19.9**
17												**19.9**
18												**20.0**
19												**20.0**
20												**20.0**
area	**16.1**	**20.3**	**19.7**	**28.3**	**24.3**	**22.8**	**12.8**	**8.5**	**5.8**	**3.6**	**4.3**	**20.0**

Table 16a. Back-calculated length-at-age (FL, in mm) for striped bass sampled from the James and Rappahannock rivers during spring, 2014.

Year Class	n	length-at-age (FL, in mm)							
		1	2	3	4	5	6	7	8
2011	57	148.0	256.9						
2010	45	141.8	253.6	356.3					
2009	18	139.0	243.6	348.4	437.1				
2008	0								
2007	1	152.3	254.3	347.1	435.0	498.7	561.6		
2006	8	136.4	234.3	334.6	427.6	513.8	594.7	663.5	
2005	11	147.6	249.1	345.9	436.3	526.5	609.6	681.0	738.4
2004	23	149.2	246.5	341.5	432.2	522.7	601.9	674.4	738.0
2003	26	141.1	245.5	336.8	421.9	505.8	585.6	654.1	719.0
2002	9	142.3	231.6	319.6	406.1	488.7	565.2	632.9	705.3
2001	14	135.3	223.6	312.1	400.0	475.6	548.0	615.9	680.6
2000	9	146.6	238.2	332.2	417.5	499.4	571.4	640.5	700.1
1999	0								
1998	4	133.9	221.0	298.4	372.6	438.7	506.0	566.8	635.0
1997	1	149.9	240.3	336.9	416.4	488.9	562.8	621.1	677.4
1996	3	147.1	237.7	323.2	401.0	471.3	537.1	595.6	645.4
all	218	144.7	247.1	339.4	419.9	502.1	579.8	648.4	711.3

Table 16b. Back-calculated length-at-age (FL, in mm) for striped bass sampled from the James and Rappahannock rivers during spring, 2014.

Year Class	n	length-at-age (FL, in mm)									
		9	10	11	12	13	14	15	16	17	18
2011	11										
2010	18										
2009	18										
2008	16										
2007	16										
2006	18										
2005	24										
2004	23	790.2									
2003	26	776.8	821.4								
2002	9	766.2	819.4	865.8							
2001	14	740.1	795.4	846.2	889.3						
2000	9	757.1	807.0	850.4	894.0	928.8					
1999	0										
1998	4	700.0	754.2	804.4	849.6	893.8	934.0	957.0			
1997	1	732.5	779.4	824.5	868.1	920.3	963.1	1007	1050		
1996	3	690.1	732.3	772.3	815.4	849.3	892.4	931.8	969.8	1000	
all	218	765.9	810.1	845.2	881.3	911.6	942.5	953.8	982.2	1000	

Table 17. Data matrix comparing 2014 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**	**22**
1	**0**																					
2		**0**	0																			
3			**7**	0																		
4			4	**7**	1																	
5				1	**10**	1	1															
6					2	**1**	3	1														
7						0	**1**	1	1	1												
8						1	1	**0**	1	0	0	0										
9								1	**1**	0	1	0	0									
10									0	**1**	6	6	1	0								
11										0	**5**	9	0	0	0	1						
12											1	**12**	2	0	0	0						
13											1	3	**1**	0	0	0	0					
14													0	**0**	0	0	0	0				
15														0	**0**	0	0	0	0			
16															0	**0**	0	1	0	0		
17																0	**0**	0	0	0	0	
18																	0	**0**	0	0	0	0
19																		0	**0**	0	0	0
20																			0	**0**	0	0
21																				0	**0**	0
22																					0	**0**

Table 18. Relative contributions of striped bass age classes as determined by ageing specimens (n = 71) by reading both their scales and otoliths, spring 2014.

Age	**Scale age**		**Otolith age**	
	n	**prop**	**n**	**Prop**
1	0	0.0000	0	0.0000
2	0	0.0000	0	0.0000
3	7	0.0986	12	0.1690
4	13	0.1831	8	0.1127
5	13	0.1831	13	0.1831
6	7	0.0986	3	0.0423
7	4	0.0563	6	0.0845
8	3	0.0423	3	0.0423
9	3	0.0423	3	0.0423
10	9	0.1268	3	0.0423
11	6	0.0845	14	0.1972
12	3	0.0423	0	0.0000
13	2	0.0282	4	0.0563
14	0	0.0000	0	0.0000
15	0	0.0000	0	0.0000
16	1	0.0141	1	0.0141
17	0	0.0000	0	0.0000
18	0	0.0000	1	0.0141
19	0	0.0038	0	0.0000
20	0	0.0000	0	0.0000
21	0	0.0000	0	0.0000
	Age = 6.94		*Age* = 7.24	

Table 19. Mean scale and standard error for each otolith age from ages derived from the same specimen.

N	Otolith age	Mean scale age	SE
91	2	2.31	0.47
161	3	3.26	0.47
198	4	4.30	0.61
186	5	5.05	0.67
147	6	5.97	0.83
199	7	6.66	1.13
252	8	8.08	0.98
295	9	8.96	1.13
344	10	9.77	1.17
322	11	10.82	1.10
249	12	11.43	1.17
125	13	12.03	1.26
85	14	12.19	1.22
53	15	13.36	1.35
47	16	14.72	1.44
28	17	14.61	1.29
10	18	15.60	0.97
6	19	16.00	2.10
4	20	16.50	1.00
8	21	16.85	2.10

Table 20. Data matrix comparing 2003-2014 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 A	**Otolith age**																		
	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20+**
2	**62**	2	0																
3	29	**115**	14	2															
4		44	**112**	25	3	5													
5			70	**120**	40	27	0	2											
6			2	35	**65**	50	10	1	0										
7				2	36	**74**	58	21	7	0	1	1							
8					3	35	**106**	74	44	5	2	1							
9						7	61	**110**	71	30	7	1	0						
10						1	14	64	**138**	81	44	7	2	1					
11							3	19	64	**129**	66	29	6	4	1				
12								4	14	60	**90**	39	26	8	2	1			
13									6	12	33	**38**	24	16	9	5	0		1
14										5	6	6	**22**	11	15	6	2	1	0
15												3	3	**12**	10	11	1	2	1
16													1	1	**6**	2	6	2	6
17													1	0	3	**3**	1	0	1
18															1	0	**0**	0	3
19																	0	**0**	3
20+																		1	**1**

Table 21. Relative contributions of striped bass age classes as determined by ageing specimens (n = 2,815) by reading both their scales and otoliths, springs 2003-2014.

Age	**Scale age**		**Otolith age**	
	n	**prop**	**n**	**Prop**
1	0	0.0000	0	0.0000
2	64	0.0228	91	0.0324
3	162	0.0577	161	0.0573
4	189	0.0673	198	0.0705
5	259	0.0922	186	0.0662
6	163	0.0580	147	0.0523
7	200	0.0712	199	0.0708
8	270	0.0961	252	0.0897
9	287	0.1021	295	0.1050
10	352	0.1253	344	0.1224
11	321	0.1142	322	0.1146
12	244	0.0868	249	0.0886
13	144	0.0512	125	0.0445
14	74	0.0263	85	0.0302
15	43	0.0153	53	0.0189
16	22	0.0078	47	0.0167
17	9	0.0032	28	0.0100
18	4	0.0014	10	0.0036
19	2	0.0007	6	0.0021
20	1	0.0003	4	0.0014
21	0	0.0000	8	0.0028
	Age = 8.52		Age = 8.78	

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 1991-2014.

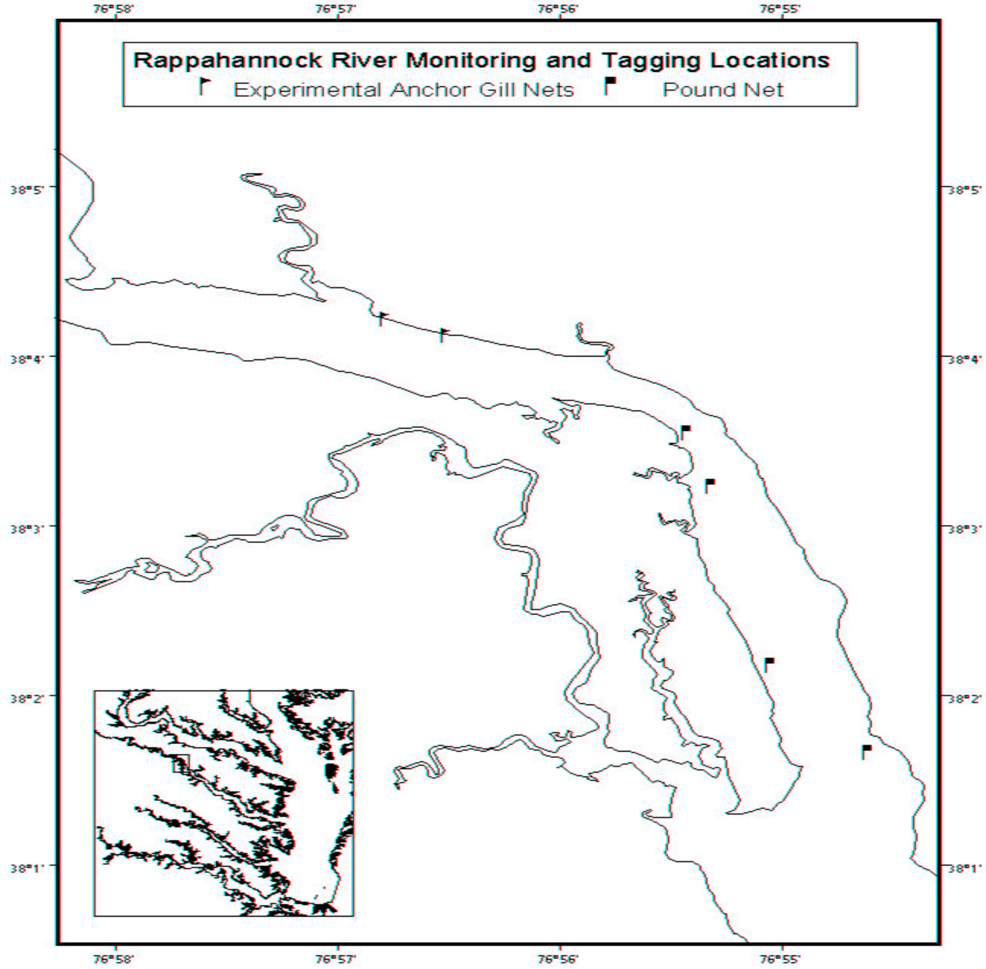


Figure 2. Daily and historic mean river flows (cf/s) for the Rappahannock River during the 30 March – 3 May spawning stock assessment period, spring 2014.

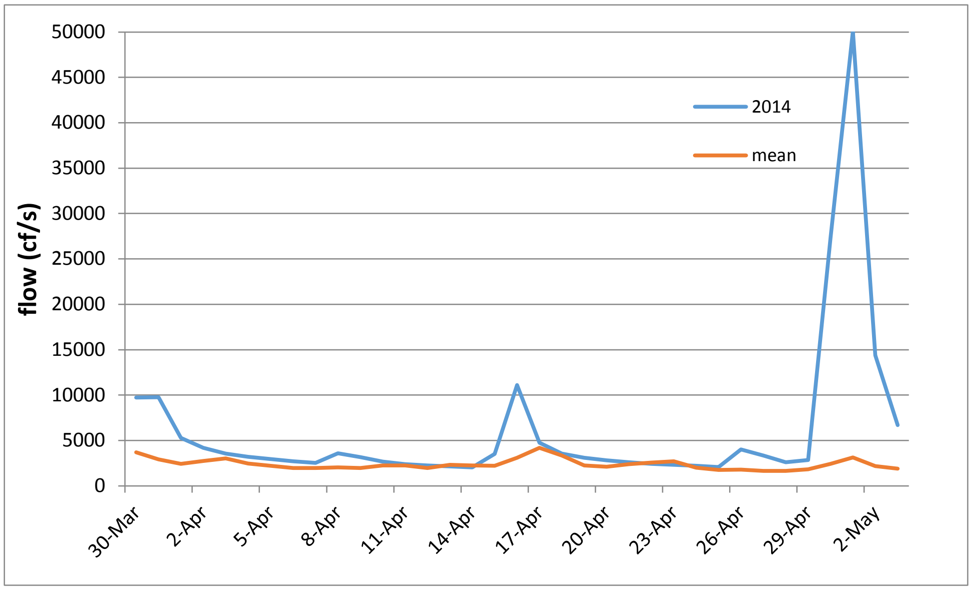
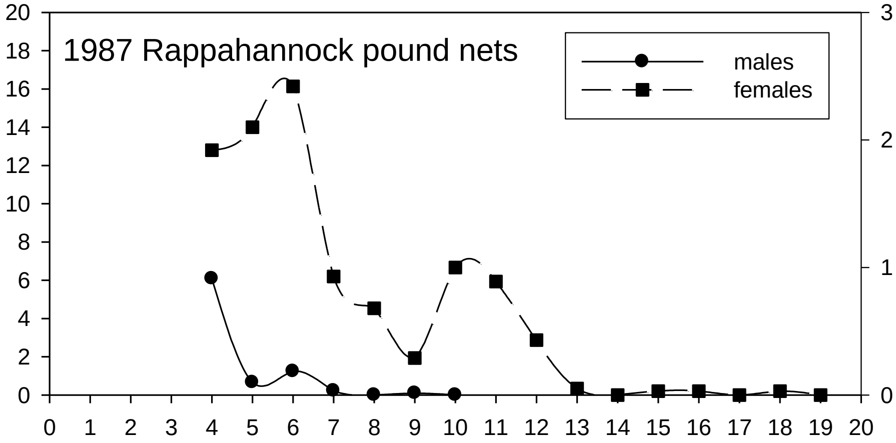


Figure 3. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1987 and 1988 year classes of striped bass from the Rappahannock River pound nets, springs 1991-2014.



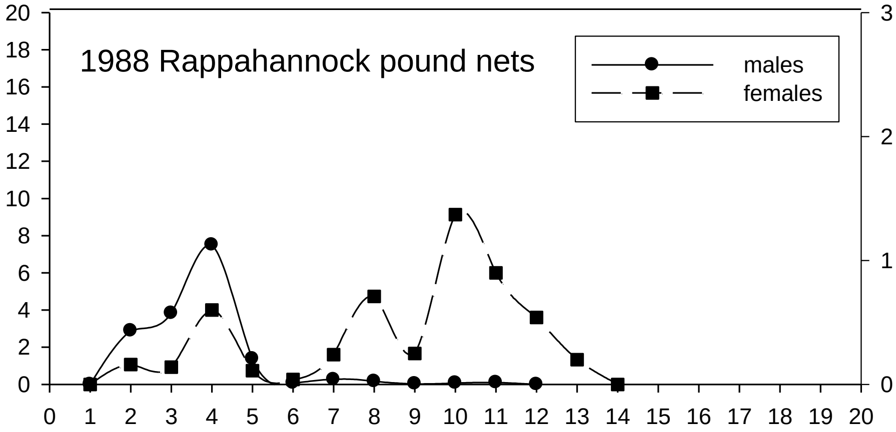
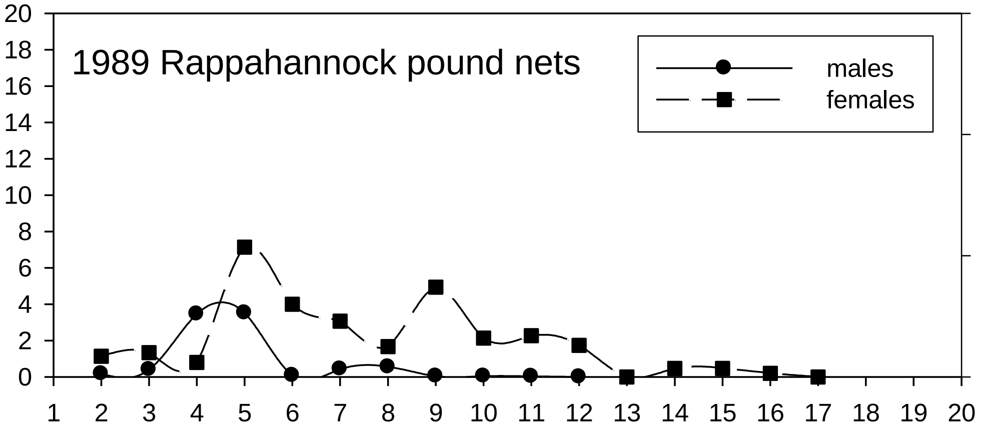


Figure 4. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1989 and 1990 year classes of striped bass from the Rappahannock River pound nets, springs 1991-2014.



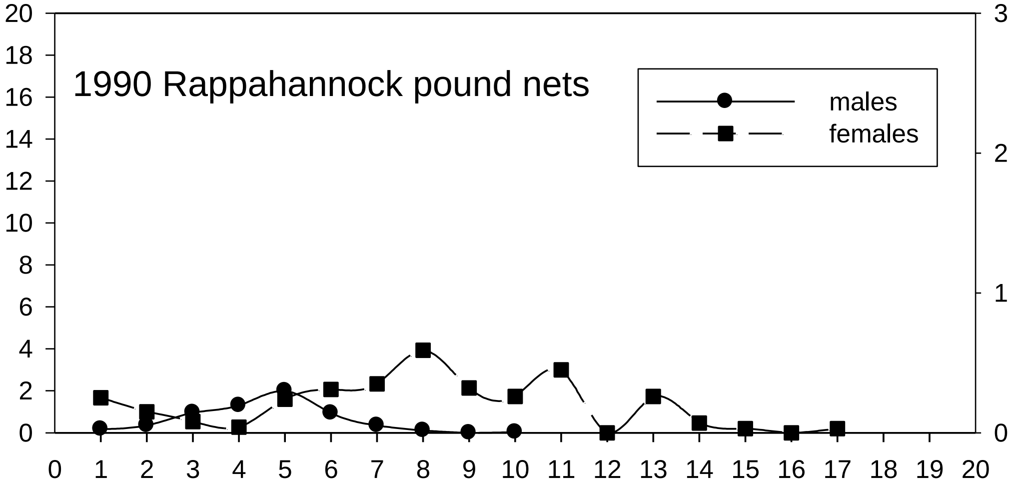
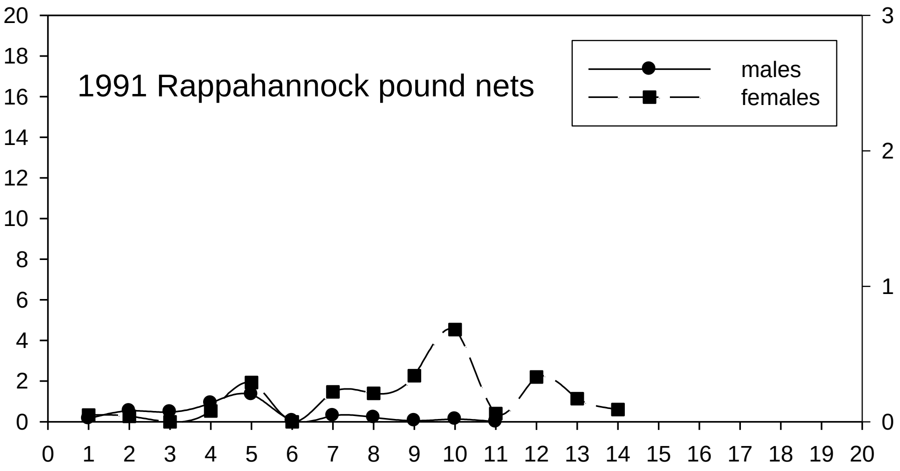


Figure 5. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1991 and 1992 year classes of striped bass from the Rappahannock River pound nets, springs 1991-2014.



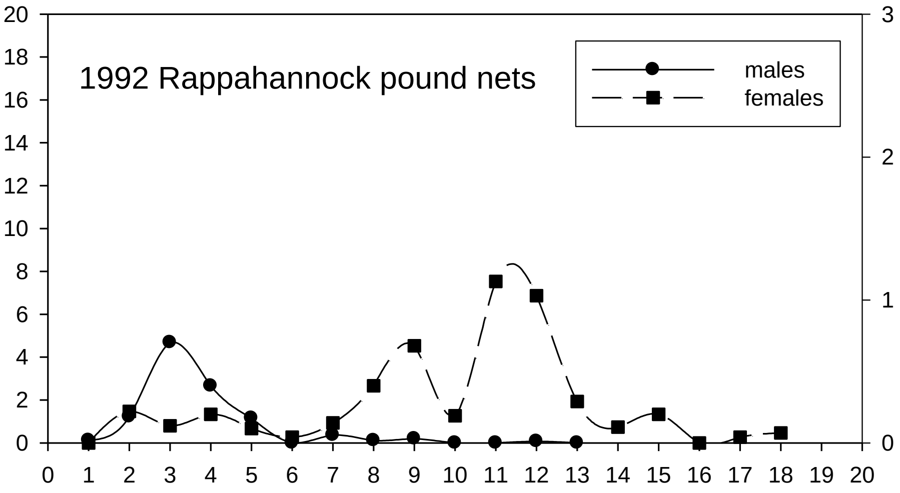
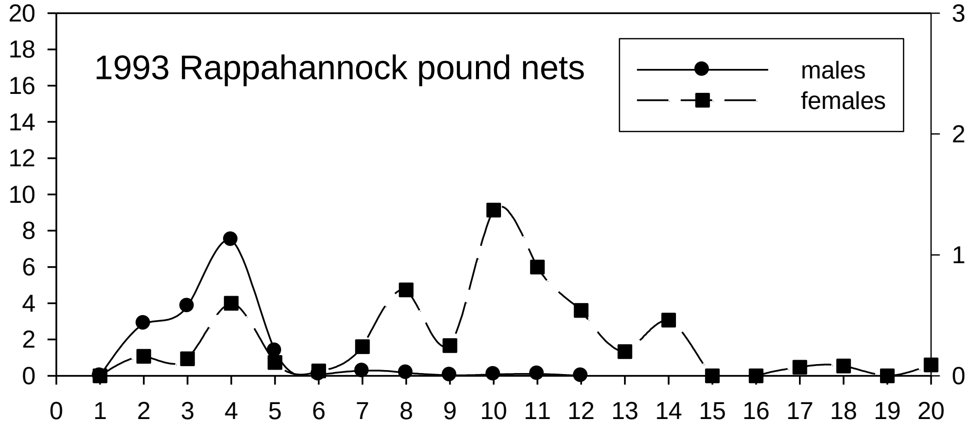


Figure 6. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1993 and 1994 year classes of striped bass from the Rappahannock River pound nets, springs 1994-2014.



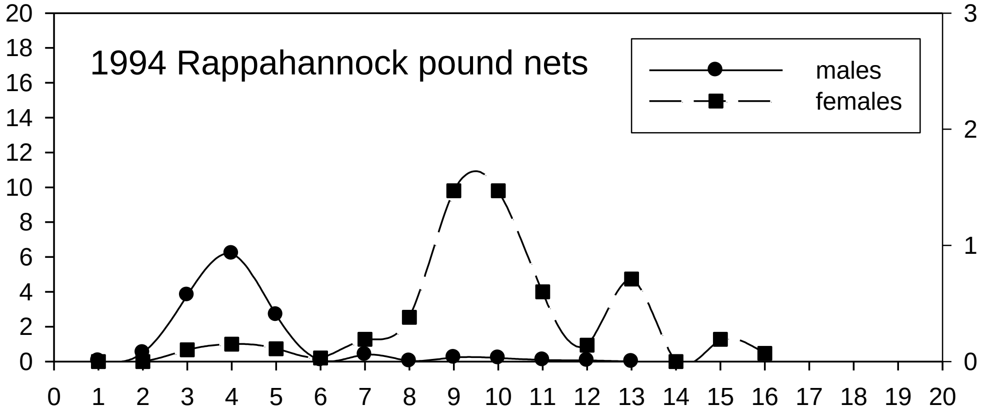


Figure 7. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1995 and 1996 year classes of striped bass from the Rappahannock River pound nets, springs 1996-2014.

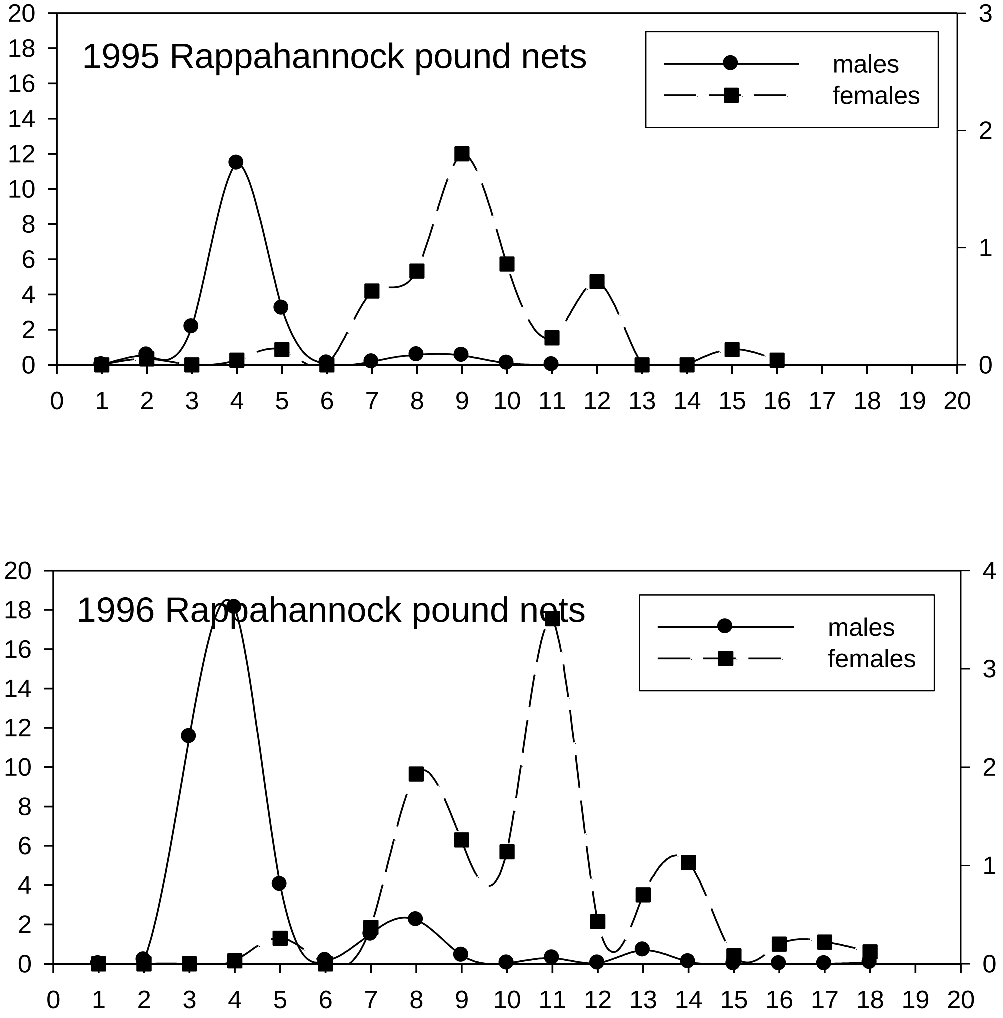
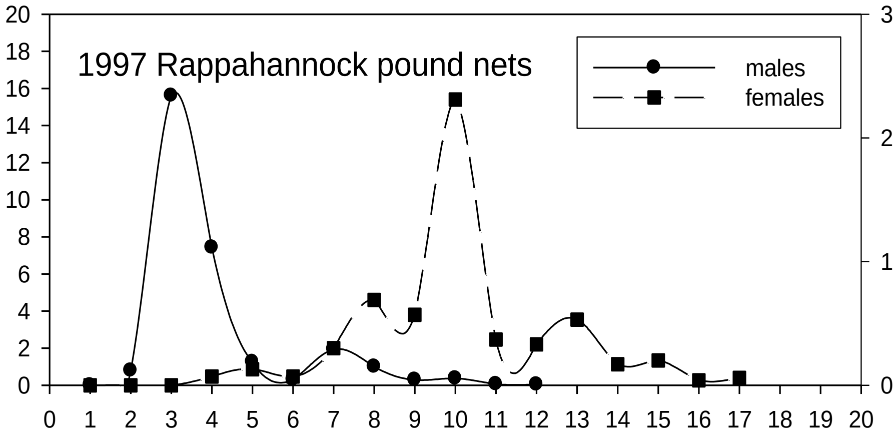


Figure 8. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1997 and 1998 year classes of striped bass from the Rappahannock River pound nets, springs 1998-2014.



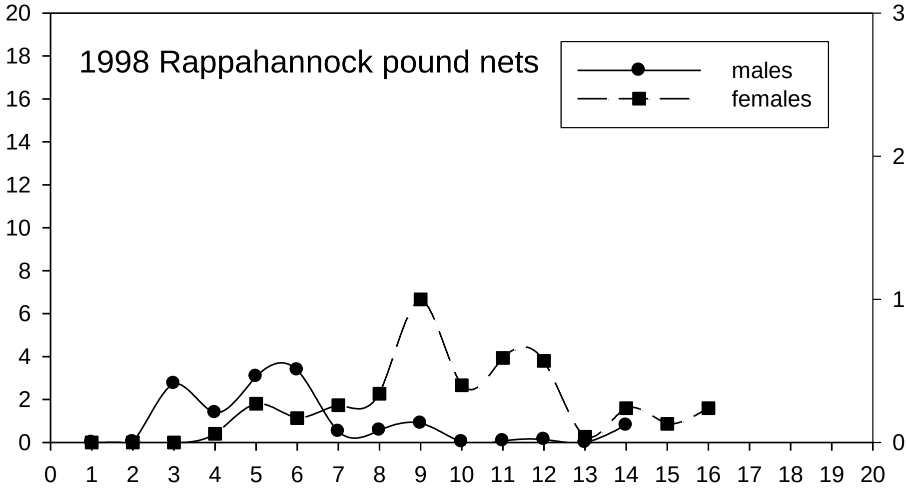
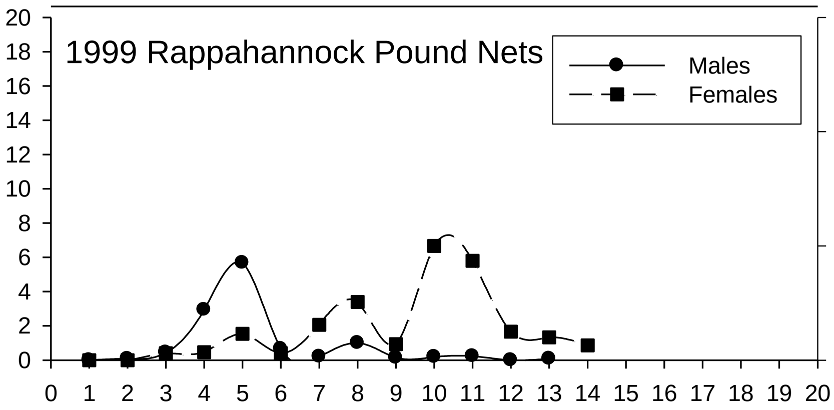


Figure 9. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1999 and 2000 year classes of striped bass from the Rappahannock River pound nets, springs 2000-2014.



