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Evaluation of Striped Bass Stocks in Virginia: Monitoring and Tagging Studies, 2015-2019 Progress Report 1 September 2016 - 31 November 2017

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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 2016 through 31 August 2017. It includes an assessment of the biological characteristics of striped bass taken from the 2017 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 and an evaluation of mortality rates associated with the bacterial dermal disease mycobacteriosis in relation to water temperatures and dissolved oxygen. 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. In 2015, tagging and monitoring activities were expanded to encompass three rivers – the James, York and Rappahannock Rivers.

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 Albert Oliff, Wayne Fisher, Clark Trader, Wayne France, Glenn Wyatt, Louis Wyatt and Kevin Wyatt; and Maryland Department of Natural Resources (Md DNR) biologists Beth Versak and Alexi Sharov.

Executive Summary

I. Assessment of the spawning stocks of striped bass in the Rappahannock and James rivers, Virginia, spring 2017.

Catch Summaries:

1. In 2017, 221 striped bass were sampled between 10 April and 27 April from the commercial pound nets in the Rappahannock River. The samples were predominantly male (91.8%) but had few fish in the 5-8 year range (26.2%). Females dominated the age nine and older age classes (77.8%). The mean age of the male striped bass was 3.9 years. The mean age of the female striped bass was 8.4 years.

2. During the 10 April – 27 April period, the 2013 and 2014 year classes were the most abundant in the Rappahannock River pound net samples and were 99.3% male. The contribution of age six and older males was only 11.3% of the total aged catch. Age seven and older females, presumably repeat spawners, were 3.6% of the total catch but represented 44.4% of all females caught.

3. The Spawning Stock Biomass Index (SSBI) from the Rappahannock River pound nets was 10.4 kg/day for male striped bass and 5.7 kg/day for female striped bass. The male index was the fourth lowest in the 1991-2017 time series. The 2017 female index was 71.5% lower than the 2016 index and 83.3% below the 27-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 2017 Egg Production Potential Index (EPPI, millions of eggs/day) for the Rappahannock River pound nets was 0.86 million eggs/day. This was the lowest EPPI of the 2001-2017 time series. Female stripers in the 2001-2005 year class were responsible for 70.2% of the index.

5. The cumulative catch rate (all age classes, sexes combined) from the Rappahannock River pound nets (10.55 fish/day) was 42.3% below the 27-year time series. The cumulative catch rate of male striped bass (10.53 fish/day) was the ninth lowest in the time series. The cumulative catch rate of female striped bass (0.88 fish/day) was the lowest in the time series and 56.9% lower than the rate in 2016.

6. Year class-specific estimates of annual survival (S) for pound net data varied widely between years. The geometric mean S of the 1985-2010 year classes varied from 0.395-0.726 (mean = 0.596). The geometric mean survival rates differed between sexes. Mean survival rates for male stripers (1985-2010 year classes) varied from 0.222-0.657 (mean = 0.456) while mean survival rates of female stripers (1985-2009 year classes) varied from 0.382-0.732 (mean = 0.594).

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 651 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 2,989 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 2016-2017.

1. A total of 552 striped bass were tagged and released from pound nets in the Rappahannock River between 10 April and 27 April, 2017. Of this total, 275 were between 457-710 mm total length and considered to be predominantly resident striped bass and 33 were considered to be predominantly migrant striped bass (>710 mm TL).

2. A total of 304 striped bass were tagged and released from gill nets in the James River between 10 March and 2 May, 2017. Of this total, 187 were resident striped bass and 28 were migrant striped bass.

3. A total of 185 striped bass were tagged and released from gill nets in the York River between 8 March and 1 May, 2017. Of this total, 116 were resident striped bass and 21 were migrant striped bass.

4. The median date of resident tag releases for all rivers combined was 17 April, while the median date of migrant tag releases for all rivers combined was 11 April.

5. A total of 43 striped bass (>457 mm TL), tagged during springs 1990-2016, were recaptured between 1 January and 31 December, 2016, and were used to estimate mortality. Most recaptures (97.7%) were caught within Chesapeake Bay (76.7% in Virginia, 20.9% in Maryland). Only one more recapture came from New York.

6. A total of 19 migratory striped bass (>710 mm total length), tagged during springs 1990-2016, were recaptured between 1 January and 31 December, 2016, and were used to estimate the mortality. Most recaptures (47.4% each) came from Chesapeake Bay (31.6% in Virginia and 15.8% in Maryland). Other recaptures came from New York (21.1%), Maine (15.8%), and Connecticut, New Jersey, and Rhode Island (5.3% 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 0.39 (> 457 mm TL) and 0.32 (>711 mm TL). The estimates of survival for the Rappahannock, York and James rivers were similar with the estimates of 0.36 (>457 mm TL) and 0.24 (>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 0.03 (>457 mm TL) and 0.05 (>711 mm TL). The estimates of fishing mortality were 0.04 (>457 mm TL) and 0.09 (>711 mm TL). For the James, York and Rappahannock river releases, the estimates of exploitation were 0.04 (>457 mm TL) and 0.08 (>710 mm TL). The estimates of fishing mortality were 0.07 (>457 mm TL) and 0.16 (>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 1998-2016 for striped bass greater than 18 inches TL; 1990-2003 and 2004-2016 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 0.05 (>457 mm TL) with an estimated natural mortality of 0.622 and 0.04 (>711 mm TL, N = 0.463). In the James, York and Rappahannock river releases, the estimates of survival were 0.51 (>457 mm TL) and 0.59 (>710 mm TL). The estimates of fishing mortality were 0.05 (>457 mm TL, N = 0.622) and 0.05 (>710 mm TL, N = 0.471).

10. Two papers have been written on the association of dermal mycobacteriosis with elevated levels of mortality. The first paper (Hoenig et al. 2017) uses a logistic model of relative survival to quantify elevated levels of mortality in fish with moderate and severe infections.

The second paper (Groner et al. in review) demonstrates that higher temperatures are associated with higher mortality of striped bass with mycobacteriosis.

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 estimation. In theory, close kinship is based on 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 a sample would contain 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 1,309 fin clips from striped bass from the Rappahannock River (study system of choice). Data was collected 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. Of this sample, the final dataset included 371 adults and 389 YOY.

3. With the parameters collected for this study, the estimated adult abundance was 145,081 with a CV of 0.71.

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I. Assessment of the spawning stocks of striped bass in the Rappahannock River, Virginia, spring 2017.

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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 10 April – 27 April, 2017. 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 10 April, 2017. 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. The final scheduled sampling date, 1 May, was cancelled by the fisherman.

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 2017, 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= 221) were sampled between 10 April – 27 April, 2017 from the pound nets in the Rappahannock River. The number of striped bass sampled was 39% less than the sample from 2016 (n= 362) and 57.6% lower than the 27-year average (n=521.7). Total catches varied from 6-64 striped bass, with the peak catch on 20 April (Table 1). Surface water temperatures were above normal at the start of the season (16.0℃) , but rose slowly through the season, peaking at 20.3℃ on 17 April. River flows were above average at the start of the season but mostly remained below average throughout the sampling season (Figure 2). Salinities increased from 0.1-0.4 p.p.t. throughout the sampling season. Catches of female striped bass peaked on 13 April and was dominated by the pre-2008 year classes. Males made up 91.8% of the total catch, which was well above the 27-year average (75.4%). The 2009-2012 year classes (five to eight years old) comprised 26.2% of the total catch. This was lower than the 2016 samples where the 2008-2011 year classes comprised 32.9% of the total catch. Males dominated the 2013-2015 year classes (99.3%) and the 2009-2012 year classes (82.8%), while females dominated the 2001-2008 year classes (77.8%).

Biomass catch rate (g/day) of males peaked on 20 April and female striped bass peaked on 13 April (Table 2). The numeric catch rate of males exceeded that of females on all sampling dates. Unlike most previous years, the biomass catch rates for males exceeded that for females overall (1.87:1), peaking on 27 April (all male) and 17 April (91.3:1). The mean ages of male striped bass varied from 3.3 – 5.0 years by sampling date, with the oldest mean age occurring on 24 April. The mean ages of females varied from 3.0 – 10.6 years by sampling date, peaking on 13 April.

There was a broad peak in abundance of striped bass (mostly male) between 370-440 mm total lengths in the pound net samples (Table 3). This size range accounted for 34.4% of the total sampled. There was a second peak in abundance of predominantly male striped bass between 550-580 mm total lengths. Inconsistent with previous years, there was not a peak of abundance related to predominantly female striped bass. The total contribution of striped bass greater than 710 mm total length (the minimum total length for the coastal fishery) was 4.5% (vs. 12.4% in 2016).

During the 10 April – 27 April period, the 2014 (46.2%) and 2013 (20.4%) year classes were the most abundant (Table 4). These year classes were 99.3% male. The contribution of males age six and older (the pre-2011 year classes) was 11.3% 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 3.6% of the total aged catch, but was also 44.4% of the total females captured. The catch rate (fish/day) of male striped bass was 9.7, which is 29.7% below the 27-year average (Table 5). The catch rate of female striped bass (0.9 fish/day) was 80% below the 27-year average, making it the lowest of the time series. The biomass catch rates (kg/day) of males were below the average of the 27-year time series and 23.7% below the rate in 2016. The rates of females were also the lowest of the 27-year average. The mean age of the male striped bass was the fifth lowest in the 27-year time series. The mean age of the female striped bass was lower than 2016 and the eighth lowest value in the time series.

Spawning Stock Biomass Indexes.

The Spawning Stock Biomass Index (SSBI) for spring 2017 was 10.4 kg/day for male striped bass and 5.7 kg/day for female striped bass. The index for male striped bass was 23.5% below the value for 2016. It was the fourth lowest in the 27-year time series and 58.1% below the overall average (Table 6). The magnitude of the index for male striped bass was largely determined by the 2011-2014 (85.2%) year classes. The index for female striped bass was 71.5% lower than the 2016 index. It was the lowest in the time series, and 83.3% below the 27-year average (Table 6). The magnitude of the index for the females was largely determined by the 2001-2005 year classes (67.6%).

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 2017 Egg Production Potential Indexes (EPPI, Table 8) for the Rappahannock River was 0.86. The indexes for the Rappahannock River were heavily dependent on the egg production potential of the 2001-2005 year class females (70.2%). Previous values for the EPPI for 2001-2017 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, 3.18 and 3.09 (Sadler et al 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015 and 2016). Thus, the EPPI values for the pound nets in the Rappahannock River, which had rebounded in 2012-2014, declined from 2015-2017. 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 1993-2017 samples are presented in Tables 9-11. The cumulative annual catch rate of all year classes for 2017 was 22.6% below the cumulative catch rate for 2016 but 42.3% below the 27-year average of 18.29 (Tables 9a,b). The decrease was the result of lower catch rates in the 2011-2012 year classes (six and seven year old striped bass). The catch rate of males was dominated by two - six year olds (2011-2015 year classes, Tables 10a,b). These five age classes contributed 94.0% of the total male catch. Using the maximum catch rate of the resident males as an indicator, the 1995-1997 year classes were strongest and the 1990 and 1991 year classes were the weakest. No pre-2004 year class males were captured. The cumulative catch rate of female stripers was 56.9% lower than the catch rate in 2016 and was 80.5% lower than the 27-year average of 4.52 (Tables 11a,b). The 2001-2007 year classes (10-16 year old stripers) accounted for 45.5% of the total female catch while the 2011 and 2012 year classes (five and six year old stripers) accounted for 48.9% of the total female catch.

The range of overall ages was unchanged from 1991-2017, 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, 2013 and again in 2017. 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, .775 in 2016 and .511 in 2017.

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 (1991-2017) of the 1985-2010 year classes (sexes combined) varied from 0.395-0.726 (Tables 12a,b) with an overall mean survival rate of 0.596. 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 (1991-2017) of the 1985-2010 year classes of males varied from 0.222-0.657 (Tables 13a,b) with an overall mean survival rate of 0.456. These year classes have been the major target of the fall recreational and commercial fisheries that reopened in 1993. The geometric mean survival rate (1991-2017) of the 1985-2009 year classes of females varied from 0.382-0.732 (Tables 14a,b) with an overall mean survival rate of 0.594.

Catch Rate Histories of the 1987-2010 Year Classes

The catch rate histories of the 1987-2010 year classes are depicted in Figures 3-14. Consistent among the year classes are a peak of male striped bass at age four or five followed by a rapid decline in the catch rate and a secondary peak of mostly female striped bass around age 10. This secondary peak is best defined from the pound net data. 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 2017.

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 2017.

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 2017.

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 2017.

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 2017.

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 2017.

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 slightly below the median among the year classes and but above the mean from the pound net samples in the Rappahannock River. No 1993 year class striped bass were captured in 2017.

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 near the median among the age classes and slightly above the mean from the pound net samples in the Rappahannock River. No 1994 year class striped bass were captured in 2017.

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 32.7% 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 2017.

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 2017.

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 2017.

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 eighth lowest among the year classes and 12.3% below average in the Rappahannock River pound nets. No 1998 year class striped bass were captured in 2017.

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 sixth lowest among the year classes and 19.9% below the average in the Rappahannock River. No 1999 year class striped bass were captured in 2017.

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 18.7% below the average in the pound nets. No 2000 year class striped bass were captured in 2017.

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. One female 2001 year class striped bass was captured in 2017.

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 9.9% above the average in the pound nets in the Rappahannock River. No 2002 year class striped bass were captured in 2017.

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. Two female 2003 year class striped bass were captured in 2017.

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. Two female and one male 2004 year class striped bass were captured in 2017.

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 the fourth highest overall in the Rappahannock River. One female 2005 year class striped bass was captured in 2017.

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 24.6% below average and the sixth lowest overall in the Rappahannock River. No 2006 year class striped bass were captured in 2017.

2007 Year class: Peak abundance of both male and female occurred at age five in the pound nets in the Rappahannock River (Figure 13). The CCA was the third lowest among the year classes and half the overall average. One female 2007 year class striped bass was captured in 2017.

2008 Year class: Peak abundance of male striped bass occurred at age four in the pound nets in the Rappahannock River (Figure 13). Peak abundance of female striped bass occurred at age five. The CCA through age nine is the second lowest among the year classes 62.7% below the mean. One male 2008 year class striped bass was captured in 2017.

2009 Year class: Peak abundance of male striped bass occurred at age three in the pound nets in the Rappahannock River (Figure 14). Peak abundance of female striped bass occurred at age four. The CCA through age eight is the lowest among the year classes and 74.3% below the mean. One male and one female striped bass were captured in 2017.

2010 Year class: Peak abundance of male striped bass occurred at age four in the pound nets in the Rappahannock River (Figure 14). Peak abundance of female striped bass occurred at age five. The CCA through age seven is the fourth lowest among the year classes and 58% below the mean. Five male striped bass were captured in 2017.

Growth Rate of Striped Bass Derived from Annuli Measurements

The scales of 651 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 10th year (Tables16a,b). Interestingly, the growth rates of the most recent year classes were the highest, although the growth rate of the oldest year classes were based on very few specimens. Based on these growth estimates, an 18 inch (457 mm) total length striped bass would be 3.5 years of age during the fall recreational fishery in Chesapeake Bay. These striped bass reach the 28 inch (711 mm) total length minimum for the coastal fishery at age eight.

Age Determinations using Scales and Otoliths

2017 data

Again in 2017, we explored methodologies to establish combined tagging and monitoring programs for the James and York rivers. As a result, only 89 specimens were returned to VIMS for otolith extraction. This number was insufficient for a 2017-specific analytical comparison and the results were appended to the 2003-2016 data for analysis.

2003-2017 data

A total of 2,989 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 15).

Tests of symmetry: The scale and otolith ages from the same specimen were in agreement 44.0% (1314/2989) of the time and within one year 83.3% (2489/2989) 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 = 53). We tested the hypothesis that the observed age differences were symmetrically distributed about the main table diagonal. The hypothesis was rejected (X^2 = 311.79, 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 16). The otolith-derived age exceeded the scale age 33.2% of the total examined (59.2% 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 = 178.9, 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=2989) determined by reading the otoliths was greater than the mean age determined by reading the scales (by 0.24 years, Table 19). The test results were:

$$\overline{Age}_{otolith} = 8.56 \qquad \overline{Age}_{scale} = 8.32$$

$$S_{otolith} = 3.00 \qquad S_{scale} = 2.79$$

$$df = 5977$$

$$p < .001$$

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= 2988, $p < .001$) 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 ($K_{.05}$):

$$D_{max} = 0.0281 \qquad K_{.05} = 1.3581$$

$$D_{.05} = K_{.05}\sqrt{\frac{(2989)+(2989)}{(2989)^2}} = 0.0351$$

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 2017, the first set was established by 10 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 1991-2017. 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 2015-2017. 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 later start to the sampling in 2017 the total catch and biomass was less than in 2016, but continue a series of reduced catches since 2010.

For the second straight year there were no 1996 year class striped bass captured in 2017. 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. It is noteworthy that the expected strong 2011 year class has only displayed near average strength to date.The 2003-2005 year classes appear to now be the dominant year classes of the migrant stock.

The 2017 value of the Spawning Stock Biomass Index (SSBI) for the Rappahannock River pound nets was much lower than the SSBI for 2016, due entirely to a decreased capture of female striped bass, which resulted in the lowest value measured. The SSBI for male striped bass captured in the pound nets was only slightly less than the index for 2016 but still 58% below the mean of the 1991-2017 time series. However, the SSBI for female striped bass was less than one third the 2016 value and 83.2% 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 down across all age classes.

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 2017, the contribution of 8+ year old females was 47.1% of the total number, 81.2% of the biomass, and 83.2% of the calculated egg potential. It should be noted that our fecundity estimates for individual striped bass are well below those reported by Setzler et al. (1980). Our methodology differs from the previous studies, but the relative contribution in potential egg production of the older females may be underestimated at present.

In our analysis of pound net catch rates, we observed a distinctive bimodal distribution of the striped bass. These striped bass appeared in greatest abundance at age five or six (especially males), at lower abundance at age six to eight (both sexes), and then higher abundance at ages nine 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 2004-2017, 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 1983-2009 year classes that were captured for at least five years subsequent to their peak in abundance at age four or five. The survival estimate of female striped bass of the 1985-2007 year classes in the Rappahannock River was 0.602. The survival estimate of 1986-2006 year class male striped bass was 0.468. 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 1987-2010 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 2014 year class in fall 2017) and the 28 in. (711 mm) minimum total length for the coastal fishery at age eight.

Since 2003 we have aged 2,989 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 44.0% 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 2013-2015, 2009-2012 and 2001-2008) from pound nets in the Rappahannock River, by sampling date, spring, 2017. M = males, F = females.

Date	n	Year Class							
		No age		2013-2015		2009-2012		2001-2008	
		M	F	M	F	M	F	M	F
10 April	49	0	0	45	0	3	1	0	0
13 April	28	0	0	12	0	6	3	1	6
17 April	43	1	0	31	1	10	0	0	0
20 April	64	2	0	45	0	15	1	0	1
24 April	31	1	0	12	0	12	5	1	0
27 April	6	1	0	3	0	2	0	0	0
Total	**221**	**5**	**0**	**148**	**1**	**48**	**10**	**2**	**7**

Table 2. Net-specific summary of catch rates and mean ages of striped bass (n=221) in pound nets on the Rappahannock River, spring, 2017. 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**
10 April	S462	49	12.0	0.3	8,466.4	1,557.2	3.3	8.0
13 April	S473	28	6.3	3.0	8,189.9	29,251.2	4.3	10.6
17 April	S462	43	10.5	0.3	11,892.6	130.3	4.0	3.0
20 April	S473	64	20.7	0.7	21,695.6	4,413.8	3.9	9.5
24 April	S473	31	6.5	1.3	10,999.3	2,927.9	5.0	5.4
27 April	S462	6	2.0	0.0	2,593.3	0.0	4.2	
Totals	S462	98	8.7	0.2	8,110.5	613.6	3.6	5.5
	S473	123	10.7	1.6	13,365.4	11,270.7	4.2	8.8
Season		221	**9.6**	**0.9**	**10,612.8**	**5,688.4**	**3.9**	**8.4**

Table 3. Length frequencies (TL in mm) of striped bass sampled from the pound nets in the Rappahannock River, spring, 2017.

TL	n	TL	n	TL	n	TL	n	TL	n	TL	n
<290	2	**440-**	10	**600-**	3	**760-**	0	**920-**	0	**1080-**	1
290-	0	**450-**	4	**610-**	1	**770-**	0	**930-**	1	**1090-**	2
300-	2	**460-**	6	**620-**	1	**780-**	0	**940-**	1	**1100-**	0
310-	4	**470-**	3	**630-**	2	**790-**	0	**950-**	0	**1110-**	0
320-	5	**480-**	6	**640-**	0	**800-**	1	**960-**	0	**1120-**	0
330-	6	**490-**	6	**650-**	0	**810-**	0	**970-**	1	**1130-**	0
340-	6	**500-**	5	**660-**	0	**820-**	0	**980-**	0	**1140-**	0
350-	8	**510-**	6	**670-**	1	**830-**	0	**990-**	1	**1150-**	0
360-	7	**520-**	4	**680-**	1	**840-**	0	**1000-**	0	**1160-**	0
370-	11	**530-**	5	**690-**	0	**850-**	0	**1010-**	0	**1170-**	0
380-	12	**540-**	3	**700-**	0	**860-**	0	**1020-**	0	**1180-**	0
390-	9	**550-**	11	**710-**	0	**870-**	0	**1030-**	0	**1190-**	0
400-	10	**560-**	8	**720-**	0	**880-**	0	**1040-**	0	**1200-**	0
410-	9	**570-**	9	**730-**	0	**890-**	0	**1050-**	0	**1210-**	0
420-	9	**580-**	7	**740-**	0	**900-**	0	**1060-**	1	**1220-**	0
430-	6	**590-**	3	**750-**	1	**910-**	0	**1070-**	0	**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 2017.

Year Class	Sex	n	Fork Length Mean	Fork Length SD	Weight Mean	Weight SD	CPUE F/day	CPUE W/day
2015	male	2	269.0	33.9	252.3	132.4	0.1	24.0
2014	male	101	352.5	32.9	575.1	157.4	4.8	2,765.9
	female	1	320.0		521.2		0.0	24.8
2013	male	45	442.7	26.6	1,133.0	205.9	2.1	2,427.9
2012	male	25	508.2	24.5	1,716.5	245.4	1.2	2,043.4
	female	5	534.6	14.7	2,300.6	178.7	0.2	547.8
2011	male	17	535.8	24.8	2,019.4	284.7	0.8	1,631.1
	female	4	565.8	31.5	2,722.5	437.9	0.2	518.6
2010	male	5	561.0	42.5	2,336.8	566.6	0.2	556.4
2009	male	1	637.0		3,389.9		0.0	161.4
	female	1	755.0		6,628.6		0.0	315.6
2008	male	1	697.0		4,457.7		0.0	212.3
2007	female	1	870.0		9,382.9		0.0	446.8
2005	female	1	910.0		10,684.4		0.0	508.8
2004	male	1	880.0		9,059.8		0.0	431.4
	female	2	952.5	88.4	12,334.4	3,273.2	0.1	1,174.7
2003	female	2	1,036.5	14.8	15,568.2	644.5	0.1	1.482.7
2001	female	1	1,010.0		14,441.4		0.0	687.7
Not Aged	male	5	467.2	117.5	1,507.3	778.5	0.2	358.9
	female	0						

Table 5. Summary of the seasonal mean catch rates and ages, by sex, from the pound nets in the Rappahannock River, springs 1991-2017. M = male, F = female.

		CPUE (fish/day)		CPUE (g/day)		Mean age	
Year	**n**	**M**	**F**	**M**	**F**	**M**	**F**
2017	221	9.7	0.9	10,428.3	5,688.4	3.9	8.4
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	**521.7**	**13.8**	**4.5**	**24,838.3**	**33,645.1**	**4.5**	**8.9**

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 – 2017.

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
2017	211.0	17.0	10.4	5.7	16.1					
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 2017. The Egg Production Potential Index (millions of eggs/day) is in bold.

Age	n	E	%
4	0	0.000	0.00
5	5	0.074	8.57
6	4	0.071	8.23
7	0	0.000	0.00
8	1	0.044	5.10
9	0	0.000	0.00
10	1	0.068	7.88
11	0	0.000	0.00
12	1	0.078	9.04
13	2	0.183	21.20
14	2	0.236	27.35
15	0	0.000	0.00
16	1	0.109	12.63
17	0	0.000	0.00
18	0	0.000	0.00
19	0	0.000	0.00
20	0	0.000	0.00
n/age	0	0.000	0.00
Total	17	**0.863**	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, 1993-2017. Maximum catch rate for each year class is in bold type.

Year Class	CPUE (fish/day)												
	1993	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
2002													1.83
2001												3.47	**5.43**
2000											0.76	**5.57**	2.77
1999									0.07	0.51	3.00	**5.90**	0.71
1998								0.03	2.74	1.44	3.33	**3.50**	0.77
1997							0.79	**15.61**	7.49	1.38	0.37	2.23	1.69
1996						0.19	11.54	**18.13**	4.29	0.25	1.83	4.16	1.69
1995					0.60	2.15	**11.50**	3.34	0.10	0.68	1.40	2.33	0.94
1994			0.04	0.51	3.90	**6.33**	2.79	0.11	0.58	0.41	1.70	1.67	0.69
1993			3.04	3.97	**8.10**	1.48	0.11	0.50	0.87	0.28	1.43	1.00	0.57
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	0.29
1991	0.57	0.48	1.00	**1.63**	0.05	0.52	0.43	0.40	0.81	0.06	0.33	0.17	0.09
1990	1.04	1.33	**2.24**	1.26	0.70	0.70	0.32	0.29	0.45	0.00	0.27	0.07	0.03
1989	3.58	**4.59**	0.68	0.89	0.80	0.78	0.36	0.37	0.26	0.00	0.07	0.07	0.03
1988	**9.54**	1.15	0.60	0.37	1.50	0.89	0.39	0.05	0.10	0.05	0.00	0.00	0.00
1987	**3.65**	1.15	0.68	0.37	1.00	0.89	0.43	0.05	0.00	0.00	0.03	0.03	0.00
1986	0.65	0.59	0.40	0.09	**1.00**	0.22	0.04	0.00	0.00	0.00	0.00	0.00	0.00
1985	0.42	**0.52**	0.08	0.00	0.35	0.15	0.11	0.00	0.00	0.00	0.00	0.00	0.00
1984	**0.58**	0.33	0.28	0.00	0.35	0.07	0.04	0.00	0.00	0.00	0.00	0.00	0.00
1983	**0.46**	0.33	0.08	0.03	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.38	0.56	0.60	0.32	0.50	0.44	0.54	0.32	0.00	0.00	0.00	0.00	0.49
Total	**21.72**	**13.87**	**14.52**	**12.30**	**20.30**	**14.85**	**29.89**	**39.70**	**18.63**	**5.23**	**15.65**	**31.64**	**18.05**

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, 1993-2017. Maximum catch rate for each year class is in bold type.

Year Class	CPUE (fish/day)											
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
2015												0.10
2014												**4.86**
2013											**2.50**	2.14
2012										0.60	**4.29**	1.43
2011									3.35	3.12	**3.61**	1.00
2010								1.65	**2.65**	1.12	0.36	0.24
2009						0.08	1.40	**1.74**	0.41	0.09	0.14	0.10
2008					0.23	0.46	**3.20**	1.91	0.00	0.14	0.14	0.05
2007				0.07	2.63	1.08	**3.80**	0.83	0.06	0.09	0.00	0.05
2006			0.17	1.89	**6.50**	1.38	2.12	0.30	0.47	0.00	0.07	0.00
2005		0.03	4.40	5.07	**10.43**	0.96	1.04	0.26	0.65	0.51	0.50	0.05
2004		2.52	**7.20**	6.93	4.23	0.79	0.92	0.30	1.35	0.33	0.18	0.14
2003	7.89	**8.55**	3.26	2.15	1.53	0.88	1.28	1.13	1.53	0.42	0.39	0.10
2002	**6.40**	6.17	0.51	1.22	1.03	0.96	0.84	0.39	0.53	0.09	0.04	0.00
2001	3.17	1.14	0.60	1.22	1.27	1.04	0.96	0.87	0.88	0.23	0.14	0.05
2000	0.14	1.12	0.57	1.19	1.77	0.63	0.44	0.48	0.65	0.09	0.07	0.00
1999	0.51	1.51	0.29	1.19	1.10	0.25	0.28	0.13	0.00	0.05	0.00	0.00
1998	0.91	1.89	0.43	0.67	0.70	0.04	0.32	0.13	0.24	0.05	0.11	0.00
1997	0.86	2.68	0.43	0.37	0.53	0.17	0.20	0.04	0.06	0.05	0.00	0.00
1996	1.17	3.80	0.46	0.70	1.13	0.08	0.20	0.22	0.18	0.09	0.00	0.00
1995	0.23	0.71	0.00	0.00	0.13	0.04	0.00	0.00	0.00	0.00	0.00	0.00
1994	0.20	0.71	0.00	0.19	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.20	0.46	0.00	0.00	0.07	0.08	0.00	0.09	0.00	0.00	0.00	0.00
1992	0.11	0.20	0.00	0.03	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.26	0.00	0.00	0.07	1.47	0.04	0.44	0.17	0.00	0.00	0.14	0.24
Total	**22.05**	**31.52**	**18.35**	**22.96**	**34.89**	**8.88**	**17.44**	**10.64**	**13.00**	**7.07**	**12.93**	**10.55**

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 1993-2017. Maximum catch rate for each year class is in bold type.

