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Evaluation of Striped Bass Stocks in Virginia: Monitoring and Tagging Studies, 2015-2019 Progress Report 1 September 2014 - 31 August 2015

Philp W. Sadler
Virginia Institute of Marine Science

John M. Hoenig
Virginia Institute of Marine Science

Lydia M. Goins
Virginia Institute of Marine Science

Quang Huynh
Virginia Institute of Marine Science

Robert E. Harris
Virginia Institute of Marine Science

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Progress Report

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Principal Investigator: **John M. Hoenig**

Prepared by:

Philip W. Sadler, John M. Hoenig, Lydia M. Goins, Quang Huynh and Robert E. Harris

Department of Fisheries Science
School of Marine Science
Virginia Institute of Marine Science
The College of William and Mary
Gloucester Point, VA 23062-1346

Submitted To:

Virginia Marine Resources Commission
P.O. Box 756
Newport News, VA 23607-0756

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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 2014 through 31 August 2015. It includes an assessment of the biological characteristics of striped bass taken from the 2015 spring spawning run and estimates of annual survival and fishing mortality based on annual spring tagging. Also included is information on gear selectivity of recreational anglers for striped bass. The information contained in this report is required by the Atlantic States Marine Fisheries Commission and is used to implement a coordinated management plan for striped bass in Virginia, and along the eastern seaboard.

      Striped bass have historically supported one of the most important recreational and commercial fisheries along the Atlantic coast. In colonial times, striped bass were abundant in most coastal rivers from New Brunswick to Georgia, but overfishing, pollution and reduction of spawning habitat have resulted in periodic crashes in stocks and an overall reduction of biomass (Merriman 1941, Pearson 1938). Striped bass populations at the northern and southern extremes of the Atlantic are apparently non-migratory (Raney 1957). Presently, important sources of striped bass in their native range are found in the Roanoke, Delaware and Hudson rivers and the major tributaries of Chesapeake Bay (Lewis 1957) with the Chesapeake Bay and Hudson River being the primary sources of the coastal migratory population (Dorazio *et al*. 1994).

      Examination of meristic characteristics indicate that the coastal migratory population consists of distinct sub-populations from the Hudson River, James River, Rappahannock - York rivers, and upper Chesapeake Bay (Raney 1957). The Roanoke River striped bass may represent another distinct sub-population (Raney 1957). The relative contribution of each area to the coastal population varies. Berggren and Lieberman (1978) concluded from a morphological study that Chesapeake Bay striped bass were the major contributor (90.8%) to the Atlantic coast fisheries, and the Hudson River and Roanoke River stocks were minor contributors. However, they estimated that the exceptionally strong 1970 year class constituted 40% of their total sample. Van Winkle *et al*. (1988) estimated that the Hudson River stock constituted 40% - 50% of the striped bass caught in the Atlantic coastal fishery in 1965. Regardless of the exact proportion, management of striped bass is a multi-jurisdictional concern as spawning success in one area probably influences fishing success in many areas. Furthermore, recent evidence suggests the presence of divergent migratory behavior at intra-population levels (Secor 1999). The extent to which these levels of behavioral complexity impact management strategies in Chesapeake Bay and other stocks is unknown.

      Concern about the decline in striped bass landings along the Atlantic coast since the mid-1970s prompted the development of an interstate fisheries management plan (FMP) under the auspices of the Atlantic States Marine Fisheries Management Program (ASMFC 1981). Federal legislation was enacted in 1984 (Public Law 98-613, the Atlantic Striped Bass Conservation Act) which enables Federal imposition of a moratorium for an indefinite period in those states that fail

to comply with the coast-wide plan. To be in compliance with the plan, coastal states have imposed restrictions on their commercial and recreational striped bass fisheries ranging from combinations of catch quotas, size limits, closed periods and year-round moratoriums. Due to an improvement in spawning success, as judged by increases in annual values of the Maryland juvenile index, a limited fishery was established in fall, 1990. This transitional fishery existed until 1995 when spawning stock biomass reached sufficiently healthy levels (Field 1997). ASMFC subsequently declared Chesapeake Bay stocks to have reached benchmark levels and adopted Amendment 5 to the original FMP that allowed expanded state fisheries.

To document continued compliance with Federal law, the Virginia Institute of Marine Science (VIMS) has monitored the size and age composition, sex ratio and maturity schedules of the spawning striped bass stock in the Rappahannock River since December 1981 utilizing commercial pound nets and, from 1991-2014, variable-mesh experimental gill nets. Spawning stock assessment was expanded to include the James River in 1994, utilizing commercial fyke nets and variable-mesh experimental gill nets. An experimental fyke net was established in the James River to assess its potential as a source for tagging striped bass. The use of fyke nets was discontinued after 1997. In conjunction with the monitoring studies, tagging programs have been conducted in the James and Rappahannock rivers since 1987. These studies were established to document the migration and relative contribution of these Chesapeake Bay stocks to the coastal population and to provide a means to estimate annual survival rates (S). With the re-establishment of fall recreational fisheries in 1993, the tagging studies were expanded to include the York River and western Chesapeake Bay to provide a direct estimation of the resultant fishing mortality (F). Commencing in 2005, these estimates of F were estimated from the striped bass tagged during the spring in the Rappahannock River.

Acknowledgments

New this year: We continued our expansion of the tagging program by relocating the anchor gill nets from the Rappahannock River to the York and Mattaponi rivers. Parallel MARK and instantaneous rate analyses of Rappahannock river releases and combined James and Rappahannock rivers releases are presented. We also examined the use of generalized age-length keys as a means for improving the precision of age composition estimates and as a substitute for missing age data for striped bass.

I. Assessment of the spawning stocks of striped bass in the Rappahannock and James rivers, Virginia, spring 2015.

Catch Summaries:

1. In 2015, 152 striped bass were sampled between 17 April and 7 May from the commercial pound nets in the Rappahannock River. The samples were predominantly male (70.4%) but had few fish in the 5-8 year range (20.3%). Females dominated the age nine and older age classes (92.6%). The mean age of the male striped bass was 4.4 years. The mean age of the female striped bass was 11.5 years.

2. During the 17 April – 7 May period, the 2010 and 2011 year classes were the most abundant in the Rappahannock River pound net samples and were 94.5% male. The contribution of age six and older males was only 5.3% of the total aged catch. Age seven and older females, presumably repeat spawners, were 26.3% of the total catch but represented 88.9% of all females caught.

3. The Spawning Stock Biomass Index (SSBI) from the Rappahannock River pound nets was 7.3 kg/day for male striped bass and 20.6 kg/day for female striped bass. The male index was the third lowest in the 1991-2015 time series. The 2015 female index was 63.5% lower than the 2014 index and 41.6% below the 25-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 2015 Egg Production Potential Index (EPPI, millions of eggs/day) for the Rappahannock River pound nets was 3.18 million eggs/day. This was the second lowest EPPI of the 2001-2015 time series. Female stripers in the 2001-2005 year class were responsible for 68.7% of the index.

5. The cumulative catch rate (all age classes, sexes combined) from the Rappahannock River pound nets (7.07 fish/day) was the 62.4% below the 25-year time series. There was a decrease in almost all year classes from the 2014 values. The cumulative catch rate of male striped bass (4.97 fish/day) was the third lowest in the time series. The cumulative catch rate of female striped bass (2.09 fish/day) was the third lowest in the time series and 63.5% lower than the rate in 2014.

6. Year class-specific estimates of annual survival (S) for pound net data varied widely between

years. The geometric mean S of the 1985-2006 year classes varied from 0.398-0.729 (mean = 0.634). The geometric mean survival rates differed between sexes. Mean survival rates for male stripers (1985-2006 year classes) varied from 0.276-0.657 (mean = 0.460) while mean survival rates of female stripers (1985-2001 year classes) varied from 0.462-0.687 (mean = 0.614).

7. Plots of year class-specific catch rates vs. year in the Rappahannock River from 1991-2015 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 149 striped bass were digitally measured and the increments between annuli were used to determine their growth history. On average, striped bass grow about 149 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 2,833 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 2014-2015.

1. A total of 377 striped bass were tagged and released from pound nets in the Rappahannock River between 17 April and 18 May, 2015. Of this total, 239 were between 457-710 mm total length and considered to be predominantly resident striped bass and 75 were considered to be predominantly migrant striped bass (>710 mm TL).

2. A total of 68 striped bass were tagged and released from gill nets in the James River between 31 March and 8 May, 2015. Of this total, 44 were resident striped bass and 14 were migrant striped bass.

3. A total of 126 striped bass were tagged and released from gill nets in the York River between 30 March and 6 May, 2015. Of this total, 93 were resident striped bass and 27 were migrant striped bass.

4. The median date of resident tag releases for all rivers combined was 27 April, while the median date of migrant tag releases for all rivers combined was 23 April.

5. A total of 38 striped bass (>457 mm TL), tagged during springs 1990-2014, were recaptured between 1 January and 31 December, 2014, and were used to estimate mortality. Most recaptures (68.4%) were caught within Chesapeake Bay (42.1% in Virginia, 26.3% in Maryland). Other recaptures came from Massachusetts (13.1%), New York (10.5%), Rhode Island (5.3%) and New Jersey (2.7%).

6. A total of 16 migratory striped bass (>710 mm total length), tagged during springs 1990-2014, were recaptured between 1 January and 31 December, 2014, and were used to estimate the mortality. Most recaptures (31.3% each) came from Chesapeake Bay (18.8% in Virginia, 12.5% in Maryland) and Massachusetts. Other recaptures came from New York (18.8%), Rhode Island (12.5%), and New Jersey (6.3%).

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 0.46 (> 457 mm TL) and 0.62 (>711 mm TL). The estimates of survival for the Rappahannock and James rivers were almost identical with the estimates of 0.46 (>457 mm TL) and 0.61 (>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 0.04 (>457 mm TL) and 0.04 (>711 mm TL). The estimates of fishing mortality were 0.05 (>457 mm TL) and 0.05 (>711 mm TL). For the James and Rappahannock river releases, the estimates of exploitation were 0.06 (>457 mm TL) and 0.03 (>710 mm TL). The estimates of fishing mortality were 0.09 (>457 mm TL) and 0.04 (>710 mm TL).

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. 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 0.04 (>457 mm TL) and 0.04 (>711 mm TL). In the James and Rappahannock river releases, the estimates of survival were 0.51 (>457 mm TL) and 0.60

(>710 mm TL). The estimates of fishing mortality were 0.04 (>457 mm TL) and 0.04 (>710 mm TL).

III. Alternative procedures for estimating age composition.

1. The use of a generalized age-length key was evaluated as an alternative to the classic age-length key. In theory, the simultaneous estimation of age composition for several years leads to more precise estimates, providing growth rates do not change over time. Simulation results shows that the generalized key provides biased but more precise estimates of age composition. The simulation results did not provide a compelling reason to adopt the new methodology.

2. The Rappahannock River data shows that the mean length of multiple age classes has changed (decreased) over time which violates an assumption of the methodology.

Table of Contents

List of Tables

II. Mortality estimates of striped bass (*Morone saxatilis*) that spawn in the Rappahannock River, Virginia, spring 2014-2015.

List of Figures

I. Assessment of spawning stocks of striped bass in the Rappahannock river, Virginia, spring 2015.

III. Alternative procedure for estimating age composition.

Appendix A. Daily river flows for the Rappahannock River, 30 March – 3 May, 1985-2014.

I. Assessment of the spawning stocks of striped bass in the Rappahannock River, Virginia, spring 2015.

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

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 17 April – 7 May, 2015. This year, prolonged ice and snow in March, coupled with adverse weather conditions in early April, prevented setting of the pound nets at the start of the season. Therefore, samples from these pound nets were delayed until 17 April, 2015. In addition, one of the three pound nets normally sampled (net at mile 45) was not set this year. Due to the delay, measurements and sex of the striped bass from the net designated for the monitoring sample were recorded and the stripers greater than 18 inches then tagged and released. All 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.

Striped bass collected from the monitoring sites were measured and weighed on a Limnoterra FMB IV electronic fish measuring board interfaced with a Mettler PM 30000-K electronic balance. The board records lengths (FL and TL) to the nearest mm, receives weight (g) input from the balance, and allows manual input of sex and gonad maturity into a data file for subsequent analysis. Scales were collected from between the spinous and soft dorsal fins above the lateral line for subsequent aging, using the method established by Merriman (1941), except that impressions made in acetate sheets replaced the glass slide and acetone. Otoliths were extracted from the striped bass, processed for aging, and compared to their scale-derived ages. The weights of the striped bass tagged and released rather than brought to the lab were estimated using sex-specific regressions of weight vs. length.

The otoliths were cleansed of external tissue material by successive rinses in water immediately after extraction. The otoliths were prepared for ageing by placing the left sagitta on melted crystal bond and sectioned to a one millimeter thickness on a Buehler isomet saw. The sections were then polished on a Metaserv 2000 grinder. The polished section was immersed in a drop of mineral oil and viewed through an Olympus BX60 compound microscope at 4-20X. Each otolith was aged at least twice at different times by each of two readers using the methods described by Wischniowski and Bobko (1998).

All readable scales from the 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 1 April - 2 May mean CPUE (kg/net day) of mature males (age 3 years and older), females (age 4 years and older) and the combined sample (males and females of the specified ages). An alternative index, based on the fecundity potential of the female striped bass sampled, was investigated and the results compared with the index based on mean female biomass.

To determine fecundity, the geometric mean of the egg counts of the gonad subsamples for each ripe female striped bass collected in 2001-2003 was calculated. A non-linear regression was fitted to data of total oocytes versus fork length. The resultant equation was then applied to the fork lengths of all mature (4+ years old) females from the pound net and gill net samples and the Egg Production Potential Index (EPPI) was defined as the mean number of eggs potentially produced per day of fishing effort by the mature female (age 4+) striped bass sampled from 1 April - 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= 152) were sampled between 17 April - 7 May, 2015 from the pound nets in the Rappahannock River. The number of striped bass sampled was 31.2% lower than the sample in 2014 (n= 221) and 71.9% lower than the 25-year average (n=540.2). Total catches varied from 11-32 striped bass, with the peak catch on 27 April (Table 1). Surface water temperatures were below normal, increasing from 8.6℃ on 30 March to 12.9℃ on 6 April, then increased steadily to 20.5℃ on 7 May. River flows were below average at the start of the season and remained below average throughout the sampling season, except for a short-lived strong pulse of water the week of 21-28 April (Figure 2). Salinities were 0.0-0.1 p.p.t. throughout the sampling season. Catches of female striped bass peaked on 17 and 23 April and were dominated by the pre-2006 year classes. Males made up 70.4% of the total catch, which was below the 25-year average (74.6%). The 2007-2010 year classes (five to eight years old) comprised 20.3% of the total catch. This was well above the 2014 samples where the 2006-2009 year classes comprised 7.2% of the total catch. Males dominated the 2011-2013 year classes (100%) and the 2007-2010 year classes (77.4%), while females dominated the 1996-2006 year classes (92.6%).

Biomass catch rate (g/day) of males peaked on 30 April and female striped bass peaked on 17 April (Table 2). The numeric catch rate of males exceeded that of females on all but two sampling dates. Unlike 2008, but consistent with most previous years, the biomass catch rates for female striped bass exceeded that for males overall (2.81:1), peaking on 17 April (12.66:1). The mean ages of male striped bass varied from 4.1-5.4 years by sampling date, with the oldest mean age occurring on 23 April. The mean ages of females varied from 6.8-13.9 years by sampling date, peaking on 20 April.

There was a broad peak in abundance of striped bass (mostly male) between 430-510 mm total lengths in the pound net samples (Table 3). This size range accounted for 46.1% of the total sampled. There was a secondary peak in abundance of predominantly female striped bass between 920-1010 mm total lengths. Consistent with previous years, the striped bass from 640-710 mm total length accounted for only 1.3% of the total sample. The total contribution of

striped bass greater than 710 mm total length (the minimum total length for the coastal fishery) was 28.3% (vs. 49.8% in 2014).

During the 17 April – 7 May period, the 2011 (44.1%) and 2010 (15.8%) year classes were the most abundant (Table 4). These year classes were 94.5% male. The contribution of males age six and older (the pre-2010 year classes) was 5.3% 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 26.3% of the total aged catch, but was also 88.9% of the total females captured. The catch rate (fish/day) of male striped bass was 5.0, which is 64.5% below the 25-year average (Table 5). The catch rate of female striped bass (2.1 fish/day) was 56.2% below the 25-year average and the lowest since 2002. The biomass catch rates (kg/day) of males were well below the average of the 25-year time series and the lowest since 2002. The rates of females were also well below the 25-year average. The mean age of the male striped bass was the near the average in the 25-year time series. The mean age of the female striped bass was higher than 2014 and the highest value in the time series.

Spawning Stock Biomass Indexes.

The Spawning Stock Biomass Index (SSBI) for spring 2015 was 7.3 kg/day for male striped bass and 20.6 kg/day for female striped bass. The index for male striped bass was 46.3% below the value for 2014. It was the third lowest in the 25-year time series and 71.9% below the overall average (Table 6). The magnitude of the index for male striped bass was largely determined by the 2010-2011 (71.6%) year classes. The index for female striped bass was 63.5% lower than the 2014 index. It was the eight lowest in the time series, and 41.6% below the 25-year average (Table 6). The magnitude of the index for the females was largely determined by the 2000-2005 year classes (79.3%).

Egg Production Potential Index.

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

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

where N_0 is the total number of oocytes and FL is the fork length (>400) in millimeters. Using this relationship, the predicted egg production was 125,000 oocytes for a 400-mm female and 3,719,000 oocytes for a 1180-mm female striped bass (Table 7).

The 2015 Egg Production Potential Indexes (EPPI, Table 8) for the Rappahannock River was 3.18. The indexes for the Rappahannock River were heavily dependent on the egg production potential of the 2001-2005 year class females (68.7%). Previous values for the EPPI for 2001-2014 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 and 8.70 (Sadler et al 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, and 2014). Thus, the EPPI values for the pound nets in the Rappahannock River, which had rebounded in 2012-2014, declined to their lowest value since 2002. Modest changes in the methodology (utilizing fully mature ovaries solely rather than ovaries in various states of maturation) in the 2001-2014 indexes preclude direct comparison with the 1999 and 2000 indexes.

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

Numeric catch rates (fish/day) of individual year classes from the 1991-2015 samples are presented in Tables 9-11. The cumulative annual catch rate of all year classes for 2015 was 45.6% less than the cumulative catch rate for 2014 and 62.4% below the 25-year average of 18.81 (Tables 9a,b). The decrease was the result of lower catch rates in most of the represented year classes. The catch rate of males was dominated by three and four year olds (2010-2011 year classes, Tables 10a,b). These two age classes contributed 80.5% 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-2003 year class males were captured. Likewise, the cumulative catch rate of female stripers was 63.5% lower than the catch rate in 2014 and was 46.1% lower than the 25-year average of 4.76 (Tables 11a,b). The 2001-2005 year classes accounted for 68.9% of the total female catch.