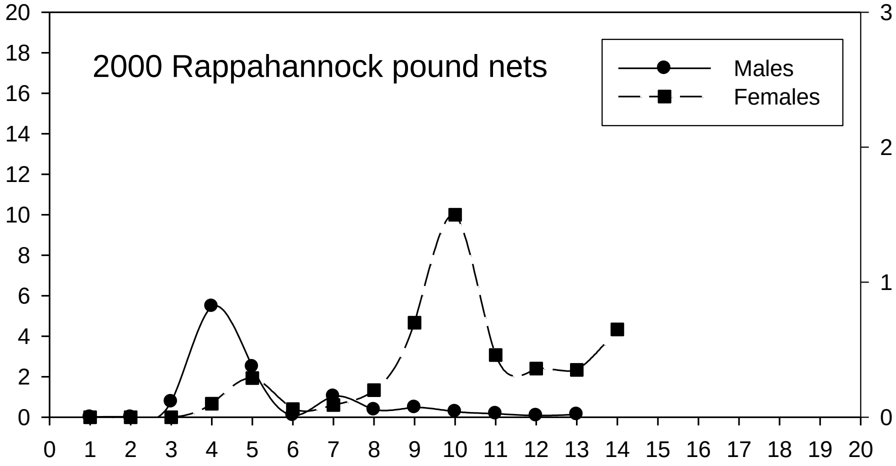


Figure 10. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 2001 and 2002 year classes of striped bass from the Rappahannock River pound nets, springs 2001-2014.

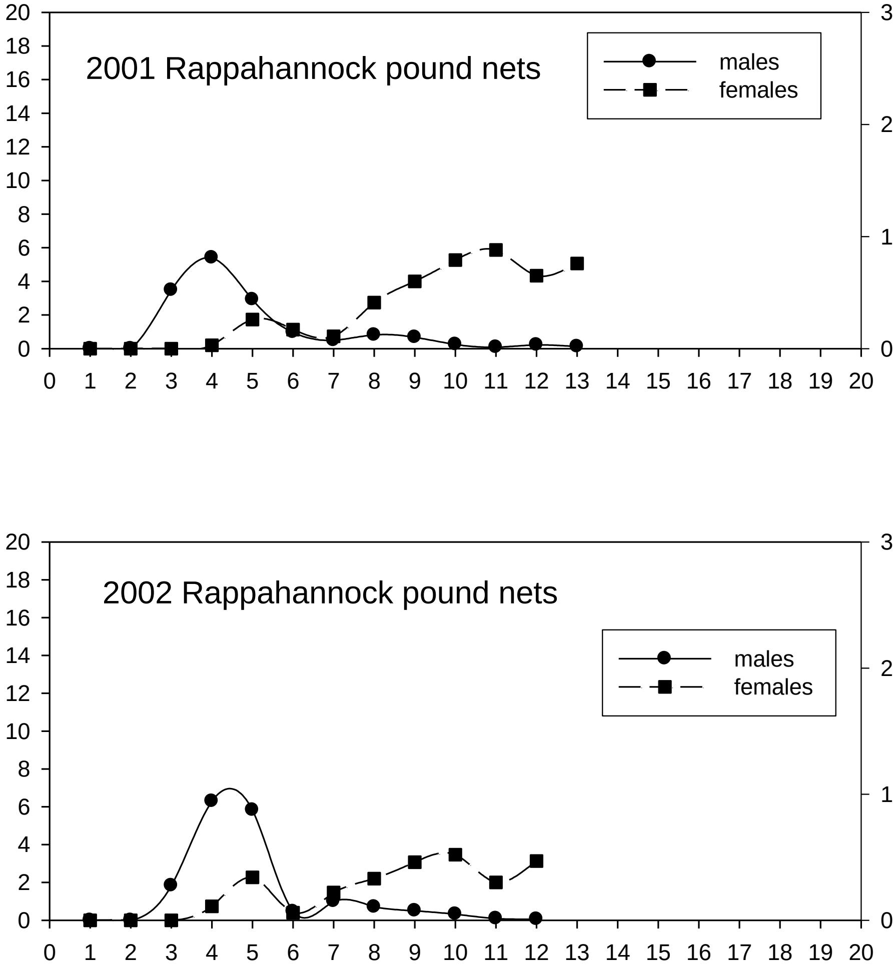


Figure 11. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 2003 and 2004 year classes of striped bass from the Rappahannock River pound nets, springs 2003-2014.

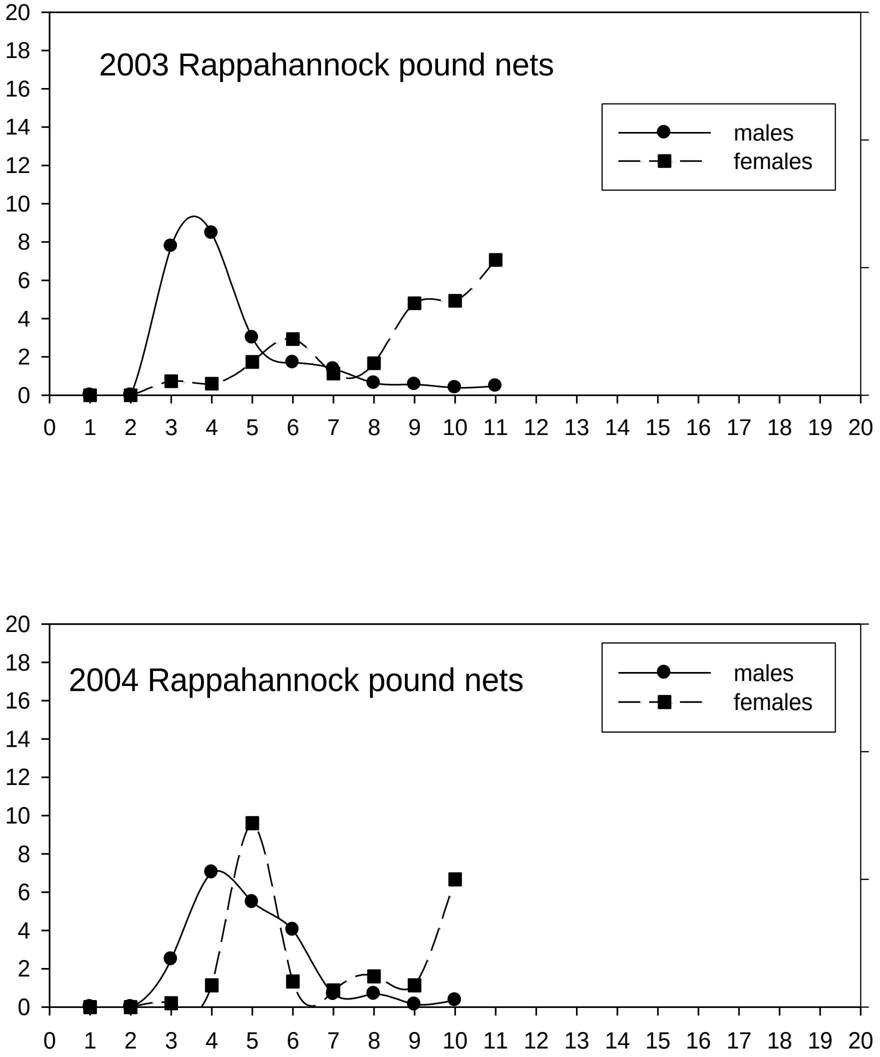


Figure 12. Magnitude of the age differences (n = 71) by reading both their scales and otoliths, spring, 2014.

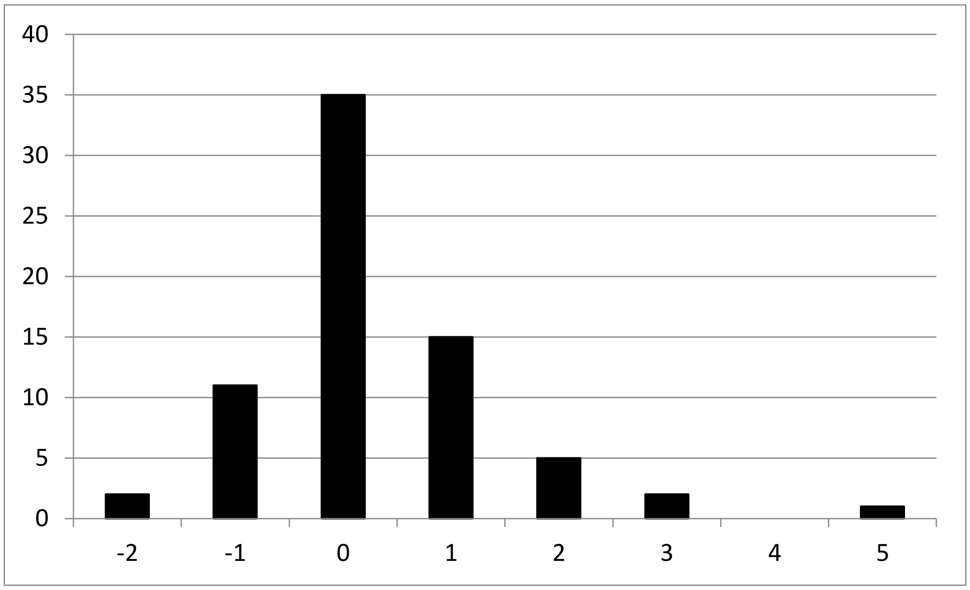


Figure 13. Comparison of otolith ages (diagonal) with their respective mean scale ages from the paired ageing methodology study, 2003-2014.

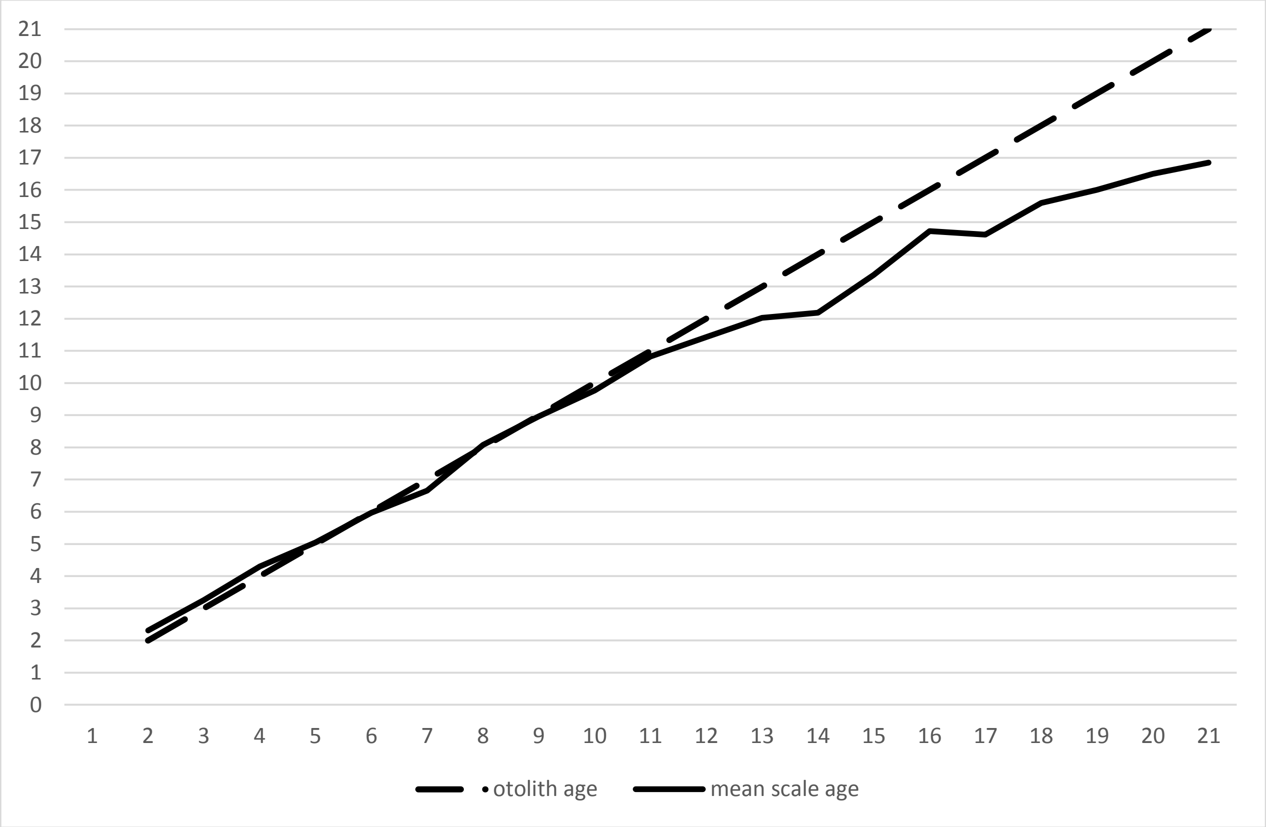
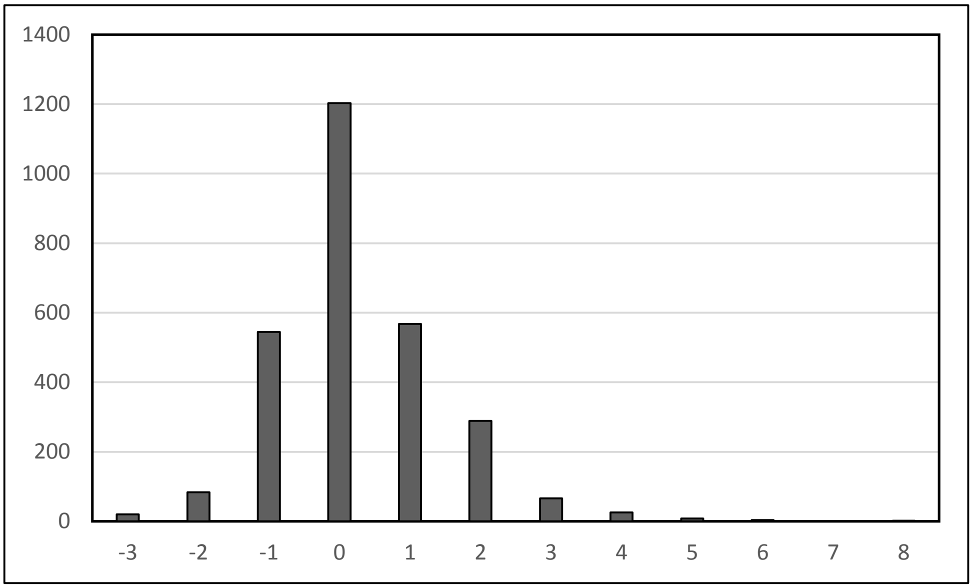


Figure 14. Magnitude of the age differences (n = 2,815) by reading both their scales and otoliths, springs, 2003-2014.



II. Mortality estimates of striped bass (*Morone saxatilis*) that spawn in the Rappahannock River, Virginia, spring, 2013-2014.

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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.

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

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

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

Rappahannock River: Each year from 1991 to 2014, 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 cooperating commercial fishermen. The pound net is a fixed trap that is presumed to be non-size selective in its catch of striped bass, and has been historically used by commercial fishermen in the Rappahannock River. These pound nets are located between river miles 45 – 56.

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.

In 2014, the multiple-mesh experimental gill nets previously utilized to supplement the pound nets to derive estimates of spawning stock biomass were retasked to supplement the tag release totals in the Rappahannock River. The multiple-mesh gill nets deployed 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.

The nets were set between river miles 42-48 and fished for 2-4 sets of one to three hours duration, dependent on success of the catch and/or water temperature and conditions. The risk of the nets becoming snagged on submerged object known to exist above mile 48 limited the extent to which we could deploy the nets.

James River: In 2014, the multiple-mesh experimental gill nets previously used as the source of a monitoring index in the James River was also retasked to initiate a tagging program to expand and supplement the data produced in the Rappahannock River. The same panel size and mesh order were kept, however each net was constructed as two half nets of 150 feet in length. These nets were deployed between river miles 55 to 68 and fished for two to four sets of up to two hours soak time to maximize catch and minimize net mortality.

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 2012 analysis, the last regulatory period (2003-present in previous years), was redefined as two periods (2003-2006 and 2007-present) to reflect the adoption of the latest amendment to the Federal Management Plan (FMP). In 2012, the slate of candidate models were examined and non-performing models were eliminated from the analysis. The candidate models for striped bass survival (S) and tag recovery (r) rates are now:

S(t)r(t)	Survival 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 2003-2006 and 2007-2013) and tag-recovery rates are time-specific.
S(v)r(p)	Survival and tag-recovery rates vary over different regulatory periods (v= constant 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011, and 2012-2013).

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 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:

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

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 2012, an examination of the results using one and two-period natural mortality rates were examined. The Tagging Subcommittee decided that the results from the two-period mortality models provided the more reliable parameter estimates and the one period mortality models were excluded in the analysis protocol. The committee also concluded that the models assuming constant parameters were not realistic and were eliminated from the analysis protocol.

To determine when to separate the two periods all possible two- 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 > 710 mm TL. These periods were used in the models this year, with the terminal year being 2011. The candidate models for fishing mortality (F), release mortality (F') and natural mortality (M) are:

F(t) F'(t)	Fishing and release mortalities time-specific.
F(p)F'(t)	Fishing mortality period-specific (1990-1994, 1995-1999, 2000-2002 and 2003-2006 and 2007-2013); release mortality time-specific.
F(t)F'(p)	Fishing mortality time-specific; release mortality period-specific.
F(p)F'(p)	Fishing and release mortalities period-specific.
F(d)F'(d)	Fishing and release mortalities vary over a different periods (1990-1994, 1995-1999,2000-2002,2003-2006, 2007-2012 and 2013).
F(v)F'(v)	Fishing and release mortalities vary over different periods (1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011 and 2012-2013).

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 2014 Tag Release summary

A total of 454 striped bass were tagged and released from the pound nets and gill nets in the Rappahannock River between 2 April and 15 May, 2014 (Table 1). There were 205 resident striped bass (457-710 mm TL) tagged and released. These stripers were predominantly male (91.7%), but the female stripers were larger on average. In addition, a total of 160 striped bass were tagged and released from gill nets in the James River between 28 March and 16 May, 2014 (Table 2). There were 122 resident striped bass tagged and released. These stripers were predominantly male (75.4%), but the female stripers were larger on average. The median date of these tag releases (both rivers combined), to be used as the beginning of the 2014-2015 recapture interval, was 28 April.

There were 249 migrant striped bass (>710 mm TL) tagged and released in the Rappahannock River (Table 1) and 38 migrant striped bass tagged and released in the James River (Table 2). These stripers were predominantly female (73.9% in the Rappahannock River and 76.3% in the James River)) and their average size was larger than for the male striped bass. The median date of these tag releases (both rivers combined) was 21 April. The tag release totals were 19.3% lower than the release total for 2013. They were well below the release target of 700 resident striped bass, but just below the target of 300 migratory striped bass.

Mortality Estimates, 2013-2014

Tag recapture summary: A total of 56 striped bass (>457 mm TL) were recaptured between 1 January and 31 December, 2013. The largest source of recaptures (82.1%) was from Chesapeake Bay (51.8% in Virginia, 30.4% in Maryland, Table 3). Other recaptures came from Massachusetts and New Jersey (5.4% each), Rhode Island (3.6%), Connecticut, and New York

(1.8% each). There were no recaptures reported from Maine, New Hampshire, Delaware or North Carolina. The peak months for recaptures were in May and June, but there were recaptures in every month of the year except January.

A total of 16 migratory striped bass (>710 mm total length) were recaptured between 1 January and 31 December, 2013. The largest source of the recaptured tagged striped bass (37.5%) was from Chesapeake Bay (31.3% in Virginia, 6.3% in Maryland, Table 4). Other recaptures came from Massachusetts and New Jersey (18.8% each), Rhode Island (12.5%), and Connecticut and New York (6.3% each). There were no recaptures reported from Maine, New Hampshire, Delaware, or North Carolina. The peak month for recaptures was in May and again in July, but the migrant striped bass were recaptured from May through December (except August).

ASMFC protocol: Survival estimates were made utilizing the mark-recapture data for the Rappahannock River from 1990-2013. The suite of Seber (1970) models consisted of three models that each reflected a different parameterization over time. 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. In 2012, models that specified constant parameters throughout the time series were also eliminated.

Estimates of survival using MARK: Thirty-six striped bass (≥ 457 mm TL) tagged in spring 2013 and 20 striped bass tagged in previous springs were harvested during the 2013-14 recapture interval. These were added to complete the input matrix (Table 5) for annual estimates of survival using program MARK. Likewise, there were 10 striped bass (≥ 711 mm TL) tagged in spring 2013 and seven striped bass tagged in previous springs harvested during the 2013-14 recapture interval and used to complete the input matrix (Table 6).

The suite of three models were ranked and weighted by MARK according to their QAIC values. For striped bass ≥ 457 mm TL, the time-specific model received 100.0% of the weighting (Table 7). The 2013 estimate of survival was 0.443 which became 0.452 when adjusted for release bias (Table 8). The 2013 survival estimate was higher than the 2012 estimate and much higher than the 2010 and 2011 estimates. However, these estimates are lower than the survival estimates from 2002-2009. The ranking and weighting among the three models were much different for striped bass ≥ 711 mm TL. The time-specific model was again highest, but with 0,606 of the weighting while the vic model received 0.352 (Table 9). The 2013 estimate of survival was 0.754 (0.759 after bias adjustment) which was also higher than the 2012 survival estimate and the highest since 2003 (Table 10).

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 2013 estimates for striped bass ≥ 457 mm TL were 0.79 (Z), 0.55 (A), 0.06 (U), 0.08 (F) and 0.66 (M, Table 11). 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 1996 (except 2003). The 2013 estimates for striped bass ≥ 711 mm TL were 0.28 (Z), 0.24 (A), 0.04 (U), 0.04 (F) and 0.23 (M, Table 12). 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 2009.

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 1998-2013 M periods for striped bass ≥ 457 mm TL and 1990-2003 and 2004-2013 M periods for striped bass ≥ 711 mm TL.

Twenty-three striped bass (≥ 457 mm TL) tagged in spring 2013 and an additional 14 tagged in previous springs were harvested during the 2013-2014 recapture interval. In addition, there were seven 2013-released striped bass and two striped bass tagged in previous springs that were captured and released during the same recapture interval. These were added to their respective input matrixes (Tables 13a,b) for estimating survival and mortality parameters using the instantaneous rates model. Likewise there were 12 harvested (five from 2013 releases) and one released striped bass (from 2013 releases) from striped bass ≥ 711 mm TL tagged in spring 2013 and recaptured during the 2013-2014 recapture interval and used to complete their respective instantaneous rate model input matrixes (Tables 14a, b).

The F(t) f'(5p) model received most (96.2%) of the weighting among the six models defined in the IRCR analysis (Table 15). This same model was also the top weighted model in the 2012 analysis (90.0%). The other models each contributed less than 2% to the weighting. The resultant parameter estimates for 2013 are 0.507 (survival, Table 16), 0.626 (natural mortality) and 0.051 (fishing mortality). There is a notable decline in the estimates of fishing mortality from 2003-2013 while the estimate for natural mortality continues to increase and greatly exceeds the generally assumed value of 0.15 throughout the time series

The Vic period model received the heaviest weighting (92.6%) for the IRCR analysis for striped bass ≥ 711 mm TL with the Des period model (6.7%) also influencing the estimates (Table 17). The order and relative weightings of the models were almost unchanged from the 2011 and 2012 results. The 2013 IRCR estimate of survival was 0.592 (Table 18). The 2013 estimate of natural mortality was 0.475 while the estimate of fishing mortality was 0.048. Consistent with the estimates of natural mortality for the ≥ 457 mm TL striped bass, the estimates of natural mortality for the migrant striped bass have increased with time and have generally been consistently higher than the assumed value of 0.15 since 2000.

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

In spring 2014, the release total for striped bass tagged in the Rappahannock was lower than the release total for spring 2013 and well below the target for striped bass. Persistent poor weather in March and early April 2014 resulted in reduced gear availability for the year. In addition, a major flooding event on 30 April – 2 May damaged the pound nets in the Rappahannock and negatively affected the catches in both rivers thereafter. The recapture rate for all 2013 releases was 0.074 (56/760) which was higher than the rate for 2012 releases and above the overall mean recapture rate of 0.066. It should be noted that recapture rates have generally declined over time. The mean recapture rate for 1990-2003 was 0.076 (range 0.056-0.111) but is 0.052 for 2004-2013 (range 0.023-0.074). Thus, the aberrant recapture rate for the 2010 releases (0.023) has greatly influenced the most recent estimates of survival and other parameters.

The program MARK survival estimates for 2013 were 0.452 for striped bass greater than 18 inches (457 mm) total length and 0.759 for striped bass greater than 28 inches (711 mm) total length (migratory). The survival estimate for striped bass greater than 18 inches was much higher than the downward-revised estimate for 2012. However, the result of this year's analysis was not enough to reverse much lower survival estimates for the period after 2009. The 2013 survival estimate for striped bass greater than 28 inches (0.759) was greater than the revised 2012 and is the highest reported since 2008.

Again in 2013, the resultant MARK estimates of fishing mortality were well above the 0.27 limit endorsed by the ASMFC for all striped bass greater than 18 inches total length. However, these estimates are considered suspect as they result in estimate both below zero and above one for multiple years and have been excluded in ASMFC stock analyses. The MARK analysis for striped bass greater than 28 inches total length had produced rational results and had been used. The estimates of fishing mortality for these striped bass have been within ASMFC requirements.

In 2006 the final period in the period-based models was redefined and partitioned into two periods (coined Des and Vic). In 2012, the Des variant was dropped in addition to models that assumed that either survival or reporting rate were constant throughout the time series. 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. However, these new models haven't been fully evaluated and the results are contrary to the other analytical methods. Starting in 2011, new estimates of natural mortality have been use with the mortality increasing to 0.30 starting in 1998 for resident striped bass and in 2004 for migratory, coastal striped bass.

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 2013 estimates of fishing mortality of 0.04-0.08 for the two size classifications of striped bass, well below the ASMFC threshold. It also produced estimates of natural mortality above 0.15 and even in both size groups and above 0.30 for the greater than 18" cohort.

In 2012, the Tagging Subcommittee concluded that using instantaneous rates models to study mortality rates of resident and migratory striped bass should be the preferred analytical approach. 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 in 2008, the protocol was modified to allow for an increase in natural mortality in recent years (2M periods vs. constant M) and these models were found to better fit the data and are now used exclusively for estimating the desired parameters The estimates of fishing mortality were 0.08 for striped bass >18 inches TL and 0.04 for striped bass >28 inches TL. The IRCR analyses also estimated that the natural mortality has greatly increased in the recent years for both size classes.

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, Gauthier 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 method 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 but have declined 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 and gill nets in the Rappahannock River, spring 2014.

Date	n	457-710 mm TL				> 710 mm TL			
		Males		Females		Males		Females	
		n	$\overline{TL}$	n	$\overline{TL}$		$\overline{TL}$		$\overline{TL}$
2 Apr	2	1	467.0	0		0		1	907.0
3 Apr	4	1	474.0	0		0		3	972.0
7 Apr	14	1	532.0	0		8	845.3	5	968.4
10 Apr	11	1	518.0	0		5	905.6	5	905.0
14 Apr	84	17	577.2	5	558.0	14	833.4	48	981.8
17 Apr	52	22	552.6	1	545.0	9	873.4	20	963.1
21 Apr	40	16	559.8	2	659.0	3	787.0	19	922.9
28 Apr	108	50	545.6	0		10	895.5	48	968.0
5 May	49	21	527.7	2	602.5	7	838.9	19	926.3
8 May	29	10	505.6	2	642.5	8	862.5	9	912.4
12 May	41	33	522.7	2	568.5	0		6	921.7
15 May	20	15	520.0	3	567.3	1	1050.0	1	768.0
total	454	188	540.2	17	587.2	65	863.2	184	954.8

Table 2. Summary data of striped bass tagged and released from gill nets in the James River, spring 2014.

Date	N	457-710 mm TL				> 710 mm TL			
		Males		Females		Males		Females	
		n	$\overline{TL}$	n	$\overline{TL}$		$\overline{TL}$		$\overline{TL}$
28 Mar	1	1	617.0	0		0		0	
1 Apr	1	1	506.0	0		0		0	
4 Apr	40	34	533.7	3	552.7	1	712.0	2	1130.0
8 Apr	7	3	507.0	1	591.0	1	845.0	2	953.5
11 Apr	6	1	484.0	2	600.0	1	837.0	2	891.5
16 Apr	23	19	510.5	0		1	744.0	3	902.7
18 Apr	6	2	528.0	1	593.0	0		3	1041.0
22 Apr	4	1	464.0	3	589.3	0		0	
25 Apr	3	1	557.0	1	570.0	0		1	888.0
29 Apr	31	10	551.6	11	637.5	1	869.0	9	953.4
1 May	9	3	517.0	0		1	838.0	5	950.2
6 May	1	0		1	607.0	0		0	
9 May	27	16	527.3	6	606.5	3	791.7	2	807.5
13 May	0	0		0		0		0	
16 May	1	0		1	540.0	0		0	
total	160	92	528.0	30	602.7	9	802.2	29	952.3

Table 3. Location of striped bass (≥ 457 mm TL), recaptured in 2013, that were originally tagged and released in the Rappahannock River during springs 1990-2013.