Year Class	CPUE (fish/day)												
	1993	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
2002													1.83
2001												3.47	**5.40**
2000											0.76	**5.47**	2.49
1999									0.07	0.44	2.93	**5.67**	0.66
1998								0.03	2.74	1.38	3.07	**3.37**	**0.51**
1997							0.79	**15.61**	7.42	1.25	0.30	1.93	1.00
1996						0.19	11.54	**18.11**	4.03	0.16	1.50	2.23	0.43
1995					0.55	2.15	**11.46**	3.21	0.10	0.03	0.56	0.53	0.09
1994			0.04	0.51	3.80	**6.19**	2.68	0.08	0.39	0.03	0.23	0.20	0.09
1993			2.88	3.83	**7.50**	1.37	0.07	0.26	0.16	0.00	0.07	0.10	0.00
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	0.00
1991	0.54	0.48	0.92	**1.34**	0.05	0.30	0.21	0.05	0.13	0.00	0.00	0.00	0.00
1990	0.96	1.30	**2.00**	0.94	0.35	0.11	0.00	0.03	0.00	0.00	0.00	0.00	0.00
1989	3.46	**3.52**	0.08	0.43	0.55	0.04	0.04	0.03	0.00	0.00	0.00	0.00	0.00
1988	**7.54**	1.11	0.12	0.03	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	**1.23**	0.22	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1986	**0.15**	0.11	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1985	**0.04**	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1984	**0.08**	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	0.27	0.41	0.44	0.23	0.25	0.33	0.54	0.32	0.00	0.00	0.00	0.40	0.43
Total	**14.39**	**8.45**	**11.20**	**10.06**	**14.40**	**10.68**	**27.69**	**37.84**	**15.23**	**3.54**	**9.42**	**23.44**	**12.96**

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, 1993-2017. Maximum catch rate for each year class is in bold type.

Year Class	**CPUE (fish/day)**											
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
2015												**0.95**
2014												**4.81**
2013											**2.50**	2.14
2012										0.60	**4.25**	1.19
2011									3.29	3.11	**3.29**	0.81
2010								1.65	**2.47**	0.88	0.29	0.24
2009							**1.40**	1.39	0.29	0.09	0.07	0.05
2008					0.13	0.46	**3.20**	1.43	0.00	0.05	0.07	0.05
2007				0.07	2.53	1.04	**3.36**	0.70	0.06	0.09	0.00	0.00
2006			0.11	1.78	**6.30**	1.00	1.60	0.17	0.06	0.00	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	0.00
2004		2.49	**7.03**	5.48	4.03	0.67	0.68	0.13	0.35	0.05	0.00	0.05
2003	7.77	**8.46**	3.00	1.70	1.37	0.63	0.56	0.39	0.47	0.05	0.00	0.00
2002	**6.29**	5.83	0.46	1.00	0.70	0.50	0.32	0.09	0.06	0.00	0.00	0.00
2001	2.91	0.97	0.49	0.81	0.67	0.25	0.08	0.22	0.12	0.00	0.00	0.00
2000	0.09	1.03	0.37	0.48	0.27	0.17	0.08	0.13	0.00	0.00	0.00	0.00
1999	0.20	1.00	0.14	0.19	0.23	0.00	0.08	0.00	0.00	0.00	0.00	0.00
1998	0.57	0.89	0.03	0.07	0.13	0.00	0.08	0.00	0.00	0.00	0.00	0.00
1997	0.29	0.37	0.06	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1996	0.03	0.29	0.03	0.70	0.10	0.00	0.00	0.00	0.06	0.00	0.00	0.00
1995	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994	0.06	0.00	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
N/A	0.29	0.00	0.00	0.07	1.40	0.04	0.44	0.17	0.00	0.00	0.14	0.24
Total	**18.50**	**21.36**	**16.09**	**16.87**	**27.50**	**5.43**	**12.80**	**6.56**	**7.29**	**4.97**	**10.65**	**10.53**

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, 1993-2017. Maximum catch rate for each year class is in bold type.

Year Class	CPUE (fish/day)												
	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
2001													0.03
2000												0.10	0.29
1999										0.06	0.07	0.23	0.06
1998										0.06	0.27	0.17	0.26
1997									0.07	0.13	0.07	0.30	0.69
1996								0.03	0.26	0.00	0.37	1.93	1.26
1995					0.05	0.05	0.04	0.13	0.00	0.63	0.80	1.80	0.86
1994					0.10	0.15	0.11	0.03	0.19	0.38	1.47	1.47	0.60
1993			0.16	0.14	0.60	0.11	0.04	0.24	0.71	0.25	1.37	0.90	0.54
1992		0.22	0.12	0.20	0.10	0.04	0.14	0.40	0.68	0.19	1.13	1.03	0.29
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	0.09
1990	0.08	0.04	0.24	0.31	0.35	0.59	0.32	0.26	0.45	0.00	0.26	0.07	0.03
1989	0.12	1.07	0.60	0.46	0.25	0.74	0.32	0.34	0.26	0.00	0.07	0.07	0.03
1988	2.00	1.11	0.48	0.34	1.30	0.89	0.39	0.05	0.10	0.00	0.00	0.00	0.00
1987	2.42	0.93	0.68	0.29	1.00	0.89	0.43	0.05	0.00	0.03	0.03	0.00	0.03
1986	0.50	0.48	0.36	0.09	1.00	0.22	0.04	0.00	0.00	0.00	0.00	0.00	0.00
1985	0.39	0.48	0.08	0.00	0.35	0.15	0.11	0.10	0.00	0.00	0.00	0.00	0.00
1984	0.50	0.33	0.28	0.00	0.35	0.07	0.04	0.00	0.00	0.00	0.00	0.00	0.00
≤1983	1.19	0.59	0.08	0.03	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.12	0.15	0.16	0.09	0.25	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Total	**7.36**	**5.40**	**3.32**	**2.24**	**5.90**	**4.18**	**2.19**	**1.87**	**3.40**	**1.79**	**6.24**	**8.24**	**5.09**

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, 1993-2017. Maximum catch rate for each year class is in bold type.

Year Class	CPUE (fish/day)											
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
2012												**0.24**
2011									0.06	0.00	**0.32**	0.19
2010									0.18	**0.23**	0.07	0.00
2009						0.00	0.04	**0.35**	0.12	0.00	0.07	0.05
2008					0.10	0.00	0.00	**0.48**	0.00	0.09	0.07	0.00
2007					0.10	0.04	**0.44**	0.13	0.00	0.00	0.00	0.05
2006			0.06	0.11	0.20	0.38	**0.52**	0.13	0.41	0.00	0.07	0.05
2005		0.00	0.06	0.59	**0.80**	0.29	0.08	0.17	0.59	0.47	0.46	0.05
2004		0.03	0.17	**1.44**	0.20	0.13	0.24	0.17	1.00	0.28	0.18	0.10
2003	0.11	0.09	0.26	0.44	0.17	0.25	0.72	0.74	**1.06**	0.37	0.39	0.10
2002	0.11	0.34	0.06	0.22	0.33	0.46	**0.52**	0.30	0.47	0.09	0.04	0.00
2001	0.26	0.17	0.11	0.41	0.60	0.79	**0.88**	0.65	0.76	0.23	0.14	0.05
2000	0.06	0.09	0.20	0.70	**1.50**	0.46	0.36	0.35	0.65	0.09	0.07	0.00
1999	0.31	0.51	0.14	**1.00**	0.87	0.25	0.20	0.13	0.00	0.05	0.00	0.00
1998	0.34	**1.00**	0.40	0.59	0.57	0.04	0.24	0.13	0.24	0.05	0.11	0.00
1997	0.57	**2.31**	0.37	0.33	0.53	0.17	0.20	0.04	0.06	0.05	0.00	0.00
1996	1.14	**3.51**	0.43	0.70	1.03	0.08	0.20	0.22	0.12	0.09	0.00	0.00
1995	0.23	0.71	0.00	0.00	0.13	0.04	0.00	0.00	0.00	0.00	0.00	0.00
1994	0.14	0.71	0.00	0.19	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.20	0.46	0.00	0.00	0.07	0.08	0.00	0.09	0.00	0.00	0.00	0.00
1992	0.11	0.20	0.00	0.04	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**3.58**	**10.16**	**2.26**	**6.67**	**7.40**	**3.46**	**4.64**	**4.08**	**5.72**	**2.09**	**2.04**	**0.88**

Table 12a. Estimated annual and geometric mean survival (S) rates for year classes of striped bass (sexes combined), 30 March – 3 May, 1991-2017.

	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
16-17													
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, 1991-2017.

	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	.745	.418	.584	.321
16-17	.000		.000	.357	.000	.256	.778	.100	.000	.745	.357	.714	.667
mean	**.677**	**.590**	**.668**	**.677**	**.576**	**.641**	**.645**	**.466**	**.395**	**.420**	**.435**	**.490**	**.449**

Table 13a. Estimated annual and geometric mean survival (S) rates for year classes of male striped bass, 30 March – 3 May, 1991-2017.

	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													
16-17													
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, 1991-2017.

	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	.523	.833	.000	.359	.366	.310	.356
15-16						.000	.523	.800		.000	.366	.778	.330
16-17							.523	.000			.714	.714	.828
mean	**.545**	**.508**	**.584**	**.599**	**.504**	**.519**	**.577**	**.398**	**.276**	**.222**	**.435**	**.513**	**.460**

Table 14a. Estimated annual and geometric mean survival (S) rates for year classes of female striped bass, 30 March – 3 May, 1991-2017.

	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
16-17													
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, 1991-2017.

	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	.788	.433	.343
14-15	.677	.620	.138	.303	.191	.607	.280	.797	.413	.788	.433	.764
15-16	.677	.000	.778	.609	.444	.607	.643	.979	.413	.788	.778	.764
16-17	.000		.000	.357	.000	.256	.656	.109	.714	.788	.000	.714
mean	**.682**	**.520**	**.553**	**.564**	**.456**	**.455**	**.732**	**.673**	**.626**	**.647**	**.382**	**.615**

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, 1991-2017.

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	20.6
17	8.4	14.6	20.6	19.6	23.7	49.8	34.5	17.0	15.5	16.3	
18	8.4	14.7	20.7	19.6	23.7	50.0	34.5	17.1	15.5		
19	8.4	14.7	20.7	19.6	23.7	50.1	34.5	17.1			
20	8.4	14.7	20.8	19.6	23.7	50.1	34.5				
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, 1991-2017.

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	6.3	**12.6**
6	14.8	21.9	20.9	20.9	12.0	8.4	5.8	3.7	5.8	11.1		**13.5**
7	16.0	23.5	21.7	21.9	12.3	8.5	5.9	3.8	6.0			**14.3**
8	17.0	24.4	22.6	22.2	12.8	8.6	6.0	3.9				**15.2**
9	18.0	25.7	22.9	22.8	12.8	8.6	6.0					**16.1**
10	18.8	26.8	24.3	23.3	12.9	8.7						**17.1**
11	19.2	28.3	24.6	23.8	12.9							**18.0**
12	19.7	28.7	24.8	23.8								**18.5**
13	19.8	29.1	24.9									**18.9**
14	19.8	29.2										**19.2**
15	19.8											**19.3**
16												**19.4**
17												**19.4**
18												**19.5**
19												**19.5**
20												**19.5**
area	**19.8**	**29.2**	**24.9**	**23.8**	**12.9**	**8.7**	**6.0**	**3.9**	**6.0**	**11.1**	**6.3**	**19.5**

Table 16a. Back-calculated length-at-age (FL, in mm) for striped bass sampled from the James, York and Rappahannock rivers during spring, 2017.

Year Class	n	length-at-age (FL, in mm)							
		1	2	3	4	5	6	7	8
2015	2	156.0							
2014	199	146.1	252.1						
2013	203	146.1	256.2	361.2					
2012	113	138.3	243.4	343.9	435.0				
2011	64	133.7	231.1	326.9	415.2	480.2			
2010	19	131.1	221.2	306.2	394.8	476.2	542.8		
2009	7	131.8	219.4	307.8	391.4	468.1	539.5	602.3	
2008	3	133.2	225.9	307.6	400.7	491.3	566.5	633.5	666.9
2007	5	139.5	219.7	307.5	394.0	472.4	553.8	630.3	696.8
2006	7	141.2	232.9	320.6	403.8	483.2	558.2	623.6	692.2
2005	6	146.3	235.2	320.0	408.0	488.2	565.0	636.8	699.0
2004	6	144.2	237.1	329.0	417.4	490.6	559.0	623.0	686.1
2003	9	151.2	247.0	338.0	422.6	497.4	570.2	639.8	704.2
2002	0								
2001	4	138.3	229.8	315.8	394.6	477.1	551.3	608.6	666.6
2000	3	150.4	233.7	319.4	396.8	468.4	535.6	600.7	661.1
1999	0								
1998	1	158.7	265.2	344.8	434.8	520.4	590.0	666.6	715.5
all	651	142.8	247.4	341.1	424.5	489.1	545.8	613.4	685.1

Table 16b. Back-calculated length-at-age (FL, in mm) for striped bass sampled from the James, York and Rappahannock rivers during spring, 2017.

Year Class	n	length-at-age (FL, in mm)									
		9	10	11	12	13	14	15	16	17	18
2015	2										
2014	199										
2013	203										
2012	113										
2011	64										
2010	19										
2009	7										
2008	3										
2007	5	766.2									
2006	7	753.6	804.9								
2005	6	757.3	812.2	869.6							
2004	6	749.3	806.7	855.3	897.6						
2003	9	764.9	818.5	875.9	926.9	968.5					
2002	0										
2001	4	718.8	772.4	820.1	864.7	904.8	947.3	980.8			
2000	3	719.9	768.3	819.8	863.5	904.7	945.6	983.4	1015.0		
1999	0										
1998	1	756.5	794.4	829.3	872.3	909.9	949.9	985.7	1021.3	1048.6	1071.1
all	651	749.7	804.8	851.8	900.3	936.4	971.9	982.4	1011.5	1048.6	1071.1

Table 17. Mean scale and standard error for each otolith age from ages derived from the same specimen, 2003-2017.

N	Otolith age	Mean scale age	SE
99	2	2.31	0.47
197	3	3.26	0.46
240	4	4.29	0.59
222	5	5.02	0.66
177	6	5.95	0.81
207	7	6.66	1.12
254	8	8.07	0.98
295	9	8.96	1.13
344	10	9.77	1.17
330	11	10.82	1.09
252	12	11.42	1.16
128	13	12.04	1.25
86	14	12.90	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 2003-2017 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	**68**	2	0																
3	31	**141**	15	4															
4		54	**142**	31	3	5													
5			81	**145**	51	27	0	2											
6			2	40	**78**	54	10	1	0										
7				2	42	**77**	59	21	7	0	1	1							
8					3	36	**107**	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	**134**	68	30	6	4	1				
12								4	14	60	**91**	39	26	8	2	1			
13									6	12	33	**40**	25	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 = 2,989) by reading both their scales and otoliths, springs 2003-2017.

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
	Age = 8.45		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 1991-2017.

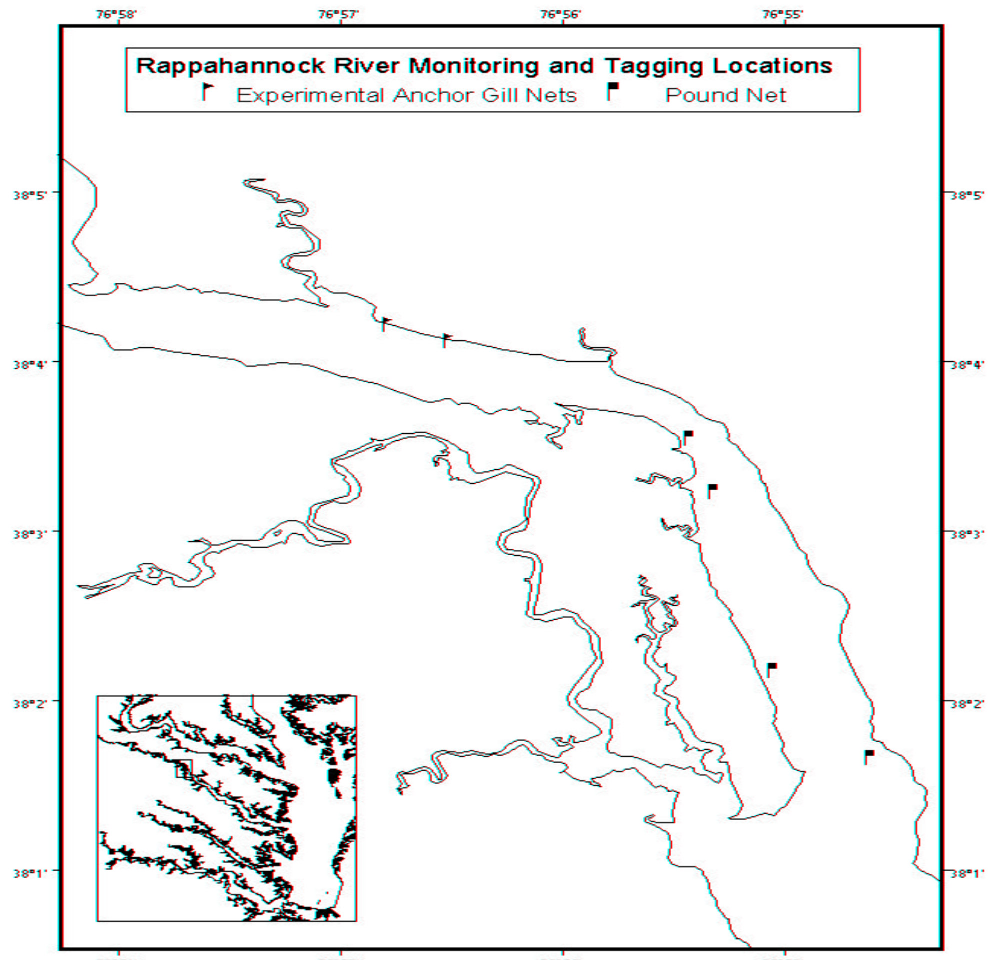


Figure 2. Daily and historic mean river flows (cf/s) for the Rappahannock River during the 30 March – 3 May spawning stock assessment period, spring 2017.

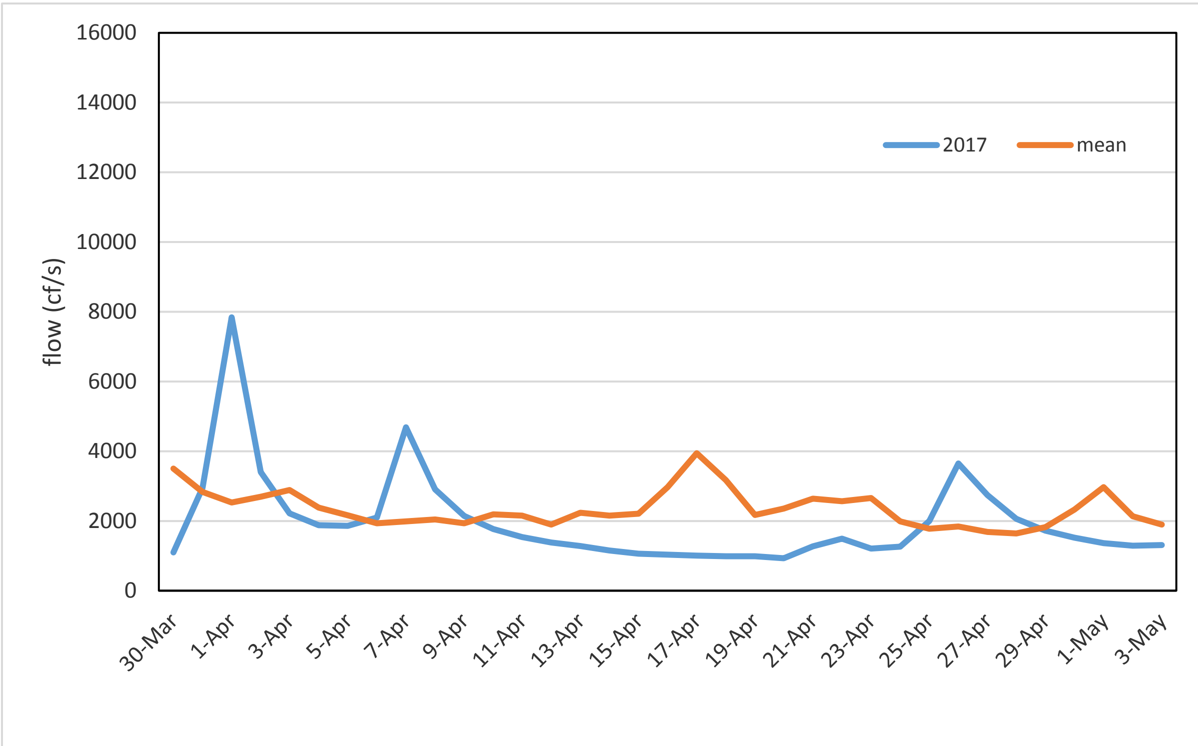
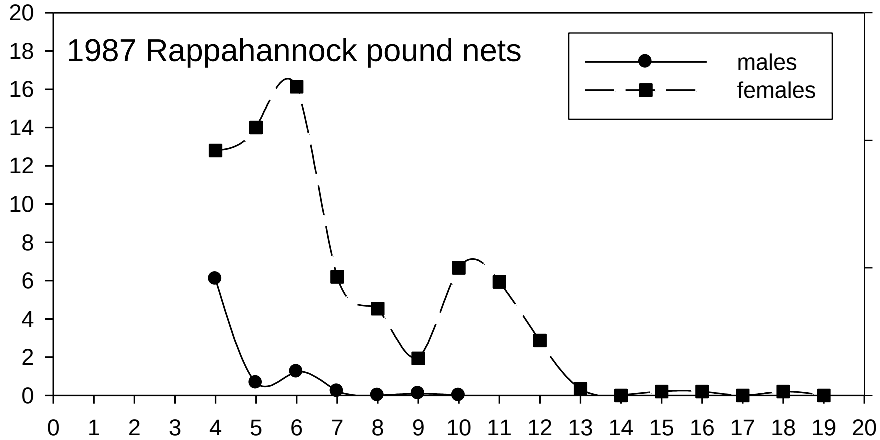


Figure 3. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1987 and 1988 year classes of striped bass from the Rappahannock River pound nets, springs 1991-2017.



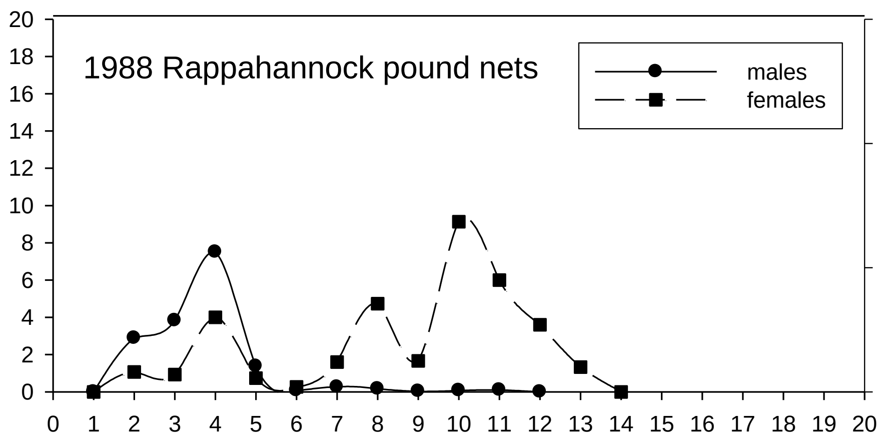
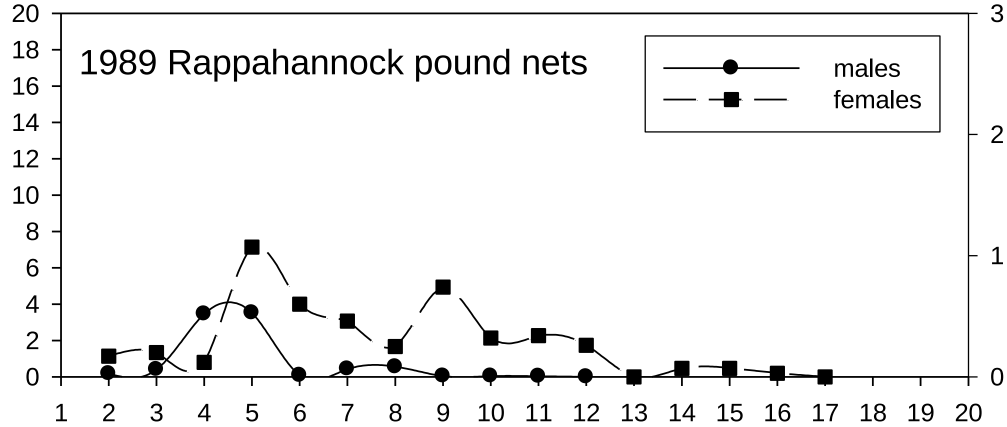


Figure 4. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1989 and 1990 year classes of striped bass from the Rappahannock River pound nets, springs 1991-2017.



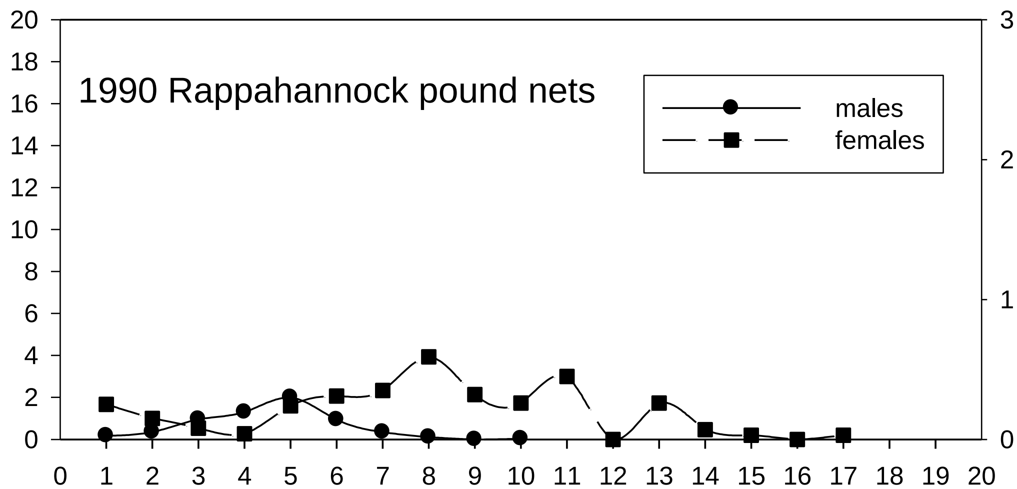
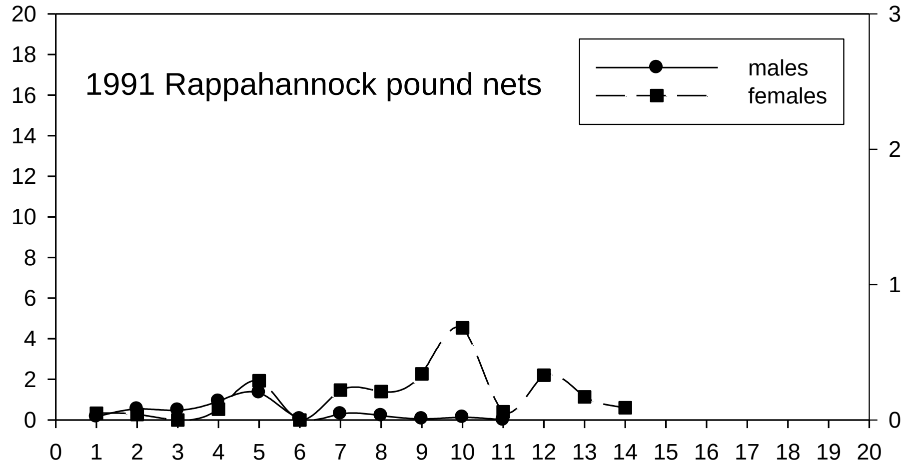


Figure 5. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1991 and 1992 year classes of striped bass from the Rappahannock River pound nets, springs 1991-2017.



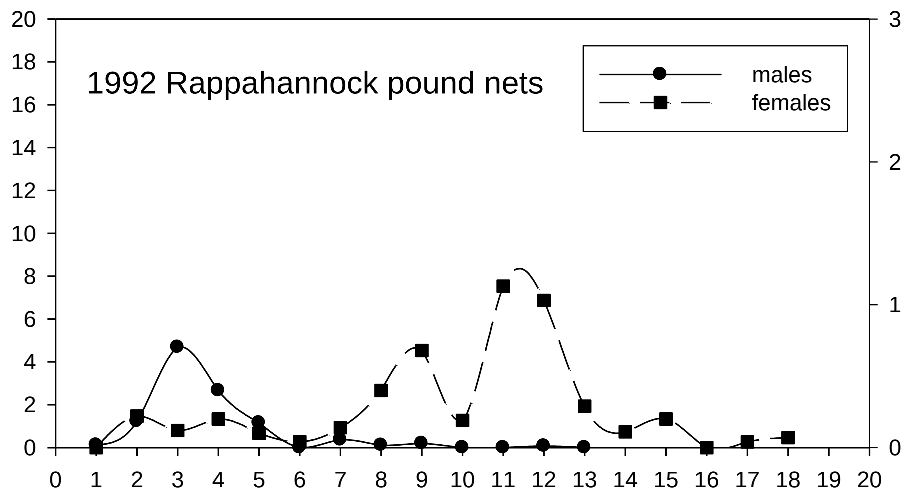


Figure 6. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1993 and 1994 year classes of striped bass from the Rappahannock River pound nets, springs 1994-2017.

