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Evaluation of Striped Bass Stocks in Virginia: Monitoring and Tagging Studies, 2015-2019 : Progress Report 1 September 2015 - 31 August 2016

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Progress Report

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Preface

This report presents the results of striped bass (*Morone saxatilis*) tagging and monitoring activities in Virginia during the period 1 September 2015 through 31 August 2016. It includes an assessment of the biological characteristics of striped bass taken from the 2016 spring spawning run and estimates of annual survival and fishing mortality based on annual spring tagging. Also included is an investigation on the potential use of close-kin analyses to determine the size of the spawning stock in the Rappahannock River. 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 the late Stanley Oliff, Albert Oliff, Wayne Fisher, Clark Trader, Wayne France, Glenn Wyatt and Louis Wyatt; Maryland Department of Natural Resources (Md DNR) Beth Versak and Alexi Sharov.

Executive Summary

New this year: We continued our expansion of the tagging program by relocating and increasing the length of the gill nets in the James River and introducing drift gill nets as a supplemental source of taggable striped bass in the James and Mattaponi rivers. Parallel MARK and instantaneous rate analyses of Rappahannock river releases and combined James, York and Rappahannock rivers releases are presented. We also introduce a study on the use of close-kin analysis for spawning stock size determination.

I. Assessment of the spawning stocks of striped bass in the Rappahannock and James rivers, Virginia, spring 2016.

Catch Summaries:

1. In 2016, 362 striped bass were sampled between 4 April and 28 April from the commercial pound nets in the Rappahannock River. The samples were predominantly male (84.3%) but had few fish in the 5-8 year range (32.9%). Females dominated the age nine and older age classes (97.6%). The mean age of the male striped bass was 4.2 years. The mean age of the female striped bass was 10.8 years.

2. During the 4 April – 28 April period, the 2011 and 2012 year classes were the most abundant in the Rappahannock River pound net samples and were 95.5% male. The contribution of age six and older males was only 3.6% of the total aged catch. Age seven and older females, presumably repeat spawners, were 11% of the total catch but represented 76.9% of all females caught.

3. The Spawning Stock Biomass Index (SSBI) from the Rappahannock River pound nets was 13.6 kg/day for male striped bass and 20.0 kg/day for female striped bass. The male index was the sixth lowest in the 1991-2016 time series. The 2016 female index was 1.9% lower than the 2015 index and 41.5% below the 26-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 2016 Egg Production Potential Index (EPPI, millions of eggs/day) for the Rappahannock River pound nets was 3.09 million eggs/day. This was the lowest EPPI of the 2001-2016 time series. Female stripers in the 2001-2005 year class were responsible for 73.7% of the index.

5. The cumulative catch rate (all age classes, sexes combined) from the Rappahannock River pound nets (12.93 fish/day) was 30.4% below the 26-year time series. The cumulative catch rate of male striped bass (10.65 fish/day) was the ninth lowest in the time series. The cumulative catch rate of female striped bass (2.04 fish/day) was the second lowest in the time series and 2.4% lower than the rate in 2015.

6. Year class-specific estimates of annual survival (S) for pound net data varied widely between years. The geometric mean S of the 1985-2008 year classes varied from 0.211-0.749 (mean = 0.611). The geometric mean survival rates differed between sexes. Mean survival rates for male stripers (1985-2009 year classes) varied from 0.222-0.657 (mean = 0.448) while mean survival rates of female stripers (1985-2006 year classes) varied from 0.462-0.912 (mean = 0.624).

7. Plots of year class-specific catch rates vs. year in the Rappahannock River from 1991-2016 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 1996 and 1997 year classes were the strongest, and the 1990 and 1991 year classes the weakest in the Rappahannock River from 1987.

9. The scales of 695 striped bass were digitally measured and the increments between annuli were used to determine their growth history. On average, striped bass grow about 134 mm fork length in their first year. The growth rate decreases with age to about 45 mm per year by age 10. 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.

10. A total of 2,901 fish 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, but diverged steadily thereafter.

11. 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 ($p<.005$).

12. 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 ($p<.001$).

13. 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 2015-2016.

1. A total of 1,093 striped bass were tagged and released from pound nets in the Rappahannock River between 4 April and 26 May, 2016. Of this total, 701 were between 457-710 mm total length and considered to be predominantly resident striped bass and 99 were considered to be predominantly migrant striped bass (>710 mm TL).

2. A total of 246 striped bass were tagged and released from gill nets in the James River between 22 March and 29 April, 2016. Of this total, 156 were resident striped bass and 24 were migrant striped bass.

3. A total of 205 striped bass were tagged and released from gill nets in the York River between 24 March and 27 April, 2016. Of this total, 131 were resident striped bass and 41 were migrant striped bass.

4. The median date of resident tag releases for all rivers combined was 21 April, while the median date of migrant tag releases for all rivers combined was 18 April.

5. A total of 36 striped bass (>457 mm TL), tagged during springs 1990-2015, were recaptured between 1 January and 31 December, 2015, and were used to estimate mortality. Most recaptures (72.2%) were caught within Chesapeake Bay (41.6% in Virginia, 30.6% in Maryland). Other recaptures came from %), Rhode Island (11.1%), Massachusetts and New York (5.6% each), New Jersey and Maine (2.7% each).

6. A total of 15 migratory striped bass (>710 mm total length), tagged during springs 1990-2015, were recaptured between 1 January and 31 December, 2015, and were used to estimate the mortality. Most recaptures (40.0% each) came from Chesapeake Bay (26.7% in Maryland and 13.3% in Virginia,). Other recaptures came from Rhode Island (20.0%), Massachusetts and New York (13.3% each), Maine and New Jersey (6.7% each).

7. 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. Three of these models were applied to the recapture matrix, each reflecting a different parameterization over time. The resultant estimates of survival for Rappahannock River releases were 0.36 (> 457 mm TL) and 0.56 (>711 mm TL). The estimates of survival for the Rappahannock, York and James rivers were similar with the estimates of 0.39 (>457 mm TL) and 0.50 (>710 mm TL).

8. The MARK survival estimates were used to estimate exploitation rate, fishing mortality and natural mortality using Baranov's catch equation. For the Rappahannock River releases, the estimates of exploitation were 0.17 (>457 mm TL) and 0.03 (>711 mm TL). The estimates of fishing mortality were 0.28 (>457 mm TL) and 0.04 (>711 mm TL). For the James, York and Rappahannock river releases, the estimates of exploitation were 0.13 (>457 mm TL) and 0.05 (>710 mm TL). The estimates of fishing mortality were 0.20 (>457 mm TL) and 0.07 (>710 mm TL). The estimates of fishing mortality assume natural mortality constant at 0.15.

9. 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 periods of natural mortality was found to fit the data better than if constant natural mortality was used (1990-1997 and 1998-2015 for striped bass greater than 18 inches TL; 1990-2003 and 2004-2015 for striped bass greater than 28 inches TL). In the Rappahannock River releases, the estimates of survival were 0.51 (>457 mm TL)

and 0.60 (>711 mm TL). The estimates of fishing mortality were 0.06 (>457 mm TL) with an estimated natural mortality of 0.623 and 0.05 (>711 mm TL, N = 0.458). In the James, York and Rappahannock river releases, the estimates of survival were 0.51 (>457 mm TL) and 0.60 (>710 mm TL). The estimates of fishing mortality were 0.05 (>457 mm TL, N = 0.621) and 0.05 (>710 mm TL, N = 0.460).

III. The feasibility of close kinship analysis as a new methodology for estimation of spawning population size of striped bass in the Rappahannock River.

1. A new methodology utilizing close kinship analysis will be evaluated as a compliment to the classic methodologies of abundance estimates. In theory, close kinship works off of the simple idea that each sampled juvenile (or young of year) must have two parents. If a population of spawners is large, then it would be expected that there would be a low number of offspring (juvenile) matches with spawners (parents), or a lower number parent offspring pairs (POPs)-the number of spawners is inversely related to the number of POPs made.

2. Utilizing sampling programs currently in place at the Virginia Institute of Marine Science, it has been possible to collect spawning adults (n=757) and young of year (n=591) from the Rappahannock River (study system of choice). Data collection is currently underway in order to test if this new analysis could provide an alternative and/or companion estimate of abundance for striped bass within major river systems

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I. Assessment of the spawning stocks of striped bass in the Rappahannock River, Virginia, spring 2016.

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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 4 April – 28 April, 2016. This year, persistent winds in March prevented setting of the pound nets at the start of the season. Therefore, samples from these pound nets were delayed until 4 April, 2016. 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 total length, then tagged and released. Finally, on the final designated sampling date of 2 May, exceptional tides overflowed the nets compromising the catch.

All dead stripers 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.

In 2016, the catches from multiple-meshed anchor gill nets (3”, 3 ¾”, 4 ½”, 5 ¼”, 6”, 6 ½”, 7”, 8”, 9” and 10”) were used to initiate abundance indexes for the York/Mattaponi and James rivers. Two nets of five mesh sizes each were set on each river (5x120’ on the James and 5x60’ on the York) and fished for 45 min – 2 hrs. depending on water temp and time taken to complete the effort. Viable striped bass encountered were tagged and released and moribund and dead striped bass were returned to VIMS for necropsy.

Striped bass collected from the monitoring sites were measured and weighed on a Scantrol FishMeter 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 monitoring specimens 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.

The spawning stock biomass index (SSBI) for striped bass was defined (Sadler et al. 1999) as the 30 March – 3 May mean CPUE (kg/net day) of mature males (age 3 years and older), females (age 4 years and older) and the combined sample (males and females of the specified ages). An alternative index, based on the fecundity potential of the female striped bass sampled, was investigated and the results compared with the index based on mean female biomass.

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

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

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

Results

Catch Summary.

Striped bass (n= 362) were sampled between 4 April – 28 April, 2016 from the pound nets in the Rappahannock River. The number of striped bass sampled was more than twice the amount of the sample in 2015 (n= 152) and 32.1% lower than the 26-year average (n=533.3). Total catches varied from 13-89 striped bass, with the peak catch on 21 April (Table 1). Surface water temperatures were above normal at the start of the season (14.6℃) , but rose slowly through the season, peaking at 19.4℃ on 25 April. River flows were below average at the start of the season and remained below average throughout the sampling season (Figure 2). Salinities increased from 0.1-0.7 p.p.t. throughout the sampling season. Catches of female striped bass peaked on 4 and 18 April and were dominated by the pre-2007 year classes. Males made up 84.3% of the total catch, which was below the 26-year average (74.7%). The 2008-2011 year classes (five to eight years old) comprised 32.9% of the total catch. This was higher than the 2015 samples where the 2007-2010 year classes comprised 20.3% of the total catch. Males dominated the 2012-2014 year classes (99.5%) and the 2008-2011 year classes (87.4%), while females dominated the 1998-2007 year classes (97.6%).

Biomass catch rate (g/day) of males peaked on 21 April and female striped bass peaked on 4 April with a secondary peak on 18 April (Table 2). The numeric catch rate of males exceeded that of females on all sampling dates. Unlike 2008, but consistent with most previous years, the biomass catch rates for female striped bass exceeded that for males overall (1.46:1), peaking on 4 April (5.09:1). The mean ages of male striped bass varied from 3.6 – 5.1 years by sampling date, with the oldest mean age occurring on 4 April. The mean ages of females varied from 7.0 – 12.1 years by sampling date, peaking on 4 April.

There was a broad peak in abundance of striped bass (mostly male) between 420-510 mm total lengths in the pound net samples (Table 3). This size range accounted for 44.2% of the total sampled. There was a second peak in abundance of predominantly female striped bass between 960-1000 mm total lengths. Consistent with previous years, the striped bass from 640-710 mm total length accounted for only 1.9% of the total sample. The total contribution of striped bass greater than 710 mm total length (the minimum total length for the coastal fishery) was 12.4% (vs. 28.3% in 2015).

During the 4 April – 28 April period, the 2012 (32.8%) and 2011 (25.4%) year classes were the most abundant (Table 4). These year classes were 95.5% male. The contribution of males age six and older (the pre-2011 year classes) was 3.6% of the total aged catch. These year classes were most vulnerable to commercial and recreational exploitation within Chesapeake Bay. The contribution of females age seven and older, presumably repeat spawners, was 11% of the total aged catch, but was also 76.9% of the total females captured. The catch rate (fish/day) of male striped bass was 10.9, which is 27.5% below the 26-year average (Table 5). The catch rate of female striped bass (2.0 fish/day) was 57.4% below the 26-year average and the lowest since 2002. The biomass catch rates (kg/day) of males were below the average of the 26-year time series but almost double the rate in 2015. The rates of females were also well below the 26-year average. The mean age of the male striped bass was near the average in the 26-year time series. The mean age of the female striped bass was lower than 2015 and the third highest value in the time series.

Spawning Stock Biomass Indexes.

The Spawning Stock Biomass Index (SSBI) for spring 2016 was 13.6 kg/day for male striped bass and 20.0 kg/day for female striped bass. The index for male striped bass was 86.3% above the value for 2015. It was the sixth lowest in the 26-year time series and 45.2% below the overall average (Table 6). The magnitude of the index for male striped bass was largely determined by the 2011-2013 (88.7%) year classes. The index for female striped bass was 1.9%

lower than the 2015 index. It was the eight lowest in the time series, and 41.5% below the 26-year average (Table 6). The magnitude of the index for the females was largely determined by the 2000-2005 year classes (78.4%).

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 2016 Egg Production Potential Indexes (EPPI, Table 8) for the Rappahannock River was 3.09. The indexes for the Rappahannock River were heavily dependent on the egg production potential of the 2001-2005 year class females (73.7%). Previous values for the EPPI for 2001-2016 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, 5.35, 8.70 and 3.18 (Sadler et al 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014 and 2015). Thus, the EPPI values for the pound nets in the Rappahannock River, which had rebounded in 2012-2014, declined in 2015 and 2016. Modest changes in the methodology (utilizing fully mature ovaries solely rather than ovaries in various states of maturation) in the 2001-2015 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 1991-2016 samples are presented in Tables 9-11. The cumulative annual catch rate of all year classes for 2016 was 82.8% greater than the cumulative catch rate for 2015 but 30.4% below the 26-year average of 18.59 (Tables 9a,b). The decrease was the result of lower catch rates in the 2006-2010 year classes (six – 10 year old striped bass). The catch rate of males was dominated by two - four year olds (2011-2013 year classes, Tables 10a,b). These three age classes contributed 94.3% of the total male catch. Using the maximum catch rate of the resident males as an indicator, the 1995-1997 year classes were strongest and the 1990 and 1991 year classes were the weakest. No pre-2005 year class males were captured. The cumulative catch rate of female stripers was 2.4% lower than the catch rate in 2015 and was 43.8% lower than the 26-year average of 4.66 (Tables 11a,b). The 2001-2005 year classes accounted for 59.3% of the total female catch.

The range of overall ages was unchanged from 1991-2016, 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 2014-2016). 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, increased strongly to .914 2014 but fell back to .847 in 2015 and .775 in 2016.

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 (1991-2016) of the 1985-2008 year classes (sexes combined) varied from 0.211-0.749 (Tables 12a,b) with an overall mean survival rate of 0.611. 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 (1991-2016) of the 1985-2009 year classes of males varied from 0.222-0.657 (Tables 13a,b) with an overall mean survival rate of 0.448. These year classes have been the major target of the fall recreational and commercial fisheries that reopened in 1993. The geometric mean survival rate (1991-2016) of the 1985-2006 year classes of females varied from 0.462-0.912 (Tables 14a,b) with an overall mean survival rate of 0.624.

Catch Rate Histories of the 1987-2006 Year Classes

The catch rate histories of the 1987-2006 year classes are depicted in Figures 3-12. 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 1990-2012 (Table 15a, b). The relative ranking of the year classes was found not to change after age ten and these partial CCAs were compared to indicate year class strengths for as many year 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 2016.

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 2016.

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. No 1989 year class striped bass were captured in 2016.

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 2016.

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 2016.

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, and but well below the mean in the Rappahannock River. No 1992 year class striped bass were captured in 2016.

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 near the median among the year classes and slightly above the mean from the pound net samples in the Rappahannock River. No 1993 year class striped bass were captured in 2016.

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 2016.

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 the sixth highest among the year classes and 31.1% 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 2016.

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. No 1996 year class striped bass were captured in 2016.

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. No 1997 year class striped bass were captured in 2016.

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 the seventh lowest among the year classes and 13.3% below average in the Rappahannock River pound nets. Three female 1998 year class striped bass were captured in 2016.

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 the fifth lowest among the year classes and 20.9% below the average in the Rappahannock River. No female 1999 year class striped bass were captured in 2016.

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. Two female 2000 year class striped bass were captured in 2016.

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 median and the average among all year classes. Four female 2001 year class striped bass were captured in 2016.

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. One female 2002 year class striped bass were captured in 2016.

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. Eleven female 2003 year class striped bass were captured in 2016.

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. Five female 2004 year class striped bass were captured in 2016.

2005 Year class: Peak abundance of male striped bass occurred at age five in the pound nets in the Rappahannock River (Figure 12). Peak abundance of female striped bass also occurred at age five. The CCA was well above average and the fifth highest overall in the Rappahannock River. Fourteen (13 females and one male) 2005 year class striped bass were captured in 2016.

2006 Year class: Peak abundance of male striped bass occurred at age four in the pound nets in the Rappahannock River (Figure 12). Peak abundance of female striped bass occurred at age 10. The CCA was well below average and the third lowest overall in the Rappahannock River. Two female 2006 year class striped bass were captured in 2016.

Growth Rate of Striped Bass Derived from Annuli Measurements

The scales of 695 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 134 mm at age one (Table 16a). The rate of growth was about 100 mm in their second year and decreased gradually with age to about 70 mm in their fifth year and to about 45 mm in their 10^{th} 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

2016 data

Again in 2016, we explored methodologies to establish combined tagging and monitoring programs for the James and York rivers. As a result, only 74 specimens were returned to VIMS for otolith extraction. This number was insufficient for a 2016-specific analytical comparison and the results were appended to the 2003-2015 data for analysis.

2003-2016 data

A total of 2,901 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 17), but diverged steadily thereafter (Figure 13).

Tests of symmetry: The scale and otolith ages from the same specimen were in agreement 43.2% (1254/2901) of the time and within one year 82.9% (2405/2901) of the time. A chi-square test was performed to test the hypothesis that an m x m contingency table (Table 18) 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 = 47). 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 = 296.52, $p<.005$), indicating non-random differences between the two ageing methodologies.

Differences between the scale and otolith age from the same specimen ranged from zero to eight years (Figure 14). The otolith-derived age exceeded the scale age 33.9% 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 (79.2%). 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 ($X^2 = 177.8$, 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=2901) determined by reading the otoliths was greater than the mean age determined by reading the scales (by 0.26 years, Table 19). The test results were:

$$\overline{Age}_{otolith} = 8.71 \qquad \overline{Age}_{scale} = 8.45$$

$$S_{otolith} = 3.71 \qquad S_{scale} = 3.38$$

df = 5801
$p < .001$

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= 5800, $p < .001$) 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 19). This compares the maximum difference in the relative proportions that an age class contributes to the test statistic ($K_{.05}$):

$$D_{max} = 0.0252 \qquad K_{.05} = 1.3581$$

$$D_{.05} = K_{.05}\sqrt{\frac{(2901)+(2901)}{(2901)^2}} = 0.0357$$

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- 2015, persistent, bad weather delayed efforts by our fishermen to establish their first net (usually done in mid-March) until as late as 17 April in 2015 and precluded setting the third net at mile 45. In 2016, the first set was established by 4 April but again the third net was never set. Hence we now tag and release all striped bass greater than 290 mm and used a sex and size-based regression to estimate biomass for our pound net index.

In past years, duration of the pound net set was as low as 24 hrs, and as large as 196 hrs, if the fisherman was unable to fish the scheduled net on the scheduled sampling date. Although these events were uncommon, we were unable to assess whether varying effort influenced estimates of catch rate. The 1997 and 1998 data include a pound net at mile 46 that had an orientation and catch characteristics similar to the net at mile 47. This net was also sampled on one date (7 April) in 2003. In 2005 this net was substituted entirely for the net at mile 47 due to extensive damage to the net at mile 47 in a maritime accident. The 1991 data included samples taken from a pound net at river mile 25 and were weekly vs. twice-weekly samples, but with similar total effort. While this net is far enough within the Rappahannock to preclude significant contamination from stocks from other rivers, it does not meet the criteria established in 1993, restricting sampling to gears located within the designated spawning grounds (above river mile 37). The catches from these other nets were similar in sex and age composition to the nets presently used and their exclusion would adversely affect our ability to assess the status of the spawning stocks in those years.

The biological characterization of the spawning stock of striped bass in the Rappahannock River changed dramatically from 1991-2016. 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, but again declined in 2015 and 2016. 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 earlier start to the sampling in 2016 the total catch and biomass was greater than in 2015, but below the values for 2003-2014.

For the first time since 1998, there were no 1996 year class striped bass captured in 2016. This year class had been above-average in abundance since recruiting to the gears at age three, which indicates that it is a very strong year class. The 2003-2005 year classes appear to now be the dominant year classes of the migrant stock.

The 2016 value of the Spawning Stock Biomass Index (SSBI) for the Rappahannock River pound nets was greater than the SSBI for 2015, due entirely to an increased capture of male striped bass, but was still almost one half the overall mean. The SSBI for male striped bass captured in the pound nets was almost double the index for 2015 but still 45% below the mean of the 1991-2016 time series. However, the SSBI for female striped bass was equivalent to the 2015 value and 42% below the mean of the time series. The male component of the SSBI was dominated by three to five year-old striped bass while the female component was dominated by 10+ year old striped bass. While the combined index was greater than in 2015, the female biomass index was the lowest since 2008.

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 2016, the contribution of 8+ year old females was 78.9% of the total number (there were very few four to eight year old females caught in 2016), 93.9% of the biomass, and 93.8% 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 to 12 (especially females). Also, prior to 1995, the peak catch rates of male and female striped bass (ages four and five) were similar. The catches of these age classes are now almost exclusively male. Thus, the 1991-1996 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 2004-2016, the second group expanded to 750-1200 mm as the strong 1996-1998 year classes and now the 2003-2005 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, 2003 and 2005, and weak year classes occurred in 1990,1991 and 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 1985-2006 year classes in the Rappahannock River was 0.624. The survival estimate of 1985-2009 year class male striped bass was 0.448. 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 1987-2005 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. 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 140 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 2013 year class in fall 2016) and the 28 in. (711 mm) minimum total length for the coastal fishery at age eight.

Since 2003 we have aged 2,901 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. Overall agreement between the two ageing methodologies was 43.2% and varied annually from 33.7% to 55.7%. 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. In addition, 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 2012-2014, 2008-2011 and 1998-2007) from pound nets in the Rappahannock River, by sampling date, spring, 2016. M = males, F = females.

		Year Class							
		No age		2012-2014		2008-2011		1998-2007	
Date	**n**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
4 April	36	0	0	7	0	12	2	1	14
7 April	18	1	0	9	0	5	1	0	2
11 April	13	0	0	8	1	2	0	0	2
14 April	25	0	0	11	0	7	1	0	6
18 April	60	0	0	29	0	15	6	0	10
21 April	89	3	0	56	0	26	3	0	1
25 April	83	0	0	56	0	19	2	0	6
28 April	38	0	0	20	0	18	0	0	0
Total	**362**	**4**	**0**	**196**	**1**	**104**	**15**	**1**	**41**

Table 2. Net-specific summary of catch rates and mean ages of striped bass (n=362) in pound nets on the Rappahannock River, spring, 2016. Values in bold are the grand means for each column. M = male, F=female.

			CPUE (fish/day)		CPUE (g/day)		Mean age	
Date	**Net ID**	**n**	**M**	**F**	**M**	**F**	**M**	**F**
4 April	S462	36	5.0	4.0	9,409.3	47,937.0	5.1	12.1
7 April	S473	18	5.0	1.0	6,275.6	7,986.0	4.1	9.3
11 April	S473	11	2.5	0.8	2,078.7	6,500.8	3.6	10.0
14 April	S473	25	6.0	2.3	7,445.9	25,360.4	4.2	11.9
18 April	S462	60	11.0	4.0	14,892.0	35,707.7	4.3	10.2
21 April	S462	89	28.3	1.3	34,891.3	7,186.4	4.1	7.0
25 April	S473	83	18.8	2.0	19,946.4	19,531.4	3.8	11.4
28 April	S462	38	12.7	0.0	17,419.1	0.0	4.3	
Totals	S462	223	13.4	2.6	18,152.6	25,438.4	4.3	10.7
	S473	139	8.4	1.5	9,233.2	14,583.4	3.9	11.0
Season		362	**10.9**	**2.0**	**13,692.9**	**20,010.9**	**4.2**	**10.8**

Table 3. Length frequencies (TL in mm) of striped bass sampled from the pound nets in the Rappahannock River, spring, 2016.

TL	n	TL	n	TL	n	TL	n	TL	n	TL	n
<290	5	**440-**	13	**600-**	6	**760-**	1	**920-**	0	**1080-**	0
290-	3	**450-**	13	**610-**	5	**770-**	0	**930-**	1	**1090-**	0
300-	2	**460-**	18	**620-**	2	**780-**	1	**940-**	1	**1100-**	0
310-	1	**470-**	13	**630-**	3	**790-**	1	**950-**	1	**1110-**	2
320-	3	**480-**	19	**640-**	1	**800-**	0	**960-**	3	**1120-**	0
330-	2	**490-**	14	**650-**	0	**810-**	0	**970-**	7	**1130-**	1
340-	5	**500-**	20	**660-**	5	**820-**	0	**980-**	1	**1140-**	1
350-	7	**510-**	26	**670-**	0	**830-**	0	**990-**	4	**1150-**	0
360-	8	**520-**	8	**680-**	0	**840-**	0	**1000-**	8	**1160-**	0
370-	4	**530-**	13	**690-**	1	**850-**	0	**1010-**	1	**1170-**	0
380-	6	**540-**	6	**700-**	0	**860-**	0	**1020-**	1	**1180-**	0
390-	2	**550-**	13	**710-**	0	**870-**	0	**1030-**	3	**1190-**	0
400-	4	**560-**	14	**720-**	2	**880-**	0	**1040-**	1	**1200-**	0
410-	7	**570-**	8	**730-**	0	**890-**	0	**1050-**	0	**1210-**	0
420-	13	**580-**	9	**740-**	0	**900-**	0	**1060-**	2	**1220-**	0
430-	11	**590-**	4	**750-**	0	**910-**	0	**1070-**	2	**1230-**	0

Table 4. Mean fork length (mm), weight (g), standard deviation (SD) and CPUE (fish per day; weight per day) of striped bass from pound nets in the Rappahannock River, spring 2016.

Year			Fork Length		Weight		CPUE	
Class	Sex	n	Mean	SD	Mean	SD	F/day	W/day
2014	male	7	246.7	33.7	198.2	68.1	0.3	49.5
2013	male	70	357.1	38.1	602.8	186.6	2.5	1,506.9
2012	male	119	444.5	25.0	1,146.0	192.7	4.3	4,870.4
	female	1	477.0		1,652.7		0.0	59.0
2011	male	92	511.3	29.6	1,732.4	340.6	3.3	5,692.2
	female	9	549.2	24.5	2,495.1	321.4	0.3	802.0
2010	male	8	579.6	23.7	2,555.5	323.6	0.3	730.1
	female	2	610.5	9.2	3,372.0	146.6	0.1	240.9
2009	male	2	587.5	17.7	2,654.2	248.3	0.1	189.6
	female	2	651.0	43.8	4,432.7	296.8	0.1	316.6
2008	male	2	664.5	16.3	3,858.7		0.0	256.3
	female	2	728.0	18.4	5,611.2	409.3	0.1	400.8
2007		0					0.0	0.0
2006	female	2	885.5	6.4	9,874.8	205.1	0.1	705.3
2005	male	1	752.0		5,616.4		0.0	200.6
	female	13	921.0	21.4	11,077.0	755.5	0.5	5,142.9
2004	female	5	945.6	20.2	11,949.5	749.1	0.2	2,133.8
2003	female	11	960.5	25.4	13,603.7	978.8	0.4	4.914.4
2002	female	1	935.0		11,554.9		0.0	412.7
2001	female	4	1,003.8	38.5	14,227.2	1,558.8	0.1	2,032.5
2000	female	2	1,016.0	35.4	14,715.1	1,477.6	0.1	1,051.1
1999		0					0.0	0.0
1998	female	3	1,064.0	9.6	16,789.9	437.8	0.1	1,798.9
Not	male	4	455.5	41.3	1,245.5	317.5	0.1	177.9
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 1991-2016. M = male, F = female.

Year	n	CPUE (fish/day)		CPUE (g/day)		Mean age	
		M	F	M	F	M	F
2016	362	10.9	2.0	13,673.5	20,010.9	4.2	10.8
2015	152	5.0	2.1	7,339.5	20,578.2	4.4	11.5
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	**533.3**	**13.9**	**4.7**	**24,969.5**	**34,720.3**	**4.5**	**9.0**

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 – 2016.