 The range of overall ages was unchanged from 1991-2015, 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, 2014 and 2015). The catch rate of four and five year olds were near equal in 2003 and 2004 and again in 2011and 2012, but the peak was age three in 2005 and again in 2013. There has been an even more significant change in the age composition of the female spawning stock. From 1991-1996, the cumulative proportion of females age eight and older ranged from 0.134-0.468 (mean = 0.294) as their cumulative catch rate ranged from 0.75-2.1 fish/day (mean = 1.32). From 1997-2001 the range in the cumulative proportion of females age eight and older increased to 0.770-0.872 (mean = 0.825) as cumulative catch rates ranged from 1.4-4.5 fish/day (mean = 2.84). In 2002, the cumulative proportion of female striped bass age eight and older decreased to 0.508, then increased to 0.787-0.929 from 2003-2007. However, the cumulative catch rate dropped to 0.678 in 2008 and 0.593 in 2009, rebounded to 0.733-0.780 from 2010-2013 and increased strongly to .914 in 2014 and .847 in 2015.

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 (1991-2015) of the 1985-2006 year classes (sexes combined) varied from 0.398-0.729 (Tables 12a,b) with an overall mean survival rate of 0.634. 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 (1991-2015) of the 1985-2006 year classes of males varied from 0.276-0.657 (Tables 13a,b) with an overall mean survival rate of 0.460. These year classes have been the major target of the fall recreational and commercial fisheries

that reopened in 1993. The geometric mean survival rate (1991-2015) of the 1985-2000 year classes of females varied from 0.462-0.687 (Tables 14a,b) with an overall mean survival rate of 0.614.

Catch Rate Histories of the 1987-2005 Year Classes

The catch rate histories of the 1987-2005 year classes are depicted in Figures 3-12. Consistent among the year classes are a peak of male striped bass at age four or five followed by a rapid decline in the catch rate and a secondary peak of mostly female striped bass around age 10. This secondary peak is best defined from the pound net data. In our pound net samples the catch rates of male striped bass was an order of magnitude greater than the catch rates of female striped bass.

Numeric catch rates for male striped bass decreased rapidly subsequent to their peak of abundance at age four or five in both gears. These fish are the primary target for the commercial and recreational fisheries within Chesapeake Bay. Catch rates of female striped bass also show a steep decline after their initial peak in abundance, presumably due to their migratory behavior, but, at least in the Rappahannock River, also exhibited a secondary peak in the catch rates of 9-11 year old females that persisted across several year classes. This secondary peak was due to the relative lack of intermediate sized (590-710 mm TL) striped bass in the samples. This pattern was not evident in the catches from 1991-1996 but has been persistent thereafter.

The area under the catch curves (CCA) was calculated for each year class (sexes combined) from 1990-2011 (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 2015.

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 2015.

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 2015.

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 2015.

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 2015.

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 2015.

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 nnear the median among the year classes and slightly above the mean from the pound net samples in the Rappahannock River. No 1993 year class striped bass were captured in 2015.

1994 Year class: Peak abundance of male striped bass occurred at age four in the Rappahannock River (Figure 6). Peak abundance of female striped bass occurred at age 10 in the Rappahannock River. Again, there were relatively few ages five and six female striped bass captured in the Rappahannock River. The CCA was slightly above the mean from the pound net sample in the Rappahannock River. No 1994 year class striped bass were captured in 2015.

1995 Year class: Peak abundance of male striped bass occurred at age four in the Rappahannock River (Figure 7). Peak abundance of female striped bass occurred at age nine in the Rappahannock River. Again, there were relatively few ages five and six female striped bass captured in the Rappahannock River. The CCA was the sixth highest among the year classes and 31.2% 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 2015.

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. Two female 1996 year class striped bass were captured in 2015.

1997 Year class: Peak abundance of male striped bass occurred at age three in the Rappahannock River (Figure 8). Age ten females showed an increase in abundance in the Rappahannock River. The CCA was the second highest in the Rappahannock River pound nets. One female 1997 year class striped bass was captured in 2015.

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 sixth lowest among the year classes and 13.3% below average in the Rappahannock River pound nets. One female 1998 year class striped bass was captured in 2015.

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 fourth lowest among the year classes and 20.8% below the average in the Rappahannock River. One female 1999 year class striped bass was captured in 2015.

2000 Year class: Peak abundance of male striped bass occurred at age four in the Rappahannock River (Figure 9). The peak abundance of female striped bass was age five in the pound nets in the Rappahannock River. The CCA almost equal to the 1999 year class and well below the average in the pound nets. Two female 2000 year class striped bass were captured in 2015.

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. Five female 2001 year class striped bass were captured in 2015.

2002 Year class: Peak abundance of male striped bass occurred at age four in the Rappahannock River (Figure 10). Peak abundance of female striped bass occurred at age five in the Rappahannock River. The CCA was slightly above the average in the pound nets in the Rappahannock River. Two female 2002 year class striped bass were captured in 2015.

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. Nine (eight females and one male) 2003 year class striped bass were captured in 2015.

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. Seven (six females and one male) 2004 year class striped bass were captured in 2015.

2005 Year class: Peak abundance of male striped bass occurred at age five in the pound nets in the Rappahannock River (Figure 12). Peak abundance of female striped bass also occurred at age five. The CCA was well above average and the fifth highest overall in the Rappahannock River. Eleven (10 females and one male) 2005 year class striped bass were captured in 2015.

Growth Rate of Striped Bass Derived from Annuli Measurements

The scales of 149 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 149 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 85 mm in their fifth year and to about 45 mm in their 10th year (Tables16a,b). Interestingly, the growth rates of the most recent year classes were the highest, although the growth rate of the oldest year classes were based on very few specimens. Based on these growth estimates, an 18 inch (457 mm) total length striped bass would be 3.5 years of age during the fall recreational fishery in Chesapeake Bay. These striped bass reach the 28 inch (711 mm) total length minimum for the coastal fishery at age eight.

Age Determinations using Scales and Otoliths

2015 data
In 2015, we explored methodologies to establish combined tagging and monitoring programs for the James and York rivers. As a result, only 17 specimens were returned to VIMS for otolith extraction. This number was insufficient for a 2015-specific analytical comparison and the results were appended to the 2003-2014 data for analysis.

2003-2015 data
A total of 2,833 were aged by reading both their scales and otoliths. The mean age from the scale pairs from each otolith age varied by less than 0.5 years for ages 2-11 (Table 17), but diverged steadily thereafter (Figure 13).

Tests of symmetry: The scale and otolith ages from the same specimen were in agreement 42.8% (1212/2833) of the time and within one year 82.4% (2334/2833) of the time. A chi-square test was performed to test the hypothesis that an *m* x *m* contingency table (Table 18) consisting of two classifications of a sample into categories is symmetric about the main diagonal.

A test of symmetry that is significant indicates that there is a systematic difference between the aging methods. The number of degrees of freedom is equal to the number of non-zero age pair comparisons (here = 47). We tested the hypothesis that the observed age differences were symmetrically distributed about the main table diagonal (Table 19). The hypothesis was rejected ($X^2 = 284.85$, p<.005), indicating non-random differences between the two ageing methodologies.

Differences between the scale and otolith age from the same specimen ranged from zero to eight years (Figure 14). The otolith-derived age exceeded the scale age 34.2% of the total examined (59.7% of the non-zero differences). When the differences in ages were greater than one year, the otolith age was even more likely to be the older age (79.2%). Another test of symmetry that compared the negative and positive differences of the same magnitude (i.e. -4 and 4, -3 and 3, etc., Evans and Hoenig, 1998) rejected the hypothesis that these differences were random (X^2 = 177.8, df = 6, p< 0.005). This test has far fewer degrees of freedom than did the previous test of symmetry.

T-tests: Next, t-tests of the resultant means of the two ageing methods were performed. A two-tailed t-test was made to test the null hypothesis that the mean ages determined by the two methods were not different from zero. The mean age of the sample (n=2833) determined by reading the otoliths was greater than the mean age determined by reading the scales (by 0.27 years, Table 19). The test results were:

$$\overline{Age}_{otolith}= 8.52 \qquad\qquad \overline{Age}_{scale}= 8.79$$

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

$$df = 5665$$
$$p < .001$$

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= 5665, 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 ($K_{.05}$):

$$D_{max}= 0.0264 \qquad\qquad K_{.05}= 1.3581$$

$$D_{.05}= K_{.05} \sqrt{\frac{(2832)+(2832)}{(2832)^2}}=0.0361$$

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 17 April (one net) and precluded setting the third net at mile 45. Hence we tagged and released all striped bass greater than 457 mm and used a sex and size-based regression to estimate biomass for our pound net index.

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 1991-2015. There was a steady decrease in the relative abundance of five to seven year-old striped bass from 1991-2001, but these ages were proportionally more abundant in 2002-2014. The males in these age classes had been the target of the recreational and commercial fisheries, but with the increase in the availability of larger striped bass in recent years, the younger striped bass may be under less fishing pressure. Current regulations protect females from harvest during their annual migration by higher minimum lengths in the coastal fishery (711 mm TL vs. 458 mm TL within Chesapeake Bay) and the closure of the fishery in the bay during the April spawning run. The result has been a general increase in the abundance of older females throughout the period. Due to the late start to the sampling and the interruption due to flooding, total catches were lower in 2015 than in 2014, but the reduced biomass catch rates were consistent with low catches from the gill net-based tagging efforts in the James and York rivers which started on 30 March.

Of note again in the 2015 samples was the relative abundance of 1996 year class (19 year old) male and female stripers. This year class has been above-average in abundance since recruiting to the gears at age three, which indicates that it is a very strong year class. However, the 1993 year class, abundant in 2005-2007 and captured again in 2010-2013 was absent in the 2014 and 2015 samples.

The 2015 value of the Spawning Stock Biomass Index (SSBI) for the Rappahannock River pound nets was less than one half the SSBI for 2015 and less than one half the overall mean. The SSBI for male striped bass captured in the pound nets was 46% below the index for 2014 and nearly 72% below the mean of the 1991-2015 time series. Similarly the SSBI for female striped bass was also less than one half the 2014 value and 42% below the mean of the time series. The male component of the SSBI was dominated by three to five year-old striped bass while the female component was dominated by 10+ year old striped bass. This was the worst SSBI estimate since 2002.

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 2015, the contribution of 8+ year old females was 84.4% of the total number (there were very few four to eight year old females caught in 2015), 95.6% of the biomass, and 95.9% 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 2004-2015, the second group expanded to 750-1200 mm as the strong 1996-1998 year classes were caught in abundance.

The time series of the catch rates by age class and by year class indicate that the age of peak abundance in the rivers has changed, from five or six years in 1992-1994 to three to four years in 2000-2002, then four to five years since 2003. Changes in the annual catch rates by year class in the Rappahannock River indicated that strong year classes occurred in 1988, 1989, 1996, 1997 and 2003, and weak year classes occurred in 1990,1991and 2002. The relative abundance of ten-year old, 1992 year class, striped bass of both sexes in both 2001 and 2002, indicate that the 1992 year class was also strong.

The time series allows estimates of the instantaneous rates of survival of the year classes using catch curves, especially for the 1983-2006 year classes that were captured for four or five years subsequent to their peak in abundance at age four or five. The survival estimate of female striped bass of the 1985-2000 year classes in the Rappahannock River was 0.614. The survival estimate of 1985-2006 year class male striped bass was 0.460. The higher survival estimates for the females may be the result of their differential maturation rates. These differences cause lower peaks in abundance (usually at age five) as only fractions of each year class mature and are depicted in their lower peak abundance values. The large differences between the sexes also reflect a management strategy that targets males.

The catch histories of the 1987-2005 year classes in the Rappahannock River show two distinct patterns. The 1987-1990 year classes had initial peaks of abundance of both sexes at ages four or five and a secondary peak in the abundance of female striped bass after age eight. Subsequent year classes did not have the initial peak in abundance of female striped bass, but only what was the secondary peak of eight to 12 year-olds. Using the area under the catch curve as an indicator of year class strength, the 1993, 1996, 1997 and 2003 year classes were the strongest and the 1990, 1991 and 2002 year classes were the weakest.

Back-calculation of the growth based on measurements between scale annuli indicated that striped bass grow about 150 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 2011 year class in fall 2014) and the 28 in. (711 mm) minimum total length for the coastal fishery at age eight.

Since 2003 we have aged 2,833 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 42.8% and varied annually from 33.7% to 51.2%. When there was disagreement between methodologies, the otolith age was 1.5 times more likely to have been aged older than the respective scale-derived age. When the age difference was two years or greater, the otolith age was 3.8 times more likely to be the older age. The differences were found not to be statistically non-random and different from zero. 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 2011-2013, 2007-2010 and 1996-2006) from pound nets in the Rappahannock River, by sampling date, spring, 2015. M = males, F = females.

| | | Year Class | | | | | | | |
| | | No age | | 2011-2013 | | 2007-2010 | | 1996-2006 | |
Date	n	M	F	M	F	M	F	M	F
17 April	20	0	0	6	0	2	0	0	12
20 April	21	0	0	11	0	3	0	0	7
23 April	23	0	0	7	0	5	1	1	9
27 April	32	0	0	21	0	6	2	0	3
30 April	26	0	0	17	0	3	1	1	4
4 May	19	0	0	12	0	2	3	1	1
7 May	11	0	0	6	0	3	0	0	2
Total	**152**	**0**	**0**	**80**	**0**	**24**	**7**	**3**	**38**

Table 2. Net-specific summary of catch rates and mean ages of striped bass (n=152) in pound nets on the Rappahannock River, spring, 2015. Values in bold are the grand means for each column. M = male, F=female.

Date	Net ID	n	CPUE (fish/day)		CPUE (g/day)		Mean age	
			M	F	M	F	M	F
17 April	S462	20	5.3	8.0	7,436.9	94,135.3	4.1	12.8
20 April	S462	21	4.7	2.3	5,712.5	27,401.1	4.1	13.9
23 April	S462	23	4.3	3.3	9,388.8	32,381.5	5.4	10.8
27 April	S462	32	6.8	1.3	9,273.9	10,575.9	4.1	11.0
30 April	S462	26	7.0	1.7	10,340.7	14,188.2	4.4	10.8
4 May	S462	19	3.8	4.3	5,264.1	4,054.6	4.5	6.8
7 May	S462	11	3.0	1.7	4,002.6	6,931.5	4.3	11.0
Totals	S462	152	5.0	2.1	7,333.9	20,578.2	4.8	11.1
	S473	0						
Season		152	**5.0**	**2.1**	**7,333.9**	**20,578.2**	**4.4**	**11.5**

Table 3. Length frequencies (TL in mm) of striped bass sampled from the pound nets in the Rappahannock River, spring, 2015.

TL	n	TL	n	TL	n	TL	n	TL	n	TL	n
280-	0	440-	5	600-	2	760-	0	920-	2	1080-	1
290-	0	450-	6	610-	0	770-	1	930-	3	1090-	0
300-	0	460-	13	620-	1	780-	0	940-	2	1100-	0
310-	0	470-	9	630-	0	790-	0	950-	3	1110-	1
320-	0	480-	13	640-	0	800-	1	960-	6	1120-	0
330-	0	490-	3	650-	0	810-	0	970-	2	1130-	1
340-	0	500-	5	660-	0	820-	0	980-	3	1140-	0
350-	0	510-	9	670-	1	830-	0	990-	2	1150-	0
360-	0	520-	3	680-	0	840-	1	1000-	1	1160-	0
370-	0	530-	6	690-	1	850-	0	1010-	4	1170-	0
380-	0	540-	2	700-	0	860-	1	1020-	1	1180-	0
390-	0	550-	7	710-	0	870-	2	1030-	0	1190-	0
400-	0	560-	2	720-	0	880-	0	1040-	0	1200-	0
410-	4	570-	0	730-	2	890-	0	1050-	1	1210-	0
420-	3	580-	6	740-	0	900-	1	1060-	0	1220-	0
430-	7	590-	1	750-	0	910-	0	1070-	1	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 2015.

Year Class	Sex	n	Fork Length Mean	Fork Length SD	Weight Mean	Weight SD	CPUE F/day	CPUE W/day
2012	male	13	397.7	9.6	810.1	58.8	0.6	489.8
2011	male	67	480.5	25.6	1,170.7	195.3	3.1	3,648.4
2010	male	19	513.4	21.1	1,789.3	231.4	0.9	1,581.2
	female	5	535.2	38.4	2,329.8	452.5	0.2	541.8
2009	male	2	562.0	19.8	2,320.3	248.3	0.1	215.8
2008	male	1	627.0		3230.6		0.0	150.3
	female	2	666.5	26.2	3,890.8	161.1	0.1	361.9
2007	male	2	626.5	82.7	3,310.1	1,298.6	0.1	307.9
2006	male	0					0.0	0.0
2005	male	1	786.0		6,425.0		0.0	298.8
	female	10	849.0	44.1	8,794.1	1,261.2	0.5	4,090.3
2004	male	1	734.0		5,217.3		0.0	242.7
	female	6	901.7	12.7	10,408.8	422.6	0.3	2,904.8
2003	male	1	863.0		8,537.0		0.0	397.1
	female	8	928.5	16.3	11,332.6	583.8	0.4	4,216.8
2002	female	2	938.0	8.5	11,663.7	304.9	0.1	1,085.0
2001	female	5	946.2	27.4	11,981.3	989.0	0.2	2,786.3
2000	female	2	986.5	40.3	13,522.3	1,593.4	0.1	1,257.9
1999	female	1	893.0		10,117.7		0.0	470.6
1998	female	1	1,010.0		14,441.4		0.0	671.7
1997	female	1	992.0		13,710.1		0.0	637.7
1996	female	2	1,062.0	12.7	16,699.6	578.3	0.1	1,553.5
Not	male	0						
Aged	female	0						

Table 5. Summary of the seasonal mean catch rates and ages, by sex, from the pound nets in the Rappahannock River, springs 1991-2015.   M = male, F = female.

Year	n	CPUE (fish/day)		CPUE (g/day)		Mean age	
		M	F	M	F	M	F
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	**540.2**	**14.1**	**4.8**	**24,621.3**	**35,308.7**	**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 – 2015

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| 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
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	**415.3**	**130.2**	**26.0**	**35.3**	**61.3**	**376.6**	**60.3**	**76.3**	**42.4**	**118.7**

Table 7. Predicted values of fecundity (in millions of eggs) of female striped bass with increasing fork length (mm), James and Rappahannock rivers combined.

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

Table 8. Total, age-specific, estimated total egg potential (E, in millions of eggs/day) from mature (ages 4 and older) female striped bass from the Rappahannock River, spring 2015. The Egg Production Potential Indexes (millions of eggs/day) are in bold.

Age	n	E	%
4	0	0.000	0.00
5	5	0.073	2.29
6	0	0.000	0.00
7	2	0.058	1.83
8	0	0.000	0.00
9	0	0.000	0.00
10	10	0.621	19.54
11	6	0.446	14.03
12	8	0.653	20.55
13	2	0.168	5.29
14	5	0.434	13.66
15	2	0.198	6.23
16	1	0.072	2.27
17	1	0.106	3.33
18	1	0.100	3.14
19	2	0.249	7.84
20	0	0.000	0.00
n/age	0	0.000	0.00
Total	45	**3.178**	100.00

Table 9a. Catch rates (fish/day) of year classes of striped bass (sexes combined) sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2015. Maximum catch rate for each year class is in bold type.