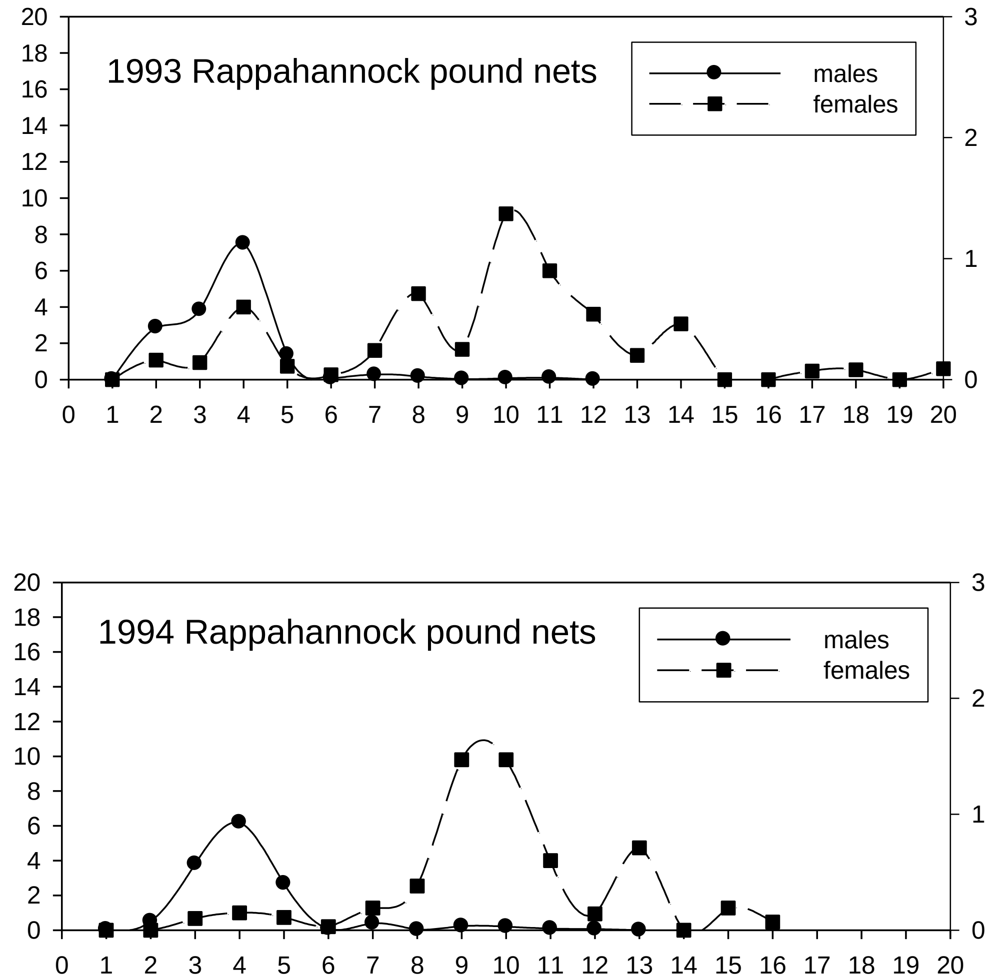


Figure 7. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1995 and 1996 year classes of striped bass from the Rappahannock River pound nets, springs 1996-2017.

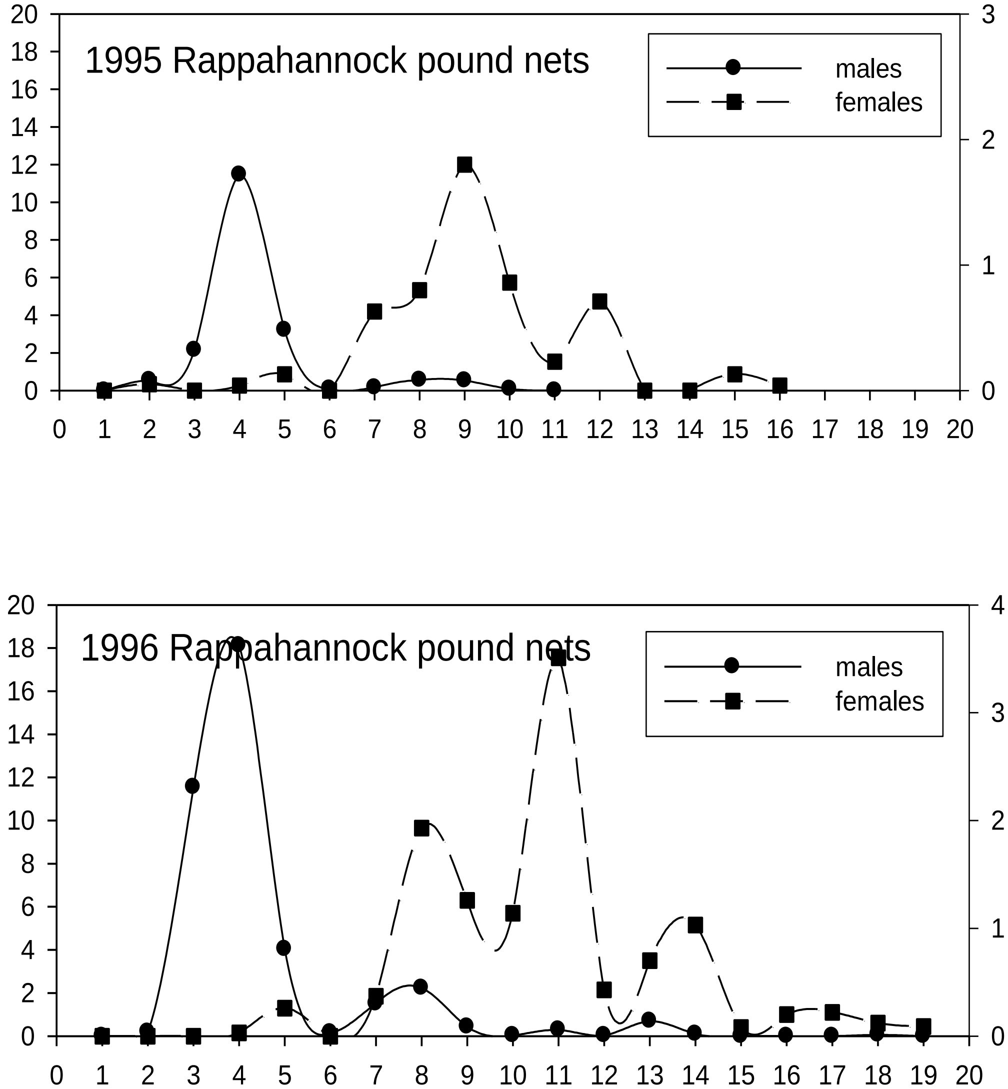
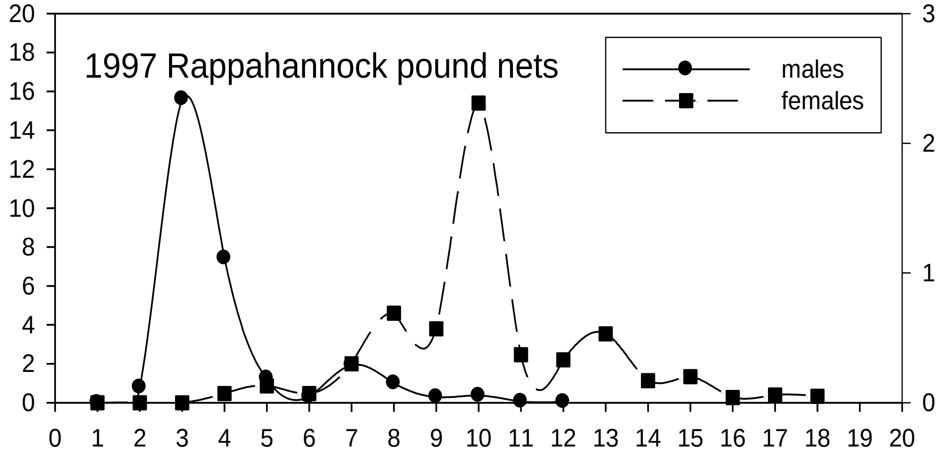


Figure 8. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1997 and 1998 year classes of striped bass from the Rappahannock River pound nets, springs 1998-2017.



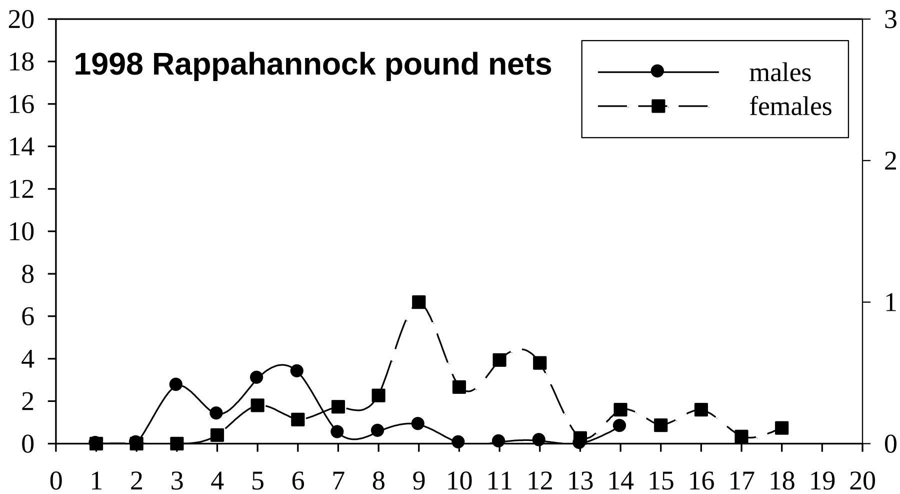
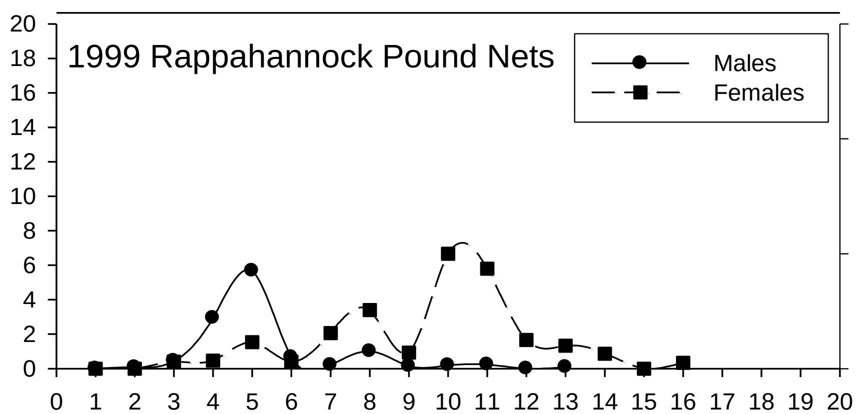


Figure 9. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1999 and 2000 year classes of striped bass from the Rappahannock River pound nets, springs 2000-2017.



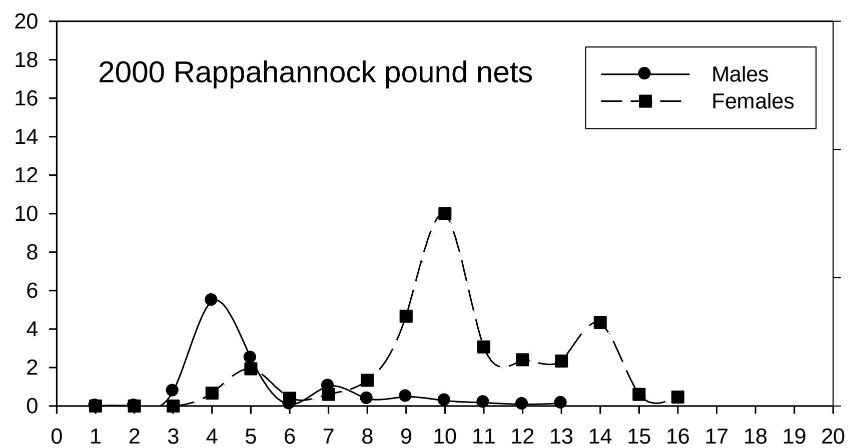
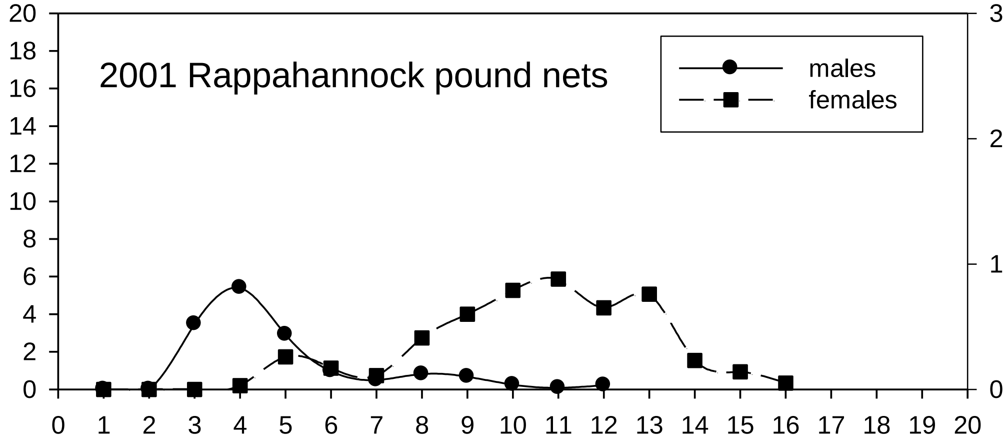


Figure 10. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 2001 and 2002 year classes of striped bass from the Rappahannock River pound nets, springs 2001-2017.



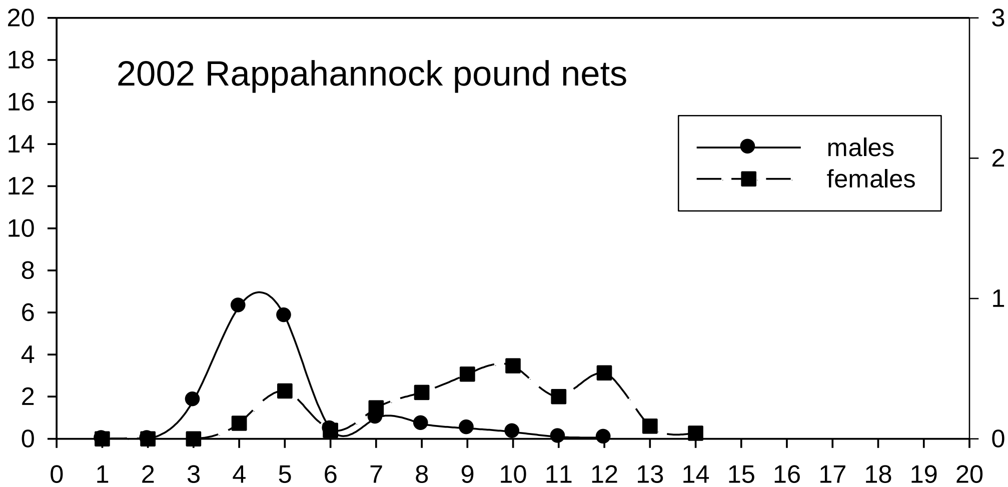
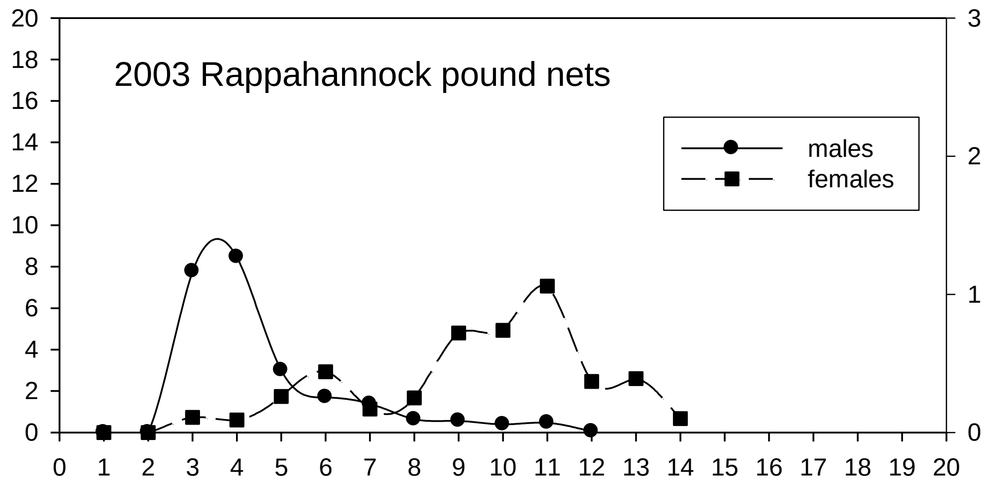


Figure 11. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 2003 and 2004 year classes of striped bass from the Rappahannock River pound nets, springs 2003-2017.



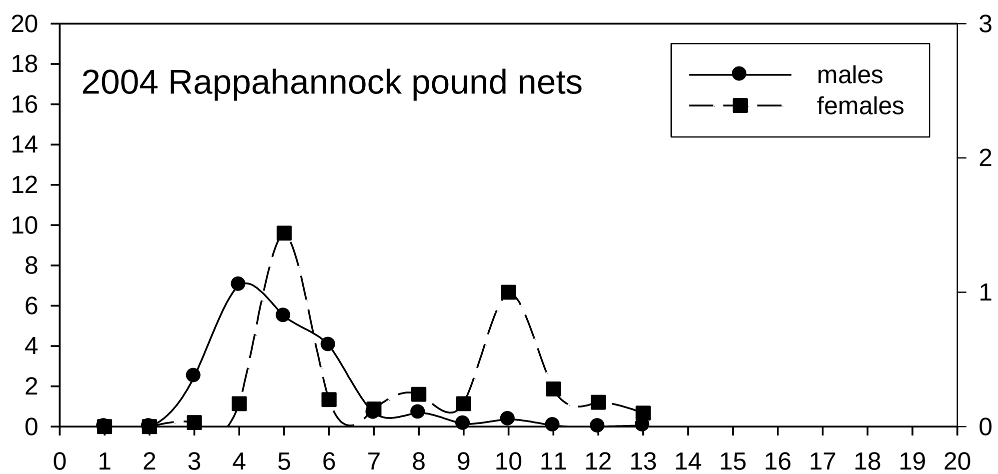
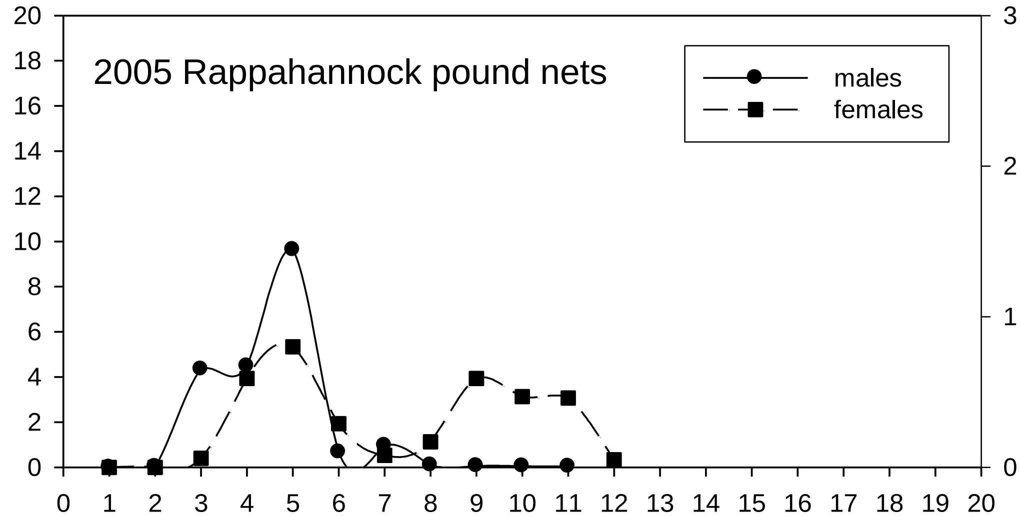


Figure 12. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 2005 and 2006 year classes of striped bass from the Rappahannock River pound nets, springs 2003-2017.



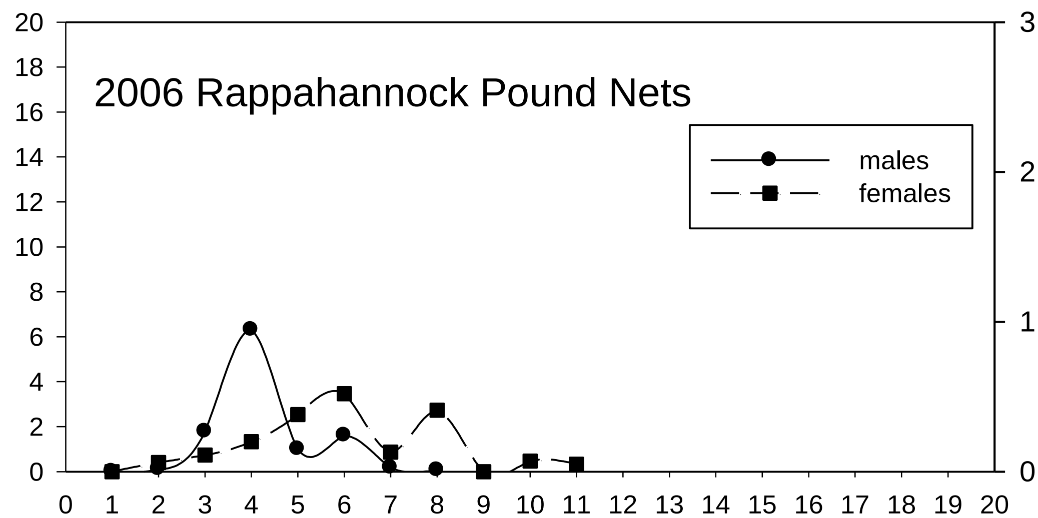
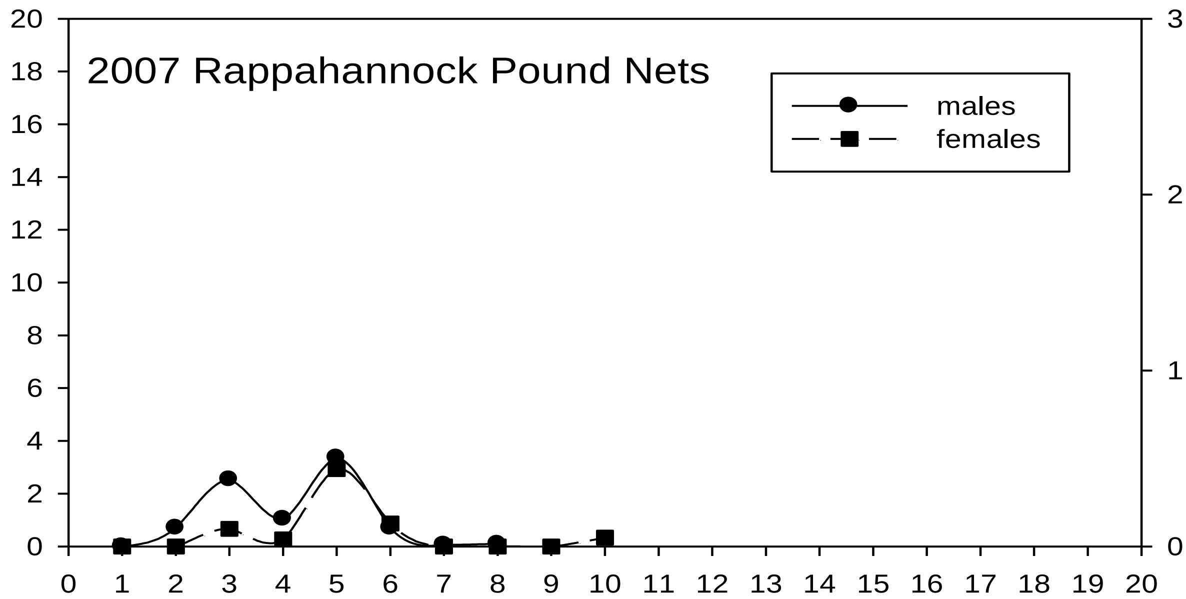


Figure 13. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 2007 and 2008 year class of striped bass from the Rappahannock River pound nets, springs 2005-2017.



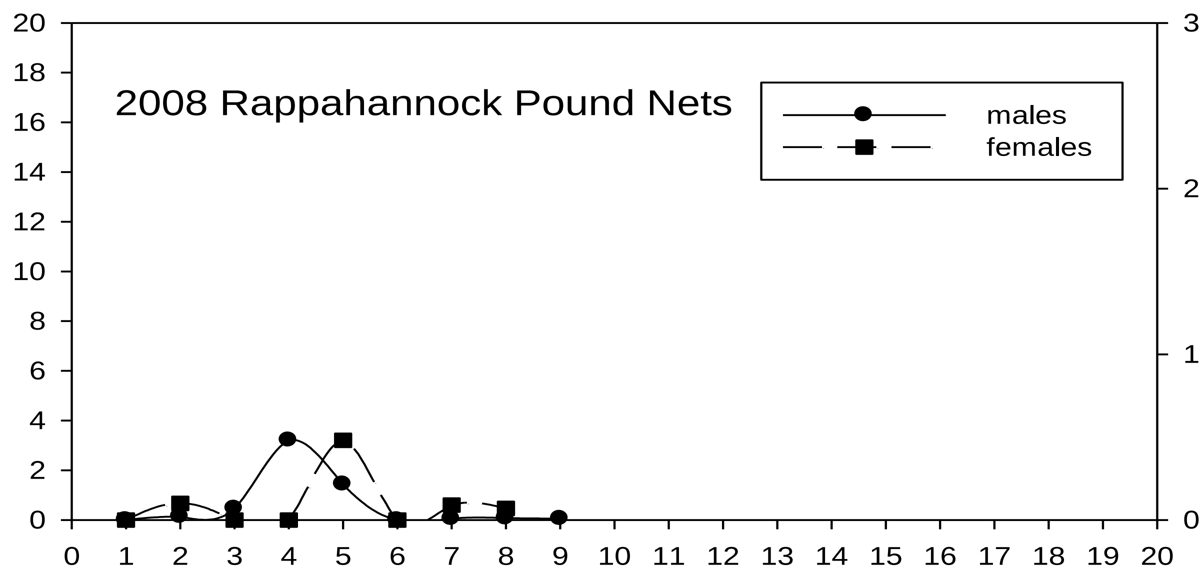
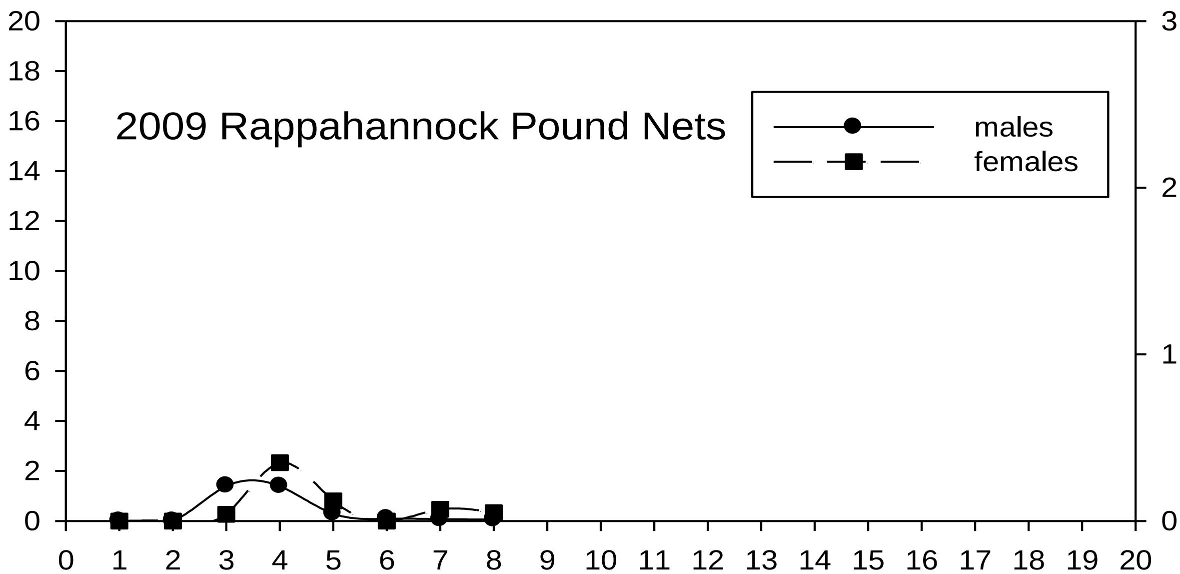


Figure 14. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 2009 and 2010 year class of striped bass from the Rappahannock River pound nets, springs 2007-2017.