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
2016	298.0	57.0	13.6	20.0	33.6					
2015	107.0	45.0	7.3	20.6	27.9					
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	**398.9**	**124.0**	**24.8**	**34.2**	**59.0**	**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 2016. The Egg Production Potential Index (millions of eggs/day) is in bold.

Age	n	E	%
4	1	0.008	0.26
5	9	0.109	3.52
6	2	0.034	1.10
7	2	0.041	1.33
8	2	0.058	1.88
9	0	0.000	0.00
10	2	0.108	3.49
11	13	0.795	25.72
12	5	0.332	10.74
13	11	0.767	24.81
14	1	0.064	2.07
15	4	0.321	10.39
16	2	0.166	5.37
17	0	0.000	0.00
18	3	0.288	9.32
19	0	0.000	0.00
20	0	0.000	0.00
n/age	0	0.000	0.00
Total	57	**3.091**	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, 1992-2016. Maximum catch rate for each year class is in bold type.

Year Class	CPUE (fish/day)												
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
2001													3.47
2000												0.76	**5.57**
1999										0.07	0.51	3.00	**5.90**
1998									0.03	2.74	1.44	3.33	**3.50**
1997								0.79	**15.61**	7.49	1.38	0.37	2.23
1996							0.19	11.54	**18.13**	4.29	0.25	1.83	4.16
1995						0.60	2.15	**11.50**	3.34	0.10	0.68	1.40	2.33
1994				0.04	0.51	3.90	**6.33**	2.79	0.11	0.58	0.41	1.70	1.67
1993				3.04	3.97	**8.10**	1.48	0.11	0.50	0.87	0.28	1.43	1.00
1992		0.12	1.44	**4.80**	2.86	1.25	0.04	0.50	0.50	0.87	0.19	1.13	1.10
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	0.17
1990	0.50	1.04	1.33	**2.24**	1.26	0.70	0.70	0.32	0.29	0.45	0.00	0.27	0.07
1989	0.60	3.58	**4.59**	0.68	0.89	0.80	0.78	0.36	0.37	0.26	0.00	0.07	0.07
1988	1.60	**9.54**	2.22	0.60	0.37	1.50	0.89	0.39	0.05	0.10	0.00	0.00	0.00
1987	2.75	**3.65**	1.15	0.68	0.37	1.00	0.89	0.43	0.05	0.00	0.03	0.03	0.00
1986	**1.15**	0.65	0.59	0.40	0.09	1.00	0.22	0.04	0.00	0.00	0.00	0.00	0.00
1985	0.30	0.42	**0.52**	0.08	0.00	0.35	0.15	0.11	0.00	0.00	0.00	0.00	0.00
1984	0.40	**0.58**	0.33	0.28	0.00	0.35	0.07	0.04	0.00	0.00	0.00	0.00	0.00
1983	0.20	**0.46**	0.33	0.08	0.03	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
>1983	0.45	**0.73**	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.30	0.38	0.56	0.60	0.32	0.50	0.44	0.54	0.32	0.00	0.00	0.00	0.40
Total	**8.45**	**21.72**	**13.87**	**14.52**	**12.30**	**20.30**	**14.85**	**29.89**	**39.70**	**18.63**	**5.23**	**15.65**	**31.64**

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, 1992-2016. Maximum catch rate for each year class is in bold type.

Year Class	CPUE (fish/day)											
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
2013												**2.50**
2012											0.60	**4.29**
2011										3.35	3.12	**3.61**
2010									1.65	**2.65**	1.12	0.36
2009							0.08	1.40	**1.74**	0.41	0.09	0.14
2008						0.23	0.46	**3.20**	1.91	0.00	0.14	0.14
2007					0.07	2.63	1.08	**3.80**	0.83	0.06	0.09	0.00
2006				0.17	1.89	**6.50**	1.38	2.12	0.30	0.47	0.00	0.07
2005			0.03	4.40	5.07	**10.43**	0.96	1.04	0.26	0.65	0.51	0.50
2004			2.52	**7.20**	6.93	4.23	0.79	0.92	0.30	1.35	0.33	0.18
2003		7.89	**8.55**	3.26	2.15	1.53	0.88	1.28	1.13	1.53	0.42	0.39
2002	1.83	**6.40**	6.17	0.51	1.22	1.03	0.96	0.84	0.39	0.53	0.09	0.04
2001	**5.43**	3.17	1.14	0.60	1.22	1.27	1.04	0.96	0.87	0.88	0.23	0.14
2000	2.77	0.14	1.12	0.57	1.19	1.77	0.63	0.44	0.48	0.65	0.09	0.07
1999	0.71	0.51	1.51	0.29	1.19	1.10	0.25	0.28	0.13	0.00	0.05	0.00
1998	0.77	0.91	1.89	0.43	0.67	0.70	0.04	0.32	0.13	0.24	0.05	0.11
1997	1.69	0.86	2.68	0.43	0.37	0.53	0.17	0.20	0.04	0.06	0.05	0.00
1996	1.69	1.17	3.80	0.46	0.70	1.13	0.08	0.20	0.22	0.18	0.09	0.00
1995	0.94	0.23	0.71	0.00	0.00	0.13	0.04	0.00	0.00	0.00	0.00	0.00
1994	0.69	0.20	0.71	0.00	0.19	0.07	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.57	0.20	0.46	0.00	0.00	0.07	0.08	0.00	0.09	0.00	0.00	0.00
1992	0.29	0.11	0.20	0.00	0.03	0.07	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.49	0.26	0.00	0.00	0.07	1.47	0.04	0.44	0.17	0.00	0.00	0.14
Total	**18.05**	**22.05**	**31.52**	**18.35**	**22.96**	**34.89**	**8.88**	**17.44**	**10.64**	**13.00**	**7.07**	**12.93**

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 1992-2016. Maximum catch rate for each year class is in bold type.

Year Class	CPUE (fish/day)												
	1992	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
2001													**3.47**
2000												0.76	**5.47**
1999										0.07	0.44	2.93	**5.67**
1998									0.03	2.74	1.38	3.07	**3.37**
1997								0.79	**15.61**	7.42	1.25	0.30	1.93
1996							0.19	11.54	**18.11**	4.03	0.16	1.50	2.23
1995						0.55	2.15	**11.46**	3.21	0.10	0.03	0.56	0.53
1994				0.04	0.51	3.80	**6.19**	2.68	0.08	0.39	0.03	0.23	0.20
1993				2.88	3.83	**7.50**	1.37	0.07	0.26	0.16	0.00	0.07	0.10
1992		0.12	1.22	**4.68**	2.66	1.15	0.00	0.36	0.11	0.19	0.00	0.00	0.07
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	0.00
1990	0.35	0.96	1.30	**2.00**	0.94	0.35	0.11	0.00	0.03	0.00	0.00	0.00	0.00
1989	0.40	3.46	**3.52**	0.08	0.43	0.55	0.04	0.04	0.03	0.00	0.00	0.00	0.00
1988	0.90	**7.54**	1.11	0.12	0.03	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.65	1.23	0.22	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1986	0.30	0.15	0.11	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1985	0.05	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1984	**0.15**	0.08	0.00	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	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.10	0.27	0.41	0.44	0.23	0.25	0.33	0.54	0.32	0.00	0.00	0.00	0.40
Total	**3.05**	**14.39**	**8.45**	**11.20**	**10.06**	**14.40**	**10.68**	**27.69**	**37.84**	**15.23**	**3.54**	**9.42**	**23.44**

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, 1992-2016. Maximum catch rate for each year class is in bold type.

Year Class	CPUE (fish/day)											
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
2013												**2.50**
2012											0.60	**4.25**
2011										3.29	3.11	**3.29**
2010									1.65	**2.47**	0.88	0.29
2009								**1.40**	1.39	0.29	0.09	0.07
2008						0.13	0.46	**3.20**	1.43	0.00	0.05	0.07
2007					0.07	2.53	1.04	**3.36**	0.70	0.06	0.09	0.00
2006				0.11	1.78	**6.30**	1.00	1.60	0.17	0.06	0.00	0.00
2005			0.03	4.34	4.48	**9.63**	0.67	0.96	0.09	0.06	0.05	0.04
2004			2.49	**7.03**	5.48	4.03	0.67	0.68	0.13	0.35	0.05	0.00
2003		7.77	**8.46**	3.00	1.70	1.37	0.63	0.56	0.39	0.47	0.05	0.00
2002	1.83	**6.29**	5.83	0.46	1.00	0.70	0.50	0.32	0.09	0.06	0.00	0.00
2001	**5.40**	2.91	0.97	0.49	0.81	0.67	0.25	0.08	0.22	0.12	0.00	0.00
2000	2.49	0.09	1.03	0.37	0.48	0.27	0.17	0.08	0.13	0.00	0.00	0.00
1999	0.66	0.20	1.00	0.14	0.19	0.23	0.00	0.08	0.00	0.00	0.00	0.00
1998	0.51	0.57	0.89	0.03	0.07	0.13	0.00	0.08	0.00	0.00	0.00	0.00
1997	1.00	0.29	0.37	0.06	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1996	0.43	0.03	0.29	0.03	0.70	0.10	0.00	0.00	0.00	0.06	0.00	0.00
1995	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994	0.09	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1992	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.46	0.29	0.00	0.00	0.07	1.40	0.04	0.44	0.17	0.00	0.00	0.14
Total	**12.96**	**18.50**	**21.36**	**16.09**	**16.87**	**27.50**	**5.43**	**12.80**	**6.56**	**7.29**	**4.97**	**10.65**

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, 1992-2016. Maximum catch rate for each year class is in bold type.

Year Class	CPUE (fish/day)												
	1992	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
2000													0.10
1999											0.06	0.07	0.23
1998											0.06	0.27	0.17
1997										0.07	0.13	0.07	0.30
1996									0.03	0.26	0.00	0.37	1.93
1995						0.05	0.00	0.04	0.13	0.00	0.63	0.80	**1.80**
1994						0.10	0.15	0.11	0.03	0.19	0.38	1.47	**1.47**
1993				0.16	0.14	0.60	0.11	0.04	0.24	0.71	0.25	**1.37**	0.90
1992			0.22	0.12	0.20	0.10	0.04	0.14	0.40	0.68	0.19	**1.13**	1.03
1991		0.04	0.00	0.08	0.29	0.00	0.22	0.21	0.34	**0.68**	0.06	0.33	0.17
1990	0.15	0.08	0.04	0.24	0.31	0.35	**0.59**	0.32	0.26	0.45	0.00	0.26	0.07
1989	0.20	0.12	**1.07**	0.60	0.46	0.25	0.74	0.32	0.34	0.26	0.00	0.07	0.07
1988	0.70	**2.00**	1.11	0.48	0.34	1.30	0.89	0.39	0.05	0.10	0.00	0.00	0.00
1987	2.10	**2.42**	0.93	0.68	0.29	1.00	0.89	0.43	0.05	0.00	0.03	0.03	0.00
1986	0.85	0.50	0.48	0.36	0.09	1.00	0.22	0.04	0.00	0.00	0.00	0.00	0.00
1985	0.25	0.39	0.48	0.08	0.00	0.35	0.15	0.11	0.00	0.00	0.00	0.00	0.00
1984	0.25	**0.50**	0.33	0.28	0.00	0.35	0.07	0.04	0.00	0.00	0.00	0.00	0.00
>1983	0.65	**1.19**	0.59	0.08	0.03	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.20	0.12	0.15	0.16	0.09	0.25	0.11	0.00	0.00	0.00	0.00	0.00	0.00
Total	**5.40**	**7.36**	**5.40**	**3.32**	**2.24**	**5.90**	**4.18**	**2.19**	**1.87**	**3.40**	**1.79**	**6.24**	**8.24**

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, 1992-2016. Maximum catch rate for each year class is in bold type.

Year Class	CPUE (fish/day)											
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
2011										0.06	0.00	**0.32**
2010										0.18	**0.23**	0.07
2009							0.00	0.04	**0.35**	0.12	0.00	0.07
2008						0.10	0.00	0.00	**0.48**	0.00	0.09	0.07
2007						0.10	0.04	**0.44**	0.13	0.00	0.00	0.00
2006				0.06	0.11	0.20	0.38	**0.52**	0.13	0.41	0.00	0.07
2005			0.00	0.06	0.59	**0.80**	0.29	0.08	0.17	0.59	0.47	0.46
2004			0.03	0.17	**1.44**	0.20	0.13	0.24	0.17	1.00	0.28	0.18
2003		0.11	0.09	0.26	0.44	0.17	0.25	0.72	0.74	**1.06**	0.37	0.39
2002		0.11	0.34	0.06	0.22	0.33	0.46	**0.52**	0.30	0.47	0.09	0.04
2001	0.03	0.26	0.17	0.11	0.41	0.60	0.79	**0.88**	0.65	0.76	0.23	0.14
2000	0.29	0.06	0.09	0.20	0.70	**1.50**	0.46	0.36	0.35	0.65	0.09	0.07
1999	0.06	0.31	0.51	0.14	**1.00**	0.87	0.25	0.20	0.13	0.00	0.05	0.00
1998	0.26	0.34	**1.00**	0.40	0.59	0.57	0.04	0.24	0.13	0.24	0.05	0.11
1997	0.69	0.57	**2.31**	0.37	0.33	0.53	0.17	0.20	0.04	0.06	0.05	0.00
1996	1.26	1.14	**3.51**	0.43	0.70	1.03	0.08	0.20	0.22	0.12	0.09	0.00
1995	0.86	0.23	0.71	0.00	0.00	0.13	0.04	0.00	0.00	0.00	0.00	0.00
1994	0.60	0.14	0.71	0.00	0.19	0.07	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.54	0.20	0.46	0.00	0.00	0.07	0.08	0.00	0.09	0.00	0.00	0.00
1992	0.29	0.11	0.20	0.00	0.04	0.07	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.03	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00
Total	**5.09**	**3.58**	**10.16**	**2.26**	**6.67**	**7.40**	**3.46**	**4.64**	**4.08**	**5.72**	**2.09**	**2.04**

Table 12a. Estimated annual and geometric mean survival (S) rates for year classes of striped bass (sexes combined), 30 March – 3 May, 1991-2016.

	Year Class												
	1985	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
91-92	.678	.431	.675										
92-93	.678	.972	.675										
93-94	.678	.972	.315	.233									
94-95	.876	.972	.955	.878	.440								
95-96	.876	.972	.955	.878	.440	.563		.596					
96-97	.876	.972	.955	.878	.899	.745	.868	.437					
97-98	.429	.220	.890	.593	.975	.745	.869	.983	.183				
98-99	.733	.182	.483	.438	.689	.863	.869	.983	.993	.441			
99-00	.000	.000	.116	.506	.689	.863	.869	.983	.993	.884	.290		
00-01			.903	.506	.703	.863	.869	.983	.993	.884	.914	.237	.480
01-02			.903	.000	.646	.775	.638	.983	.993	.884	.914	.990	.842
02-03			.903		.646	.775	.638	.983	.993	.884	.914	.990	.842
03-04			.903		.646	.259	.515	.894	.699	.982	.914	.990	.842
04-05			.903		.429	.754	.529	.264	.570	.752	.403	.970	.842
05-06			.000		.000	.754	.000	.830	.898	.752	.869	.970	.842
06-07						.754		.830	.898	.752	.869	.970	.842
07-08						.000		.705	.762	.517	.568	.667	.583
08-09								.705	.762	.517	.568	.667	.583
09-10								.705	.762	.368	.568	.667	.583
10-11								.000	.762	.000	.308	.580	.614
11-12									.762		.000	.580	.614
12-13									.762			.580	.548
13-14									.000			.818	.548
14-15												.500	.833
15-16												.000	.000
mean	**.621**	**.581**	**.668**	**.517**	**.579**	**.647**	**.641**	**.714**	**.726**	**.638**	**.594**	**.671**	**.636**

Table 12b. Estimated annual and geometric mean survival (S) rates for year classes of striped bass (sexes combined), 30 March – 3 May, 1991-2016.

	Year Class												
	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
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	.814	.635	.497										
05-06	.814	.635	.914	.584									
06-07	.814	.635	.914	.796	.964								
07-08	.718	.888	.914	.796	.445	.381							
08-09	.718	.888	.914	.796	.445	.660	.963						
09-10	.718	.924	.914	.796	.844	.935	.610						
10-11	.676	.505	.778	.819	.932	.934	.752	.316	.571				
11-12	.676	.505	.778	.923	.875	.934	.752	.316	.571				
12-13	.866	.464	.778	.957	.794	.934	.752	.791	.471	.218	.597		
13-14	.866	.620	.778	.957	.794	.934	.752	.791	.471	.329	.418	.236	
14-15	.677	.620	.138	.261	.170	.275	.244	.785	.386	.329	.418	.584	.423
15-16	.677	.000	.778	.609	.444	.929	.545	.980	.386	.000	.418	.584	.321
mean	**.749**	**.590**	**.694**	**.717**	**.602**	**.710**	**.631**	**.603**	**.470**	**.211**	**.457**	**.432**	**.368**

Table 13a. Estimated annual and geometric mean survival (S) rates for year classes of male striped bass, 30 March – 3 May, 1991-2016.

	Year Class												
	1985	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
91-92	.100	.116	.450										
92-93	.894	.500	.450										
93-94	.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	.223	.475
01-02							.000	.000	.855	.768	.559	.821	.639
02-03									.855	.768	.559	.821	.639
03-04									.855	.870	.946	.821	.639
04-05									.000	.450	.170	.793	.518
05-06										.667	.000	.793	.608
06-07										.000		.793	.608
07-08												.793	.162
08-09												.793	.667
09-10												.143	.000
10-11												.880	
11-12												.880	
12-13												.880	
13-14												.880	
14-15												.000	
15-16													
mean	**.409**	**.317**	**.372**	**.345**	**.395**	**.353**	**.508**	**.490**	**.496**	**.501**	**.409**	**.657**	**.477**

Table 13b. Estimated annual and geometric mean survival (S) rates for year classes of male striped bass, 30 March – 3 May, 1991-2016.

	Year Class												
	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
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	.642	.561	.455										
05-06	.642	.561	.643	.539									
06-07	.642	.561	.643	.333	.927								
07-08	.527	.613	.683	.914	.414	.355							
08-09	.527	.613	.683	.914	.414	.567	.780						
09-10	.527	.613	.563	.827	.700	.806	.735						
10-11	.784	.590	.630	.373	.714	.460	.411	.316	.504				
11-12	.784	.590	.874	.938	.640	.889	.411	.316	.504				
12-13	.000	.000	.874	.938	.281	.916	.717	.094	.106	.208	.447	.993	
13-14			.000	.545	.667	.916	.717	.667	.353	.359	.366	.207	
14-15				.000	.000	.106	.143	.833	.000	.359	.366	.310	.356
15-16						.000	.000	.800		.000	.366	.778	.330
mean	**.545**	**.508**	**.584**	**.599**	**.504**	**.519**	**.460**	**.401**	**.276**	**.222**	**.385**	**.472**	**.343**

Table 14a. Estimated annual and geometric mean survival (S) rates for year classes of female striped bass, 30 March – 3 May, 1991-2016.

	Year Class												
	1985	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
91-92	.743	.987											
92-93	.743	.987											
93-94	.743	.987	.802	.898									
94-95	.900	.987	.802	.898	.912								
95-96	.900	.987	.802	.898	.912								
96-97	.900	.987	.802	.898	.912								
97-98	.429	.220	.890	.685	.912								
98-99	.733	.182	.483	.438	.678	.914							
99-00	.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	.665	.612
08-09								.705	.762	.517	.568	.665	.612
09-10								.705	.762	.368	.568	.665	.612
10-11								.000	.762	.000	.000	.598	.614
11-12									.762			.598	.614
12-13									.762			.598	.548
13-14									.000			.545	.548
14-15												.750	.833
15-16												.000	.000
mean	**.649**	**.646**	**.673**	**.607**	**.655**	**.649**	**.462**	**.589**	**.676**	**.563**	**.542**	**.548**	**.537**

Table 14b. Estimated annual and geometric mean survival (S) rates for year classes of female striped bass, 30 March – 3 May, 1991-2016.

	Year Class											
	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
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	.768											
08-09	.768											
09-10	.966	.870					.930					
10-11	.806	.287	.811				.930	.927				
11-12	.806	.800	.811				.930	.927				
12-13	.806	.650	.811	.929	.951		.930	.927	.888	.295		
13-14	.806	.620	.811	.929	.951		.930	.927	.888	.000	.433	.343
14-15	.677	.620	.138	.303	.191	.607	.280	.797	.413		.433	.764
15-16	.677	.000	.778	.609	.444	.607	.643	.979	.413		.778	.764
mean	**.783**	**.520**	**.600**	**.632**	**.526**	**.607**	**.743**	**.912**	**.606**	**.138**	**.526**	**.585**

Table 15a. Comparison of the area under the catch curve (fish/ day) of the 1991-2012 year classes of striped bass from pound nets in the Rappahannock River, 1991-2016.

age	year class										
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
2	0.3	0.7	1.5	0.3	0.3	0.1	0.4	0.0	0.0	0.0	0.0
3	0.8	5.5	5.5	4.2	2.5	11.6	16.0	2.7	0.6	0.8	3.5
4	1.8	8.4	13.6	10.5	14.0	29.8	23.5	4.2	3.6	6.3	8.9
5	3.4	9.6	15.1	13.3	17.3	34.1	24.9	7.5	9.5	9.1	12.1
6	3.5	9.7	15.2	13.4	17.4	34.3	25.3	11.0	10.2	9.2	13.3
7	4.0	10.2	15.7	14.0	18.1	36.1	27.5	11.8	10.7	10.3	13.9
8	4.4	10.7	16.6	14.4	19.5	40.3	29.2	12.7	12.2	10.9	15.1
9	4.8	11.5	16.8	16.1	21.8	42.0	30.1	14.6	12.5	12.1	16.4
10	5.7	11.7	18.3	17.8	22.7	43.2	32.8	15.0	13.7	13.9	17.5
11	5.9	12.9	19.3	18.4	22.9	47.0	33.2	15.7	14.8	14.6	18.5
12	7.0	14.0	19.8	18.6	23.6	47.5	33.5	16.4	15.1	15.0	19.4
13	8.1	14.3	20.0	19.3	23.6	48.2	34.0	16.4	15.4	15.5	20.3
14	8.4	14.4	20.5	19.3	23.6	49.3	34.2	16.7	15.5	16.1	20.5
15	8.4	14.6	20.5	19.5	23.7	49.4	34.4	16.8	15.5	16.2	20.6
16	8.4	14.6	20.5	19.6	23.7	49.6	34.4	17.0	15.5	16.3	
17	8.4	14.6	20.6	19.6	23.7	49.8	34.5	17.0	15.5		
18	8.4	14.7	20.7	19.6	23.7	50.0	34.5	17.1			
19	8.4	14.7	20.7	19.6	23.7	50.1	34.5				
20	8.4	14.7	20.8	19.6	23.7	50.1					
area	**8.4**	**14.7**	**20.8**	**19.6**	**23.7**	**50.1**	**34.5**	**17.1**	**15.5**	**16.3**	**20.6**

Table 15b. Comparison of the area under the catch curve (fish/ day) of the 1991-2012 year classes of striped bass from pound nets in the Rappahannock River, 1991-2016.

age	year class											mean
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	
2	0.0	0.0	0.1	0.0	0.1	0.1	0.2	0.1	0.0	0.0	0.0	0.2
3	1.8	7.9	2.6	4.4	2.0	2.7	0.7	1.5	1.7	3.4	0.6	3.8
4	8.2	16.5	9.8	9.5	8.5	3.8	3.9	3.2	4.3	6.5	4.9	9.3
5	14.3	19.8	16.7	19.9	9.9	7.6	5.8	3.6	5.4	10.1		12.6
6	14.8	21.9	20.9	20.9	12.0	8.4	5.8	3.7	5.8			13.5
7	16.0	23.5	21.7	21.9	12.3	8.5	5.9	3.8				14.3
8	17.0	24.4	22.6	22.2	12.8	8.6	6.0					15.3
9	18.0	25.7	22.9	22.8	12.8	8.6						16.2
10	18.8	26.8	24.3	23.3	12.9							17.3
11	19.2	28.3	24.6	23.8								18.2
12	19.7	28.7	24.8									18.8
13	19.8	29.1										19.2
14	19.8											19.5
15												19.6
16												19.7
17												19.7
18												19.8
19												19.8
20												19.8
area	19.8	29.1	24.8	23.8	12.9	8.6	6.0	3.8	5.8	10.1	4.9	19.8

Table 16a. Back-calculated length-at-age (FL, in mm) for striped bass sampled from the James, York and Rappahannock rivers during spring, 2016.

Year Class	n	length-at-age (FL, in mm)							
		1	2	3	4	5	6	7	8
2014	8	126.7							
2013	119	139.0	245.7						
2012	171	139.0	247.9	348.7					
2011	207	132.2	238.3	341.9	432.8				
2010	58	130.2	231.6	332.1	423.8	502.6			
2009	27	125.8	216.3	309.5	396.3	485.6	555.7		
2008	10	123.0	209.8	291.2	379.5	463.0	539.2	606.9	
2007	5	116.2	200.5	285.5	370.5	444.9	514.4	567.0	618.6
2006	9	126.4	219.6	317.7	411.2	508.3	590.0	663.2	726.9
2005	23	131.2	224.6	315.2	402.8	491.1	568.1	640.2	708.5
2004	13	130.5	223.7	313.7	402.3	489.1	565.3	635.4	704.3
2003	21	128.9	216.9	304.3	388.9	468.5	544.2	610.4	675.9
2002	3	113.1	186.9	260.9	333.9	403.3	474.5	544.0	618.3
2001	12	124.9	210.1	294.8	377.5	455.5	528.3	598.6	661.5
2000	4	130.0	215.0	302.4	379.0	462.9	538.0	600.6	669.2
1999	0								
1998	4	122.5	202.2	284.2	365.4	437.5	506.0	576.5	645.6
1996	1	123.2	203.7	273.4	354.0	427.0	494.3	573.1	629.3
all	695	133.8	236.8	332.4	417.9	489.4	551.1	613.6	681.3

Table 16b. Back-calculated length-at-age (FL, in mm) for striped bass sampled from the James, York and Rappahannock rivers during spring, 2016.

Year Class	n	length-at-age (FL, in mm)									
		9	10	11	12	13	14	15	16	17	18
2014	8										
2013	119										
2012	171										
2011	207										
2010	58										
2009	27										
2008	10										
2007	5										
2006	9	785.9									
2005	23	775.9	833.5								
2004	13	766.7	825.3	877.4							
2003	21	736.8	795.1	849.4	900.0						
2002	3	684.9	748.9	802.7	859.5	900.7					
2001	12	717.9	772.6	821.3	872.0	920.6	963.0				
2000	4	727.9	787.7	837.2	888.6	929.0	974.5	1009.3			
1999	0										
1998	4	712.1	766.3	821.5	870.5	912.8	955.3	991.3	1026.7	1059.0	
1996	1	681.9	739.4	783.2	834.3	878.4	929.7	974.1	1021.8	1047.4	1079.9
all	695	744.7	805.9	852.2	890.7	925.2	957.7	994.2	1025.7	1056.7	1079.9

Table 17. Mean scale and standard error for each otolith age from ages derived from the same specimen, 2003-2016.

N	Otolith age	Mean scale age	SE
94	2	2.31	0.46
171	3	3.27	0.47
210	4	4.30	0.60
215	5	5.02	0.66
164	6	5.97	0.82
205	7	6.66	1.12
253	8	8.08	0.98
295	9	8.96	1.13
344	10	9.77	1.17
328	11	10.82	1.09
252	12	11.42	1.16
128	13	12.04	1.25
85	14	12.19	1.22
53	15	13.36	1.35
47	16	14.40	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 18. Data matrix comparing 2003-2016 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.

SA	Otolith age																		
	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20+**
2	**65**	2	0																
3	29	**120**	14	4															
4		49	**121**	30	3	5													
5			73	**140**	46	27	0	2											
6			2	39	**71**	53	10	1	0										
7				2	41	**76**	59	21	7	0	1	1							
8					3	36	**106**	74	44	5	2	1							
9						7	61	**110**	71	30	7	1	0						
10						1	14	64	**138**	84	44	7	2	1					
11							3	19	64	**132**	68	29	6	4	1				
12								4	14	60	**91**	39	26	8	2	1			
13									6	12	33	**40**	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 19. Relative contributions of striped bass age classes as determined by ageing specimens (n = 2,901) by reading both their scales and otoliths, springs 2003-2016.