State	Month												total
	J	F	M	A	M	J	J	A	S	O	N	D	
Maine	0	0	0	0	0	0	0	0	0	0	0	0	0
New Hampshire	0	0	0	0	0	0	0	0	0	0	0	0	0
Massachusetts	0	0	0	0	0	0	3	0	0	0	0	0	3
Rhode Island	0	0	0	0	0	1	1	0	0	0	0	0	2
Connecticut	0	0	0	0	1	0	0	0	0	0	0	0	1
New York	0	0	0	0	0	0	0	0	0	1	0	0	1
New Jersey	0	0	0	0	2	0	0	0	0	0	1	0	3
Delaware	0	0	0	0	0	0	0	0	0	0	0	0	0
Maryland	0	0	0	0	2	7	1	2	1	2	1	1	17
Virginia	0	1	2	2	7	3	2	1	1	4	3	3	29
North Carolina	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	1	2	2	12	11	7	3	2	7	5	4	56

Table 4. Location of striped bass (≥ 711 mm TL), recaptured in 2013, that were originally tagged and released in the Rappahannock River during springs 1990-2013.

State	Month												total
	J	F	M	A	M	J	J	A	S	O	N	D	
Maine	0	0	0	0	0	0	0	0	0	0	0	0	0
New Hampshire	0	0	0	0	0	0	0	0	0	0	0	0	0
Massachusetts	0	0	0	0	0	0	3	0	0	0	0	0	3
Rhode Island	0	0	0	0	0	1	1	0	0	0	0	0	2
Connecticut	0	0	0	0	1	0	0	0	0	0	0	0	1
New York	0	0	0	0	0	0	0	0	0	1	0	0	1
New Jersey	0	0	0	0	2	0	0	0	0	0	1	0	3
Delaware	0	0	0	0	0	0	0	0	0	0	0	0	0
Maryland	0	0	0	0	0	0	0	0	0	0	0	1	1
Virginia	0	0	0	0	3	0	0	0	1	1	0	0	5
North Carolina	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	6	1	4	0	1	2	1	1	16

Table 5. Input recapture matrix for program MARK: from striped bass (>457 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2013.

Release		Recapture year																							
No.N	**Year**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**
1,464	**1990**	162	64	47	25	12	10	3	2	3	1	1	0	0	1	0	0	0	0	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	0	0	0	0
130	**1992**			14	8	6	5	1	1	1	1	0	0	0	0	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	0	0	0	0
195	**1994**					13	10	5	4	4	0	0	0	0	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	0	0	0	0
376	**1996**							21	18	7	3	1	1	1	0	0	1	0	0	0	0	0	0	0	0
712	**1997**								47	26	14	3	0	1	2	1	0	0	0	0	0	0	0	0	0
784	**1998**									55	26	2	3	3	1	0	0	0	0	0	0	0	0	0	0
853	**1999**										66	23	9	5	3	0	0	0	0	0	0	1	0	0	0
1,765	**2000**											122	51	23	16	6	5	1	1	0	0	0	0	0	0
797	**2001**												61	23	16	7	2	2	2	0	0	0	0	0	0
315	**2002**													20	8	15	1	1	2	1	0	0	0	0	0
852	**2003**														58	37	9	4	5	3	2	3	0	0	0
1,477	**2004**															80	21	13	7	4	2	1	0	0	0
921	**2005**																44	26	10	2	5	4	0	0	0
668	**2006**																	49	11	6	6	3	4	0	0
1,961	**2007**																		117	50	24	4	6	1	1
523	**2008**																			30	9	2	0	0	2
867	**2009**																				43	10	3	2	0
2050	**2010**																					47	9	8	2
416	**2011**																						24	4	1
1,222	**2012**																							57	14
760	**2013**																								36

Table 6. Input recapture matrix for program MARK: from striped bass (>710 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2013.

Release		Recapture year																							
No.	**Year**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**
301	1990	26	9	15	2	4	6	1	0	2	1	1	0	0	1	0	0	0	0	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	0	0	0	0
40	1992			4	3	2	2	0	0	0	1	0	0	0	0	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	0	0	0	0
123	1994					9	7	5	1	2	0	0	0	0	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	0	0	0	0
67	1996							1	3	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
212	1997								15	13	8	3	0	1	2	1	0	0	0	0	0	0	0	0	0
158	1998									24	13	2	3	2	0	0	0	0	0	0	0	0	0	0	0
162	1999										17	6	2	3	2	0	0	0	0	0	0	1	0	0	0
365	2000											28	19	14	9	4	3	0	1	0	0	0	0	0	0
269	2001												19	14	4	6	2	1	1	0	0	0	0	0	0
122	2002													10	6	7	1	0	2	1	0	0	0	0	0
400	2003														35	24	7	1	3	3	2	3	0	0	0
686	2004															39	12	13	5	4	2	1	0	0	0
284	2005																16	11	8	1	4	3	0	0	0
175	2006																	13	4	4	3	1	4	0	0
840	2007																		55	30	18	3	5	1	1
75	2008																			6	2	0	0	0	0
241	2009																				7	5	1	1	0
483	2010																					17	6	4	2
190	2011																						12	2	0
325	2012																							12	4
243	2013																								10

Table 7. 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; parameters constant from 1990-1994, 1995-1999, 2000-2002, 2003-2006 and 2007-2013 (p); parameters vary in 2012-2013 (v), otherwise the same as p; and parameters are time-specific (t).

Model	$QAIC_c$	$\Delta\ QAIC_c$	$QAIC_c$ **weight**	**number of parameters**
S(t)r(t)	14,166.87	0.00	1.00000	47
S(p)r(t)	14,212.38	45.52	0.00000	29
S(v)r(p)	14,238.04	71.18	0.00000	11

Table 8. 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, 1990-2013.

Year	$\hat{S}$	**SE** ($\hat{S}$)	P_l	**Bias**	$\hat{S}_{adj}$	$\hat{F}$	**95% CI** $\hat{F}$
1990	0.816	0.091	0.481	-0.143	0.952	-0.101	-0.24, 0.25
1991	0.276	0.054	0.524	-0.082	0.301	1.051	0.70, 1.46
1992	0.804	0.171	0.408	-0.142	0.938	-0.086	-0.27, 0.82
1993	0.604	0.137	0.456	-0.105	0.675	0.243	-0.07, 0.84
1994	0.568	0.133	0.381	-0.087	0.623	0.324	-0.01, 0.92
1995	0.684	0.141	0.262	-0.054	0.723	0.174	-0.09, 0.78
1996	0.639	0.139	0.274	-0.040	0.666	0.257	-0.03, 0.85
1997	0.567	0.112	0.330	-0.057	0.601	0.359	0.06, 0.85
1998	0.409	0.082	0.362	-0.059	0.435	0.532	0.20, 0.97
1999	0.374	0.068	0.286	-0.059	0.398	0.622	0.30, 1.02
2000	0.428	0.067	0.436	-0.074	0.463	0.471	0.20, 0.81
2001	0.463	0.101	0.367	-0.068	0.497	0.399	0.05, 0.90
2002	0.607	0.132	0.368	-0.063	0.648	0.134	-0.17, 0.70
2003	0.842	0.146	0.271	-0.049	0.885	-0.018	-0.33, 0.61
2004	0.346	0.067	0.281	-0.038	0.359	0.724	0.38, 1.14
2005	0.458	0.093	0.274	-0.031	0.473	0.449	0.12, 0.91
2006	0.537	0.101	0.354	-0.057	0.569	0.264	-0.03, 0.71
2007	0.581	0.128	0.303	-0.043	0.608	0.198	-0.12, 0.76
2008	0.559	0.150	0.208	-0.024	0.572	0.258	-0.11, 0.96
2009	0.708	0.191	0.231	-0.026	0.726	0.020	-0.26, 0.93
2010	0.155	0.050	0.267	-0.014	0.157	1.549	0.96, 2.21
2011	0.376	0.134	0.152	-0.019	0.383	0.659	0.11, 1.48
2012	0.267	0.095	0.264	-0.030	0.275	0.991	0.39, 1.77
2013	0.443	0.028	0.161	-0.020	0.452	0.495	0.38, 0.63

Table 9. 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; parameters constant from 1990-1994, 1995-1999, 2000-2002, and 2003-2006 and 2007-2013 (p); otherwise the same as p; parameters vary in 2012 and 2013 (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)	7,817.98	0.00	0.60585	47
S(v)r(p)	7,819.06	1.08	0.35247	11
S(p)r(t)	7,823.33	5.35	0.04168	29

Table 10. Seber (1970) model estimates (SBTC) of unadjusted survival ($\hat{S}$) rates and adjusted rates of survival ($\hat{S}_{adj}$) and fishing mortality ($\hat{F}$) of striped bass (> 710 mm TL) derived from the proportion of recaptures released alive (P_l) in the Rappahannock River, 1990-2013.

Year	$\hat{S}$	**SE** ($\hat{S}$)	P_l	**Bias**	$\hat{S}_{\text{adj}}$	$\hat{F}$	**95% CI**
1990	0.568	0.066	0.577	-0.127	0.651	0.280	0.03, 0.65
1991	0.598	0.107	0.560	-0.131	0.688	0.225	-0.08, 0.78
1992	0.642	0.122	0.535	-0.172	0.776	0.104	-0.19, 0.73
1993	0.795	0.020	0.349	-0.093	0.877	-0.018	-0.20, 0.59
1994	0.508	0.057	0.318	-0.070	0.547	0.454	0.11, 1.00
1995	0.761	0.023	0.204	-0.079	0.827	0.040	-0.17, 0.67
1996	0.558	0.082	0.125	-0.016	0.567	0.418	0.15, 0.83
1997	0.499	0.069	0.167	-0.036	0.518	0.507	0.18, 0.99
1998	0.707	0.124	0.217	-0.084	0.772	0.109	-0.16, 0.92
1999	0.486	0.071	0.200	-0.058	0.516	0.512	0.15, 1.06
2000	0.735	0.105	0.349	-0.072	0.791	0.084	-0.13, 0.62
2001	0.558	0.086	0.298	-0.052	0.589	0.380	0.05, 0.97
2002	0.664	0.102	0.295	-0.078	0.720	0.179	-0.06, 0.64
2003	0.784	0.019	0.246	-0.059	0.834	0.032	-0.32, 0.66
2004	0.442	0.052	0.321	-0.049	0.464	0.617	0.02, 1.16
2005	0.579	0.096	0.238	-0.035	0.600	0.362	-0.07, 0.68
2006	0.686	0.111	0.282	-0.048	0.720	0.178	-0.24, 0.69
2007	0.638	0.116	0.228	-0.036	0.662	0.262	-0.19, 0.78
2008	0.793	0.022	0.163	-0.021	0.810	0.061	-0.30, 0.99
2009	0.477	0.097	0.105	-0.009	0.481	0.581	0.03, 1.06
2010	0.427	0.090	0.235	-0.020	0.435	0.682	0.04, 1.33
2011	0.473	0.131	0.071	-0.010	0.480	0.588	-0.04, 1.32
2012	0.485	0.121	0.150	-0.014	0.492	0.559	-0.18, 1.89
2013	0.754	0.051	0.059	-0.006	0.759	0.126	-0.18, 0.26

Table 11. 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, 1990-2013.

Year	Z	A	U	F	M
1990	0.05	0.05	0.17	0.18	-0.13
1992	1.20	0.70	0.14	0.24	0.96
1992	0.06	0.06	0.31	0.32	-0.25
1993	0.39	0.32	0.23	0.28	0.12
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	0.23
1997	0.51	0.40	0.20	0.25	0.26
1998	0.83	0.56	0.15	0.23	0.61
1999	0.92	0.60	0.13	0.20	0.72
2000	0.77	0.54	0.12	0.17	0.60
2001	0.70	0.50	0.16	0.22	0.48
2002	0.43	0.35	0.15	0.19	0.25
2003	0.12	0.11	0.16	0.17	-0.04
2004	1.02	0.64	0.10	0.16	0.86
2005	0.75	0.53	0.12	0.17	0.58
2006	0.56	0.43	0.14	0.19	0.38
2007	0.50	0.39	0.12	0.16	0.34
2008	0.56	0.43	0.08	0.11	0.45
2009	0.32	0.27	0.09	0.11	0.21
2010	1.84	0.84	0.05	0.10	1.75
2011	0.96	0.62	0.08	0.12	0.84
2012	1.29	0.73	0.07	0.13	1.16
2013	0.79	0.55	0.06	0.08	0.71

Table 12. 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, 1990-2013.

Year	Z	A	U	F	M
1990	0.43	0.35	0.25	0.31	0.12
1992	0.37	0.31	0.36	0.44	-0.06
1992	0.25	0.22	0.37	0.42	-0.16
1993	0.13	0.12	0.37	0.39	-0.26
1994	0.60	0.45	0.25	0.34	0.26
1995	0.19	0.17	0.41	0.45	-0.26
1996	0.57	0.43	0.18	0.23	0.34
1997	0.66	0.48	0.38	0.51	0.14
1998	0.26	0.23	0.45	0.52	-0.26
1999	0.66	0.48	0.30	0.40	0.26
2000	0.23	0.21	0.25	0.28	-0.05
2001	0.53	0.41	0.21	0.27	0.26
2002	0.33	0.28	0.28	0.33	-0.01
2003	0.18	0.17	0.23	0.25	-0.07
2004	0.77	0.54	0.13	0.19	0.58
2005	0.51	0.40	0.19	0.24	0.27
2006	0.33	0.28	0.25	0.30	0.03
2007	0.41	0.34	0.17	0.21	0.21
2008	0.21	0.19	0.16	0.17	0.04
2009	0.73	0.52	0.08	0.11	0.62
2010	0.83	0.56	0.09	0.13	0.70
2011	0.74	0.52	0.09	0.12	0.61
2012	0.71	0.51	0.07	0.10	0.60
2013	0.28	0.24	0.04	0.04	0.23

Table 13a. Input recapture matrix for IRCR analysis: from striped bass (>457 mm TL) tagged and released in the Rappahannock River, springs 1990-2013. Harvested recaptures only.

Release		**Recapture year**																							
No.	**Year**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**
1,464	**1990**	21	20	24	10	8	9	2	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0
2,481	**1991**		48	38	22	14	3	1	2	1	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0
130	**1992**			7	4	1	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
621	**1993**				18	17	12	5	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
195	**1994**					6	7	4	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
698	**1995**						24	12	9	4	1	1	2	0	1	0	0	0	0	0	0	0	0	0	0
376	**1996**							3	10	3	2	1	1	1	0	0	1	0	0	0	0	0	0	0	0
712	**1997**								26	17	10	2	0	1	1	1	0	0	0	0	0	0	0	0	0
784	**1998**									28	16	1	3	1	0	0	0	0	0	0	0	0	0	0	0
853	**1999**										30	7	4	2	2	0	0	0	0	0	0	0	0	0	0
1,765	**2000**											44	23	11	7	4	5	1	1	0	0	0	0	0	0
797	**2001**												31	14	5	7	1	0	0	0	0	0	0	0	0
315	**2002**													10	4	6	1	1	1	1	0	0	0	0	0
852	**2003**														32	20	5	3	3	2	1	2	0	0	0
1,477	**2004**															45	14	8	4	3	1	1	0	0	0
921	**2005**																27	17	6	1	4	1	0	0	0
668	**2006**																	27	4	5	5	3	4	0	0
1,961	**2007**																		63	34	16	3	5	0	1
523	**2008**																			17	4	0	0	0	0
867	**2009**																				26	7	2	2	0
2050	**2010**																					29	7	8	2
416	**2011**																						13	4	0
1,222	**2012**																							34	11
760	**2013**																								23

Table 13b. Input recapture matrix for IRCR analysis: from striped bass (>457 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2013. Recaptures released with streamers cut off only.

Release		Recapture year																							
No.	**Year**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**
1,464	**1990**	76	28	18	9	1	1	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,481	**1991**		93	33	24	10	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130	**1992**			6	3	3	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
621	**1993**				26	16	3	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
195	**1994**					6	1	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
698	**1995**						20	7	8	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
376	**1996**							10	7	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
712	**1997**								14	6	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0
784	**1998**									21	7	0	0	1	1	0	0	0	0	0	0	0	0	0	0
853	**1999**										22	12	1	2	0	0	0	0	0	0	0	0	0	0	0
1,765	**2000**											49	23	7	3	0	0	0	0	0	0	0	0	0	0
797	**2001**												20	6	7	0	1	0	1	0	0	0	0	0	0
315	**2002**													7	3	2	0	0	1	0	0	0	0	0	0
852	**2003**														12	11	3	1	1	0	0	0	0	0	0
1,477	**2004**															25	5	5	1	0	1	0	0	0	0
921	**2005**																14	8	2	1	0	1	0	0	0
668	**2006**																	19	6	1	1	0	0	0	0
1,961	**2007**																		34	10	1	1	0	1	0
523	**2008**																			7	2	2	0	0	0
867	**2009**																				16	2	0	0	0
2050	**2010**																					14	2	0	0
416	**2011**																						5	0	0
1,222	**2012**																							18	2
760	**2013**																								7

Table 14a. Input recapture matrix for IRCR analysis: from striped bass (>710 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2013. Harvested recaptures only.

Release		**Recapture year**																					
No.	**Year**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**
301	**1990**	10	1	6	1	3	5	1	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0
390	**1991**		19	10	12	9	2	1	2	0	2	0	0	0	1	0	0	0	0	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	0	0	0	0
212	**1993**				11	11	5	2	3	0	0	0	0	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	0	0	0	0
210	**1995**						18	6	5	2	1	1	2	0	1	0	0	0	0	0	0	0	0	0	0
67	**1996**							0	3	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
212	**1997**								11	12	6	2	0	1	1	1	0	0	0	0	0	0	0	0	0
158	**1998**									16	9	1	3	1	0	0	0	0	0	0	0	0	0	0	0
162	**1999**										13	2	1	2	1	0	0	0	0	0	0	1	0	0	0
365	**2000**											13	11	6	5	3	3	0	1	0	0	0	0	0	0
269	**2001**												9	8	2	6	1	0	0	0	0	0	0	0	0
122	**2002**													7	3	5	1	0	1	1	0	0	0	0	0
400	**2003**														23	13	3	1	2	2	1	2	0	0	0
686	**2004**															21	8	8	3	3	1	1	0	0	0
284	**2005**																12	7	5	1	3	0	0	0	0
175	**2006**																	10	3	3	2	1	4	0	0
840	**2007**																		33	22	11	2	4	0	1
75	**2008**																			5	1	0	0	0	0
241	**2009**																				5	3	0	1	0
483	**2010**																					11	5	4	2
190	**2011**																						7	2	0
325	**2012**																							9	4
243	**2013**																								5

Table 14b. Input recapture matrix for IRCR analysis: from striped bass (>710 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2013. Recaptures released with streamers cut off only.

Release			Recapture year																						
No.	**Year**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**
301	**1990**	15	8	8	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
390	**1991**		20	13	4	2	1	0	0	0	0	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	0	0	0	0
212	**1993**				10	7	1	0	1	0	0	1	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	0	0	0	0
210	**1995**						7	2	3	1	0	1	0	0	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	0	0	0	0
212	**1997**								2	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
158	**1998**									6	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0
162	**1999**										3	3	0	1	0	0	0	0	0	0	0	0	0	0	0
365	**2000**											9	7	4	2	0	0	0	0	0	0	0	0	0	0
269	**2001**												7	4	2	0	1	0	1	0	0	0	0	0	0
122	**2002**													2	2	0	0	0	1	0	0	0	0	0	0
400	**2003**														8	8	3	0	0	0	0	0	0	0	0
686	**2004**															16	2	5	1	0	1	0	0	0	0
284	**2005**																4	4	1	0	0	1	0	0	0
175	**2006**																	2	1	1	1	0	0	0	0
840	**2007**																		12	7	1	1	0	1	0
75	**2008**																			0	0	0	0	0	0
241	**2009**																				1	1	0	0	0
483	**2010**																					5	1	0	0
190	**2011**																						1	0	0
325	**2012**																							2	0
243	**2013**																								1

Table 15. Model Akaike weighting results (striped bass ≥ 457 mm TL) for the 2M IRCR analyses. Model notations: Fishing mortality (F), release mortality (F') and natural mortality (M), annual estimates (t) and period estimates (5p- 1990-1994, 1995-1999, 2000-2002 and 2003-2006 and 2007-2013; d- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2012 and 2013; v- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011 and 2012-2013).

2M (1990-1997, 1998-2013)			
model	**$QAIC_c$**	**weight**	**parameters**
F(t), F'(5p)	12,757.4	0.962	31
F(5p),F'(5p)	12,765.6	0.016	12
F(v), F'(v)	12,766.3	0.012	14
F(d), F'(d)	12,766.6	0.019	14
F(t), F'(t)	12,773.6	0.000	50
F(5p), F'(t)	12,781.1	0.000	31

Table 16. 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, 1990-2013.

Year	2M			
	S	M	F	SE
1990	0.641	0.392	0.044	0.009
1991	0.627	0.392	0.065	0.009
1992	0.600	0.392	0.109	0.012
1993	0.607	0.392	0.097	0.012
1994	0.591	0.392	0.124	0.016
1995	0.588	0.392	0.134	0.017
1996	0.625	0.392	0.073	0.014
1997	0.599	0.392	0.115	0.015
1998	0.482	0.626	0.099	0.013
1999	0.474	0.626	0.115	0.014
2000	0.496	0.626	0.070	0.011
2001	0.483	0.626	0.096	0.012
2002	0.486	0.626	0.090	0.014
2003	0.482	0.626	0.101	0.013
2004	0.479	0.626	0.107	0.012
2005	0.491	0.626	0.081	0.012
2006	0.481	0.626	0.103	0.013
2007	0.489	0.626	0.087	0.009
2008	0.483	0.626	0.099	0.011
2009	0.485	0.626	0.094	0.011
2010	0.510	0.626	0.046	0.007
2011	0.511	0.626	0.044	0.008
2012	0.504	0.626	0.057	0.008
2013	0.507	0.626	0.051	0.009

Table 17. Model Akaike weighting results (striped bass ≥ 711 mm TL) for the 2M IRCR analyses. Model notations: Fishing mortality (F), release mortality (F') and natural mortality (M), annual estimates (t) and period estimates (5p- 1990-1994, 1995-1999, 2000-2002, 2003-2006 and 2007-2013; d- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2012 and 2013; v- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011 and 2012-2013).

2M (1990-2003, 2004-2013)			
model	**QAIC$_c$**	**weight**	**parameters**
F(v), F'(v)	8,864.2	0.926	14
F(d),F'(d)	8,869.4	0.067	14
F(t), F'(5p)	8,876.7	0.004	31
F(5p), F'(5p)	8,878.1	0.002	12
F(t), F'(t)	8,892.3	0.000	50
F(5p), F'(t)	8,893.1	0.000	31

Table 18. 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, 1990-2013.

Year	2M			
	S	M	F	SE
1990	0.668	0.252	0.141	0.022
1991	0.668	0.252	0.141	0.018
1992	0.668	0.252	0.141	0.023
1993	0.668	0.252	0.141	0.023
1994	0.668	0.252	0.141	0.029
1995	0.623	0.252	0.216	0.032
1996	0.624	0.252	0.215	0.028
1997	0.624	0.252	0.215	0.029
1998	0.623	0.252	0.216	0.031
1999	0.623	0.252	0.216	0.034
2000	0.701	0.252	0.099	0.016
2001	0.701	0.252	0.099	0.016
2002	0.701	0.252	0.099	0.017
2003	0.701	0.252	0.100	0.014
2004	0.561	0.475	0.100	0.012
2005	0.561	0.475	0.100	0.012
2006	0.561	0.475	0.100	0.014
2007	0.565	0.475	0.094	0.012
2008	0.565	0.475	0.094	0.016
2009	0.565	0.475	0.094	0.015
2010	0.565	0.475	0.094	0.011
2011	0.565	0.475	0.094	0.012
2012	0.591	0.475	0.051	0.011
2013	0.592	0.475	0.048	0.011

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 prevalence 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 five pound nets in the upper Rappahannock River (river miles 45-56) and from five pound nets in the lower Rappahannock River (river miles 0-5) from 2005-2012. 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 Rebel T2i camera. Overview and close-up photos are made for each side to document the initial assessment and to provide a basis for comparison when project personnel obtain recaptured striped bass. We identify 3 discrete lesion categories:

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

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

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

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

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

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

Analytical Approach:

Disease progression: The duration of the stages (i.e., the time it takes to progress from one condition to the next) can be estimated from tagging data if it is assumed that transitions are asynchronous across the population. This means that at the time of tagging, a fish can be anywhere in the time interval it takes to progress from one stage to the next. The methodology is analogous to that used to estimate intermolt periods in crustaceans and insects (Willoughby and Hurley 1987, Restrepo and Hoenig 1988, Hoenig and Restrepo 1989, Millar and Hoenig 1997). In the crustacean molt models, the data consist of size at tagging, time at liberty, and size at recapture. If the size at recapture is greater than the size at tagging then the animal has molted. Thus, the data reduce to time at liberty and an indicator of whether the animal molted. In the case of striped bass with dermal mycobacteriosis, the data consist of condition class at tagging, time at liberty, and condition class at recapture. Thus, the data reduce to time at liberty and an indicator of whether the animal has progressed to the next disease condition class.

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

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

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

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

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

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

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

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

The categories for disease progression are defined as:

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

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

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

Hoenig (1997) generalized the approach of Hoenig and Restrepo to allow for individual variability in stage duration.

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

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

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

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

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

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

(Rosner 1990). The odds of obtaining a tag return from a fish with lesions is a/b; the odds ratio is simply the ratio of the odds for the two groups (fish with and without external lesions). Thus, odds ratio = $(a/b)/(c/d) = ad/bc$. The odds ratio can take on values between 0 and infinity. In the above example, the odds ratio would be 0.46. A value less than one indicates that fish with lesions have lower survival than fish without lesions.

It is of interest to examine whether the ratio of survival changes over time. If the ratio of survival is constant over time, then a plot of log(ratio of recaptures) will be a linear function of time at liberty with slope equal to the difference in instantaneous mortality rates (i.e., exp(slope) estimates the ratio of survival rates). Note, that for this analysis to be valid, it is necessary to assume that the *ratio* of tag reporting rates for the two groups remains constant over time but *not* that the reporting rates for the two groups are equal nor that the rates are unchanging. Departures from a linear relationship indicate that the ratio of survival rates or the ratio of reporting rates is changing over time (or both are changing). This model is a logistic model; consequently, standard methods are available for fitting and examining the model (Hoenig et al. 1990, Hueter *et al*. 2006).

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

Suppose the survival rate of "clean" fish is S_o and the survival rate of fish in disease condition x is S_x. We tag and release some fish in each category and the ratio of fish in condition x to condition 0 is R in the releases. We then obtain recaptures at time t, for $t = 1, 2, \ldots$ 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 (2005-2012)

Fall releases: A total of 17,999 striped bass were tagged, assessed for external disease indications, photographed and released from five pound nets in the lower Rappahannock River during falls 2005-2012. There were 2,303 striped bass tagged at the upper Rappahannock River nets during falls 2005-2010. The striped bass tagged were mostly 430-540 mm in fork length. An increase of disease prevalence with size is observed in both the downriver and upriver fish (Figure 3). Only 31.1% (5,601/17,999) of the fish tagged in the lower Rappahannock were without any external sign of mycobacteriosis. Likewise, 30.9% (711/2,303) of the striped bass tagged in the upper Rappahannock were without external sign of the disease. The lightly-infected group (41.9%) had the second highest prevalence (combined), while moderate and heavily infected had lower percentages of 16.6% and 9.8%.

The youngest age of striped bass in our survey was three years old. The prevalence of mycobacterial infection at this age varied from 45-70% but the prevalence was showing a gradual decrease from 2009-2012 (Figure 4). At age four the prevalence of mycobacterial infection varied from 65-80% (Figure 5) and at age five varied from 80-100% (Figure 6). The mean prevalence of mycobacterial infection increased from 62% at age three to 90% at age six while the prevalence of severely infected stripers increased from 7% at age 3 to 32% at age six (Figure 7).

Spring releases: A total of 2,481 striped bass were tagged, assessed for external disease indications, photographed and released from five pound nets in the lower Rappahannock River during springs 2006-2012. An addition 68 stripers were tagged and assessed in the upper Rappahannock River in spring 2006. While the numbers released were too low to analyzed discretely, the releases provided a useful contrast for disease progression compared with the striped bass assessed during the falls.

Tag Recapture Summary 2005-2012

Current year: A total of 117 striped bass tagged and released in the lower Rappahannock River were recaptured and reported between September 21, 2013 and September 20, 2014 (Table 2). A total of seven striped bass from the upper Rappahannock River releases were also reported. Fifty two of these striped bass were necropsied and reassessed by VIMS personnel. Most recaptures occurred from the falls (Table 2) and from the Rappahannock River, especially from the area immediately around the release sites (Table 3).

Fall releases: A total of 2,433 striped bass tagged during falls 2005-2012 in the lower Rappahannock River were recaptured prior to 20 September, 2014. The overall recapture rate was 0.135. In addition, a total of 372 striped bass tagged in the upper Rappahannock River were recaptured (recapture rate 0.162). The combined incidence of immediate (< 7 days) recapture was 3.7%. Examination of the disease severity prevalence in the immediate (less than 7 days at large) recaptures shows that 26.3% were clean (vs. 31.1% of releases), 41.7% were lightly infected (vs. 41.9%), 18.2% were moderately infected (vs. 16.6%) and 13.8% were heavily infected (vs. 9.8%). The annual recapture rate declined from 10.6% in year one, 3.9% in year two, 0.7% in year three, 0.2% in year four to less than 0.1% thereafter.

Most recaptured striped bass (61.5%) came from the immediate area of their release, with 42.3% coming in the first fall of their release (Table 4). However, tagged striped bass were recaptured throughout Chesapeake Bay during their first fall of release. Excluding the recaptures from the initial fall of release, 51.8% of the recaptures were from the Rappahannock River, 24.2% were from Maryland portions of Chesapeake Bay, 4.8% from the Potomac River, 17.5% were from Virginia portions of Chesapeake Bay and 1.7% were recaptured in the Atlantic Ocean. The recaptures from Virginia were predominantly reported in the fall while the recaptures reported from Maryland were predominantly in the summer.

There were differences in the degree of migration and the severity of mycobacteriosis assess at the time of release. During the first fall of release the ratio of recaptures (clean:light:moderate:heavy) in the Rappahannock River was 1.85:2.55:1.18:1. Outside of the Rappahannock River the ratio was 2.0: 3.6:1.44:1 with no heavy recaptures occurring in the upper Chesapeake in Maryland or the Atlantic Ocean. Subsequent to the initial fall of release, the ratio in the Rappahannock River was 3.53: 3.78: 1.51:1 but was 4.29:4.29:2.57:1 in the upper Maryland portion of Chesapeake Bay and no heavy recaptures from the Atlantic Ocean.