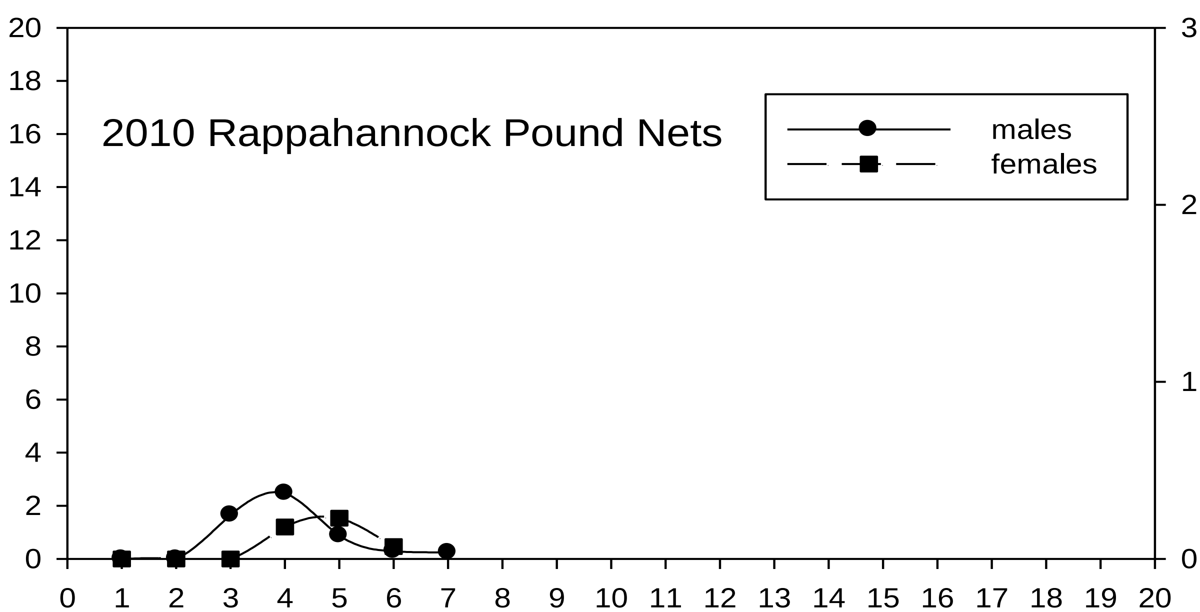


Figure 15. Comparison of otolith ages (diagonal) with their respective mean scale ages from the paired ageing methodology study, 2003-2017.

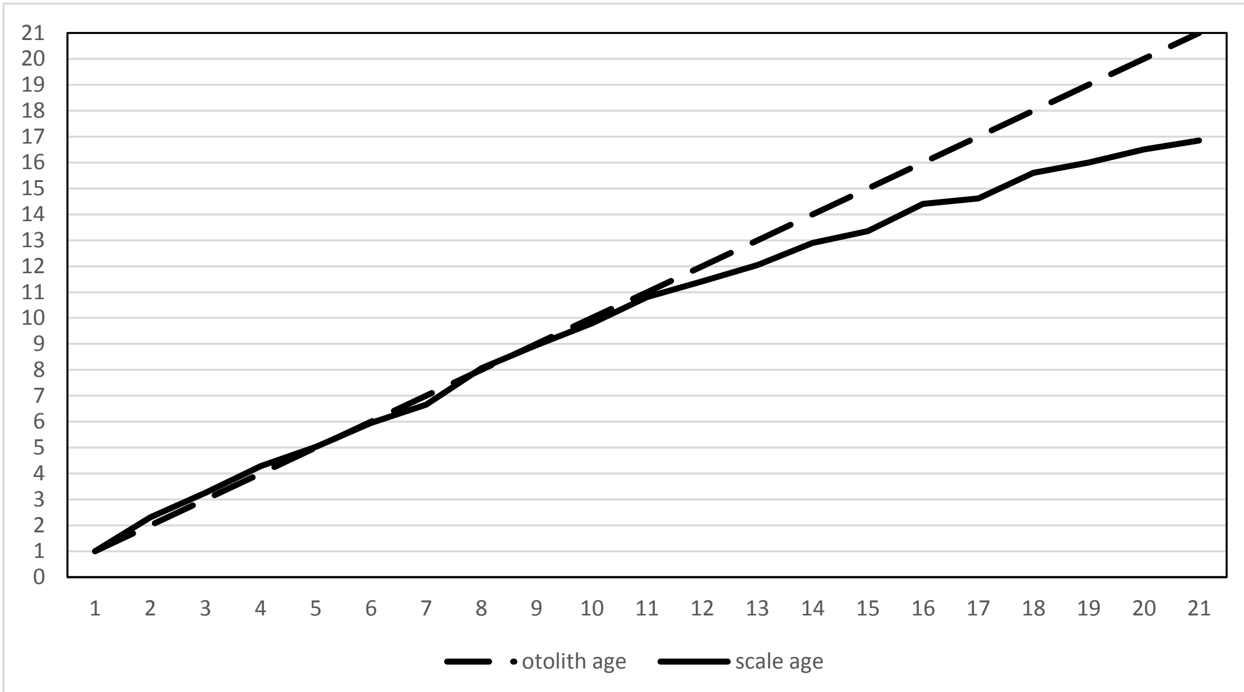
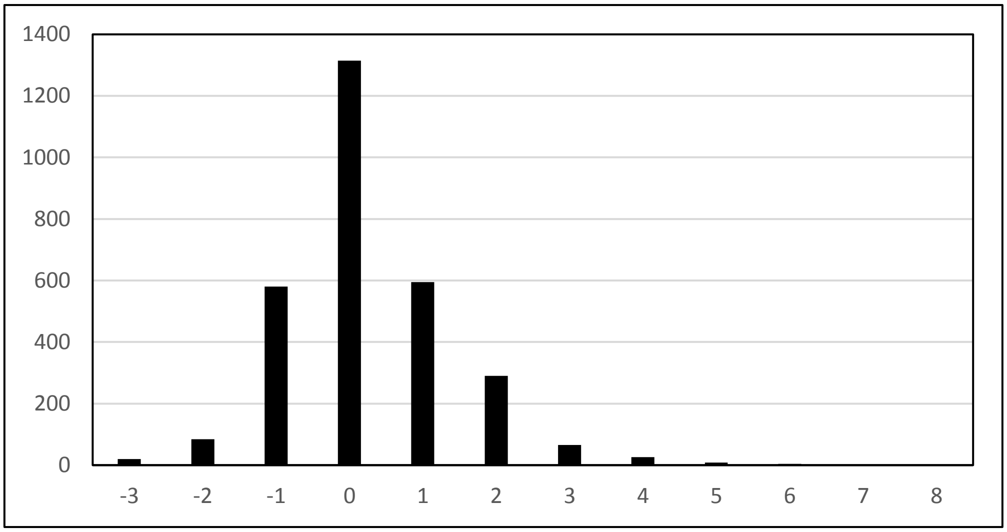


Figure 16. Magnitude of the age differences (n=2,989) by reading both their scales and otoliths, springs, 2003-2017.



II. Mortality estimates of striped bass (*Morone saxatilis*) that spawn in the Rappahannock River, Virginia, spring, 2016-2017.

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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.

From 2005 to 2013, the impact of dermal mycobacteriosis was studied by noting the condition (not diseased, mildly diseased, moderately diseased or heavily diseased) of each fish at the time of tagging and evaluating the rate of return of tags from each disease state.

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) and MARK (White and Burnham 1999).

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

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

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)

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

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; and Then et al. 2015), 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).

Disease Models: If disease has no effect on fish survival then we should expect the same fraction of tags returned from all of the disease categories. The logarithm of the ratio of returns of diseased and healthy fish estimates the difference in (instantaneous) mortality rates. More generally, the model is equivalent to a logistic regression (Hoenig et al. 2017).

We also estimate absolute, as opposed to relative, mortality rates using multistate mark-recapture models (Groner et al. in review). These models allow for uncertainty in disease state and also allowed us to model and test the effects of temperature and dissolved oxygen on survival.

Materials and Methods

Capture and Tagging Protocol

Rappahannock River: Each year from 1991 to 2017, 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 (five 120’ panels each) 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 51 to 62 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 (5 x 60' 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. In spring 2017, the drift net was again replaced with a 375' net. The deployment and fishing protocol was the same as described for the James River. These nets were deployed from river mile 30 to mile 44 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). Starting with the 2015 analyses, the final period was again separated into two periods, 2007-2011 and 2012-present. 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 2012-2016) 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, 2012-2014 and 2015-2016).

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, 1998-2016 for striped bass > 457 mm TL and 1990-2002, 2003-2016 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 2012-2016); 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, 2012-2015 and 2016).
F(v)F'(v)	Fishing and release mortalities vary over different periods (1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011, 2012-2014 and 2015-2016).

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).

Disease Models: Relative survival rates were estimated by logistic regression using a routine in R for generalized linear models. Multistate mark-recapture models were fitted using the ESURGE software.

Results

Spring 2017 Tag Release summary

A total of 552 striped bass were tagged and released from the pound nets in the Rappahannock River between 10 April and 27 April, 2017 (Table 1). There were 275 resident striped bass (457-710 mm TL) tagged and released. These stripers were predominantly male (92.4%), but the female stripers were larger on average. A total of 304 striped bass were tagged and released from gill nets in the James River between 10 March and 2 May, 2017 (Table 2). There were 187 resident striped bass tagged and released. These stripers were predominantly male (73.8%), but the female stripers were larger on average. In addition, tag releases from the York River system yielded 185 striped bass between 8 March and 1 May, 2017 (Table 3). There were 116 resident striped bass tagged and released. These were predominantly male (93.1%) 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 2017-2018 recapture interval, was 17 April.

There were 33 migrant striped bass (>710 mm TL) tagged and released in the Rappahannock River (Table 1), 28 migrant striped bass tagged and released in the James River (Table 2) and 21 migrant striped bass tagged and released in the York River (Table 3). These stripers were predominantly female (72.7% in the Rappahannock River, 92.9% in the James River and 90.5% 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 11 April. The tag release totals of striped bass greater than 457 mm TL (n=578) were 41.3% lower than the release total for 2016 and were below the tag release target of 700 releases. The tag release totals for striped bass greater than 710mm TL (n=82) were exactly half the amount in 2016, and were well below the tag release target of 300 migratory striped bass.

Mortality Estimates, 2016-2017

Tag recapture summary: A total of 43 striped bass (>457 mm TL) were recaptured between 1 January and 31 December, 2016. The largest source of recaptures (97.7%) was from Chesapeake Bay (76.7% in Virginia, 20.9% in Maryland, Table 4). Only one more recapture came from New York. There were no recaptures from Rhode Island, Massachusetts, New Jersey, Maine, New Hampshire, Connecticut, Delaware or North Carolina. The peak months for recaptures were in May and June and again in September, but there were recaptures in every month of the year except February and March.

A total of 19 migratory striped bass (>710 mm total length) were recaptured between 1 January and 31 December, 2016. The largest sources of the recaptured tagged striped bass (47.4%) were from Chesapeake Bay (31.6% in Virginia and 15.8% in Maryland,) (Table 5). Other recaptures came from New York (21.1%), Maine (15.8%), Rhode Island, Connecticut, and New Jersey (5.3% each). There were no recaptures reported from New Hampshire, Massachusetts, Delaware, or North Carolina. The peak month for recaptures was also in April through June and again in August, but the migrant striped bass were recaptured from March through November (except October).

ASMFC protocol: Survival estimates were made utilizing the mark-recapture data for the Rappahannock River from 1990-2016. 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: Twenty-five striped bass (≥ 457 mm TL) tagged in spring 2016 and 12 striped bass tagged in previous springs were harvested during the 2016-17 recapture interval. These were added to complete the input matrix (Table 6) for annual estimates of survival using program MARK. Likewise, there were 5 striped bass (≥ 711 mm TL) tagged in spring 2016 and 5 striped bass tagged in previous springs harvested during the 2016-17 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 vic-period model received 99.9% of the weighting (Table 8). The 2016 estimate of survival was 0.376 which became 0.385 when adjusted for release bias (Table 9). The 2016 survival estimate, although slightly higher than the 2015 estimate, is consistent with a trend of declining survival estimates throughout the time series.

The ranking and weighting among the three models were very different for striped bass ≥ 711 mm with the vic-period model highest with 0.849 of the weighting while the time-specific model received 0.122 and the period model the remaining 0.029 (Table 10). The 2016 estimate of survival was 0.314 (0.317 after bias adjustment) which was slightly higher than the 2015 survival estimate, but these two years are the lowest of the time series by far within a trend of continual decline throughout the time series (Table 11).

Rappahannock, York and James rivers releases: Forty striped bass (≥ 457 mm TL) tagged in spring 2016 and 13 striped bass tagged in previous springs were harvested during the 2016-17 recapture interval. These were added to complete the input matrix (Table 12) for annual estimates of survival using program MARK. Likewise, there were 10 striped bass (≥ 711 mm TL) tagged in spring 2016 and 5 striped bass tagged in previous springs harvested during the 2016-17 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 vic-period model received 99.9% of the weighting (Table 14). The 2016 estimate of survival was 0.353 which became 0.361 when adjusted for release bias (Table 15). The 2016 survival estimate was little changed from the 2015 estimate consistent with a temporal decline throughout the time series.

The ranking and weighting among the three models differed only slightly from the Rappahannock only analysis for striped bass ≥ 711 mm TL. The vic-period model was again highest with 0.929 of the weighting while the time-specific model received 0.045 and the period model received 0.026 (Table 16). The 2016 estimate of survival was 0.231 (0.235 after bias adjustment) which was little changed from the 2015 survival estimate and the lowest pair in the time series by far (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 2016 estimates for striped bass ≥ 457 mm TL were 0.96 (Z), 0.62 (A), 0.03 (U), 0.04 (F) and 0.91 (M, Table 18). The estimates of U and F were decreased from 2015, and had declined steadily since 2001 while the estimate of M has fluctuated, but remained well above the assumed value of 0.15 every year except 1992.

The 2016 estimates for striped bass ≥ 711 mm TL were 1.15 (Z), 0.68 (A), 0.05 (U), 0.09 (F) and 1.06 (M, Table 19). The estimates of F and U were higher than the estimates for 2015, but have declined through the time series, but the M estimate 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 2016 estimates for striped bass ≥ 457 mm TL were 1.02 (Z), 0.64 (A), 0.04 (U), 0.07 (F) and 0.96 (M, Table 20). The estimates of U and F were higher than the respective Rappahannock River-specific estimates, while the estimate of M fluctuated, but remained well above the assumed value of 0.15.

The 2016 estimates for striped bass ≥ 711 mm TL were 1.45 (Z), 0.77 (A), 0.08 (U), 0.16 (F) and 1.30 (M, Table 21). The estimates of F and U were almost double their respective Rappahannock River-specific estimates while the M estimate 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 1998-2016 M periods for striped bass ≥ 457 mm TL and 1990-2003 and 2004-2016 M periods for striped bass ≥ 711 mm TL.

Rappahannock River releases: Eleven striped bass (≥ 457 mm TL) tagged in spring 2016 and an additional 9 tagged in previous springs were harvested during the 2016-2017 recapture interval. In addition, there were eleven 2016-released striped bass and one 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 seven harvested (three from 2016 releases) and one released striped bass from striped bass ≥ 711 mm TL tagged in spring 2016 and recaptured during the 2016-2017 recapture interval and used to complete their respective instantaneous rate model input matrixes (Tables 23a, b).

The F(6p) f'(6p) model received most (73.7%) of the weighting among the six models defined in the IRCR analysis while the F(d)F'(d) contributed 14.9% (Table 24). Only one other model (F(v),F'(v)) contributed the remaining 11.4%. The resultant parameter estimates for 2016 are 0.510 (survival, Table 25), 0.622 (natural mortality) and 0.049 (fishing mortality). There has been a steady decline in the estimates of fishing mortality from 2005-2016 while the estimate for natural mortality continues greatly exceed the generally assumed value of 0.15 throughout the time series.

The F(6p)F'(6p) model received 75.1% of the weighting for the IRCR analysis for striped bass ≥ 711 mm TL with the F(d) F'(d) model (13.1%) along with the vic (11.7%) models most influencing the estimates (Table 26). The 2016 IRCR estimate of survival was 0.601 (Table 27). The 2016 estimate of natural mortality was 0.463 while the estimate of fishing mortality was 0.044. 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. The estimates for fishing mortality have been below 0.10 since 2002 and continue to decline.

James, York and Rappahannock rivers releases: Twenty-one striped bass (≥ 457 mm TL) tagged in spring 2016 and an additional 9 tagged in previous springs were harvested during the 2016-2017 recapture interval. In addition, there were 15 2016-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 ten harvested (seven from 2016 releases) and 2 released striped bass (one from 2016 releases) from striped bass ≥ 711 mm TL tagged in spring 2016 and recaptured during the 2016-2017 recapture interval and used to complete their respective instantaneous rate model input matrixes (Tables 29a, b).

The F(6p)F'(6p) model received most (74.8% combined) of the weighting among the six models defined in the IRCR analysis (Table 30). The F(t)F'(6p) model had dominated the 2013-2015 analyses (>95%), but received no weighting in the 2016 analysis. The F(d),F'(d) model received 13.6%, while the vic model received 11.6% of the weighting. The resultant parameter estimates for 2016 are 0.510 (survival, Table 31), 0.622 (natural mortality) and 0.049 (fishing mortality). Interestingly, these values are identical to the results for the Rappahannock-specific analysis. There is a steady decline in the estimates of fishing mortality from 2006-2016 while the estimate for natural mortality continues to increase and greatly exceeds the generally assumed value of 0.15 throughout the time series.

Similarly, the F(6p)F'(6p) model received 70.9% weighting for the IRCR analysis for striped bass ≥ 711 mm TL. The Vic period model (19.5%) and the Des model (9.5%) also influenced the estimates (Table 32). The 2016 IRCR estimate of survival was 0.593 (Table 33). The 2016 estimate of natural mortality was 0.471 while the estimate of fishing mortality was 0.051. 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 2007.

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.

Disease Models: Logistic regression models of relative survival of diseased and undiseased striped bass indicate that survival of moderate and severely diseased fish (comprising 15% and 11%, respectively, of the population of fish three year old and older) was 84% (70-100%, 95% CI) and 54% (42-68%, 95% CI) that of healthy striped bass (Hoenig et al. 2017). The disease adjusted natural mortality rate was 0.29, nearly double the previously accepted value which did not include the effects of mycobacteriosis. The multistate mark-recapture models (Groner et al. in review) indicate that mortality of diseased fish is high, particularly for severely diseased fish where it reaches nearly 80% in typical years. For both healthy and diseased fish, mortality increases with the estimated average summer sea surface temperature (SST) at the mouth of the Rappahannock River. In warm summers (SST=29° C), a cohort is predicted to experience >98% mortality in three years. The effect of dissolved oxygen on survival rates was small but statistically significant.

Discussion

In spring 2017, the release total for striped bass tagged in the Rappahannock was lower than the release total for spring 2016 and well below the target for striped bass. The winter of 2017 was exceptionally mild and we started our tagging efforts much earlier, but catches were poor throughout the season.. The recapture rate of Rappahannock River released stripers from 2016 was 0.031 (25/798) which was lower than for 2015 (0.045) and below the overall recapture rate of 0.057. The recapture rate for all 2016 releases was 0.035 (40/1150) which was little different 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 was 0.052 for 2004-2013 (range 0.023-0.074) and 0.036 for 2014-2016 (range 0.031-0.045).

The program MARK survival estimates for 2016 were 0.385 for striped bass greater than 18 inches (457 mm) total length tagged in the Rappahannock River and 0.361 from combined James, York and Rappahannock releases. The survival estimates were 0.317 for striped bass greater than 28 inches (711 mm) total length (migratory) released in the Rappahannock River and 0.231 from the James, York 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, but not 2016, the addition of the additional releases produced higher survival estimates for the greater than 18” cohort, and lower estimates for the greater than 28” striped bass in all three years. It should be noted that the estimate for c-hat was much higher this year and the adjustment resulted in the period models becoming the dominant models rather than the time-specific model as in previous analyses.

Again in 2016, 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, the estimates for fishing mortality have not been accepted as credible by the ASMFC. While MARK analysis for striped bass greater than 28 inches total length had produced rational results and had been used, the most recent estimates of fishing mortality for these striped bass have also seem to be suspect.

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 2016 estimates of fishing mortality of 0.07 (all river)-0.04 (Rappahannock River) for the greater than 18” cohort but estimates of 0.09 (Rappahannock River) and 0.16 (all rivers) for striped bass greater than 28” total length. It also produced estimates of natural mortality above 0.15 in both size groups, but the recent estimates are unreasonable large.

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 2016 estimates of fishing mortality were 0.05 for both the Rappahannock-specific and the combined James-Rappahannock analyses for striped bass >18 inches TL and 0.04-0.0 for striped bass >28 inches TL. The IRCR analyses also estimated that the natural mortality has greatly increased in the recent years for both size classes.

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

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

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

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Table 1. Summary data of striped bass tagged and released from pound nets in the Rappahannock River, spring 2017.

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	$\overline{TL}$
10 Apr	62	50	374.3	8	546.9	0		1	750.0	3	939.3
13 Apr	32	15	398.8	8	596.5	2	584.0	2	843.5	5	1,062.0
17 Apr	165	66	374.6	83	545.5	4	561.0	4	812.5	8	1,009.3
20 Apr	165	67	389.9	90	532.2	3	631.0	0		5	1,041.0
24 Apr	98	33	402.3	54	537.9	8	580.1	2	852.5	1	925.0
27 Apr	30	13	394.4	11	529.8	4	554.3	0		2	844.0
total	552	244	385.0	254	557.9	21	579.2	9	821.3	24	1,000.8

Table 2. Summary data of striped bass tagged and released from gill nets in the James River, spring 2017.

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	$\overline{TL}$
10 Mar	6	2	437.0	4	504.3	0		0		0	
17 Mar	3	0		2	525.0	0		0		1	1,142.0
21 Mar	0	0		0		0		0		0	
24 Mar	14	2	411.0	12	522.5	0		0		0	
31 Mar	98	39	419.6	51	519.9	6	537.0	1	780.0	1	981.0
4 Apr	63	27	418.8	29	545.2	7	548.9	0		0	
11 Apr	13	3	433.7	3	498.0	1	547.0	1	873.0	5	1,056.6
14 Apr	27	1	433.0	9	482.8	11	541.5	0		6	971.0
18 Apr	49	10	412.2	18	498.6	14	563.6	0		7	1,024.9
21 Apr	26	4	401.8	8	504.3	8	569.3	0		6	922.8
28 Apr	5	1	351.0	2	510.0	2	525.5	0		0	
2 May	0	0		0		0		0		0	
total	304	89	417.8	138	518.3	49	552.3	2	826.5	26	997.8

Table 3. Summary data of striped bass tagged and released from gill nets in the York and Mattaponi rivers, spring 2017.

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	$\overline{TL}$
8 Mar	6	0		4	497.3	2	558.0	0		0	
20 Mar	3	1	445.0	2	551.5	0		0		0	
22 Mar	1	0		1	467.0	0		0		0	
27 Mar	3	1	343.0	2	537.5	0		0		0	
29 Mar	77	11	423.8	65	531.9	0		0		1	1,139.0
3 Apr	36	15	380.7	14	538.2	0		1	858.0	6	1,044.7
5 Apr	36	15	346.1	16	569.1	2	597.0	1	721.0	2	1,001.0
10 Apr	3	0		1	591.0	0		0		2	985.0
12 Apr	2	0		1	508.0	0		0		1	977.0
17 Apr	10	2	418.5	0		3	598.0	0		5	955.0
19 Apr	3	1	413.0	1	603.0	1	555.0	0		0	
24 Apr	0	0		0		0		0		0	
26 Apr	5	0		3	601.3	0		0		2	957.5
1 May	0	0		0		0		0		0	
total	185	46	382.7	110	539.6	8	582.4	2	789.5	19	1,002.4

Table 4. Location of striped bass (≥ 457 mm TL), recaptured in 2016, that were originally tagged and released in the Rappahannock River during springs 1990-2016.

State	Month												total
	J	F	M	A	M	J	J	A	S	O	N	D	
Maine	0	0	0	0	0	0	0	0	0	0	0	0	0
New Hampshire	0	0	0	0	0	0	0	0	0	0	0	0	0
Massachusetts	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhode Island	0	0	0	0	0	0	0	0	0	0	0	0	0
Connecticut	0	0	0	0	0	0	0	0	0	0	0	0	0
New York	0	0	0	0	0	0	0	0	1	0	0	0	1
New Jersey	0	0	0	0	0	0	0	0	0	0	0	0	0
Delaware	0	0	0	0	0	0	0	0	0	0	0	0	0
Maryland	1	0	0	0	0	1	0	3	3	1	0	0	9
Virginia	1	0	0	1	17	4	2	1	1	1	3	2	33
North Carolina	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	2	0	0	1	17	5	2	4	5	2	3	2	43

Table 5. Location of striped bass (≥ 711 mm TL), recaptured in 2016, that were originally tagged and released in the Rappahannock River during springs 1990-2016.

State	Month												total
	J	F	M	A	M	J	J	A	S	O	N	D	
Maine	0	0	0	0	0	1	0	2	0	0	0	0	3
New Hampshire	0	0	0	0	0	0	0	0	0	0	0	0	0
Massachusetts	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhode Island	0	0	0	0	0	0	0	1	0	0	0	0	1
Connecticut	0	0	0	0	0	0	1	0	0	0	0	0	1
New York	0	0	0	0	0	1	1	0	2	0	0	0	4
New Jersey	0	0	0	0	0	1	0	0	0	0	0	0	1
Delaware	0	0	0	0	0	0	0	0	0	0	0	0	0
Maryland	0	0	0	1	2	0	0	0	0	0	0	0	3
Virginia	0	0	1	3	1	0	0	0	0	0	1	0	6
North Carolina	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	1	4	3	3	2	3	2	0	1	0	19

Table 6. Input recapture matrix for program MARK: from striped bass (>457 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2016.

Release		Recapture year																										
N	**Y**	**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**	**16**
1,464	**90**	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	0
2,481	**91**		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	0
130	**92**			14	8	6	5	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
621	**93**				50	37	17	8	9	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
195	**94**					13	10	5	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
698	**95**						55	30	20	5	4	2	3	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
376	**96**							21	18	7	3	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
712	**97**								47	26	14	3	0	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0
784	**98**									55	26	2	3	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0
853	**99**										66	23	9	5	3	0	0	0	0	0	0	1	0	0	0	0	0	0
1,765	**00**											122	51	23	16	6	5	1	1	0	0	0	0	0	0	0	0	0
797	**01**												61	23	16	7	2	2	2	0	0	0	0	0	0	0	0	0
315	**02**													20	8	15	1	1	2	1	0	0	0	0	0	0	0	0
852	**03**														58	37	9	4	5	3	2	3	0	0	0	0	1	1
1,477	**04**															80	21	13	7	4	2	1	0	0	0	0	0	0
921	**05**																44	26	10	2	5	4	0	0	0	0	0	0
668	**06**																	49	11	6	6	3	4	0	0	0	0	0
1,961	**07**																		117	50	24	4	6	1	1	2	1	0
523	**08**																			30	9	2	0	0	2	1	0	0
867	**09**																				43	10	3	2	0	1	0	0
2,050	**10**																					47	9	8	2	1	1	0
416	**11**																						24	4	1	0	1	2
1,222	**12**																							57	14	5	2	0
760	**13**																								36	9	8	1
454	**14**																									16	6	4
313	**15**																										14	4
798	**16**																											25

Table 7. Input recapture matrix for program MARK: from striped bass (>710 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2016.

Release			Recapture year																									
N	**Yr**	**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**	**16**
301	**90**	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	0
390	**91**		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	0
40	**92**			4	3	2	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
212	**93**				22	18	7	4	7	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
123	**94**					9	7	5	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
210	**95**						29	11	8	3	3	2	3	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
67	**96**							1	3	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
212	**97**								15	13	8	3	0	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0
158	**98**									24	13	2	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
162	**99**										17	6	2	3	2	0	0	0	0	0	0	1	0	0	0	0	0	0
365	**00**											28	19	14	9	4	3	0	1	0	0	0	0	0	0	0	0	0
269	**01**												19	14	4	6	2	1	1	0	0	0	0	0	0	0	0	0
122	**02**													10	6	7	1	0	2	1	0	0	0	0	0	0	0	0
400	**03**														35	24	7	1	3	3	2	3	0	0	0	0	1	0
686	**04**															39	12	13	5	4	2	1	0	0	0	0	0	0
284	**05**																16	11	8	1	4	3	0	0	0	0	0	0
175	**06**																	13	4	4	3	1	4	0	0	0	0	0
840	**07**																		55	30	18	3	5	1	1	1	1	0
75	**08**																			6	2	0	0	0	0	1	0	0
241	**09**																				7	5	1	1	0	1	0	0
483	**10**																					17	6	4	2	0	1	0
190	**11**																						12	2	0	0	1	2
325	**12**																							12	4	1	1	0
243	**13**																								10	3	3	0
247	**14**																									9	4	3
75	**15**																										2	0
99	**16**																											5

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 2012-2016 (p); parameters vary in 2015-2016 (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(v)r(p)	6,150.10	0.00	0.99942	13
S(p)r(t)	6,165.04	14.94	0.00057	33
S(t)r(t)	6,173.11	23.01	0.00001	53

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, 1990-2016.