Age	Scale age		Otolith age	
	n	prop	n	Prop
1	1	0.0003	1	0.0003
2	67	0.0231	94	0.0324
3	167	0.0576	171	0.0589
4	208	0.0717	210	0.0724
5	288	0.0993	215	0.0741
6	176	0.0607	164	0.0565
7	208	0.0717	205	0.0707
8	271	0.0934	253	0.0872
9	287	0.0989	295	0.1017
10	355	0.1224	344	0.1186
11	327	0.1127	328	0.1131
12	245	0.0845	252	0.0869
13	146	0.0503	128	0.0441
14	74	0.0255	85	0.0293
15	43	0.0148	52	0.0179
16	24	0.0083	47	0.0162
17	9	0.0031	28	0.0097
18	4	0.0014	10	0.0034
19	1	0.0003	6	0.0021
20	0	0.0000	4	0.0014
21	0	0.0000	8	0.0029
	$\overline{Age}$ = 8.45		$\overline{Age}$ = 8.71	

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 1991-2015.

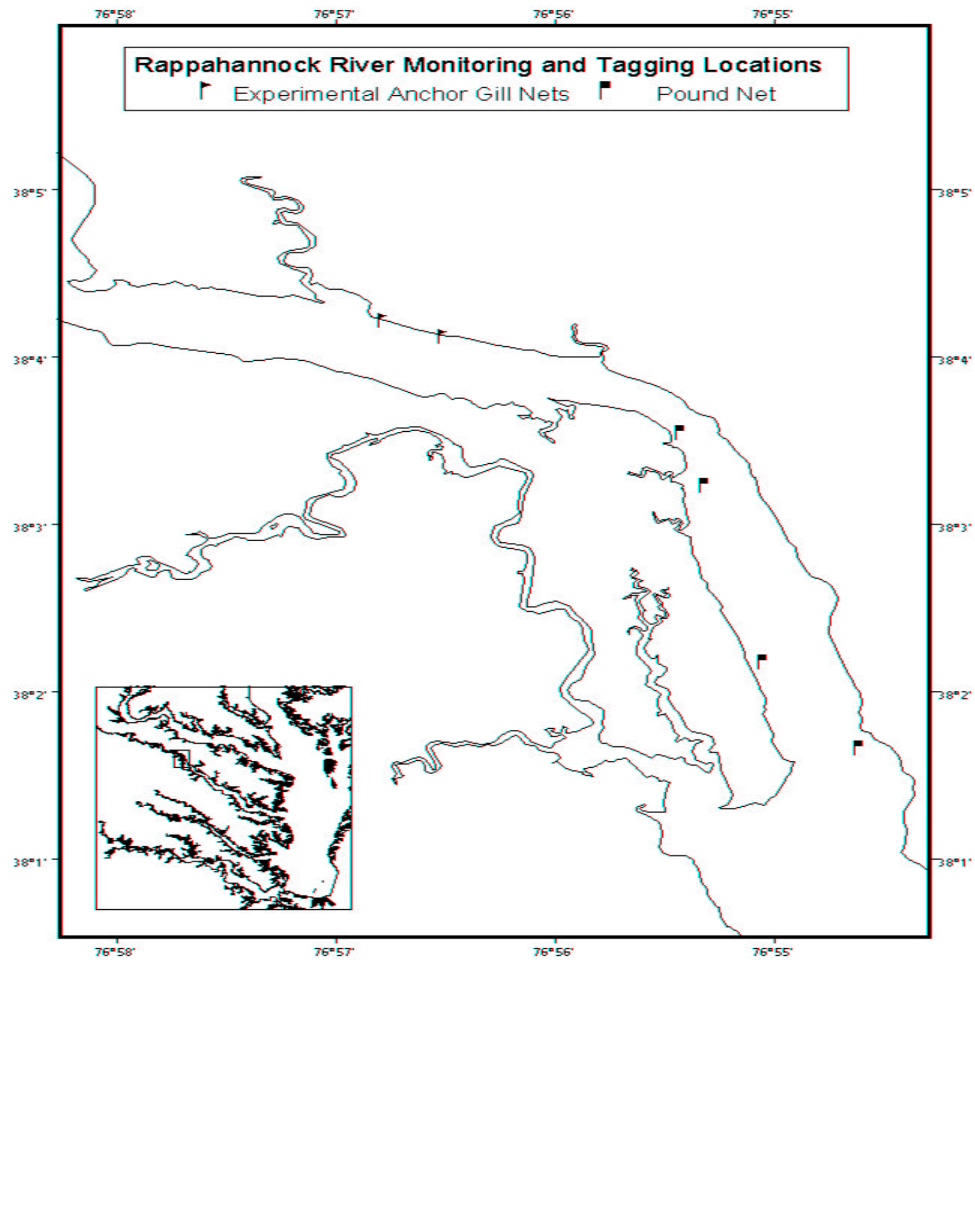


Figure 2. Daily and historic mean river flows (cf/s) for the Rappahannock River during the 30 March – 3 May spawning stock assessment period, spring 2016.

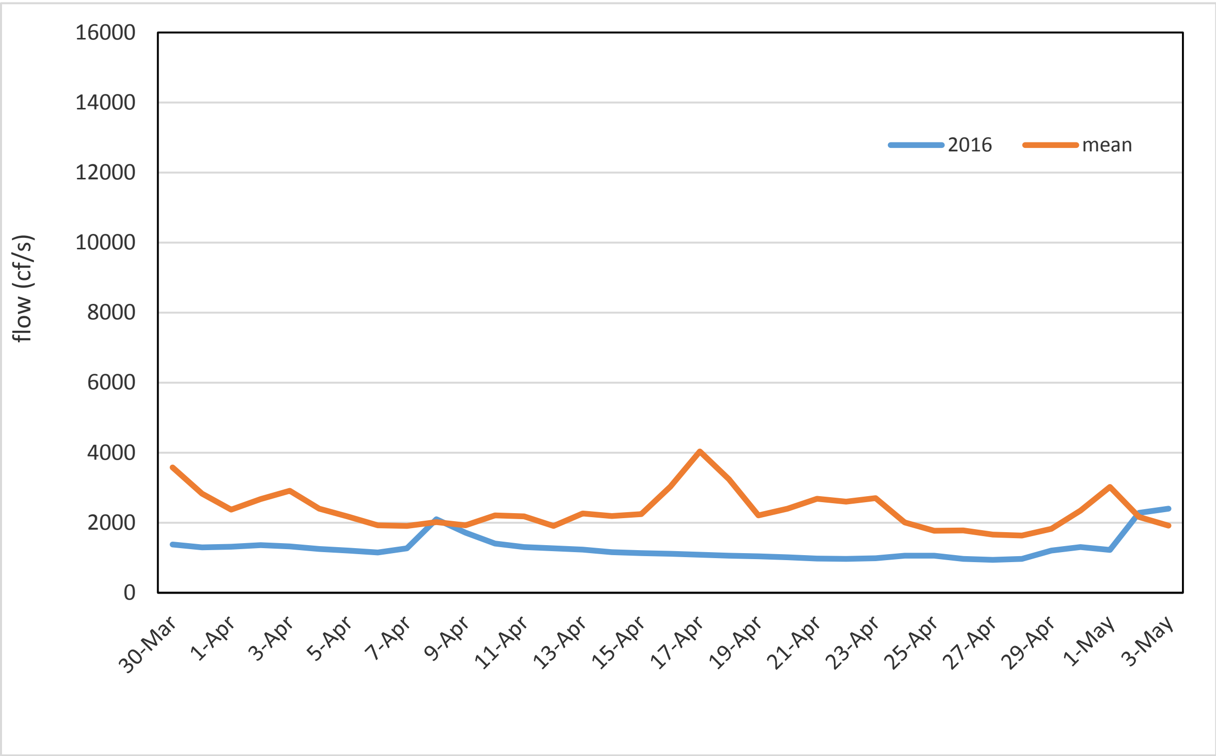


Figure 3. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1987 and 1988 year classes of striped bass from the Rappahannock River pound nets, springs 1991-2016.

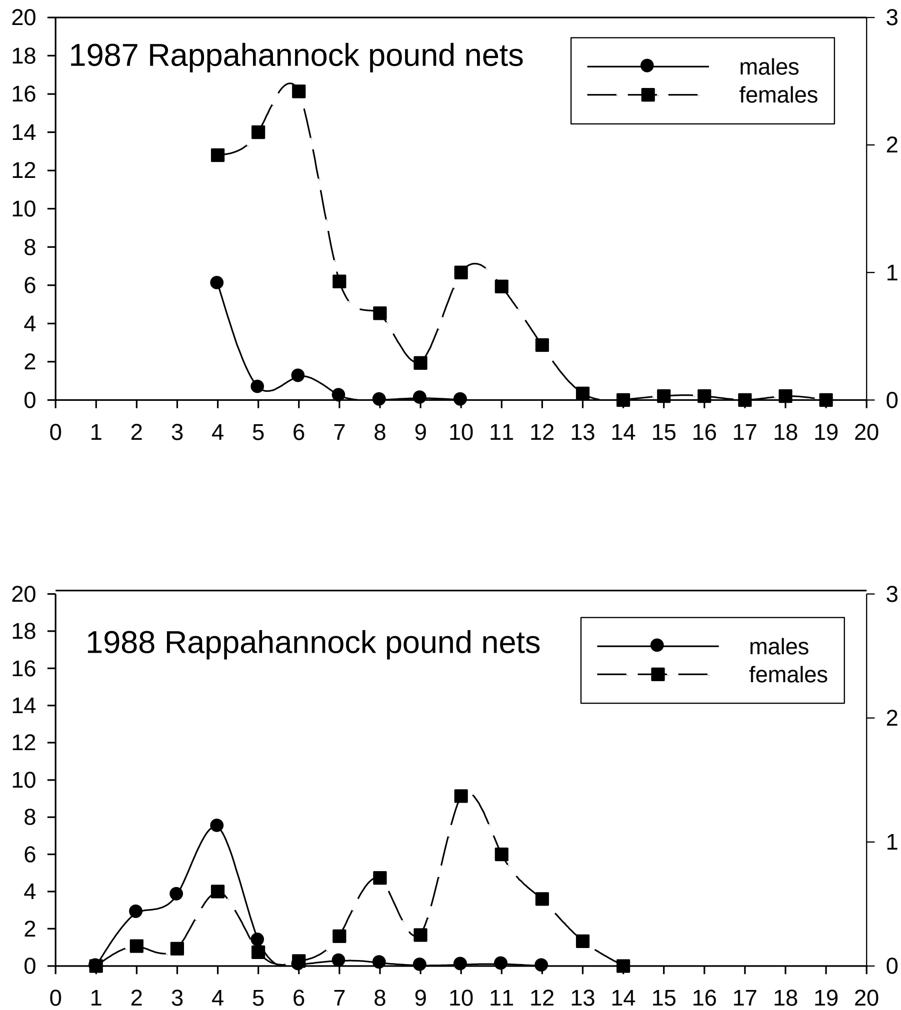
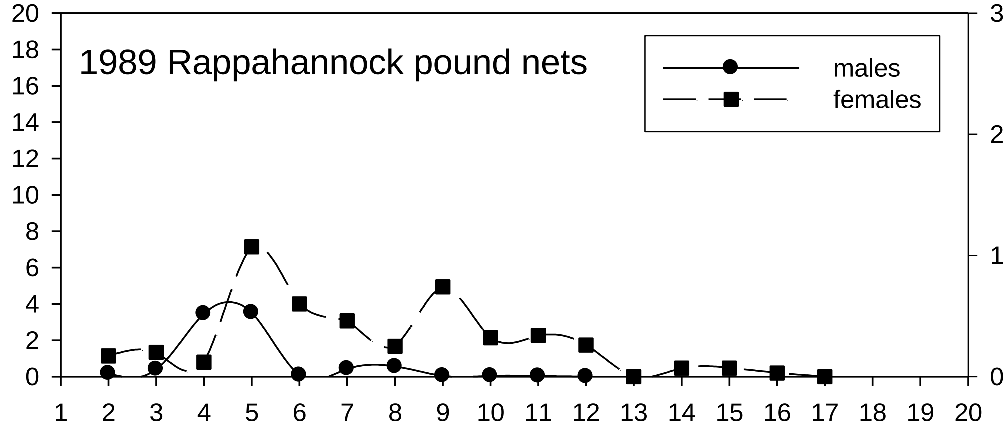


Figure 4. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1989 and 1990 year classes of striped bass from the Rappahannock River pound nets, springs 1991-2016.



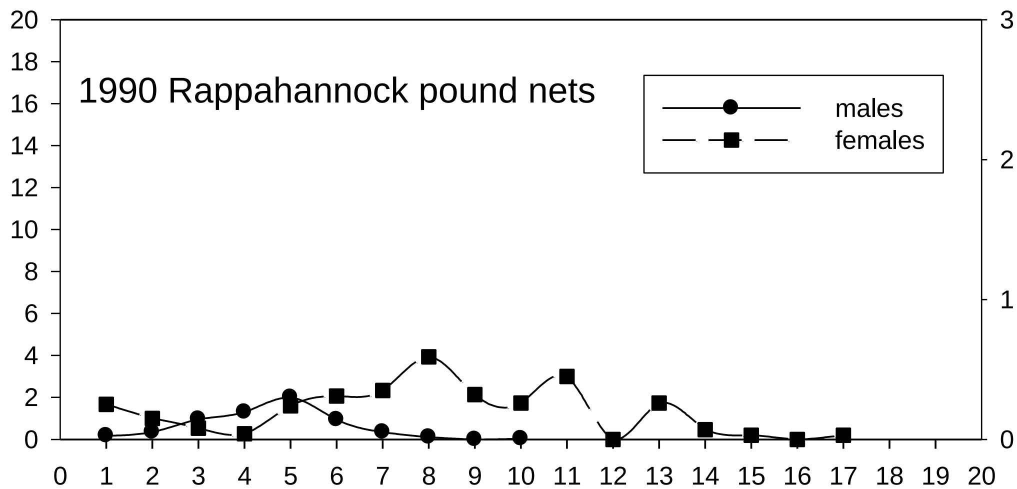
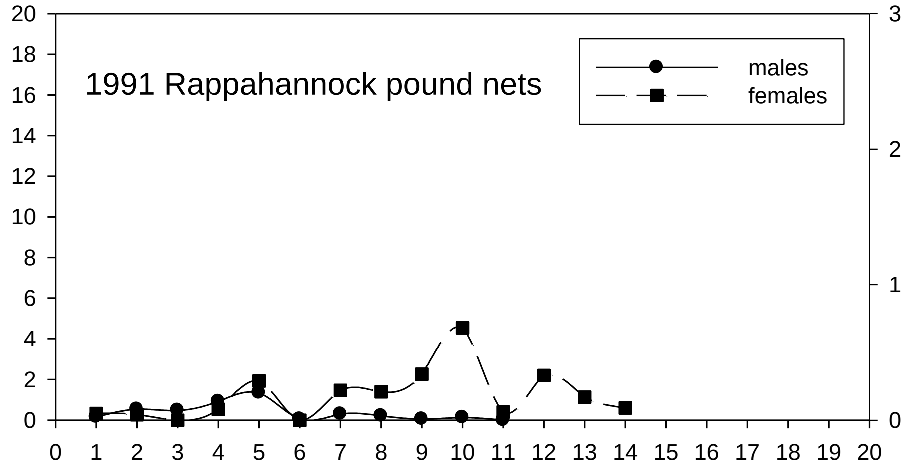


Figure 5. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1991 and 1992 year classes of striped bass from the Rappahannock River pound nets, springs 1991-2016.



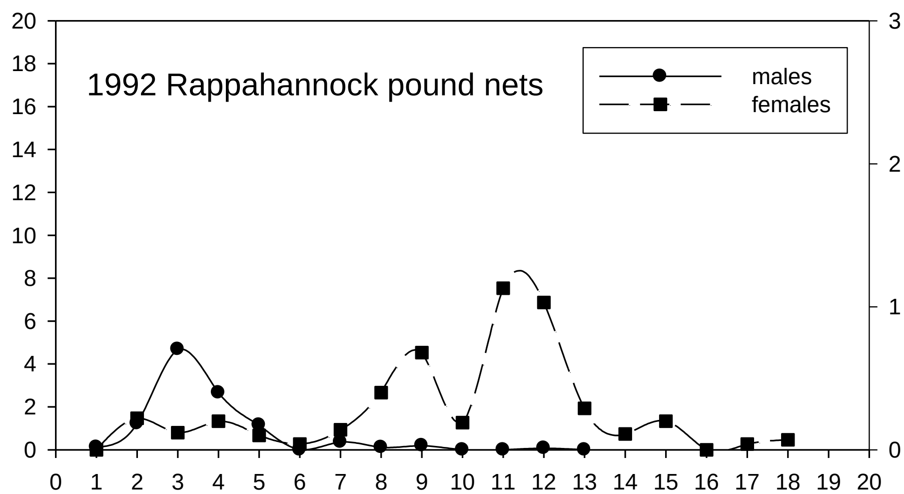
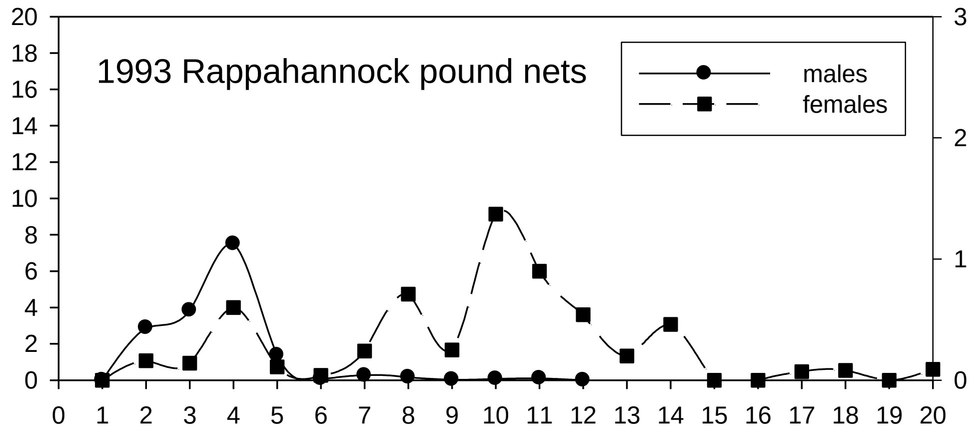


Figure 6. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1993 and 1994 year classes of striped bass from the Rappahannock River pound nets, springs 1994-2016.



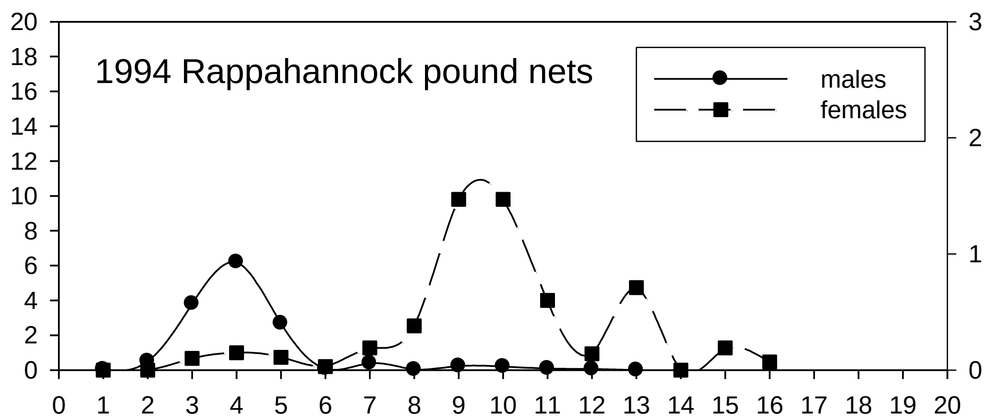
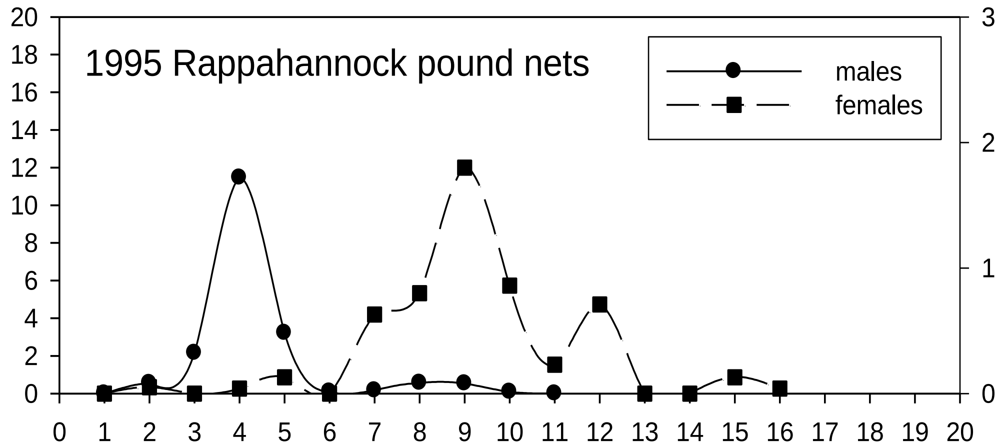


Figure 7. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1995 and 1996 year classes of striped bass from the Rappahannock River pound nets, springs 1996-2016.



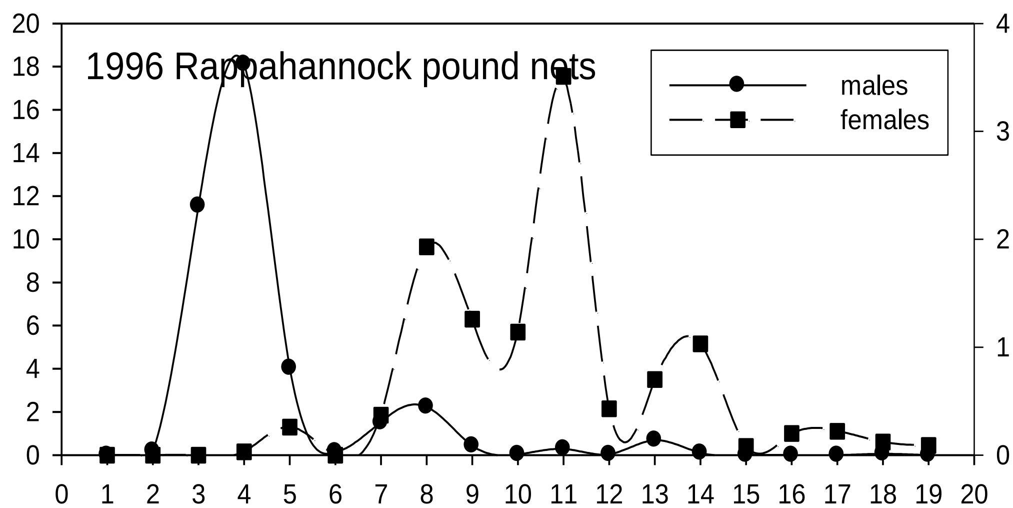


Figure 8. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1997 and 1998 year classes of striped bass from the Rappahannock River pound nets, springs 1998-2016.

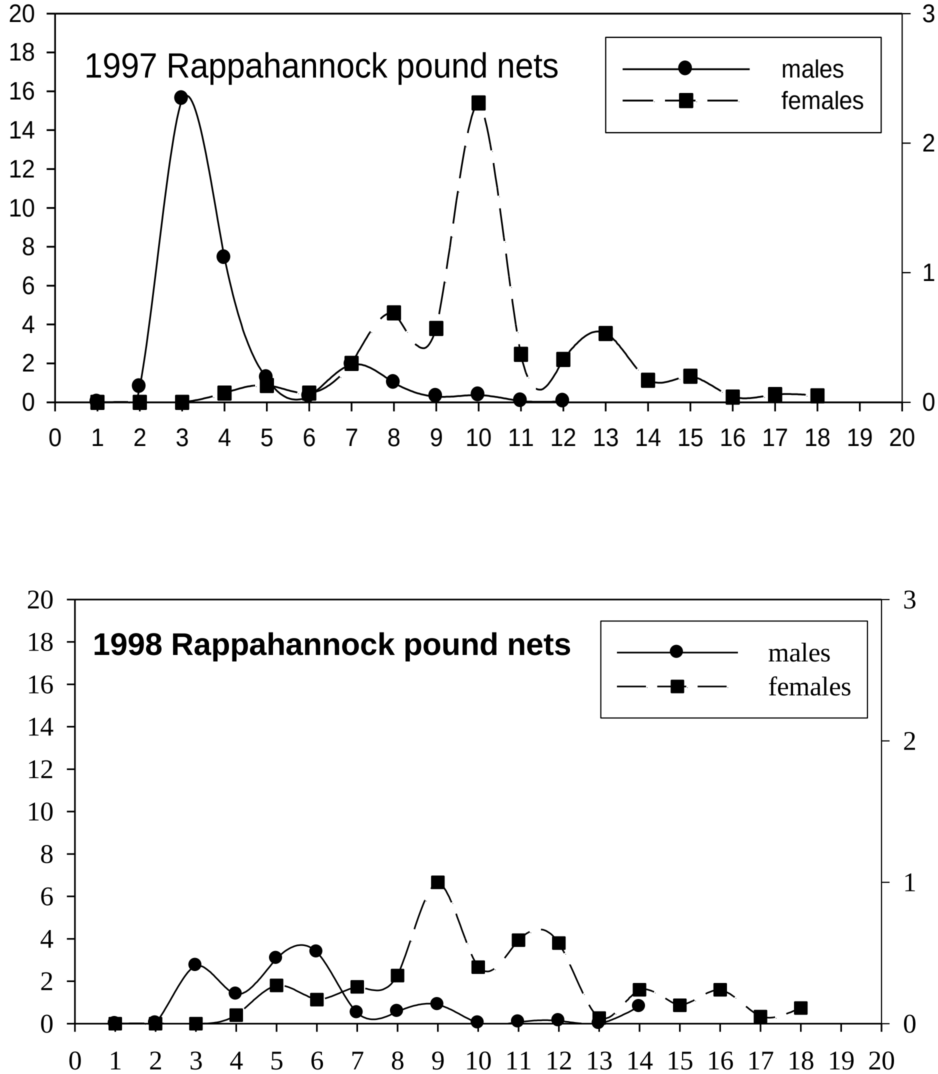
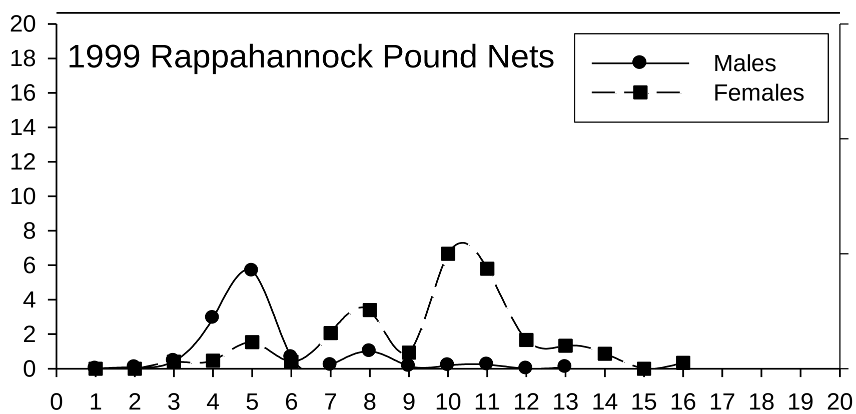


Figure 9. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1999 and 2000 year classes of striped bass from the Rappahannock River pound nets, springs 2000-2016.



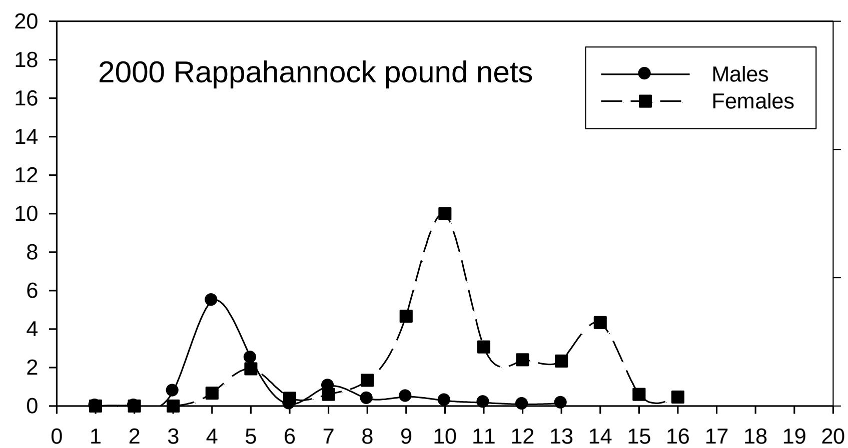


Figure 10. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 2001 and 2002 year classes of striped bass from the Rappahannock River pound nets, springs 2001-2016.