Spring releases: A total of 556 striped bass tagged during springs 2006-2012 were recaptured prior to September 20, 2014 combined in the Rappahannock River. The overall recapture rate was 0.230. The incidence of immediate recapture was 8.4%. Examination of the disease severity prevalence showed that 38.8% were clean (vs 38.3% of releases), 35.6% were lightly infected (vs 37.4% of releases), 13.8% were moderately infected (vs 11.3%) and 11.7% were heavily infected (vs 9.2%).

Most recaptured striped bass (70.5%) came from the immediate area of their release, with 50.0% coming in the first spring of their release (Table 5). Recaptures occurred from through Chesapeake Bay and in the Atlantic Ocean, but in very small numbers. No striped bass that were heavily infected at the time of their release were recaptured from the upper Maryland portion of Chesapeake Bay or from the Atlantic Ocean.

Disease progression in Rappahannock River Striped Bass, 2005-2014

A total of 1065 tagged striped bass have been recaptured and returned to VIMS for necropsy and disease reassessment from fall 2005 to present. This represents 4.67% 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 428 recaptures originally assessed as light and 169 recaptures originally assessed as moderate that were returned to VIMS and had their external disease status reassessed. The proportion of recaptures progressing in severity was plotted versus time and the resultant regression estimates 100% progression in 407 days (SE = 10 days). Likewise the plot of the progression in the disease of striped bass originally assessed as moderate (Figure 9) was described by yields an estimate of 100% progression to severe at 634 days (SE=69 days).

While it is impossible to obtain direct estimates of progression rate for fish released “clean,” exploration of the data shows the trend that all fish released clean in the fall of 2005 - 2012, and subsequently recaptured have progressed to a classifiable disease condition within one year at large (Figure 10). 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 upper and lower Rappahannock River releases

Of the 1065 tagged striped bass that have been recaptured and returned to VIMS for necropsy and disease reassessment, 186 were released in the upper Rappahannock, and 879 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. Of fish that were released clean and recaptured as heavily diseased, the mean fork length at the lower Rappahannock was 524.5 mm compared with 495.8 mm at the upper river locations. Similar trends occur for other release disease conditions. For releases only, fish released at the lower site tended to be larger than the fish released at the upper Rappahannock (mean = 492.7 mm vs 483.0 mm, respectively). Changes in fork length vary between the two sites, with the lower river having a greater change in fork length for animals progressing from clean (40.54 mm moderate and 38.65 mm severe), while the upper river had a greater change in fork length for fish remaining at their current condition (19.3 mm).

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. Fish released at the upriver site assessed as clean, had a mean days at liberty of 110 for clean recaptures, 253 for light, 416 for moderate, and 461 for severe. In contrast, fish for the downriver site had a mean days at liberty of 100 for clean recaptures, 192 for light, 374 for moderate, and 356 for severe. Again, trends continued for light and moderate releases.

Estimation of survival rates and relative survival rates

Logistic model: The rate of return of tags from diseased fish is clearly lower than that for “clean” fish (showing no overt signs of disease). If the rate of return were equal for the two groups, a plot of the ratio of returns (or the log of the ratio) versus time would be a horizontal line. But, it can be seen in Figures 11a-c that the slope is negative indicating that diseased fish are not surviving as well as clean fish or that diseased fish are less catchable than clean fish. The slope of the regression lines in Figures 11a-c 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 (severely infected) and 2 (moderately infected) have estimated elevations of natural mortality rate M above that of clean fish of .48 and .41, respectively (Figures 11a,b). This implies annual survival rates for fish in disease conditions 3 and 2 that are 54% with a 95% confidence interval (43% , 73%) and 84% with 95% confidence interval (68% , 102%), respectively, of the survival of clean fish.

Fish in disease condition 1 appear to have a slightly elevated mortality rate relative to clean fish but not a significant one (Figure 11c). The estimated difference in instantaneous natural mortality rates is 0.034 and the ratio of survival rates is 98%, 95% confidence interval of (85%, 113%).

The survival estimate for condition 3 is highly statistically significant (p-value = <0.001). While condition 2 fish also have an increased morality over 15% compared to clean fish, the result is not significant (p=0.10). The estimated slope for condition 1 fish indicates a relative survival rate that is over 90% compared to 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 = 0.79) so the possibility that condition 1 fish have a varied mortality rate from clean fish cannot be ruled out at this time. Though we did not get a significant p value for disease condition 1, the trend has continued from previous years and a decline in relative survival rates was seen in all disease classes with the addition of another year of recaptures. The past year of tag returns improved our ability to estimate the relative mortality rate of infected fish versus clean fish, but the decline in expected returns with the cessation of the tagging after 2012 indicate that these results will be our final estimate.

Estimation of relative growth rates

A comparison was made between the average growth per day of recaptured infected and non-infected striped bass. There was a nearly 25% decrease in observed mean growth with increased severity of infection for the fall released striped bass (Figure 12). The spring released striped bass also exhibited an apparent, although lesser, decrease in relative growth with disease severity, but the results are confounded by the low numbers of returns. The decreases in relative growth were not statistically significant.

Discussion

The results to date 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 14.77% of releases, 3365/22783), and of tagged carcasses (4.67%, 1065/22783), 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. This could possibly be due to behavioral differences resulting in more heavily infected fish being more easily captured. 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. For example, heavily infected striped bass were only rarely recaptured in the upper Maryland portions of Chesapeake Bay and were never recaptured from the Atlantic Ocean. Last year we reported an 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 sites.

The prevalence of mycobacterial infections has been shown to increase with size from slightly less than 50% at 18 inches total length (typically age 3) to near 90% for striped bass greater than 23 inches total length (ages 6+). Most importantly, the prevalence of heavily infected striped bass increased from less than 10% to more than 30% over the same interval.

While the overall progression on myco with size and age shows a steady progression of the disease, there is a lot of individual variation. 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. Our progression estimates indicate that in 407 days 100% of lightly infected striped bass will have progressed to be moderately infected and in 634 days 100% of moderately infected striped bass will progress to be heavily infected.

The lower prevalence of mycobacterial infections in the larger, migrant striped bass encountered in the spring tagging 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 have survival rates that may approach 50% of that for uninfected striped bass. Even striped bass with only the early signs of the disease appear to have slightly reduced survival relative to fish without signs of the disease. 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. 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 falls 2005-2012 and recaptured fall 2013 – summer 2014.

Date	**release area**	**n**	**infection index**				
			clean	**light**	**moderate**	**heavy**	**other**
Fall 2013	upper	4	1	2	1	0	0
	lower	98	46	31	11	10	0
Winter 2013	upper	2	2	0	0	0	0
	lower	7	1	5	0	1	0
Spring 2014	upper	1	0	1	0	0	0
	lower	6	4	2	1	0	0
Summer 2014	upper	0	0	0	0	0	0
	lower	6	3	1	2	0	0
totals	upper	7	3	3	1	0	0
	lower	117	54	39	14	11	0
	both	124	57	42	15	11	0

Table 3. Spatial recapture summary, by mycobacteria infection index and release area, of striped bass tagged and released in the upper and lower Rappahannock River during falls 2005-2012 and recaptured fall 2013-summer 2014.

recapture area	release area	n	infection index				
			clean	light	moderate	heavy	other
release area	upper	0	0	0	0	0	0
	lower	53	28	16	3	6	0
Rappahannock River	upper	8	4	3	1	0	0
	lower	5	2	2	0	1	0
upper Chesapeake Bay (Maryland)	upper	0	0	0	0	0	0
	lower	14	4	2	6	2	0
lower Chesapeake Bay (Maryland)	upper	0	0	0	0	0	0
	lower	8	2	4	1	1	0
Potomac River	upper	0	0	0	0	0	0
	lower	1	0	1	0	0	0
upper Chesapeake Bay (Virginia)	upper	0	0	0	0	0	0
	lower	24	8	12	3	1	0
lower Chesapeake Bay (Virginia)	upper	0	0	0	0	0	0
	lower	8	7	1	0	0	0
Atlantic Ocean	upper	0	0	0	0	0	0
	lower	4	2	1	1	0	0
totals	upper	7	3	3	1	0	0
	lower	117	53	39	14	11	0
	both	124	56	42	15	11	0

Table 4. Spatial recapture summary, by mycobacteria infection index, of striped bass tagged and released in the upper and lower Rappahannock River during falls 2005-2012.

	Release	First year at large				Subsequent years at large			
Recapture area	**index**	**Fall**	**winter**	**spring**	**summer**	**Fall**	**winter**	**spring**	**summer**
Release area	**Clean**	325	29	41	15	102	6	2	3
	Light	450	38	38	20	80	10	7	4
	Moderate	212	20	19	8	29	0	2	3
	Heavy	186	10	11	8	25	0	2	1
Rest of Rappahannock River	**Clean**	28	11	10	2	21	7	4	5
	Light	37	9	7	6	38	13	6	0
	Moderate	13	6	8	5	9	0	1	0
	Heavy	5	3	4	3	3	3	0	1
Upper Chesapeake Bay (Maryland)	**Clean**	0	4	8	29	5	0	7	7
	Light	1	1	8	35	6	0	3	9
	Moderate	1	0	2	18	3	0	2	11
	Heavy	0	0	3	6	3	0	0	2
Lower Chesapeake Bay (Maryland)	**Clean**	6	0	10	18	11	2	4	7
	Light	7	1	11	42	14	2	5	1
	Moderate	1	1	3	15	3	0	2	0
	Heavy	3	0	4	5	1	0	1	0
Potomac River	**Clean**	7	1	1	5	3	4	0	3
	Light	5	1	4	7	5	2	3	1
	Moderate	2	2	4	0	2	0	0	0
	heavy	1	2	4	1	0	0	0	0
Upper Chesapeake Bay (Virginia)	**Clean**	18	0	11	2	23	0	2	0
	Light	35	0	21	4	37	0	0	1
	Moderate	17	0	8	0	6	0	1	0
	Heavy	6	0	12	1	6	0	3	1
Lower Chesapeake Bay (Virginia)	**Clean**	5	10	11	3	7	6	1	0
	Light	17	9	12	3	8	8	1	0
	Moderate	5	5	2	1	4	0	0	0
	Heavy	7	5	4	0	2	1	0	0
Atlantic Ocean	**Clean**	0	0	2	1	2	1	4	1
	Light	0	4	3	1	0	2	1	1
	Moderate	0	0	0	1	0	0	0	0
	heavy	0	0	0	0	0	0	0	0

Table 5. Spatial recapture summary, by mycobacteria infection index, of striped bass tagged and released in the upper and lower Rappahannock River during springs 2006-2012.

	Release	**First year at large**				**Subsequent years at large**			
Recapture area	**index**	**spring**	**summer**	**fall**	**winter**	**spring**	**summer**	**fall**	**winter**
Release area	**Clean**	92	12	23	3	8	1	2	0
	Light	101	10	20	1	6	1	4	0
	Moderate	48	7	8	0	4	0	0	0
	Heavy	37	1	3	0	1	0	0	0
Rest of Rappahannock River	**Clean**	1	0	9	1	3	0	3	0
	Light	5	2	3	1	3	1	1	1
	Moderate	1	0	1	0	1	0	0	0
	Heavy	3	2	1	0	0	0	0	0
Upper Chesapeake Bay (Maryland)	**Clean**	1	2	2	0	0	0	0	0
	Light	3	2	0	0	1	1	0	0
	Moderate	0	2	0	0	0	0	0	0
	Heavy	0	0	0	0	0	0	0	0
Lower Chesapeake Bay (Maryland)	**Clean**	1	4	1	0	0	0	2	0
	Light	0	6	4	0	2	0	1	0
	Moderate	1	3	1	0	2	0	0	0
	Heavy	2	1	0	0	0	0	0	0
Potomac River	**Clean**	2	3	1	1	0	0	0	0
	Light	2	5	0	0	0	0	0	0
	Moderate	1	1	0	0	0	0	0	0
	heavy	1	0	0	1	0	0	0	0
Upper Chesapeake Bay (Virginia)	**Clean**	5	1	3	0	0	0	1	1
	Light	5	1	5	0	1	0	1	0
	Moderate	2	1	3	0	0	0	0	0
	Heavy	3	0	1	0	0	0	0	0
Lower Chesapeake Bay (Virginia)	**Clean**	1	2	3	1	1	0	1	0
	Light	0	0	1	1	0	1	0	2
	Moderate	0	0	2	0	1	0	1	0
	Heavy	0	2	0	0	0	0	0	0
Atlantic Ocean	**Clean**	0	0	0	0	1	0	0	0
	Light	0	0	0	0	1	0	0	0
	Moderate	0	0	0	1	0	1	0	0
	heavy	0	0	0	0	0	0	0	0

Figure 1. Gross clinical signs of mycobacteriosis in Chesapeake Bay striped bass

A) Severe ulcerative dermatitis. Note shallow, rough textured hemorrhagi 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).

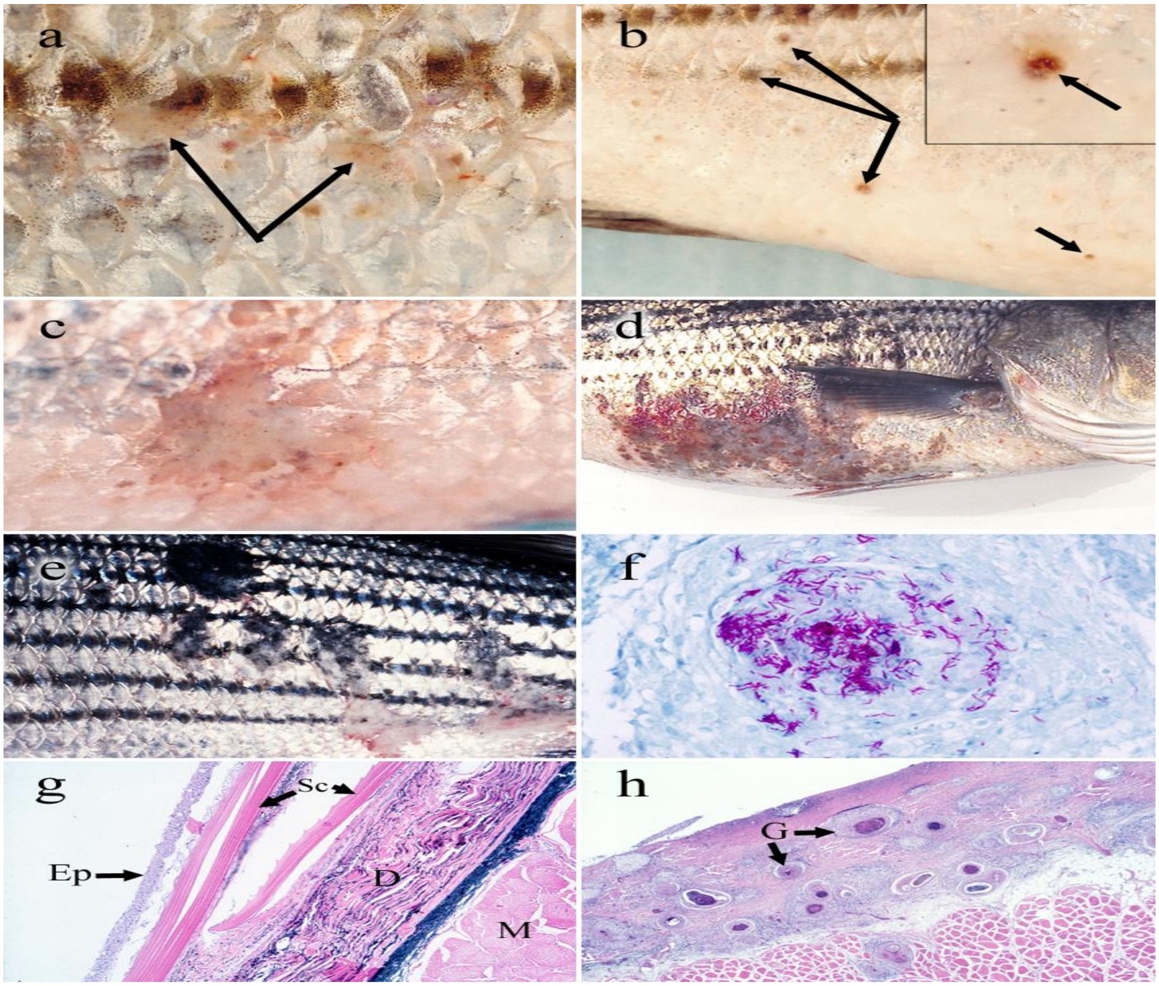
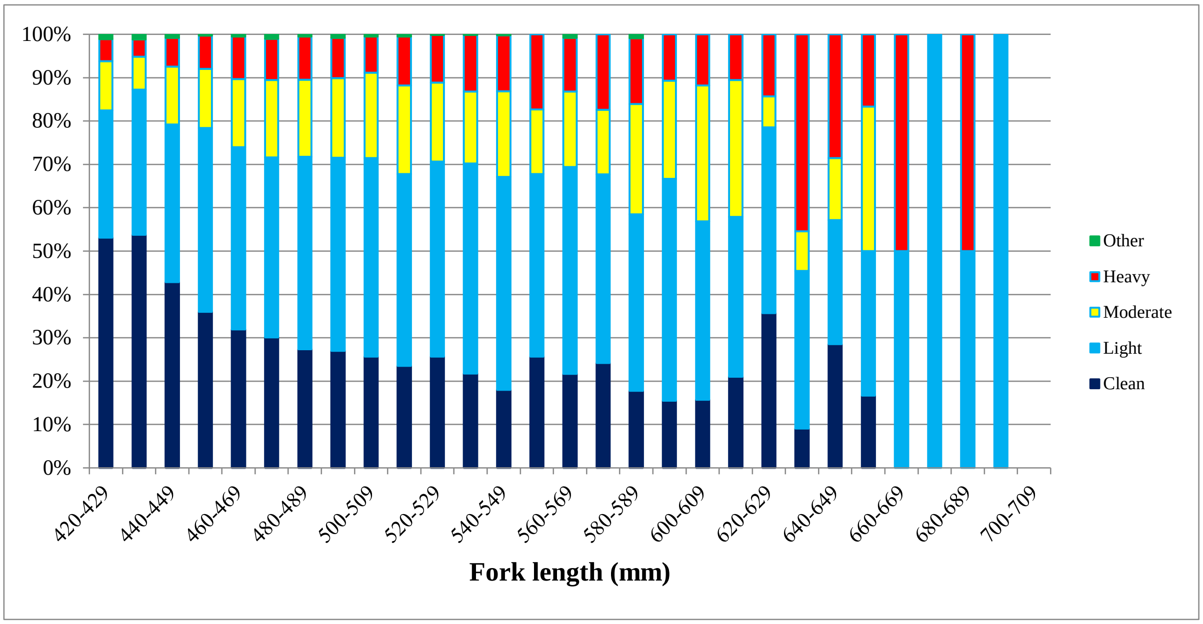


Figure 3. Relative composition of striped bass tag releases, by absence or severity of mycobacterial infection, with increasing size (FL in mm) of striped bass tagged from the lower (top) and upper (bottom) Rappahannock River, falls 2005-2012.



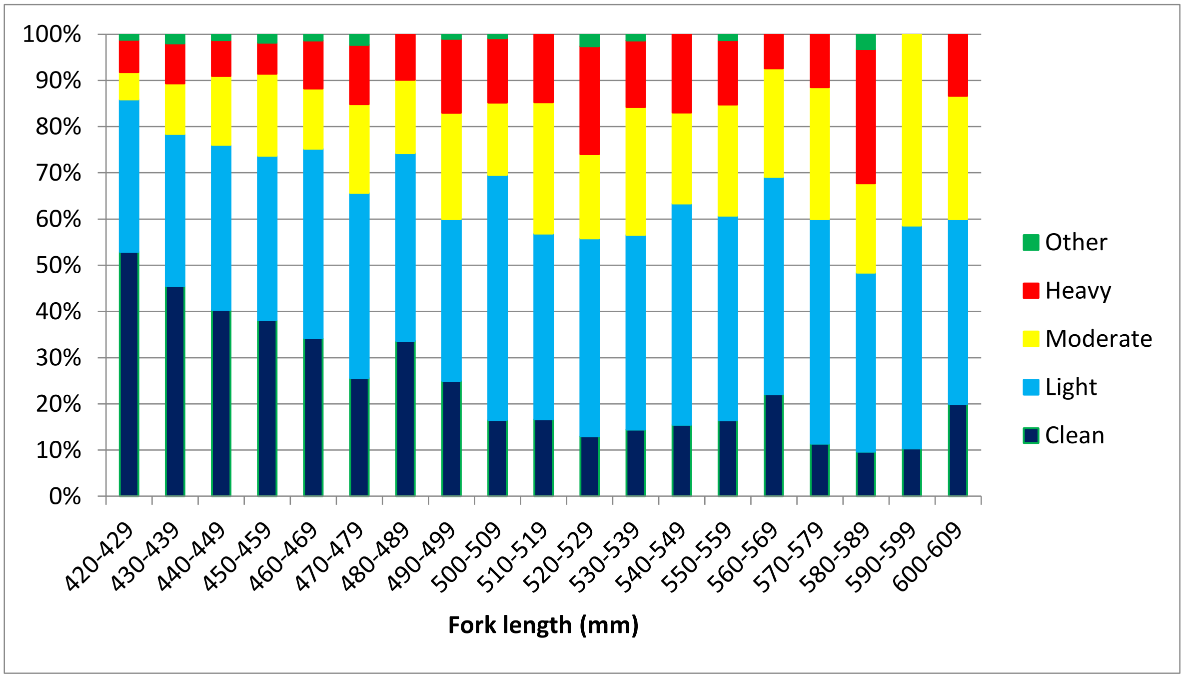
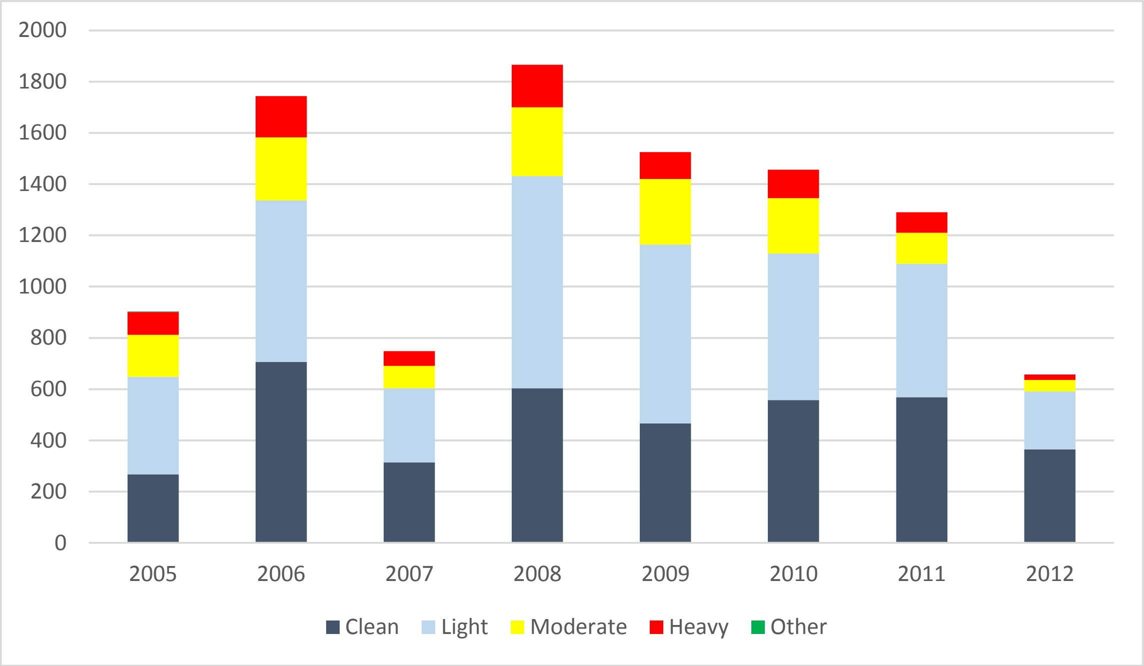


Figure 4. Annual absolute (top) and relative (bottom) composition of striped bass tag releases, by absence or severity of mycobacterial infection, of age 3 striped bass from the lower Rappahannock River, falls 2005-2012.



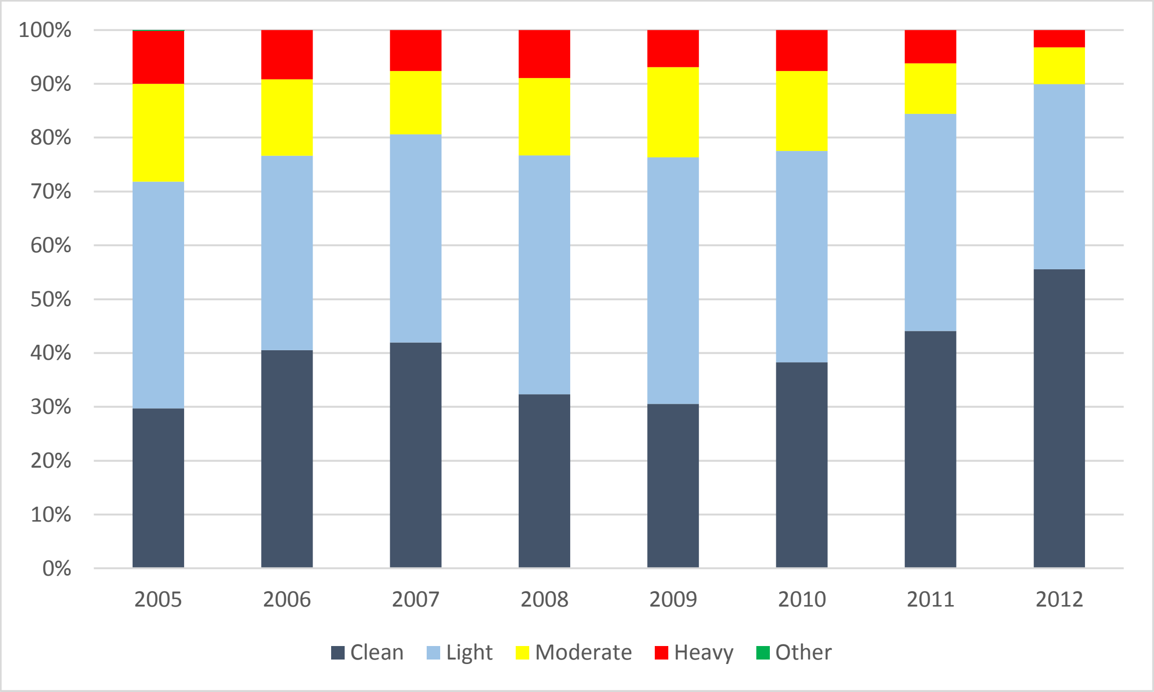
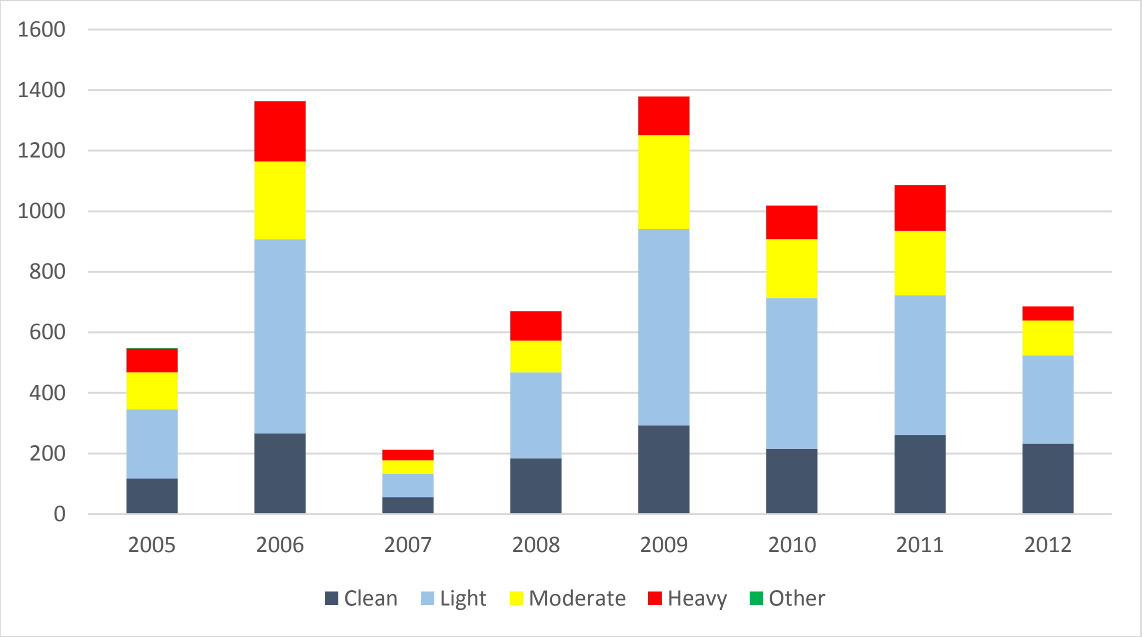


Figure 5. Annual absolute (top) and relative (bottom) composition of striped bass tag releases, by absence or severity of mycobacterial infection, of age 4 striped bass from the lower Rappahannock River, falls 2005-2012.