Year	$\hat{S}$	SE ($\hat{S}$)	P_l	Bias	$\hat{S}_{adj}$	$\hat{F}$	95% CI $\hat{F}$
1990	0.561	0.027	0.481	-0.143	0.655	0.274	0.19, 0.37
1991	0.561	0.027	0.524	-0.082	0.611	0.342	0.25, 0.44
1992	0.561	0.027	0.408	-0.142	0.654	0.275	0.19, 0.37
1993	0.561	0.027	0.456	-0.105	0.627	0.317	0.23, 0.42
1994	0.561	0.027	0.381	-0.087	0.615	0.337	0.25, 0.44
1995	0.518	0.036	0.262	-0.054	0.548	0.452	0.33, 0.60
1996	0.518	0.036	0.274	-0.040	0.540	0.467	0.34, 0.61
1997	0.518	0.036	0.330	-0.057	0.550	0.449	0.32, 0.59
1998	0.518	0.036	0.362	-0.059	0.550	0.447	0.17, 0.44
1999	0.518	0.036	0.286	-0.059	0.551	0.447	0.17, 0.44
2000	0.518	0.039	0.436	-0.066	0.554	0.440	0.16, 0.45
2001	0.518	0.039	0.367	-0.059	0.550	0.448	0.16, 0.46
2002	0.518	0.039	0.368	-0.050	0.545	0.457	0.17, 0.47
2003	0.527	0.039	0.271	-0.039	0.549	0.450	0.17, 0.46
2004	0.527	0.039	0.281	-0.030	0.543	0.460	0.18, 0.47
2005	0.527	0.039	0.274	-0.024	0.540	0.466	0.18, 0.47
2006	0.527	0.039	0.354	-0.045	0.552	0.444	0.16, 0.45
2007	0.456	0.039	0.303	-0.034	0.472	0.600	0.30, 0.63
2008	0.456	0.039	0.208	-0.020	0.465	0.615	0.31, 0.64
2009	0.456	0.039	0.231	-0.022	0.466	0.613	0.31, 0.64
2010	0.456	0.039	0.267	-0.011	0.461	0.624	0.32, 0.65
2011	0.462	0.039	0.152	-0.013	0.462	0.621	0.32, 0.65
2012	0.404	0.063	0.264	-0.022	0.412	0.736	0.31, 0.92
2013	0.404	0.063	0.161	-0.014	0.409	0.744	0.32, 0.93
2014	0.404	0.063	0.278	-0.018	0.411	0.739	0.31, 0.93
2015	0.376	0.167	0.235	-0.021	0.384	0.808	0.02, 1.72
2016	0.376	0.167	0.235	-0.021	0.385	0.804	0.02, 1.72

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 2012-2016 (p); otherwise the same as p; parameters vary in 2015 and 2016 (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)	9,000.42	0.00	0.84925	13
S(t)r(t)	9,004.30	3.88	0.12169	53
S(p)r(t)	9,007.17	6.75	0.02906	33

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, 1990-2016.

Year	$\hat{S}$	SE ($\hat{S}$)	P_l	Bias	$\hat{S}$ adj	$\hat{F}$	95% CI	
1990	0.618	0.051	0.577	-0.127	0.708	0.196	0.05,	0.38
1991	0.624	0.061	0.560	-0.131	0.718	0.182	0.02,	0.40
1992	0.633	0.066	0.535	-0.172	0.765	0.118	-0.05,	0.36
1993	0.664	0.092	0.349	-0.093	0.731	0.163	-0.04,	0.61
1994	0.606	0.074	0.318	-0.070	0.652	0.278	0.08,	0.56
1995	0.620	0.099	0.204	-0.079	0.674	0.245	0.01,	0.64
1996	0.579	0.049	0.125	-0.016	0.589	0.380	0.23,	0.56
1997	0.568	0.062	0.167	-0.036	0.589	0.379	0.20,	0.62
1998	0.609	0.094	0.217	-0.084	0.666	0.257	0.02,	0.63
1999	0.565	0.068	0.200	-0.058	0.600	0.361	0.16,	0.63
2000	0.684	0.070	0.349	-0.063	0.730	0.164	0.00,	0.41
2001	0.649	0.080	0.298	-0.045	0.679	0.237	0.04,	0.54
2002	0.670	0.059	0.295	-0.062	0.714	0.187	0.04,	0.39
2003	0.625	0.110	0.246	-0.048	0.657	0.271	-0.14,	0.57
2004	0.557	0.083	0.321	-0.039	0.580	0.395	0.00,	0.59
2005	0.584	0.053	0.238	-0.029	0.602	0.358	0.05,	0.41
2006	0.605	0.079	0.282	-0.041	0.630	0.312	-0.05,	0.47
2007	0.588	0.067	0.228	-0.031	0.607	0.350	0.01,	0.46
2008	0.621	0.125	0.163	-0.020	0.634	0.306	-0.12,	0.68
2009	0.566	0.064	0.105	-0.008	0.571	0.411	0.07,	0.51
2010	0.546	0.093	0.235	-0.015	0.555	0.439	0.02,	0.69
2011	0.588	0.097	0.071	-0.007	0.592	0.374	-0.03,	0.62
2012	0.494	0.081	0.150	-0.008	0.498	0.547	0.13,	0.77
2013	0.509	0.085	0.059	-0.004	0.511	0.521	0.10,	0.75
2014	0.563	0.159	0.188	-0.011	0.570	0.413	-0.11,	1.01
2015	0.297	0.144	0.214	-0.009	0.300	1.055	0.17,	2.01
2016	0.314	0.139	0.100	-0.010	0.317	0.998	0.17,	1.86

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 1990-2016.

Release		Recapture year																										
N	Y	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	16
1,464	90	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	0
2,481	91		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	0
130	92			14	8	6	5	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
621	93				50	37	17	8	9	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
195	94					13	10	5	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
698	95						55	30	20	5	4	2	3	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
376	96							21	18	7	3	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
712	97								47	26	14	3	0	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0
784	98									55	26	2	3	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0
853	99										66	23	9	5	3	0	0	0	0	0	0	1	0	0	0	0	0	0
1,765	00											122	51	23	16	6	5	1	1	0	0	0	0	0	0	0	0	0
797	01												61	23	16	7	2	2	2	0	0	0	0	0	0	0	0	0
315	02													20	8	15	1	1	2	1	0	0	0	0	0	0	0	0
852	03														58	37	9	4	5	3	2	3	0	0	0	0	0	1
1,477	04															80	21	13	7	4	2	1	0	0	0	0	0	0
921	05																44	26	10	2	5	4	0	0	0	0	0	0
668	06																	49	11	6	6	3	4	0	0	0	0	0
1,961	07																		117	50	24	4	6	1	1	2	1	0
523	08																			30	9	2	0	0	2	1	0	0
867	09																				43	10	3	2	0	1	0	0
2,050	10																					47	9	8	2	1	1	0
416	11																						24	4	1	0	1	2
1,222	12																							57	14	5	2	0
760	13																								36	9	8	1
614	14																									20	6	5
490	15																										20	4
1,150	16																											40

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 1990-2016.

Release		Recapture year																										
N	**Y**	**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**	**16**
301	90	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	0
390	91		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	0
40	92			4	3	2	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
212	93				22	18	7	4	7	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
123	94					9	7	5	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
210	95						29	11	8	3	3	2	3	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
67	96							1	3	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
212	97								15	13	8	3	0	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0
158	98									24	13	2	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
162	99										17	6	2	3	2	0	0	0	0	0	0	1	0	0	0	0	0	0
365	00											28	19	14	9	4	3	0	1	0	0	0	0	0	0	0	0	0
269	01												19	14	4	6	2	1	1	0	0	0	0	0	0	0	0	0
122	02													10	6	7	1	0	2	1	0	0	0	0	0	0	0	0
400	03														35	24	7	1	3	3	2	3	0	0	0	0	1	0
686	04															39	12	13	5	4	2	1	0	0	0	0	0	0
284	05																16	11	8	1	4	3	0	0	0	0	0	0
175	06																	13	4	4	3	1	4	0	0	0	0	0
840	07																		55	30	18	3	5	1	1	1	1	0
75	08																			6	2	0	0	0	0	1	0	0
241	09																				7	5	1	1	0	1	0	0
483	10																					17	6	4	2	0	1	0
190	11																						12	2	0	0	1	2
325	12																							12	4	1	1	0
243	13																								10	3	3	0
285	14																									10	5	3
116	15																										5	0
164	16																											10

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 2012-2016 (p); parameters vary in 2015-2016 (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(v)r(p)	4,982.06	0.00	0.99994	13
S(p)r(t)	5,001.50	19.44	0.00006	33
S(t)r(t)	5,015.90	33.83	0.00000	53

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, 1990-2016.

Year	$\hat{S}$	SE ($\hat{S}$)	P_l	Bias	$\hat{S}_{adj}$	$\hat{F}$	95% CI $\hat{F}$
1990	0.561	0.030	0.469	-0.140	0.652	0.278	0.18, 0.39
1991	0.561	0.030	0.524	-0.082	0.611	0.343	0.24, 0.45
1992	0.561	0.030	0.401	-0.140	0.652	0.278	0.18, 0.39
1993	0.561	0.030	0.453	-0.105	0.626	0.318	0.22, 0.43
1994	0.561	0.030	0.371	-0.085	0.613	0.340	0.24, 0.45
1995	0.522	0.041	0.262	-0.054	0.552	0.444	0.30, 0.61
1996	0.522	0.041	0.274	-0.040	0.544	0.459	0.32, 0.62
1997	0.522	0.041	0.330	-0.057	0.554	0.440	0.30, 0.61
1998	0.522	0.041	0.343	-0.056	0.553	0.442	0.15, 0.46
1999	0.522	0.041	0.277	-0.058	0.554	0.440	0.15, 0.45
2000	0.513	0.048	0.410	-0.070	0.547	0.454	0.14, 0.50
2001	0.513	0.048	0.344	-0.064	0.543	0.461	0.15, 0.51
2002	0.513	0.048	0.303	-0.052	0.535	0.476	0.16, 0.53
2003	0.528	0.047	0.243	-0.045	0.547	0.453	0.15, 0.49
2004	0.528	0.047	0.260	-0.030	0.543	0.461	0.15, 0.50
2005	0.528	0.047	0.274	-0.035	0.541	0.464	0.16, 0.50
2006	0.528	0.047	0.344	-0.055	0.552	0.444	0.14, 0.48
2007	0.459	0.043	0.297	-0.042	0.475	0.595	0.27, 0.64
2008	0.459	0.043	0.198	-0.022	0.467	0.611	0.29, 0.66
2009	0.459	0.043	0.231	-0.025	0.469	0.607	0.29, 0.66
2010	0.459	0.043	0.267	-0.013	0.464	0.618	0.30, 0.67
2011	0.459	0.043	0.152	-0.017	0.465	0.616	0.29, 0.67
2012	0.400	0.070	0.264	-0.027	0.409	0.745	0.29, 0.97
2013	0.400	0.070	0.161	-0.017	0.405	0.753	0.30, 0.98
2014	0.400	0.070	0.282	-0.020	0.406	0.751	0.30, 0.98
2015	0.353	0.175	0.250	-0.023	0.360	0.873	0.02, 1.90
2016	0.353	0.175	0.340	-0.029	0.361	0.868	0.02, 1.90

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 2012-2016 (p); otherwise the same as p; parameters vary in 2015 and 2016 (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)	8,840.43	0.00	0.92939	13
S(t)r(t)	8,846.51	6.08	0.04456	53
S(p)r(t)	8,847.58	7.15	0.02605	33

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, 1990-2016.

Year	$\hat{S}$	SE ($\hat{S}$)	P_l	Bias	$\hat{S}$ adj	$\hat{F}$	95% CI
1990	0.626	0.037	0.577	-0.127	0.717	0.183	0.08, 0.31
1991	0.628	0.042	0.560	-0.131	0.723	0.175	0.06, 0.32
1992	0.631	0.045	0.535	-0.172	0.763	0.121	0.00, 0.28
1993	0.643	0.061	0.349	-0.093	0.708	0.195	0.04, 0.41
1994	0.622	0.051	0.318	-0.070	0.669	0.253	0.11, 0.43
1995	0.598	0.066	0.204	-0.079	0.649	0.282	0.10, 0.53
1996	0.583	0.037	0.125	-0.016	0.592	0.374	0.26, 0.51
1997	0.579	0.044	0.167	-0.036	0.601	0.360	0.23, 0.52
1998	0.594	0.062	0.218	-0.084	0.613	0.283	0.11, 0.52
1999	0.578	0.047	0.200	-0.058	0.610	0.339	0.20, 0.52
2000	0.676	0.053	0.349	-0.063	0.722	0.176	0.05, 0.35
2001	0.663	0.059	0.298	-0.045	0.695	0.215	0.07, 0.42
2002	0.671	0.047	0.295	-0.062	0.715	0.185	0.06, 0.34
2003	0.600	0.047	0.246	-0.048	0.631	0.311	-0.04, 0.44
2004	0.575	0.057	0.321	-0.039	0.599	0.362	0.04, 0.43
2005	0.585	0.039	0.238	-0.029	0.603	0.356	0.09, 0.35
2006	0.593	0.054	0.282	-0.041	0.618	0.331	0.03, 0.38
2007	0.580	0.048	0.228	-0.031	0.599	0.363	0.07, 0.39
2008	0.592	0.082	0.163	-0.020	0.604	0.354	-0.02, 0.53
2009	0.572	0.046	0.105	-0.008	0.576	0.401	0.11, 0.43
2010	0.566	0.060	0.235	-0.015	0.574	0.404	0.07, 0.49
2011	0.579	0.062	0.071	-0.007	0.583	0.390	0.06, 0.48
2012	0.496	0.064	0.150	-0.008	0.500	0.543	0.17, 0.68
2013	0.502	0.066	0.059	-0.004	0.503	0.536	0.16, 0.68
2014	0.512	0.111	0.044	-0.003	0.513	0.517	0.03, 0.89
2015	0.228	0.108	0.222	-0.014	0.231	1.316	0.39, 2.20
2016	0.231	0.107	0.133	-0.016	0.235	1.299	0.39, 2.15

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, 1990-2016.

Year	Z	A	U	F	M
1990	0.42	0.35	0.17	0.21	0.21
1992	0.49	0.39	0.14	0.17	0.32
1992	0.42	0.35	0.31	0.38	0.05
1993	0.47	0.37	0.23	0.29	0.18
1994	0.49	0.39	0.25	0.31	0.17
1995	0.60	0.45	0.19	0.25	0.35
1996	0.62	0.46	0.15	0.20	0.42
1997	0.60	0.45	0.20	0.26	0.34
1998	0.60	0.45	0.15	0.20	0.39
1999	0.60	0.45	0.13	0.18	0.42
2000	0.59	0.45	0.12	0.16	0.43
2001	0.60	0.45	0.16	0.21	0.39
2002	0.61	0.46	0.15	0.20	0.41
2003	0.60	0.45	0.16	0.21	0.39
2004	0.61	0.46	0.10	0.13	0.48
2005	0.62	0.46	0.12	0.16	0.46
2006	0.60	0.45	0.14	0.19	0.41
2007	0.75	0.53	0.12	0.18	0.57
2008	0.77	0.53	0.09	0.12	0.64
2009	0.76	0.53	0.09	0.13	0.63
2010	0.77	0.54	0.05	0.07	0.71
2011	0.77	0.54	0.08	0.11	0.66
2012	0.89	0.59	0.08	0.12	0.76
2013	0.89	0.59	0.10	0.15	0.75
2014	0.89	0.59	0.06	0.10	0.79
2015	0.96	0.62	0.07	0.11	0.84
2016	0.96	0.62	0.03	0.04	0.91

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, 1990-2016.

Year	Z	A	U	F	M
1990	0.35	0.29	0.25	0.30	0.05
1992	0.33	0.28	0.36	0.43	-0.10
1992	0.27	0.24	0.37	0.42	-0.15
1993	0.31	0.27	0.37	0.43	-0.12
1994	0.43	0.35	0.25	0.31	0.11
1995	0.40	0.33	0.41	0.50	-0.10
1996	0.53	0.41	0.18	0.23	0.30
1997	0.53	0.41	0.38	0.49	0.04
1998	0.41	0.33	0.45	0.55	-0.15
1999	0.51	0.40	0.30	0.38	0.13
2000	0.31	0.27	0.25	0.29	0.02
2001	0.39	0.32	0.21	0.25	0.14
2002	0.34	0.29	0.29	0.34	0.00
2003	0.42	0.34	0.24	0.29	0.13
2004	0.54	0.42	0.13	0.17	0.37
2005	0.51	0.40	0.20	0.26	0.25
2006	0.46	0.37	0.27	0.34	0.12
2007	0.50	0.39	0.19	0.24	0.26
2008	0.46	0.37	0.19	0.24	0.22
2009	0.56	0.43	0.09	0.11	0.45
2010	0.59	0.45	0.09	0.12	0.47
2011	0.52	0.41	0.09	0.11	0.41
2012	0.70	0.50	0.08	0.12	0.58
2013	0.67	0.49	0.08	0.11	0.56
2014	0.56	0.43	0.07	0.10	0.47
2015	1.21	0.70	0.03	0.04	1.16
2016	1.15	0.68	0.05	0.09	1.06

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, 1990-2016.

Year	Z	A	U	F	M
1990	0.43	0.35	0.17	0.21	0.21
1992	0.49	0.39	0.14	0.17	0.32
1992	0.43	0.35	0.31	0.38	0.05
1993	0.47	0.37	0.23	0.29	0.18
1994	0.49	0.39	0.25	0.31	0.17
1995	0.59	0.45	0.19	0.25	0.34
1996	0.61	0.46	0.15	0.19	0.41
1997	0.59	0.45	0.20	0.26	0.33
1998	0.59	0.45	0.15	0.20	0.39
1999	0.59	0.45	0.13	0.17	0.41
2000	0.60	0.45	0.12	0.16	0.44
2001	0.61	0.46	0.16	0.21	0.40
2002	0.63	0.47	0.15	0.20	0.42
2003	0.60	0.45	0.16	0.21	0.39
2004	0.61	0.45	0.10	0.13	0.48
2005	0.60	0.46	0.12	0.16	0.45
2006	0.59	0.45	0.14	0.19	0.41
2007	0.75	0.53	0.12	0.17	0.57
2008	0.76	0.53	0.09	0.12	0.64
2009	0.76	0.53	0.09	0.13	0.63
2010	0.77	0.54	0.05	0.07	0.70
2011	0.77	0.53	0.08	0.11	0.65
2012	0.89	0.59	0.08	0.12	0.77
2013	0.90	0.59	0.10	0.15	0.76
2014	0.90	0.59	0.05	0.08	0.82
2015	1.02	0.64	0.06	0.09	0.93
2016	1.02	0.64	0.04	0.07	0.96

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, 1990-2016.

Year	Z	A	U	F	M
1990	0.33	0.28	0.25	0.30	0.04
1992	0.32	0.28	0.36	0.43	-0.10
1992	0.27	0.24	0.37	0.42	-0.15
1993	0.35	0.29	0.37	0.44	-0.09
1994	0.40	0.33	0.25	0.31	0.09
1995	0.43	0.35	0.41	0.51	-0.07
1996	0.52	0.41	0.18	0.23	0.30
1997	0.51	0.40	0.38	0.48	0.03
1998	0.43	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	0.36	0.31	0.21	0.25	0.12
2002	0.34	0.28	0.29	0.34	-0.01
2003	0.46	0.37	0.24	0.30	0.16
2004	0.51	0.40	0.13	0.17	0.34
2005	0.51	0.40	0.20	0.26	0.25
2006	0.48	0.38	0.27	0.34	0.14
2007	0.51	0.40	0.19	0.24	0.27
2008	0.50	0.40	0.19	0.24	0.26
2009	0.55	0.42	0.09	0.11	0.44
2010	0.55	0.43	0.09	0.12	0.43
2011	0.54	0.42	0.10	0.12	0.42
2012	0.69	0.50	0.08	0.12	0.58
2013	0.69	0.50	0.08	0.11	0.57
2014	0.67	0.49	0.08	0.11	0.56
2015	1.47	0.77	0.05	0.09	1.37
2016	1.45	0.77	0.08	0.16	1.30

Table 22a. Input recapture matrix for IRCR analysis: from striped bass (>457 mm TL) tagged and released in the Rappahannock River, springs 1990-2016. Harvested recaptures only.

Release		Recapture year																										
N	**Y**	**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**	**16**
1,464	**90**	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	0
2,481	**91**		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	0
130	**92**			7	4	1	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
621	**93**				18	17	12	5	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
195	**94**					6	7	4	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
698	**95**						24	12	9	4	1	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
376	**96**							3	10	3	2	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
712	**97**								26	17	10	2	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
784	**98**									28	16	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
853	**99**										30	7	4	2	2	0	0	0	0	0	0	1	0	0	0	0	0	0
1,765	**00**											44	23	11	7	4	5	1	1	0	0	0	0	0	0	0	0	0
797	**01**												31	14	5	7	1	0	0	0	0	0	0	0	0	0	0	0
315	**02**													10	4	6	1	1	1	1	0	0	0	0	0	0	0	0
852	**03**														32	20	5	3	3	2	1	2	0	0	0	0	1	0
1,477	**04**															45	14	8	4	3	1	1	0	0	0	0	0	0
921	**05**																27	17	6	1	4	1	0	0	0	0	0	0
668	**06**																	27	4	5	5	3	4	0	0	0	0	0
1,961	**07**																		63	34	16	3	5	0	1	1	1	0
523	**08**																			17	4	0	0	0	0	1	0	0
867	**09**																				26	7	2	2	0	1	0	0
2050	**10**																					29	7	8	2	0	1	0
416	**11**																						12	4	0	0	1	0
1,222	**12**																							34	11	5	2	0
760	**13**																								23	8	7	1
454	**14**																									8	3	4
313	**15**																										8	4
798	**16**																											11

Table 22b. Input recapture matrix for IRCR analysis: from striped bass (>457 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2016. Recaptures released with streamers cut off only.

Release		Recapture year																										
N	Y	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	15
1,464	90	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	0
2,481	91		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	0
130	92			6	3	3	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
621	93				26	16	3	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
195	94					6	1	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
698	95						20	7	8	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
376	96							10	7	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
712	97								14	6	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
784	98									21	7	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
853	99										22	12	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,765	00											49	23	7	3	0	0	0	0	0	0	0	0	0	0	0	0	0
797	01												20	6	7	0	1	0	1	0	0	0	0	0	0	0	0	0
315	02													7	3	2	0	0	1	0	0	0	0	0	0	0	0	0
852	03														12	11	3	1	1	0	0	0	0	0	0	0	0	0
1,477	04															25	5	5	1	0	1	0	0	0	0	0	0	0
921	05																14	8	2	1	0	1	0	0	0	0	0	0
668	06																	19	6	1	1	0	0	0	0	0	0	0
1,961	07																		34	10	1	1	0	1	0	1	0	0
523	08																			7	2	2	0	0	0	0	0	0
867	09																				16	2	0	0	0	0	0	0
2050	10																					14	2	0	0	1	0	0
416	11																						5	0	0	0	0	1
1,222	12																							18	2	0	0	0
760	13																								7	1	1	0
454	14																									6	2	0
313	15																										5	0
798	16																											11

Table 23a. Input recapture matrix for IRCR analysis: from striped bass (>710 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2016 Harvested recaptures only.

Release		Recapture year																										
N	**Y**	**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**	**15**
301	**90**	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	0
390	**91**		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	0
40	**92**			2	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
212	**93**				11	11	5	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
123	**94**					4	4	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
210	**95**						18	6	5	2	1	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
67	**96**							0	3	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
212	**97**								11	12	6	2	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
158	**98**									16	9	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
162	**99**										13	2	1	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0
365	**00**											13	11	6	5	3	3	0	1	0	0	0	0	0	0	0	0	0
269	**01**												9	8	2	6	1	0	0	0	0	0	0	0	0	0	0	0
122	**02**													7	3	5	1	0	1	1	0	0	0	0	0	0	0	0
400	**03**														23	13	3	1	2	2	1	2	0	0	0	0	1	0
686	**04**															21	8	8	3	3	1	1	0	0	0	0	0	0
284	**05**																12	7	5	1	3	0	0	0	0	0	0	0
175	**06**																	10	3	3	2	1	4	0	0	0	0	0
840	**07**																		33	22	11	2	4	0	1	1	1	1
75	**08**																			5	1	0	0	0	0	1	0	0
241	**09**																				5	3	0	1	0	1	0	0
483	**10**																					11	5	4	2	0	1	0
190	**11**																						6	2	0	0	1	0
325	**12**																							9	4	1	1	0
243	**13**																								5	3	3	0
247	**14**																									5	2	3
75	**15**																										1	0
99	**16**																											3

Table 23b. Input recapture matrix for IRCR analysis: from striped bass (>710 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2016. Recaptures released with streamers cut off only.

Release		Recapture year																										
N	Y	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	15
301	90	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	0
390	91		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	0
40	92			2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
212	93				10	7	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
123	94					4	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
210	15						7	2	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67	96							1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
212	97								2	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
158	98									6	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
162	99										3	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
365	00											9	7	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0
269	01												7	4	2	0	1	0	1	0	0	0	0	0	0	0	0	0
122	02													2	2	0	0	0	1	0	0	0	0	0	0	0	0	0
400	03														8	8	3	0	0	0	0	0	0	0	0	0	0	0
686	04															16	2	5	1	0	1	0	0	0	0	0	0	0
284	05																4	4	1	0	0	1	0	0	0	0	0	0
175	06																	2	1	1	1	0	0	0	0	0	0	0
840	07																		12	7	1	1	0	1	0	0	0	0
75	08																			0	0	0	0	0	0	0	0	0
241	09																				1	1	0	0	0	0	0	0
483	10																					5	1	0	0	0	0	0
190	11																						1	0	0	0	0	1
325	12																							2	0	0	0	0
243	13																								1	0	0	0
247	14																									3	2	0
75	15																										1	0
99	16																											0

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 2012-2016; d- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011, 2012-2015 and 2016; v- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011, 2012-2014 and 2015-2016).

2M (1990-1997, 1998-2016)			
model	**$QAIC_c$**	**weight**	**parameters**
F(6p), F'(6p)	6,502.8	0.737	14
F(d),F'(d)	6,506.0	0.149	16
F(v), F'(v)	6,506.5	0.114	16
F(t), F'(6p)	6,522.5	0.000	35
F(6p), F'(t)	6,533.9	0.000	35
F(t), F'(t)	6,554.6	0.000	56

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, 1990-2016.

Year	2M			
	S	M	F	SE
1990	0.625	0.380	0.081	0.011
1991	0.625	0.380	0.081	0.011
1992	0.625	0.380	0.081	0.011
1993	0.625	0.380	0.081	0.011
1994	0.625	0.380	0.081	0.011
1995	0.612	0.380	0.105	0.015
1996	0.612	0.380	0.105	0.015
1997	0.612	0.380	0.105	0.015
1998	0.481	0.622	0.105	0.015
1999	0.481	0.622	0.105	0.015
2000	0.491	0.622	0.084	0.014
2001	0.491	0.622	0.084	0.014
2002	0.491	0.622	0.084	0.014
2003	0.486	0.622	0.097	0.013
2004	0.486	0.622	0.097	0.013
2005	0.486	0.622	0.097	0.013
2006	0.486	0.622	0.097	0.013
2007	0.499	0.622	0.071	0.009
2008	0.499	0.622	0.071	0.009
2009	0.499	0.622	0.071	0.009
2010	0.499	0.622	0.071	0.009
2011	0.499	0.622	0.071	0.009
2012	0.509	0.622	0.052	0.009
2013	0.509	0.622	0.052	0.009
2014	0.509	0.622	0.052	0.009
2015	0.509	0.622	0.051	0.010
2016	0.510	0.622	0.049	0.012

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 2012-2016; d- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011, 2012-2015 and 2016; v- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011, 2012-2014 and 2015-2016).

2M (1990-2003, 2004-2016)			
model	**$QAIC_c$**	**weight**	**parameters**
F(6p), F'(6p)	9,314.1	0.751	14
F(d),F'(d)	9,317.6	0.131	16
F(v), F'(v)	9,317.8	0.117	16
F(t), F'(6p)	9,326.6	0.001	35
F(6p), F'(t)	9,337.7	0.000	35
F(t), F'(t)	9,350.8	0.000	56

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, 1990-2016.

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	0.624	0.252	0.216	0.022
1997	0.624	0.252	0.216	0.022
1998	0.624	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	0.568	0.463	0.099	0.009
2005	0.568	0.463	0.099	0.009
2006	0.568	0.463	0.099	0.009
2007	0.573	0.463	0.091	0.009
2008	0.573	0.463	0.091	0.010
2009	0.573	0.463	0.091	0.009
2010	0.573	0.463	0.091	0.009
2011	0.573	0.463	0.091	0.009
2012	0.600	0.463	0.046	0.007
2013	0.600	0.463	0.046	0.007
2014	0.600	0.463	0.046	0.007
2015	0.600	0.463	0.046	0.008
2016	0.601	0.463	0.044	0.010

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 1990-2016. Harvested recaptures only.

Release		Recapture year																										
N	**Y**	**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**	**16**
1,464	**90**	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	0
2,481	**91**		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	0
130	**92**			7	4	1	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
621	**93**				18	17	12	5	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
195	**94**					6	7	4	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
698	**95**						24	12	9	4	1	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
376	**96**							3	10	3	2	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
712	**97**								26	17	10	2	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
784	**98**									28	16	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
853	**99**										30	7	4	2	2	0	0	0	0	0	0	1	0	0	0	0	0	0
1,765	**00**											44	23	11	7	4	5	1	1	0	0	0	0	0	0	0	0	0
797	**01**												31	14	5	7	1	0	0	0	0	0	0	0	0	0	0	0
315	**02**													10	4	6	1	1	1	1	0	0	0	0	0	0	0	0
852	**03**														32	20	5	3	3	2	1	2	0	0	0	0	1	0
1,477	**04**															45	14	8	4	3	1	1	0	0	0	0	0	0
921	**05**																27	17	6	1	4	1	0	0	0	0	0	0
668	**06**																	27	4	5	5	3	4	0	0	0	0	0
1,961	**07**																		64	34	16	3	5	0	1	1	1	0
523	**08**																			17	4	0	0	0	0	1	0	0
867	**09**																				26	7	2	2	0	1	0	0
2050	**10**																					29	7	8	2	0	1	0
416	**11**																						12	4	0	0	1	0
1,222	**12**																							34	11	5	2	0
760	**13**																								23	8	7	1
614	**14**																									9	4	4
490	**15**																										11	4
1,150	**16**																											21

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 1990-2016. Recaptures released with streamers cut off only.