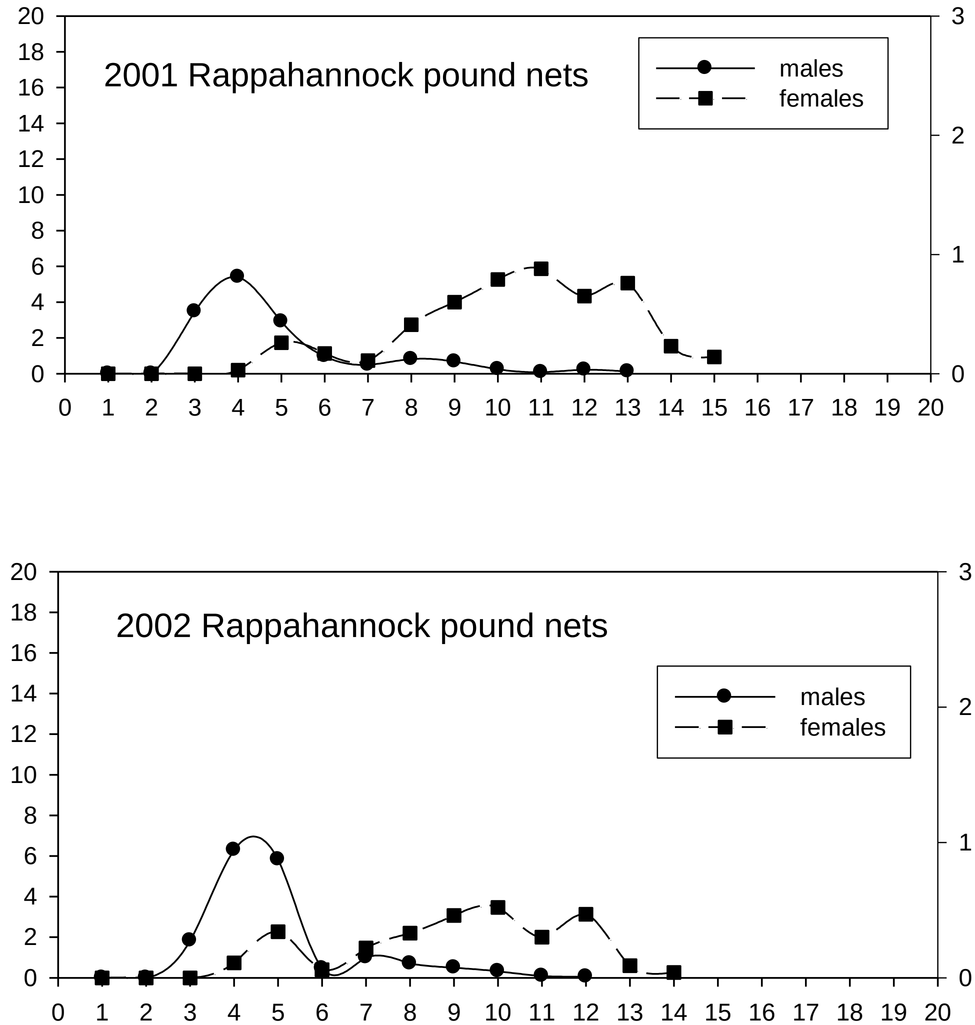
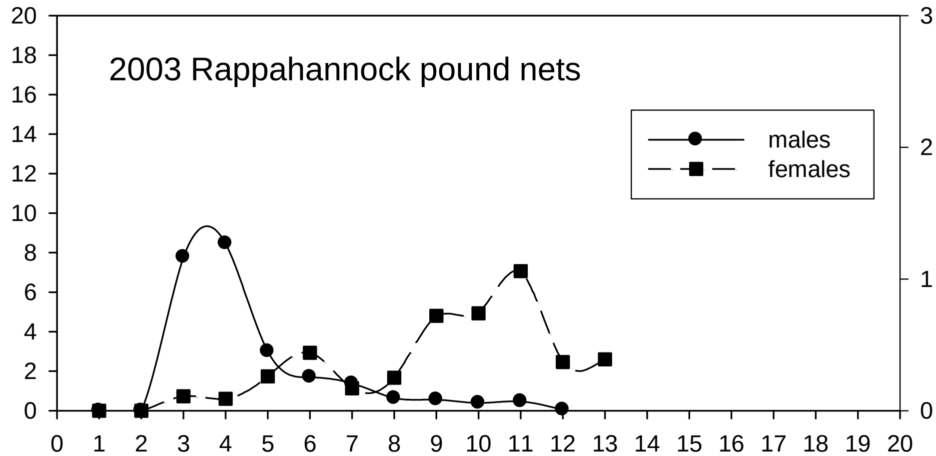


Figure 11. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 2003 and 2004 year classes of striped bass from the Rappahannock River pound nets, springs 2003-2016.



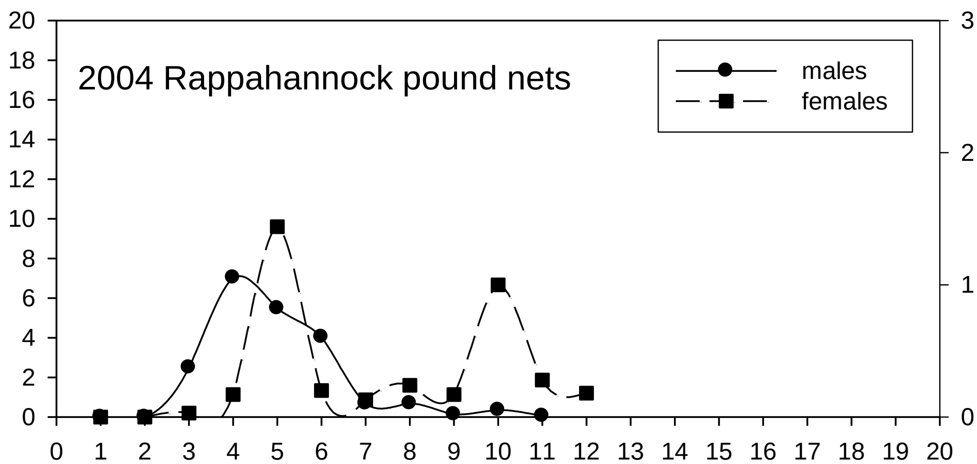
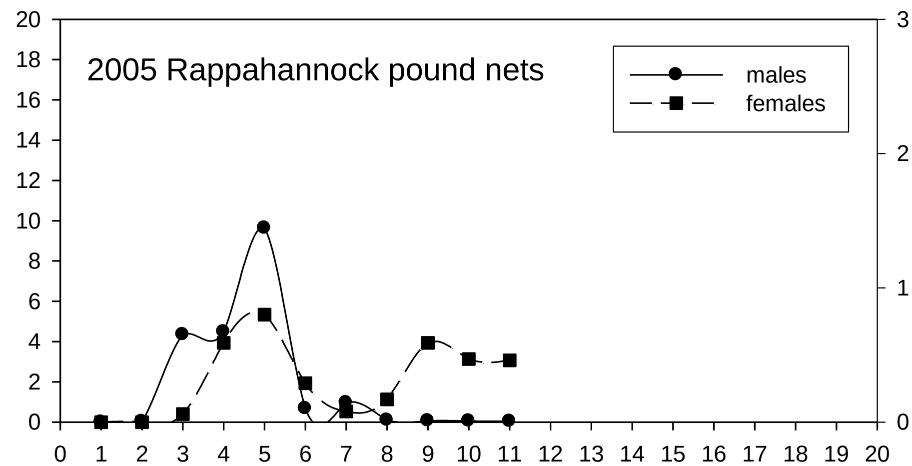


Figure 12. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 2005 and 2006 year classes of striped bass from the Rappahannock River pound nets, springs 2003-2016.



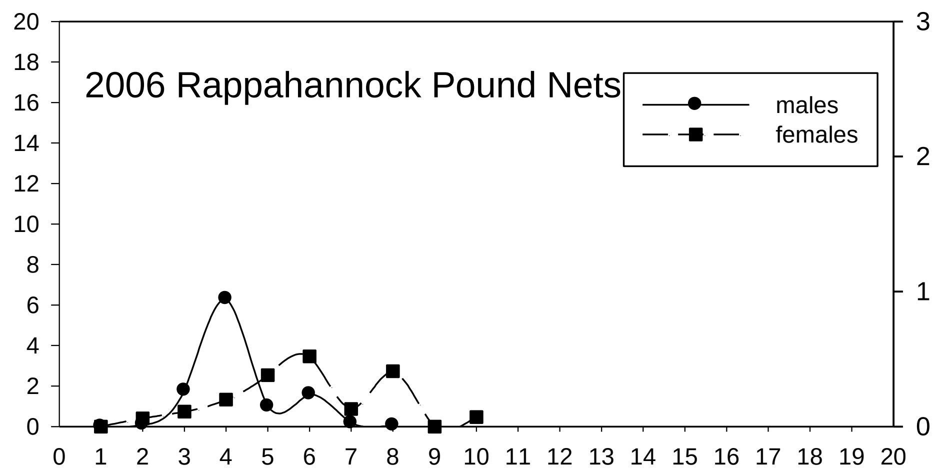


Figure 13. Comparison of otolith ages (diagonal) with their respective mean scale ages from the paired ageing methodology study, 2003-2016.

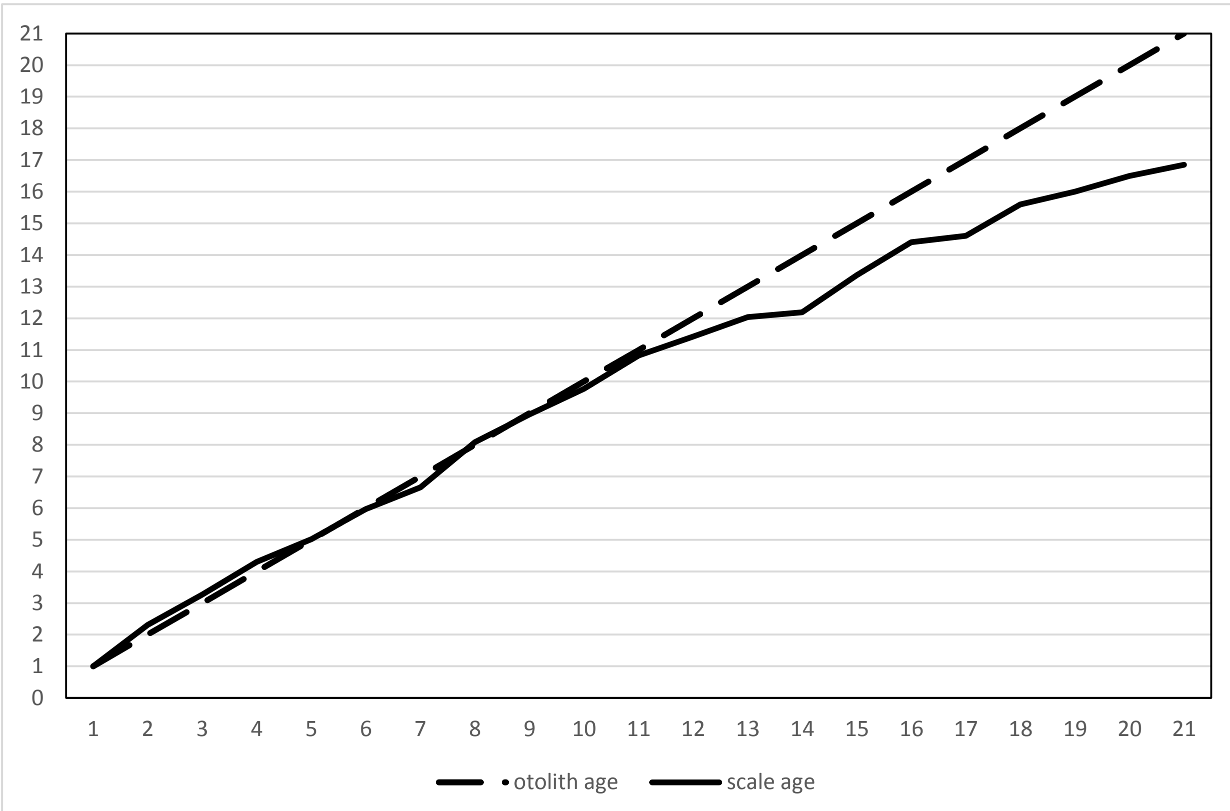
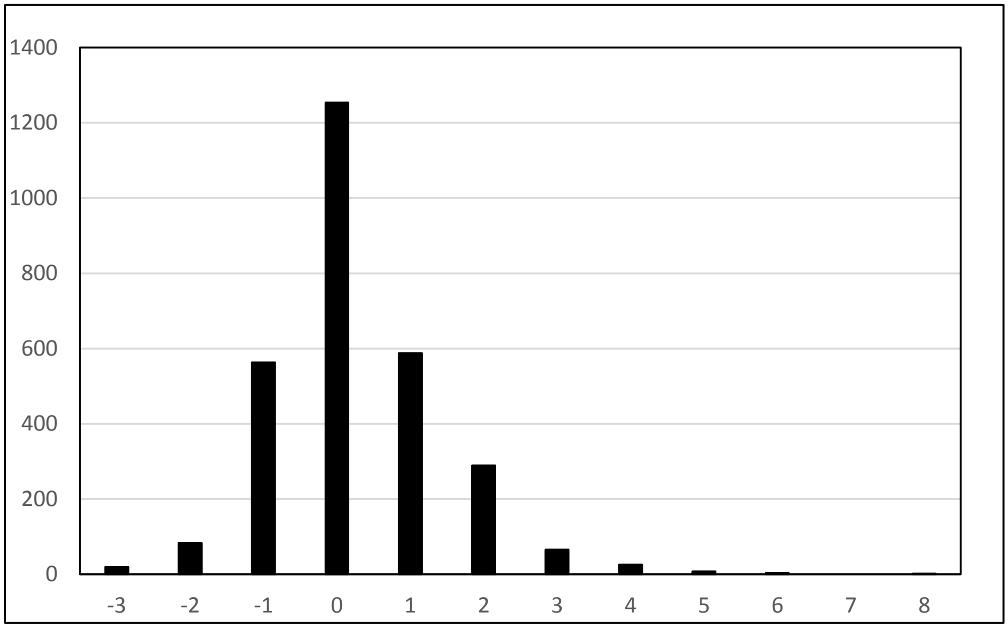


Figure 14. Magnitude of the age differences (n=2,904) by reading both their scales and otoliths, springs, 2003-2016.



II. Mortality estimates of striped bass (*Morone saxatilis*) that spawn in the Rappahannock River, Virginia, spring, 2015-2016.

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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 economic 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

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

where r_{ij} is the number of tags recovered in year j that were released in year i (note, $J \exists I$). Tagging periods do not necessarily have to be yearly intervals; however, data analysis is easiest if all periods are the same length and all tagging events are conducted at the beginning of each period.

Application of tagging models involves constructing an upper triangular matrix of expected values and comparing them to the observed data. Since the recovery data over time for each year's batch of tagged fish can be assumed to follow a multinomial distribution, the method of maximum likelihood can be used to obtain parameter estimates. Analytical solutions for the maximum likelihood parameter estimates are generally not available. Hence, several software packages that numerically maximize a product multinomial likelihood function have been developed for application of tagging models. They include programs SURVIV (White 1983), MARK (White and Burnham 1999), and AVOCADO (Hoenig et al. in prep.).

Seber models: White and Burnham (1999) reformulated the original Brownie et al. (1985) models in the way originally suggested by Seber (1970) to create a consistent framework for modeling mark-recapture data (Smith et al. 2000). This framework served as the foundation for program MARK, which is a comprehensive software package for the application of capture-recapture models. For time-specific parameterization of the Seber models, the matrix of expected values associated with equation (1) would be

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

where N_i is the number tagged in year i, S_i is the survival rate in year i and r_i is the probability a tag is recovered from a killed fish regardless of the source of mortality. For the 2006 estimates the updated version of MARK (version 4.3) replaced the version used in previous years (version 4.2).

The Seber models are simple and robust, but they do not yield direct information about exploitation (*u*) or instantaneous rates of fishing and natural mortality, which are often of interest to fisheries managers. Estimates of *S* can be converted to the instantaneous total mortality rate via the equation (Ricker 1975)

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

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

Instantaneous rate models: Hoenig et al. (1998a) modified the Brownie et al. (1985) models to allow for the estimation of instantaneous rates of fishing and natural mortality. This extension showed how information on fishing effort could be used as an auxiliary variable and also discussed generalizing the pattern of fishing within the year. The matrix of expected values corresponding to equation (1) for a model that assumes time-specific fishing mortality rates and a constant natural mortality rate would be

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

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

These models are not as simple as the Seber models, but they do yield direct estimates of F and, depending on the information available, either M or $\varphi\lambda$. Also, they can be parameterized to allow for non-mixing of newly and previously tagged animals (Hoenig *et al.* 1998b). If the goal of a particular tagging study is to estimate F and M, then auxiliary information on the tag reporting and tag-induced handling mortality rate is required to apply the instantaneous rates formulation. However, if M is known, perhaps from a study that related it to life history characteristics (e.g., Beverton and Holt 1959; Pauly 1980; Hoenig 1983; Roff 1984; Gunderson and Dygert 1988), then these models can be used to estimate F and $\varphi\lambda$.

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

Materials and Methods

Capture and Tagging Protocol

Rappahannock River: Each year from 1991 to 2016, 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 280 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.

James River: Starting in 2014, the multiple-mesh experimental gill nets previously used as the source of a monitoring index in the James River were retasked to initiate a tagging program to expand and supplement the data produced 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. In spring 2016, two 600’ nets were constructed (ten 60’ panels) utilizing the same panel size and mesh order. In addition, a 600’ drift gill net was deployed. This net was comprised of three 200’ panels of 4.5’, 6’ and 8’ mesh sizes. The sampling protocol was to set the anchor gill nets, then deploy the drift gill net for 30-45 minutes. Upon completion of tagging the drift gill net catch, the anchor nets were fished and all viable striped bass tagged and released. These nets were deployed between river miles 38 to 60 and fished for a total of one to two hours total (shorter times as water temperatures increased) soak time to maximize catch and minimize net mortality.

York River: In 2015, the gill nets formerly utilized in the Rappahannock River were relocated to initiate a tagging program in the York/Mattaponi river system. Two 300’ nets (10 x 30’ panels each) were deployed as described for the James River. In 2016, these were supplemented with a 300’ drift gill net as designed for the James River. This net was replaced with a 450’ net to maximize catch results. The deployment and fishing protocol was the same as described for the James River. These nets were deployed from river mile 30 to mile 42 in the Mattaponi River.

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, 2007-2011 and 2012-2015) 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, 2012-2013 and 2014-2015).

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 of 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:

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

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

Instantaneous rates methods: This method (defined in the multi-year tagging methods section) allows the estimate of natural mortality to be constant, or to vary by periods. In 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, 1998-2015 for striped bass > 457 mm TL and 1990-2002, 2003-2015 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, 2007-2011 and 2012-2015); 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, 2007-2011, 2012-2014 and 2015).
F(v)F'(v)	Fishing and release mortalities vary over different periods (1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011, 2012-2013 and 2014-2015).

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 2016 Tag Release summary

A total of 1,093 striped bass were tagged and released from the pound nets in the Rappahannock River between 4 April and 26 May, 2016 (Table 1). There were 701 resident striped bass (457-710 mm TL) tagged and released. These stripers were predominantly male (91.4%), but the female stripers were larger on average. A total of 246 striped bass were tagged and released from gill nets in the James River between 22 March and 29 April, 2016 (Table 2). There were 156 resident striped bass tagged and released. These stripers were predominantly male (84.0%), but the female stripers were larger on average. In addition, tag releases from the York River system yielded 205 striped bass between 24 March and 27 April, 2016 (Table 3). There were 131 resident striped bass tagged and released. These were predominantly male (84.7%) but the females were larger on average. The median date of these tag releases (all rivers combined), to be used as the beginning of the 2016-2017 recapture interval, was 21 April.

There were 99 migrant striped bass (>710 mm TL) tagged and released in the Rappahannock River (Table 1), 24 migrant striped bass tagged and released in the James River (Table 2) and 41 migrant striped bass tagged and released in the York River (Table 3). These stripers were predominantly female (83.8% in the Rappahannock River, 62.5% in the James River and 75.6% in the York River) and their average size was larger than for the male striped bass. The median date of these tag releases (all rivers combined) was 18 April. The tag release totals of striped bass greater than 457 mm TL were 135.0% greater than the release total for 2015 and exceeded the tag release target of 700 releases. The tag release totals for striped bass greater than 710mm TL were 41.4% greater than in 2015, but was below the tag release target of 300 migratory striped bass.

Mortality Estimates, 2015-2016

Tag recapture summary: A total of 36 striped bass (>457 mm TL) were recaptured between 1 January and 31 December, 2015. The largest source of recaptures (72.2%) was from Chesapeake Bay (41.6% in Virginia, 30.6% in Maryland, Table 4). Other recaptures came from Rhode Island (11.1%), Massachusetts and New York (5.6% each) and New Jersey and Maine (2.7% each). There were no recaptures reported from New Hampshire, Connecticut, Delaware or North Carolina. The peak months for recaptures were in July through September and again in December, but there were recaptures in every month of the year except January and February.

A total of 15 migratory striped bass (>710 mm total length) were recaptured between 1 January and 31 December, 2015. The largest sources of the recaptured tagged striped bass (40.0%) were from Chesapeake Bay (26.7% in Maryland and 13.3% in Virginia,) (Table 5). Other recaptures came from Rhode Island (20.0%), Massachusetts and New York (13.3% each), and Maine and New Jersey (6.7% each). There were no recaptures reported from New Hampshire, Connecticut, Delaware, or North Carolina. The peak month for recaptures was also in July through September, but the migrant striped bass were recaptured from March through December (except November).

ASMFC protocol: Survival estimates were made utilizing the mark-recapture data for the Rappahannock River from 1990-2015. 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

Rappahannock River releases: Fourteen striped bass (≥ 457 mm TL) tagged in spring 2015 and 20 striped bass tagged in previous springs were harvested during the 2015-16 recapture interval. These were added to complete the input matrix (Table 6) for annual estimates of survival using program MARK. Likewise, there were two striped bass (≥ 711 mm TL) tagged in spring 2015 and 12 striped bass tagged in previous springs harvested during the 2015-16 recapture interval and used to complete the input matrix (Table 7).

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 8). The 2015 estimate of survival was 0.355 which became 0.362 when adjusted for release bias (Table 9). The 2015 survival estimate was lower than the 2014 estimate and much lower than the 2013 estimate. However, all of these estimates are much lower than the survival estimates from 2006-2009.

The ranking and weighting among the three models were very different for striped bass ≥ 711 mm with the vic-period model highest with 0.667 of the weighting while the time-specific model received 0.203 and the period model the remaining .130 (Table 10). The 2015 estimate of survival was 0.520 (0.558 after bias adjustment) which was also lower than the 2014 survival estimate and the lowest since 2012 (Table 11).

Rappahannock, York and James rivers releases: Twenty striped bass (≥ 457 mm TL) tagged in spring 2015 and 19 striped bass tagged in previous springs were harvested during the 2015-16 recapture interval. These were added to complete the input matrix (Table 12) for annual estimates of survival using program MARK. Likewise, there were five striped bass (≥ 711 mm TL) tagged in spring 2015 and 13 striped bass tagged in previous springs harvested during the 2015-16 recapture interval and used to complete the input matrix (Table 13).

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 14). The 2015 estimate of survival was 0.376 which became 0.391 when adjusted for release bias (Table 15). However, this 2015 survival estimate was slightly higher than the 2014 estimate and much lower than the 2013 estimate.

The ranking and weighting among the three models differed only slightly from the Rappahannock only analysis for striped bass ≥ 711 mm TL. The viv-period model was again highest with 0.835 of the weighting while the period model received 0.098 and the time-specific model received 0.066 (Table 16). The 2015 estimate of survival was 0.495 (0.504 after bias adjustment) which was equal to the 2014 survival estimate and the lowest in the time series (Table 17).

Catch equation estimates of mortality and exploitation rates

Rappahannock River releases: 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 2015 estimates for striped bass ≥ 457 mm TL were 1.01 (Z), 0.64 (A), 0.17 (U), 0.28 (F) and 0.74 (M, Table 18). The estimates of U and F were increased from 2014, but had 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 2015 estimates for striped bass ≥ 711 mm TL were 0.58 (Z), 0.44 (A), 0.03 (U), 0.04 (F) and 0.55 (M, Table 19). 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 2006.

James, York and Rappahannock rivers releases: 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 2015 estimates for striped bass ≥ 457 mm TL were 0.95 (Z), 0.61 (A), 0.13 (U), 0.20 (F) and 0.74 (M, Table 20). The estimates of U and F were lower than the respective Rappahannock River-specific estimates, while the estimate of M fluctuated, but remained well above the assumed value of 0.15.

The 2015 estimates for striped bass ≥ 711 mm TL were 0.69 (Z), 0.50 (A), 0.05 (U), 0.07 (F) and 0.62 (M, Table 21). The estimates of F and U were slightly higher than their respective Rappahannock River-specific estimates while the M estimate, while lower than the value for the smaller striped bass, has also exceeded the 0.15 value.

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 1998-2015 M periods for striped bass ≥ 457 mm TL and 1990-2003 and 2004-2015 M periods for striped bass ≥ 711 mm TL.

Rappahannock River releases: Eight striped bass (≥ 457 mm TL) tagged in spring 2015 and an additional 17 tagged in previous springs were harvested during the 2015-2016 recapture interval. In addition, there were five 2015-released striped bass and three 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 22a,b) for estimating survival and mortality parameters using the instantaneous rates model.

Likewise, there were 11 harvested (one from 2015 releases) and three released striped bass (one from 2015 releases) from striped bass ≥ 711 mm TL tagged in spring 2015 and recaptured during the 2015-2016 recapture interval and used to complete their respective instantaneous rate model input matrixes (Tables 23a, b).

The F(6p) f'(6p) model received most (46.7%) of the weighting among the six models defined in the IRCR analysis while the F(t)F"(6p) contributed 38.5% (Table 24). The F(t)F"(6p) same model had been the top weighted model in the 2013 and 2014 analyses (>95%). The other models contributed almost 15% to the weighting. The resultant parameter estimates for 2015 are 0.505 (survival, Table 25), 0.623 (natural mortality) and 0.058 (fishing mortality). There has been a steady decline in the estimates of fishing mortality from 2003-2015 while the estimate for natural mortality continues to increase and greatly exceeds the generally assumed value of 0.15 throughout the time series

In contrast, the F(t)F'(6p) model received little weighting for the IRCR analysis for striped bass ≥ 711 mm TL with the F(6p) F'(6p) model (69.4%) along with the des (15.6%) and vic (14.7%) models most influencing the estimates (Table 26). The 2015 IRCR estimate of survival was 0.602 (Table 27). The 2015 estimate of natural mortality was 0.458 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. The estimates for fishing mortality have been below 0.10 since 2000 and continue to decline.

James, York and Rappahannock rivers releases: Eleven striped bass (≥ 457 mm TL) tagged in spring 2015 and an additional 17 tagged in previous springs were harvested during the 2015-2016 recapture interval. In addition, there were seven 2015-released striped bass and three 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 28a,b) for estimating survival and mortality parameters using the instantaneous rates model.

Likewise there were 13 harvested (two from 2015 releases) and four released striped bass (two from 2015 releases) from striped bass ≥ 711 mm TL tagged in spring 2015 and recaptured during the 2015-2016 recapture interval and used to complete their respective instantaneous rate model input matrixes (Tables 29a, b).

The F(6p)F'(6p) and F(t) f'(6p) models received most (96.5% combined) of the weighting among the six models defined in the IRCR analysis (Table 30). The F(t)F'(6p) model had dominated the 2013 and 2014 analyses (>95%). The other models each contributed less than 2% to the weighting. The resultant parameter estimates for 2015 are 0.508 (survival, Table 31), 0.621 (natural mortality) and 0.053 (fishing mortality). There is a steady decline in the estimates of fishing mortality from 2003-2015 while the estimate for natural mortality continues to increase and greatly exceeds the generally assumed value of 0.15 throughout the time series

In contrast, the F(t)F'(6p) model received virtually no weighting for the IRCR analysis for striped bass ≥ 711 mm TL The six period model received the most weighting (61.9%) while the Des (22.3%) and the Vic period model (15.6%) also influencing the estimates (Table 32). The F(t)F'(6p) model had dominated the 2013 and 2014 analyses. The 2015 IRCR estimate of survival was 0.600 (Table 33). The 2015 estimate of natural mortality was 0.460 while the estimate of fishing mortality was 0.050. 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. The estimates of fishing mortality have decreased steadily since 200.

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 and 2000s 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. This pattern may be repeating with below optimal recapture numbers in 2013-2015. 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 2015, the release total for striped bass tagged in the Rappahannock was lower than the release total for spring 2014 and well below the target for striped bass. Persistent poor weather, including snow in March and windy conditions in early April 2015 resulted in reduced gear availability for the year. The recapture rate of Rappahannock River released stripers was 0.109 (34/313) which was higher than for 2014 (0.079) and above the overall recapture rate of 0.066. However, the recapture rate for all 2014 releases was 0.078 (38/490) which was lower than the rate for the Rappahannock-specific releases. It will be important to document any differences in long term recapture rates as James and York River releases are added to the ones from the Rappahannock River. 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 recent estimates of survival and other parameters.