Year Class	CPUE (fish/day)												
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
2000													0.76
1999											0.07	0.51	3.00
1998										0.03	2.74	1.44	3.33
1997									0.79	**15.61**	7.49	1.38	0.37
1996								0.19	11.54	**18.13**	4.29	0.25	1.83
1995							0.60	2.15	**11.50**	3.34	0.10	0.68	1.40
1994					0.04	0.51	3.90	**6.33**	2.79	0.11	0.58	0.41	1.70
1993					3.04	3.97	**8.10**	1.48	0.11	0.50	0.87	0.28	1.43
1992			0.12	1.44	**4.80**	2.86	1.25	0.04	0.50	0.50	0.87	0.19	1.13
1991		0.20	0.57	0.48	1.00	**1.63**	0.05	0.52	0.43	0.40	0.81	0.06	0.33
1990	0.42	0.50	1.04	1.33	**2.24**	1.26	0.70	0.70	0.32	0.29	0.45	0.00	0.27
1989	0.33	0.60	3.58	**4.59**	0.68	0.89	0.80	0.78	0.36	0.37	0.26	0.00	0.07
1988	3.58	1.60	**9.54**	2.22	0.60	0.37	1.50	0.89	0.39	0.05	0.10	0.00	0.00
1987	**8.00**	2.75	3.65	1.15	0.68	0.37	1.00	0.89	0.43	0.05	0.00	0.03	0.03
1986	**2.67**	1.15	0.65	0.59	0.40	0.09	1.00	0.22	0.04	0.00	0.00	0.00	0.00
1985	**1.67**	0.30	0.42	0.52	0.08	0.00	0.35	0.15	0.11	0.00	0.00	0.00	0.00
1984	0.50	0.40	**0.58**	0.33	0.28	0.00	0.35	0.07	0.04	0.00	0.00	0.00	0.00
1983	0.25	0.20	**0.46**	0.33	0.08	0.03	0.20	0.00	0.00	0.00	0.00	0.00	0.00
>1983	**0.75**	0.45	0.73	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.58	0.30	0.38	0.56	0.60	0.32	0.50	0.44	0.54	0.32	0.00	0.00	0.00
Total	**18.75**	**8.45**	**21.72**	**13.87**	**14.52**	**12.30**	**20.30**	**14.85**	**29.89**	**39.70**	**18.63**	**5.23**	**15.65**

Table 9b. Catch rates (fish/day) of year classes of striped bass (sexes combined) sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2015. Maximum catch rate for each year class is in bold type.

Year Class	CPUE (fish/day)											
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
2012												**0.60**
2011											**3.35**	3.12
2010										1.65	**2.65**	1.12
2009								0.08	1.40	**1.74**	0.41	0.09
2008							0.23	0.46	**3.20**	1.91	0.00	0.14
2007						0.07	2.63	1.08	**3.80**	0.83	0.06	0.09
2006					0.17	1.89	**6.50**	1.38	2.12	0.30	0.47	0.00
2005				0.03	4.40	5.07	**10.43**	0.96	1.04	0.26	0.65	0.51
2004				2.52	**7.20**	6.93	4.23	0.79	0.92	0.30	1.35	0.33
2003			7.89	**8.55**	3.26	2.15	1.53	0.88	1.28	1.13	1.53	0.42
2002		1.83	**6.40**	6.17	0.51	1.22	1.03	0.96	0.84	0.39	0.53	0.09
2001	3.47	**5.43**	3.17	1.14	0.60	1.22	1.27	1.04	0.96	0.87	0.88	0.23
2000	**5.57**	2.77	0.14	1.12	0.57	1.19	1.77	0.63	0.44	0.48	0.65	0.09
1999	**5.90**	0.71	0.51	1.51	0.29	1.19	1.10	0.25	0.28	0.13	0.00	0.05
1998	**3.50**	0.77	0.91	1.89	0.43	0.67	0.70	0.04	0.32	0.13	0.24	0.05
1997	2.23	1.69	0.86	2.68	0.43	0.37	0.53	0.17	0.20	0.04	0.06	0.05
1996	4.16	1.69	1.17	3.80	0.46	0.70	1.13	0.08	0.20	0.22	0.18	0.09
1995	2.33	0.94	0.23	0.71	0.00	0.00	0.13	0.04	0.00	0.00	0.00	0.00
1994	1.67	0.69	0.20	0.71	0.00	0.19	0.07	0.00	0.00	0.00	0.00	0.00
1993	1.00	0.57	0.20	0.46	0.00	0.00	0.07	0.08	0.00	0.09	0.00	0.00
1992	1.10	0.29	0.11	0.20	0.00	0.03	0.07	0.00	0.00	0.00	0.00	0.00
1991	0.17	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.07	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	0.07	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.40	0.49	0.26	0.00	0.00	0.07	1.47	0.04	0.44	0.17	0.00	0.00
Total	**31.64**	**18.05**	**22.05**	**31.52**	**18.35**	**22.96**	**34.89**	**8.88**	**17.44**	**10.64**	**13.00**	**7.07**

Table 10a. Catch rates (fish/day) of year classes of male striped bass sampled from pound nets in the Rappahannock River, 30 March – 3 May 1991-2015. Maximum catch rate for each year class is in bold type.

Year Class	CPUE (fish/day)												
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
2000													0.76
1999											0.07	0.44	2.93
1998									0.03	2.74	1.38	3.07
1997									0.79	**15.61**	7.42	1.25	0.30
1996								0.19	11.54	**18.11**	4.03	0.16	1.50
1995							0.55	2.15	**11.46**	3.21	0.10	0.03	0.56
1994					0.04	0.51	3.80	**6.19**	2.68	0.08	0.39	0.03	0.23
1993					2.88	3.83	**7.50**	1.37	0.07	0.26	0.16	0.00	0.07
1992			0.12	1.22	**4.68**	2.66	1.15	0.00	0.36	0.11	0.19	0.00	0.00
1991		0.15	0.54	0.48	0.92	**1.34**	0.05	0.30	0.21	0.05	0.13	0.00	0.00
1990	0.17	0.35	0.96	1.30	**2.00**	0.94	0.35	0.11	0.00	0.03	0.00	0.00	0.00
1989	0.17	0.40	3.46	**3.52**	0.08	0.43	0.55	0.04	0.04	0.03	0.00	0.00	0.00
1988	3.25	0.90	**7.54**	1.11	0.12	0.03	0.20	0.00	0.00	0.00	0.00	0.00	0.00
1987	**6.08**	0.65	1.23	0.22	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1986	**2.58**	0.30	0.15	0.11	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1985	**0.50**	0.05	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.08	**0.15**	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<1984	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.25	0.10	0.27	0.41	0.44	0.23	0.25	0.33	0.54	0.32	0.00	0.00	0.00
Total	13.08	3.05	14.39	8.45	11.20	10.06	14.40	10.68	27.69	37.84	15.23	3.54	9.42

Table 10b. Catch rates (fish/day) of year classes of male striped bass sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2015. Maximum catch rate for each year class is in bold type.

Year Class	CPUE (fish/day)											
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
2012												**0.60**
2011											**3.29**	3.11
2010										1.65	**2.47**	0.88
2009									**1.40**	1.39	0.29	0.09
2008						0.13	0.46	**3.20**	1.43	0.00	0.05	
2007					0.07	2.53	1.04	**3.36**	0.70	0.06	0.09	
2006				0.11	1.78	**6.30**	1.00	1.60	0.17	0.06	0.00	
2005			0.03	4.34	4.48	**9.63**	0.67	0.96	0.09	0.06	0.05	
2004			2.49	**7.03**	5.48	4.03	0.67	0.68	0.13	0.35	0.05	
2003		7.77	**8.46**	3.00	1.70	1.37	0.63	0.56	0.39	0.47	0.05	
2002	1.83	**6.29**	5.83	0.46	1.00	0.70	0.50	0.32	0.09	0.06	0.00	
2001	3.47	**5.40**	2.91	0.97	0.49	0.81	0.67	0.25	0.08	0.22	0.12	0.00
2000	**5.47**	2.49	0.09	1.03	0.37	0.48	0.27	0.17	0.08	0.13	0.00	0.00
1999	**5.67**	0.66	0.20	1.00	0.14	0.19	0.23	0.00	0.08	0.00	0.00	0.00
1998	**3.37**	0.51	0.57	0.89	0.03	0.07	0.13	0.00	0.08	0.00	0.00	0.00
1997	1.93	1.00	0.29	0.37	0.06	0.04	0.00	0.00	0.00	0.00	0.00	0.00
1996	2.23	0.43	0.03	0.29	0.03	0.70	0.10	0.00	0.00	0.00	0.06	0.00
1995	0.53	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994	0.20	0.09	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1992	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	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
N/A	0.40	0.46	0.29	0.00	0.00	0.07	1.40	0.04	0.44	0.17	0.00	0.00
Total	23.44	12.96	18.50	21.36	16.09	16.87	27.50	5.43	12.80	6.56	7.29	4.97

31

Table 11a. Catch rates (fish/day) of year classes of female striped bass sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2015. Maximum catch rate for each year class is in bold type.

Year Class	CPUE (fish/day)												
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
1999												0.06	0.07
1998												0.06	0.27
1997											0.07	0.13	0.07
1996										0.03	0.26	0.00	0.37
1995							0.05	0.00	0.04	0.13	0.00	0.63	0.80
1994							0.10	0.15	0.11	0.03	0.19	0.38	**1.47**
1993					0.16	0.14	0.60	0.11	0.04	0.24	0.71	0.25	**1.37**
1992				0.22	0.12	0.20	0.10	0.04	0.14	0.40	0.68	0.19	**1.13**
1991		0.05	0.04	0.00	0.08	0.29	0.00	0.22	0.21	0.34	**0.68**	0.06	0.33
1990	0.25	0.15	0.08	0.04	0.24	0.31	0.35	**0.59**	0.32	0.26	0.45	0.00	0.26
1989	0.17	0.20	0.12	**1.07**	0.60	0.46	0.25	0.74	0.32	0.34	0.26	0.00	0.07
1988	0.33	0.70	**2.00**	1.11	0.48	0.34	1.30	0.89	0.39	0.05	0.10	0.00	0.00
1987	1.92	2.10	**2.42**	0.93	0.68	0.29	1.00	0.89	0.43	0.05	0.00	0.03	0.03
1986	**1.08**	0.85	0.50	0.48	0.36	0.09	1.00	0.22	0.04	0.00	0.00	0.00	0.00
1985	**1.17**	0.25	0.39	0.48	0.08	0.00	0.35	0.15	0.11	0.00	0.00	0.00	0.00
1984	0.42	0.25	**0.50**	0.33	0.28	0.00	0.35	0.07	0.04	0.00	0.00	0.00	0.00
>1983	0.83	0.65	**1.19**	0.59	0.08	0.03	0.20	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.25	0.20	0.12	0.15	0.16	0.09	0.25	0.11	0.00	0.00	0.00	0.00	0.00
Total	**6.42**	**5.40**	**7.36**	**5.40**	**3.32**	**2.24**	**5.90**	**4.18**	**2.19**	**1.87**	**3.40**	**1.79**	**6.24**

Table 11b. Catch rates (fish/day) of year classes of female striped bass sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2015. Maximum catch rate for each year class is in bold type.

Year Class	CPUE (fish/day)											
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
2011											**0.06**	0.00
2010											0.18	**0.23**
2009								0.00	0.04	**0.35**	0.12	0.00
2008							0.10	0.00	0.00	**0.48**	0.00	0.09
2007							0.10	0.04	**0.44**	0.13	0.00	0.00
2006					0.06	0.11	0.20	0.38	**0.52**	0.13	0.41	0.00
2005				0.00	0.06	0.59	**0.80**	0.29	0.08	0.17	0.59	0.47
2004				0.03	0.17	**1.44**	0.20	0.13	0.24	0.17	1.00	0.28
2003			0.11	0.09	0.26	0.44	0.17	0.25	0.72	0.74	**1.06**	0.37
2002			0.11	0.34	0.06	0.22	0.33	0.46	**0.52**	0.30	0.47	0.09
2001		0.03	0.26	0.17	0.11	0.41	0.60	0.79	**0.88**	0.65	0.76	0.23
2000	0.10	0.29	0.06	0.09	0.20	0.70	**1.50**	0.46	0.36	0.35	0.65	0.09
1999	0.23	0.06	0.31	0.51	0.14	**1.00**	0.87	0.25	0.20	0.13	0.00	0.05
1998	0.17	0.26	0.34	**1.00**	0.40	0.59	0.57	0.04	0.24	0.13	0.24	0.05
1997	0.30	0.69	0.57	**2.31**	0.37	0.33	0.53	0.17	0.20	0.04	0.06	0.05
1996	1.93	1.26	1.14	**3.51**	0.43	0.70	1.03	0.08	0.20	0.22	0.12	0.09
1995	**1.80**	0.86	0.23	0.71	0.00	0.00	0.13	0.04	0.00	0.00	0.00	0.00
1994	**1.47**	0.60	0.14	0.71	0.00	0.19	0.07	0.00	0.00	0.00	0.00	0.00
1993	0.90	0.54	0.20	0.46	0.00	0.00	0.07	0.08	0.00	0.09	0.00	0.00
1992	1.03	0.29	0.11	0.20	0.00	0.04	0.07	0.00	0.00	0.00	0.00	0.00
1991	0.17	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.07	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	0.07	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N/A	0.00	0.03	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00
Total	8.24	5.09	3.58	10.16	2.26	6.67	7.40	3.46	4.64	4.08	5.72	2.09

Table 12a. Estimated annual and geometric mean survival (S) rates for year classes of striped bass (sexes combined) sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2015.

	Year Class											
	1985	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**
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
01-02			.903	.000	.646	.775	.638	.983	.993	.884	.914	.990
02-03			.903		.646	.775	.638	.983	.993	.884	.914	.990
03-04			.903		.646	.259	.515	.894	.699	.982	.914	.990
04-05			.903		.429	.754	.529	.264	.570	.752	.403	.970
05-06			.000		.000	.754	.000	.830	.898	.752	.869	.970
06-07						.754		.830	.898	.752	.869	.970
07-08						.000		.705	.762	.517	.568	.667
08-09								.705	.762	.517	.568	.667
09-10								.705	.762	.368	.568	.667
10-11								.000	.762	.000	.308	.580
11-12									.762		.000	.580
12-13									.762			.580
13-14									.000			.818
14-15												.500
mean	**.621**	**.581**	**.668**	**.517**	**.579**	**.647**	**.641**	**.714**	**.726**	**.638**	**.594**	**.702**

Table 12b.   Estimated annual and geometric mean survival (S) rates for year classes of striped bass (sexes combined) sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2015.

	Year Class												
	1997	**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	.480												
01-02	.842												
02-03	.842												
03-04	.842												
04-05	.842	.814	.635	.497									
05-06	.842	.814	.635	.914	.584								
06-07	.842	.814	.635	.914	.796	.964							
07-08	.583	.718	.888	.914	.796	.445	.381						
08-09	.583	.718	.888	.914	.796	.445	.660	.963					
09-10	.583	.718	.924	.914	.796	.844	.935	.610					
10-11	.614	.676	.505	.778	.819	.932	.934	.752	.316	.571			
11-12	.614	.676	.505	.778	.923	.875	.934	.752	.316	.571			
12-13	.548	.866	.464	.778	.957	.794	.934	.752	.791	.471	.218	.597	
13-14	.548	.866	.620	.778	.957	.794	.934	.752	.791	.471	.329	.271	.236
14-15	.833	.208	.620	.138	.261	.170	.275	.244	.785	.000	.329	.271	.220
mean	**.682**	**.679**	**.648**	**.687**	**.729**	**.623**	**.686**	**.644**	**.547**	**.398**	**.287**	**.353**	**.228**

Table 13a. Estimated annual and geometric mean survival (S) rates for year classes of male striped bass sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2015.

	Year Class											
	1985	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**
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
01-02							.000	.000	.855	.768	.559	.821
02-03									.855	.768	.559	.821
03-04									.855	.870	.946	.821
04-05									.000	.450	.170	.793
05-06										.667	.000	.793
06-07										.000		.793
07-08												.793
08-09												.793
09-10												.143
10-11												.880
11-12												.880
12-13												.880
13-14												.880
14-15												.000
mean	**.409**	**.317**	**.372**	**.345**	**.395**	**.353**	**.508**	**.490**	**.496**	**.501**	**.409**	**.657**

Table 13b. Estimated annual and geometric mean survival (S) rates for year classes of male striped bass sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2015.

	Year Class												
	1997	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	.475												
01-02	.639												
02-03	.639												
03-04	.639												
04-05	.518	.642	.561	.455									
05-06	.608	.642	.561	.643	.539								
06-07	.608	.642	.561	.643	.333	.927							
07-08	.162	.527	.613	.683	.914	.414	.355						
08-09	.667	.527	.613	.683	.914	.414	.567	.780					
09-10	.000	.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	.187	.207
14-15					.000	.000	.106	.143	.833	.000	.359	.187	.310
mean	**.477**	**.545**	**.508**	**.584**	**.599**	**.504**	**.526**	**.493**	**.350**	**.276**	**.299**	**.257**	**.399**

Table 14a. Estimated annual and geometric mean survival (S) rates for year classes of female striped bass sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2015.

	Year Class											
	1985	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**
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
08-09								.705	.762	.517	.568	.665
09-10								.705	.762	.368	.568	.665
10-11								.000	.762	.000	.000	.598
11-12									.762			.598
12-13									.762			.598
13-14									.000			.545
14-15												.750
mean	**.649**	**.646**	**.673**	**.607**	**.655**	**.649**	**.462**	**.589**	**.676**	**.563**	**.542**	**.633**

Table 14b. Estimated annual and geometric mean survival (S) rates for year classes of female striped bass sampled from pound nets in the Rappahannock River, 30 March – 3 May, 1991-2015.