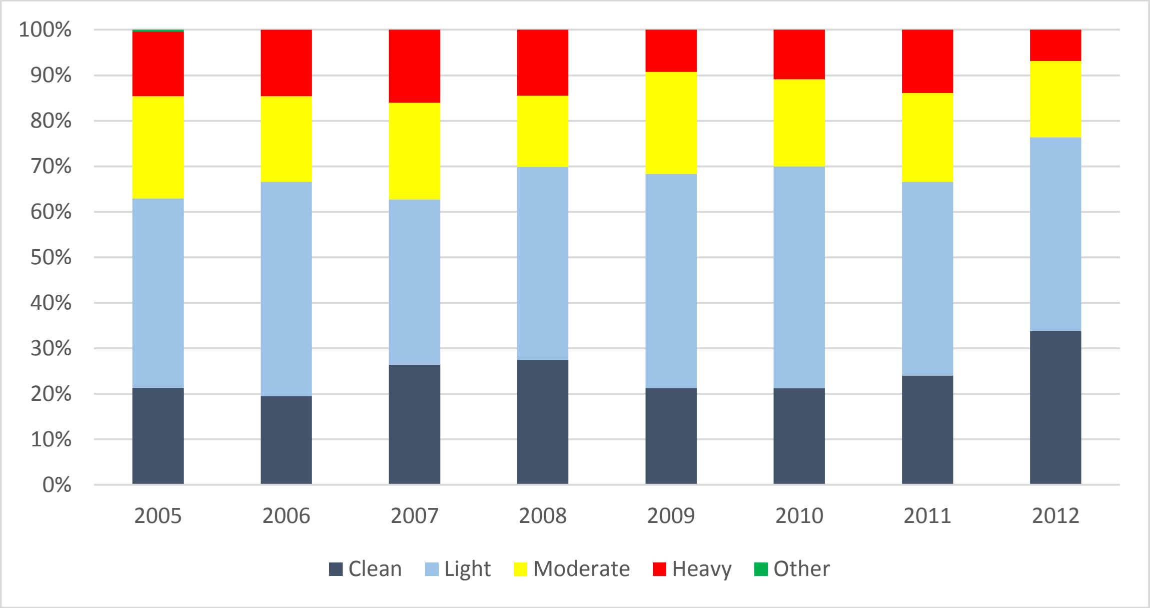


Figure 6. Annual absolute (top) and relative (bottom) composition of striped bass tag releases, by absence or severity of mycobacterial infection, of age 5 striped bass from the lower Rappahannock River, falls 2005-2012.

Figure 7. Relative composition of striped bass tag releases, by absence or severity of mycobacterial infection, of age 3-6 striped bass from the lower Rappahannock River, falls 2005-2012.

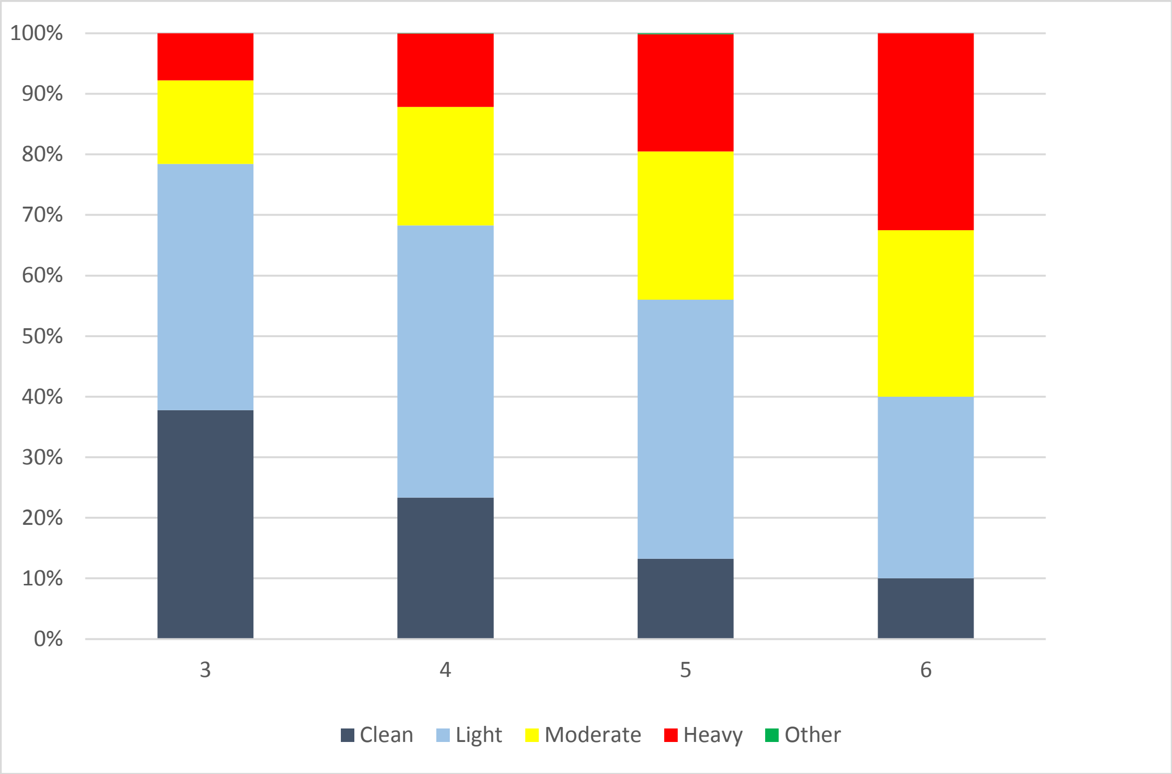


Figure 8. Progression of mycobacteriosis from lightly diseased at time of release to moderately diseased versus time-at-large for striped bass tagged and released in the Rappahannock River, fall 2005 to present (combined). Numbers next to the data points indicate number of recaptures.

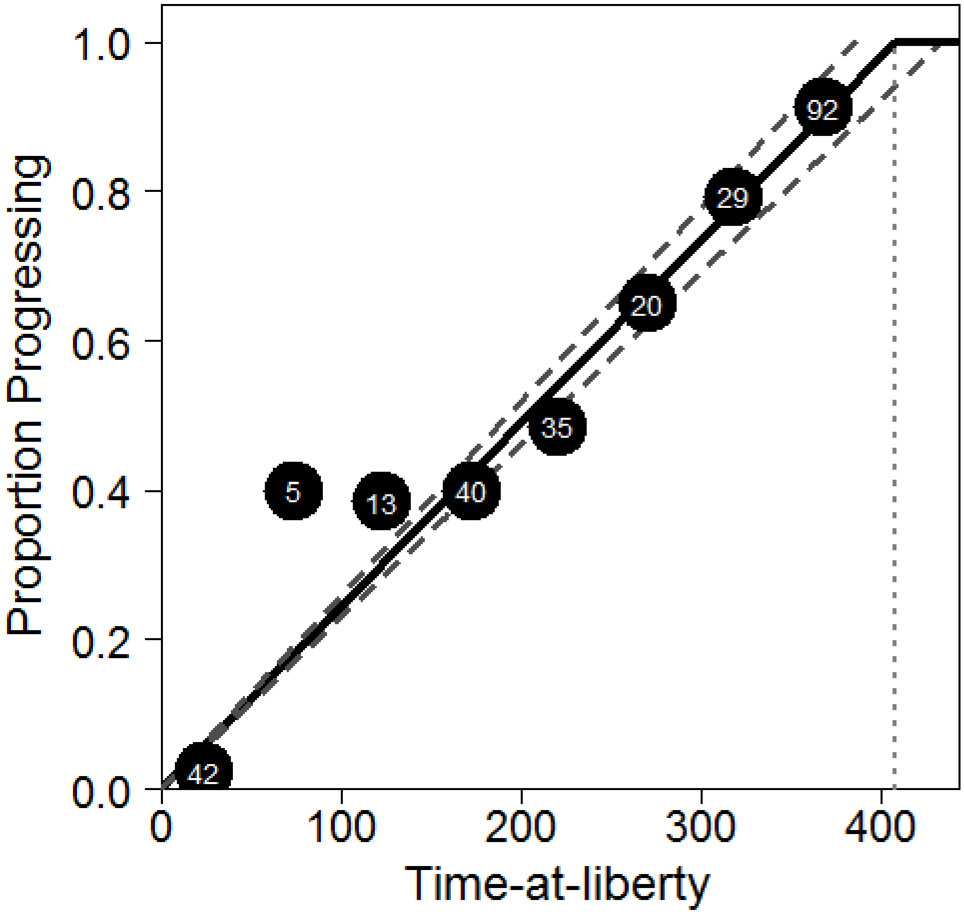


Figure 9. Progression of mycobacteriosis from moderately diseased at time of release to severely diseased versus time-at-large for striped bass tagged and released in the Rappahannock River, fall 2005 to present (combined). Numbers next to the data points indicate number of recaptures.

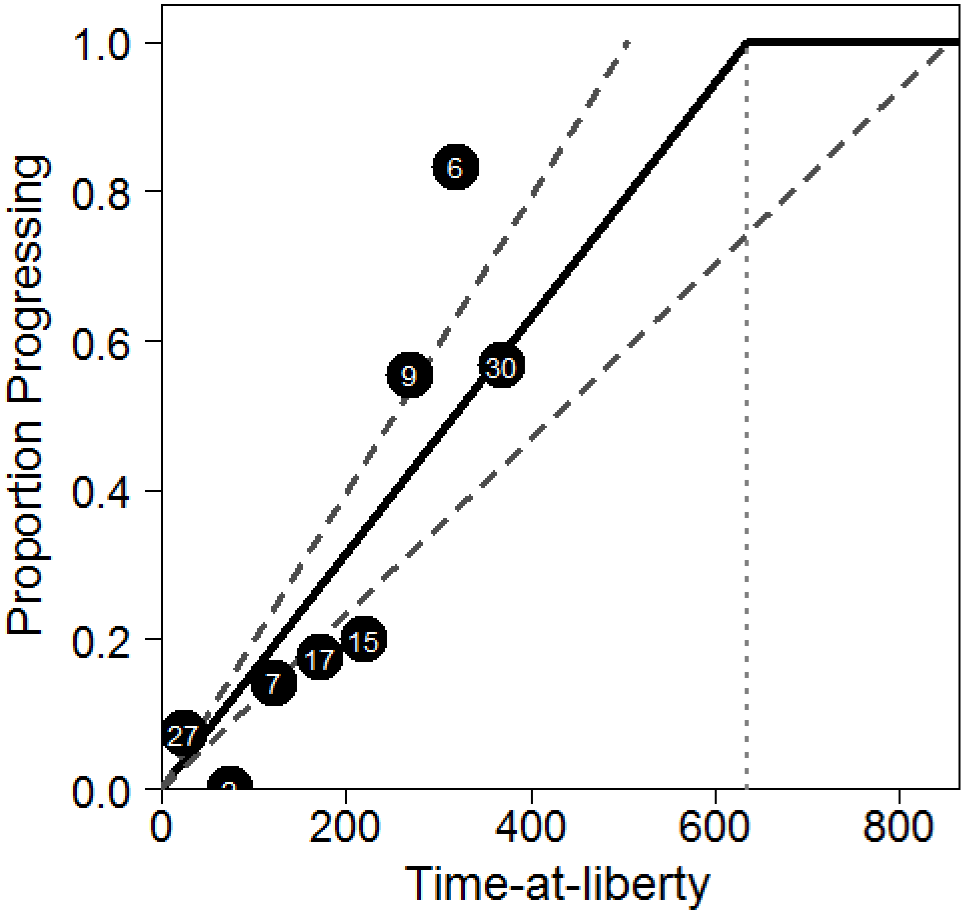


Figure 10. Progression of pigmented foci (PF) of uninfected striped bass based on reassessment of recaptured striped bass originally tagged and released in the Rappahannock River, falls 2005-2012.

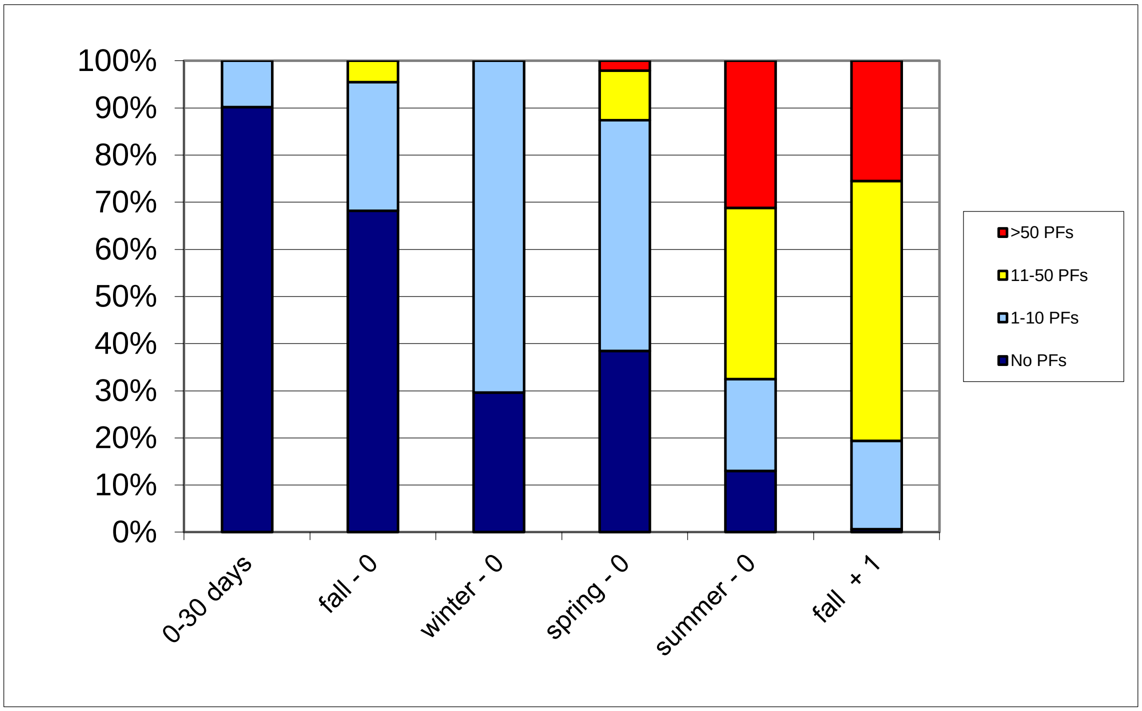


Figure 11. Logarithm of the ratio of returns of fish tagged in disease condition *x* and disease condition 0 (fish in condition 0 are “clean”, showing no signs of the disease) as a function of time at liberty. Symbol size is the square root of the number of recaptures. a) Condition 3 versus condition 0. b) Condition 2 versus condition 0. c) Condition 1 versus condition 0.

Figure 11a.

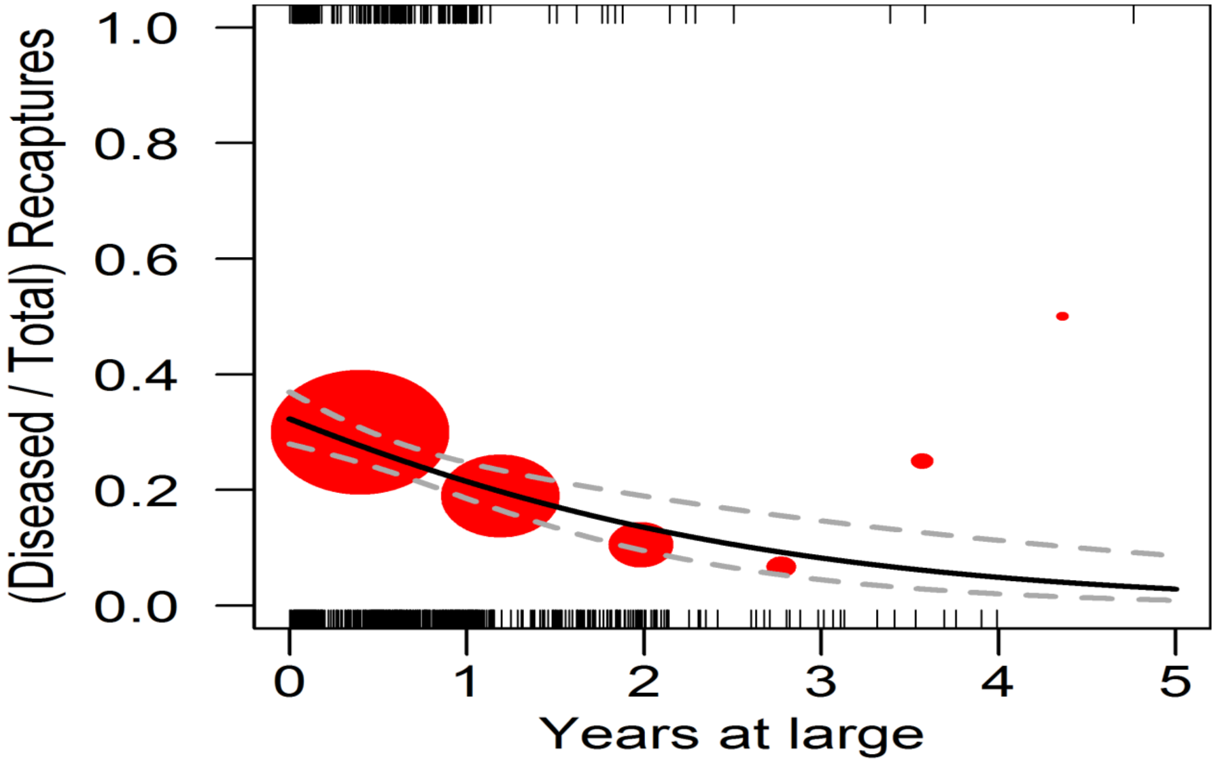


Figure 11b.

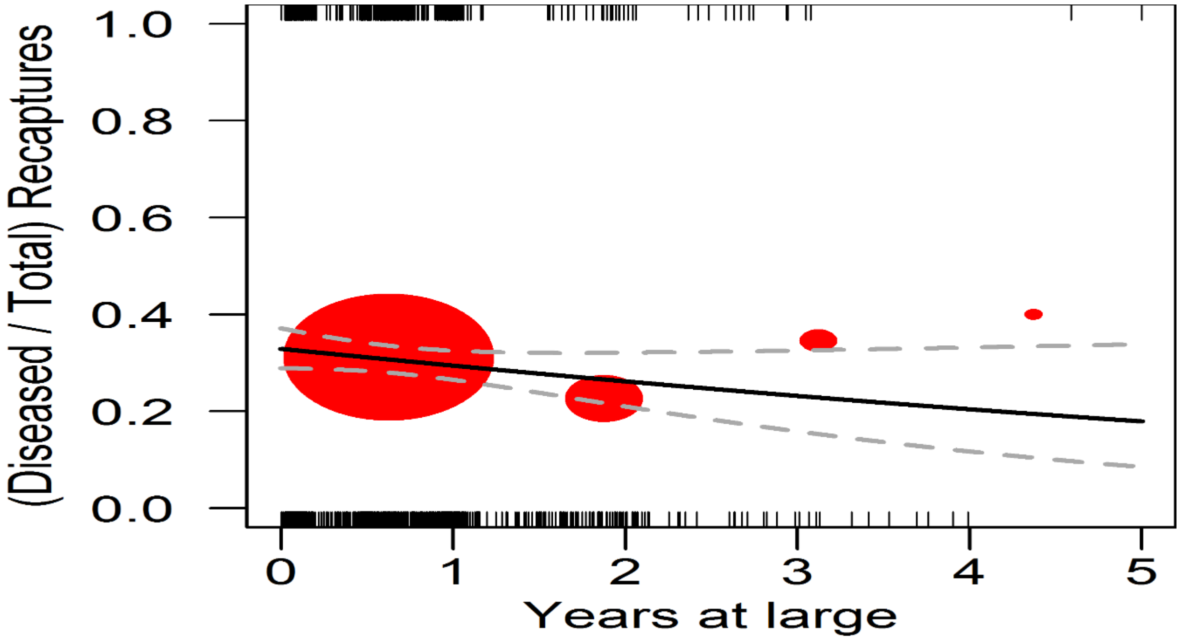


Figure 11c.

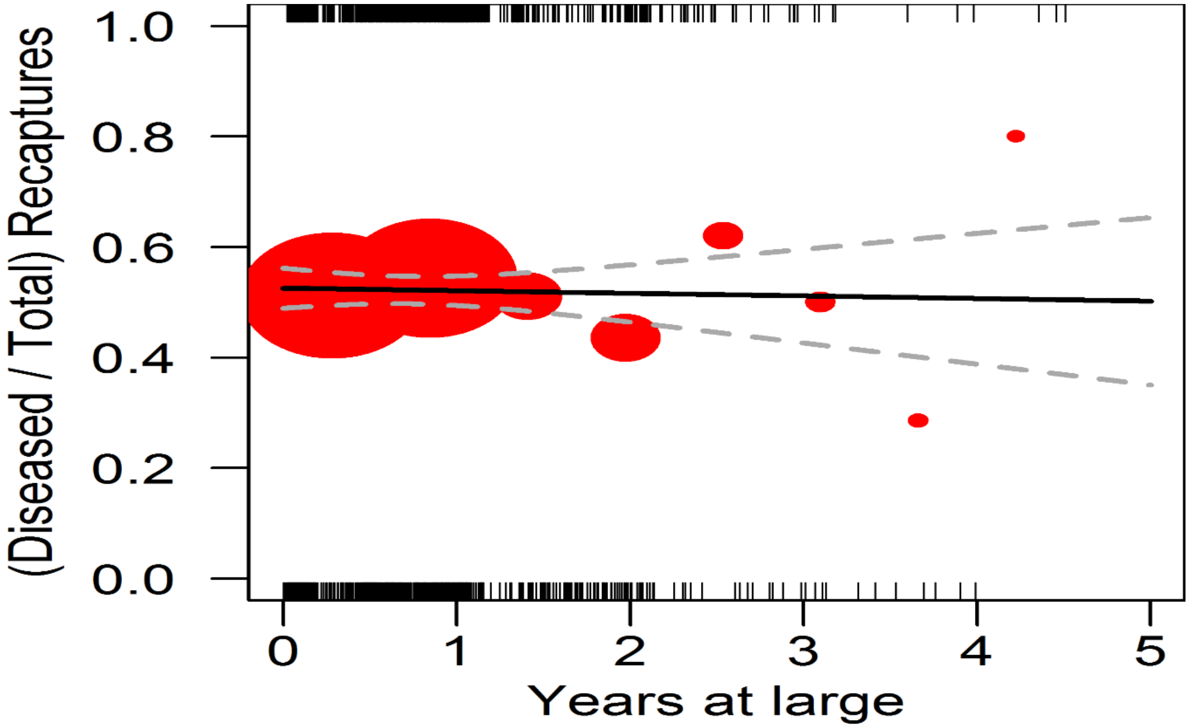
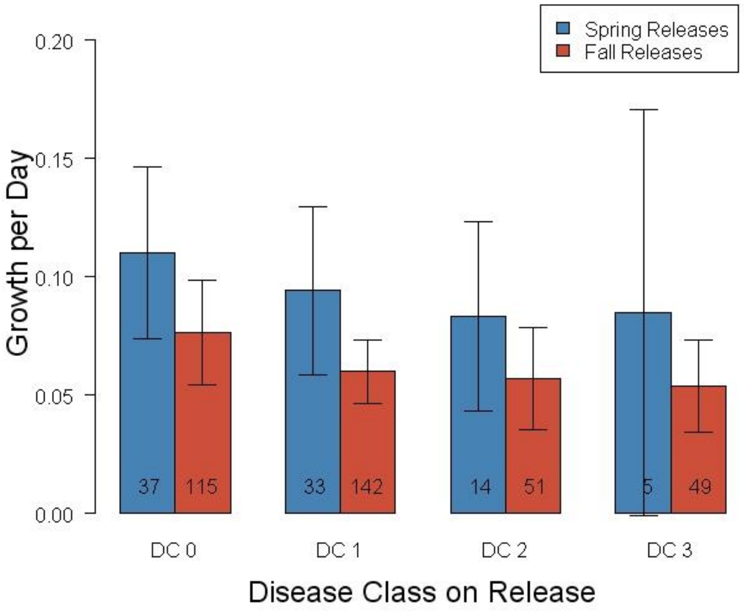


Figure 12. Comparison of growth of striped bass, by disease severity, based on recaptured striped bass originally tagged and released in the Rappahannock River, 2005-2012.



Analysis on fish at large > 30 days,
error bars represent 95% confidence intervals

IV. Length-specific recreational angling selectivity for striped bass caught in the Chesapeake Bay

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M.S. thesis in statistics (2013)
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Introduction

The anadromous striped bass, *Morone saxatilis*, is one of the most sought after species of finfish in the Chesapeake Bay. Prior to the early 1970's, striped bass were abundant throughout their coastal range and exploited in the Chesapeake Bay by an under-regulated fishery composed of commercial and recreational fishermen. Overfishing during this time period resulted in the striped bass population declining rapidly in the 1970's and early1980's. In 1979, Congress enacted the Emergency Striped Bass Act aimed at quantifying the population, understanding the causes of the decline and recommending potential restoration plans. This study suggested, among other things, that reduced fishing pressure would provide immediate benefits for rebuilding the population (Rago et al. 1989). Consequently, strict management limits were established coast wide and partial fishing moratoria were enacted. Under these restrictive management conditions, the population rapidly rebuilt and the Chesapeake Bay fishery was reopened in 1990 to limited fishing by both commercial and recreational fishermen. Since 1995 the fishery has been fully reopened and the population continues to thrive with the most current stock assessment finding that striped bass are not overfished and overfishing is not occurring.

Over the last two to three decades, recreational anglers have been the dominant source of fishing pressure in the striped bass fishery and presently account for an annual harvest of between 2 to 3 million fish coast wide (ASMFC 2011). This harvest, which is nearly four times that taken by commercial fishermen, is the largest source of non-natural mortality in the striped bass population and, consequently, is highly influential in shaping the abundance, and age/size composition of the population. Fishing gear, including hook and line gear, does not catch fish of all available length groups equally well (Millar and Fryer 1999). Thus, understanding gear selectivity is important to stock assessment scientists, fishery managers, and fishers for at least three reasons. First, fishers are interested in optimizing the catches and size compositions of desirable species while decreasing catches of undesired ones. Second, stock assessment scientists use information on selectivity to interpret catch data from samples from the fishery and from research surveys; selectivity parameters are incorporated into various assessment models. Third, modification of gear selectivity, either directly or indirectly, is a major management tool for fishery managers. Selectivity can vary widely among types of fishing gear even when they target the same fishery (Myers and Hoenig 1997). \

Often overlooked aspects of selectivity are possible differences in catchability due to sex and disposition of the fish. Estimates of sexual differences in catchability are important for management and can be quantified as sex-specific estimates of q, the catchability coefficient, or as a sexual component of gear selectivity (Methot and Wetzel 2013). Striped bass are known to exhibit sexually dimorphic growth, with females typically growing faster and larger than males (Mansueti 1961). Additionally, females have higher bioenergetics costs associated with spawning which may lead to increased feeding rates and susceptibility to angling. The recreational striped bass fishery experiences catch and release and harvest fishing in the Chesapeake Bay making it of interest to examine selectivity for both types of capture dispositions. These will be referred to as capture and harvest selectivity, respectively. Capture selectivity, also known as population selectivity (Millar and Fryer 1999), is the relative catchability of the various components of the population. Harvest selectivity refers to the combined effects of capture selectivity and the decision to retain or release a fish of a given population component. The difference in definition between these two forms of selectivity is subtle but important because the harvest and capture selectivity curves can be substantially different under certain management scenarios.

Direct estimates of selectivity can be obtained from tagged fish (Hamley and Regier 1973; Myers and Hoenig 1997; Millar and Fryer 1999; Frusher and Hoenig 2001; Clark and Kaimmer 2006; Bacheler et al. 2010). The generalized linear modeling approach as proposed by Myers and Hoenig (1997) is used to model simultaneously the effects of length, sex, disposition and their interaction on tag-return rate in the striped bass dataset. A major advantage of this method is that it allows for data obtained from multiple experiments to be combined in a statistically rigorous fashion.

The primary objective of this study is to use tagging data, obtained through 16 years of Maryland and Virginia research programs, to estimate gear selectivity for hook and line caught striped bass taken by recreational anglers in the Chesapeake Bay. Length-based estimates of selectivity will be obtained and the influence of sex and capture disposition on selectivity will be explored. The goal of this thesis is to determine if striped bass selectivity estimates obtained from an independent tagging database agree with the selectivity estimates currently being obtained within a statistical catch-at-age model used to assess striped bass.

Materials and methods

Striped bass tagging data: All states participating in the Atlantic striped bass fishery are required to conduct annual monitoring programs to assess the health of the striped bass population. These monitoring programs include long term tagging studies in which a variety of gears are used to collect striped bass by state fisheries scientists, biological data is collected, the fish are tagged with Floy® internal anchor tags, and released. Tags are labeled with a unique identifying number, “REWARD” message, and a phone number to report the tag. Recaptured fish are reported to the United States Fish and Wildlife Service which maintains a comprehensive database of all participating states’ tagging study data. The data obtained from the Maryland Department of Natural Resources (MDDNR) tagging program and the Virginia Institute of Marine Science (VIMS) tagging program was used for this study. Records for these two programs go back as far as 1984; however, only data from 1990 – 2006 were used. This time period was selected because there were consistent fishery regulations in place throughout. Differences in fishing regulations can profoundly affect gear selectivity estimates necessitating the dataset truncation. Fish recovered outside of Maryland and Virginia jurisdictional waters were excluded from the analysis given that different fishing regulations existed in the other states.

A wide array of variables was recorded for each fish; a select few were used in this study. At the time of tagging each fish had its, individual tag number, date of release, state of release, total length, and sex recorded. Total length was measured in millimeters from the terminus of the mouth to the longest tip of the caudal fin. Only fish that could have sex positively identified through gamete expression were included in the dataset. Upon being recaptured and reported, information on the date of recapture, location of recapture, type of gear used to catch the fish, type of fisherman (e.g., recreational, commercial, researcher, …), and the disposition of the fish (harvested or caught and released) was recorded. From each complete release and recapture record, days at large were calculated as the difference in Julian days of the date of recapture and the date of release. Not all variables were recorded for each fish requiring some recapture and release records to be removed prior to selectivity analysis.

Generalized linear model to estimate selectivity: Length based selectivity was estimated using 14 total length (TL) bins of 25mm each. All fish less than or equal to 550mm were grouped into a single length bin (minus group) as were all fish greater than 850mm (plus group). Sensitivity of the results to the selection of bin size was explored by repeating selectivity analyses with fish binned in 20mm and 30mm TL bins. These scenarios used the same minus and plus groups as before and had 17 and 12 TL bins respectively. Fish at large more than 180 days were excluded from the analysis to ensure they did not grow into the next largest length bin prior to recapture. In cases were an animal was recaptured and reported multiple times the first recapture event, with all the required variables recorded, was used.