The program MARK survival estimates for 2015 were 0.362 for striped bass greater than 18 inches (457 mm) total length tagged in the Rappahannock River and 0.376 from combined James, York and Rappahannock releases. The survival estimates were 0.520 for striped bass greater than 28 inches (711 mm) total length (migratory) released in the Rappahannock River and 0.495 from the James and Rappahannock River combined releases. The survival estimates continue to decline from their more stable 2005-2009 levels. While the expansion of the tagging program into the James and York rivers increases the release totals, their effect on the parameter estimates remains undetermined. In both 2014 and 2015 the addition of the additional releases produced higher survival estimates fot the greater than 18” cohort, but lower estimates for the greater than 28” striped bass.

Again in 2015, 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 estimates 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. However, the most recent estimates of fishing mortality for these striped bass have also increased beyond the ASMFC threshold.

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 2015 estimates of fishing mortality of 0.20 (all river)-0.28 (Rappahannock River) for the greater than 18” cohort but estimates of 0.04 (Rappahannock River)- 0.07 (all rivers) for striped bass greater than 28” total length. 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 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.

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 2015 estimates of fishing mortality were 0.05-0.06 for both the Rappahannock-specific and the combined James-Rappahannock analyses for striped bass >18 inches TL and 0.05 (both analyses) 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 ≥ 18 inches TL and fish ≥ 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 in the Rappahannock River, spring 2016

Date	n	<457 mm		457-710 mm TL				> 710 mm TL			
				Males		Females		Males		Females	
		n	$\overline{TL}$	n	$\overline{TL}$	n	$\overline{TL}$	n	$\overline{TL}$	n	$\overline{TL}$
4 Apr	36	2	385.5	16	536.7	2	654.0	2	759.5	14	1,035.9
7 Apr	16	7	411.9	6	530.2	1	590.0	0		2	966.0
11 Apr	13	7	363.7	3	527.3	1	505.0	0		2	1,014.5
14 Apr	23	5	401.6	11	541.8	1	553.0	0		6	1,011.7
18 Apr	130	38	407.9	69	521.5	4	618.8	2	968.5	17	984.1
21 Apr	319	92	402.6	201	520.3	8	573.1	3	852.0	15	977.2
25 Apr	223	63	399.2	133	519.5	7	593.4	4	763.3	16	916.3
28 Apr	151	33	393.0	100	526.2	11	585.6	5	839.4	2	1,027.0
2 May	16	4	385.8	8	535.1	2	587.0	0		2	980.0
5 May	17	3	414.0	10	539.7	3	598.7	0		1	947.0
9 May	16	2	401.5	13	517.1	0		0		1	980.0
12 May	23	4	396.8	13	543.8	5	588.8	0		1	958.0
19 May	55	14	417.3	27	542.9	10	573.1	0		4	862.5
26 May	55	19	392.1	31	514.4	5	566.2	0		0	
total	1,093	293	400.5	641	514.0	60	583.1	16	828.9	83	975.1

Table 2. Summary data of striped bass tagged and released from gill nets in the James River, spring 2016.

Date	n	<457 mm		457-710 mm TL				> 710 mm TL			
				Males		Females		Males		Females	
		n	$\overline{TL}$	n	$\overline{TL}$	n	$\overline{TL}$	n	$\overline{TL}$	n	$\overline{TL}$
22 Mar	17	1	434.0	10	580.2	1	652.0	4	750.5	1	724.0
25 Mar	26	7	404.1	16	533.8	1	588.0	2	906.0	0	
29 Mar	17	5	393.8	8	552.6	3	624.7	0		1	1,036.0
31 Mar	36	13	437.0	14	539.2	4	563.5	1	756.0	4	979.3
5 Apr	7	4	414.8	2	472.5	1	459.0	0		0	
8 Apr	4	1	440.0	3	562.7	0		0		0	
13 Apr	25	1	384.0	14	557.2	7	632.6	0		3	1,099.0
15 Apr	50	25	380.4	23	538.6	1	500.0	0		1	1,023.0
19 Apr	17	4	403.3	9	533.4	2	616.0	0		2	959.5
22 Apr	43	5	405.6	30	546.6	4	592.8	2	742.5	2	924.0
26 Apr	4	0		2	562.0	1	664.0	0		1	1,026.0
29 Apr	0	0		0		0		0		0	
total	246	66	402.2	131	545.5	25	600.9	9	783.9	15	986.0

Table 3. Summary data of striped bass tagged and released from gill nets in the York and Mattaponi rivers, spring 2016.

Date	n	<457 mm		457-710 mm TL				> 710 mm TL			
				Males		Females		Males		Females	
		n	$\overline{TL}$	n	$\overline{TL}$	n	$\overline{TL}$	n	$\overline{TL}$	n	$\overline{TL}$
24 Mar	7	2	404.0	5	589.6	0		0		0	
28 Mar	6	0		5	572.0	1	564.0	0		0	
30 Mar	5	0		3	539.0	0		1	874.0	1	1,139.0
6 Apr	11	2	437.0	5	567.2	2	607.5	0		2	934.5
11 Apr	8	0		2	606.0	0		0		6	1,004.3
13 Apr	66	5	396.6	47	549.9	3	632.0	2	808.0	9	954.0
18 Apr	69	22	416.0	32	549.7	4	604.0	6	858.8	5	1,033.2
20 Apr	17	2	314.5	8	513.9	3	596.0	0		4	1,002.0
25 Apr	9	0		3	532.7	3	642.7	1	732.0	2	909.0
27 Apr	7	0		1	524.0	4	608.5	0		2	991.0
total	205	33	407.5	111	550.8	20	612.1	10	837.5	31	986.9

Table 4. Location of striped bass (≥ 457 mm TL), recaptured in 2015, that were originally tagged and released in the Rappahannock River during springs 1990-2015.

State	Month												total
	J	F	M	A	M	J	J	A	S	O	N	D	
Maine	0	0	0	0	0	0	1	0	0	0	0	0	1
New Hampshire	0	0	0	0	0	0	0	0	0	0	0	0	0
Massachusetts	0	0	0	0	0	0	0	1	0	1	0	0	2
Rhode Island	0	0	0	0	0	0	1	1	2	0	0	0	4
Connecticut	0	0	0	0	0	0	0	0	0	0	0	0	0
New York	0	0	0	0	0	0	1	0	1	0	0	0	2
New Jersey	0	0	0	0	0	0	0	0	0	1	0	0	1
Delaware	0	0	0	0	0	0	0	0	0	0	0	0	0
Maryland	0	0	0	2	2	1	2	2	2	0	0	0	11
Virginia	0	0	2	0	1	1	0	2	1	1	3	4	15
North Carolina	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	2	2	3	2	5	6	6	3	3	4	36

Table 5. Location of striped bass (≥ 711 mm TL), recaptured in 2015, that were originally tagged and released in the Rappahannock River during springs 1990-2015.

State	Month												total
	J	F	M	A	M	J	J	A	S	O	N	D	
Maine	0	0	0	0	0	0	1	0	0	0	0	0	1
New Hampshire	0	0	0	0	0	0	0	0	0	0	0	0	0
Massachusetts	0	0	0	0	0	0	0	1	0	1	0	0	2
Rhode Island	0	0	0	0	0	0	1	0	2	0	0	0	3
Connecticut	0	0	0	0	0	0	0	0	0	0	0	0	0
New York	0	0	0	0	0	0	1	0	1	0	0	0	2
New Jersey	0	0	0	0	0	0	0	0	0	1	0	0	1
Delaware	0	0	0	0	0	0	0	0	0	0	0	0	0
Maryland	0	0	0	2	1	1	0	0	0	0	0	0	4
Virginia	0	0	1	0	0	0	0	0	0	0	0	1	2
North Carolina	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	1	2	1	1	3	1	3	2	0	1	15

Table 6. Input recapture matrix for program MARK: from striped bass (>457 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2015.

Release		Recapture year																									
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	14	15
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	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	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	0	0
621	1993				50	37	17	8	9	2	0	1	0	0	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	0	0
698	1995						55	30	20	5	4	2	3	0	1	0	1	0	0	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	0	0
712	1997								47	26	14	3	0	1	2	1	0	0	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	0	0
853	1999										66	23	9	5	3	0	0	0	0	0	0	1	0	0	0	0	0
1,765	2000											122	51	23	16	6	5	1	1	0	0	0	0	0	0	0	0
797	2001												61	23	16	7	2	2	2	0	0	0	0	0	0	0	0
315	2002													20	8	15	1	1	2	1	0	0	0	0	0	0	0
852	2003														58	37	9	4	5	3	2	3	0	0	0	0	1
1,477	2004															80	21	13	7	4	2	1	0	0	0	0	0
921	2005																44	26	10	2	5	4	0	0	0	0	0
668	2006																	49	11	6	6	3	4	0	0	0	0
1,961	2007																		117	50	24	4	6	1	1	2	1
523	2008																			30	9	2	0	0	2	1	0
867	2009																				43	10	3	2	0	1	0
2050	2010																					47	9	8	2	1	1
416	2011																						24	4	1	0	1
1,222	2012																							57	14	5	2
760	2013																								36	9	8
454	2014																									16	6
313	2015																										14

Table 7. Input recapture matrix for program MARK: from striped bass (>710 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2015.

Release		Recapture year																									
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	14	15
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	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	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	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	0	0
123	1994					9	7	5	1	2	0	0	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	0	0
67	1996							1	3	1	0	0	1	0	0	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	0	0
158	1998									24	13	2	3	2	0	0	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	0	0
365	2000											28	19	14	9	4	3	0	1	0	0	0	0	0	0	0	0
269	2001												19	14	4	6	2	1	1	0	0	0	0	0	0	0	0
122	2002													10	6	7	1	0	2	1	0	0	0	0	0	0	0
400	2003														35	24	7	1	3	3	2	3	0	0	0	0	1
686	2004															39	12	13	5	4	2	1	0	0	0	0	0
284	2005																16	11	8	1	4	3	0	0	0	0	0
175	2006																	13	4	4	3	1	4	0	0	0	0
840	2007																		55	30	18	3	5	1	1	1	1
75	2008																			6	2	0	0	0	0	1	0
241	2009																				7	5	1	1	0	1	0
483	2010																					17	6	4	2	0	1
190	2011																						12	2	0	0	1
325	2012																							12	4	1	1
243	2013																								10	3	3
247	2014																									9	4
75	2015																										2

Table 8. 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 for Rappahannock River releases. 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, 2007-2011 and 2012-2015 (p); parameters vary in 2014-2015 (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)	20,760.43	0.00	1.00000	51
S(p)r(t)	20,831.97	71.55	0.00000	32
S(v)r(p)	20,883.83	123.40	0.00000	13

Table 9. 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, 1990-2015.

Year	$\hat{S}$	SE ($\hat{S}$)	P_l	Bias	$\hat{S}_{adj}$	$\hat{F}$	95% CI $\hat{F}$
1990	0.816	0.076	0.481	-0.143	0.952	-0.101	-0.22, 0.17
1991	0.276	0.045	0.524	-0.082	0.301	1.051	0.75, 1.39
1992	0.805	0.144	0.408	-0.142	0.938	-0.086	-0.26, 0.60
1993	0.604	0.115	0.456	-0.105	0.675	0.243	-0.03, 0.72
1994	0.568	0.111	0.381	-0.087	0.623	0.324	0.03, 0.81
1995	0.684	0.119	0.262	-0.054	0.723	0.174	-0.06, 0.65
1996	0.639	0.117	0.274	-0.040	0.666	0.257	0.00, 0.73
1997	0.567	0.094	0.330	-0.057	0.601	0.359	0.10, 0.75
1998	0.409	0.068	0.362	-0.059	0.435	0.682	0.24, 0.90
1999	0.374	0.057	0.286	-0.059	0.398	0.772	0.35, 0.95
2000	0.428	0.056	0.436	-0.066	0.459	0.630	0.25, 0.76
2001	0.463	0.085	0.367	-0.059	0.492	0.559	0.11, 0.82
2002	0.602	0.110	0.368	-0.050	0.634	0.306	-0.11, 0.61
2003	0.852	0.124	0.271	-0.039	0.887	-0.030	-0.31, 0.44
2004	0.348	0.057	0.281	-0.030	0.359	0.875	0.43, 1.07
2005	0.460	0.078	0.274	-0.024	0.472	0.601	0.17, 0.83
2006	0.532	0.084	0.354	-0.045	0.557	0.435	0.03, 0.65
2007	0.586	0.107	0.303	-0.034	0.607	0.350	-0.07, 0.65
2008	0.581	0.128	0.208	-0.020	0.592	0.374	-0.09, 0.79
2009	0.755	0.165	0.231	-0.022	0.772	0.109	-0.27, 0.73
2010	0.175	0.045	0.267	-0.011	0.177	1.583	0.96, 1.96
2011	0.446	0.120	0.152	-0.013	0.452	0.644	0.08, 1.12
2012	0.305	0.071	0.264	-0.022	0.312	1.015	0.46, 1.37
2013	0.510	0.152	0.161	-0.014	0.518	0.508	-0.06, 1.11
2014	0.405	0.163	0.278	-0.018	0.412	0.737	0.01, 1.56
2015	0.355	0.043	0.235	-0.021	0.362	0.865	0.49, 0.97

Table 10. 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 for Rappahannock River releases. 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, 2007-2011 and 2012-2015 (p); otherwise the same as p; parameters vary in 2014 and 2015 (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(v)r(p)	8,879.58	0.00	0.66654	13
S(t)r(t)	8,881.96	2.38	0.20298	52
S(p)r(t)	8,882.83	3.26	0.13048	32

Table 11. 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, 1990-2015.

Year	$\hat{S}$	SE ($\hat{S}$)	P_l	Bias	$\hat{S}_{adj}$	$\hat{F}$	95% CI	
1990	0.609	0.061	0.577	-0.082	0.663	0.261	0.09,	0.49
1991	0.619	0.075	0.560	-0.061	0.659	0.267	0.07,	0.55
1992	0.633	0.083	0.535	-0.139	0.735	0.157	-0.05,	0.47
1993	0.685	0.113	0.349	-0.048	0.719	0.179	-0.05,	0.62
1994	0.589	0.090	0.318	-0.053	0.622	0.325	0.09,	0.69
1995	0.645	0.119	0.204	-0.030	0.665	0.258	0.00,	0.75
1996	0.577	0.059	0.125	-0.015	0.586	0.385	0.21,	0.61
1997	0.557	0.075	0.167	-0.024	0.571	0.411	0.19,	0.72
1998	0.627	0.116	0.217	-0.037	0.651	0.280	0.02,	0.76
1999	0.553	0.082	0.200	-0.034	0.572	0.409	0.17,	0.75
2000	0.688	0.086	0.349	-0.036	0.714	0.187	0.00,	0.50
2001	0.629	0.095	0.298	-0.031	0.649	0.282	0.05,	0.66
2002	0.664	0.071	0.295	-0.041	0.693	0.217	0.05,	0.47
2003	0.653	0.134	0.246	-0.022	0.668	0.253	-0.17,	0.67
2004	0.540	0.102	0.321	-0.021	0.552	0.445	0.00,	0.74
2005	0.585	0.066	0.238	-0.023	0.599	0.362	0.02,	0.47
2006	0.619	0.097	0.282	-0.035	0.641	0.295	-0.09,	0.53
2007	0.598	0.083	0.228	-0.015	0.607	0.349	-0.02,	0.53
2008	0.655	0.151	0.163	-0.022	0.669	0.251	-0.19,	0.76
2009	0.563	0.081	0.105	-0.010	0.569	0.414	0.03,	0.60
2010	0.538	0.105	0.235	-0.019	0.549	0.450	0.00,	0.76
2011	0.575	0.103	0.071	-0.009	0.581	0.394	-0.03,	0.68
2012	0.481	0.111	0.150	-0.014	0.488	0.567	0.06,	0.96
2013	0.524	0.134	0.059	-0.006	0.528	0.489	-0.03,	0.98
2014	0.586	0.345	0.188	-0.020	0.598	0.364	-0.28,	2.20
2015	0.520	0.127	0.286	-0.069	0.558	0.433	-0.08,	0.88

Table 12. Input recapture matrix for program MARK: from striped bass (>457 mm TL) that were tagged and released in the James, York and Rappahannock rivers, springs 1990-2015.

Release		Recapture year																									
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**	**14**	**15**
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	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	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	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	0	0
195	**1994**					13	10	5	4	4	0	0	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	0	0
376	**1996**							21	18	7	3	1	1	1	0	0	1	0	0	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	0	0
784	**1998**									55	26	2	3	3	1	0	0	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	0	0
1,765	**2000**											122	51	23	16	6	5	1	1	0	0	0	0	0	0	0	0
797	**2001**												61	23	16	7	2	2	2	0	0	0	0	0	0	0	0
315	**2002**													20	8	15	1	1	2	1	0	0	0	0	0	0	0
852	**2003**														58	37	9	4	5	3	2	3	0	0	0	0	0
1,477	**2004**															80	21	13	7	4	2	1	0	0	0	0	0
921	**2005**																44	26	10	2	5	4	0	0	0	0	0
668	**2006**																	49	11	6	6	3	4	0	0	0	0
1,961	**2007**																		117	50	24	4	6	1	1	2	1
523	**2008**																			30	9	2	0	0	2	1	0
867	**2009**																				43	10	3	2	0	1	0
2050	**2010**																					47	9	8	2	1	1
416	**2011**																						24	4	1	0	1
1,222	**2012**																							57	14	5	2
760	**2013**																								36	9	8
614	**2014**																									20	6
490	**2015**																										20

Table 13. Input recapture matrix for program MARK: from striped bass (>710 mm TL) that were tagged and released in the James, York and Rappahannock rivers, springs 1990-2015.

Release		Recapture year																									
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**	**14**	**15**
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	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	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	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	0	0
123	**1994**					9	7	5	1	2	0	0	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	0	0
67	**1996**							1	3	1	0	0	1	0	0	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	0	0
158	**1998**									24	13	2	3	2	0	0	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	0	0
365	**2000**											28	19	14	9	4	3	0	1	0	0	0	0	0	0	0	0
269	**2001**												19	14	4	6	2	1	1	0	0	0	0	0	0	0	0
122	**2002**													10	6	7	1	0	2	1	0	0	0	0	0	0	0
400	**2003**														35	24	7	1	3	3	2	3	0	0	0	0	1
686	**2004**															39	12	13	5	4	2	1	0	0	0	0	0
284	**2005**																16	11	8	1	4	3	0	0	0	0	0
175	**2006**																	13	4	4	3	1	4	0	0	0	0
840	**2007**																		55	30	18	3	5	1	1	1	1
75	**2008**																			6	2	0	0	0	0	1	0
241	**2009**																				7	5	1	1	0	1	0
483	**2010**																					17	6	4	2	0	1
190	**2011**																						12	2	0	0	1
325	**2012**																							12	4	1	1
243	**2013**																								10	3	3
285	**2014**																									10	5
116	**2015**																										5

Table 14. 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 for James, York and Rappahannock river releases. 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, 2007-2011 and 2012-2015 (p); parameters vary in 2013-2015 (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)	23,761.84	0.00	1.00000	51
S(p)r(t)	23,850.17	88.33	0.00000	32
S(v)r(p)	23,913.45	151.61	0.00000	13

Table 15. 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 James, York and Rappahannock rivers, 1990-2015.

Year	$\hat{S}$	SE ($\hat{S}$)	P_l	Bias	$\hat{S}_{adj}$	$\hat{F}$	95% CI $\hat{F}$
1990	0.816	0.110	0.481	-0.143	0.952	-0.101	-0.25, 0.37
1991	0.276	0.065	0.524	-0.082	0.301	1.050	0.63, 1.55
1992	0.804	0.208	0.408	-0.142	0.937	-0.085	-0.29, 1.14
1993	0.604	0.166	0.456	-0.105	0.675	0.243	-0.11, 1.01
1994	0.568	0.161	0.381	-0.087	0.623	0.324	-0.05, 1.08
1995	0.684	0.172	0.262	-0.054	0.723	0.175	-0.11, 0.95
1996	0.639	0.168	0.274	-0.040	0.666	0.257	-0.06, 1.02
1997	0.567	0.136	0.330	-0.057	0.601	0.359	0.02, 0.97
1998	0.409	0.099	0.362	-0.059	0.435	0.532	0.14, 1.08
1999	0.374	0.083	0.286	-0.059	0.398	0.622	0.25, 1.11
2000	0.428	0.081	0.436	-0.074	0.463	0.470	0.15, 0.89
2001	0.463	0.122	0.367	-0.068	0.497	0.399	0.00, 1.02
2002	0.602	0.158	0.368	-0.063	0.642	0.143	-0.20, 0.86
2003	0.852	0.178	0.271	-0.050	0.897	-0.191	-0.34, 0.98
2004	0.348	0.081	0.281	-0.037	0.362	0.717	0.32, 1.23
2005	0.460	0.113	0.274	-0.031	0.475	0.445	0.06, 1.02
2006	0.532	0.121	0.354	-0.057	0.564	0.273	-0.07, 0.83
2007	0.586	0.154	0.303	-0.043	0.612	0.191	-0.16, 0.89
2008	0.581	0.185	0.208	-0.024	0.595	0.220	-0.17, 1.11
2009	0.755	0.239	0.231	-0.025	0.774	-0.044	-0.30, 1.30
2010	0.175	0.065	0.267	-0.013	0.177	1.429	0.76, 2.21
2011	0.446	0.173	0.152	-0.017	0.454	0.490	-0.04, 1.46
2012	0.305	0.103	0.264	-0.028	0.314	0.858	0.30, 1.60
2013	0.610	0.255	0.161	-0.018	0.622	0.175	-0.24, 1.51
2014	0.352	0.186	0.308	-0.021	0.359	0.724	0.00, 1.99
2015	0.376	0.074	0.375	-0.038	0.391	0.639	0.30, 1.06

Table 16. 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 for James, York and Rappahannock river releases. 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, 2007-2011 and 2012-2015 (p); otherwise the same as p; parameters vary in 2014 and 2015 (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(v)r(p)	8,283.67	0.00	0.83519	13
S(p)r(t)	8,287.95	4.28	0.09836	32
S(t)r(t)	8,288.73	5.06	0.06645	51

Table 17. 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 James, York and Rappahannock rivers, 1990-2015.

Year	$\hat{S}$	SE ($\hat{S}$)	P_l	Bias	$\hat{S}$ adj	$\hat{F}$	95% CI	
1990	0.623	0.043	0.577	-0.127	0.713	0.188	0.07,	0.34
1991	0.626	0.050	0.560	-0.131	0.721	0.178	0.04,	0.35
1992	0.631	0.054	0.535	-0.172	0.763	0.121	-0.02,	0.31
1993	0.648	0.073	0.349	-0.093	0.714	0.187	0.01,	0.45
1994	0.616	0.059	0.318	-0.070	0.663	0.261	0.10,	0.48
1995	0.605	0.077	0.204	-0.079	0.657	0.270	0.07,	0.57
1996	0.583	0.042	0.125	-0.016	0.592	0.375	0.25,	0.53
1997	0.576	0.051	0.167	-0.036	0.598	0.364	0.21,	0.56
1998	0.599	0.074	0.217	-0.084	0.654	0.275	0.07,	0.56
1999	0.575	0.055	0.200	-0.058	0.610	0.344	0.18,	0.56
2000	0.675	0.061	0.349	-0.063	0.721	0.177	0.03,	0.39
2001	0.656	0.067	0.298	-0.045	0.687	0.225	0.06,	0.47
2002	0.667	0.054	0.295	-0.062	0.712	0.190	0.06,	0.37
2003	0.608	0.086	0.246	-0.048	0.639	0.298	-0.07,	0.49
2004	0.571	0.067	0.321	-0.039	0.595	0.370	0.02,	0.48
2005	0.586	0.046	0.238	-0.029	0.604	0.355	0.07,	0.37
2006	0.597	0.063	0.282	-0.041	0.622	0.324	0.00,	0.41
2007	0.582	0.057	0.228	-0.031	0.601	0.359	0.04,	0.43
2008	0.601	0.099	0.163	-0.020	0.613	0.340	-0.06,	0.59
2009	0.571	0.055	0.105	-0.008	0.575	0.403	0.09,	0.47
2010	0.563	0.069	0.235	-0.015	0.572	0.410	0.06,	0.54
2011	0.575	0.067	0.071	-0.007	0.579	0.397	0.05,	0.51
2012	0.496	0.092	0.150	-0.009	0.500	0.543	0.09,	0.82
2013	0.510	0.101	0.059	-0.004	0.512	0.520	0.06,	0.83
2014	0.497	0.142	0.044	-0.002	0.498	0.546	-0.02,	1.10
2015	0.495	0.122	0.222	-0.018	0.504	0.535	0.01,	0.98

Table 18. 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, 1990-2015.

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	0.26	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	0.78	0.54	0.12	0.17	0.60
2001	0.71	0.51	0.16	0.22	0.49
2002	0.46	0.37	0.15	0.19	0.27
2003	0.12	0.11	0.16	0.17	-0.05
2004	1.03	0.64	0.10	0.16	0.86
2005	0.75	0.53	0.12	0.17	0.58
2006	0.59	0.44	0.14	0.19	0.40
2007	0.50	0.39	0.12	0.16	0.34
2008	0.52	0.41	0.08	0.11	0.42
2009	0.26	0.23	0.09	0.10	0.16
2010	1.73	0.82	0.05	0.10	1.64
2011	0.79	0.55	0.08	0.11	0.68
2012	1.16	0.69	0.07	0.12	1.04
2013	0.66	0.48	0.06	0.08	0.58
2014	0.89	0.59	0.11	0.17	0.72
2015	1.01	0.64	0.17	0.28	0.74

Table 19. 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, 1990-2015.

Year	Z	A	U	F	M
1990	0.41	0.34	0.25	0.31	0.10
1992	0.42	0.34	0.36	0.45	-0.03
1992	0.31	0.26	0.37	0.43	-0.12
1993	0.33	0.28	0.37	0.43	-0.10
1994	0.48	0.38	0.25	0.32	0.15
1995	0.41	0.33	0.41	0.50	-0.09
1996	0.54	0.41	0.18	0.23	0.31
1997	0.56	0.43	0.38	0.49	0.07
1998	0.43	0.35	0.45	0.56	-0.13
1999	0.56	0.43	0.30	0.39	0.17
2000	0.34	0.29	0.25	0.29	0.04
2001	0.43	0.35	0.21	0.25	0.18
2002	0.37	0.31	0.29	0.35	0.02
2003	0.40	0.33	0.24	0.29	0.11
2004	0.60	0.45	0.13	0.17	0.42
2005	0.51	0.40	0.20	0.26	0.25
2006	0.44	0.36	0.27	0.34	0.11
2007	0.50	0.39	0.19	0.24	0.26
2008	0.40	0.33	0.19	0.23	0.17
2009	0.56	0.43	0.09	0.11	0.45
2010	0.60	0.45	0.09	0.12	0.48
2011	0.54	0.42	0.09	0.12	0.42
2012	0.72	0.51	0.08	0.12	0.60
2013	0.64	0.47	0.08	0.11	0.53
2014	0.51	0.40	0.07	0.09	0.43
2015	0.58	0.44	0.03	0.04	0.55

Table 20. 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 James, York and Rappahannock rivers, springs, 1990-2015.

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	0.78	0.54	0.12	0.17	0.60
2001	0.71	0.51	0.16	0.22	0.49
2002	0.46	0.37	0.15	0.19	0.27
2003	0.12	0.11	0.16	0.17	-0.05
2004	1.03	0.64	0.10	0.16	0.86
2005	0.75	0.53	0.12	0.17	0.58
2006	0.59	0.44	0.14	0.19	0.40
2007	0.50	0.39	0.12	0.16	0.34
2008	0.52	0.41	0.09	0.11	0.41
2009	0.26	0.23	0.09	0.11	0.15
2010	1.73	0.82	0.05	0.10	1.64
2011	0.79	0.55	0.08	0.11	0.68
2012	1.16	0.69	0.08	0.13	1.03
2013	0.48	0.38	0.08	0.10	0.38
2014	1.03	0.64	0.09	0.14	0.88
2015	0.95	0.61	0.13	0.20	0.74

Table 21. 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 James, York and Rappahannock rivers, springs, 1990-2015.