	Year Class											
	1997	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
91-92												
92-93												
93-94												
94-95												
95-96												
96-97												
97-98												
98-99												
99-00												
00-01												
01-02												
02-03												
03-04												
04-05												
05-06												
06-07												
07-08	.612	.768										
08-09	.612	.768										
09-10	.612	.966	.870					.930				
10-11	.614	.806	.287	.811				.930	.927			
11-12	.614	.806	.800	.811				.930	.927			
12-13	.548	.806	.650	.811	.929	.951		.930	.927	.888	.295	
13-14	.548	.806	.620	.811	.929	.951		.930	.927	.888	.000	.433
14-15	.833	.208	.620	.138	.303	.191	.349	.280	.797	.000		.433
mean	**.619**	**.687**	**.607**	**.569**	**.634**	**.557**	**.349**	**.761**	**.899**	**.528**	**.138**	**.433**

39

Table 15a. Comparison of the area under the catch curve (fish/ day) of the 1990-2011 year classes of striped bass from pound nets in the Rappahannock River, 1991-2015.

age	year class										
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
2	0.3	0.3	0.7	1.5	0.3	0.3	0.1	0.4	0.0	0.0	0.0
3	1.3	0.8	5.5	5.5	4.2	2.5	11.6	16.0	2.7	0.6	0.8
4	2.6	1.8	8.4	13.6	10.5	14.0	29.8	23.5	4.2	3.6	6.3
5	4.9	3.4	9.6	15.1	13.3	17.3	34.1	24.9	7.5	9.5	9.1
6	6.1	3.5	9.7	15.2	13.4	17.4	34.3	25.3	11.0	10.2	9.2
7	6.8	4.0	10.2	15.7	14.0	18.1	36.1	27.5	11.8	10.7	10.3
8	7.5	4.4	10.7	16.6	14.4	19.5	40.3	29.2	12.7	12.2	10.9
9	7.8	4.8	11.5	16.8	16.1	21.8	42.0	30.1	14.6	12.5	12.1
10	8.1	5.7	11.7	18.3	17.8	22.7	43.2	32.8	15.0	13.7	13.9
11	8.6	5.9	12.9	19.3	18.4	22.9	47.0	33.2	15.7	14.8	14.6
12	8.6	7.0	14.0	19.8	18.6	23.6	47.5	33.5	16.4	15.1	15.0
13	8.9	8.1	14.3	20.0	19.3	23.6	48.2	34.0	16.4	15.4	15.5
14	8.9	8.4	14.4	20.5	19.3	23.6	49.3	34.2	16.7	15.5	16.1
15	9.0	8.4	14.6	20.5	19.5	23.7	49.4	34.4	16.8	15.5	16.2
16	9.0	8.4	14.6	20.5	19.6	23.7	49.6	34.4	17.0	15.5	
17	9.0	8.4	14.6	20.6	19.6	23.7	49.8	34.5	17.0		
18	9.0	8.4	14.7	20.7	19.6	23.7	50.0	34.5			
19	9.0	8.4	14.7	20.7	19.6	23.7	50.1				
20	9.0	8.4	14.7	20.8	19.6	23.7					
area	9.0	8.4	14.7	20.8	19.6	23.7	50.1	34.5	17.0	15.5	16.2

Table 15b. Comparison of the area under the catch curve (fish/ day) of the 1990-2011 year classes of striped bass from pound nets in the Rappahannock River, 1991-2015.

age	year class											mean
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	
2	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.2	0.1	0.0	0.0	**0.2**
3	3.5	1.8	7.9	2.6	4.4	2.0	2.7	0.7	1.5	1.7	3.4	**3.8**
4	8.9	8.2	16.5	9.8	9.5	8.5	3.8	3.9	3.2	4.3	6.5	**9.2**
5	12.1	14.3	19.8	16.7	19.9	9.9	7.6	5.8	3.6	5.4		**12.5**
6	13.3	14.8	21.9	20.9	20.9	12.0	8.4	5.8	3.7			**13.4**
7	13.9	16.0	23.5	21.7	21.9	12.3	8.5	5.9				**14.2**
8	15.1	17.0	24.4	22.6	22.2	12.8	8.6					**15.2**
9	16.4	18.0	25.7	22.9	22.8	12.8						**16.2**
10	17.5	18.8	26.8	24.3	23.3							**17.3**
11	18.5	19.2	28.3	24.6								**18.3**
12	19.4	19.7	28.7									**18.8**
13	20.3	19.8										**19.3**
14	20.5											**19.5**
15												**19.6**
16												**19.7**
17												**19.7**
18												**19.8**
19												**19.8**
20												**19.8**
area	**20.5**	**19.8**	**28.7**	**24.6**	**23.3**	**12.8**	**8.6**	**5.9**	**3.7**	**5.4**	**6.5**	**19.8**

Table 16a. Back-calculated length-at-age (FL, in mm) for striped bass sampled from the James and Rappahannock rivers during spring, 2015.

Year Class	n	length-at-age (FL, in mm)							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
2012	13	162.6	286.3						
2011	66	152.6	265.1	366.2					
2010	24	144.5	249.9	355.3	441.4				
2009	2	130.6	242.4	353.9	438.7	509.7			
2008	3	141.8	238.7	347.3	448.2	535.6	595.8		
2007	2	140.9	219.4	308.2	391.9	455.1	521.7	581.8	
2006	0								
2005	11	142.5	243.1	337.3	428.5	513.8	596.8	669.4	729.7
2004	7	148.1	240.3	334.0	424.2	514.2	594.4	665.3	736.2
2003	8	144.7	241.9	330.7	415.5	495.6	573.8	651.9	721.9
2002	2	130.1	219.7	313.7	402.3	496.5	569.1	635.9	707.1
2001	5	149.0	243.3	343.3	435.4	515.3	591.4	658.8	713.7
2000	1	166.2	256.4	342.9	417.1	495.7	547.1	608.7	655.8
1999	1	165.6	231.1	318.9	397.3	458.0	517.6	567.1	603.2
1998	1	139.9	240.1	318.7	401.8	468.1	521.1	573.7	630.4
1997	1	116.6	190.1	259.6	313.8	376.8	444.9	501.3	570.1
1996	2	129.4	205.9	280.5	365.1	440.3	507.1	579.0	638.6
all	149	149.2	255.9	353.4	427.0	498.7	573.6	642.9	704.8

Table 16b.   Back-calculated length-at-age (FL, in mm) for striped bass sampled from the James and Rappahannock rivers during spring, 2015.

Year Class	n	length-at-age (FL, in mm)									
		9	10	11	12	13	14	15	16	17	18
2012											
2011	11										
2010	18										
2009	18										
2008	16										
2007	16										
2006	18										
2005	11	785.4									
2004	7	790.1	835.3								
2003	8	779.7	829.3	870.2							
2002	2	755.1	810.0	854.7	894.0						
2001	1	762.2	810.4	850.4	884.2	913.1					
2000	1	707.0	756.4	790.4	829.7	875.0	916.7				
1999	1	633.2	668.3	711.7	761.5	794.9	821.4	849.2			
1998	1	693.0	749.6	803.7	841.9	874.7	916.0	951.6	976.1		
1997	1	622.4	673.7	716.5	757.7	806.0	844.9	880.2	914.7	947.8	
1996	2	687.5	739.7	777.2	813.1	849.0	887.2	919.6	953.9	985.9	1012
all	149	763.1	808.7	840.9	870.6	881.5	902.9	909.4	949.7	973.2	1012

Table 17.   Mean scale and standard error for each otolith age from ages derived from the same specimen, 2003-2015.

N	Otolith age	Mean scale age	SE
91	2	2.31	0.47
161	3	3.26	0.47
204	4	4.30	0.61
186	5	5.05	0.67
151	6	5.99	0.83
203	7	6.66	1.12
253	8	8.08	0.98
295	9	8.96	1.13
344	10	9.77	1.17
324	11	10.82	1.10
250	12	11.42	1.16
125	13	12.03	1.26
85	14	12.19	1.22
53	15	13.36	1.35
47	16	14.72	1.44
28	17	14.61	1.29
10	18	15.60	0.97
6	19	16.00	2.10
4	20	16.50	1.00
8	21	16.85	2.10

Table 18. Data matrix comparing 2003-2015 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	**62**	2	0																
3	29	**115**	14	4															
4		44	**116**	25	3	5													
5			72	**120**	40	27	0	2											
6			2	35	**67**	52	10	1	0										
7				2	38	**76**	59	21	7	0	1	1							
8					3	35	**106**	74	44	5	2	1							
9						7	61	**110**	71	30	7	1	0						
10						1	14	64	**138**	82	44	7	2	1					
11							3	19	64	**130**	67	29	6	4	1				
12								4	14	60	**90**	39	26	8	2	1			
13									6	12	33	**38**	24	16	9	5	0		1
14										5	6	6	**22**	11	15	6	2	1	0
15												3	3	**12**	10	11	1	2	1
16													1	1	**6**	2	6	2	6
17													1	0	3	**3**	1	0	1
18															1	0	**0**	0	3
19																	0	**0**	3
20+																		1	**1**

45

Table 19. Relative contributions of striped bass age classes as determined by ageing specimens (n = 2,833) by reading both their scales and otoliths, springs 2003-2015.

Age	Scale age		Otolith age	
	n	**prop**	**n**	**Prop**
1	1	0.0004	1	0.0004
2	64	0.0226	91	0.0321
3	162	0.0572	161	0.0568
4	193	0.0681	204	0.0720
5	261	0.0921	186	0.0657
6	167	0.0589	151	0.0533
7	205	0.0724	203	0.0717
8	270	0.0953	253	0.0893
9	287	0.1013	295	0.1041
10	353	0.1246	344	0.1214
11	323	0.1140	324	0.1144
12	244	0.0861	250	0.0882
13	144	0.0508	125	0.0441
14	74	0.0261	85	0.0300
15	43	0.0152	53	0.0187
16	24	0.0085	47	0.0166
17	9	0.0032	28	0.0099
18	4	0.0014	10	0.0035
19	3	0.0011	6	0.0021
20	2	0.0007	4	0.0014
21	0	0.0000	8	0.0028
	$\mathscr{A}\!ge = 8.52$		$\mathscr{A}\!ge = 8.79$	

Figure 1. Locations of the commercial pound nets and experimental gill nets sampled in spring spawning stock assessments of striped bass in the Rappahannock River, springs 1991-2015.
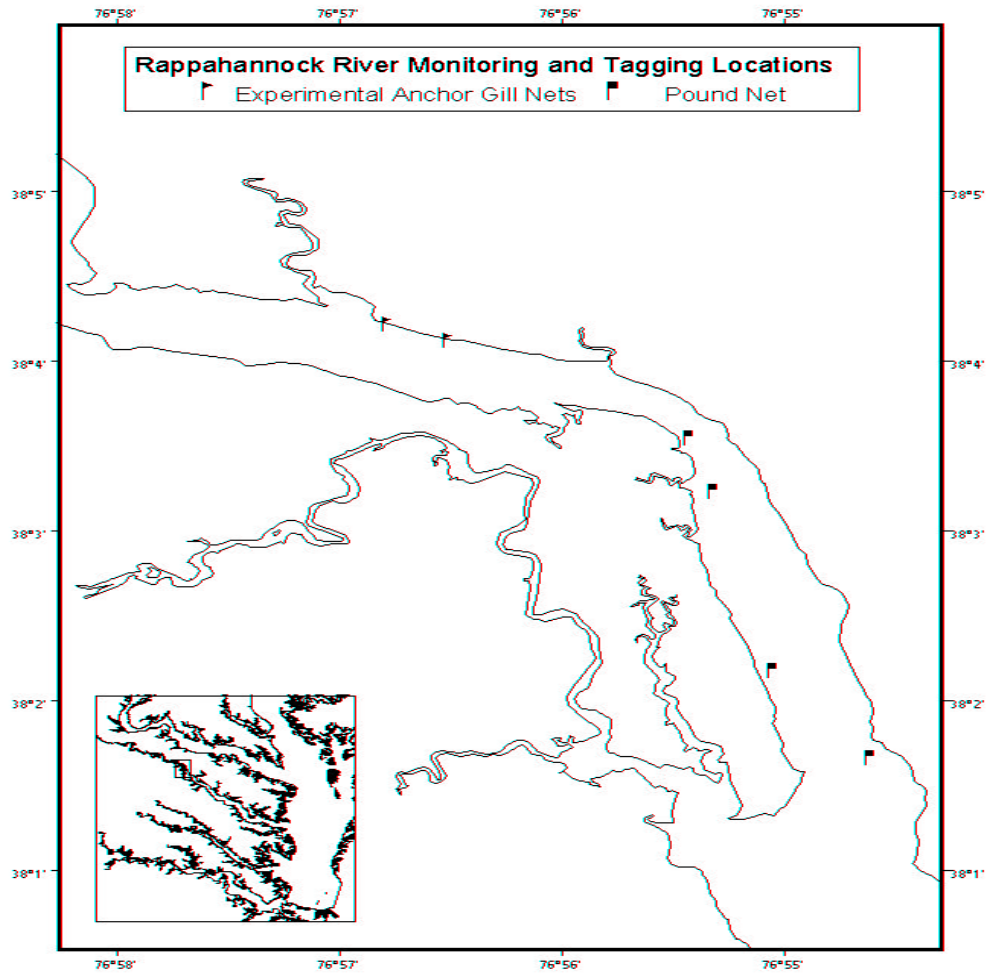
Figure 2. Daily and historic mean river flows (cf/s) for the Rappahannock River during the 30 March – 3 May spawning stock assessment period, spring 2015.
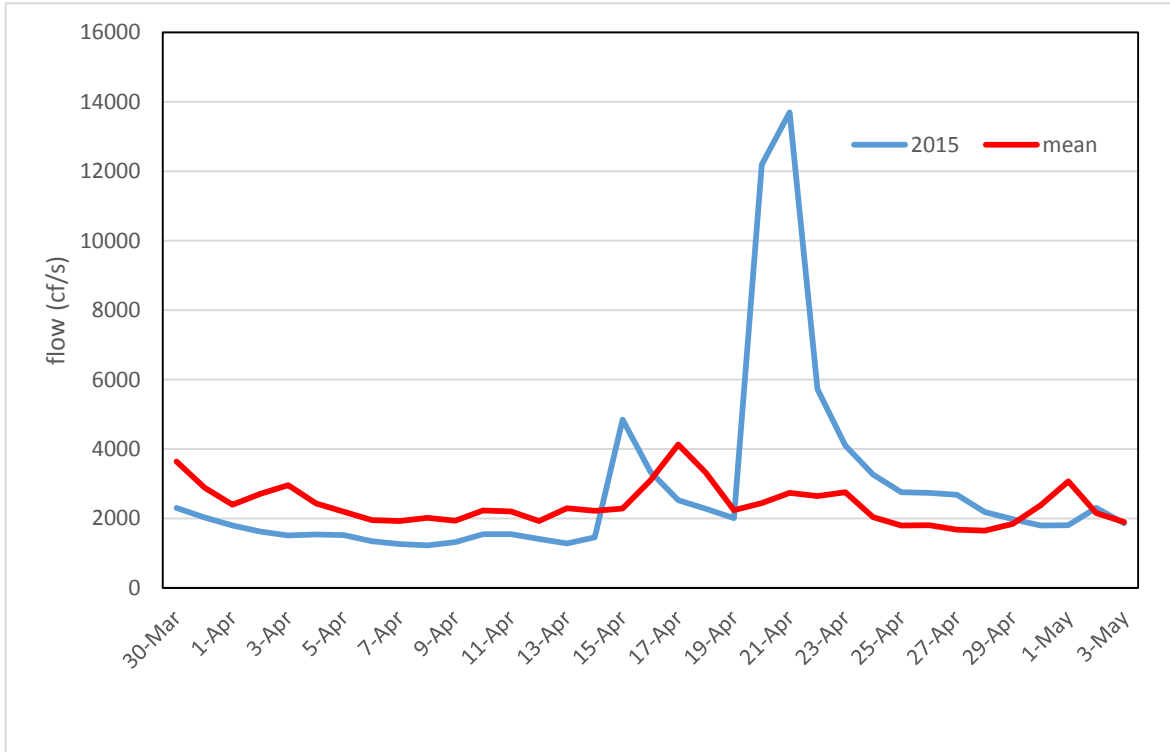
Figure 3.   Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1987 and 1988 year classes of striped bass from the Rappahannock River pound nets, springs 1991-2015.
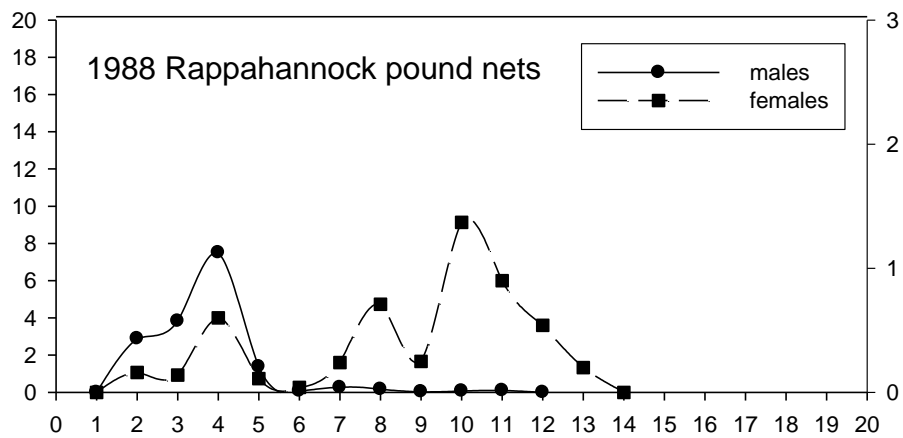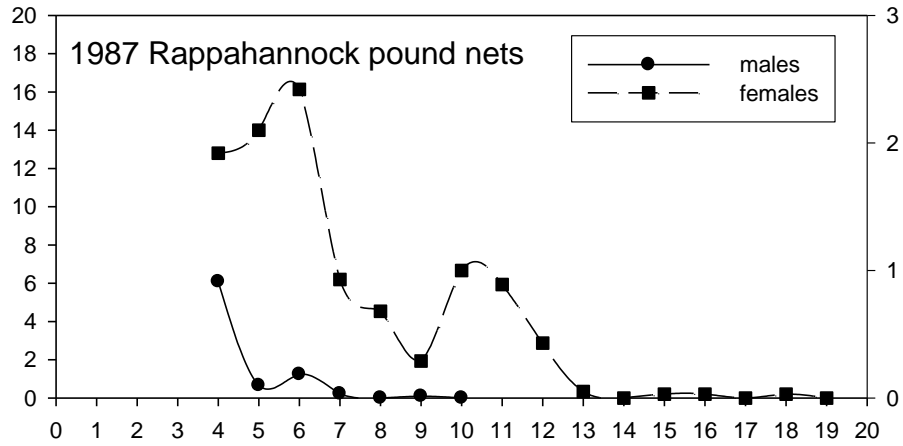
Figure 4. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1989 and 1990 year classes of striped bass from the Rappahannock River pound nets, springs 1991-2015.
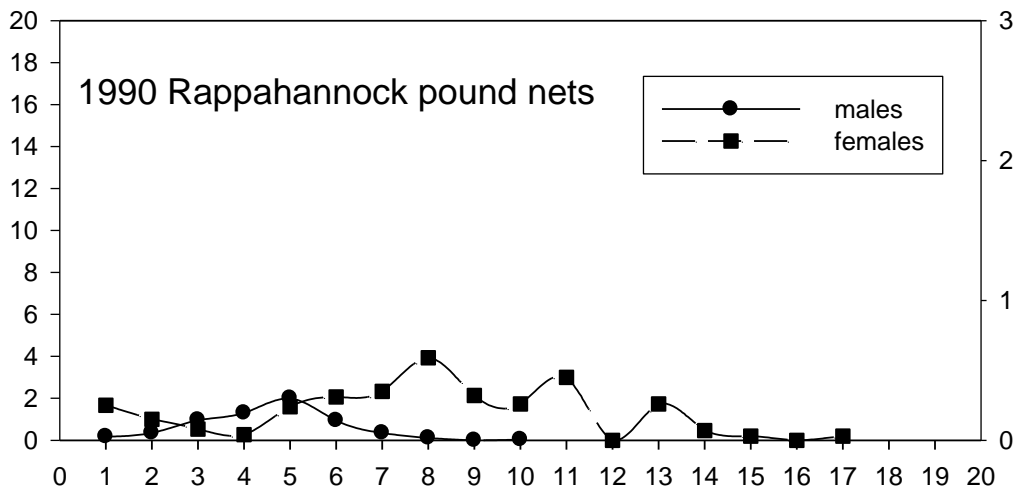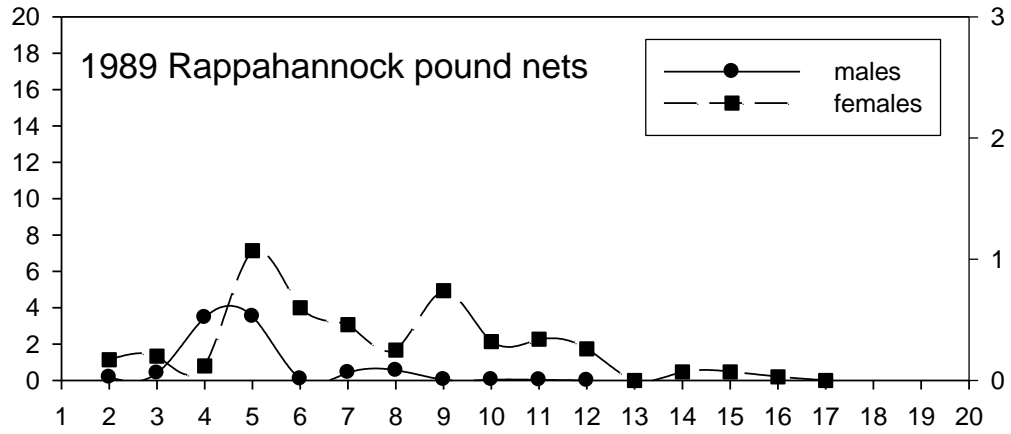
Figure 5. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1991 and 1992 year classes of striped bass from the Rappahannock River pound nets, springs 1991-2015.