Release		Recapture year																										
N	Y	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	16
1,464	90	76	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	0
2,481	91		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	0
130	92			6	3	3	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
621	93				26	16	3	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
195	94					6	1	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
698	95						20	7	8	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
376	96							10	7	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
712	97								14	6	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
784	98									21	7	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
853	99										22	12	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,765	00											49	23	7	3	0	0	0	0	0	0	0	0	0	0	0	0	0
797	01												20	6	7	0	1	0	1	0	0	0	0	0	0	0	0	0
315	02													7	3	2	0	0	1	0	0	0	0	0	0	0	0	0
852	03														12	11	3	1	1	0	0	0	0	0	0	0	0	1
1,477	04															25	5	5	1	0	1	0	0	0	0	0	0	0
921	05																14	8	2	1	0	1	0	0	0	0	0	0
668	06																	19	6	1	1	0	0	0	0	0	0	0
1,961	07																		34	10	1	1	0	1	0	1	0	0
523	08																			7	2	2	0	0	0	0	0	0
867	09																				16	2	0	0	0	0	0	0
2050	10																					14	2	0	0	1	0	0
416	11																						5	0	0	0	0	1
1,222	12																							18	2	0	0	0
760	13																								7	1	1	0
614	14																									8	2	1
490	15																										7	0
1,150	16																											15

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 1990-2016. Harvested recaptures only.

Release		Recapture year																										
N	**Y**	**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**	**16**
301	**90**	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	0
390	**91**		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	0
40	**92**			2	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
212	**93**				11	11	5	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
123	**94**					4	4	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
210	**95**						18	6	5	2	1	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
67	**96**							0	3	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
212	**97**								11	12	6	2	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
158	**98**									16	9	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
162	**99**										13	2	1	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0
365	**00**											13	11	6	5	3	3	0	1	0	0	0	0	0	0	0	0	0
269	**01**												9	8	2	6	1	0	0	0	0	0	0	0	0	0	0	0
122	**02**													7	3	5	1	0	1	1	0	0	0	0	0	0	0	0
400	**03**														23	13	3	1	2	2	1	2	0	0	0	0	1	0
686	**04**															21	8	8	3	3	1	1	0	0	0	0	0	0
284	**05**																12	7	5	1	3	0	0	0	0	0	0	0
175	**06**																	10	3	3	2	1	4	0	0	0	0	0
840	**07**																		33	22	11	2	4	0	1	1	1	0
75	**08**																			5	1	0	0	0	0	1	0	0
241	**09**																				5	3	0	1	0	1	0	0
483	**10**																					11	5	4	2	0	1	0
190	**11**																						6	2	0	0	1	0
325	**12**																							9	4	1	1	0
243	**13**																								5	3	3	0
285	**14**																									6	3	3
116	**15**																										2	0
164	**16**																											7

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 1990-2016. Recaptures released with streamers cut off only.

Release		Recapture year																										
N	Y	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	16
301	90	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	0
390	91		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	0
40	92			2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
212	93				10	7	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
123	94					4	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
210	95						7	2	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67	96							1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
212	97								2	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
158	18									6	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
162	99										3	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
365	00											9	7	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0
269	01												7	4	2	0	1	0	1	0	0	0	0	0	0	0	0	0
122	02													2	2	0	0	0	1	0	0	0	0	0	0	0	0	0
400	03														8	8	3	0	0	0	0	0	0	0	0	0	0	0
686	04															16	2	5	1	0	1	0	0	0	0	0	0	0
284	05																4	4	1	0	0	1	0	0	0	0	0	0
175	06																	2	1	1	1	0	0	0	0	0	0	0
840	07																		12	7	1	1	0	1	0	0	0	0
75	08																			0	0	0	0	0	0	0	0	0
241	09																				1	1	0	0	0	0	0	0
483	10																					5	1	0	0	0	0	0
190	11																						1	0	0	0	0	1
325	12																							2	0	0	0	0
243	13																								1	0	0	0
285	14																									3	2	0
116	15																										2	0
164	16																											1

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 2012-2016; d- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011, 2012-2015 and 2016; v- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011, 2012-2014 and 2015-2016).

2M (1990-1997, 1998-2016)			
model	**$QAIC_c$**	**weight**	**parameters**
F(6p), F'(6p)	6,573.0	0.748	14
F(d),F'(d)	6,576.4	0.136	16
F(v), F'(v)	6,576.7	0.116	16
F(t), F'(6p)	6,592.8	0.000	35
F(6p), F'(t)	6,604.0	0.000	35
F(t), F'(t)	6,624.8	0.000	56

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, 1990-2016.

Year	2M			
	S	M	F	SE
1990	0.625	0.380	0.081	0.011
1991	0.625	0.380	0.081	0.011
1992	0.625	0.380	0.081	0.011
1993	0.625	0.380	0.081	0.011
1994	0.625	0.380	0.081	0.011
1995	0.612	0.380	0.105	0.015
1996	0.612	0.380	0.105	0.015
1997	0.612	0.380	0.105	0.015
1998	0.481	0.622	0.105	0.015
1999	0.481	0.622	0.105	0.015
2000	0.491	0.622	0.084	0.014
2001	0.491	0.622	0.084	0.014
2002	0.491	0.622	0.084	0.014
2003	0.486	0.622	0.097	0.013
2004	0.486	0.622	0.097	0.013
2005	0.486	0.622	0.097	0.013
2006	0.486	0.622	0.097	0.013
2007	0.499	0.622	0.070	0.009
2008	0.499	0.622	0.070	0.009
2009	0.499	0.622	0.070	0.009
2010	0.499	0.622	0.070	0.009
2011	0.499	0.622	0.070	0.009
2012	0.510	0.622	0.050	0.009
2013	0.510	0.622	0.050	0.009
2014	0.510	0.622	0.050	0.009
2015	0.510	0.622	0.050	0.009
2016	0.510	0.622	0.049	0.010

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 2012-2016; d- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011, 2012-2015 and 2016; v- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2011, 2012-2014 and 2015-2016).

2M (1990-2003, 2004-2016)			
model	**$QAIC_c$**	**weight**	**parameters**
F(6p), F'(6p)	9,401.1	0.709	14
F(v),F'(v)	9,403.6	0.195	16
F(d), F'(d)	9,405.1	0.095	16
F(t), F'(6p)	9,413.7	0.001	35
F(6p), F'(t)	9,423.3	0.000	35
F(t), F'(t)	9,437.8	0.000	56

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, 1990-2016.

Year	2M			
	S	M	F	SE
1990	0.668	0.252	0.141	0.015
1991	0.668	0.252	0.141	0.015
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	0.624	0.252	0.216	0.022
1996	0.624	0.252	0.216	0.022
1997	0.624	0.252	0.216	0.022
1998	0.624	0.252	0.216	0.022
1999	0.624	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	0.100	0.009
2004	0.563	0.471	0.100	0.009
2005	0.563	0.471	0.100	0.009
2006	0.563	0.471	0.100	0.009
2007	0.568	0.471	0.093	0.009
2008	0.568	0.471	0.093	0.010
2009	0.568	0.471	0.093	0.009
2010	0.568	0.471	0.093	0.010
2011	0.568	0.471	0.093	0.010
2012	0.594	0.471	0.049	0.008
2013	0.594	0.471	0.049	0.008
2014	0.594	0.471	0.049	0.008
2015	0.593	0.471	0.050	0.009
2016	0.593	0.471	0.051	0.010

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. The latest benchmark striped bass stock assessment in 2013 reported a need to develop fishery independent estimates of abundance for striped bass. For many years, conventional tagging programs in Virginia and Maryland have been used to estimate exploitation, survival, and mortality rates of striped bass, but they have not been used to estimate abundance or SSB. 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 mark-recapture analysis (CKMR). 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).

The objective of this study was to evaluate the basic theory of CKMR on a model river system, the Rappahannock River, to determine if a large enough number of parent-offspring pairs could be recovered to develop and implement CKMR. Additionally, estimates will be made into the population size of adults using the CKMR theory to investigate the relationship between POPs and total abundance as sample size changes. 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

Sampling and Amplification

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. Total genomic DNA was extracted from each genetic sample using Machary Nagel NucleoSpin® DNA tissue kits on the Tecan Freedom EVO® 75 liquid handling system.

The molecular markers used to determine POPs will be microsatellite loci (short, tandem repeats of nuclear DNA) amplified in groups called multiplexes. Microsatellites were selected from the existing literature (Couch et al., 2006; Rexroad et al., 2006; Fountain et al., 2009; Gauthier et al., 2013) and approximately 20 markers were selected based on allelic diversity, chromosome location (linkage map from Liu et al., 2012), and estimated heterozygosity. Loci were assembled into multiplex panels, or groups of markers, using Multiplex Manager (Holleley and Geerts, 2009). Markers were lab tested to ensure proper amplification in a series of multiplexes. Assembled microsatellite multiplexes were amplified 92-95 samples at a time, with controls for each step. Amplification was done using the polymerase chain reaction (PCR) in 10ul reactions with locus-specific fluorescent probes. In order to visualize PCR product, 2 ul of product was combined with 8 ul of formamide and 0.2ul 500 LIZ Gene Scan Size standard (Applied Biosystems), denatured for 10 minutes at 95°C, and sequenced on a 36cm 3130xl Capillary Genetic Analyzer (Applied Biosystems, Inc.). The output consisted of electropharagrams with different chromatic peaks representing each microsatellite locus. The electopharagrams were scored using GeneMarker v2.6.0 (SoftGenetics, LLC). To check for evidence of scoring errors and null allele presence, scores were evaluated using MicroChecker 2.2.3 (Van Oosterhout et al., 2004). Quality control checks to ensure no errors during amplification, a 5% sub-sample of samples were re-analyzed from PCR reaction to allele scoring to ensure consistency in amplification and allele calling. Additionally to ensure accuracy of allele calling, the entire data set was scored twice.

Close-Kinship Mark Recapture

CKMR analyses are similar to traditional mark-recapture studies, where individuals are marked with a physical tag (e.g. a spaghetti tag); however, in CKMR studies, individuals are marked by a 'genetic tag'. In essence, spawning adults are 'marked' by the genotypes of the young-of-year. Each YOY receives an allele from each parent at each nuclear locus, effectively 'marking' two adults. This genetic tag can then be 'recaptured' in random samples of spawning adults as parent-offspring pairs (POPs). If the population of adults is large, then the number of POPs will be low, whereas if many POPs are recovered, the population is small (Bravington et al., 2014a). The probability that a captured adult is one of the parents for a selected YOY is $2/N_a$. where N_a represents the total number of adults alive when the YOY was spawned. Comparing all sampled adults (m_a) to a selected YOY, the expected number of POPs is m_a*2/N_a. Comparing all sampled YOY (m_j) to all sampled adults (m_a), the expected number of POPS ($\mathbb{E}[H]$) is $m_j m_a*2/N_a$. Rearranging the formula to include the actual number of POPs, or hits (h):

$$N_a = \frac{2m_j m_a}{h}$$

This closely resembles the estimate of abundance using the Lincoln-Peterson abundance estimator, a conventional tag-based estimator (Bravington et al., 2016). While the relationship is useful, a more explicit statistical mark-recapture model would be needed for a realistic setting to accommodate the unique life-history of striped bass, age-dependent sampling probability, and non-equilibrium conditions in the spawning population (Bravington et al., 2014a).

To determine if CKMR analysis is feasible for striped bass, a robust number of samples were analyzed to identify POPs. As outlined in the methodology of Bravington (2014a, 2016a, 2016b), a minimum of 50 POPs should be recovered to produce a reasonable CV of the population size estimate. To determine how many POPs exist, the genotypes of all sampled adults and juveniles were compared using the parentage analysis program COLONY (Jones and Wang, 2010). The software allows for the assignment of parents to offspring while accounting for allelic dropout and mistyping. The analysis in COLONY used the full likelihood run, with a medium run length with high likelihood precision with a 5% error rate. Additionally, inbreeding and polygamy were allowed. A higher error rate was allowed to ensure that no false negatives would be missed in the analyses. All POPs that COLONY matched were screened by eye within GeneMarker to confirm that the pair had at least one allele in common at every locus.

Abundance Simulations

To provide a guideline for future studies utilizing this technique, as well as estimate rough adult abundances, a modified Lincoln-Peterson model was used. The formula used was a combination of Bravingotn et al (2014a) and the Chapman modification to the Lincoln Peterson estimator (Chapman, 1951). Equation 1 is as follows where N_a = estimated number of adults, m_j is the number of juveniles (or originally marked individuals), m_a is the number of adults (or size of second sample), and h is the number of POPs (or number of marked individuals in the second sample) (Chapman 1951; Polluck et al., 1990, Bravington et al 2014a).

$$N_a = \frac{2(m_j+1)(m_a+1)}{(h+1)}$$

Confidence intervals (95%) for the estimates of adult abundance were estimated by first determining the unbiased estimate of variance, given by equation 2, and then equation 3, where z is the standard normal variable, calculated the desired confidence interval (Seber 1970, 1982; Polluck et al., 1990)

$$var = 2\frac{(m_j+1)(m_a+1)(m_j-h)(m_a-h)}{(h+1)^2(2+2)}$$

$$CI = N_a \pm z * \sqrt{var}$$

The coefficeint of variation as calculated using the estimated adult abundance, N_a, in equation 4 taken from Bravington et al (2014a).

$$CV = \frac{\sqrt{2}}{(m_j+m_a)} * \sqrt{N_a}$$

Different scenarios were tested using these formulas, with each scenario having a different combination of adult sample sizes, juvenile samples sizes, and the number of recovered POPs.

Results

Sampling

In total, 1,309 fin clips were collected from adult and young-of-year (YOY) fish during the 2016 sampling season in the Rappahannock River (Figure 1) in conjunction with the ongoing Striped Bass Tagging Program. After quality control checks, the final dataset included 760 samples, 371 adults and 389 YOY. The population sampled includes 89 female fish, with fork lengths ranging from 440-1078 mm, and 282 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). YOY fish were collected from June to August 2016 with the majority of the fish being collected from the upper Rappahannock (mile markers: 50-73).

POPs and Adult Abundance Simulations

COLONY assigned 18 POPs from the dataset. After checking the genotypes of each POP in GeneMarker, it was found that the dataset contained 2 true POPs with 100% matches of at least one allele at each locus. Potentially, one additional POP had a mismatch at one locus, but with only likelihood 70% support it was considered a false positive. For the two recovered POPs, one parent was female 4 years of age with a total length of 498. The other POP parent was a male 5 years of age with a total length 512.

Adult abundance estimates were generated for 175 different scenarios using equation 1, with 95% confidence intervals and CVs generated with equations 2-4. With the parameters collected for this study, the estimated adult abundance was 145,081 (98,062,192,100) with a CV of .71. Scenarios evaluated included different combinations of the number of recovered POPs, (h=2, 5, 10, 15, 20, 25, 50), adult sample size (m_a=371, 500,1000,1500,2000), and YOY sample size (m_j=389, 500,1000,1500,2000). As both adults and YOY sample sizes increased, estimated adult abundance increases (Figure 2). The CV declined as the number of POPs recovered increased. The supplementary table shows all of the combinations of sample size and recovered POPs. The lowest reported CVs were found when h=50, regardless of sample size of adults or juveniles. For all other scenarios with less than 50 POPs recovered, the CV was lowest when at least one sample size, adults or juveniles, was greater than 1,000 individuals. Adult abundance estimates across all scenarios ranged from over 4 million fish to 5,800 fish.

Discussion

The management of striped bass has allowed for the recovery of striped bass stocks to support large commercial and recreational fisheries. Testing and evaluating new monitoring efforts, such as close-kinship mark-recapture (CKMR) will allow for the continued management of striped bass stocks in Virginia. Currently, there is no estimate of spawning stock biomass size for Virigina rivers, nor is there an estimate for the Chesapeake Bay. Continued tagging studies provide the framework for the implementation of a new methodology that would allow for local adult spawning striped bass biomass abundance estimates. The results of this study show that, with large enough sample sizes, rough estimates into adult abundance estimation can be made. Additionally, if this project were to be applied for future studies, the development of a full CKMR model would be possible.

The full CKMR model combines information from POP recovery, as seen in this study, and combines it with an explicit statistical mark-recapture model that includes population parameters specific to striped bass. The developed model would be similar to the models that already exist for striped bass abundance estimation, a length, sex, and age structured population dynamics model that combines POP recovery with growth, fecundity, and a time series of adult population dynamics. For a full review and discussion of CKMR methodology, Bravington et al (2016a) and Bravington et al (2016b) provide a full description of model requirements. Due to the species specific requirements of the CKMR method, a specific model for striped bass would need to be developed due to some of the unique life history aspects of the species.

For example, some studies indicate that striped bass may exhibit skip spawning, or not spawning every single year. Additionally, sex composition data from the spawning grounds indicates that the sex ratio of males to females on spawning grounds is not 1:1; this is an assumption of the CKMR model. The CKMR model also assumes that there is no genetic stock structure for a species. Evidence on stock structure for the Chesapeake Bay is debated, and a recent study has shown that the large spawning grounds on the Atlantic coast are genetically unique spawning grounds. Additionally, the Chesapeake Bay acts as a major source of recruitment to the total Atlantic stock that further complicate estimates. However, with the correct parameterization and development, CKMR can provide a powerful tool for the estimation of adult spawning biomass for Atlantic striped bass.

For this study, microsatellite markers were used due to their availability for striped bass, as well as the use of microsatellites during the development of this methodology. Due to problems with amplification, this study found that microsatellites, at least for striped bass, must be used with caution and strict quality control measures. The strict measures of this study kept the quality of data high, but reduced the overall sample size by almost 50%. To maximize sample size and efficiency, this study recommends the development and use of single-nucleotide polymorphism marks, or SNPs. Quickly becoming the molecular marker of choice, these markers are biallic and, in large numbers, offer the same power as microsatellites to match offspring to parents without the amplification problems seen in microsatellites (Anderson and Garze, 2006; Hauser et al., 2011).

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. CKMR 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 was to determine just that, and aid in providing more precise estimates of abundance.

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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.

	Overall	Male	Female
2016			
Rappahannock	371	282	89
Juvenile Rappahannock	389	-	-

Figure 1. 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.

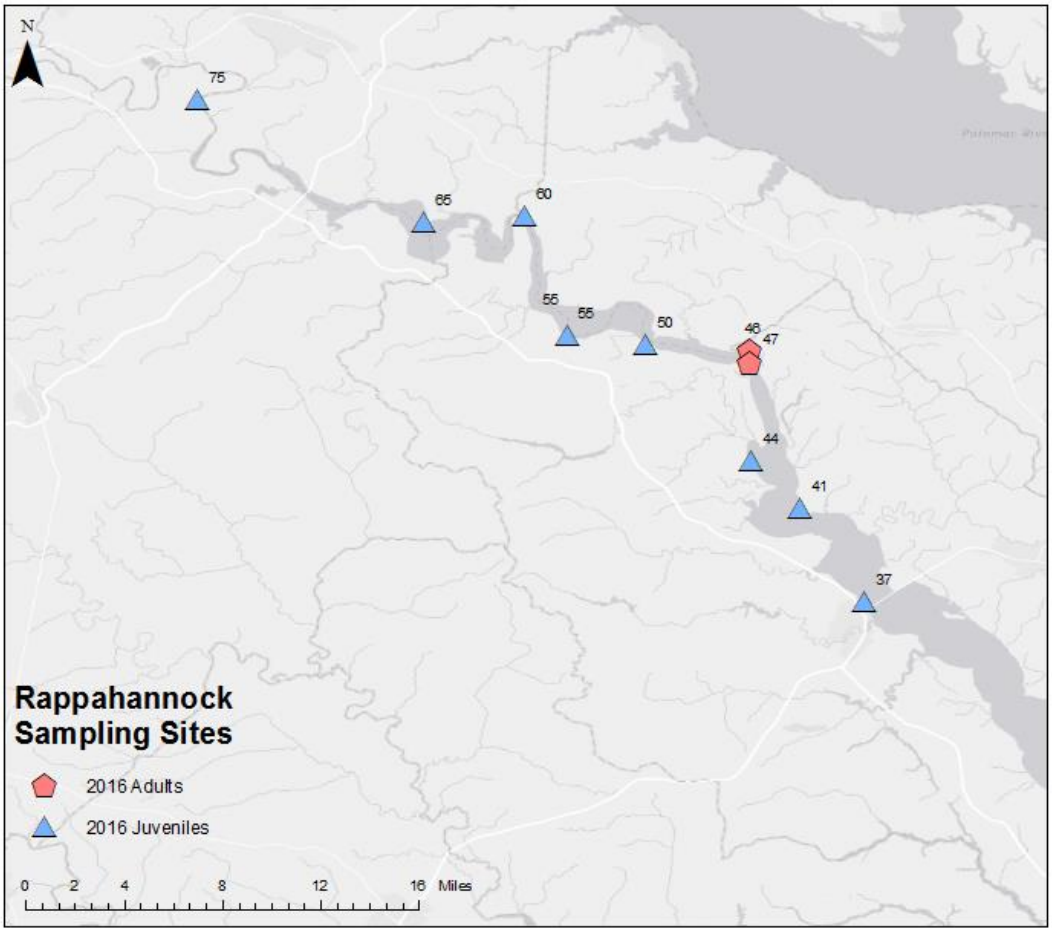
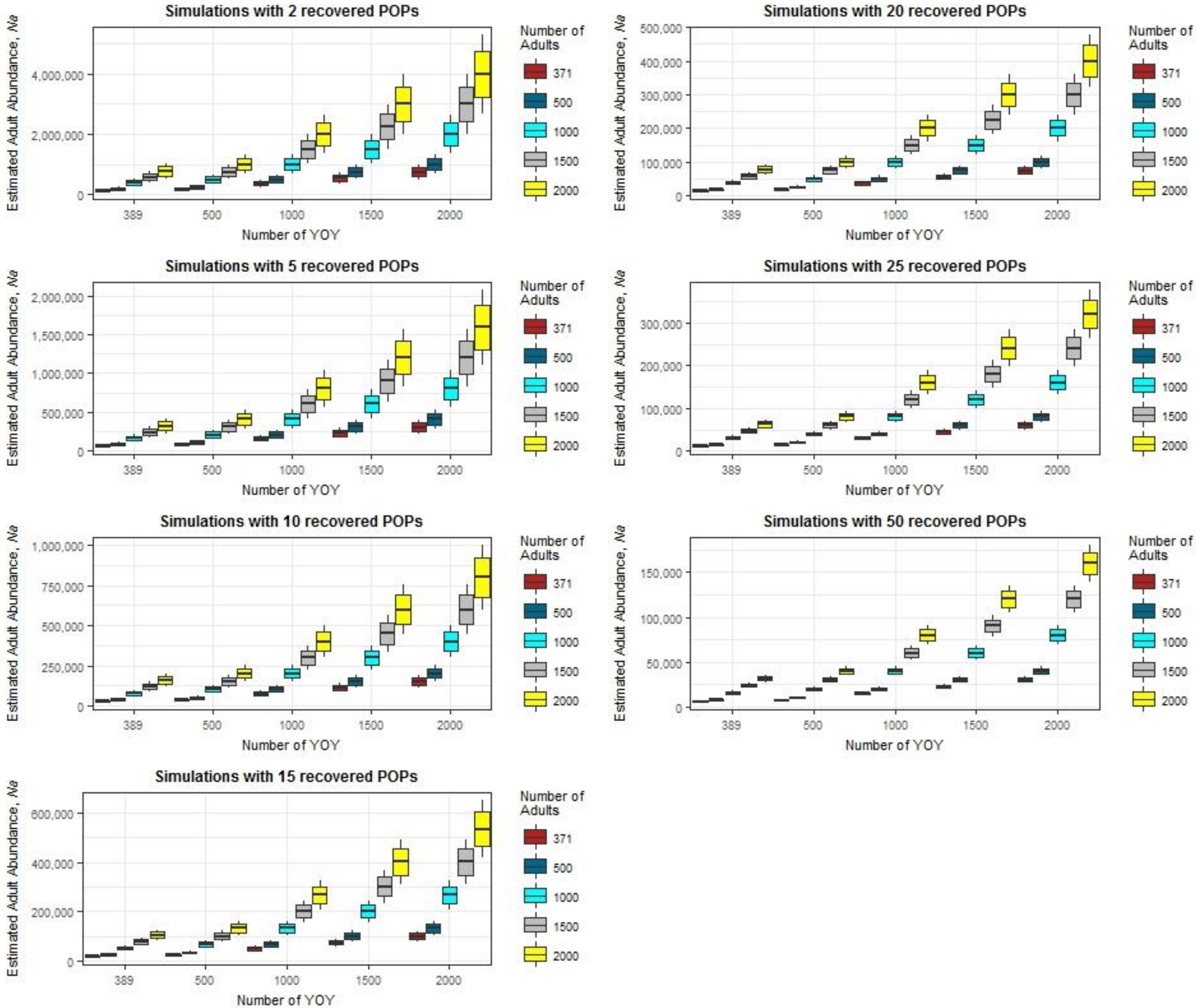


Figure 2. Box and whisker plot showing the estimated adult abundance on the y-axis, the varying numbers of YOY samples on the x-axis, and the colors represent differing samples of adults. The whiskers represent the 95% confidence intervals, with the colored boxes showing the 75% confidence intervals, and the point estimate as the black line in the box. Each graph represents estimates for different numbers of recovered POPs.


Simulations with 2 recovered POPs
Estimated Adult Abundance, Na
0
2,000,000
4,000,000
Simulations with 20 recovered POPs
0
100,000
200,000
300,000
400,000
500,000
Simulations with 5 recovered POPs
0
500,000
1,000,000
1,500,000
2,000,000
Simulations with 25 recovered POPs
0
100,000
200,000
300,000
Simulations with 10 recovered POPs
0
250,000
500,000
750,000
1,000,000
Simulations with 50 recovered POPs
0
50,000
100,000
150,000
Simulations with 15 recovered POPs
0
200,000
400,000
600,000
389
500
1000
1500
2000
Number of YOY
Number of Adults
371
500
1000
1500
2000

Appendix A. Daily flow rates of the Rappahannock River, 30 March – 3 May, 1985-2016.

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Figure 1. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, spring 2016.

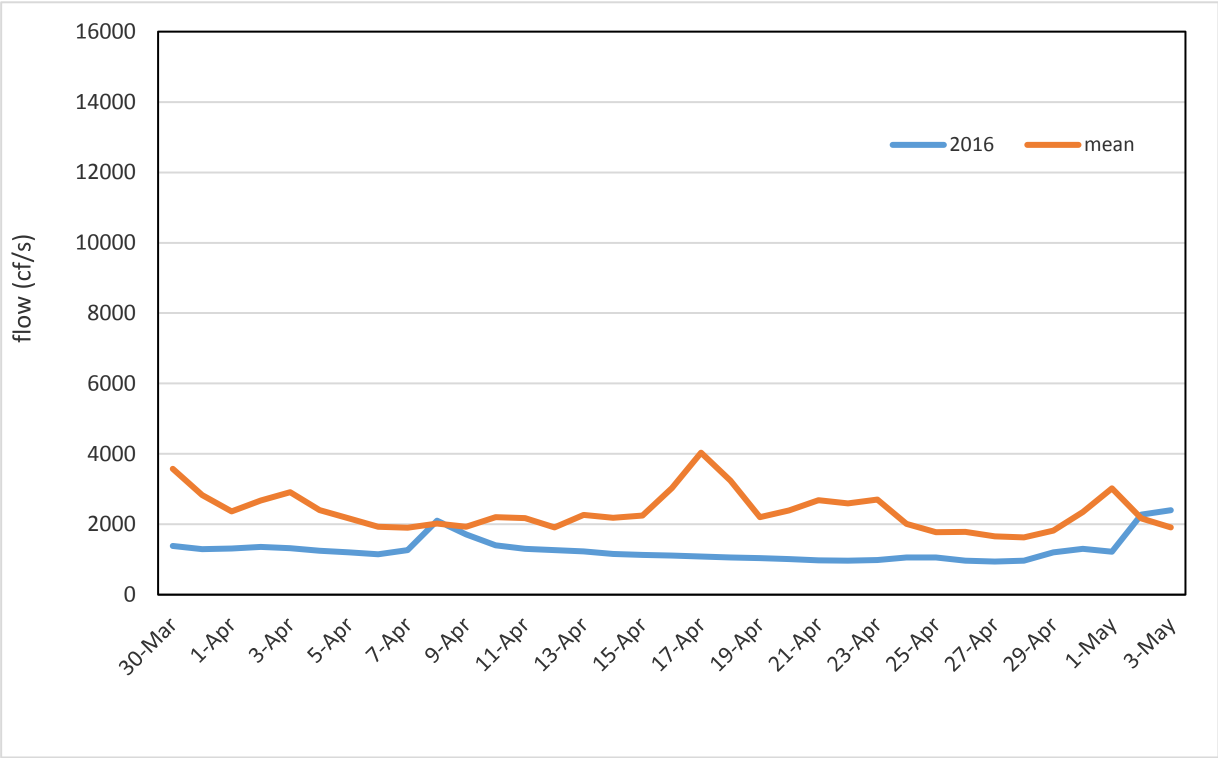
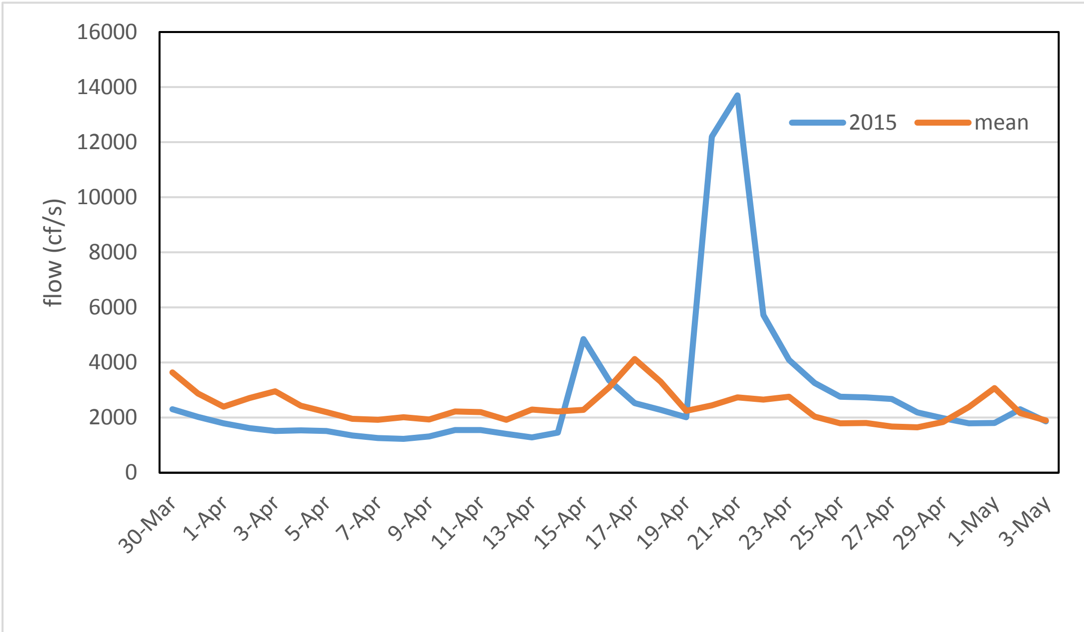


Figure 2. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2014-2015.