Year	Z	A	U	F	M
1990	0.34	0.29	0.25	0.30	0.04
1992	0.33	0.28	0.36	0.43	-0.10
1992	0.27	0.24	0.37	0.42	-0.15
1993	0.34	0.29	0.37	0.43	-0.09
1994	0.41	0.34	0.25	0.31	0.10
1995	0.42	0.34	0.41	0.50	-0.08
1996	0.52	0.41	0.18	0.23	0.29
1997	0.51	0.40	0.38	0.48	0.03
1998	0.42	0.35	0.45	0.56	-0.13
1999	0.49	0.39	0.30	0.37	0.12
2000	0.33	0.28	0.25	0.29	0.03
2001	0.38	0.31	0.21	0.25	0.13
2002	0.34	0.29	0.29	0.34	0.00
2003	0.45	0.36	0.24	0.30	0.15
2004	0.52	0.41	0.13	0.17	0.35
2005	0.51	0.40	0.20	0.26	0.25
2006	0.47	0.38	0.27	0.34	0.13
2007	0.51	0.40	0.19	0.24	0.27
2008	0.49	0.39	0.19	0.24	0.25
2009	0.55	0.42	0.09	0.11	0.44
2010	0.56	0.43	0.09	0.12	0.44
2011	0.55	0.42	0.09	0.12	0.42
2012	0.69	0.50	0.08	0.12	0.58
2013	0.67	0.49	0.08	0.11	0.56
2014	0.70	0.50	0.07	0.10	0.60
2015	0.69	0.50	0.05	0.07	0.62

Table 22a. Input recapture matrix for IRCR analysis: from striped bass (>457 mm TL) tagged and released in the Rappahannock River, springs 1990-2015. Harvested recaptures only.

Release		Recapture year																									
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	14	15
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	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	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	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	0	0
195	1994					6	7	4	1	2	0	0	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	0	0
376	1996							3	10	3	2	1	1	1	0	0	1	0	0	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	0	0
784	1998									28	16	1	3	1	0	0	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	0	0
1,765	2000											44	23	11	7	4	5	1	1	0	0	0	0	0	0	0	0
797	2001												31	14	5	7	1	0	0	0	0	0	0	0	0	0	0
315	2002													10	4	6	1	1	1	1	0	0	0	0	0	0	0
852	2003														32	20	5	3	3	2	1	2	0	0	0	0	1
1,477	2004															45	14	8	4	3	1	1	0	0	0	0	0
921	2005																27	17	6	1	4	1	0	0	0	0	0
668	2006																	27	4	5	5	3	4	0	0	0	0
1,961	2007																		63	34	16	3	5	0	1	1	1
523	2008																			17	4	0	0	0	0	1	0
867	2009																				26	7	2	2	0	1	0
2050	2010																					29	7	8	2	0	1
416	2011																						13	4	0	0	1
1,222	2012																							34	11	5	2
760	2013																								23	8	7
454	2014																									8	4
313	2015																										8

Table 22b. Input recapture matrix for IRCR analysis: from striped bass (>457 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2015. Recaptures released with streamers cut off only.

Release		Recapture year																									
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	14	15
1,464	1990	77	28	18	9	1	1	0	1	2	0	0	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	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	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	0	0
195	1994					6	1	0	3	1	0	0	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	0	0
376	1996							10	7	3	0	0	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	0	0
784	1998									21	7	0	0	1	1	0	0	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	0	0
1,765	2000											49	23	7	3	0	0	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	0	0
315	2002													7	3	2	0	0	1	0	0	0	0	0	0	0	0
852	2003														12	11	3	1	1	0	0	0	0	0	0	0	0
1,477	2004															25	5	5	1	0	1	0	0	0	0	0	0
921	2005																14	8	2	1	0	1	0	0	0	0	0
668	2006																	19	6	1	1	0	0	0	0	0	0
1,961	2007																		34	10	1	1	0	1	0	1	0
523	2008																			7	2	2	0	0	0	0	0
867	2009																				16	2	0	0	0	0	0
2050	2010																					14	2	0	0	1	0
416	2011																						5	0	0	0	0
1,222	2012																							18	2	0	0
760	2013																								7	1	1
454	2914																									6	2
313	2015																										5

Table 23a. Input recapture matrix for IRCR analysis: from striped bass (>710 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2015 Harvested recaptures only.

Release		Recapture year																									
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**	**14**	**15**
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	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	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	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	0	0
123	**1994**					4	4	4	1	0	0	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	0	0
67	**1996**							0	3	1	0	0	1	0	0	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	0	0
158	**1998**									16	9	1	3	1	0	0	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	0	0
365	**2000**											13	11	6	5	3	3	0	1	0	0	0	0	0	0	0	0
269	**2001**												9	8	2	6	1	0	0	0	0	0	0	0	0	0	0
122	**2002**													7	3	5	1	0	1	1	0	0	0	0	0	0	0
400	**2003**														23	13	3	1	2	2	1	2	0	0	0	0	1
686	**2004**															21	8	8	3	3	1	1	0	0	0	0	0
284	**2005**																12	7	5	1	3	0	0	0	0	0	0
175	**2006**																	10	3	3	2	1	4	0	0	0	0
840	**2007**																		33	22	11	2	4	0	1	1	1
75	**2008**																			5	1	0	0	0	0	1	0
241	**2009**																				5	3	0	1	0	1	0
483	**2010**																					11	5	4	2	0	1
190	**2011**																						7	2	0	0	1
325	**2012**																							9	4	1	1
243	**2013**																								5	3	3
247	**2014**																									5	2
75	**2015**																										1

Table 23b. Input recapture matrix for IRCR analysis: from striped bass (>710 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2015. Recaptures released with streamers cut off only.

Release		Recapture year																									
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**	**14**	**15**
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	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	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	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	0	0
123	**1994**					4	1	0	0	1	0	0	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	0	0
67	**1996**							1	0	0	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	0	0
158	**1998**									6	4	0	0	1	0	0	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	0	0
365	**2000**											9	7	4	2	0	0	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	0	0
122	**2002**													2	2	0	0	0	1	0	0	0	0	0	0	0	0
400	**2003**														8	8	3	0	0	0	0	0	0	0	0	0	0
686	**2004**															16	2	5	1	0	1	0	0	0	0	0	0
284	**2005**																4	4	1	0	0	1	0	0	0	0	0
175	**2006**																	2	1	1	1	0	0	0	0	0	0
840	**2007**																		12	7	1	1	0	1	0	0	0
75	**2008**																			0	0	0	0	0	0	0	0
241	**2009**																				1	1	0	0	0	0	0
483	**2010**																					5	1	0	0	0	0
190	**2011**																						1	0	0	0	0
325	**2012**																							2	0	0	0
243	**2013**																								1	0	0
247	**2014**																									3	2
75	**2015**																										1

Table 24. Model Akaike weighting results (striped bass ≥ 457 mm TL) for the 2M IRCR analyses for Rappahannock River releases. Model notations: Fishing mortality (F), release mortality (F') and natural mortality (M), annual estimates (t) and period estimates (6p- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011 and 2012-2015; d- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011, 2012-2013, 2014 and 2015; v- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011, 2012-2013 and 2014-2015).

2M (1990-1997, 1998-2015)			
model	**$QAIC_c$**	**weight**	**parameters**
F(6p), F'(6p)	11,646.2	0.467	14
F(t),F'(6p)	11,646.5	0.385	34
F(d), F'(d)	11,649.7	0.081	16
F(v), F'(v)	11,650.1	0.066	16
F(6p), F'(t)	11,666.4	0.000	34
F(t), F'(t)	11,667.8	0.000	54

Table 25. 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 of Rappahannock River releases, 1990-2015.

Year	2M			
	S	M	F	SE
1990	0.631	0.385	0.066	0.022
1991	0.626	0.385	0.075	0.013
1992	0.615	0.385	0.092	0.020
1993	0.618	0.385	0.088	0.016
1994	0.611	0.385	0.098	0.029
1995	0.603	0.385	0.117	0.024
1996	0.617	0.385	0.093	0.022
1997	0.607	0.385	0.109	0.018
1998	0.482	0.623	0.103	0.015
1999	0.479	0.623	0.109	0.017
2000	0.494	0.623	0.078	0.014
2001	0.489	0.623	0.089	0.015
2002	0.488	0.623	0.089	0.018
2003	0.485	0.623	0.099	0.015
2004	0.484	0.623	0.101	0.014
2005	0.489	0.623	0.090	0.015
2006	0.484	0.623	0.099	0.015
2007	0.496	0.623	0.077	0.013
2008	0.493	0.623	0.082	0.019
2009	0.494	0.623	0.080	0.018
2010	0.504	0.623	0.061	0.015
2011	0.504	0.623	0.060	0.016
2012	0.507	0.623	0.055	0.010
2013	0.508	0.623	0.053	0.010
2014	0.510	0.623	0.050	0.011
2015	0.505	0.623	0.058	0.015

Table 26. Model Akaike weighting results (striped bass ≥ 711 mm TL) for the 2M IRCR analyses of Rappahannock River releases. Model notations: Fishing mortality (F), release mortality (F') and natural mortality (M), annual estimates (t) and period estimates (6p- 1990-1994, 1995-1999, 2000-2002, 2003-2006,2007-2011 and 2012-2015; d- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011, 2012-2014 and 2015; v- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011, 2012-2013 and 2014-2015).

2M (1990-2003, 2004-2015)			
model	**$QAIC_c$**	**weight**	**parameters**
F(6p), F'(6p)	9,233.6	0.694	14
F(d),F'(d)	9,236.6	0.156	16
F(v), F'(v)	9,236.7	0.147	16
F(t), F'(6p)	9,244.9	0.002	34
F(6p), F'(t)	9,255.2	0.000	34
F(t), F'(t)	9,266.5	0.000	54

Table 27. 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 of Rappahannock River releases, 1990-2015.

Year	2M			
	S	M	F	SE
1990	0.668	0.252	0.141	0.016
1991	0.668	0.252	0.141	0.016
1992	0.668	0.252	0.141	0.015
1993	0.668	0.252	0.141	0.015
1994	0.668	0.252	0.141	0.016
1995	0.623	0.252	0.216	0.022
1996	0.623	0.252	0.215	0.022
1997	0.623	0.252	0.216	0.022
1998	0.623	0.252	0.216	0.022
1999	0.623	0.252	0.216	0.022
2000	0.701	0.252	0.099	0.013
2001	0.701	0.252	0.099	0.013
2002	0.701	0.252	0.099	0.013
2003	0.702	0.252	0.099	0.009
2004	0.571	0.458	0.099	0.009
2005	0.571	0.458	0.099	0.009
2006	0.571	0.458	0.099	0.009
2007	0.576	0.458	0.091	0.009
2008	0.576	0.458	0.091	0.010
2009	0.576	0.458	0.091	0.009
2010	0.576	0.458	0.091	0.010
2011	0.576	0.458	0.091	0.010
2012	0.604	0.458	0.046	0.008
2013	0.604	0.458	0.046	0.008
2914	0.603	0.458	0.046	0.008
2915	0.602	0.458	0.048	0.011

Table 28a. Input recapture matrix for IRCR analysis: from striped bass (>457 mm TL) tagged and released in the James, York and Rappahannock rivers, springs 1990-2015. Harvested recaptures only.

Release		Recapture year																									
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**	**14**	**15**
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	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	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	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	0	0
195	**1994**					6	7	4	1	2	0	0	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	0	0
376	**1996**							3	10	3	2	1	1	1	0	0	1	0	0	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	0	0
784	**1998**									28	16	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0
853	**1999**										30	7	4	2	2	0	0	0	0	0	0	1	0	0	0	0	0
1,765	**2000**											44	23	11	7	4	5	1	1	0	0	0	0	0	0	0	0
797	**2001**												31	14	5	7	1	0	0	0	0	0	0	0	0	0	0
315	**2002**													10	4	6	1	1	1	1	0	0	0	0	0	0	0
852	**2003**														32	20	5	3	3	2	1	2	0	0	0	0	1
1,477	**2004**															45	14	8	4	3	1	1	0	0	0	0	0
921	**2005**																27	17	6	1	4	1	0	0	0	0	0
668	**2006**																	27	4	5	5	3	4	0	0	0	0
1,961	**2007**																		64	34	16	3	5	0	1	1	1
523	**2008**																			17	4	0	0	0	0	1	0
867	**2009**																				26	7	2	2	0	1	0
2050	**2010**																					29	7	8	2	0	1
416	**2011**																						13	4	0	0	1
1,222	**2012**																							34	11	5	2
760	**2013**																								23	8	7
614	**2014**																									8	4
490	**2015**																										11

Table 28b. Input recapture matrix for IRCR analysis: from striped bass (>457 mm TL) that were tagged and released in the James, York and Rappahannock rivers, springs 1990-2015. Recaptures released with streamers cut off only.

Release		Recapture year																									
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**	**14**	**15**
1,464	**1990**	77	28	18	9	1	1	0	1	2	0	0	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	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	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	0	0
195	**1994**					6	1	0	3	1	0	0	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	0	0
376	**1996**							10	7	3	0	0	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	0	0
784	**1998**									21	7	0	0	1	1	0	0	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	0	0
1,765	**2000**											50	23	7	3	0	0	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	0	0
315	**2002**													7	3	2	0	0	1	0	0	0	0	0	0	0	0
852	**2003**														12	11	3	1	1	0	0	0	0	0	0	0	0
1,477	**2004**															25	5	5	1	0	1	0	0	0	0	0	0
921	**2005**																14	8	2	1	0	1	0	0	0	0	0
668	**2006**																	19	6	1	1	0	0	0	0	0	0
1,961	**2007**																		34	10	1	1	0	1	0	1	0
523	**2008**																			7	2	2	0	0	0	0	0
867	**2009**																				16	2	0	0	0	0	0
2050	**2010**																					14	2	0	0	1	0
416	**2011**																						5	0	0	0	0
1,222	**2012**																							18	2	0	0
760	**2013**																								7	1	1
614	**2914**																									8	2
490	**2015**																										7

Table 29a. Input recapture matrix for IRCR analysis: from striped bass (>710 mm TL) that were tagged and released in the James, York and Rappahannock rivers, springs 1990-2015. Harvested recaptures only.

Release		Recapture year																									
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	14	15
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	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	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	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	0	0
123	1994					4	4	4	1	0	0	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	0	0
67	1996							0	3	1	0	0	1	0	0	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	0	0
158	1998									16	9	1	3	1	0	0	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	0	0
365	2000											13	11	6	5	3	3	0	1	0	0	0	0	0	0	0	0
269	2001												9	8	2	6	1	0	0	0	0	0	0	0	0	0	0
122	2002													7	3	5	1	0	1	1	0	0	0	0	0	0	0
400	2003														23	13	3	1	2	2	1	2	0	0	0	0	1
686	2004															21	8	8	3	3	1	1	0	0	0	0	0
284	2005																12	7	5	1	3	0	0	0	0	0	0
175	2006																	10	3	3	2	1	4	0	0	0	0
840	2007																		33	22	11	2	4	0	1	1	1
75	2008																			5	1	0	0	0	0	1	0
241	2009																				5	3	0	1	0	1	0
483	2010																					11	5	4	2	0	1
190	2011																						7	2	0	0	1
325	2012																							9	4	1	1
243	2013																								5	3	3
285	2014																									5	3
116	2015																										2

Table 29b. Input recapture matrix for IRCR analysis: from striped bass (>710 mm TL) that were tagged and released in the James, York and Rappahannock rivers, springs 1990-2015. Recaptures released with streamers cut off only.

Release		Recapture year																									
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**	**14**	**15**
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	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	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	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	0	0
123	**1994**					4	1	0	0	1	0	0	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	0	0
67	**1996**							1	0	0	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	0	0
158	**1998**									6	4	0	0	1	0	0	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	0	0
365	**2000**											9	7	4	2	0	0	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	0	0
122	**2002**													2	2	0	0	0	1	0	0	0	0	0	0	0	0
400	**2003**														8	8	3	0	0	0	0	0	0	0	0	0	0
686	**2004**															16	2	5	1	0	1	0	0	0	0	0	0
284	**2005**																4	4	1	0	0	1	0	0	0	0	0
175	**2006**																	2	1	1	1	0	0	0	0	0	0
840	**2007**																		12	7	1	1	0	1	0	0	0
75	**2008**																			0	0	0	0	0	0	0	0
241	**2009**																				1	1	0	0	0	0	0
483	**2010**																					5	1	0	0	0	0
190	**2011**																						1	0	0	0	0
325	**2012**																							2	0	0	0
243	**2013**																								1	0	0
285	**2014**																									3	2
116	**2015**																										2

Table 30. Model Akaike weighting results (striped bass ≥ 457 mm TL) for the 2M IRCR analyses for James, York and Rappahannock river releases. Model notations: Fishing mortality (F), release mortality (F') and natural mortality (M), annual estimates (t) and period estimates (6p- 1990-1994, 1995-1999, 2000-2002 and 2003-2006, 2007-2011 and 2012-2015; d- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011, 2012-2014 and 2015; v- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011, 2012-2013 and 2014-2015).

2M (1990-1997, 1998-2015)			
model	**$QAIC_c$**	**weight**	**parameters**
F(6p), F'(6p)	11,759.1	0.439	14
F(t),F'(6p)	11,759.2	0.426	34
F(v), F'(v)	11,762.8	0.069	16
F(d), F'(d)	11,762.9	0.065	16
F(6p), F'(t)	11,779.2	0.000	34
F(t), F'(t)	11,780.3	0.000	54

Table 31. 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 of James, York and Rappahannock River releases, 1990-2015.

Year	2M			
	S	M	F	SE
1990	0.632	0.386	0.065	0.022
1991	0.626	0.386	0.074	0.013
1992	0.614	0.386	0.094	0.020
1993	0.617	0.386	0.088	0.016
1994	0.610	0.386	0.100	0.029
1995	0.602	0.386	0.118	0.024
1996	0.618	0.386	0.091	0.023
1997	0.606	0.386	0.110	0.018
1998	0.483	0.621	0.103	0.016
1999	0.479	0.621	0.110	0.017
2000	0.495	0.621	0.077	0.014
2001	0.489	0.621	0.089	0.015
2002	0.489	0.621	0.089	0.018
2003	0.485	0.621	0.099	0.015
2004	0.484	0.621	0.101	0.014
2005	0.490	0.621	0.090	0.015
2006	0.485	0.621	0.100	0.016
2007	0.496	0.621	0.078	0.013
2008	0.493	0.621	0.083	0.020
2009	0.494	0.621	0.081	0.018
2010	0.505	0.621	0.060	0.015
2011	0.506	0.621	0.059	0.017
2012	0.508	0.621	0.054	0.010
2013	0.509	0.621	0.051	0.010
2014	0.512	0.621	0.047	0.011
2015	0.508	0.621	0.053	0.012

Table 32. Model Akaike weighting results (striped bass ≥ 711 mm TL) for the 2M IRCR analyses of James, York and Rappahannock River releases. Model notations: Fishing mortality (F), release mortality (F') and natural mortality (M), annual estimates (t) and period estimates (6p- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011 and 2012-2015; d- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011, 2012-2014 and 2015; v- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011, 2012-2013 and 2014-2015).

2M (1990-2003, 2004-2015)			
model	**$QAIC_c$**	**weight**	**parameters**
F(6p), F'(6p)	9,273.7	0.619	14
F(d),F'(d)	9,275.7	0.223	16
F(v), F'(v)	9,276.5	0.156	16
F(t), F'(6p)	9,292.9	0.002	34
F(6p), F'(t)	9,294.7	0.000	34
F(t), F'(t)	9,306.1	0.000	54

Table 33. 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 of James, York and Rappahannock River releases, 1990-2015.

Year	2M			
	S	M	F	SE
1990	0.668	0.252	0.141	0.016
1991	0.668	0.252	0.141	0.016
1992	0.668	0.252	0.141	0.015
1993	0.668	0.252	0.141	0.015
1994	0.668	0.252	0.141	0.016
1995	0.623	0.252	0.216	0.022
1996	0.623	0.252	0.215	0.022
1997	0.623	0.252	0.216	0.022
1998	0.623	0.252	0.216	0.022
1999	0.623	0.252	0.216	0.022
2000	0.701	0.252	0.099	0.013
2001	0.701	0.252	0.099	0.013
2002	0.701	0.252	0.099	0.013
2003	0.702	0.252	0.099	0.009
2004	0.570	0.460	0.099	0.009
2005	0.570	0.460	0.099	0.009
2006	0.570	0.460	0.099	0.009
2007	0.575	0.460	0.092	0.009
2008	0.575	0.460	0.092	0.010
2009	0.575	0.460	0.092	0.010
2010	0.575	0.460	0.092	0.010
2011	0.575	0.460	0.092	0.010
2012	0.602	0.460	0.047	0.008
2013	0.602	0.460	0.047	0.008
2014	0.602	0.460	0.047	0.008
2015	0.600	0.460	0.050	0.011

III. The feasibility of close kinship analysis as a new methodology for estimation of spawning population size of striped bass in the Rappahannock River.

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Introduction

Striped bass spawning occurs in spring (March to May) upriver, with young fish gradually moving down the rivers into higher salinity waters as they grow (Secor and Houde, 1995; Secor, Gunderson, and Karlsson, 2000). The Chesapeake Bay is considered one of the most important spawning ground areas for striped bass (Kernehan 1981; Kohlenstein 1981) and is thought to contribute up to 84% of the total Atlantic population (Waldman Maceda and Wirgin, 2012). However, there is temporal uncertainty about the contribution each year based on the recruitment success within the bay. Currently, indices of abundance are estimated using fishery independent surveys from several states, each providing a catch-per-unit-effort (CPUE) index and fishery dependent survey catch rates. Abundance information is also calculated from eight tagging programs across nine states which includes programs to cover the spawning grounds and coastal areas. (ASMFC 2013). With management measures the stock has rebounded, but is still not considered fully rebuilt to the management goals.

Effective management requires confident estimates of the size of fish stocks, and having these estimates from stock assessments is key to proper management. For striped bass within Chesapeake Bay, there is still a large uncertainty in estimates of population size. Developing methods to provide a more confident, cost-effective option is highly desirable for fish of high economic and recreational interest (such as striped bass). A novel methodology to estimate population sizes is the use of close-kinship analysis (CKA). First introduced by Skaug (2001), the methodology was described in an attempt to determine a complimentary method to estimate population sizes of North Atlantic Minke Whales in Norwegian waters. Close kinship is able to estimate abundance without catch or effort data-data that can have measurement biases between different sampling programs. In recent years, the method has been successfully applied to Southern Bluefin Tuna (Bravington et al., 2014a) and Antarctic Blue Whales (Bravington et al., 2014b). A study on the feasibility of implementing the use of CKA would provide the groundwork for future research programs-often one of the most important steps in the implementation of a new analysis.

Materials and Methods

Close kinship works off of the simple idea that each sampled juvenile (or young of year) must have two parents. If a population of spawners is large, then it would be expected that there would be a low number of offspring (juvenile) matches with spawners (parents), or a lower number parent offspring pairs (POPs)-the number of spawners is inversely related to the number of POPs made (Bravington et al., 2014a). Parentage analysis has been used to estimate a variety of parameters important for informing fisheries management, including reproductive success, reproductive behaviors, self-recruitment, fine scale population structure, population connectivity, and inbreeding (Neff et al., 2000; Avise et al., 2002; Harrison 2013). For close kin-analysis to work, there must be ways to collect random samples of both juveniles and adults, which requires known knowledge about the spawning grounds and behavior of the fish. For striped bass, this methodology is already in place by utilizing pre-existing sample programs to ensure random samples of each group are collected.

All striped bass samples taken are in the form of fin-clips, with adult samples having been taken during the routine Striped Bass Tagging Survey on the Rappahannock River. Utilizing an additional annual survey at VIMS, young of year (YOY) striped bass samples came from the Juvenile Seine Survey-aimed at assessing recruitment. Adult fish are identified as those > 458 mm TL) in order to ensure that all fish sampled have the potential to be a parent to a young of year (YOY) fish that year. The molecular markers used to determine POPs will be microsatellite loci (short, tandem repeats of nuclear DNA) amplified in groups called multiplexes. Statistical power associated with the detection of parent-offspring pairs is highly dependent on the number of loci and the number of alleles at each locus (Harrison et al., 2013). Microsatellites were screened from the existing literature (Couch et al., 2006; Rexroad et al., 2006; Fountain et al., 2009; Gauthier et al., 2013) and approximately 60 markers were compiled into a large spreadsheet based on allelic diversity, chromosome location (linkage map from Liu et al., 2012), and estimated heterozygosity. Loci were further screened using Multiplex Manager (Holleley and Geerts, 2009), a program that assembles multiplex panels of up to six loci based on annealing temperatures and primer sequences. The number was reduced to 22 potential markers, with a single marker being chosen from each chromosome in order to ensure complete genome coverage and lower physical linkage issues. Markers will then be lab tested to ensure proper amplification in a series of multiplexes, and protocols will be developed for each multiplex panel. Selected markers will be further tested and screened in order to promote low error rates and power in parentage analysis. All amplification and analysis will be pre formed in-house at VIMS.

The Rappahannock River was selected as the study site for this research due to the availability of samples and it's supposed smaller population size than the James River. Close kinship analysis, if proven to be realistic given the sampling parameters, may provide population size estimates for striped bass within Chesapeake Bay. In order to successfully use this analysis, one must be able to confidently assign 50 POPs (Bravington, personal communication). If this analysis proves to be feasible it can be used to back-calculate population size of spawning adults without the need for CPUE data. If the analysis proves to be successful, an additional analyses, such as adding length and sex data, may be added to examine the relationship between parameters and reproductive output.

Results

In total, 1,341 fin clips were collected from adult and juvenile fish during the 2016 sampling season. While this study focuses primarily on Rappahannock fish, fin clips were also taken from the two other sampled rivers (Mattaponi and James) for future studies (see Table 1). Adult samples from the Rappahannock total 757 adults, and YOY samples total 591. The population sampled includes 143 female fish, with fork lengths ranging from 440-1078, and 614 males, with fork lengths ranging from 294-948. Adult fish were collected from the Rappahannock in April and May, whereas Mattaponi and James River fish were primarily collected in March and April (Table 1). Juvenile fish were collected from June to August 2016 (Table 2), with the majority of the fish being collected from the upper Rappahannock (mile markers: 50-73).

Of this total, to date all adult fin clip samples have been isolated for DNA and are ready for microsatellite sequencing. Currently, juvenile fin clips are undergoing DNA isolation, and will begin microsatellite work October 2016. As of now, a total of 20 microsatellite markers have been optimized for microsatellite work.

Discussion

Assessing the population size for striped bass is a high priority for management, and testing new techniques is an important step. Finding a way to compliment current abundance estimators will only enhance our understanding of the Virginia striped bass populations, ensuring the most appropriate and successful management. If close kinship analysis proves to be feasible way to provide alternative abundance estimates, the technique can be further applied to address other management areas. These areas include site fidelity, contribution of each sex, and even migration estimates. However, in order to examine these areas there must first be a test study in order to assure that this new methodology is applicable to striped bass. The main objective of this study is to determine just that, and aid in providing more precise estimates of abundance.

The timeline for the completion of this study extends into 2017. DNA isolation is currently underway (as referenced in the Results) for juvenile fish. Collection of genetic data will start October 2016, and continue through early 2017. Genetic results will be obtained in early Spring 2017, and the applicability of this analysis will be assessed.

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Table 1. Number of adult fish fin clips taken from each river across the three sampling months (March, April, and May). Totals for each month and river are shown.

Month	n	River		
		Rappahannock	James	Mattaponi
March	88	0	71	17
April	868	618	95	155
May	139	139	0	0
Total		757	166	172

Table 2. Number of juvenile fish fin clips taken from the upper and lower Rappahannock River during each round of sampling. Included in parentheses are the mile marker ranges defining upper and lower areas. An additional sampling time was added to the routine seine survey after to boost sample sizes.

Round	Date	Upper (Mile Marker 50-73)	Lower (Mile Marker 10-44)
Round 1	June 20 & 22, 2016	139	56
Round 2	July 5 & 7, 2016	142	40
Round 3	July 19 & 21, 2016	72	25
Round 4	August 2 & 4, 2016	52	10
Round 5	August 17 & 19, 2016	45	3
Post-Survey	September 6, 2016	7	0
Total		457	134

Appendix A. Daily flow rates of the Rappahannock River, 30 March – 3 May, 1985-2015.