1991 Rappahannock pound nets

males
females

1992 Rappahannock pound nets

males
females
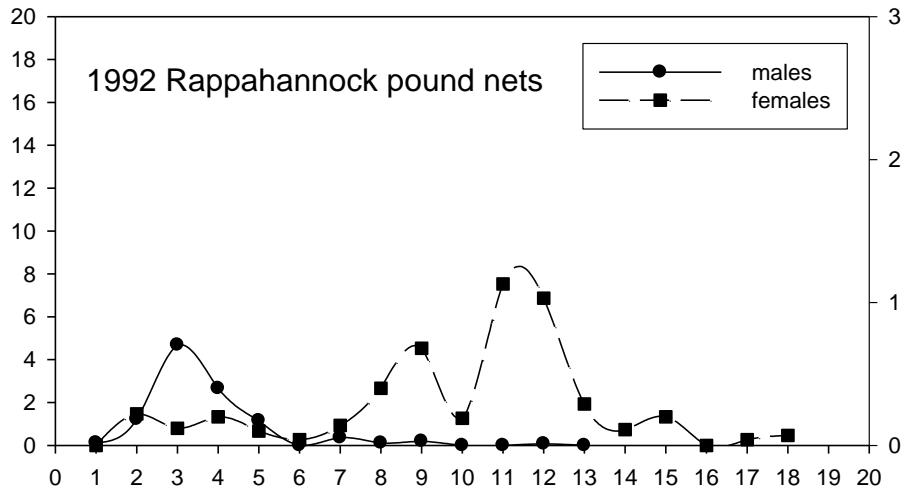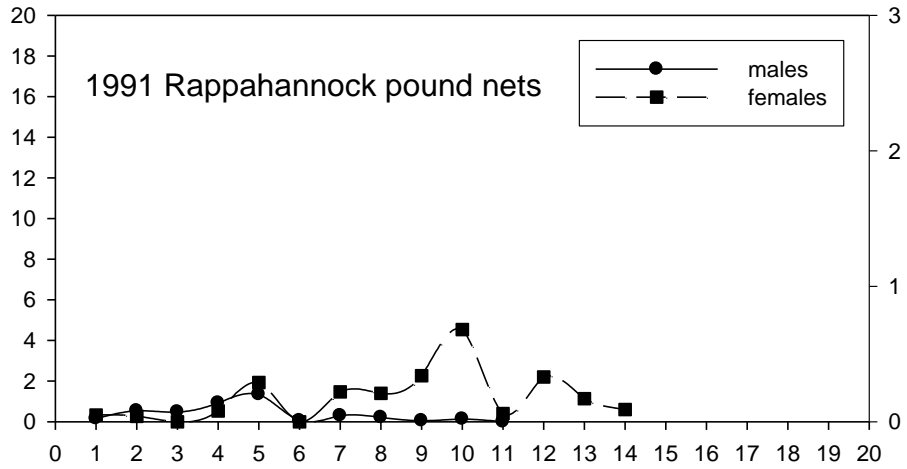
Figure 6. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1993 and 1994 year classes of striped bass from the Rappahannock River pound nets, springs 1994-2015.
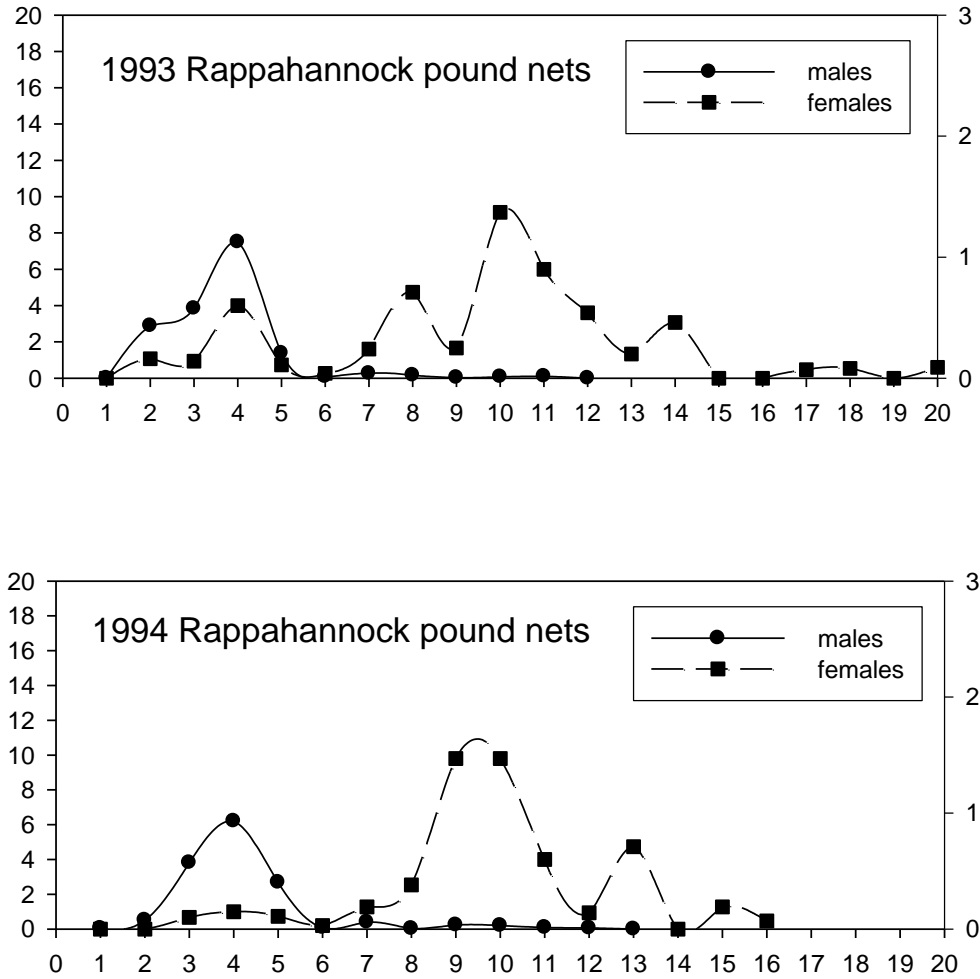
Figure 7. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1995 and 1996 year classes of striped bass from the Rappahannock River pound nets, springs 1996-2015.
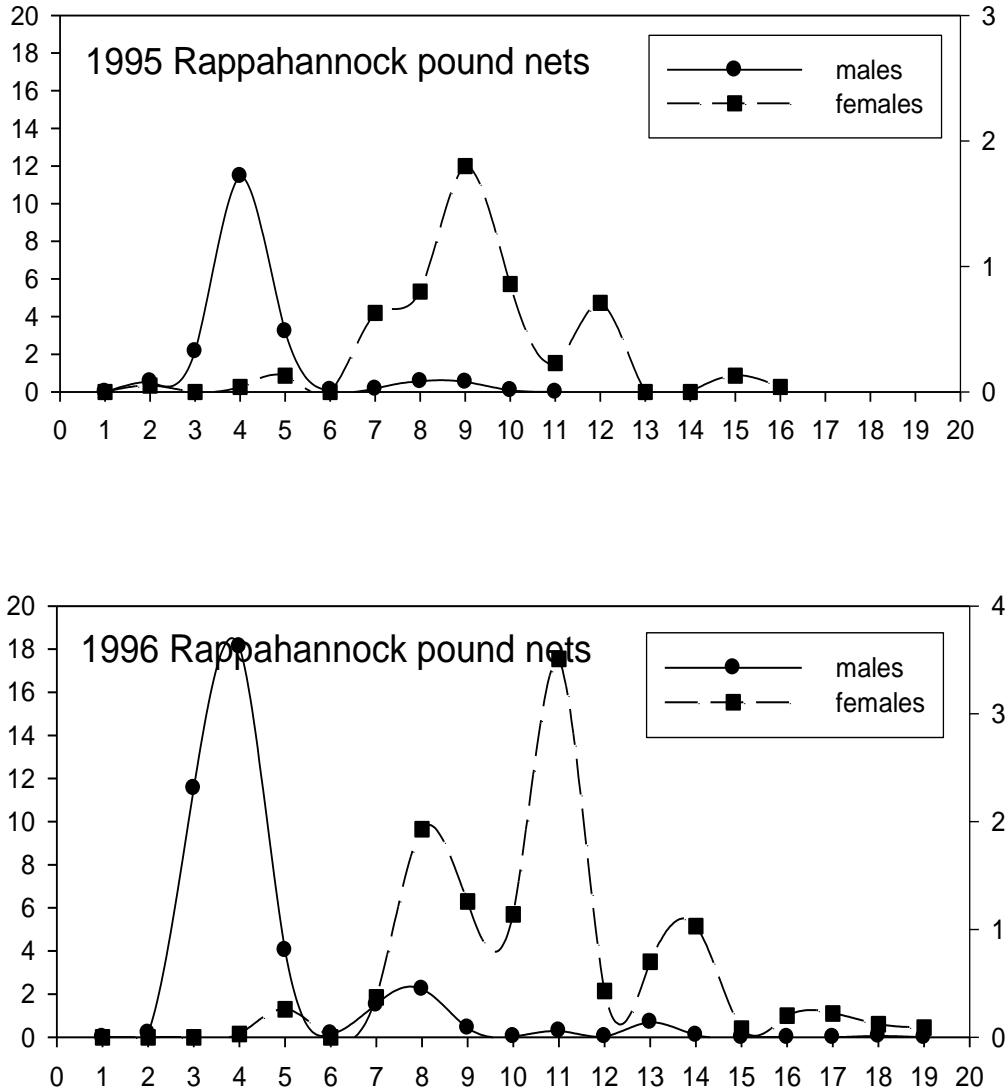
Figure 8. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1997 and 1998 year classes of striped bass from the Rappahannock River pound nets, springs 1998-2015.

1997 Rappahannock pound nets

males
females

1998 Rappahannock pound nets

males
females
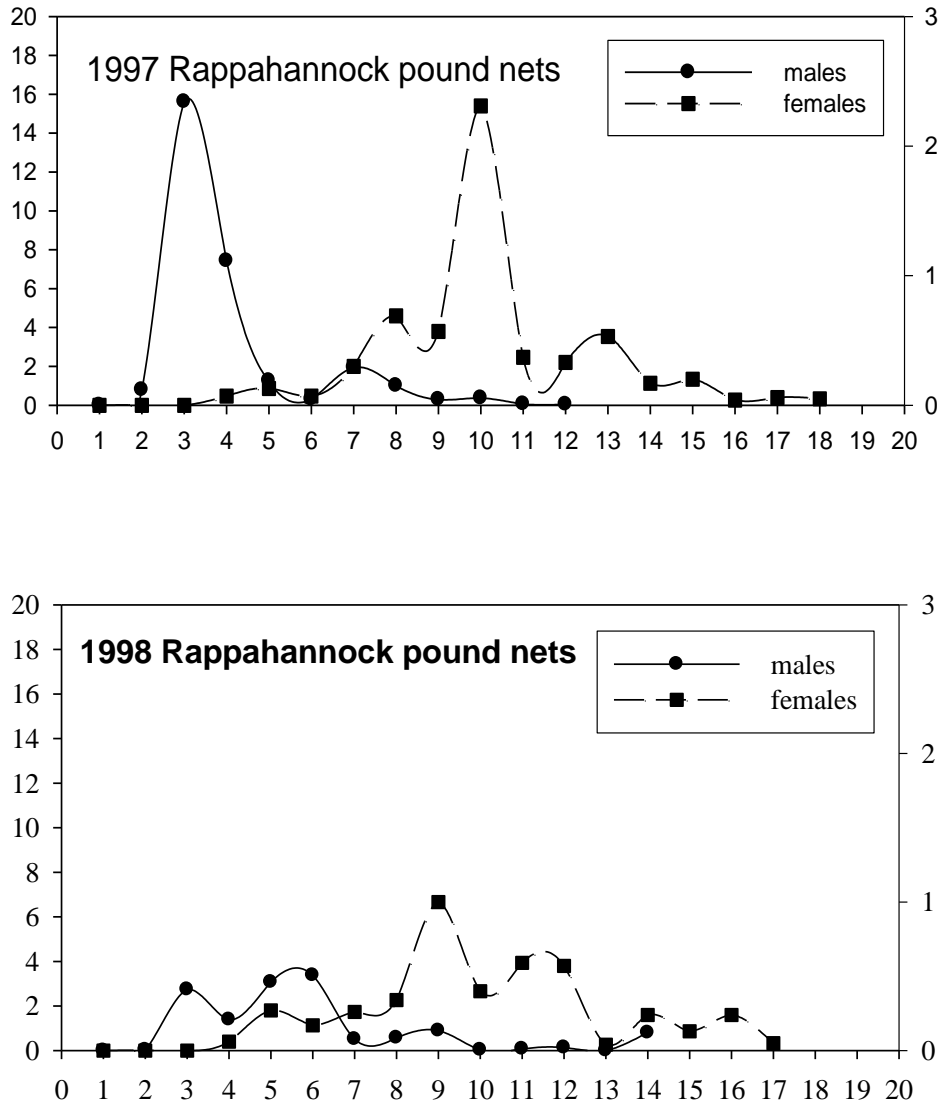
Figure 9. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 1999 and 2000 year classes of striped bass from the Rappahannock River pound nets, springs 2000-2015.
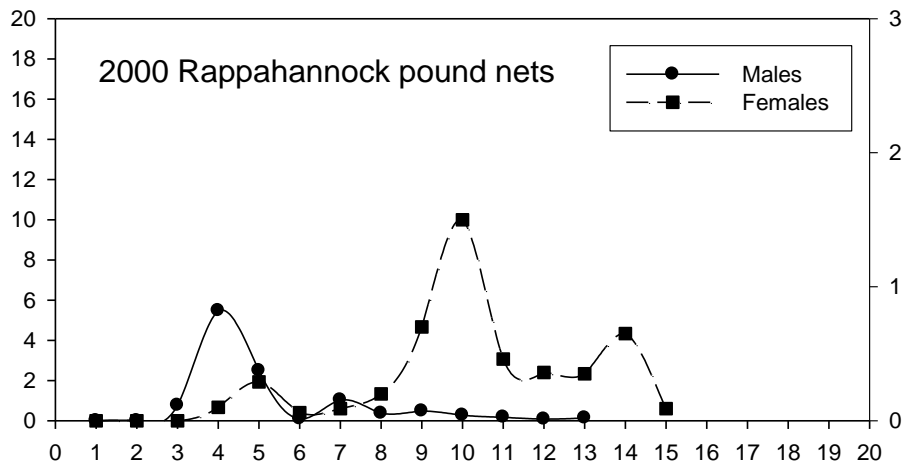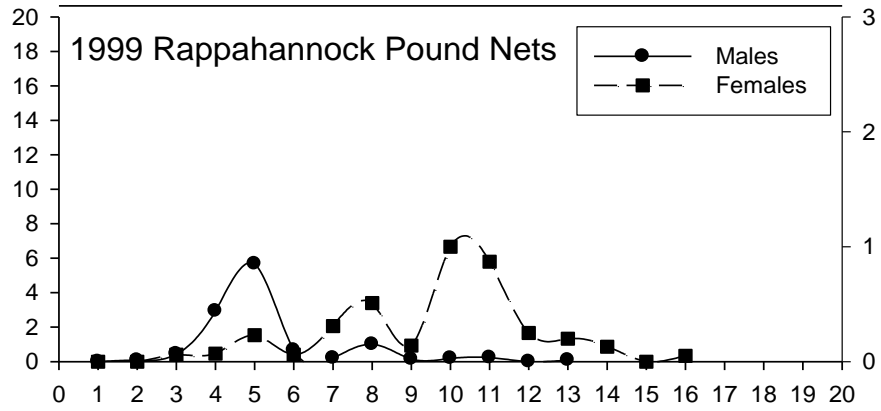
Figure 10. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 2001 and 2002 year classes of striped bass from the Rappahannock River pound nets, springs 2001-2015.
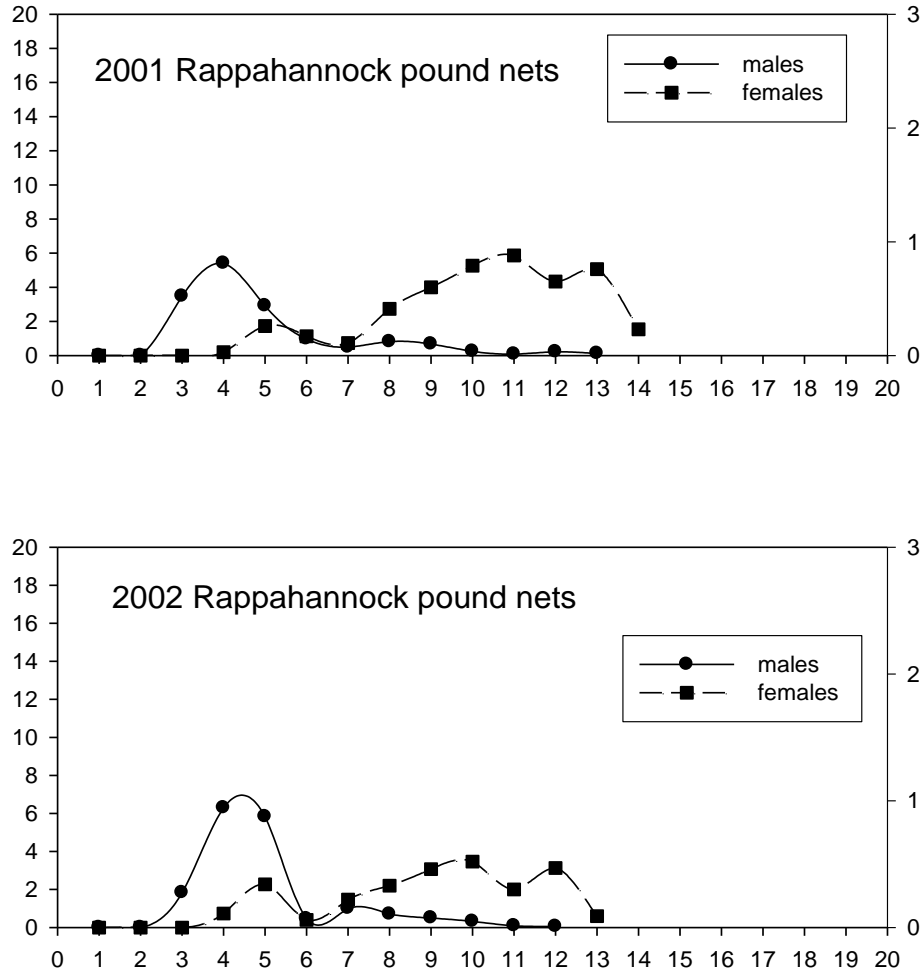
Figure 11. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 2003 and 2004 year classes of striped bass from the Rappahannock River pound nets, springs 2003-2015.
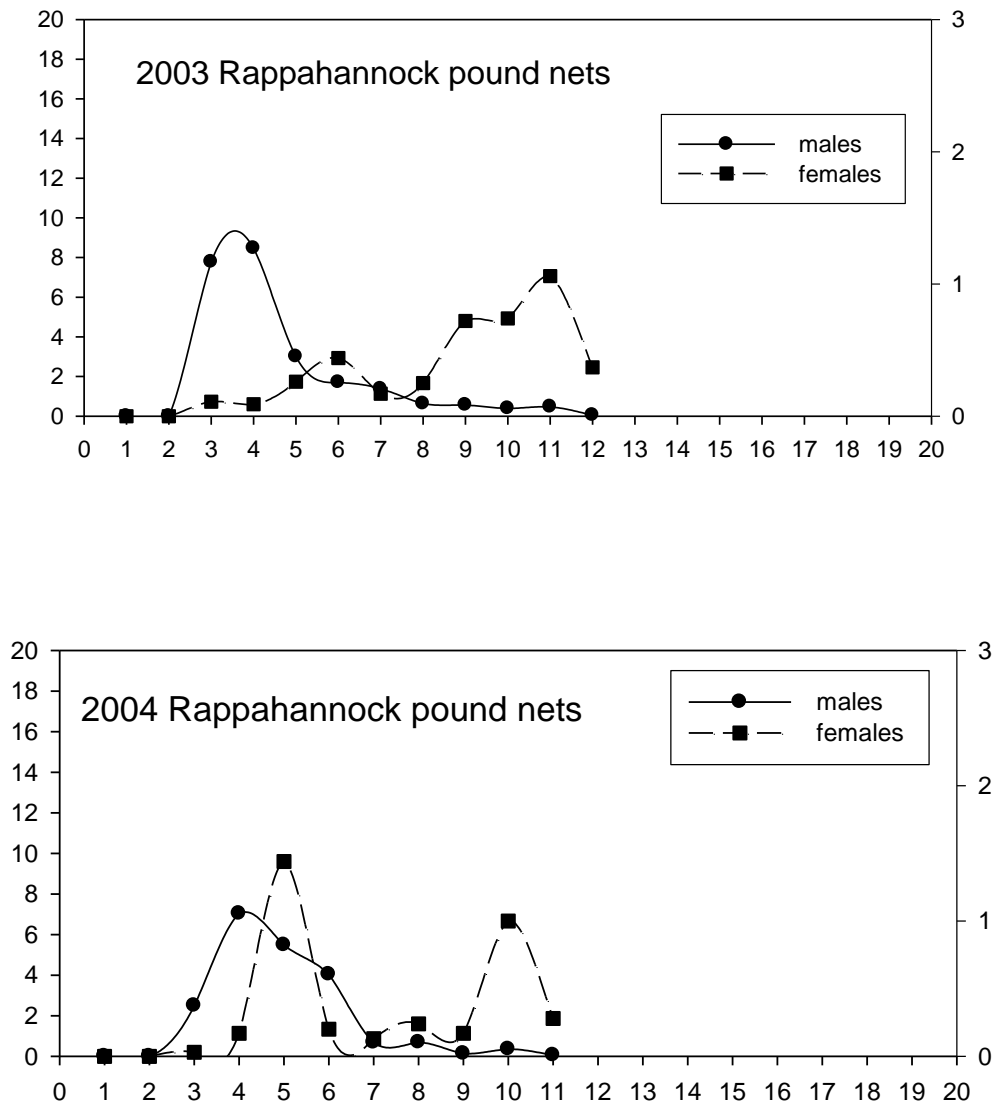
Figure 12. Age-specific catch-per-unit-effort (CPUE, fish/day) of the 2005 year class of striped bass from the Rappahannock River pound nets, springs 2003-2015.