Defining the experiment variable is essential for estimating gear selectivity with generalized linear models. For this study, an experiment was defined as all the releases by a given state in a given year. For example the fish released by Virginia in 1990 would be a different experiment than the fish released by Maryland in 1990. This definition of experiment allowed any temporal or spatial differences in tag release and recovery rates to be separated from the length-based selectivity process of interest. In addition to the experiment and length variables, sex was included in the analysis as a two level factor (Male and Female), as was disposition with factor levels equal to harvested or caught and released.

Length-specific gear selectivity estimates were obtained using the generalized linear model approach of Myers and Hoenig (1997). This approach estimates length-specific selectivity by fitting models to the expected value of the reported catch of tagged fish, $E[C_{i,l,s,d}]$ where

$$E[C_{i,l,s,d}] = N_{i,l,s} R_i U_i S_{l,s,d} \ , \qquad (1)$$

where $N_{i,l,s}$ is the number of fish of length l and sex s tagged in experiment i; R_i is the product of the proportion of fish that survived tagging, the proportion of tags that were not shed from the fish, and the proportion of recovered tags that were reported from experiment i; U_i is the exploitation rate of fish tagged in experiment i; and $S_{l,s,d}$ is the gear selectivity for length l, sex s, and disposition d. Note that R_i was assumed to be constant for all length, sex and disposition classes considered (Myers and Hoenig 1997). Tagging mortality, tag sheding, and tag non-reporting were assumed to be independent of the length, sex and disposition of the fish, but not necessarily constant from experiment to experiment and not necessarily negligible.

If the capture probabilities in an experiment were the same for all fish of a given length, sex, and disposition and the captures occurred independently and at random, then the capture probability of a tagged fish would be

$$\pi_{i,l,s,d} = R_i U_i S_{l,s,d} \ , \tag{2}$$

and the probability of observing $C_{i,l,s,d}$ recaptures would be binomial:

$$\text{Prob}(C_{i,l,s,d}) = \binom{N_{i,l,s}}{C_{i,l,s,d}} \left(\pi_{i,l,s,d}\right)^{C_{i,l,s,d}} \left(1-\pi_{i,l,s,d}\right)^{N_{i,l,s}-C_{i,l,s,d}} \ . \tag{3}$$

The likelihood follows immediately from the above distribution as the product over all experiments, lengths, sexes and dispositions of expressions of the form in equation (3).

Statistical tests and estimation were carried out by fitting generalized linear models using binomial error assumptions and a log link function. If there were differences in capture probability among fish for a given length, sex and disposition class, then the above binomial error distribution would cause the standard error of the estimates to be underestimated; however, this would not cause the estimates to be biased. If evidence of this effect were to be found, the model selection process would be modified by using quasilikelihood (McCullagh and Nelder 1989).

The ability of the preferred model to predict catch was not of interest for this study. Of primary interest are the estimated terms $s_{l,s,d}$ related to selectivity. These are a measure of relative catchability of the different groups of fish defined by the combination of length, sex and disposition. The numerical algorithm used, implemented by the glm function in the computer language R, fixes $s_{l,s,d}$ to zero for the first length, sex, and disposition classes; all other $s_{l,s,d}$ terms can thus be thought of as a measure of catchability (on the log scale) relative to the reference classes. Selectivity is relative catchability (ratio of catchability) rescaled to the interval (0, 1). To express relationships in terms of selectivity, we set $s_{l,s,d}$ to zero for the length, sex, and disposition class which had the greatest relative catchability; this made the back-transformed selectivity, $S_{l,s,d}$, equal one for that length and sex class and less than or equal to one for all other combinations of length and sex class.

Model selection: A hierarchy of models was fitted to the data. A null model, in which selectivity was assumed to be constant over all length, sex, disposition and experiment combinations, was fitted to the data. All other models tested contained experiment and length as factors. Additive models with sex, disposition and sex and disposition were fitted as were interactive models with length/disposition, length/sex, sex/disposition and length/sex/disposition interactions.

The most parsimonious model was determined using $QAIC_c$ which corrects AIC values for overdispersion in the data as well as small sample bias. $QAIC_c$ deals with the issue of overdispersion by estimating a variance inflation factor (Burnham and Anderson 2002) for a global model, which is then used to revise each candidate model's information criterion. The variance inflation factor was calculated as:

$$\hat{c} = \chi^2/\mathrm{df}, \tag{4}$$

where χ^2 is the usual goodness-of-fit test for the global model and df is the degrees of freedom for the test. The model with all two and three way interactions between length, sex, and disposition was used as the global model for estimating the variance inflation factor. This reduced model was used rather than the fully parameterized model (including experiment interactions) because the full model was over parameterized for the data available and $\hat{c}$ could not be estimated from this model.

Adjusted AIC values were calculated as:

$$QAIC_c = -\left[\frac{2\log_e(L(\hat{\theta}))}{\hat{c}}\right] + 2K + \frac{2K(K+1)}{n-K-1}\ , \tag{5}$$

where $L(\hat{\theta})$ is the maximized likelihood of the candidate model, K is the number of parameters in the candidate model, n is the sample size and $\hat{c}$ is the variance inflation factor. The last part of equation (5) serves as the small sample size correction and effectively reduces to zero as sample size increases. The number of parameters for each model was increased by one to account for the estimation of $\hat{c}$.

To better interpret the relative likelihood of each model, $\Delta QAIC_c$ values and Akaike weights (w_i) were calculated. The difference between each model *i* and the model with the lowest $QAIC_c$ value was defined as the $\Delta QAIC_c$ value for model *i*. Weights were then calculated for each candidate model as:

$$w_i = \frac{\exp\left(-\tfrac{1}{2}\Delta_i\right)}{\sum_{r=1}^{R}\exp\left(-\tfrac{1}{2}\Delta_r\right)} \tag{6}$$

where Δ_i is the $\Delta QAIC_c$ value for the i^th^ model and Δ_r is the $\Delta QAIC_c$ value for model *r* in the set of all models (*R*). The w_i can be interpreted as the weight of evidence that model *i* is the best model in the set of candidate models. The most parsimonious model – the one with the lowest $QAIC_c$ - was used to generate selectivity estimates and model averaging was not utilized.

All computations were done using the statistical language R (R Development Core Team 2010). The package AICcmodavg (Mazerolle 2011) was used to calculate K, $QAIC_c$, $\Delta QAIC_c$, w_i and log likelihood values.

Model diagnostics: There are several alternative definitions of residuals for generalized linear models (McCullagh and Nelder 1989); we examined the deviance residual, which is defined as the signed square root of the deviance of any given observation. Plots of deviance residuals versus each of the linear predictors and versus the predicted values were examined to determine model fit and identify potential failures of assumptions. Multicollinearity of the linear predictors was tested by calculating a generalized variance inflation factor. Influential observations were identified by jointly examining leverage, Cook's distance and residual values. Observations identified as being potentially highly influential were systematically excluded from the dataset, models were refit and results were compared to determine sensitivity of the coefficient estimates to these observations.

Bootstrap confidence interval: A simulation approach was used to estimate the precision of the selectivity estimates. For each unique combination of experiment, length, sex and disposition, 1000 sets of simulated tag returns were generated using a random binomial generator which required the observed number of striped bass tagged and returned. A generalized linear model was then fit to each simulated data set and selectivity estimates were calculated for each unique combination of independent variables. The standard deviation of the 1000 simulated selectivity estimates was used as a measure of precision for the selectivity estimates.

Results

A total of 50,900 striped bass was tagged and released with 35,674 (70%) of these being released by MDDNR and the remaining 15,226 (30%) being released by VIMS. Female striped bass were on average larger than males and ranged from 298 to 1,290 mm TL at tagging with males ranging from 219 – 1,163 mm TL. Releases of males, totaling 46,858 (~92%), far exceeded releases of females which totaled 4,042. Sample sizes of releases were adequately for all combinations of length bin and sex (Table 1).

A total of 1,187 striped bass were recaptured with 904 (76%) of these being fish released by MDDNR and the remaining 283 (24%) being released by VIMS. Females accounted for 123 (10%) of the recaptures and males accounted for 1,064 (90%) recaptures. Sixty-two (50%) females were harvested and 61 (50%) were caught and released. Likewise for males, 487 (46%) were harvested and 577 (54%) were caught and released. Harvested fish were, on average, larger than released fish. Harvested females ranged in length from 458 to 1,022 mm TL, harvested males from 349 to 929 mm TL, released females from 298 to 1,002 mm TL and released males from 310 to 866 mm TL. Recapture sample sizes were small for all female length bins with two catch and release length bins and one harvest length bin recording no recaptures (Table 1). Males had recaptures recorded for all length bins in both dispositions; however, sample sizes were small for large (>800 mm TL) catch and release and harvested males (Table 1).

Model selection: The preferred model based on minimum $QAIC_c$, was the model including experiment, length, sex and disposition with no interactions (Table 2). This model received 98% of the weight and all other models tested received essentially no support from the data based on ΔQAICc values and normalized Akaike model weights. The estimated value of $\hat{c}$ was 1.009 indicating that overdispersion of the data was not a problem and that unadjusted AIC could have been used to infer the best model. Model selection based on AIC scores resulted in the same model being preferred with no support from the data for any other models tested.

Analysis of the preferred model residuals showed no obvious patterns relative to the fitted values or linear predictors (Figure 1). This result combined with the lack of evidence for overdispersion suggests that the preferred model adequately described the data. Estimated values of the generalized variance inflation factor were small indicating that multicollinearity was not an issue and the selectivity coefficient estimates of interest should be stable to small changes in data or predictor variables (Table 3). Two potentially influential points (observations 322 and 55) were identified (Figure 2). Observation 322 contained a record of male, harvested fish in the ≤ 500 mm TL length bin. Recaptures totaled 17 out of 666 released which was not unusually for this length bin, sex and disposition combination. Removal of this observation and subsequent re-fitting of the model resulted in no substantial changes to the coefficient estimates. Observation 322 was not removed from the dataset. Observation 55 contained a record of male, released fish in the 651 – 675 mm TL length bin. Recaptures were 16 out of 158 released which were the largest values of all similar records; however, the proportion recaptured, 0.10, was not unusual for this combination of factor levels. Removal of observation 55 and subsequent re-fitting of the model resulted in substantial differences to the length coefficients. Estimated coefficient values increased for all length groups and the estimated length of maximum selectivity changed from 651 – 675 mm TL to 826 – 850 mm TL (Table 4). Observation 55 was kept in the dataset because the shape of the resulting selectivity curve was mostly unaffected by the changes to the estimated length bin coefficients (Figure 3) and the observation was not an obvious recording error or severe outlier.

Selectivity curve estimates and standard errors: The estimated selectivity curves for catch and release and harvested fish were generally asymptotic in nature, with the maximum selectivity occurring at 651 – 675 mm TL and remaining relatively high for all larger length groups except the last (Figure 4, Table 5). Confidence in the results is raised by the relative smoothness of the curves, the reasonably small 95% confidence intervals and the fact that use of 20mm and 30 mm TL bins did not change the overall shape of the estimated selectivity curves (Figure 4, Table 5). Confidence intervals indicated it was highly unlikely that maximum selectivity occurred before the 651- 675mm length bin but could have actually occurred at a number of larger length bins. This lends additional support to the conclusion that the selectivity of angler caught striped bass is asymptotic at least in the range of lengths studied.

Selectivity was greatest for females and anglers were more likely to catch and release fish than to harvest them. The estimated sex effect for males on the log scale was

-0.819 (SE. 0.13) which was significantly less than that of females ($p < 0.0001$). On the original scale this effect corresponds to females being 55% more likely to be caught than males. The estimated catch and release effect on the log scale was 0.199 (SE 0.058; $p = 0.0007$). On the original scale, this corresponds roughly to captured striped bass being 22% more likely to be released than harvested by recreational anglers.

Discussion

Obtaining estimates of gear selectivity is essential for conducting fishery stock assessments that utilize catch or survey indices of abundance. Length- or age-based selectivity curves provide a means to convert between catch-at-age or catch-at-length data obtained from fisheries catch and/or survey data and the true population age or length composition. A number of methods have been developed to estimate selectivity both independent of, and within an age- or length-structured assessment model. The majority of these approaches rely on indirect methods to estimate selectivity and often require an a priori assumption about the parametric shape of the selectivity curve to be computationally feasible. Indirect methods for estimating selectivity are considered “indirect” because these methods operate when the true population age or length composition is not known making it impossible to directly measure the relative catch rates for any given length or age group. The method employed here, differs from the indirect approaches because the population of tagged animals is known allowing the researcher to obtain direct measures of the relative catch rates and consequently, direct estimates of gear selectivity.

The length-based selectivity curves and the sex and disposition effects estimated in this study are consistent with what would be expected for the striped bass fishery. The estimated sex and disposition effect provide an estimate of the relative catchability of the different sexes and the proportion of caught fish that are harvest or released. These estimates are credible so long as there is no reason for tags to be disproportionately returned for one sex or disposition over the others. In the case of sex it seems unlikely that tags would be returned differently for males and females as it is nearly impossible to determine the sex of a striped bass outside of spawning season and there is no practical reason for an angler to differentiate between the two.

Disposition, however, may create a situation that results in tag return rates differing for harvested or released fish. Fish that are caught and released may not always be grounded or brought on board a fishing vessel, making it far more likely that a tag may be overlooked prior to release. Even when a fish is landed or brought on board a tag may be overlooked since catch and release anglers are often in a hurry to release the fish in order to protect it from undue stress. Regardless of the reason it is most likely that the reporting rate of catch and release tags will be less than that of harvested tags. This implies that the estimated 22% increase in catch rate for catch and release fish over harvested fish is likely an underestimate. This conclusion is supported by the recreational fishing statistics for Maryland and Virginia that estimate that in 2012 recreational fisherman harvested 332,407 striped bass and caught and released 2,308,254 (MRFSS). This equates to roughly 87% of the total recreational catch being released, substantially more than estimated by this study.

The selectivity estimated for the plus group length bin (> 850mm TL) was significantly less than the estimates obtained for the immediately smaller length bins. Consequently, the true recreational angling selectivity curve could be dome-shaped (declining selectivity in small and large length groups) rather than asymptotic (constant high selectivity for large length groups). Two possible scenarios can explain this situation. First, the selectivity of larger fish truly declines and the shape of the curve should be dome shaped. Second, selectivity of larger fish is still high (~1) but these fish are not available to the fisherman (Chesapeake Bay recreational anglers). The later scenario is more likely in the case of recreationally caught striped bass. Large striped bass are generally considered to be coastal migrants that spend the majority of the year in the ocean and make short annual or biennial migrations to the estuaries and rivers of the Chesapeake Bay to spawn. As a result the window during which these larger fish are vulnerable to inshore recreational anglers is short. Since selectivity estimates are obtained by examining the proportion of tags recovered by length group, processes, like lack of availability, will influence the estimates. A concentrated effort to tag additional larger fish and document the location and timing of the recaptures would be needed to better understand the availability and selectivity of larger striped bass.

The implications of miss-specifying the shape of the selectivity curves can be substantial for fisheries management. Use of a dome-shaped selectivity curve rather than an asymptotic curve was indicated as a likely contributor to the collapse of the Atlantic cod (Myers et al. 1996). Selectivity estimates are used to essentially inflate catch data. Thus, using a dome shaped selectivity curve will effectively increase the estimated population abundance of larger fish in the assessment model. Doing so has real impacts on the estimates of spawning stock biomass and fishing mortality rate which are commonly used to set reference points used to determine the overall health of a fishery (is the fishery overfished and is overfishing occurring). The current striped bass stock assessment assumes a variety of asymptotic selectivity curves that are estimated within the statistical catch-at-age assessment model (ASMFC 2011). The shape of these estimated selectivity curves vary slightly with time but in general maximum selectivity for striped bass caught in the fishery is achieved around age 6 or 7. From the tagging database age 6 striped bass have a mean total length about 640 mm TL and age 7 striped bass have a mean length of 720 mm TL. These values agree closely with the length of maximum selectivity estimated in this study of 651 – 675 mm TL. Thus, the conclusions of this thesis support the continued use of logistic function to model selectivity in the stock assessment at least for recreationally caught striped bass in the Chesapeake Bay.

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Table 1. Recapture and release numbers by length-bin, sex and disposition on recapture (Catch & Release or Harvested) for striped bass tagged and released by Maryland Department of Natural Resources and the Virginia Institute of Marine Science between 1990 and 2006.

Length Bin (mm)	Sex	Catch & Release	Harvested	Total	Releases
≤ 550	F	8	1	9	379
551 - 575	F	3	2	5	205
576 - 600	F	1	2	3	207
601 - 625	F	8	0	8	268
626 - 650	F	10	3	13	250
651 - 675	F	8	5	13	226
676 - 700	F	1	4	5	248
701 - 725	F	4	2	6	233
726 - 750	F	6	4	10	242
751 - 775	F	3	5	8	255
776 - 800	F	3	3	6	258
801 - 825	F	0	7	7	329
826 - 850	F	0	4	4	384
> 850	F	6	20	26	3372
≤ 550	M	321	216	537	16588
551 - 575	M	34	48	82	1978
576 - 600	M	28	28	56	1490
601 - 625	M	34	22	56	1325
626 - 650	M	32	20	52	1182
651 - 675	M	35	20	55	1100
676 - 700	M	25	32	57	1030
701 - 725	M	23	23	46	914
726 - 750	M	23	23	46	802
751 - 775	M	11	12	23	739
776 - 800	M	8	18	26	576
801 - 825	M	1	11	12	519
826 - 850	M	1	10	11	305
> 850	M	1	4	5	626

Table 2. Model selection criteria for recreational angling selectivity models fit to striped bass mark recapture data. Main factors tested are experiment (Exp), length class (Length), sex, and disposition (Disp) with interactions identified by *. The presence of an interaction implies the presence of the main effects. The number of parameters (*K*), corrected quasi-Akaike information criterion (QAIC_c), delta corrected quasi-Akaike information criterion (ΔQAIC_c), normalized Akaike weights (*w*), and the quasi-log likelihood value for each model are shown. The variance inflation factor ($\hat{c}$), obtained from the (Exp, Length*Disp, Length*Sex, Disp*Sex) model, was equal to 1.009.

Model	*K*	QAIC_c	ΔQAIC_c	*w*	Log LL
Exp, Length, Sex, Disp	50	1436.42	0.00	0.98	-661.15
Exp, Length, Sex	49	1445.27	8.85	0.01	-666.87
Exp, Length*Sex, Disp	63	1445.36	8.94	0.01	-648.09
Exp, Length*Sex	62	1452.15	15.73	0.00	-652.88
Exp, Sex, Length*Disp	63	1453.28	16.86	0.00	-652.05
Exp, Length*Disp, Length*Sex	76	1464.81	28.39	0.00	-638.93
Exp, Length, Disp	49	1466.30	29.88	0.00	-677.38
Exp, Length*Disp, Length*Sex, Disp*Sex	77	1466.77	30.35	0.00	-638.40
Exp, Length	48	1474.83	38.41	0.00	-682.93
Exp, Length*Sex*Disp	87	1495.42	58.99	0.00	-637.08
Null	2	1736.32	299.90	0.00	-866.14

Table 3. Results of test for multicollinearity for all main factors used to estimate striped bass gear selectivity in a generalized linear model. Generalized variance inflation factor (GVIF), degrees of freedom (Df) and a standardized generalized variance inflation factor (GVIF^(1/(2*Df))) are presented.

Variable	**GVIF**	**Df**	**GVIF^(1/(2*Df))**
Experiment	3.47	33	1.02
Length bin	3.77	13	1.05
Sex	2.06	1	1.43
Disposition	1.06	1	1.03

Table 4. Model coefficient estimates obtained from the preferred model fit to all the data (Original Est.) or the data minus observation 55, (Modified Est.). Difference, calculated as modified est. – original est., is presented and coefficient values substantially altered by the removal of observation 55 are highlighted within the box.

Parameter	Original Est.	Modified Est.	Difference (M - O)
(Intercept)	-2.99	-3.09	-0.10
lbin1	-1.24	-1.10	0.14
lbin2	-0.60	-0.46	0.14
lbin3	-0.58	-0.44	0.14
lbin4	-0.41	-0.27	0.14
lbin5	-0.31	-0.16	0.14
lbin7	-0.25	-0.10	0.15
lbin8	-0.18	-0.04	0.14
lbin9	-0.16	-0.02	0.14
lbin10	-0.40	-0.27	0.13
lbin11	-0.18	-0.05	0.13
lbin12	-0.18	-0.05	0.12
lbin13	-0.08	0.05	0.13
lbin14	-2.24	-2.11	0.13
sexM	-0.82	-0.83	-0.01
dispR	0.20	0.19	-0.01
exp2	0.73	0.72	-0.01
exp3	0.21	0.22	0.01
exp4	0.80	0.79	-0.02
exp5	0.66	0.53	-0.13
exp6	-0.09	-0.11	-0.02
exp7	0.24	0.23	-0.01
exp8	-0.33	-0.33	-0.01
exp9	0.57	0.55	-0.01
exp10	1.02	0.99	-0.03
exp11	1.00	0.99	-0.01
exp12	0.76	0.74	-0.02
exp13	0.83	0.82	-0.01
exp14	1.44	1.42	-0.02
exp15	1.20	1.19	-0.01
exp16	0.55	0.53	-0.02
exp17	1.40	1.38	-0.01
exp18	0.69	0.67	-0.02
exp19	0.95	0.93	-0.02
exp20	0.69	0.68	-0.02
exp21	1.43	1.42	-0.01

exp22	0.75	0.73	-0.02
exp23	1.21	1.19	-0.02
exp24	0.95	0.93	-0.02
exp25	0.86	0.85	-0.01
exp26	0.86	0.84	-0.01
exp27	1.01	0.99	-0.02
exp28	0.58	0.56	-0.02
exp29	1.02	1.01	-0.01
exp30	0.32	0.31	-0.02
exp31	0.89	0.87	-0.02
exp32	0.76	0.74	-0.02
exp33	1.24	1.22	-0.02
exp34	0.87	0.85	-0.02

Table 5. Estimates of length-based selectivity and accompanying standard errors for recreationally caught striped bass obtained from Maryland and Virginia tagging data from 1990 – 2006. Selectivity and standard error estimates were obtained for females (F) and males (M) and for fish that were caught and released and harvested.

Length Bin (mm)	Sex	Selectivity Catch & Release	Selectivity Harvested	Std. error Catch and Release	Std. error Harvest
≤ 550	F	0.29	0.24	0.04	0.03
551 - 575	F	0.55	0.45	0.08	0.07
576 - 600	F	0.56	0.46	0.09	0.08
601 - 625	F	0.66	0.54	0.10	0.09
626 - 650	F	0.74	0.60	0.11	0.10
651 - 675	F	1.00	0.82	0.12	0.10
676 - 700	F	0.78	0.64	0.12	0.11
701 - 725	F	0.83	0.68	0.13	0.12
726 - 750	F	0.86	0.70	0.13	0.12
751 - 775	F	0.67	0.55	0.12	0.11
776 - 800	F	0.83	0.68	0.14	0.12
801 - 825	F	0.84	0.69	0.17	0.14
826 - 850	F	0.93	0.76	0.17	0.15
> 850	F	0.11	0.09	0.03	0.02
≤ 550	M	0.13	0.11	0.02	0.02
551 - 575	M	0.24	0.20	0.05	0.04
576 - 600	M	0.25	0.20	0.05	0.04
601 - 625	M	0.29	0.24	0.05	0.05
626 - 650	M	0.32	0.27	0.06	0.05
651 - 675	M	0.44	0.36	0.07	0.06
676 - 700	M	0.34	0.28	0.07	0.06
701 - 725	M	0.37	0.30	0.07	0.06
726 - 750	M	0.38	0.31	0.08	0.07
751 - 775	M	0.30	0.24	0.07	0.06
776 - 800	M	0.37	0.30	0.08	0.07
801 - 825	M	0.37	0.30	0.09	0.08
826 - 850	M	0.41	0.33	0.11	0.09
> 850	M	0.05	0.04	0.02	0.01

Figure 1. Diagnostic plot of deviance residuals plotted against length class (lbin), sex, disposition (disp) variables and linear predicted values.

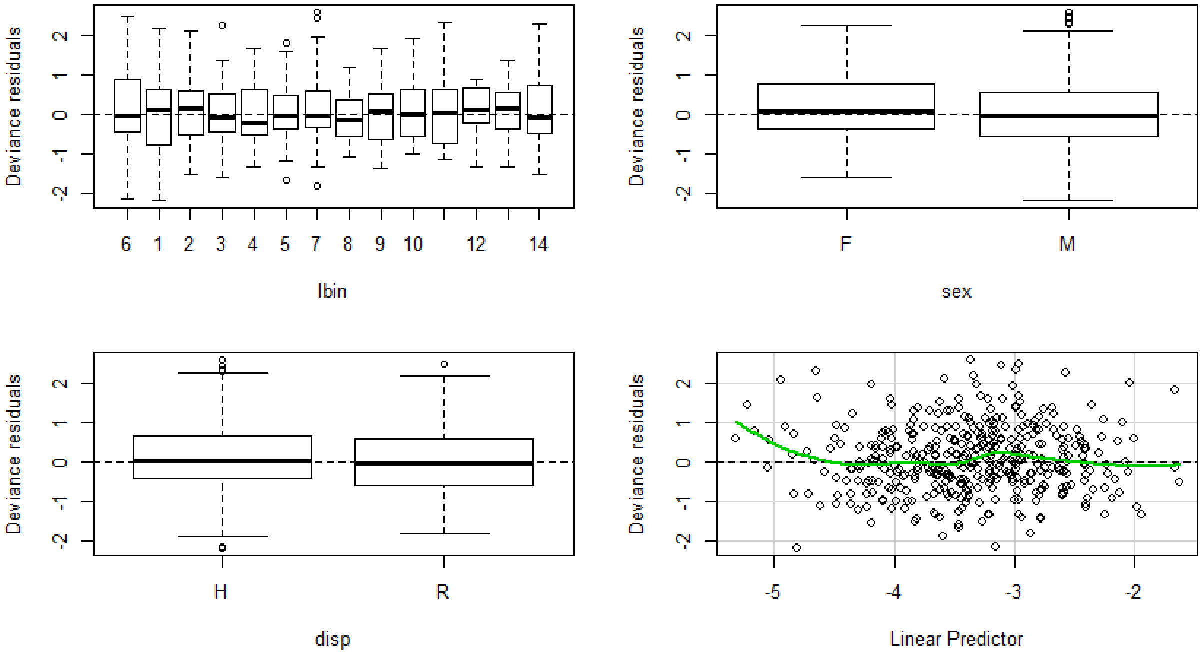


Figure 2. Three dimensional visualization of individual data points leverage (x-axis), Studentized residual (y-axis) and Cook's Distance (Proportional to circle radii). Vertical reference lines are drawn at twice and three times the average hat-value, horizontal reference lines at -2, 0, and 2 on the Studentized-residual scale. Observations 55 and 322 are identified as potentially being highly influential points.

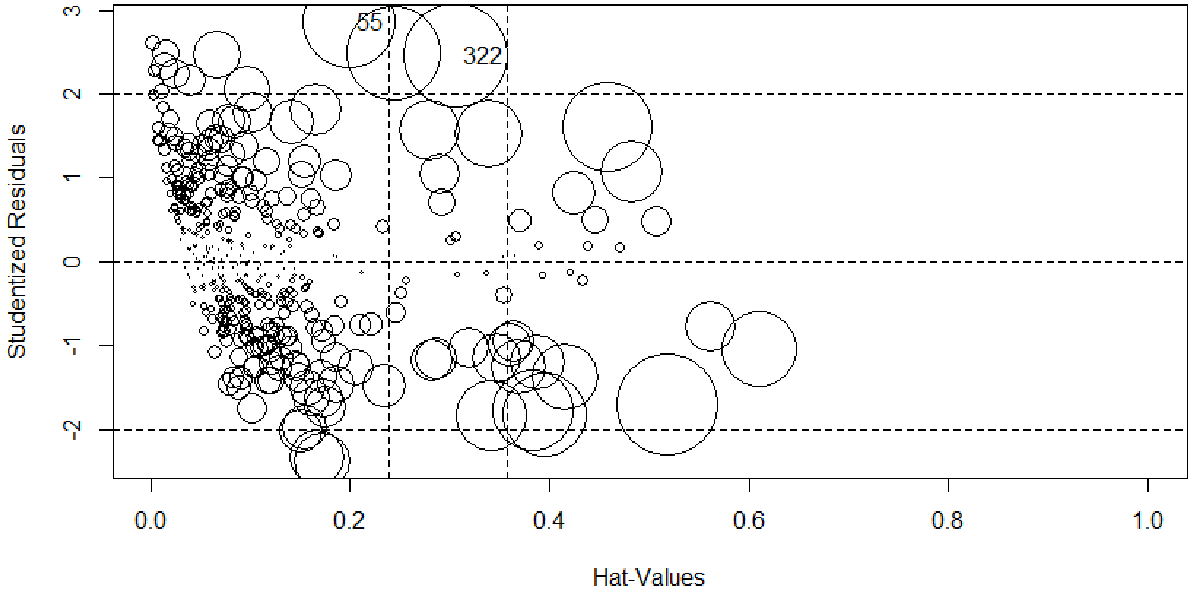


Figure 3. Estimated selectivity curves for striped bass caught by recreational anglers and either released (left column) or harvested (right column) when all available data is used (top row) and when a highly influential observation is removed (bottom row). Selectivity curves of females are shown in red and males are shown in blue. Vertical lines indicate 95% confidence intervals and horizontal dashed line marks full selectivity (1.0).