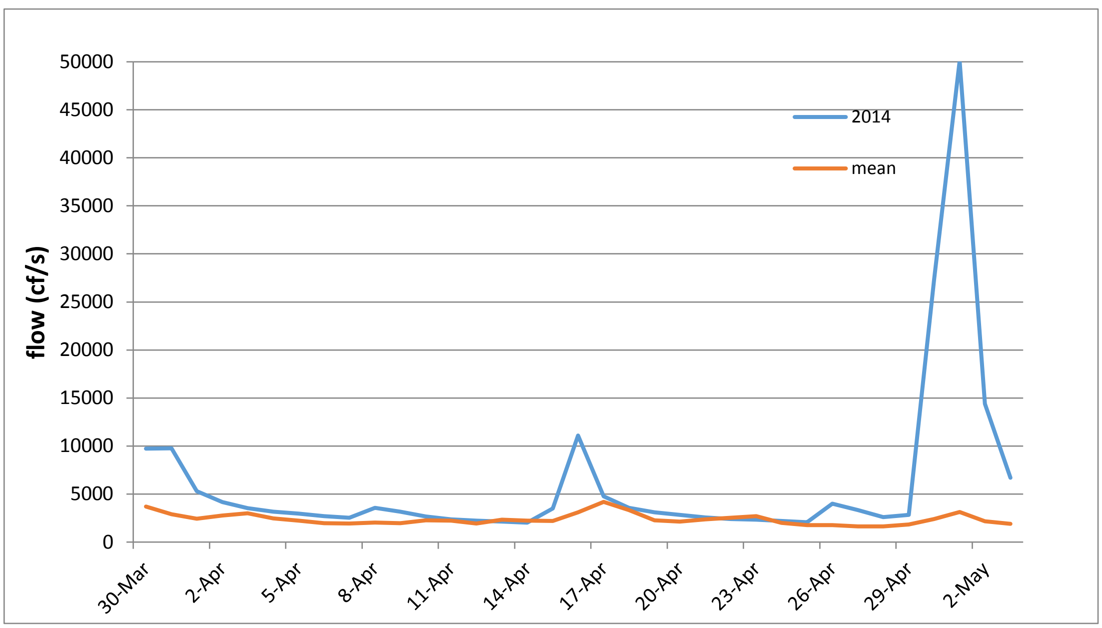
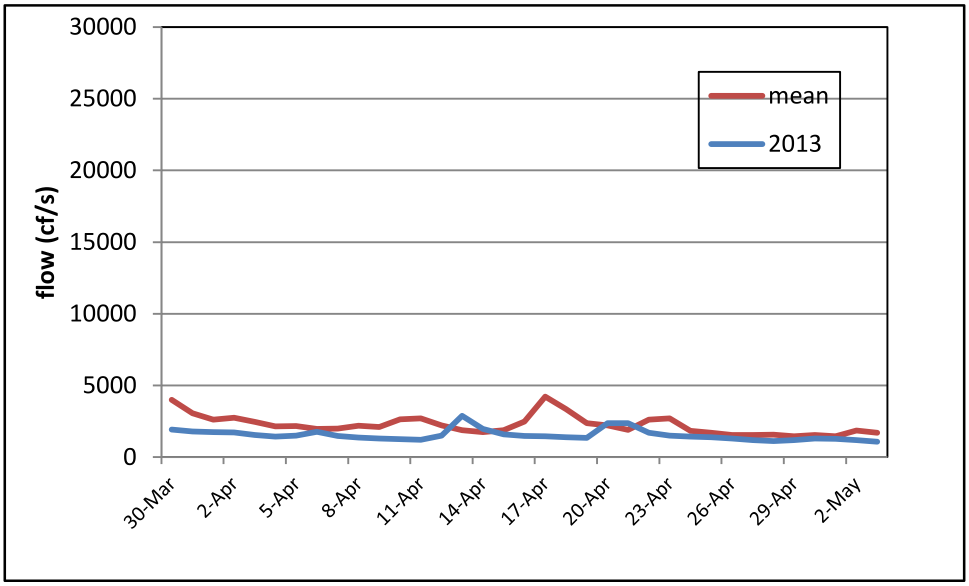


Figure 3. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, spring 2012-2013.



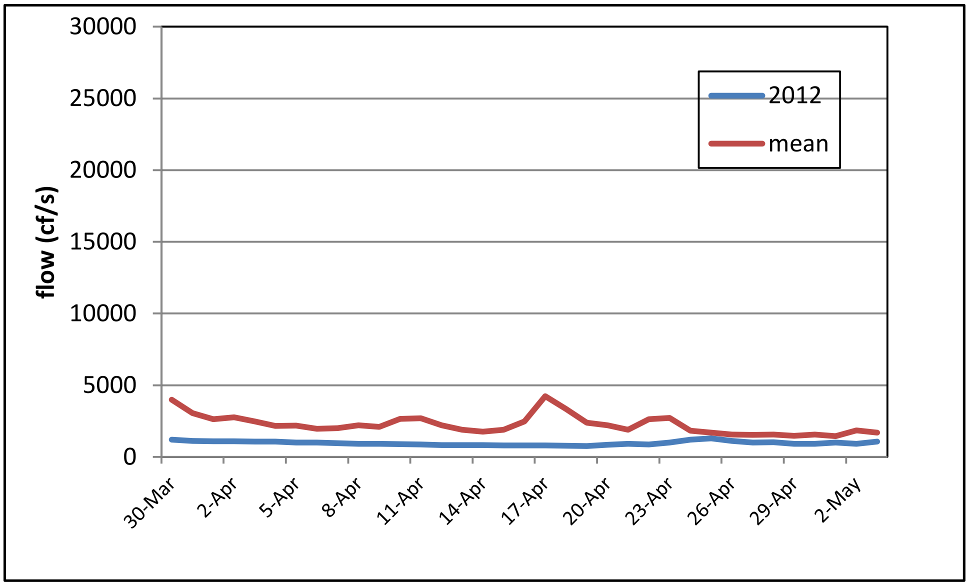
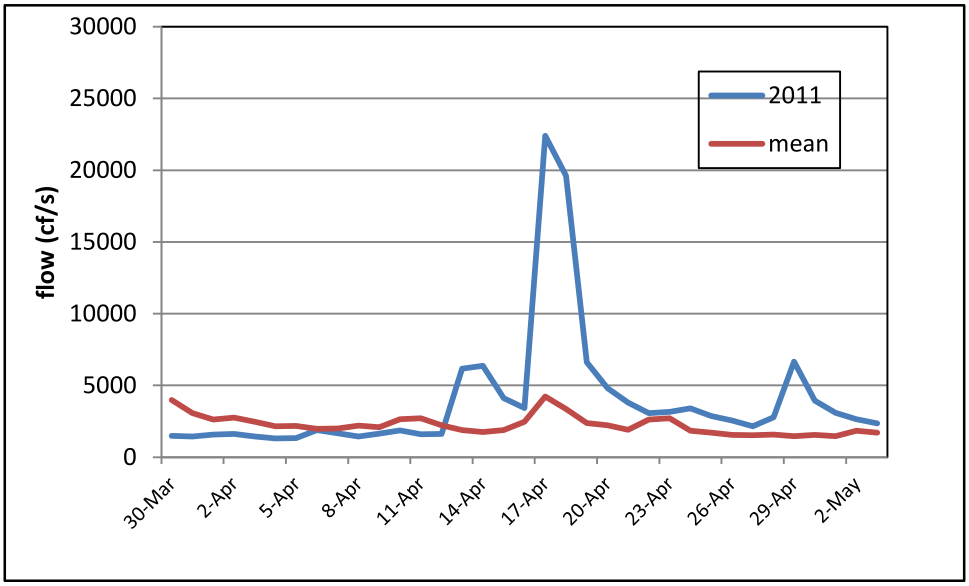


Figure 4. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2010-2011.



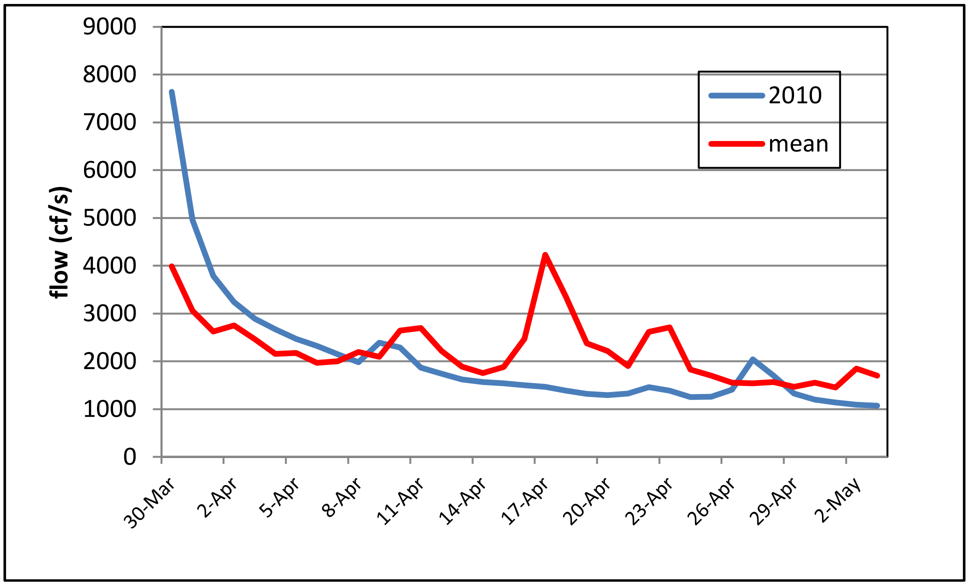
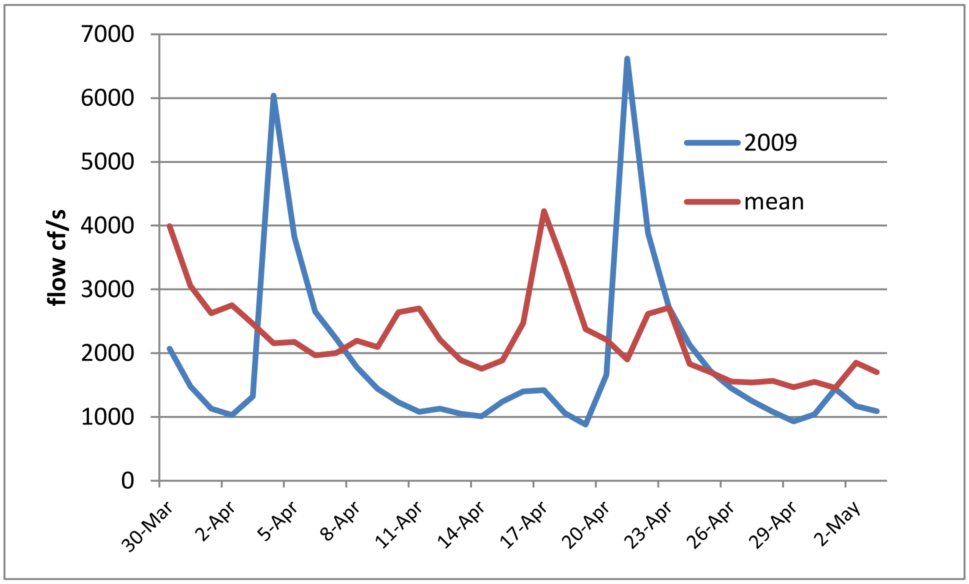


Figure 5. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2008-2009.



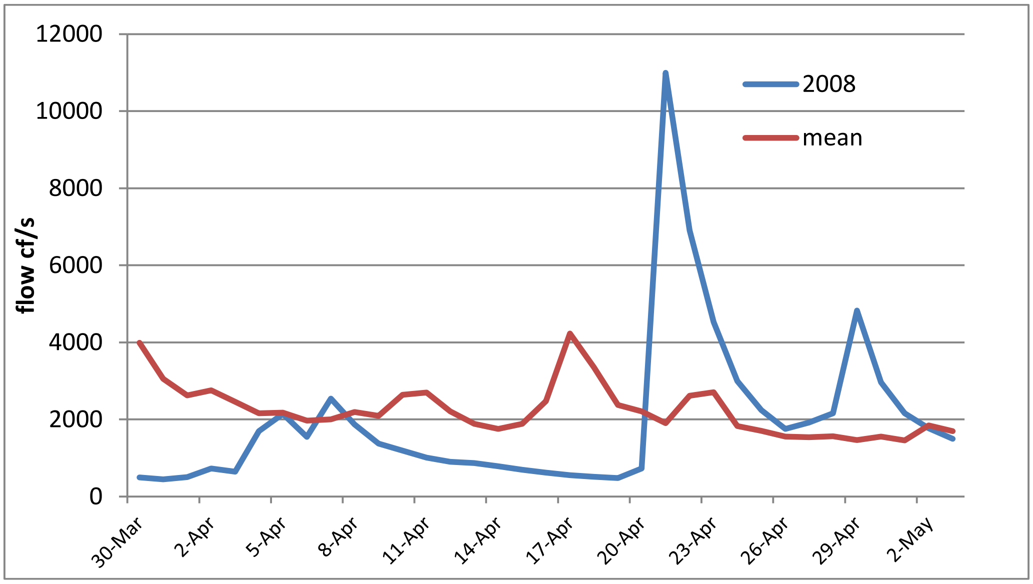
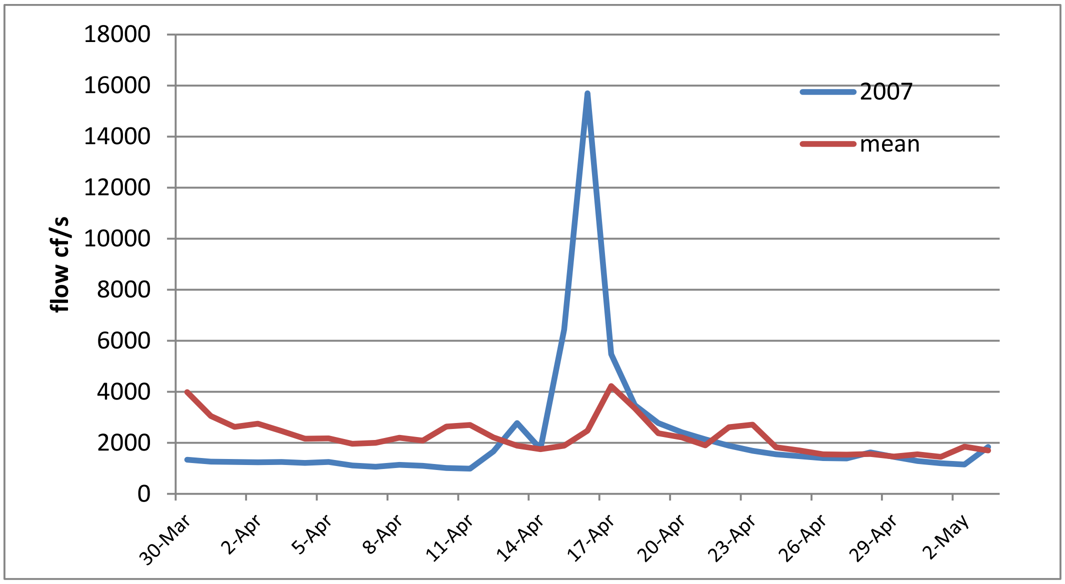


Figure 6. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2006-2007.



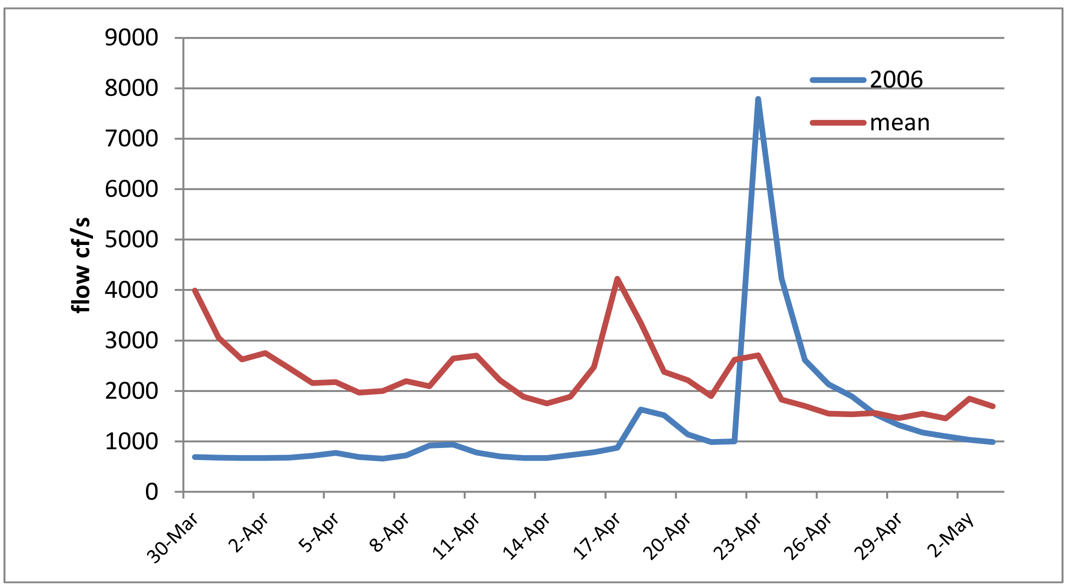
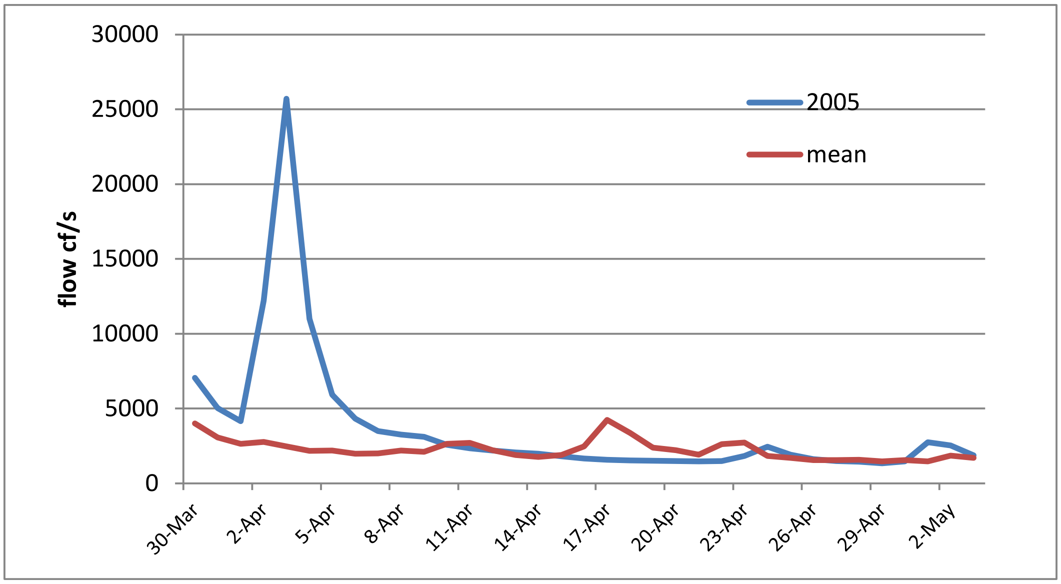


Figure 7. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2004-2005.



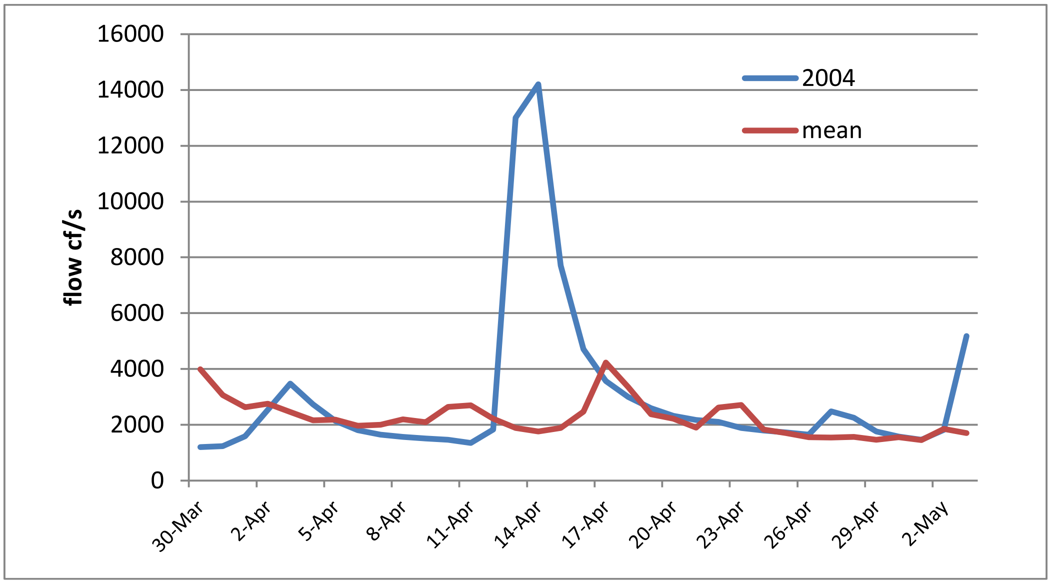
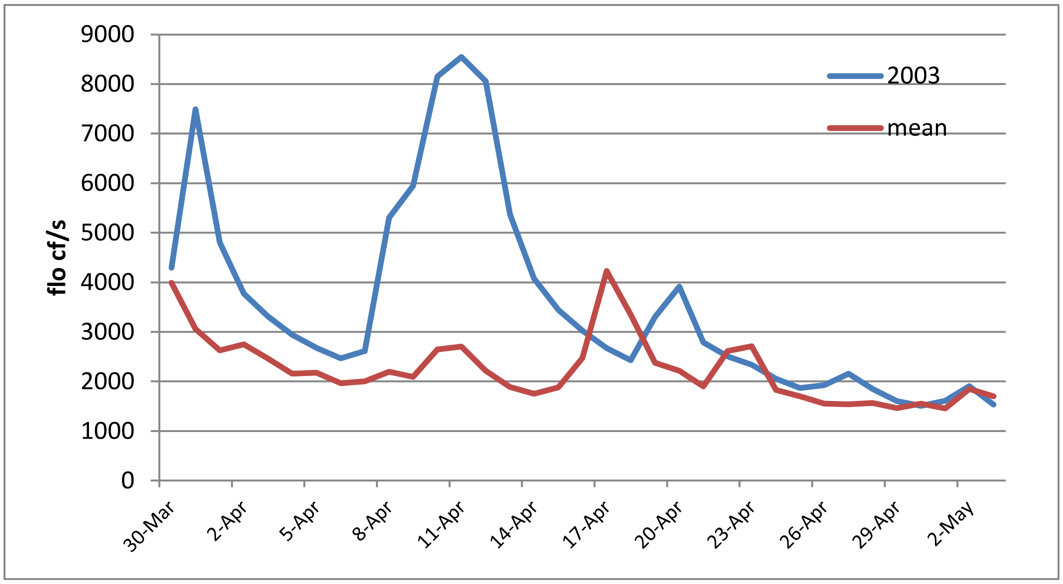


Figure 8. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2002-2003.



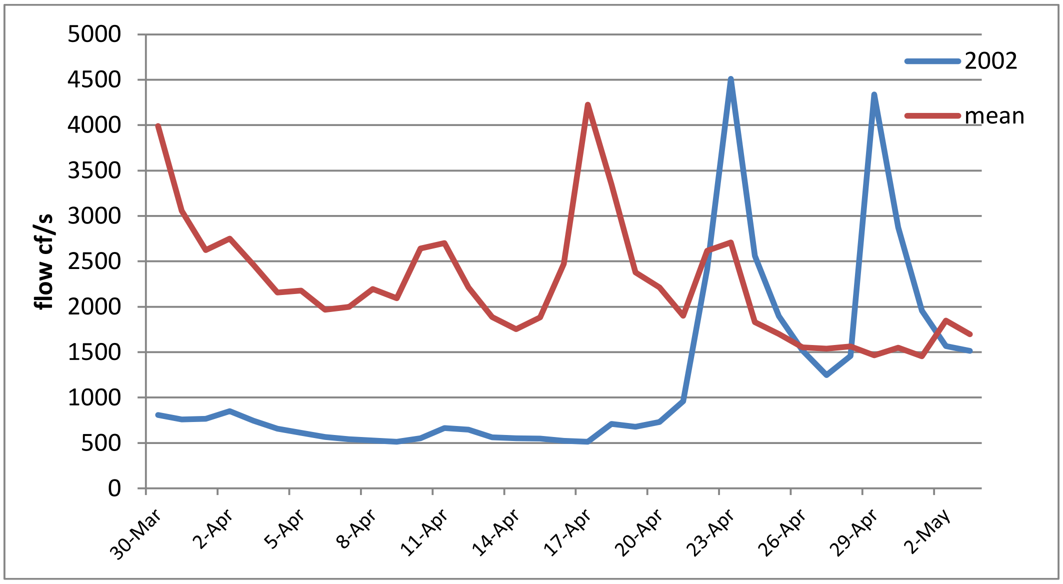
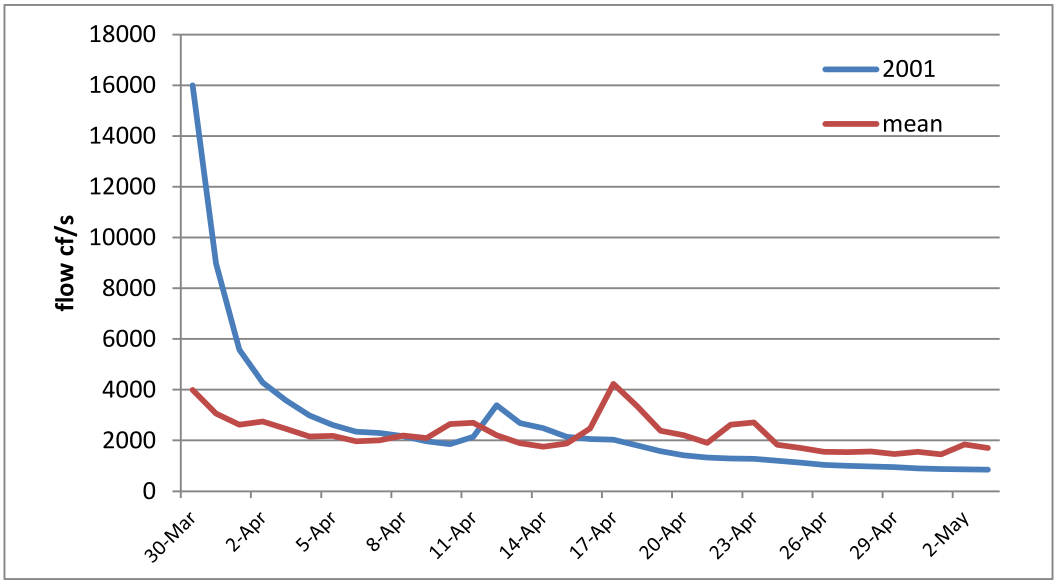


Figure 9. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2000-2001.