2005 Rappahannock pound nets

males
females
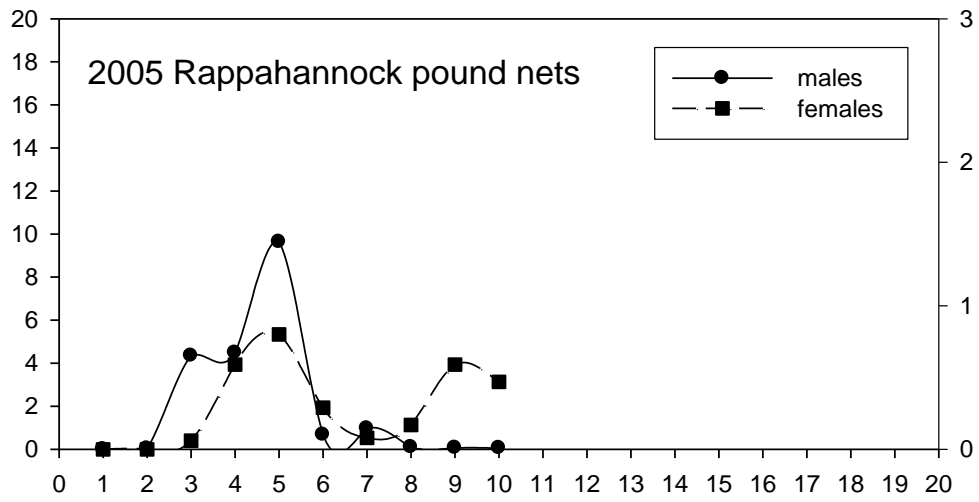
Figure 13. Comparison of otolith ages (diagonal) with their respective mean scale ages from the paired ageing methodology study, 2003-2015.
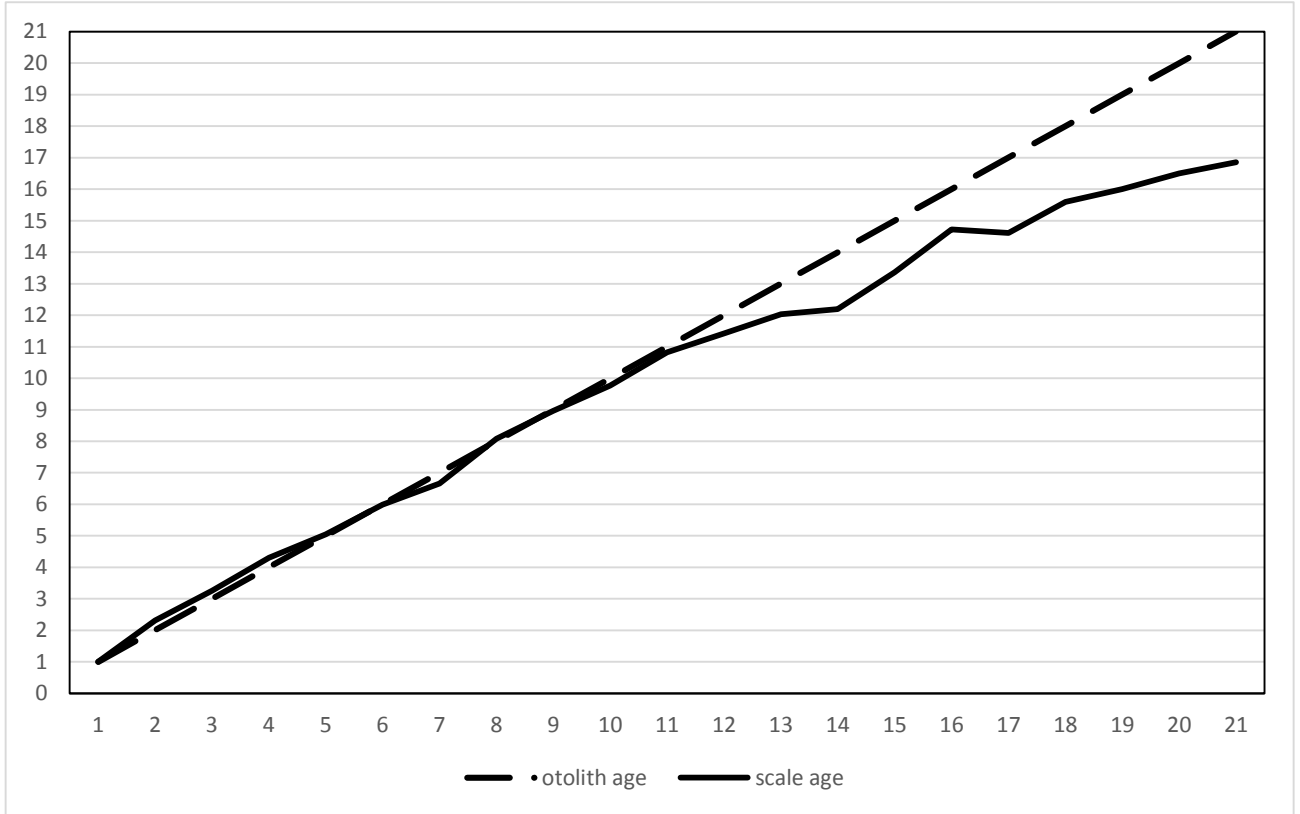
Figure 14. Magnitude of the age differences (n = 2,833) by reading both their scales and otoliths, springs, 2003-2015.
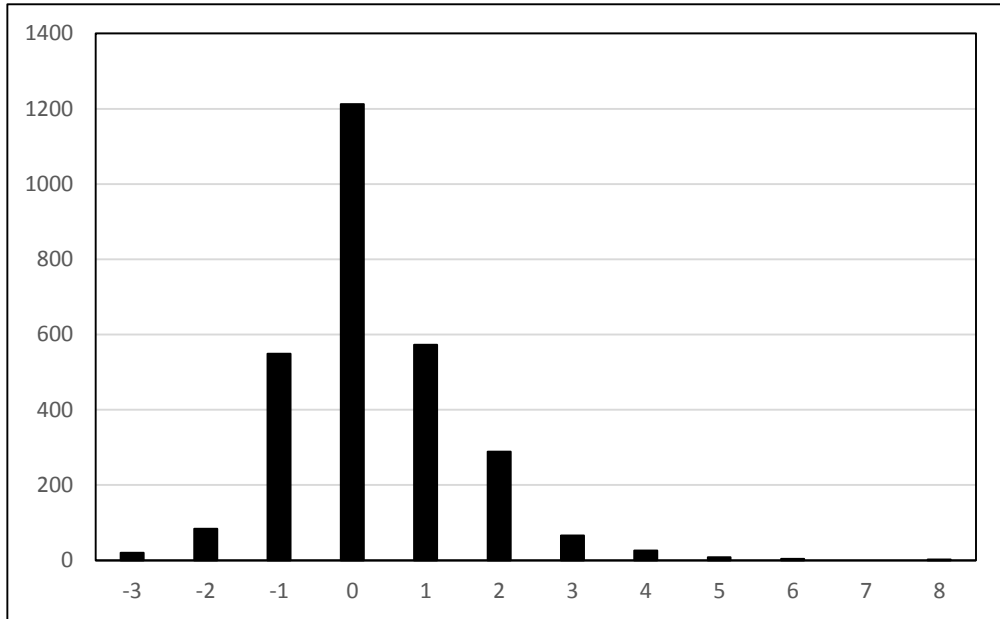
II. Mortality estimates of striped bass (*Morone saxatilis*) that spawn in the Rappahannock River, Virginia, spring, 2014-2015.

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

Introduction

Striped bass (*Morone saxatilis*) have historically supported one of the most important recreational and commercial fisheries along the Atlantic coast. The species is one of the most important economic and social components of finfish catches in the Chesapeake Bay area. From 1965 to 1972, annual commercial landings of striped bass in Virginia fluctuated from about 554 to 1,271 metric tons (MT). Recreational harvests, although not well documented, may have reached equivalent levels (Field 1997). Beginning in 1973, a dramatic decrease in catches occurred, and during the period 1978 through 1985, annual commercial landings in Virginia averaged about 162 MT. This decline in Virginia's striped bass landings was reflected in similar catch statistics from Maine to North Carolina.

Concern about the decline in striped bass landings along the Atlantic coast since the mid-1970's prompted the development of an interstate fisheries management plan (FMP) under the auspices of the Atlantic States Marine Fisheries Commission (ASMFC) as part of their Interstate Fisheries Management Program (ASMFC 1981). Federal legislation was enacted in 1984 (Public Law 98-613, The Atlantic Striped Bass Conservation Act), which enables Federal imposition of a moratorium for an indefinite period in those states that fail to comply with the coastwide plan. To be in compliance with the plan, coastal states have imposed restrictions on their commercial and recreational striped bass fisheries ranging from combinations of catch quotas, size limits, and time-limited moratoriums to year-round moratoriums. The FMP was modified three times from 1984-1985 to further restrict fishing (Weaver *et al.* 1986). The first two amendments emphasized the need to reduce fishing mortality and to set target mortality rates. The third amendment was directed specifically at Chesapeake Bay stocks and focused on ensuring success of the 1982 and later year classes by recommending that states protect 95% of those females until they had the opportunity to spawn at least once.

Due to an improvement in spawning success, as judged by increases in annual values of the Maryland juvenile index, a fourth amendment to the FMP established a limited fishery in the fall of 1990. This transitional fishery existed until 1995 when spawning stock biomass in the Chesapeake Bay reached extremely healthy levels (Field 1997). The ASMFC subsequently declared Chesapeake stocks to have reached benchmark levels and the states adopted a fifth amendment to the original FMP in order to allow expanded state fisheries.

The Striped Bass Program of the Virginia Institute of Marine Science (VIMS) has monitored the size and age composition, sex ratio and maturity schedules of the spawning striped bass stock in the Rappahannock River since 1981. In conjunction with the monitoring studies, VIMS established a tagging program in 1988 to provide information on the migration, relative contribution to the coastal population, and annual survival of striped bass that spawn in the Rappahannock River. This program is part of an active cooperative tagging study that currently involves 15 state and federal agencies along the Atlantic coast. The U.S. Fish and Wildlife Service manages the coast-wide tagging database. Hence, commercial and recreational anglers that target striped bass are encouraged to report all recovered tags to that agency. The analysis protocol, as established by the ASMFC Striped Bass Tagging Subcommittee, involves fitting a

suite of reformulated Brownie models (Brownie et al. 1985; White and Burnham 1999) to the tag return data.

Although the initial purpose of the coast-wide tagging study was to evaluate efforts to restore Atlantic striped bass stocks (Wooley *et al.* 1990), tagging data are now being collected to monitor striped bass mortality rates in a recovered fishery.

Multi-year Tagging Models

Tag return data is generally represented by constructing an upper triangular matrix of tag recoveries, where each cell of the matrix contains the number of tag returns from a particular year of tagging and recovery. For example, a study with *I* years of tagging and *J* years of recovery would yield the following data matrix

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

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

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

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

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

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

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

(4)

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

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

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

Materials and Methods

Capture and Tagging Protocol

Rappahannock River: Each year from 1991 to 2015, 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. The same panel size and mesh order were kept, however each net was constructed as two half nets of 150 feet in length. These nets were deployed between river miles 38 to 68 and fished for two to four sets of up to two hours 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 were deployed as described for the James River. These nets were deployed from river mile 28 (York River) to mile 45 (Mattaponi River).

Analysis Protocol

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

The protocol consists of six steps. First, prior to data analysis, a set of biologically reasonable candidate models is identified. Characteristics of the stock being studied (i.e., Chesapeake Bay, Hudson River, Delaware Bay, etc.) and time are used as factors in determining the parameterizations of the candidate models. These models are then fit to the tagging data (program MARK), and Akaike's Information Criterion (AIC) (Akaike 1973; Burnham and Anderson 1992), quasi-likelihood AIC (QAIC) (Akaike 1985), and goodness-of-fit (GOF) diagnostics are used to evaluate their fit (Burnham et al. 1995). The overall estimates of survival are calculated as a weighted average of survival from the best fitting models, where the weight is related to the model fit (i.e., the better the fit, the higher the weight) (Buckland et al. 1997; Burnham and Anderson 1998). For the 2012 analysis, the last regulatory period (2003-present in previous years) was redefined as two periods (2003-2006 and 2007-present) to reflect the adoption of the latest amendment to the Federal Management Plan (FMP). In 2012, the slate of candidate models were examined and non-performing models were eliminated from the analysis. The candidate models for striped bass survival (S) and tag recovery (r) rates are now:

S(t)r(t)   Survival and tag-recovery rates are time-specific.
S(p)r(t)   Survival rates vary by regulatory periods (p=constant 1990-1994, 1995-1999, 2000-2002 and 2003-2006 and 2007-2014) 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, 2007-2012, and 2013-2014).

The striped bass tagging data contain a large number of tag-recoveries reflecting catch-and-release practices (i.e., the tag of a captured fish is clipped off for the reward and the fish released back into the population). Analysis utilizing these data leads to biased survival estimates if tag recoveries for re-released fish are treated as if the fish were killed. The fifth step applies a correction term (Smith *et al.* 2000) to offset the re-release-without-tag bias assuming a tag reporting rate of 0.43 (D. Kahn, Delaware Division of Fish and Wildlife, personal communication). The sixth step converts estimates of S_i to F_i via equation (3), assuming that $Z = F + M$ and M is 0.15 (Smith *et al.* 2000).

Dunning et al. (1987) quantified the rates of tag-induced mortality and tag retention for Hudson River striped bass. They found retention of internal anchor tags placed into the body cavity via an incision midway between the vent and the posterior tip of the pelvic fin was 98% for fish kept in outdoor holding pools for 180 days. Their holding experiment revealed that the survival rates of both tagged and control fish were not significantly different over a 24-hour period. A similar study conducted on resident striped bass within the York River, Virginia, yielded survival in the presence of tagging activity and short-term tag retention rates each in excess of 98% (Sadler et al. 2001). Based on these results, the ASMFC analysis protocol specifies making no attempts to adjust for the presence of short-term tag-induced mortality or acute tag-loss.

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

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

where R_k is the number of recaptures kept with tags, R_r is the number of fish released with tags, λ is the reporting rate and M is the number of tagged striped bass released. The exploitation rate is then used to calculate the estimate of fishing mortality (F) by solving the following equation for F:

$$\mu = F / (F + M) * (1 - \exp(- M - F))$$

where natural mortality (M) is assumed to be 0.15. Other adjustments are made for tag-induced mortality (0.013) and hook-and-release mortality (0.08).

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

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

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

Instantaneous rates methods: This method (defined in the multi-year tagging methods section) allows the estimate of natural mortality to be constant, or to vary by periods. In 2012, an examination of the results using one and two-period natural mortality rates were examined. The Tagging Subcommittee decided that the results from the two-period mortality models provided the more reliable parameter estimates and the one period mortality models were excluded in the analysis protocol. The committee also concluded that the models assuming constant parameters were not realistic and were eliminated from the analysis protocol.

To determine when to separate the two periods, all possible two- period combinations were tried (1990, 1991-2008; 1990-1991, 1992-2008;…1990-2007,2008) and the minimum qAIC value used as the determinant. The resultant periods were 1990-1997, 1998-2015 for striped bass > 457 mm TL and 1990-2002, 2003-2015 for striped bass > 710 mm TL. These periods were used in the models this year, with the terminal year being 2011. The candidate models for fishing mortality (F), release mortality (F') and natural mortality (M) are:

F(t) F'(t)	Fishing and release mortalities time-specific.
F(p)F'(t)	Fishing mortality period-specific (1990-1994, 1995-1999, 2000-2002 and 2003-2006 and 2007-2014); 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, 2007-2013 and 2014).
F(v)F'(v)	Fishing and release mortalities vary over different periods (1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2012 and 2013-2014).