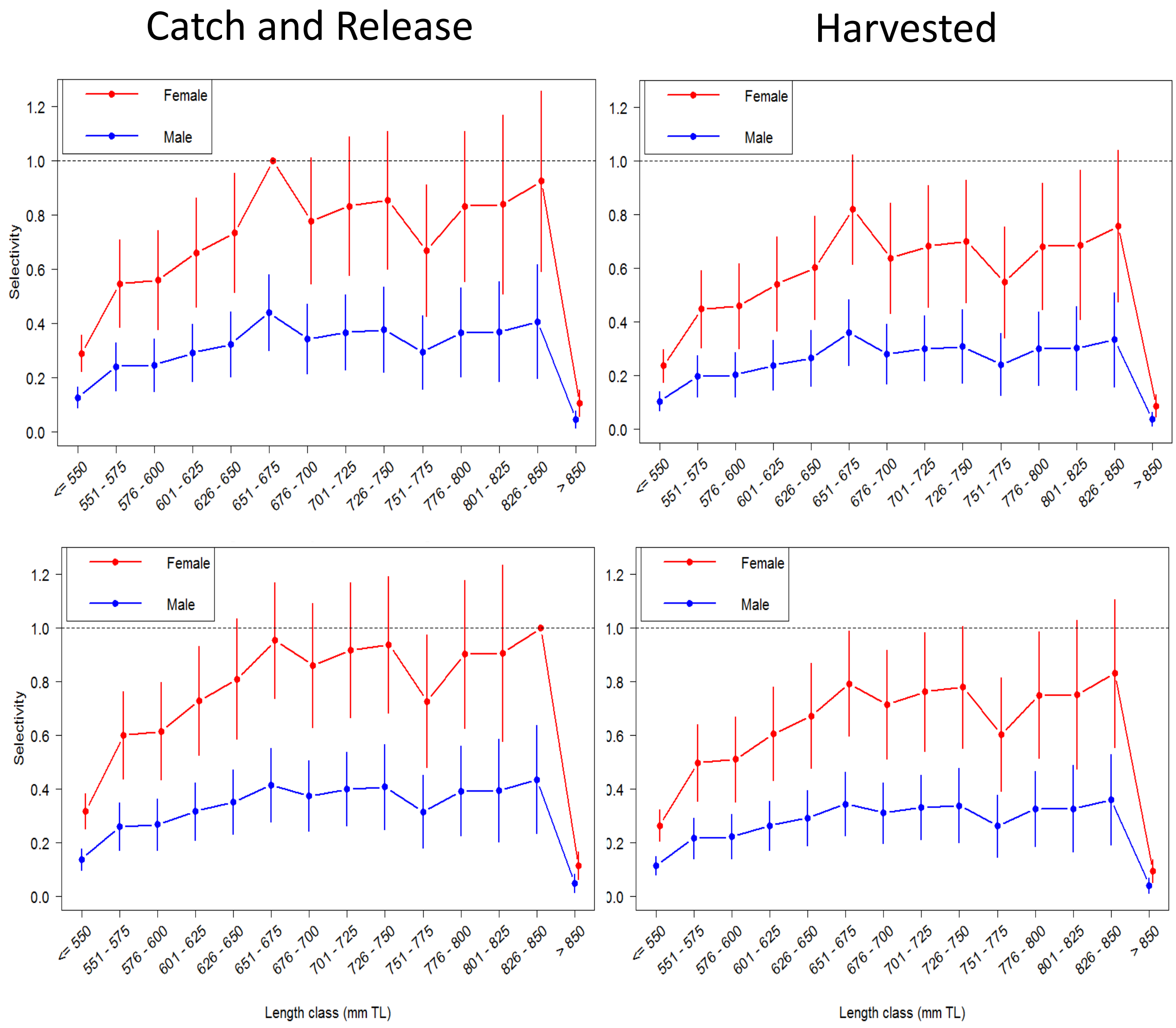
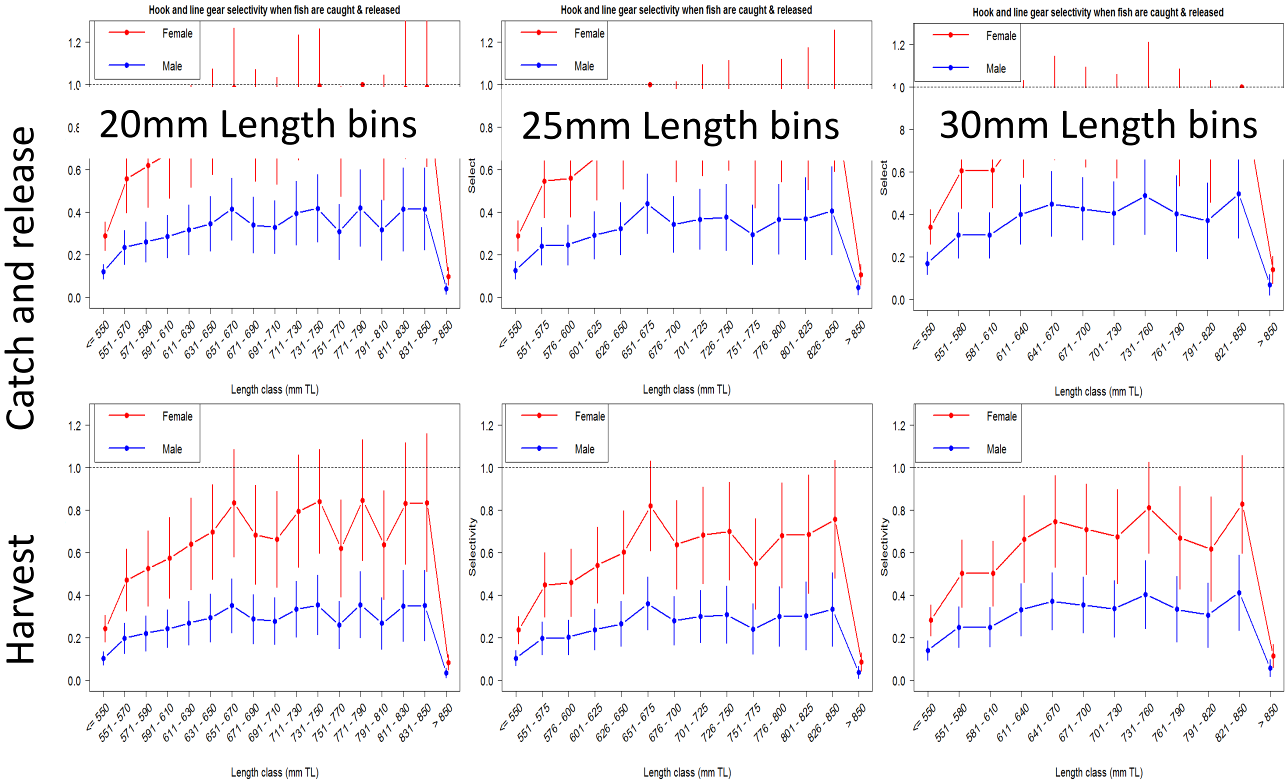


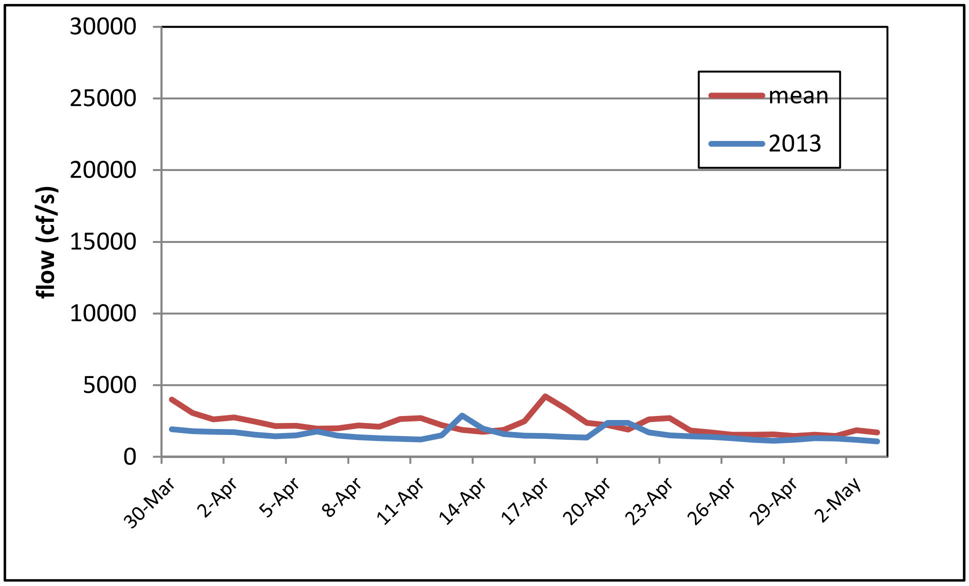
Figure 4. Estimated selectivity curves with length binned by 20, 25, or 30 mm increments for striped bass caught by recreational anglers and released (top row) or harvested (bottom row). Selectivity curves of females are shown in red and males are shown in blue. Vertical lines indicate 95% confidence intervals and horizontal dashed line marks full selectivity (1.0).



Appendix A. Daily flow rates of the Rappahannock River, 30 March – 3 May, 1985-2013.

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, spring 2012-2013.



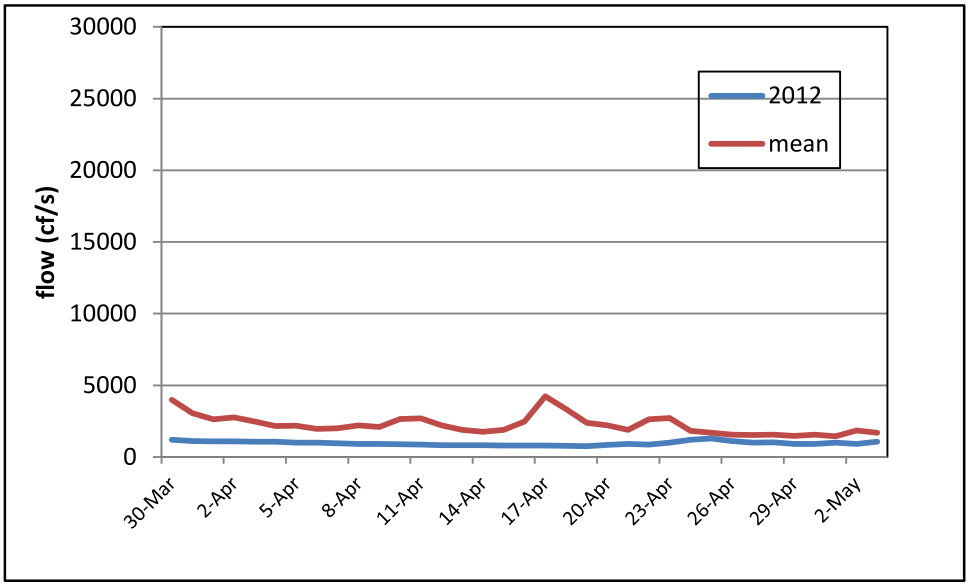
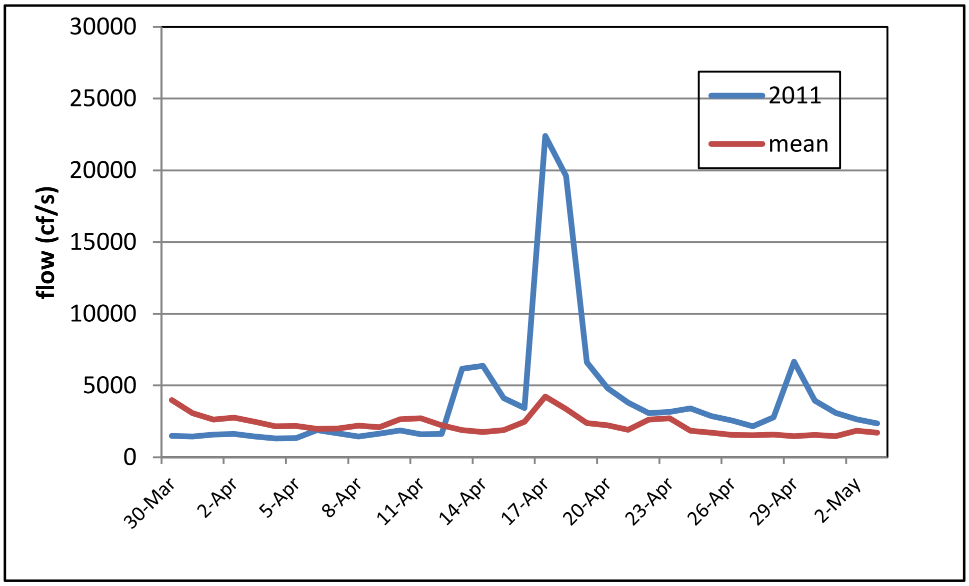


Figure 2. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2010-2011.



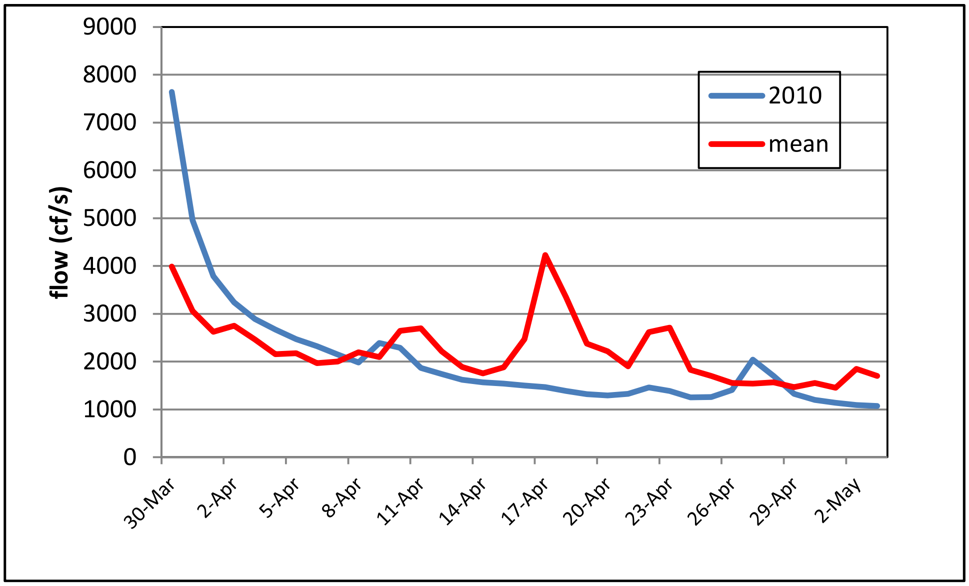
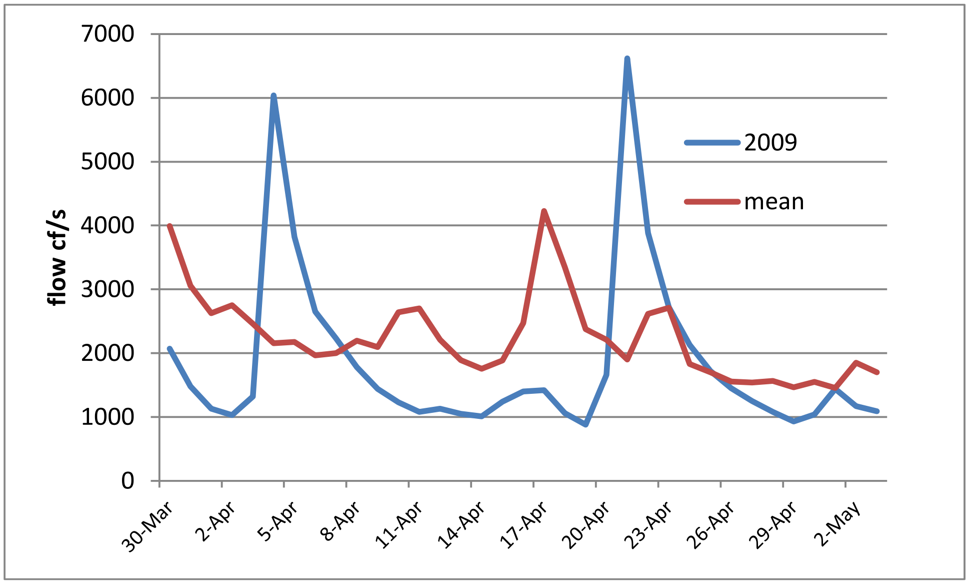


Figure 3. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2008-2009.



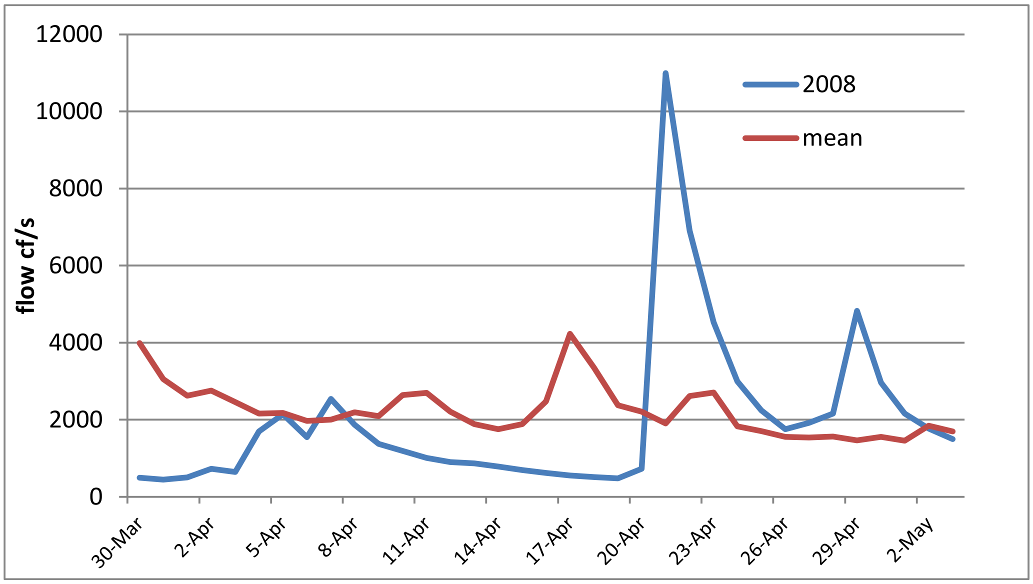
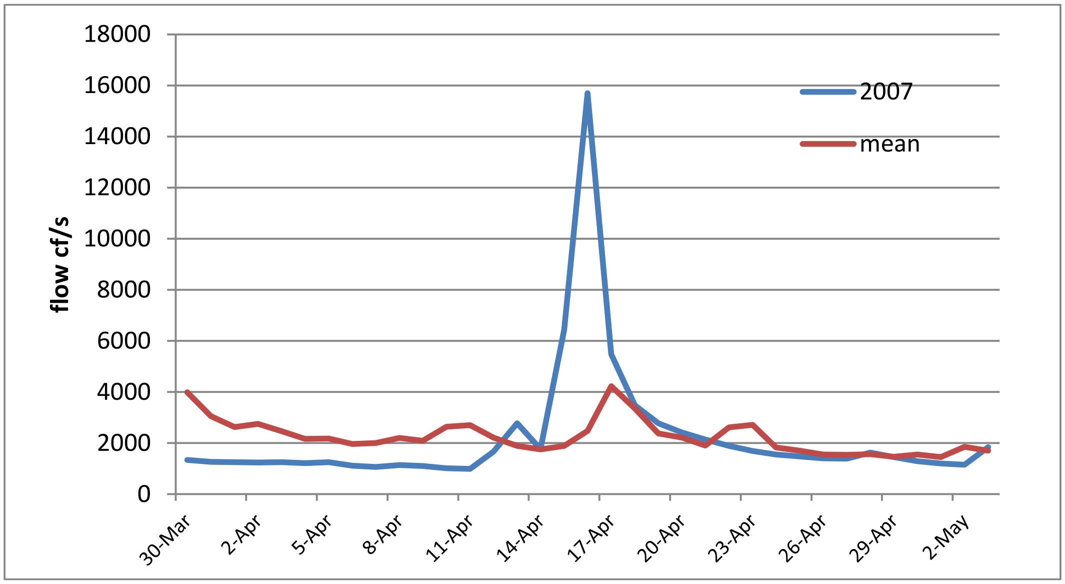


Figure 4. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2006-2007.



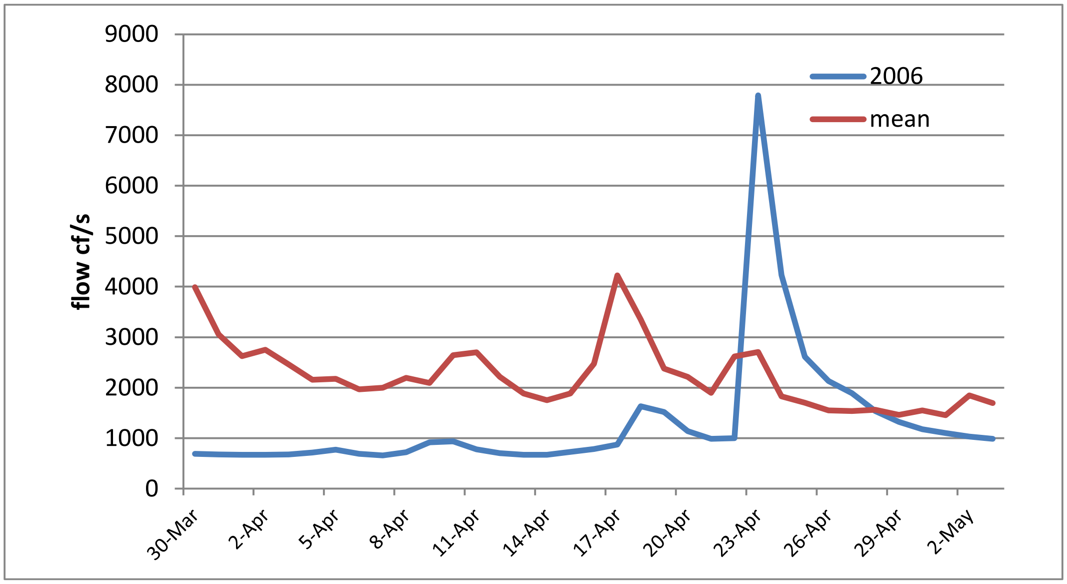
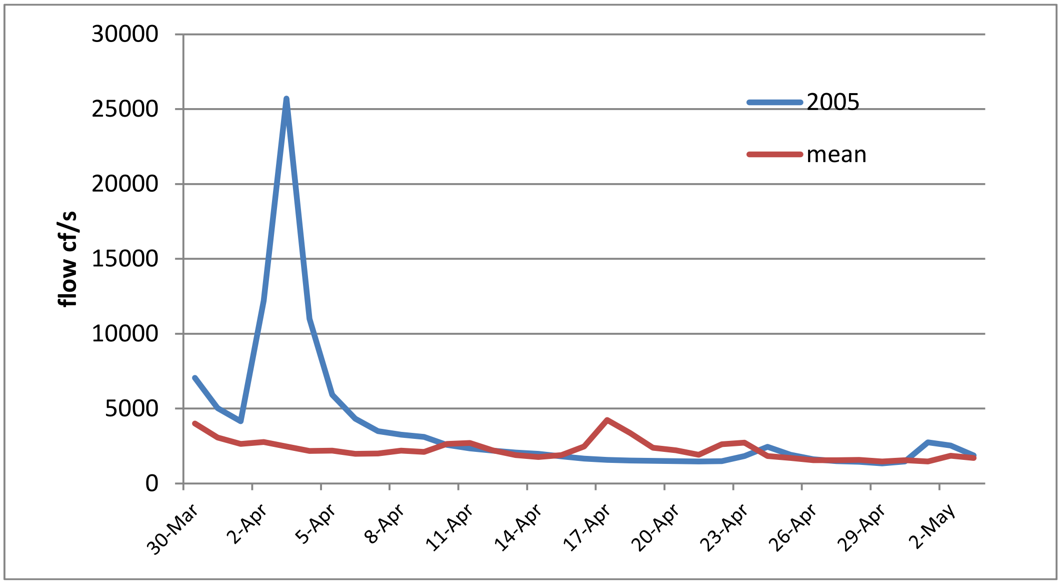


Figure 5. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2004-2005.



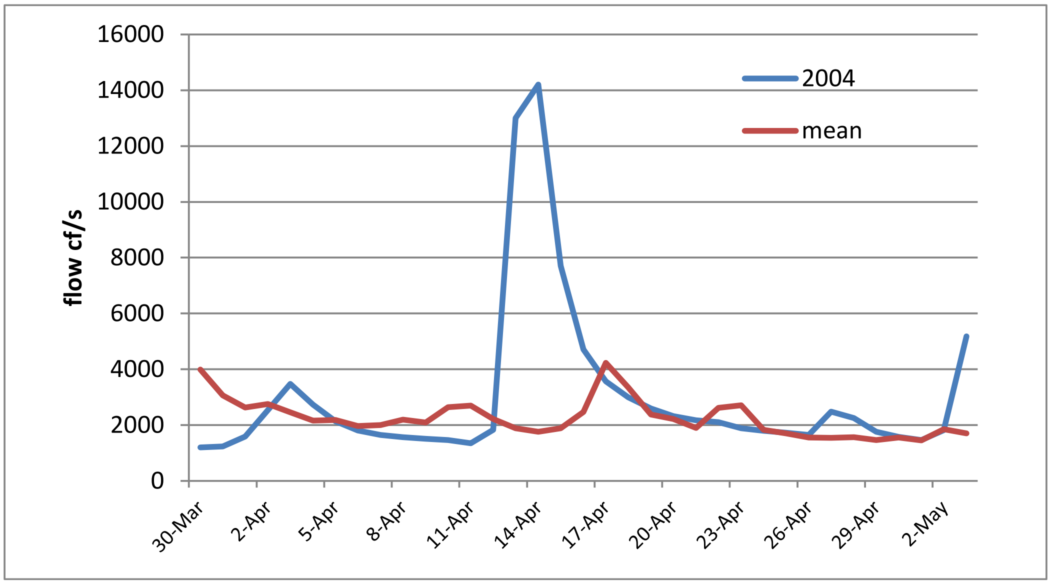
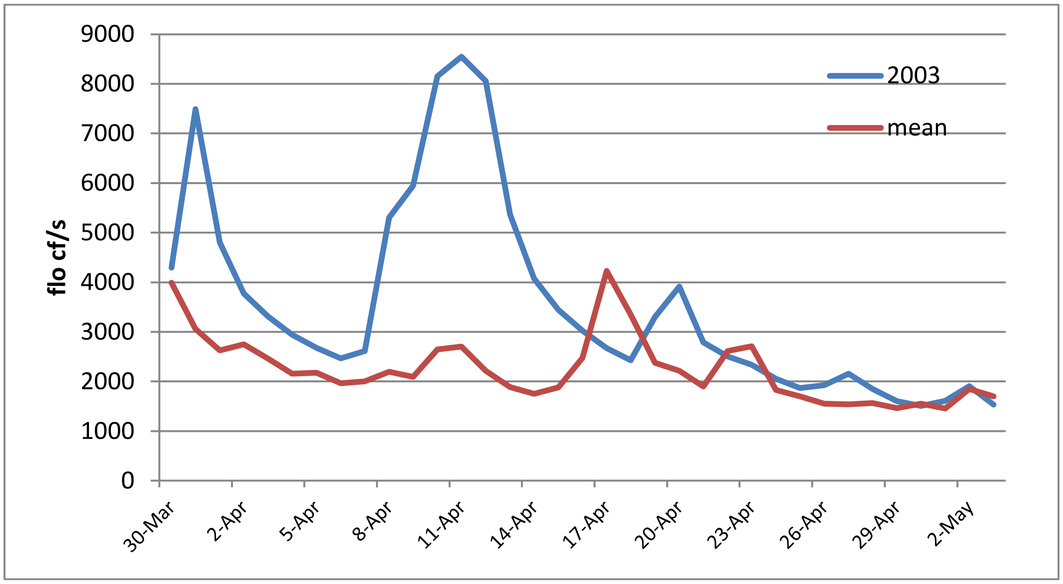


Figure 6. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2002-2003.



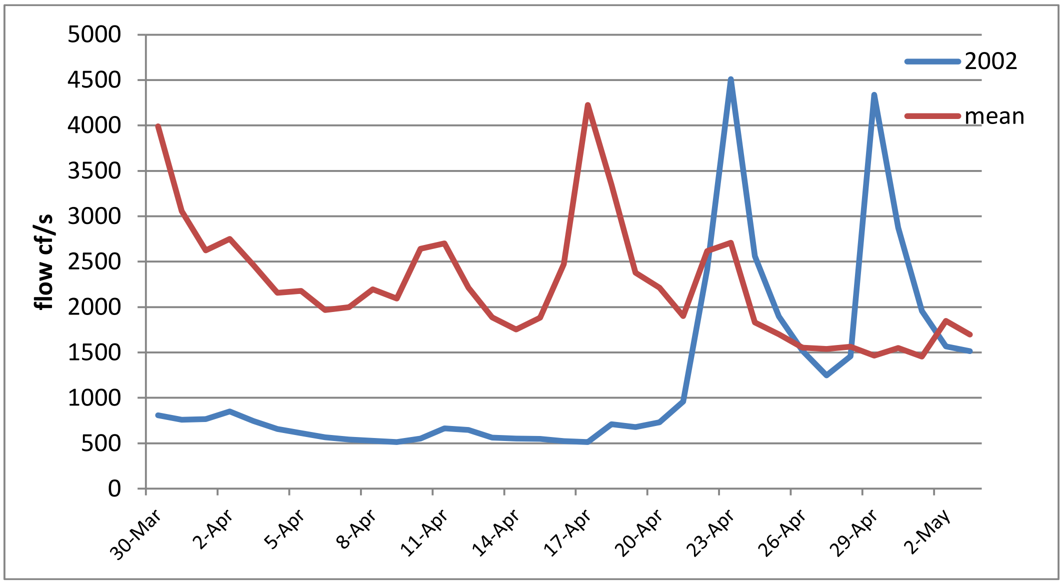
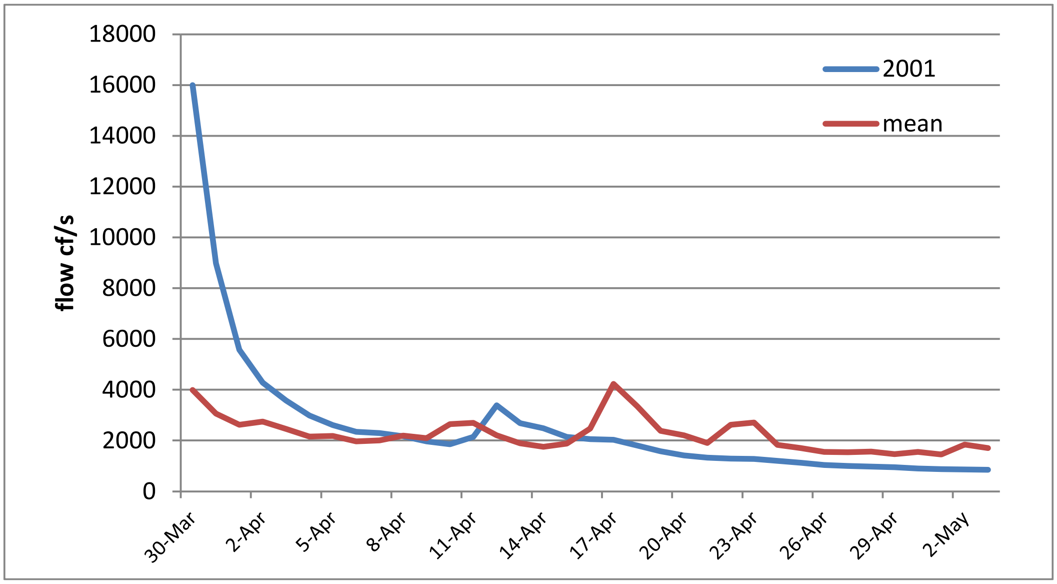


Figure 7. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2000-2001.