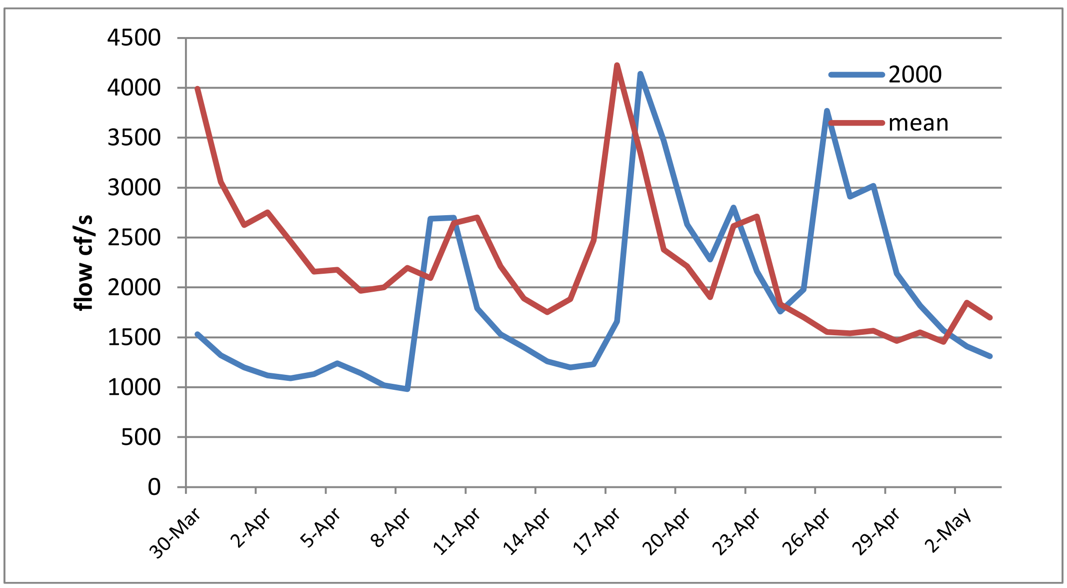
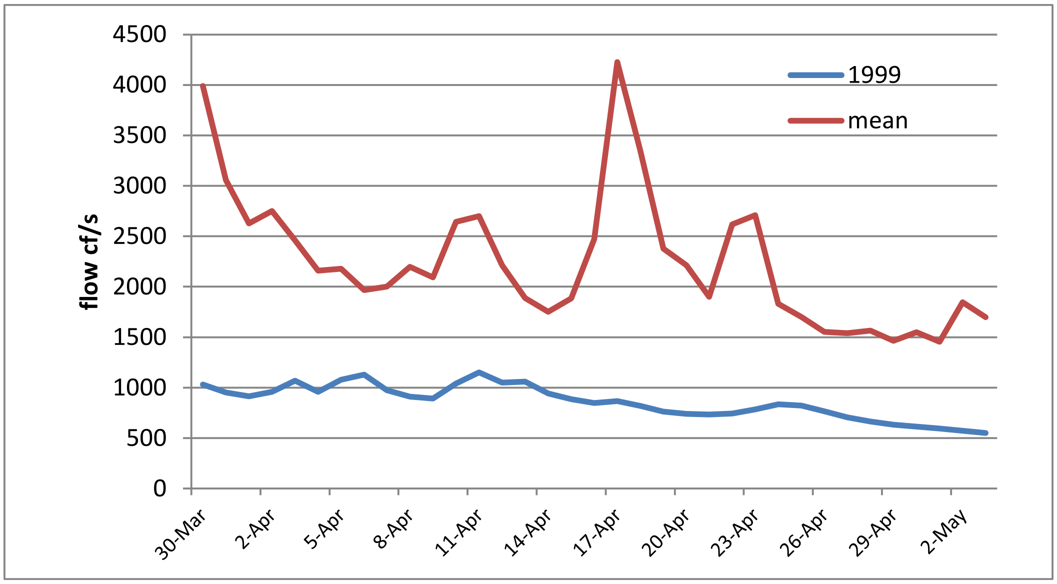


Figure 10. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1998-1999.



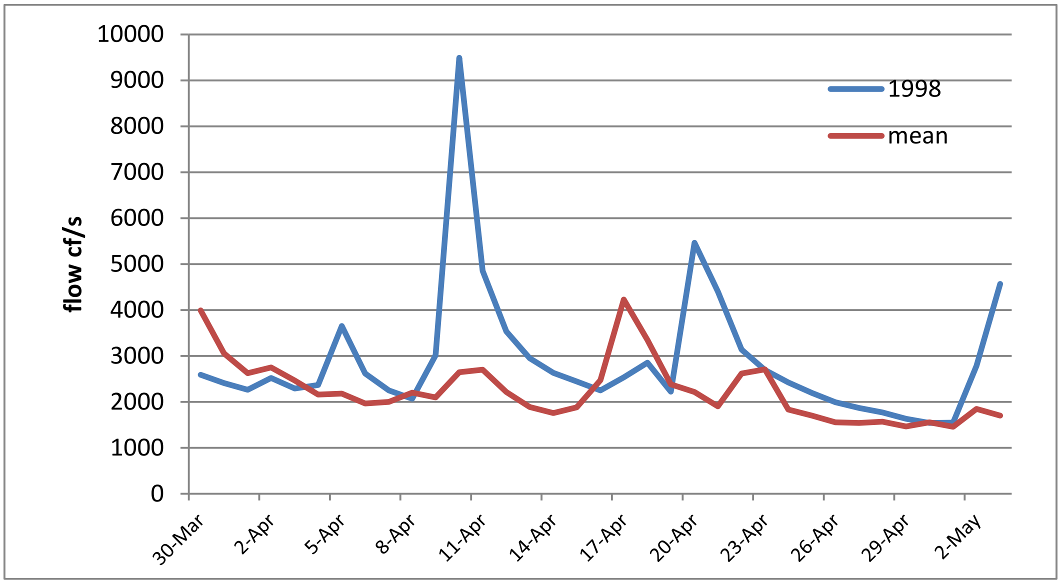
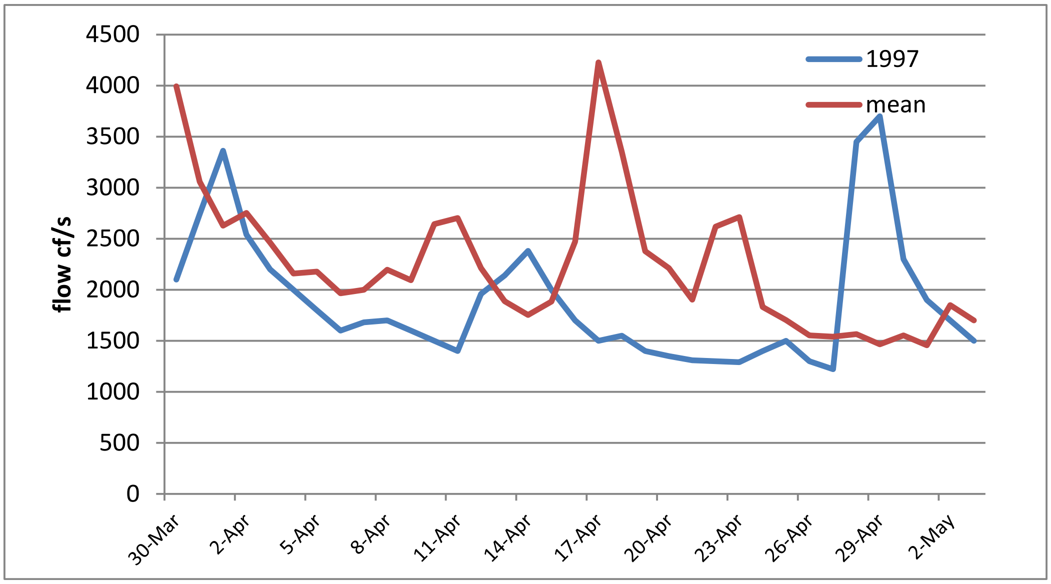


Figure 11. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1996-1997.



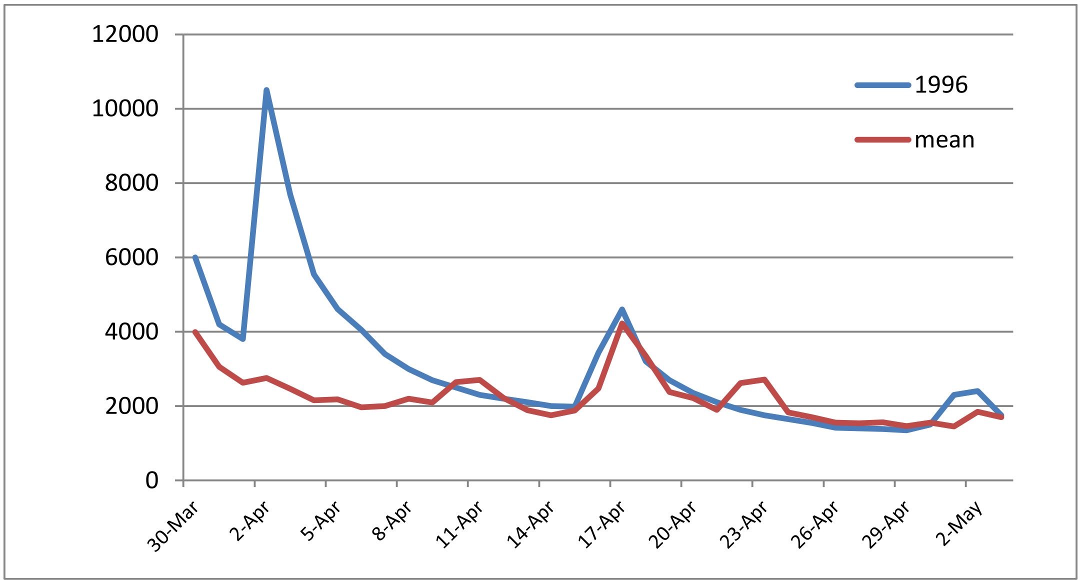
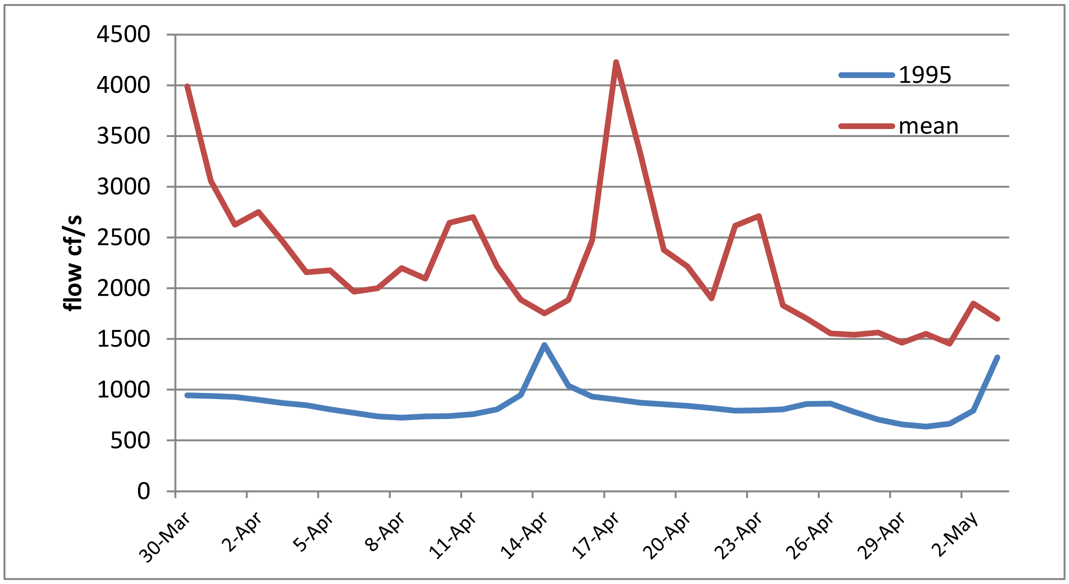


Figure 12. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1994-1995.



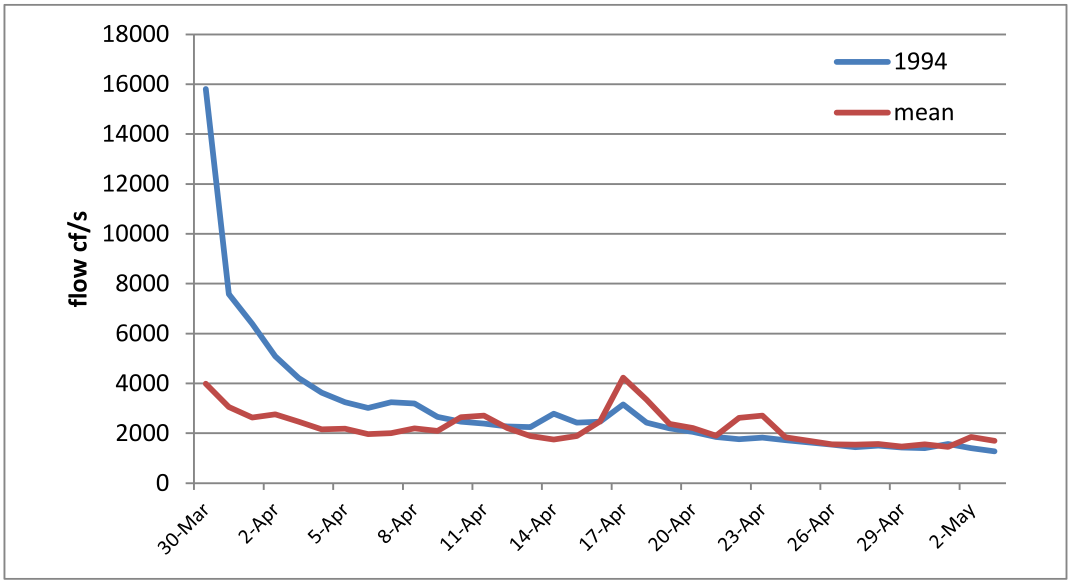
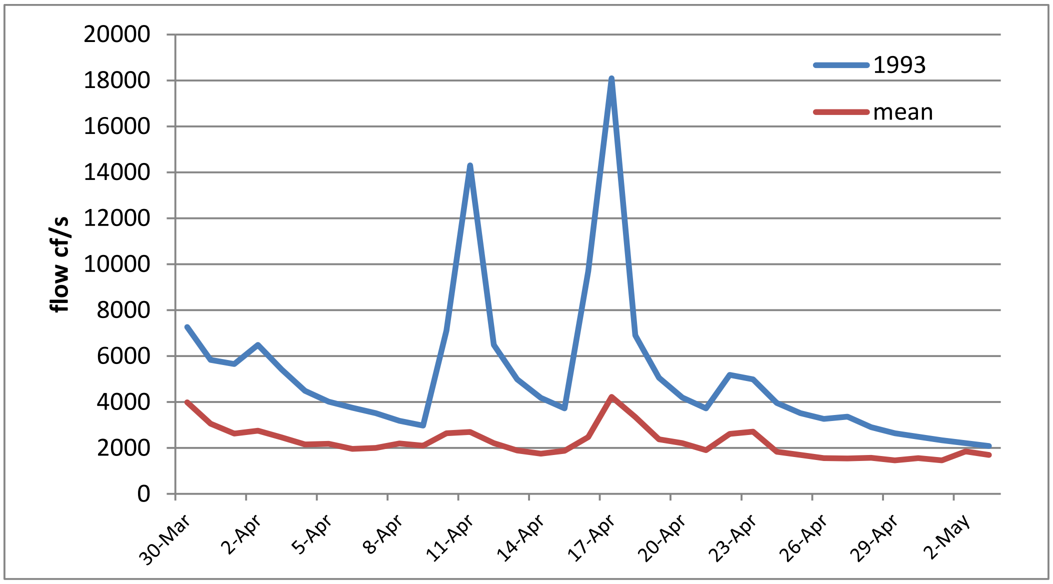


Figure 13. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1992-1993.



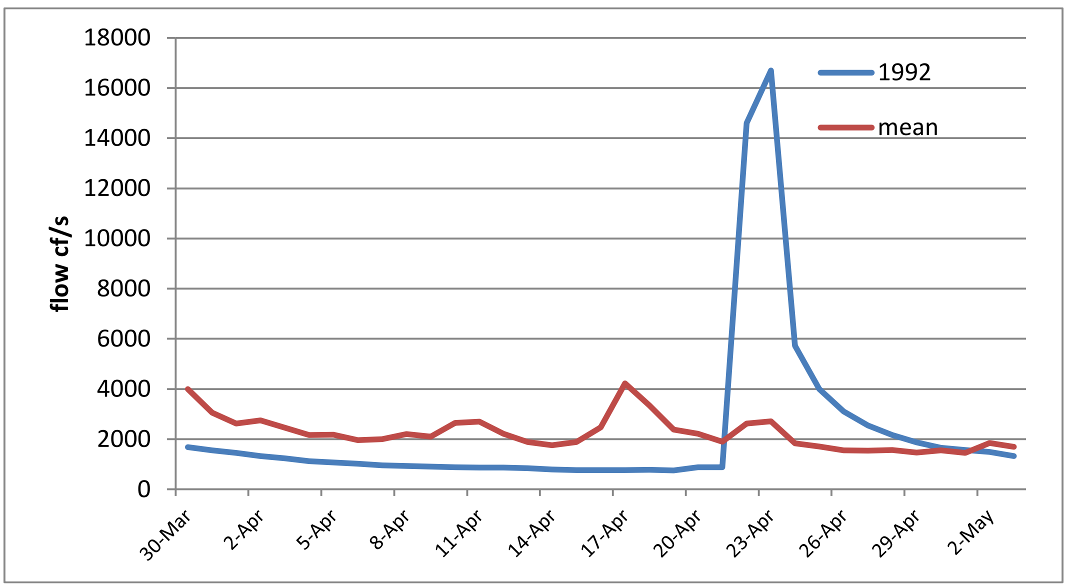
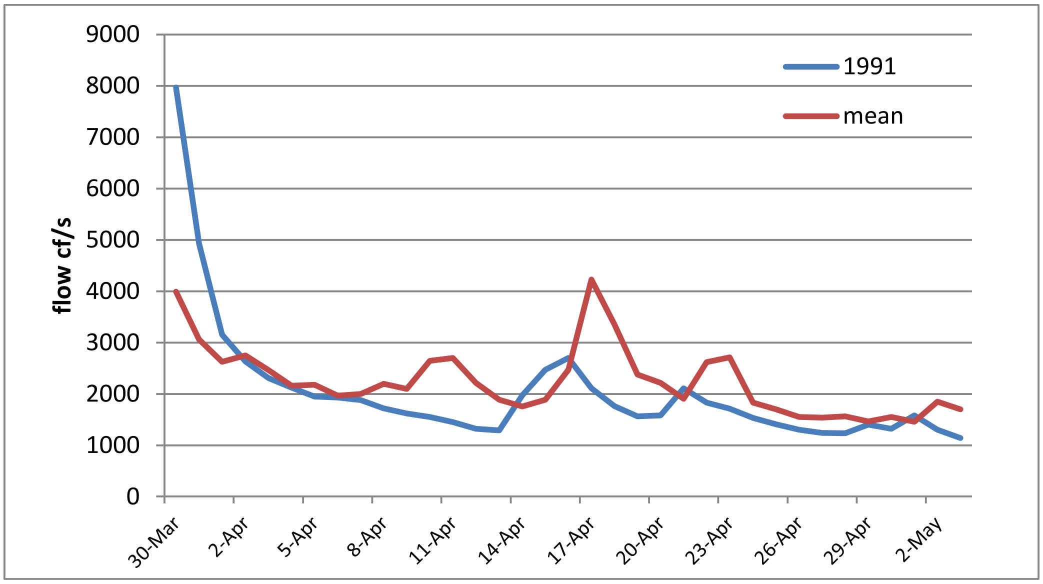


Figure 14. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1990-1991.



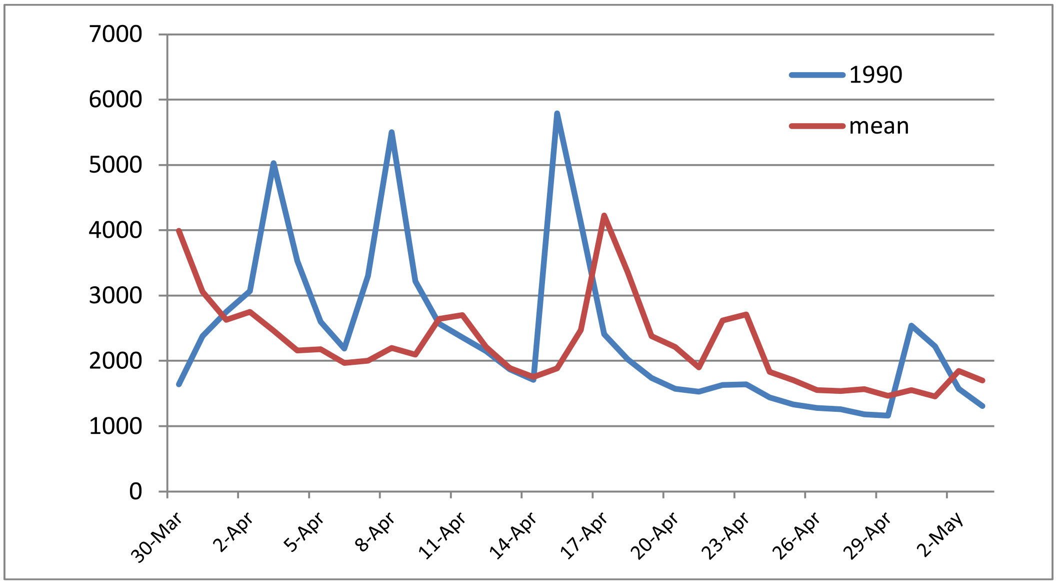
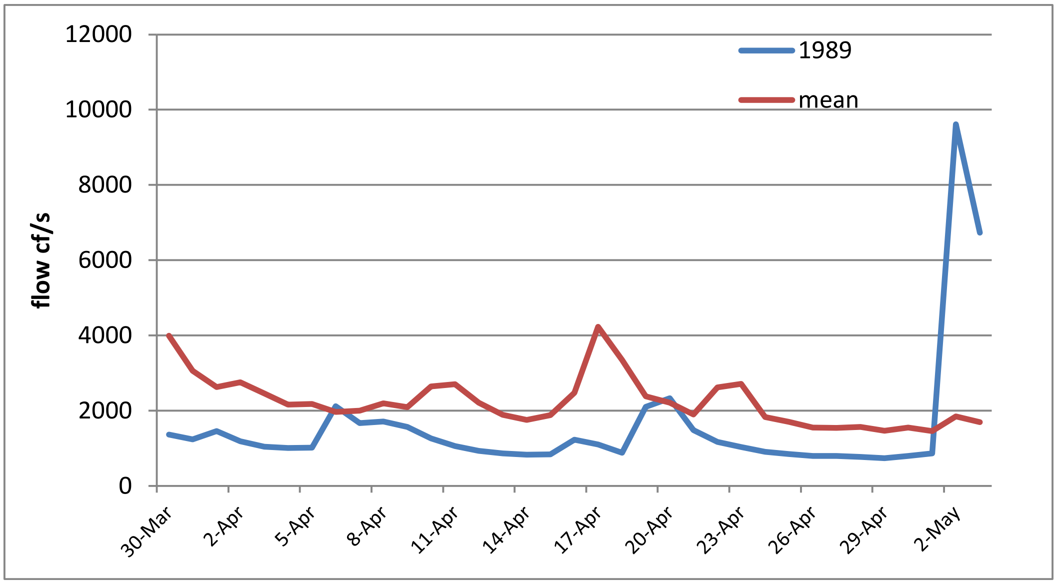


Figure 15. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1988-1989.



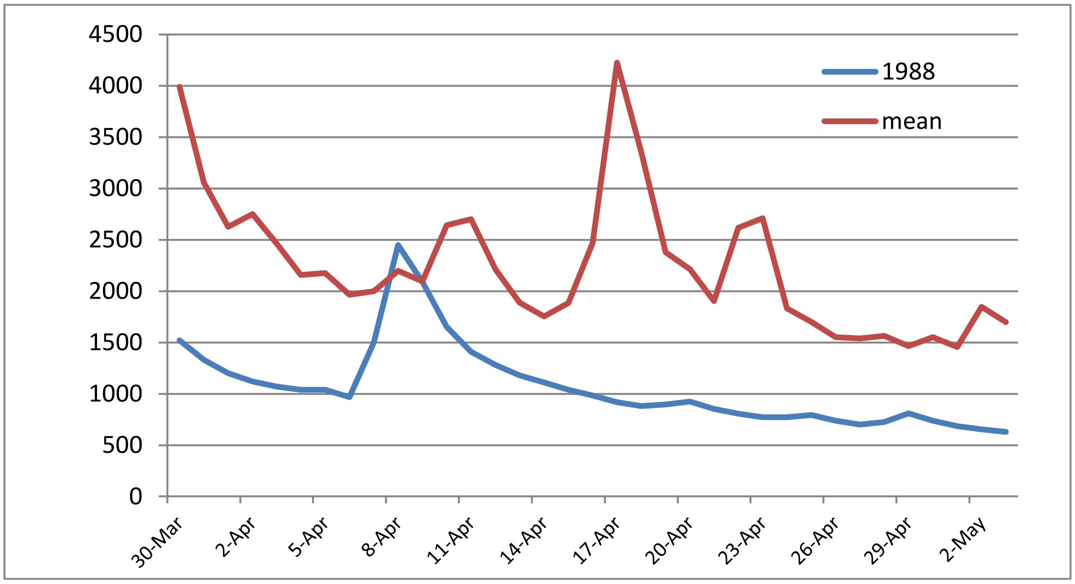
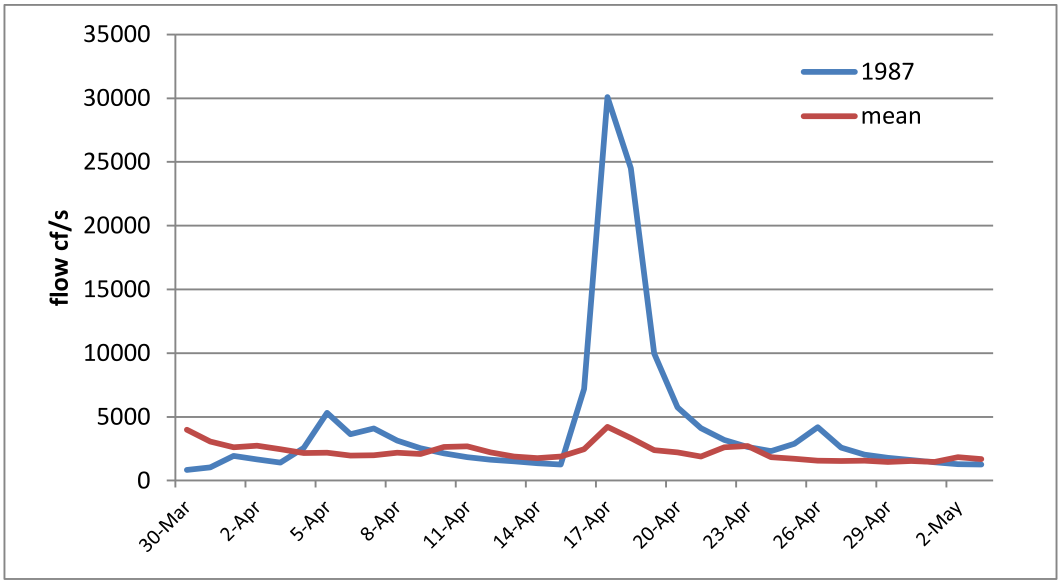


Figure 16. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1986-1987.



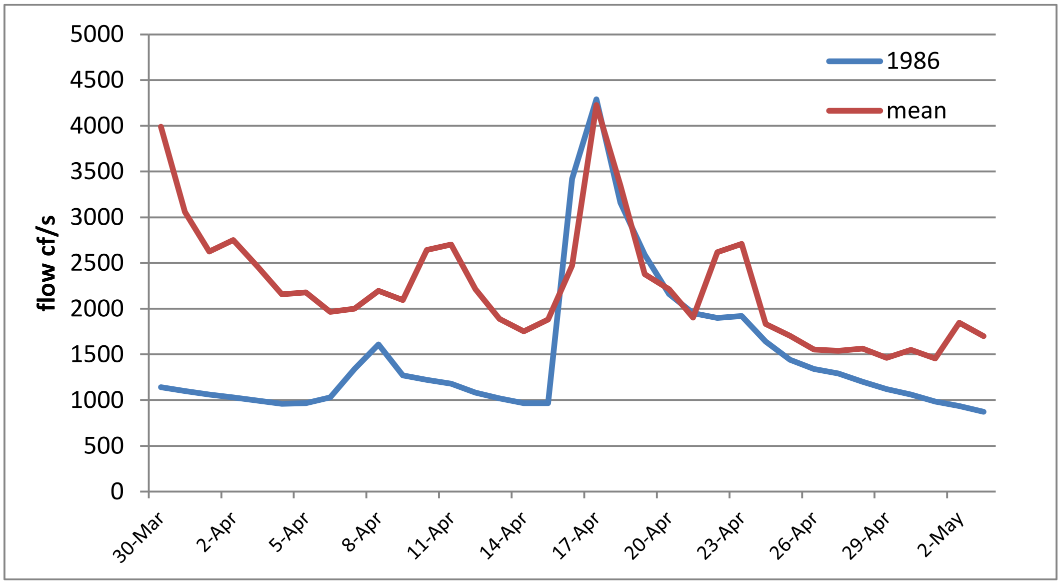


Figure 17. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, spring 1985.