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

Results

Spring 2015 Tag Release summary

A total of 377 striped bass were tagged and released from the pound nets in the Rappahannock River between 17 April and 18 May, 2015 (Table 1). There were 239 resident striped bass (457-710 mm TL) tagged and released. These stripers were predominantly male (86.6%), but the female stripers were larger on average. A total of 68 striped bass were tagged and released from gill nets in the James River between 31 March and 8 May, 2015 (Table 2). There were 44 resident striped bass tagged and released. These stripers were predominantly male (79.5%), but the female stripers were larger on average. In addition, the initial season of tag releases from the York River system yielded 126 striped bass between 30 March and 6 May, 2015 (Table 3). There were 93 resident striped bass tagged and released. These were predominantly male (94.6%) 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 2015-2016 recapture interval, was 27 April.

There were 75 migrant striped bass (>710 mm TL) tagged and released in the Rappahannock River (Table 1), 14 migrant striped bass tagged and released in the James River (Table 2) and 27 migrant striped bass tagged and released in the York River (Table 3). These stripers were predominantly female (84.0% in the Rappahannock River, 78.6% in the James River and 77.8% 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 23 April. The tag release totals of striped bass greater than 457 mm TL were 20.0% lower than the release total for 2014. They were well below the release target of 700 resident striped bass and 300 migratory striped bass.

Mortality Estimates, 2014-2015

Tag recapture summary: A total of 38 striped bass (>457 mm TL) were recaptured between 1 January and 31 December, 2014. The largest source of recaptures (68.4%) was from Chesapeake Bay (42.1% in Virginia, 26.3% in Maryland, Table 4). Other recaptures came from Massachusetts (13.1%), New York (10.5%), Rhode Island (5.3%) and New Jersey (2.7%). There were no recaptures reported from Maine, New Hampshire, Connecticut, Delaware or North Carolina. The peak months for recaptures were in May through July and again in October, but there were recaptures in every month of the year except February and April.

A total of 16 migratory striped bass (>710 mm total length) were recaptured between 1 January and 31 December, 2014. The largest sources of the recaptured tagged striped bass (31.3% each) were from Chesapeake Bay (18.8% in Virginia, 12.5% in Maryland) and Massachusetts (Table 5). Other recaptures came from New York (18.8%), Rhode Island (12.5%) and New Jersey (6.3%). There were no recaptures reported from Maine, New Hampshire, Connecticut, Delaware, or North Carolina. The peak month for recaptures was in May through August, but the migrant striped bass were recaptured from March through October (except April).

ASMFC protocol: Survival estimates were made utilizing the mark-recapture data for the Rappahannock River from 1990-2013. The suite of Seber (1970) models consisted of three models that each reflected a different parameterization over time. Since Atlantic striped bass have been subjected to a variety of harvest regulations since 1990, it was hypothesized that these harvest regulations would influence survival and catch rates. Hence, models that allowed parameters to be constant for the time periods coinciding with stable coast-wide harvest regulations were also specified. Models that allowed trends within periods and Virginia-specific models for the transition from a partial to an open fishery were eliminated prior to the 2006 analyses after the ASMFC tagging subcommittee determined that they only poorly evaluated the data and carried no weight in the model averaging for multiple years. In 2012, models that specified constant parameters throughout the time series were also eliminated.

Estimates of survival using MARK

Rappahannock River releases: Sixteen striped bass (≥ 457 mm TL) tagged in spring 2014 and 19 striped bass tagged in previous springs were harvested during the 2014-15 recapture interval. These were added to complete the input matrix (Table 6) for annual estimates of survival using program MARK. Likewise, there were nine striped bass (≥ 711 mm TL) tagged in spring 2014 and seven striped bass tagged in previous springs harvested during the 2014-15 recapture interval and used to complete the input matrix (Table 7).

The suite of three models were ranked and weighted by MARK according to their QAIC values. For striped bass ≥ 457 mm TL, the time-specific model received 100.0% of the weighting (Table 8). The 2014 estimate of survival was 0.449 which became 0.459 when adjusted for release bias (Table 9). The 2014 survival estimate was higher than the 2013 estimate and much higher than the 2010 and 2012 estimates. However, these estimates are lower than the survival estimates from 2006-2009.

The ranking and weighting among the three models were almost identical for striped bass ≥ 711 mm with the time-specific model highest, but with 0.948 of the weighting while the period model received 0.432 and the vic model the remaining .009 (Table 10). The 2014 estimate of survival was 0.606 (0.617 after bias adjustment) which was also higher than the 2013 survival estimate and the highest since 2008 (Table 11).

Rappahannock and James rivers releases: Nineteen striped bass (≥ 457 mm TL) tagged in spring 2014 and 19 striped bass tagged in previous springs were harvested during the 2014-15 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 2014 and seven striped bass tagged in previous springs harvested during the 2014-15 recapture interval and used to complete the input matrix (Table 13).

The suite of three models were ranked and weighted by MARK according to their QAIC values. For striped bass ≥ 457 mm TL, the time-specific model received 100.0% of the weighting (Table 14). The 2014 estimate of survival was 0.451 which became 0.461 when adjusted for release bias (Table 15). The 2014 survival estimate was lower than the 2013 estimate and much higher than the 2010-2012 estimates.

The ranking and weighting among the three models were slightly different for striped bass ≥ 711 mm TL. The time-specific model was again highest with 0.960 of the weighting while the period model received 0.035 and the vic model received 0.006 (Table 16). The 2014 estimate of survival was 0.599 (0.609 after bias adjustment) which was also higher than the 2013 survival estimate and the highest since 2008 (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 2014 estimates for striped bass ≥ 457 mm TL were 0.78 (Z), 0.54 (A), 0.03 (U), 0.05 (F) and 0.73 (M, Table 18). The estimates of U and F have declined steadily since 2001 while the estimate of M has fluctuated, but remained well above the assumed value of 0.15 since 1996 (except 2003).

The 2014 estimates for striped bass ≥ 711 mm TL were 0.48 (Z), 0.38 (A), 0.04 (U), 0.05 (F) and 0.43 (M, Table 19). The estimates of F and U have declined since 2003, but the M estimate, while lower than the value for the smaller striped bass, has also exceeded the 0.15 value since 2009.

James 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 2014 estimates for striped bass ≥ 457 mm TL were 0.78 (Z), 0.54 (A), 0.06 (U), 0.09 (F) and 0.69 (M, Table 20). The estimates of U and F have declined steadily since 2001 while the estimate of M has fluctuated, but remained well above the assumed value of 0.15 since 1996 (except 2003).

The 2014 estimates for striped bass ≥ 711 mm TL were 0.50 (Z), 0.39 (A), 0.03 (U), 0.04 (F) and 0.45 (M, Table 21). The estimates of F and U have declined since 2003, but the M estimate, while lower than the value for the smaller striped bass, has also exceeded the 0.15 value since 2009.

Instantaneous rates model estimates of survival, fishing and natural mortality

The results of the iterative running of two natural mortality period scenarios resulted in the adoption of 1990-1997 and 1998-2013 M periods for striped bass ≥ 457 mm TL and 1990-2003 and 2004-2013 M periods for striped bass ≥ 711 mm TL.

Rappahannock River releases: Eight striped bass (≥ 457 mm TL) tagged in spring 2014 and an additional 16 tagged in previous springs were harvested during the 2014-2015 recapture interval. In addition, there were six 2014-released striped bass and three striped bass tagged in previous springs that were captured and released during the same recapture interval. These were added to their respective input matrixes (Tables 22a,b) for estimating survival and mortality parameters using the instantaneous rates model.

Likewise, there were 12 harvested (five from 2014 releases) and three released striped bass (all from 2013 releases) from striped bass ≥ 711 mm TL tagged in spring 2014 and recaptured during the 2014-2015 recapture interval and used to complete their respective instantaneous rate model input matrixes (Tables 23a, b).

The F(t) f'(5p) model received most (98.9%) of the weighting among the six models defined in the IRCR analysis (Table 24). This same model was also the top weighted model in the 2013 analysis (96.2%). The other models each contributed less than 2% to the weighting. The resultant parameter estimates for 2014 are 0.510 (survival, Table 25), 0.626 (natural mortality) and 0.044 (fishing mortality). There is a notable decline in the estimates of fishing mortality from 2003-2014 while the estimate for natural mortality continues to increase and greatly exceeds the generally assumed value of 0.15 throughout the time series

In contrast, the Vic period model received the heaviest weighting (95.7%) for the IRCR analysis for striped bass ≥ 711 mm TL with the F(t) f'(5p) model (2.9%) also influencing the estimates (Table 26). The order and relative weightings of the models were almost unchanged from the 2011-2013 results. The 2014 IRCR estimate of survival was 0.593 (Table 27). The 2014 estimate of natural mortality was 0.478 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 since 2000.

James and Rappahannock rivers releases: Eight striped bass (≥ 457 mm TL) tagged in spring 2014 and an additional 16 tagged in previous springs were harvested during the 2014-2015 recapture interval. In addition, there were eight 2014-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 twelve harvested (five from 2014 releases) and three released striped bass (from 2014 releases) from striped bass ≥ 711 mm TL tagged in spring 2014 and recaptured

during the 2014-2015 recapture interval and used to complete their respective instantaneous rate model input matrixes (Tables 29a, b).

The F(t) f'(5p) model received most (98.5%) of the weighting among the six models defined in the IRCR analysis (Table 30). This same model was also the top weighted model in the 2014 analysis (96.2%). The other models each contributed less than 1% to the weighting. The resultant parameter estimates for 2014 are 0.513 (survival, Table 31), 0.625 (natural mortality) and 0.040 (fishing mortality). There is a notable decline in the estimates of fishing mortality from 2003-2014 while the estimate for natural mortality continues to increase and greatly exceeds the generally assumed value of 0.15 throughout the time series

The Vic period model received the heaviest weighting (96.3%) for the IRCR analysis for striped bass ≥ 711 mm TL with the five period model (2.7%) also influencing the estimates (Table 32). The order and relative weightings of the models were only slightly different from the 2011- 2013 results (the Des models were of secondary importance). The 2014 IRCR estimate of survival was 0.595 (Table 33). The 2014 estimate of natural mortality was 0.476 while the estimate of fishing mortality was 0.042. Consistent with the estimates of natural mortality for the ≥ 457 mm TL striped bass, the estimates of natural mortality for the migrant striped bass have increased with time and have generally been consistently higher than the assumed value of 0.15 since 2000.

Model Evaluations

Latour et al. (2001b) proposed a series of diagnostics that can be used in conjunction with AIC and GOF measures to assess the performance of tag-recovery models. In essence, they suggested that the fit of a model could be critically evaluated by analyzing model residuals and that patterns would be evident if particular assumptions were violated.

For the time-specific Seber (1970) model, Latour et al. (2002) proved the existence of several characteristics about the residuals. Specifically, they showed that row and column sums of the residuals matrix must total zero, and further, they showed that the residuals associated with the "never seen again" category must also always be zero unless parameter estimates fall on a boundary condition. Latour et al. (2001c) also scrutinized the residuals associated with the instantaneous rates model and found the residual matrix of this model possessed fewer constraints than the time-specific Seber model. Although the row sums category must total zero, the column sums and the associated residuals can assume any value.

ASMFC protocol: Given that management regulations applied to striped bass during the 1990s 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 and 2014. Unfortunately, numerical complications resulting from low sample size may have caused some of the more biologically reasonable models to not fit the Rappahannock River data well.

Discussion

In spring 2014, the release total for striped bass tagged in the Rappahannock was lower than the release total for spring 2013 and well below the target for striped bass. Persistent poor weather, including snow and ice in March and windy conditions in early April 2014 resulted in reduced gear availability for the year. The recapture rate of Rappahannock River released stripers was 0.079 (36/454) which was slightly higher than for 2014 and above the overall recapture rate of 0.066. However, the recapture rate for all 2014 releases was 0.062 (38/614) which was lower than the rate for 2013 releases and below the overall mean recapture rate of 0.066. It will be important to document any differences in long term recapture rates as James River releases are added to the ones from the Rappahannock River. It should be noted that recapture rates have generally declined over time. The mean recapture rate for 1990-2003 was 0.076 (range 0.056-0.111) but is 0.052 for 2004-2013 (range 0.023-0.074). Thus, the aberrant recapture rate for the 2010 releases (0.023) has greatly influenced recent estimates of survival and other parameters.

The program MARK survival estimates for 2014 were 0.449 for striped bass greater than 18 inches (457 mm) total length tagged in the Rappahannock River and 0.451 from combined James and Rappahannock releases. The survival estimates were 0.606 for striped bass greater than 28 inches (711 mm) total length (migratory) released in the Rappahannock River and 0.599 from the James and Rappahannock River combined releases. Interestingly, the revised 2013 estimate of 0.426 was lower than the 2014 estimate for Rappahannock River releases, but the revised 2013 estimate (0.485) was higher than the 2014 estimate for the combined James and Rappahannock River releases. However, the result of this year's analysis was not enough to reverse much lower survival estimates for the period after 2009. The 2014 survival estimates for striped bass greater than 28 inches were much greater than the revised 2013 estimates for both analyses and is the highest reported since 2008.

Again in 2014, the resultant MARK estimates of fishing mortality were well above the 0.27 limit endorsed by the ASMFC for all striped bass greater than 18 inches total length. However, these estimates are considered suspect as they result in estimates both below zero and above one for multiple years and have been excluded in ASMFC stock analyses. The MARK analysis for striped bass greater than 28 inches total length had produced rational results and had been used. The estimates of fishing mortality for these striped bass have been within ASMFC requirements.

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 2014 estimates of fishing mortality of 0.04-0.09 for the two size classifications of striped bass, well below the ASMFC threshold. It also

produced estimates of natural mortality above 0.15 and even in both size groups and above 0.30 for the greater than 18" cohort.

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

A number of studies in recent years have indicated a development of mycobacteriosis, a bacterial disease in Chesapeake Bay striped bass beginning around 1997 (Vogelbein et al 1999). The disease is believed to have spread significantly thereafter. It has been suggested that mycobacteriosis might lead to an increase in striped bass mortality (Jiang et al 2007, Gauthier et al 2008 and Hoenig et al 2009). Kahn and Crecco (2006) analyzed MD and VA spring tagging data for two groups of fish (fish $\geq$ 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 2015.

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	$\overline{TL}$
17 Apr	19	1	401.0	7	517.7	0		0		11	988.2
20 Apr	25	6	438.2	11	515.3	0		1	725.0	7	995.0
23 Apr	23	2	426.5	9	520.8	1	587.0	2	819.0	9	963.3
27 Apr	84	15	435.6	52	507.6	5	585.4	3	897.0	9	953.9
30 Apr	54	5	432.4	34	490.7	3	530.3	1	842.0	11	957.1
4 May	59	11	439.6	29	502.1	6	548.8	3	816.7	10	888.9
7 May	42	11	431.4	22	519.3	4	605.3	1	1,028.0	4	958.0
11 May	51	11	442.4	32	515.3	5	594.4	1	800.0	2	817.0
18 May	20	2	437.5	11	525.2	8	523.6	0		0	
total	377	64	436.4	207	508.7	32	561.9	12	847.8	63	953.7

Table 2. Summary data of striped bass tagged and released from gill nets in the James River, spring 2015.

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	$\overline{TL}$
31 Mar	4	2	310.5	1	507.0	0		0		1	1,084.0
2 Apr	6	1	294.0	4	594.8	0		0		1	1.147.0
7 Apr	18	3	365.7	11	563.7	1	587.0	3	788.9	0	
9 Apr	15	1	320.0	13	559.5	0		0		1	1,012.0
14 Apr	6	0		4	517.0	1	676.0	0		1	1.012.0
16 Apr	3	1	448.0	0		2	620.0	0		0	
21 Apr	10	1	314.0	0		5	613.2	0		4	1,131.3
24 Apr	5	1	442.0	1	642.0	0		0		3	984.7
28 Apr	1	0		1	533.0	0		0		0	
1 May	0	0		0		0		0		0	
5 May	0	0		0		0		0		0	
8 May	0	0		0		0		0		0	
total	68	10	353.6	35	557.7	9	618.8	3	788.9	11	1,066.7

Table 3. Summary data of striped bass tagged and released from gill nets in the York and Mattaponi rivers, spring 2015.

Date	n	<457 mm		457-710 mm TL				> 710 mm TL			
				Males		Females		Males		Females	
	n	n	$\overline{TL}$	n	$\overline{TL}$	n	$\overline{TL}$	n	$\overline{TL}$	n	$\overline{TL}$
30 Mar	2	0		0		0		0		2	976.5
1 Apr	6	2	439.0	4	526.5	0		0		0	
6 Apr	28	1	354.0	22	580.6	2	536.5	2	797.5	1	987.0
8 Apr	52	3	434.0	47	523.6	0		0		2	964.0
13 Apr	16	0		9	611.2	0		1	1,006.0	6	993.7
15 Apr	10	0		2	527.5	3	618.0	1	880.0	4	943.8
22 Apr	8	0		4	654.8	0		2	945.5	2	968.0
27 Apr	4	0		0		0		0		4	978.5
29 Apr	0	0		0		0		0		0	
6 May	0	0		0		0		0		0	
total	126	6	422.3	88	553.0	5	585.4	6	895.3	21	974.0

Table 4. Location of striped bass (≥ 457 mm TL), recaptured in 2014, that were originally tagged and released in the Rappahannock River during springs 1990-2014.

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	2	1	1	1	0	0	0	5
Rhode Island	0	0	0	0	0	0	1	1	0	0	0	0	2
Connecticut	0	0	0	0	0	0	0	0	0	0	0	0	0
New York	0	0	0	0	1	2	0	1	0	0	0	0	4
New Jersey	0	0	0	0	1	0	0	0	0	0	0	0	1
Delaware	0	0	0	0	0	0	0	0	0	0	0	0	0
Maryland	1	0	1	0	2	3	2	0	0	1	0	0	10
Virginia	0	0	2	0	2	1	2	1	0	5	1	2	16
North Carolina	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1	0	3	0	6	8	6	4	1	6	1	2	38

Table 5. Location of striped bass (≥ 711 mm TL), recaptured in 2014, that were originally tagged and released in the Rappahannock River during springs 1990-2014.

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	2	1	1	1	0	0	0	5
Rhode Island	0	0	0	0	0	0	1	1	0	0	0	0	2
Connecticut	0	0	0	0	0	0	0	0	0	0	0	0	0
New York	0	0	0	0	0	2	0	1	0	0	0	0	3
New Jersey	0	0	0	0	1	0	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	0	1	1	0	0	0	0	0	0	2
Virginia	0	0	1	0	1	0	0	0	0	1	0	0	3
North Carolina	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	1	0	3	5	2	3	1	1	0	0	16

Table 6. Input recapture matrix for program MARK: from striped bass (>457 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2014.