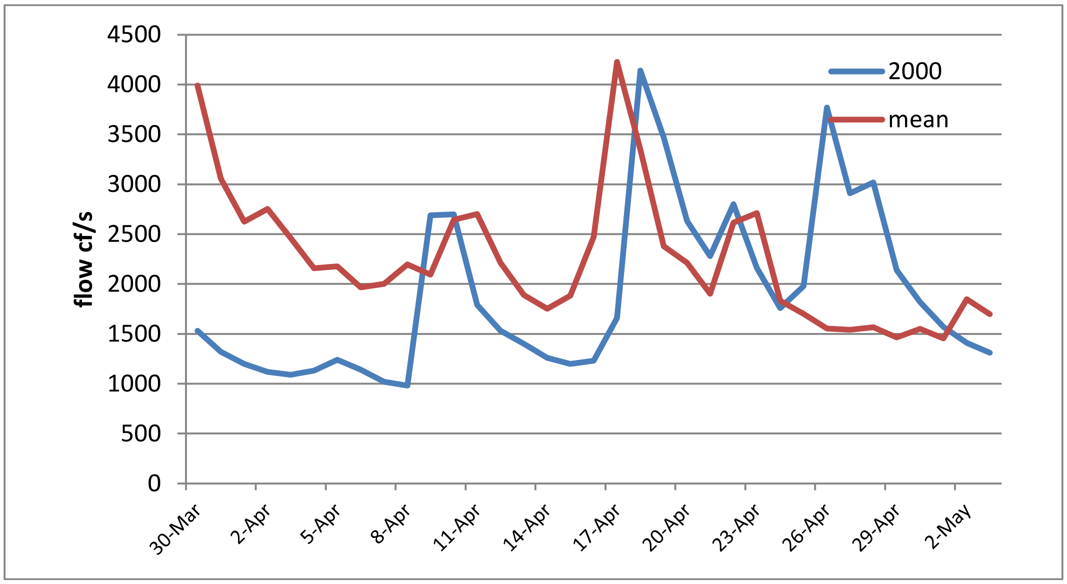
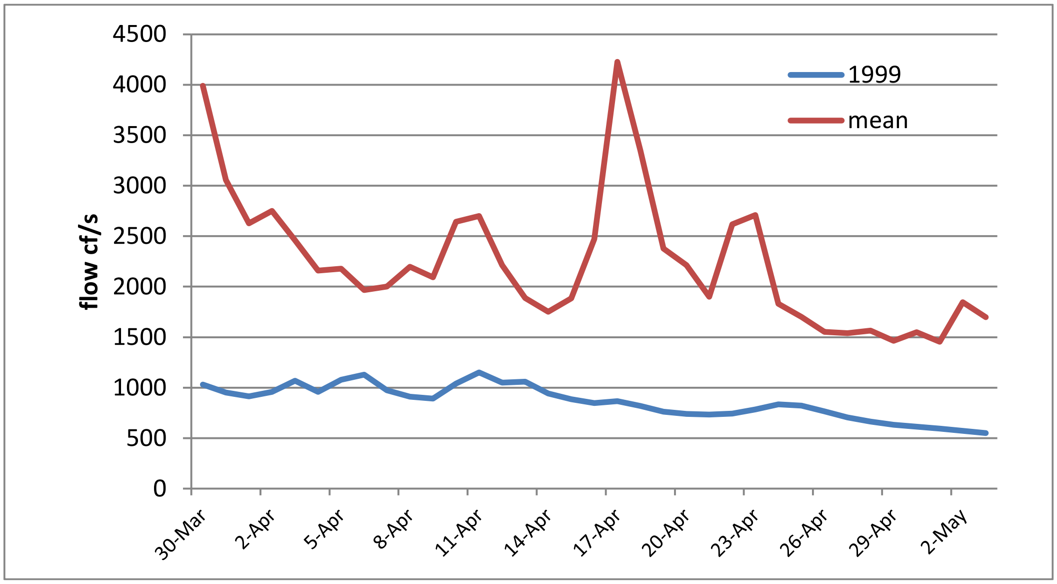


Figure 8. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1998-1999.



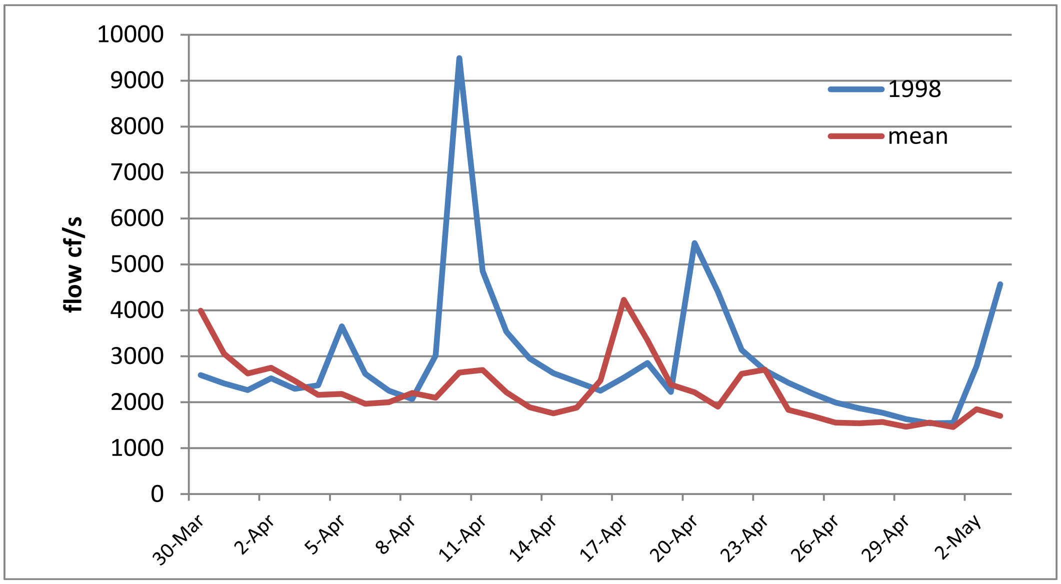
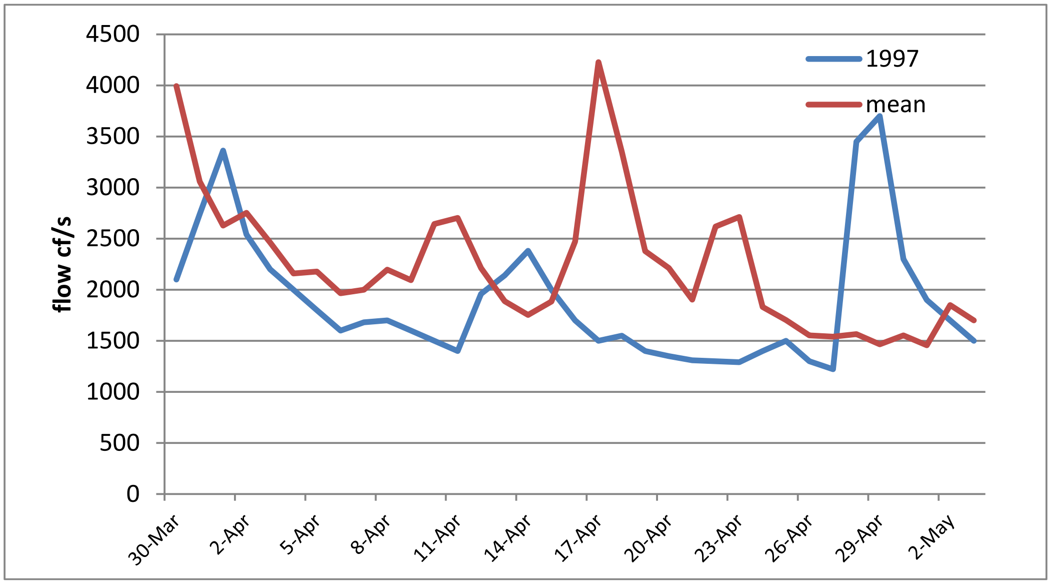


Figure 9. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1996-1997.



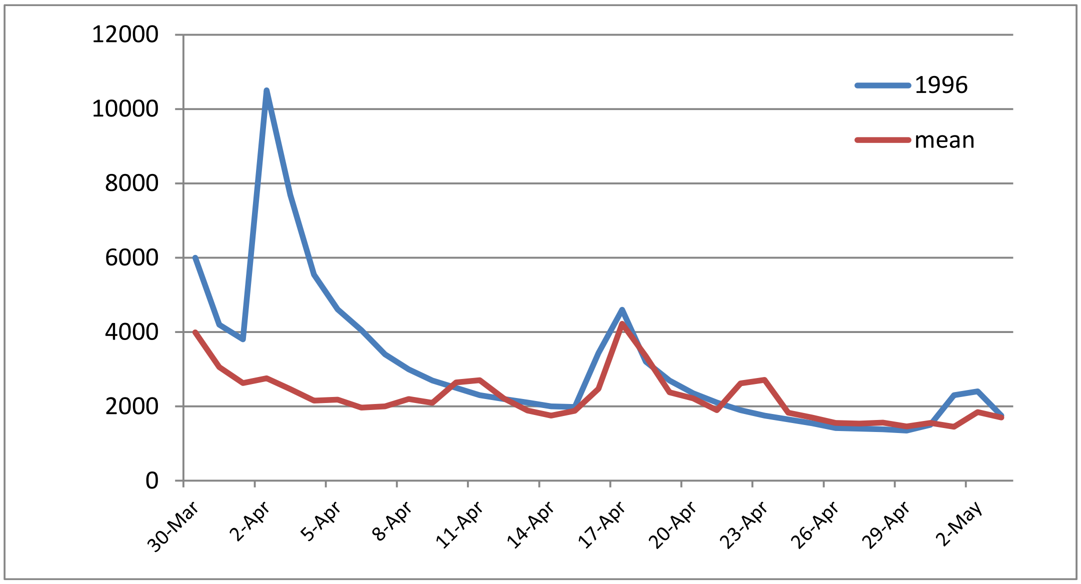
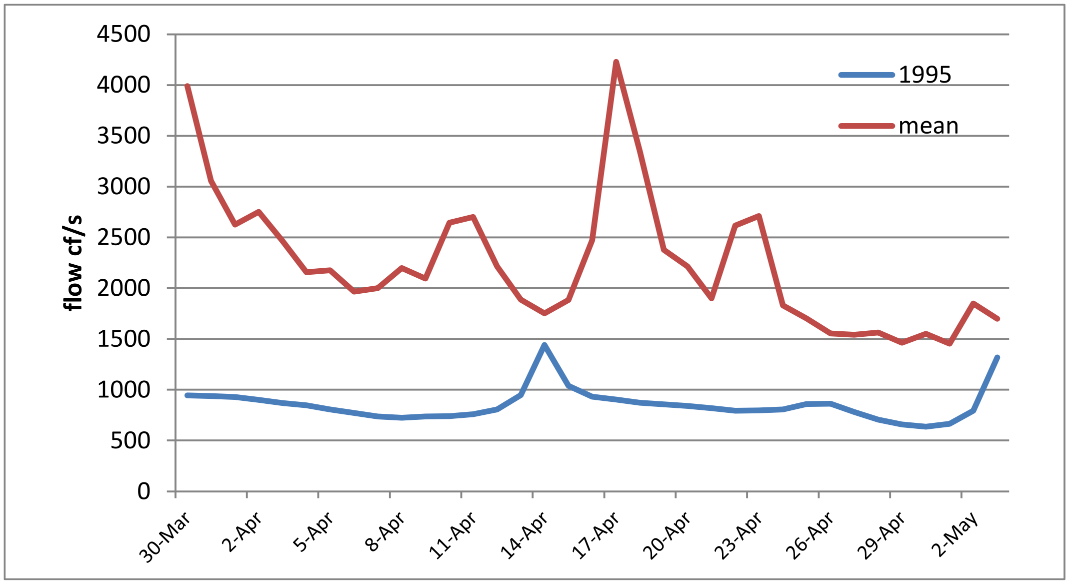


Figure 10. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1994-1995.



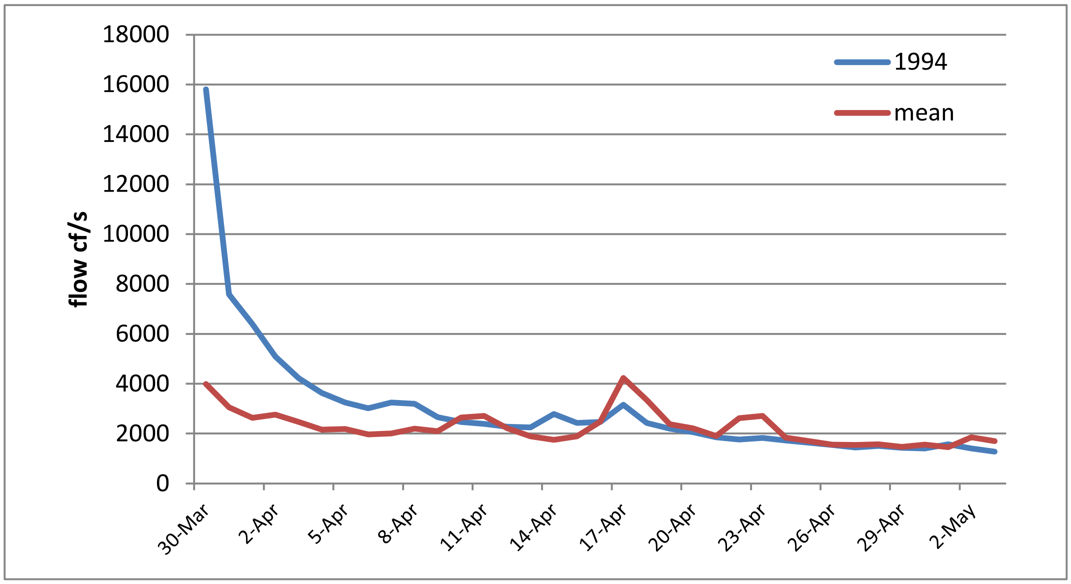
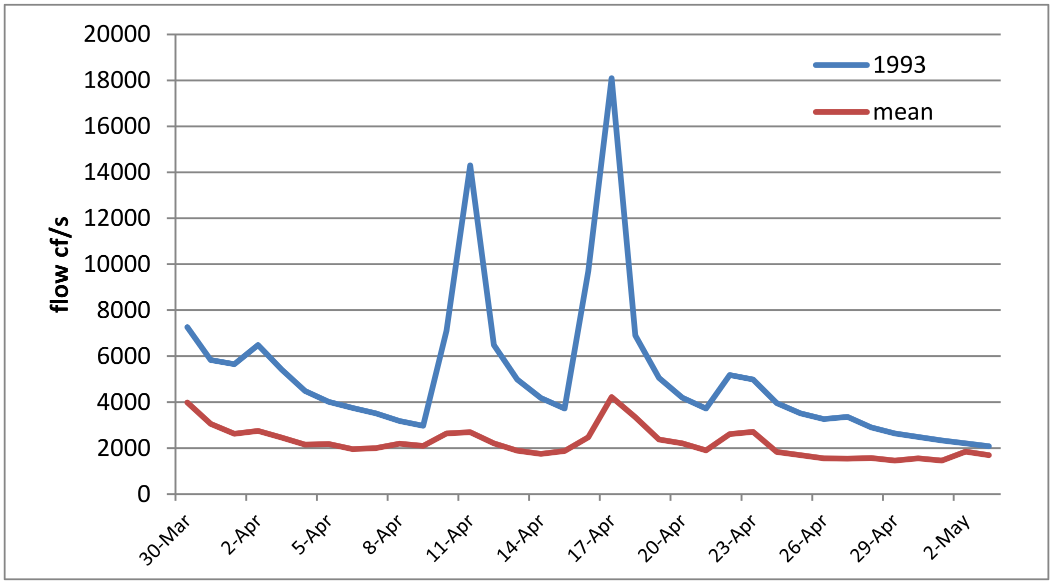


Figure 11. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1992-1993.



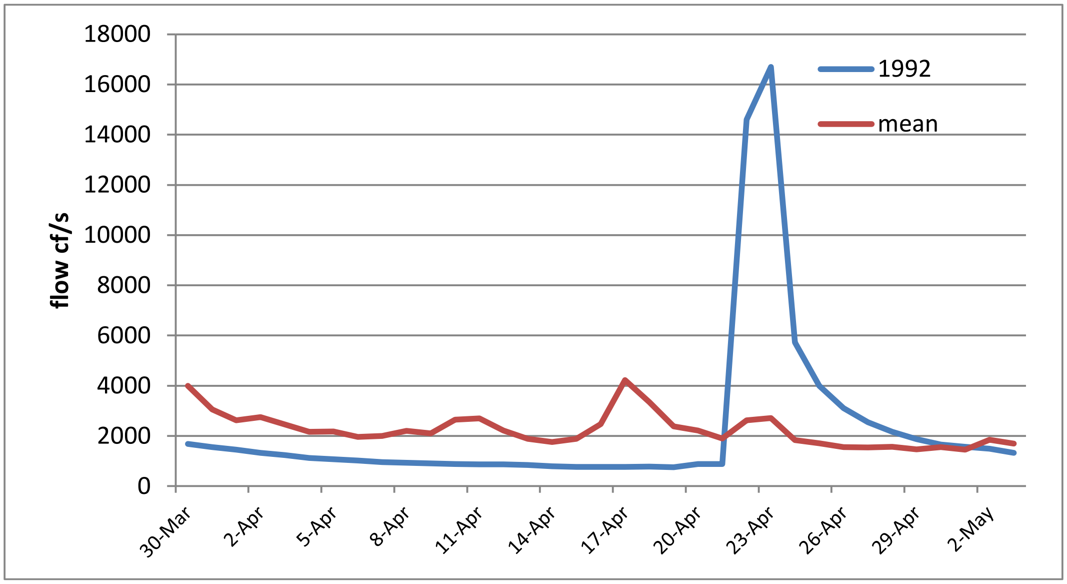
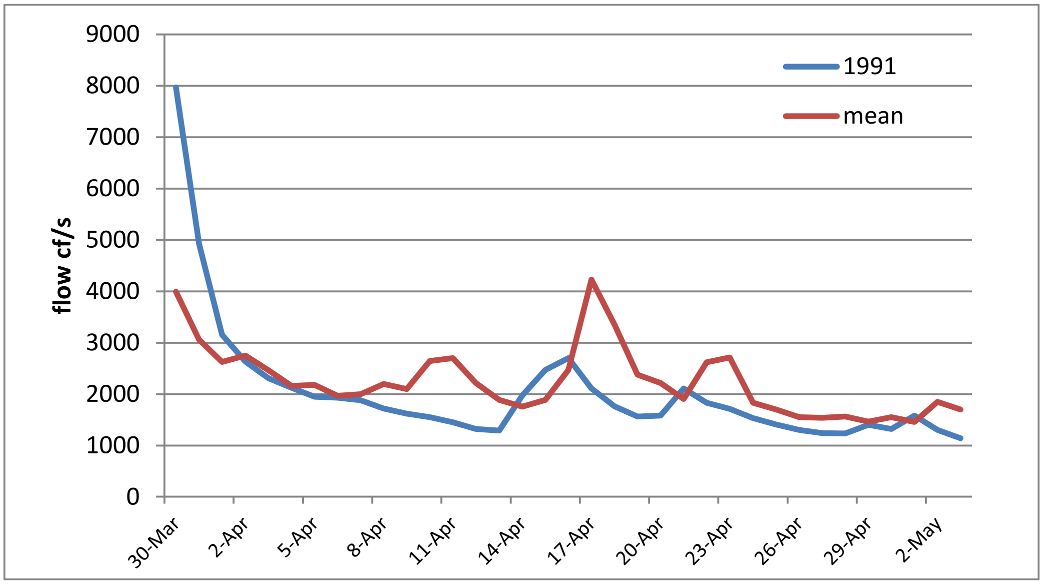


Figure 12. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1990-1991.



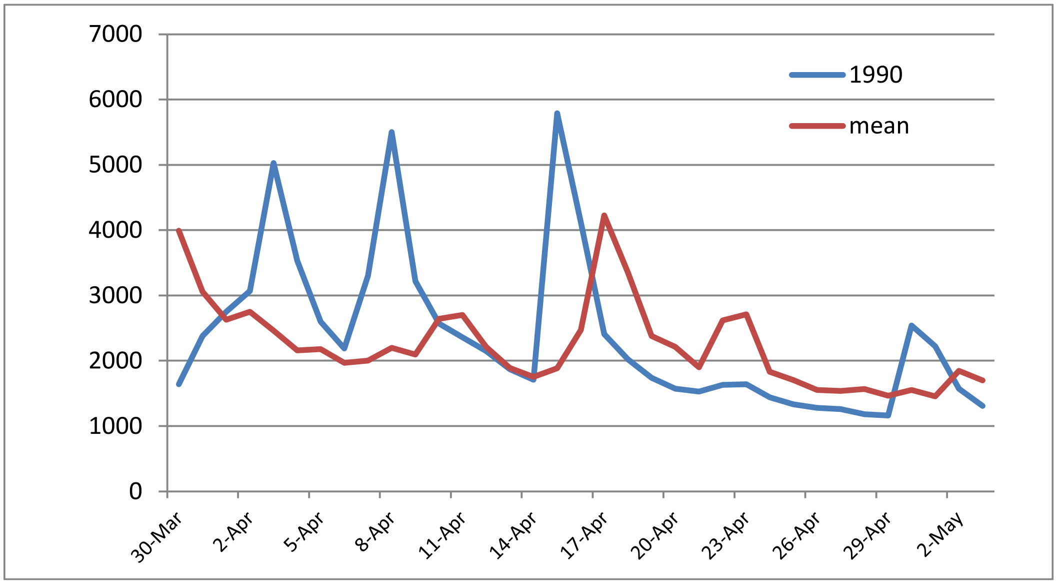
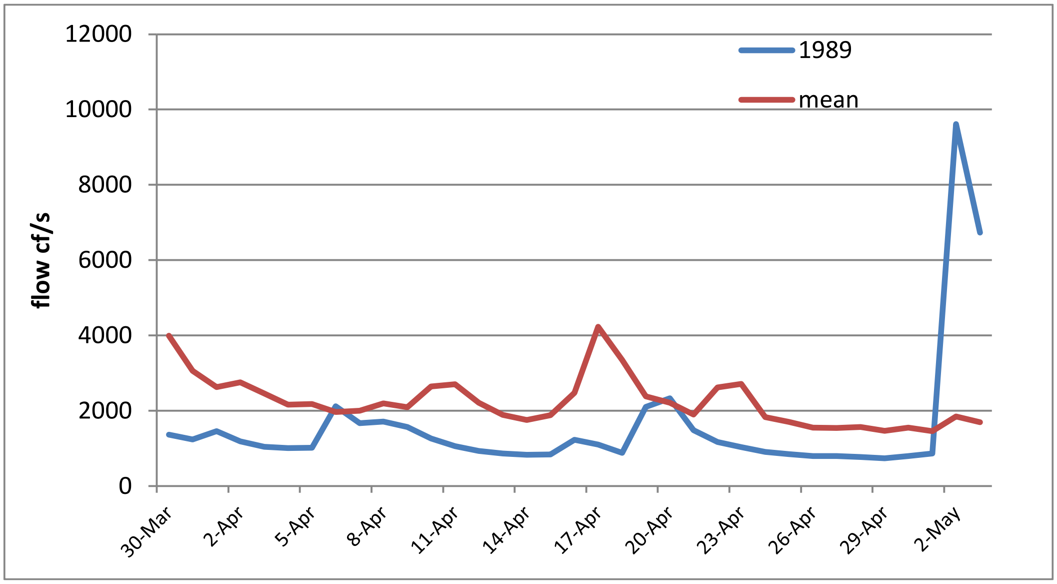


Figure 13. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1988-1989.



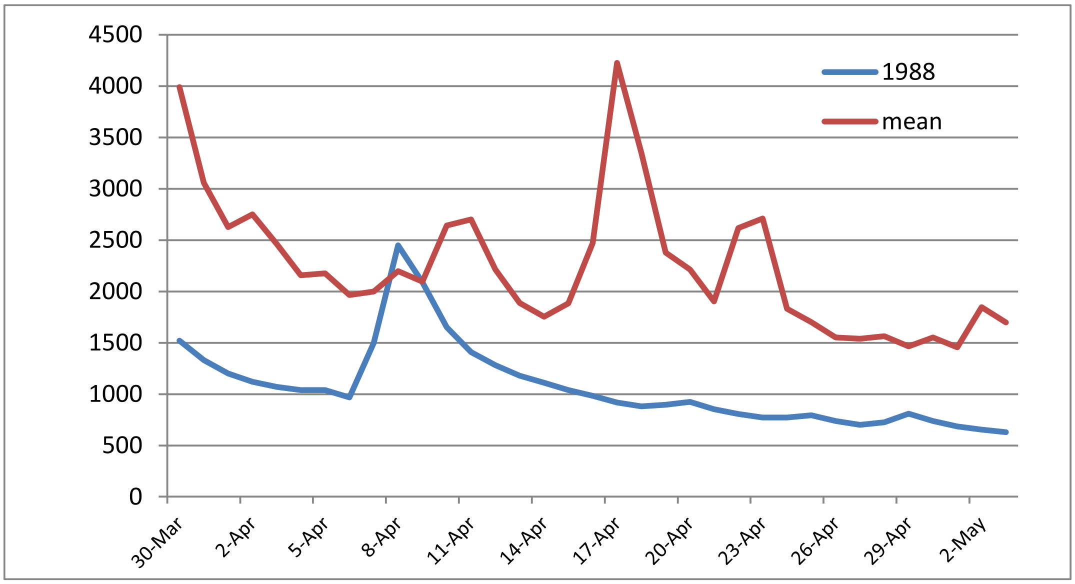
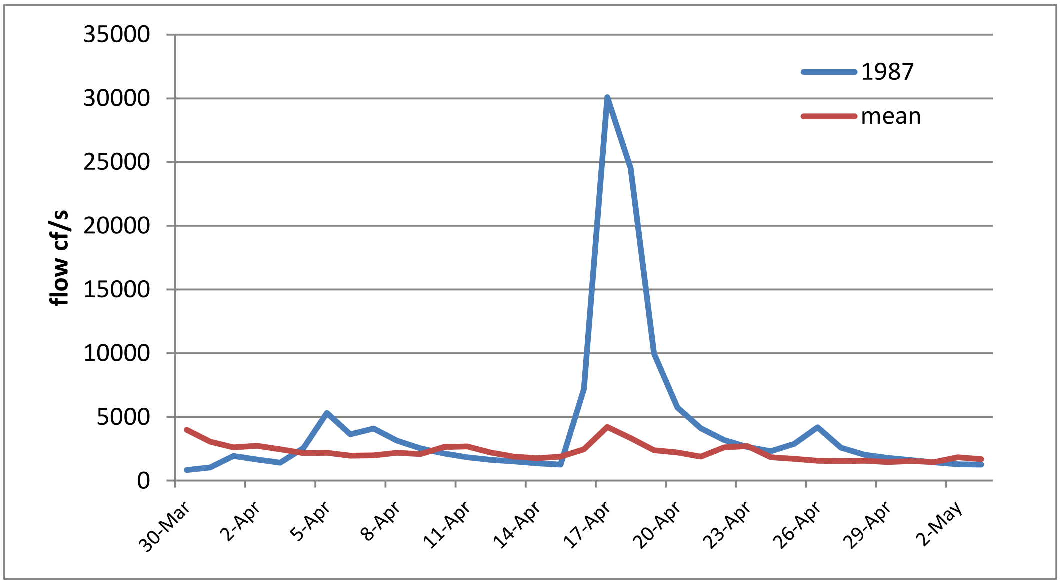


Figure 14. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1986-1987.



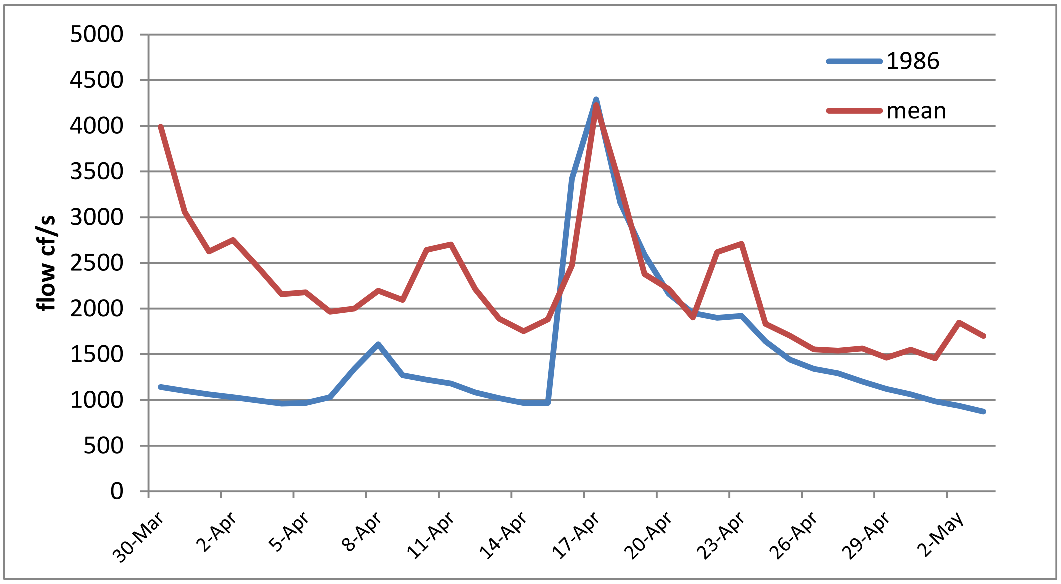


Figure 15. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, spring 1985.