Striped Bass Assessment and Monitoring Program

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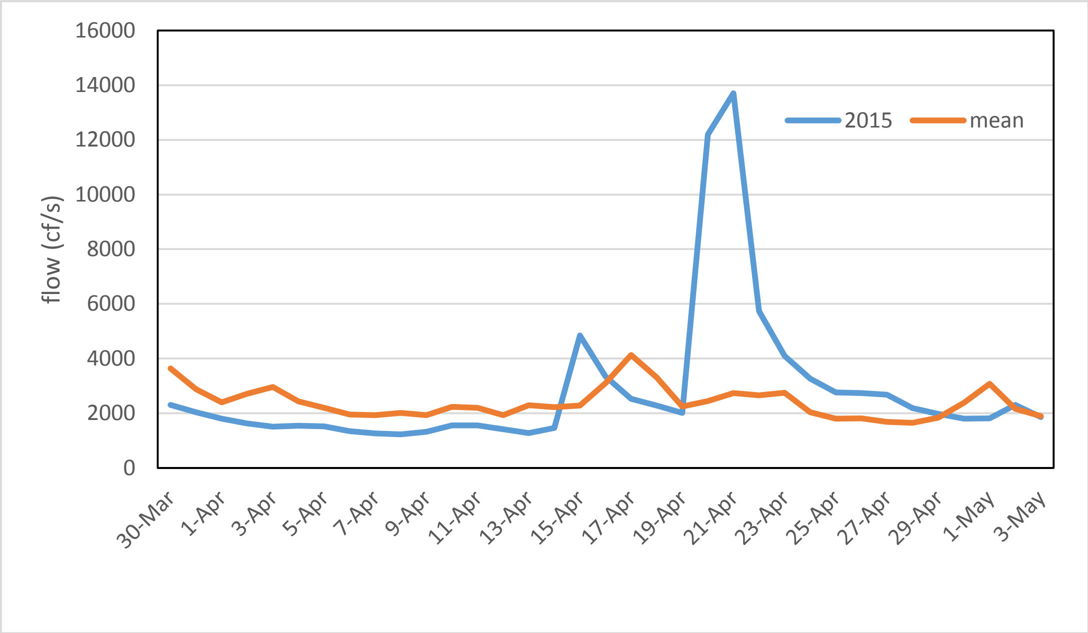
Figure 1. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2014-2015.



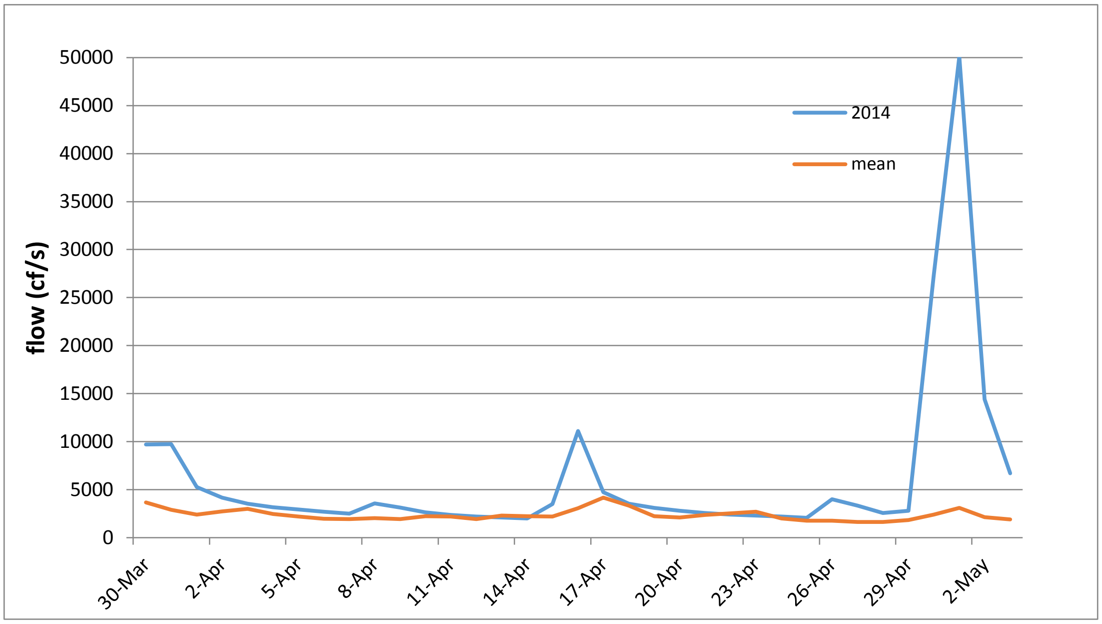
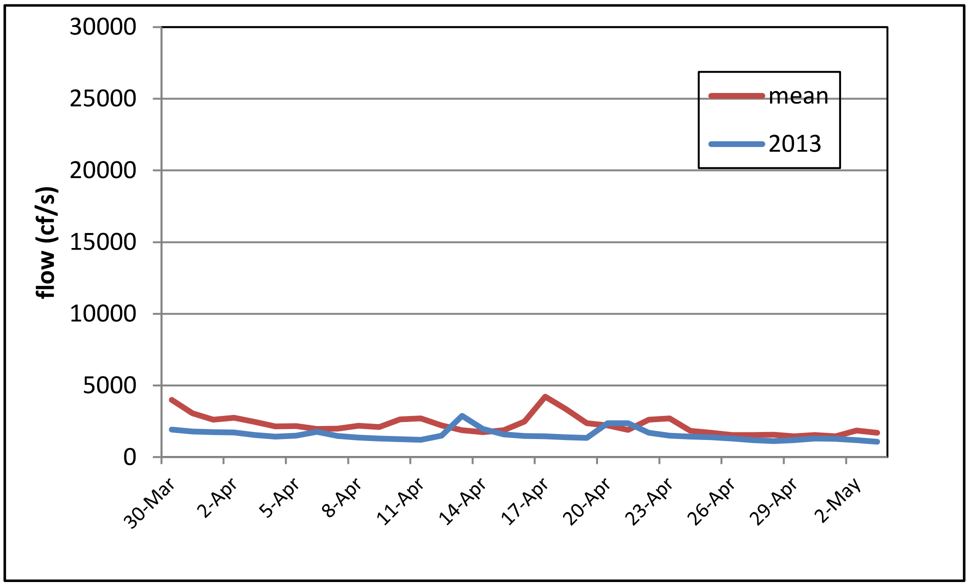


Figure 2. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, spring 2012-2013.



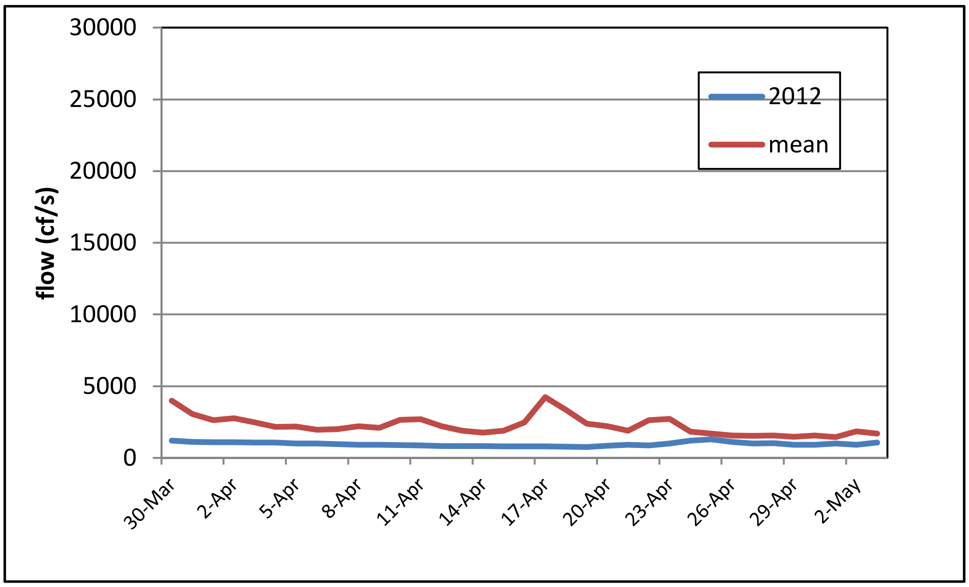
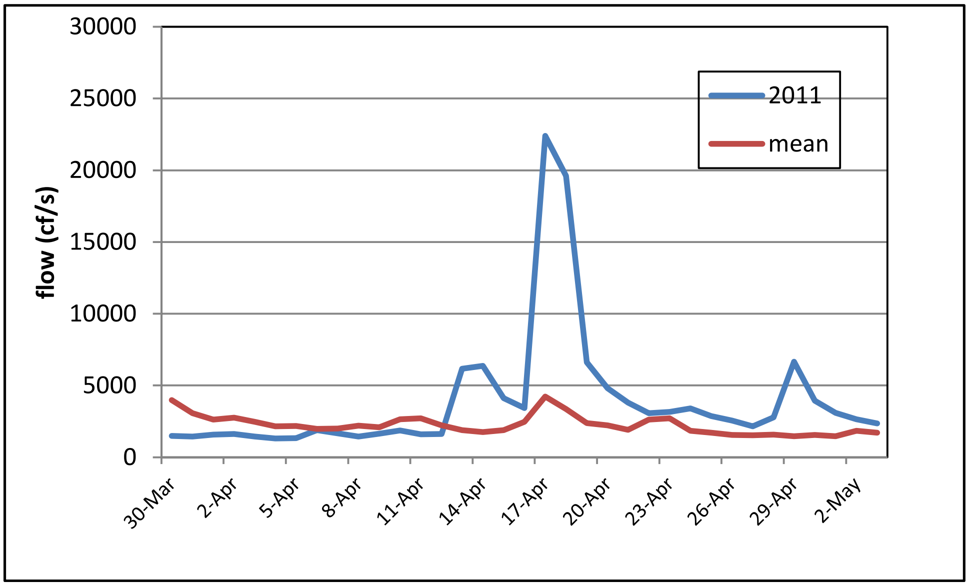


Figure 3. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2010-2011.



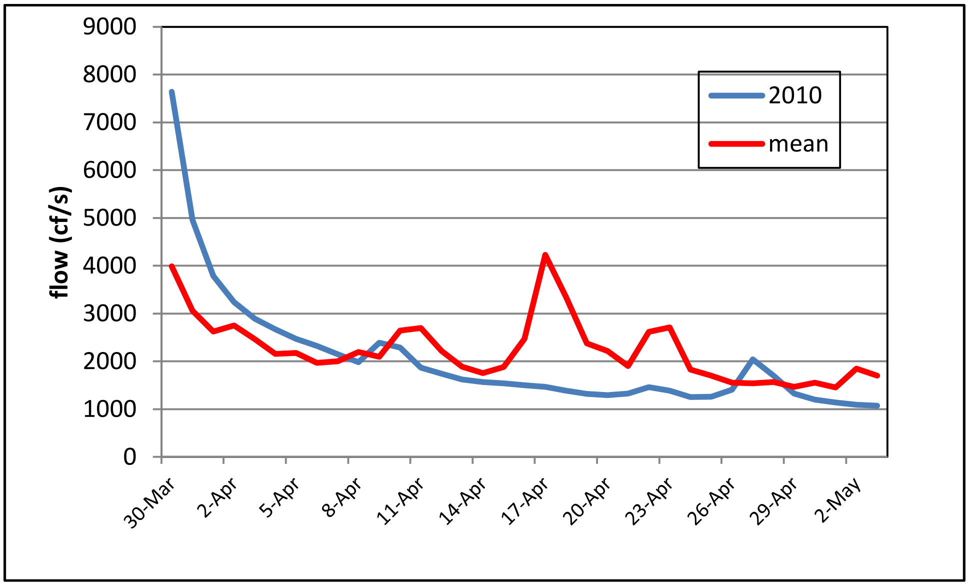
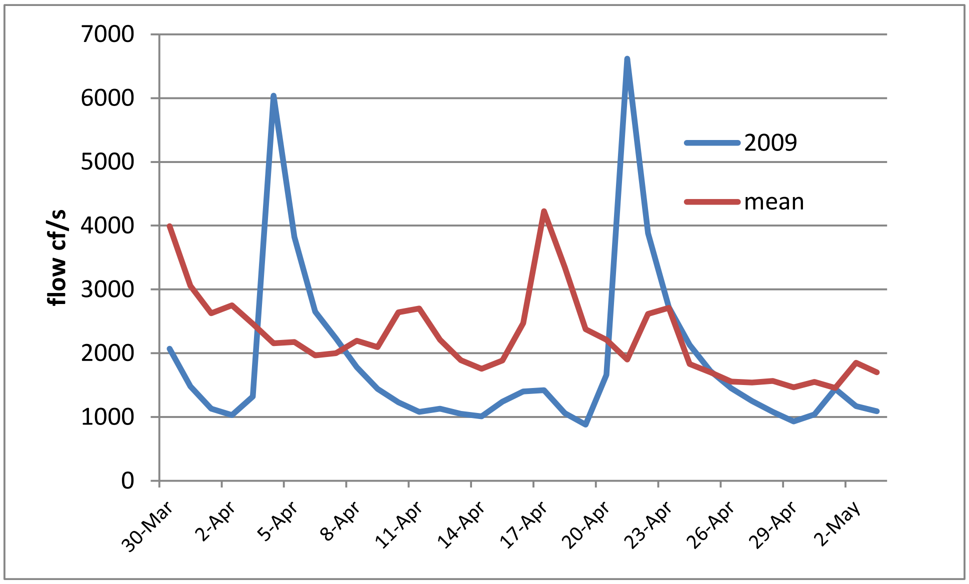


Figure 4. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2008-2009.



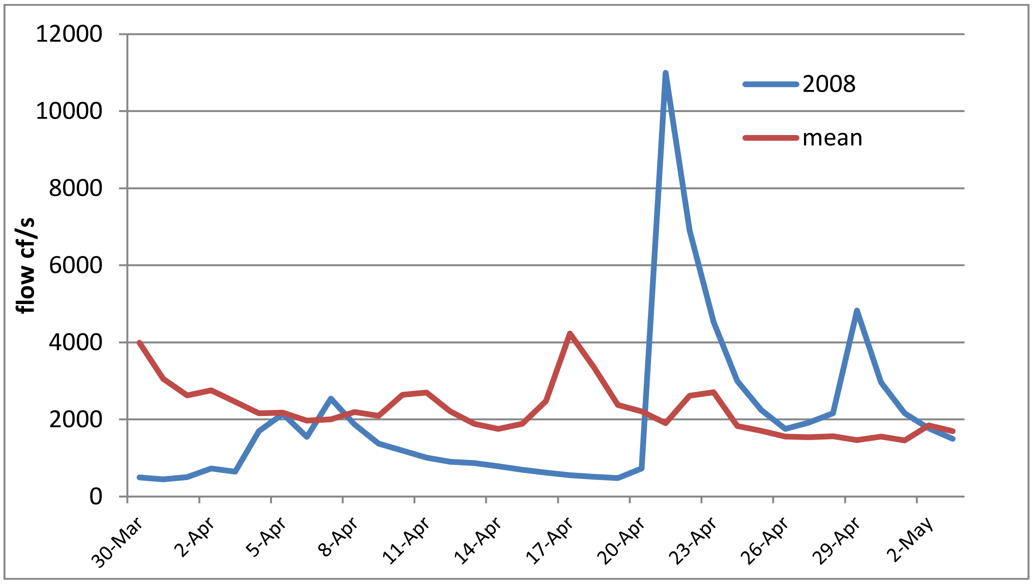
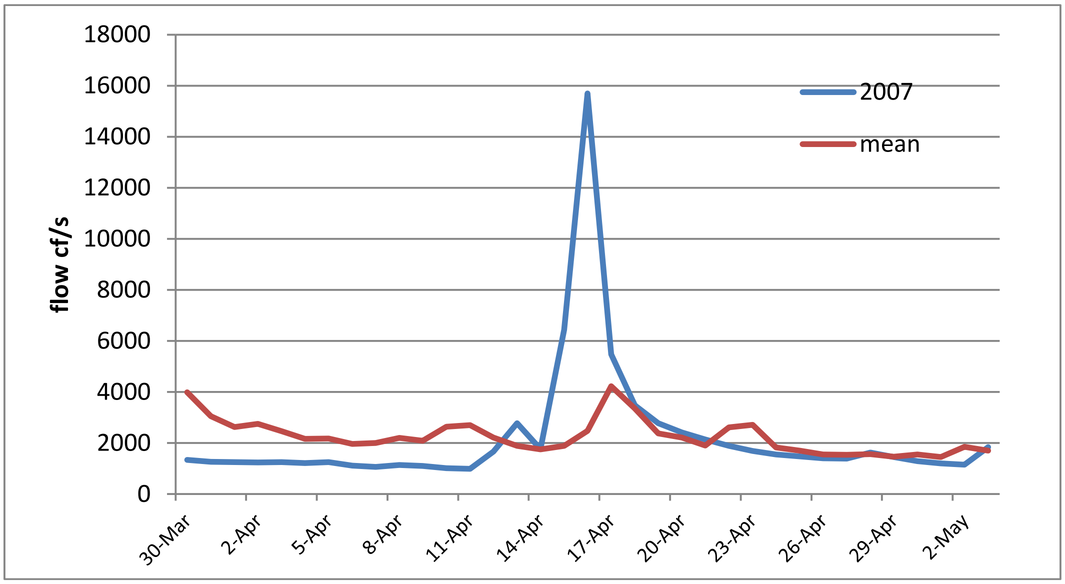


Figure 5. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2006-2007.



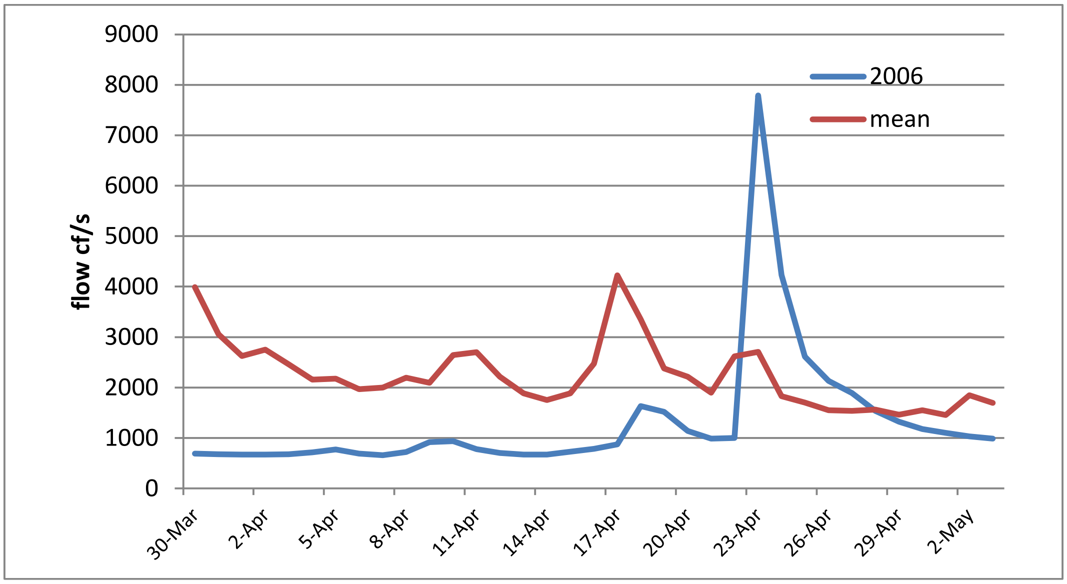
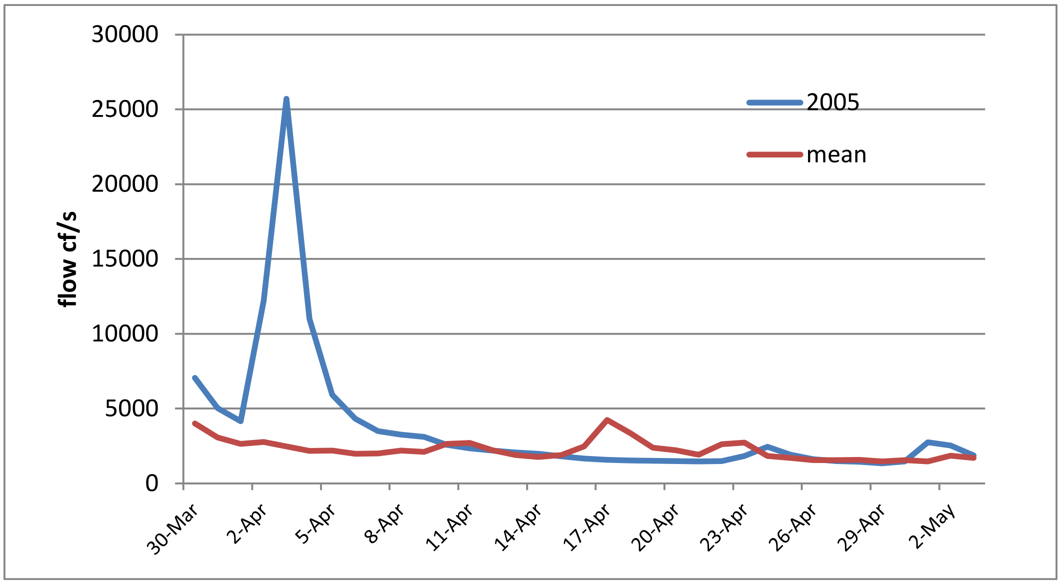


Figure 6. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2004-2005.



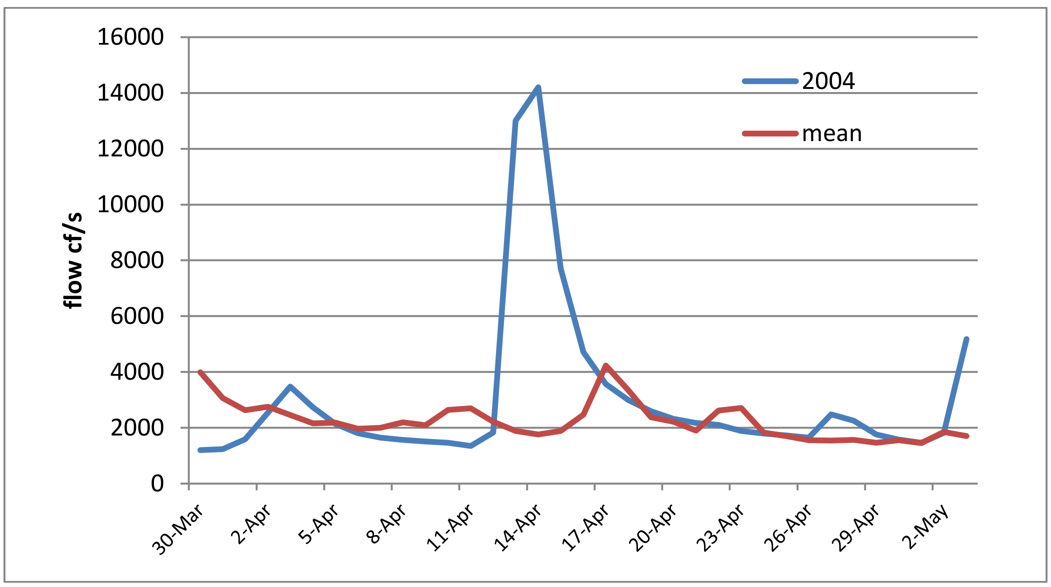
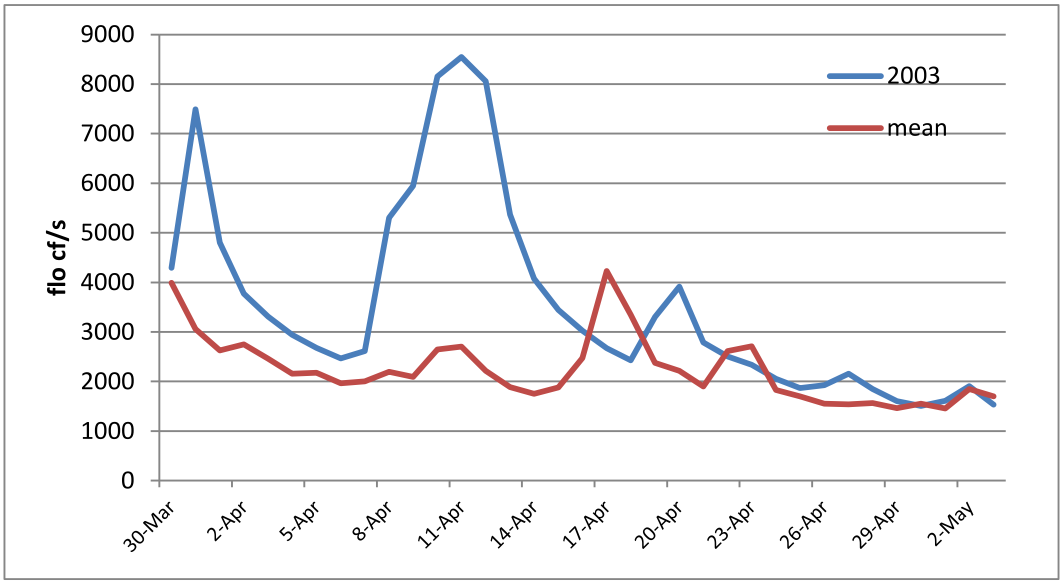


Figure 7. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2002-2003.



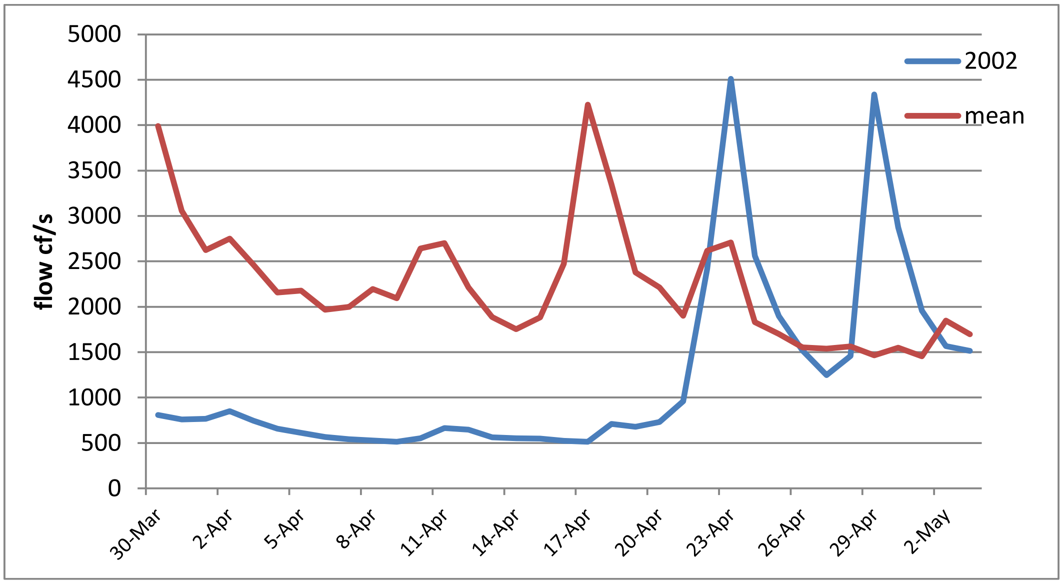
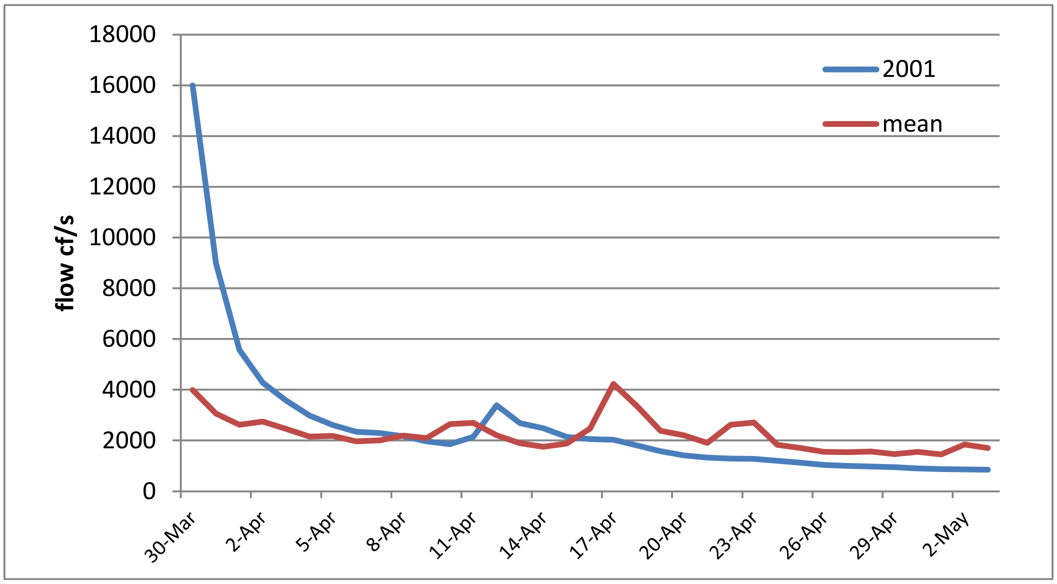


Figure 8. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2000-2001.



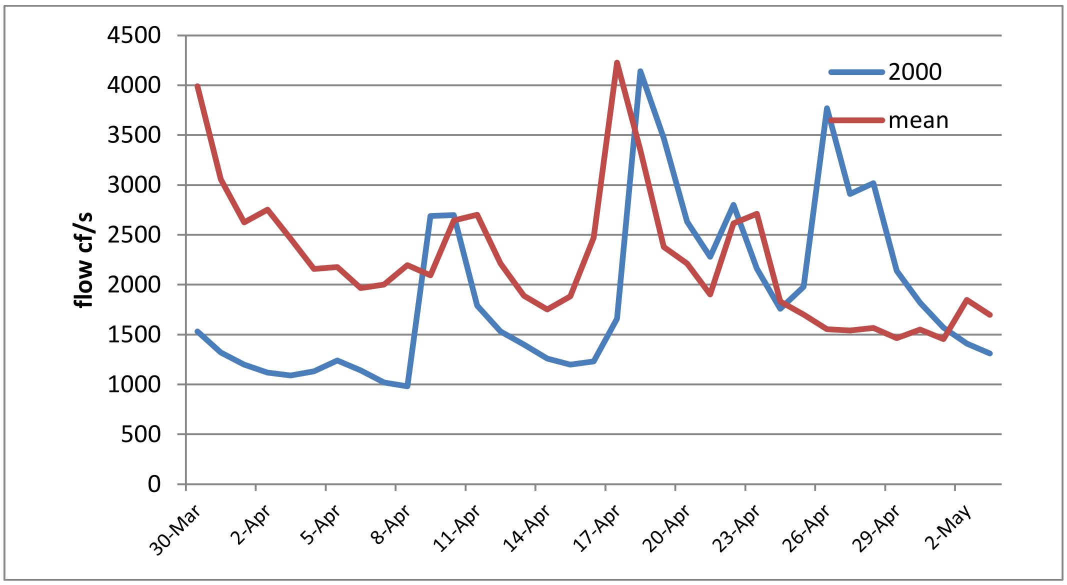
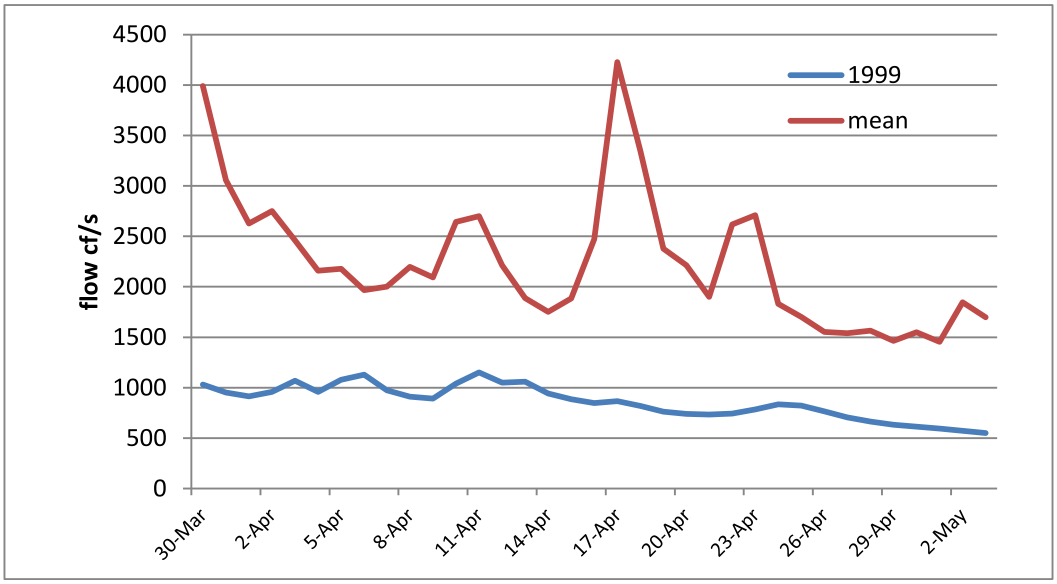


Figure 9. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1998-1999.



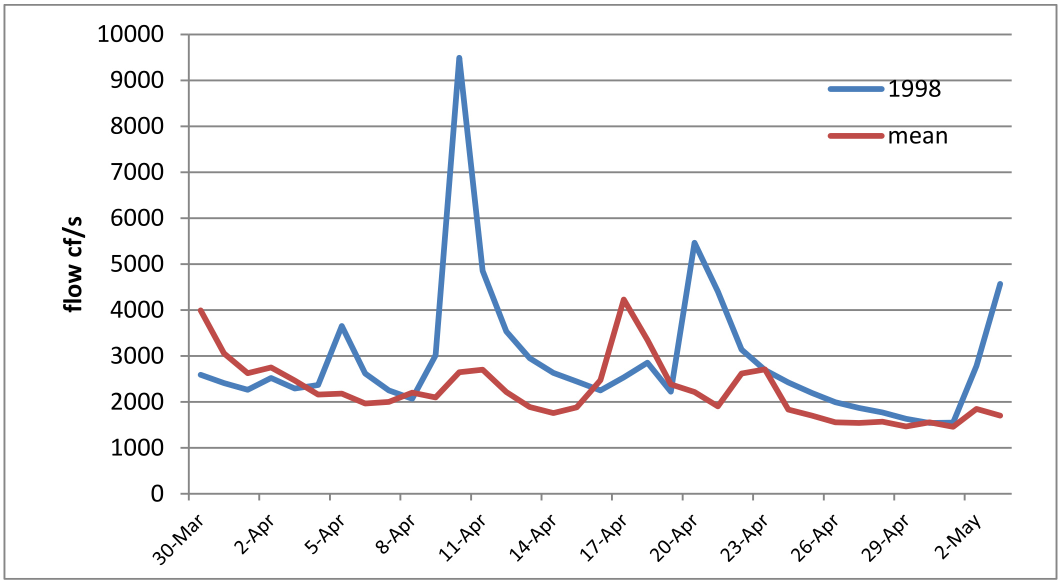
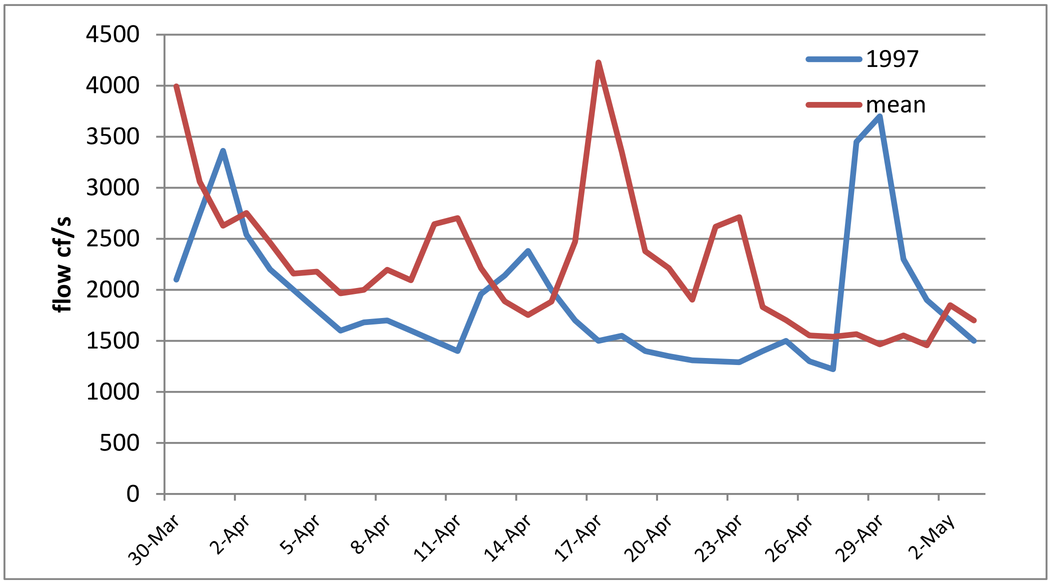


Figure 10. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1996-1997.



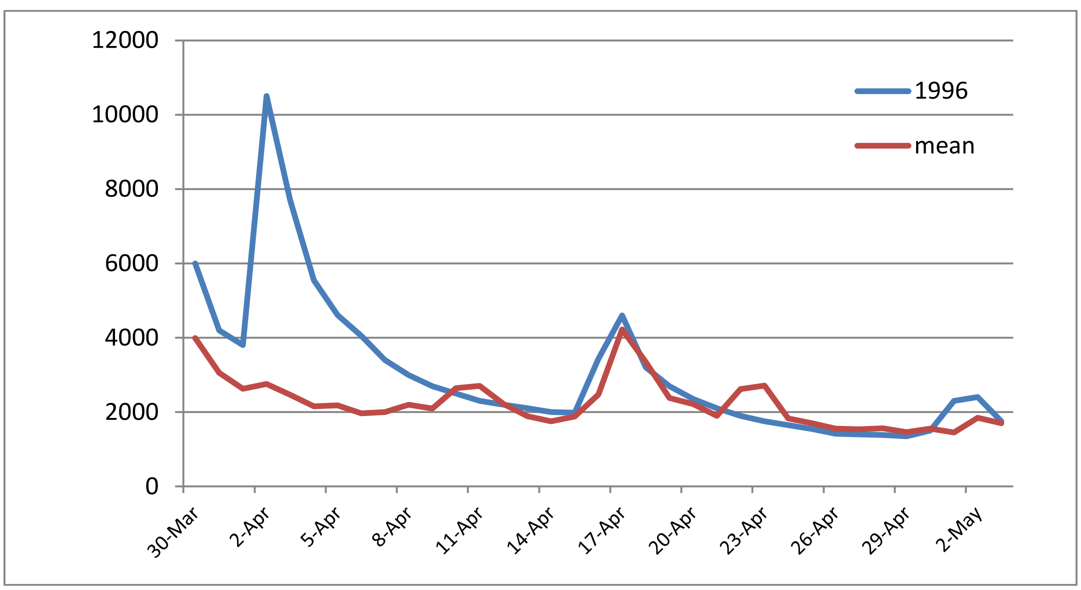
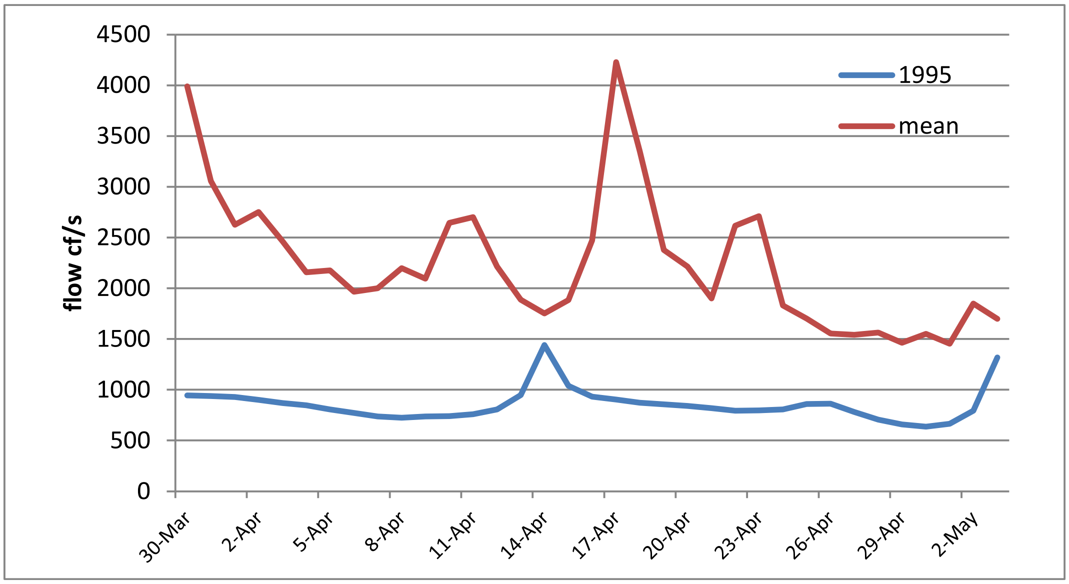


Figure 11. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1994-1995.



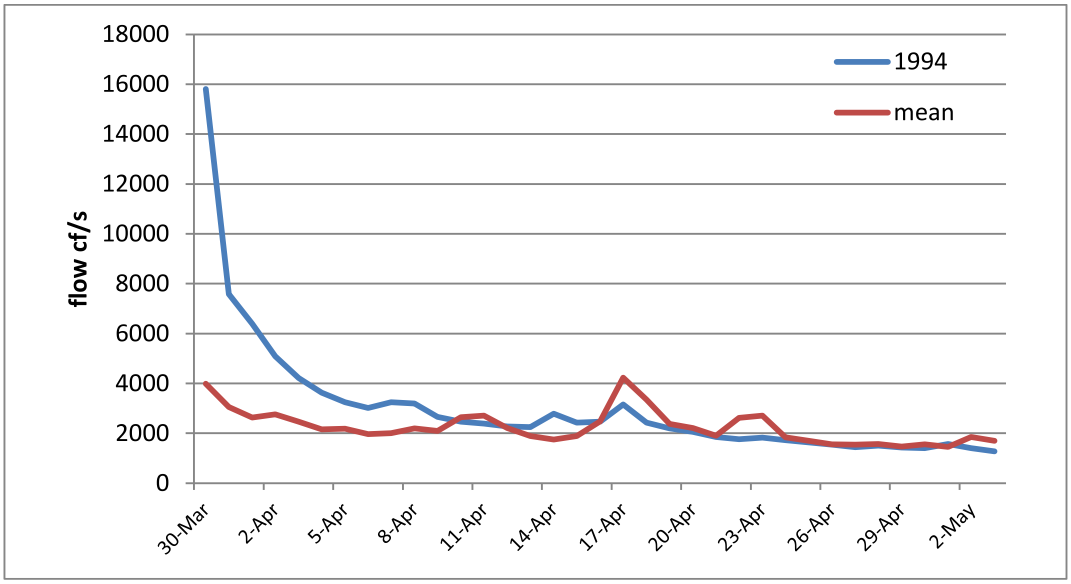
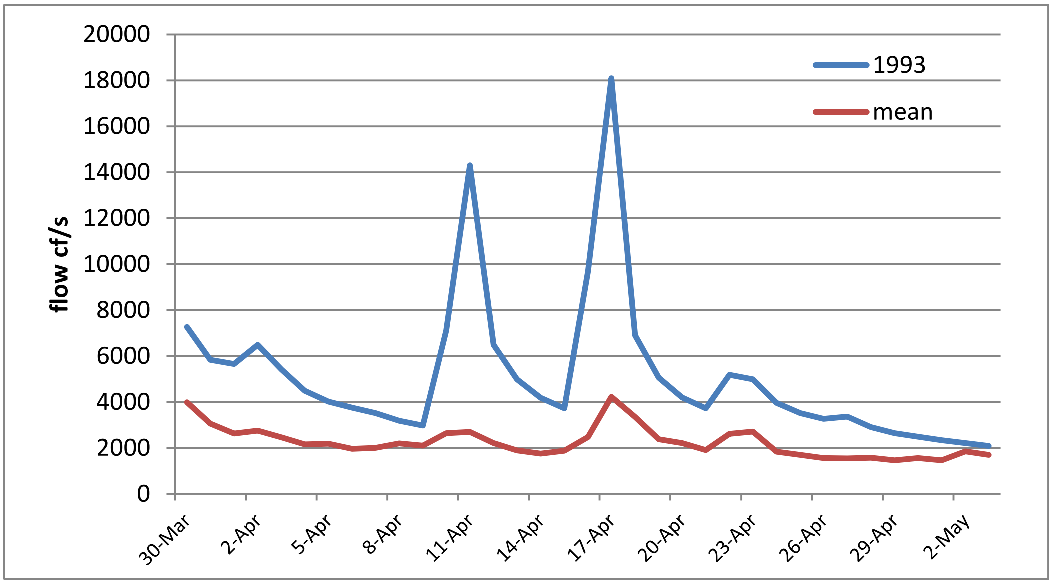


Figure 12. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1992-1993.



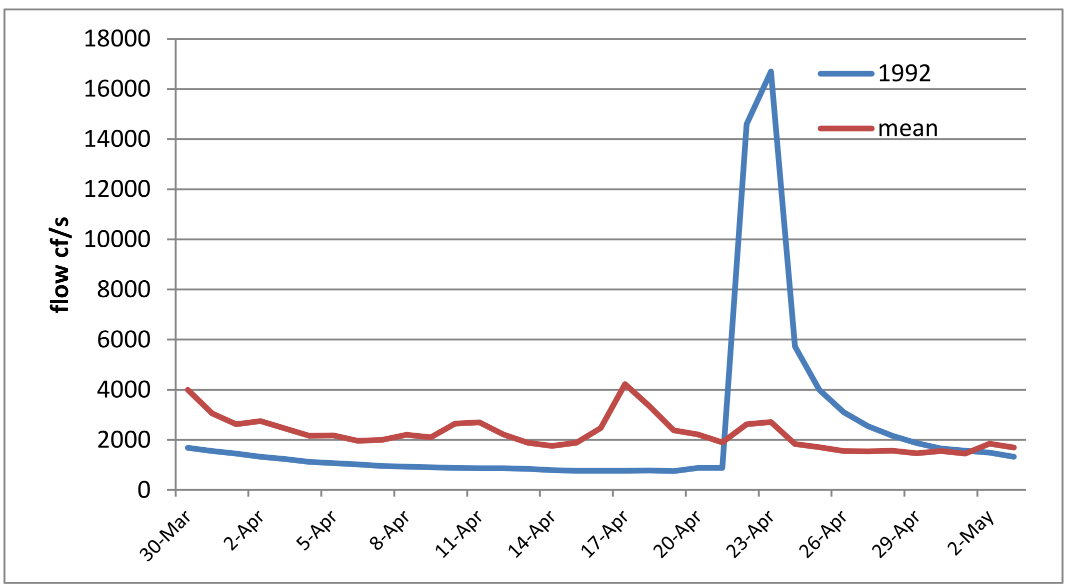
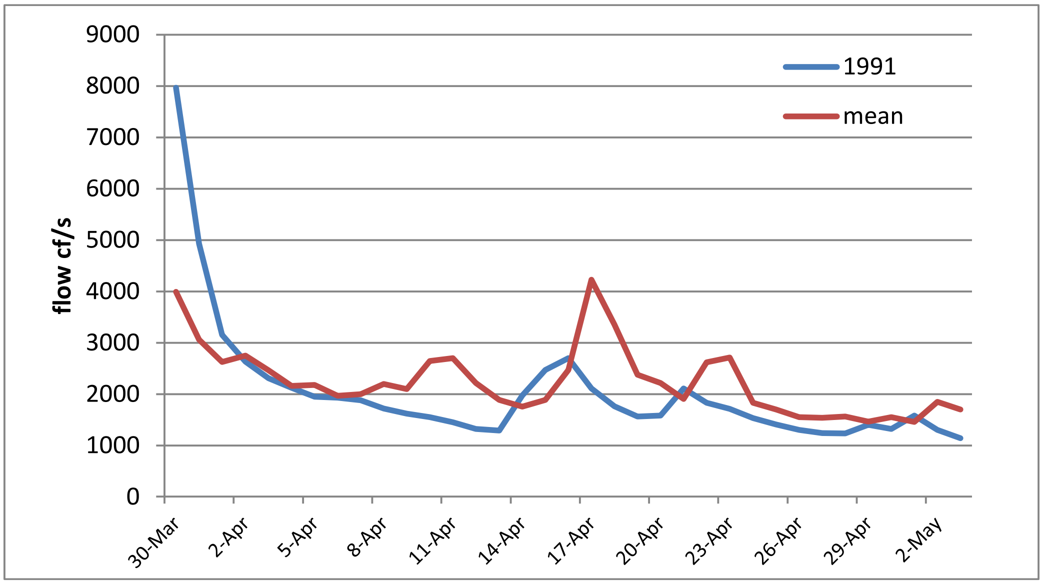


Figure 13. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1990-1991.



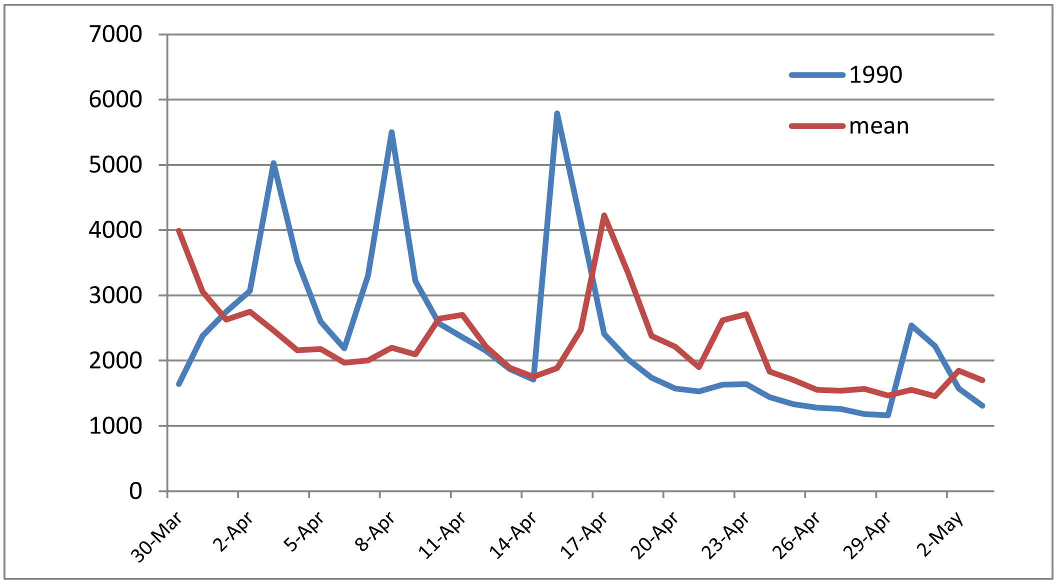


Figure 14. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1988-1989.

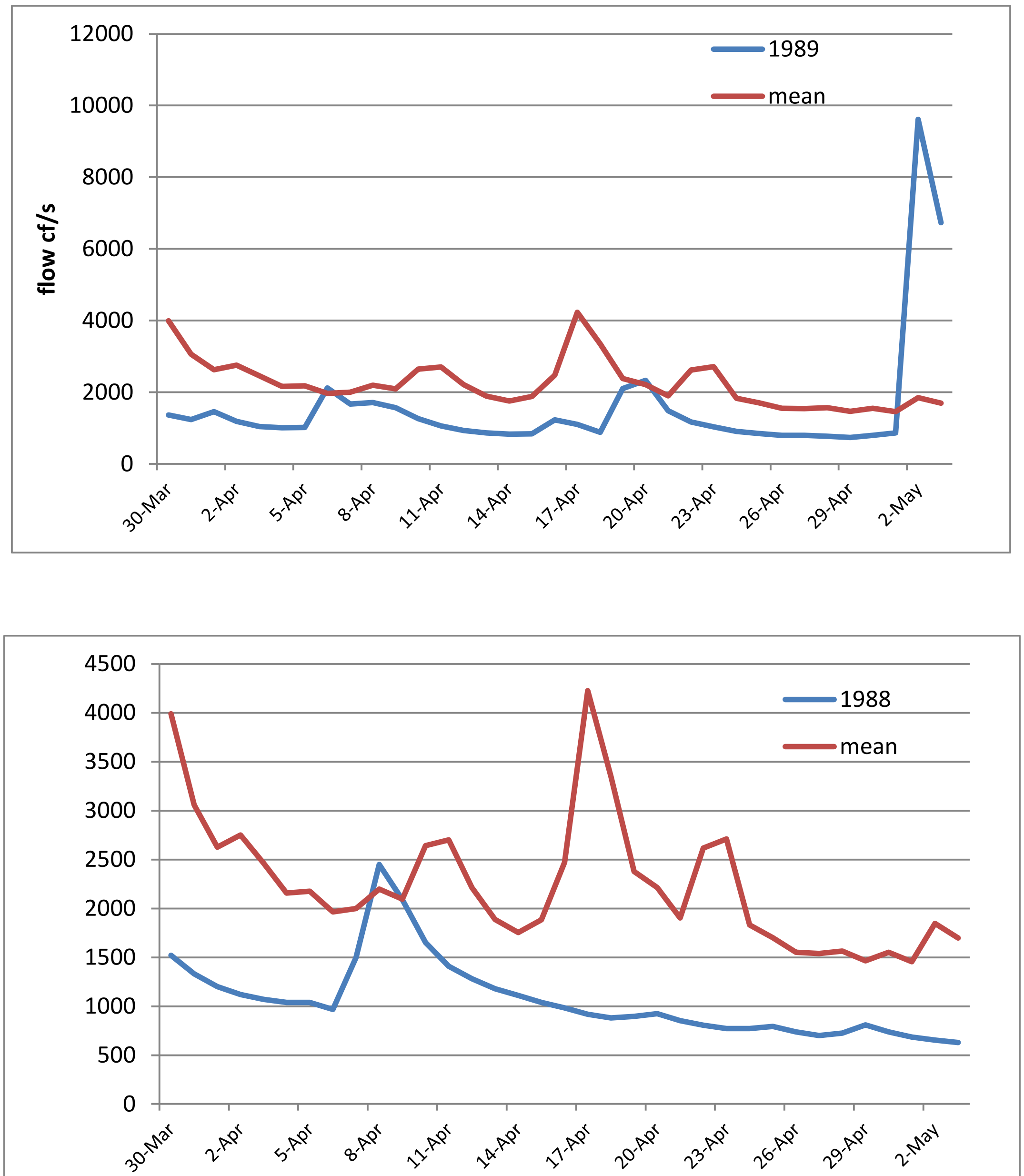


Figure 15. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1986-1987.

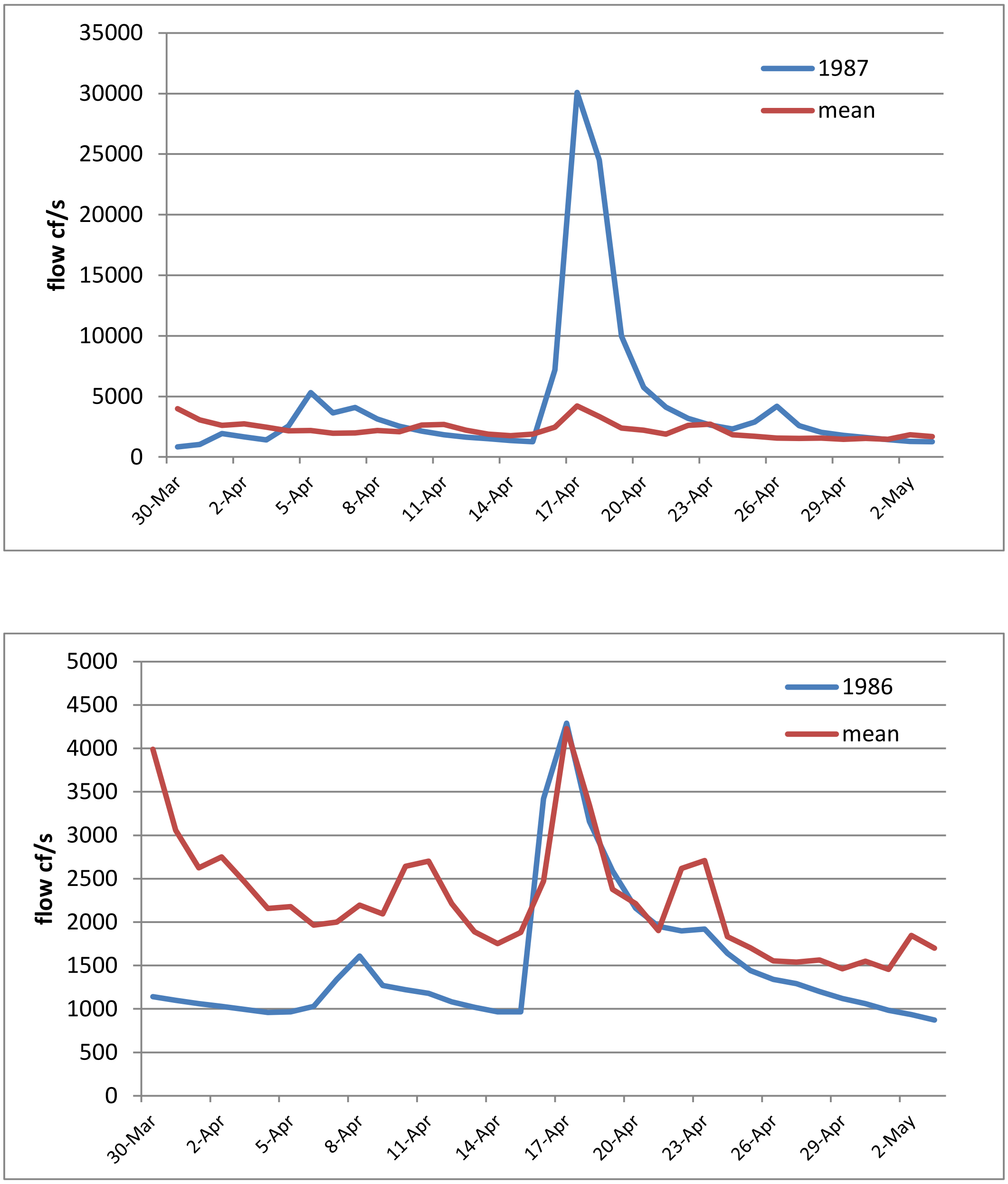


Figure 16. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, spring 1985.