No.N	Year	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14
1,464	1990	162	64	47	25	12	10	3	2	3	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
2,481	1991		167	81	53	29	6	5	2	2	4	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
130	1992			14	8	6	5	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
621	1993				50	37	17	8	9	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
195	1994					13	10	5	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
698	1995						55	30	20	5	4	2	3	0	1	0	1	0	0	0	0	0	0	0	0	0
376	1996							21	18	7	3	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0
712	1997								47	26	14	3	0	1	2	1	0	0	0	0	0	0	0	0	0	0
784	1998									55	26	2	3	3	1	0	0	0	0	0	0	0	0	0	0	0
853	1999										66	23	9	5	3	0	0	0	0	0	0	1	0	0	0	0
1,765	2000											122	51	23	16	6	5	1	1	0	0	0	0	0	0	0
797	2001												61	23	16	7	2	2	2	0	0	0	0	0	0	0
315	2002													20	8	15	1	1	2	1	0	0	0	0	0	0
852	2003														58	37	9	4	5	3	2	3	0	0	0	0
1,477	2004															80	21	13	7	4	2	1	0	0	0	0
921	2005																44	26	10	2	5	4	0	0	0	0
668	2006																	49	11	6	6	3	4	0	0	0
1,961	2007																		117	50	24	4	6	1	1	2
523	2008																			30	9	2	0	0	2	1
867	2009																				43	10	3	2	0	1
2050	2010																					47	9	8	2	1
416	2011																						24	4	1	0
1,222	2012																							57	14	5
760	2013																								36	9
454	2014																									16

Table 7.　Input recapture matrix for program MARK: from striped bass (>710 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2014.

No.	Year	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14
301	1990	26	9	15	2	4	6	1	0	2	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
390	1991		41	24	16	11	3	2	2	1	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
40	1992			4	3	2	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
212	1993				22	18	7	4	7	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
123	1994					9	7	5	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
210	1995						29	11	8	3	3	2	3	0	1	0	1	0	0	0	0	0	0	0	0	0
67	1996							1	3	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
212	1997								15	13	8	3	0	1	2	1	0	0	0	0	0	0	0	0	0	0
158	1998									24	13	2	3	2	0	0	0	0	0	0	0	0	0	0	0	0
162	1999										17	6	2	3	2	0	0	0	0	0	1	0	0	0	0	0
365	2000											28	19	14	9	4	3	0	1	0	0	0	0	0	0	0
269	2001												19	14	4	6	2	1	1	0	0	0	0	0	0	0
122	2002													10	6	7	1	0	2	1	0	0	0	0	0	0
400	2003														35	24	7	1	3	3	2	3	0	0	0	0
686	2004															39	12	13	5	4	2	1	0	0	0	0
284	2005																16	11	8	1	4	3	0	0	0	0
175	2006																	13	4	4	3	1	4	0	0	0
840	2007																		55	30	18	3	5	1	1	1
75	2008																			6	2	0	0	0	0	1
241	2009																				7	5	1	1	0	1
483	2010																					17	6	4	2	0
190	2011																						12	2	0	0
325	2012																							12	4	1
243	2013																								10	3
247	2014																									9

Release — Recapture year

86

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 and 2007-2014 (p); parameters vary in 2013-2014 (v), otherwise the same as p; and parameters are time-specific (t).

Model	$QAIC_c$	$\Delta QAIC_c$	$QAIC_c$ weight	number of parameters
S(t)r(t)	15,693.78	0.00	1.00000	49
S(p)r(t)	15,743.31	49.53	0.00000	30
S(v)r(p)	15,774.33	80.55	0.00000	11

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, 1990-2014.

Year	$\hat{S}$	SE ($\hat{S}$)	P_l	Bias	$\hat{S}_{adj}$	$\hat{F}$	95% CI $\hat{F}$	
1990	0.816	0.087	0.481	-0.143	0.952	-0.101	-0.23,	0.23
1991	0.276	0.051	0.524	-0.082	0.301	1.051	0.71,	1.44
1992	0.805	0.165	0.408	-0.142	0.938	-0.086	-0.27,	0.76
1993	0.604	0.131	0.456	-0.105	0.675	0.243	-0.06,	0.81
1994	0.568	0.127	0.381	-0.087	0.623	0.324	0.00,	0.89
1995	0.684	0.136	0.262	-0.054	0.723	0.174	-0.08,	0.74
1996	0.639	0.133	0.274	-0.040	0.666	0.257	-0.02,	0.82
1997	0.567	0.107	0.330	-0.057	0.601	0.359	0.07,	0.82
1998	0.409	0.078	0.362	-0.059	0.435	0.682	0.21,	0.95
1999	0.374	0.065	0.286	-0.059	0.398	0.772	0.32,	1.00
2000	0.428	0.064	0.436	-0.074	0.463	0.621	0.21,	0.80
2001	0.463	0.097	0.367	-0.068	0.497	0.549	0.06,	0.88
2002	0.607	0.126	0.368	-0.063	0.648	0.284	-0.16,	0.67
2003	0.842	0.140	0.271	-0.049	0.885	-0.028	-0.33,	0.55
2004	0.346	0.065	0.281	-0.038	0.359	0.874	0.40,	1.12
2005	0.458	0.089	0.274	-0.031	0.473	0.599	0.13,	0.89
2006	0.532	0.096	0.354	-0.057	0.564	0.422	-0.01,	0.70
2007	0.578	0.120	0.303	-0.043	0.605	0.353	-0.10,	0.73
2008	0.573	0.145	0.208	-0.024	0.587	0.382	-0.11,	0.89
2009	0.748	0.187	0.231	-0.025	0.767	0.116	-0.28,	0.90
2010	0.171	0.052	0.267	-0.013	0.173	1.604	0.90,	2.08
2011	0.405	0.129	0.152	-0.017	0.412	0.737	0.10,	1.34
2012	0.309	0.090	0.264	-0.029	0.318	0.995	0.35,	1.48
2013	0.426	0.180	0.161	-0.018	0.433	0.686	-0.04,	1.59
2014	0.449	0.025	0.257	-0.022	0.459	0.629	0.33,	0.59

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 and 2007-2014 (p); otherwise the same as p; parameters vary in 2013 and 2014 (v), otherwise the same as p; and parameters are time-specific (t).

Model	QAIC$_c$	Δ QAIC$_c$	QAIC$_c$ weight	number of parameters
S(t)r(t)	8,512.88	0.00	0.94788	49
S(p)r(t)	8,519.06	6.18	0.04316	30
S(v)r(p)	8,522.20	9.32	0.00896	11

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, 1990-2014.

Year	$\hat{S}$	SE ($\hat{S}$)	P_l	Bias	$\hat{S}_{adj}$	$\hat{F}$	95% CI	
1990	0.532	0.089	0.577	-0.127	0.611	0.343	0.08,	0.74
1991	0.579	0.151	0.560	-0.131	0.666	0.256	-0.09,	0.95
1992	0.648	0.175	0.535	-0.172	0.783	0.094	-0.22,	0.89
1993	0.889	0.064	0.349	-0.093	0.979	-0.129	-0.21,	0.12
1994	0.439	0.085	0.318	-0.070	0.472	0.600	0.28,	1.03
1995	0.861	0.066	0.204	-0.079	0.935	-0.083	-0.18,	0.16
1996	0.542	0.111	0.125	-0.016	0.551	0.446	0.14,	0.96
1997	0.451	0.096	0.167	-0.036	0.468	0.609	0.26,	1.09
1998	0.776	0.181	0.217	-0.084	0.847	0.016	0.23,	1.14
1999	0.430	0.101	0.200	-0.058	0.457	0.634	0.26,	1.17
2000	0.770	0.143	0.349	-0.072	0.830	0.037	-0.16,	0.68
2001	0.493	0.115	0.298	-0.052	0.521	0.503	0.15,	1.06
2002	0.660	0.135	0.295	-0.078	0.716	0.184	-0.07,	0.77
2003	0.897	0.071	0.246	-0.059	0.953	-0.102	-0.32,	0.07
2004	0.361	0.085	0.321	-0.045	0.378	0.824	0.28,	1.20
2005	0.575	0.132	0.238	-0.035	0.596	0.368	-0.10,	0.81
2006	0.737	0.156	0.282	-0.048	0.774	0.106	-0.27,	0.66
2007	0.648	0.147	0.228	-0.036	0.673	0.247	-0.19,	0.74
2008	0.927	0.086	0.163	-0.023	0.949	-0.098	-0.31,	0.34
2009	0.500	0.148	0.105	-0.009	0.504	0.535	-0.03,	1.13
2010	0.378	0.133	0.235	-0.019	0.386	0.802	0.12,	1.47
2011	0.475	0.193	0.071	-0.009	0.479	0.586	-0.09,	1.49
2012	0.358	0.157	0.150	-0.013	0.363	0.863	0.08,	1.75
2013	0.437	0.229	0.059	-0.006	0.440	0.671	-0.12,	1.89
2014	0.606	0.081	0.188	-0.017	0.617	0.334	-0.03,	0.50

Table 12. Input recapture matrix for program MARK: from striped bass (>457 mm TL) that were tagged and released in the James and Rappahannock rivers, springs 1990-2014.

Release		Recapture year																								
No.N	Year	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14
1,464	1990	162	64	47	25	12	10	3	2	3	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
2,481	1991		167	81	53	29	6	5	2	2	4	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
130	1992			14	8	6	5	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
621	1993				50	37	17	8	9	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
195	1994					13	10	5	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
698	1995						55	30	20	5	4	2	3	0	1	0	1	0	0	0	0	0	0	0	0	0
376	1996							21	18	7	3	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0
712	1997								47	26	14	3	0	1	2	1	0	0	0	0	0	0	0	0	0	0
784	1998									55	26	2	3	3	1	0	0	0	0	0	0	0	0	0	0	0
853	1999										66	23	9	5	3	0	0	0	0	0	0	1	0	0	0	0
1,765	2000											122	51	23	16	6	5	1	1	0	0	0	0	0	0	0
797	2001												61	23	16	7	2	2	2	0	0	0	0	0	0	0
315	2002													20	8	15	1	1	2	1	0	0	0	0	0	0
852	2003														58	37	9	4	5	3	2	3	0	0	0	0
1,477	2004															80	21	13	7	4	2	1	0	0	0	0
921	2005																44	26	10	2	5	4	0	0	0	0
668	2006																	49	11	6	6	3	4	0	0	0
1,961	2007																		117	50	24	4	6	1	1	2
523	2008																			30	9	2	0	0	2	1
867	2009																				43	10	3	2	0	1
2050	2010																					47	9	8	2	1
416	2011																						24	4	1	0
1,222	2012																							57	14	5
760	2013																								36	9
614	2014																									19

Table 13. Input recapture matrix for program MARK: from striped bass (>710 mm TL) that were tagged and released in the James and Rappahannock rivers, springs 1990-2014.

Release		Recapture year																								
No.	Year	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14
301	1990	26	9	15	2	4	6	1	0	2	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
390	1991		41	24	16	11	3	2	2	1	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
40	1992			4	3	2	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
212	1993				22	18	7	4	7	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
123	1994					9	7	5	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
210	1995						29	11	8	3	3	2	3	0	1	0	1	0	0	0	0	0	0	0	0	0
67	1996							1	3	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
212	1997								15	13	8	3	0	1	2	1	0	0	0	0	0	0	0	0	0	0
158	1998									24	13	2	3	2	0	0	0	0	0	0	0	0	0	0	0	0
162	1999										17	6	2	3	2	0	0	0	0	0	0	1	0	0	0	0
365	2000											28	19	14	9	4	3	0	1	0	0	0	0	0	0	0
269	2001												19	14	4	6	2	1	1	0	0	0	0	0	0	0
122	2002													10	6	7	1	0	2	1	0	0	0	0	0	0
400	2003														35	24	7	1	3	3	2	3	0	0	0	0
686	2004															39	12	13	5	4	2	1	0	0	0	0
284	2005																16	11	8	1	4	3	0	0	0	0
175	2006																	13	4	4	3	1	4	0	0	0
840	2007																		55	30	18	3	5	1	1	1
75	2008																			6	2	0	0	0	0	1
241	2009																				7	5	1	1	0	1
483	2010																					17	6	4	2	0
190	2011																						12	2	0	0
325	2012																							12	4	1
243	2013																								10	3
285	2014																									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 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 and 2007-2014 (p); parameters vary in 2013-2014 (v), otherwise the same as p; and parameters are time-specific (t).

Model	$QAIC_c$	$\varDelta\ QAIC_c$	$QAIC_c$ weight	number of parameters
S(t)r(t)	15,079.89	0.00	1.00000	49
S(p)r(t)	15,125.51	45.62	0.00000	30
S(v)r(p)	15,154.21	74.32	0.00000	11

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 and Rappahannock rivers, 1990-2014.

Year	$\hat{S}$	SE ($\hat{S}$)	P_l	Bias	$\hat{S}_{adj}$	$\hat{F}$	95% CI $\hat{F}$	
1990	0.816	0.089	0.481	-0.143	0.952	-0.101	-0.24,	0.24
1991	0.276	0.053	0.524	-0.082	0.301	1.051	0.71,	1.45
1992	0.804	0.168	0.408	-0.142	0.938	-0.086	-0.27,	0.79
1993	0.604	0.134	0.456	-0.105	0.675	0.243	-0.06,	0.83
1994	0.568	0.130	0.381	-0.087	0.623	0.324	0.00,	0.90
1995	0.684	0.139	0.262	-0.054	0.723	0.174	-0.08,	0.76
1996	0.639	0.136	0.274	-0.040	0.666	0.257	-0.03,	0.84
1997	0.567	0.110	0.330	-0.057	0.601	0.359	0.07,	0.83
1998	0.409	0.080	0.362	-0.047	0.435	0.682	0.20,	0.97
1999	0.374	0.067	0.286	-0.047	0.398	0.772	0.31,	1.02
2000	0.428	0.066	0.436	-0.066	0.463	0.621	0.20,	0.81
2001	0.463	0.099	0.367	-0.059	0.497	0.549	0.06,	0.89
2002	0.607	0.129	0.368	-0.051	0.648	0.284	-0.16,	0.69
2003	0.842	0.143	0.271	-0.040	0.885	-0.028	-0.33,	0.58
2004	0.346	0.066	0.281	-0.031	0.359	0.874	0.39,	1.13
2005	0.458	0.091	0.274	-0.026	0.473	0.599	0.12,	0.90
2006	0.531	0.098	0.354	-0.049	0.563	0.424	-0.02,	0.71
2007	0.578	0.123	0.303	-0.038	0.605	0.353	-0.10,	0.74
2008	0.573	0.148	0.208	-0.020	0.587	0.382	-0.12,	0.91
2009	0.748	0.193	0.231	-0.010	0.767	0.115	-0.28,	0.93
2010	0.171	0.053	0.267	-0.025	0.173	1.604	0.89,	2.09
2011	0.405	0.132	0.152	-0.013	0.412	0.737	0.09,	1.35
2012	0.309	0.092	0.264	-0.023	0.318	0.995	0.35,	1.49
2013	0.485	0.201	0.161	-0.010	0.494	0.556	-0.12,	1.50
2014	0.451	0.026	0.289	-0.022	0.461	0.625	0.37,	0.59

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 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 and 2007-2014 (p); otherwise the same as p; parameters vary in 2013 and 2014 (v), otherwise the same as p; and parameters are time-specific (t).

Model	QAIC$_c$	Δ QAIC$_c$	QAIC$_c$ weight	number of parameters
S(t)r(t)	8,629.09	0.00	0.95986	49
S(p)r(t)	8,635.74	6.64	0.03462	30
S(v)r(p)	8,639.41	10.32	0.00552	11

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 and Rappahannock rivers, 1990-2014.

Year	$\hat{S}$	SE ($\hat{S}$)	P_l	Bias	$\hat{S}_{adj}$	$\hat{F}$	95% CI	
1990	0.532	0.089	0.577	-0.127	0.609	0.345	0.08,	0.74
1991	0.579	0.151	0.560	-0.131	0.666	0.257	-0.09,	0.95
1992	0.648	0.175	0.535	-0.172	0.784	0.094	-0.23,	0.89
1993	0.892	0.057	0.349	-0.093	0.983	-0.133	-0.21,	0.08
1994	0.437	0.083	0.318	-0.070	0.470	0.605	0.29,	1.03
1995	0.864	0.059	0.204	-0.079	0.939	-0.087	-0.18,	0.12
1996	0.542	0.111	0.125	-0.016	0.550	0.447	0.14,	0.94
1997	0.449	0.095	0.167	-0.036	0.466	0.613	0.27,	1.09
1998	0.778	0.181	0.217	-0.084	0.850	0.013	-0.20,	0.93
1999	0.428	0.099	0.200	-0.058	0.455	0.638	0.26,	1.16
2000	0.772	0.142	0.349	-0.073	0.831	0.035	-0.17,	0.67
2001	0.491	0.114	0.298	-0.052	0.519	0.507	0.15,	1.06
2002	0.660	0.135	0.295	-0.078	0.716	0.184	-0.08,	0.75
2003	0.901	0.063	0.246	-0.059	0.957	-0.106	-0.33,	0.00
2004	0.358	0.081	0.321	-0.049	0.376	0.828	0.29,	1.17
2005	0.575	0.132	0.238	-0.035	0.596	0.368	-0.11,	0.81
2006	0.739	0.156	0.282	-0.048	0.776	0.104	-0.28,	0.65
2007	0.649	0.147	0.228	-0.036	0.674	0.245	-0.19,	0.73
2008	0.931	0.076	0.163	-0.023	0.954	-0.103	-0.32,	0.23
2009	0.499	0.148	0.105	-0.009	0.503	0.536	-0.03,	1.13
2010	0.376	0.132	0.235	-0.019	0.383	0.809	0.12,	1.47
2011	0.474	0.193	0.071	-0.009	0.478	0.588	-0.09,	1.49
2012	0.356	0.155	0.150	-0.013	0.360	0.871	0.08,	1.75
2013	0.451	0.231	0.059	-0.006	0.454	0.641	-0.13,	1.85
2014	0.599	0.074	0.176	-0.015	0.609	0.346	-0.01,	0.49

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, 1990-2014.

Year	Z	A	U	F	M
1990	0.05	0.05	0.17	0.18	-0.13
1992	1.20	0.70	0.14	0.24	0.96
1992	0.06	0.06	0.31	0.32	-0.25
1993	0.39	0.32	0.23	0.28	0.12
1994	0.47	0.38	0.25	0.31	0.16
1995	0.32	0.28	0.19	0.22	0.10
1996	0.41	0.33	0.15	0.18	0.23
1997	0.51	0.40	0.20	0.25	0.26
1998	0.83	0.56	0.15	0.22	0.61
1999	0.92	0.60	0.13	0.20	0.72
2000	0.77	0.54	0.12	0.17	0.60
2001	0.70	0.50	0.16	0.22	0.48
2002	0.43	0.35	0.15	0.18	0.25
2003	0.12	0.11	0.16	0.17	-0.04
2004	1.02	0.64	0.10	0.16	0.86
2005	0.75	0.53	0.12	0.17	0.58
2006	0.57	0.44	0.14	0.19	0.39
2007	0.50	0.40	0.12	0.16	0.35
2008	0.53	0.41	0.09	0.11	0.42
2009	0.26	0.23	0.09	0.11	0.16
2010	1.75	0.83	0.05	0.10	1.66
2011	0.89	0.59	0.08	0.12	0.77
2012	1.15	0.68	0.08	0.13	1.01
2013	0.84	0.57	0.08	0.11	0.72
2014	0.78	0.54	0.03	0.05	0.73

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, 1990-2014.

Year	Z	A	U	F	M
1990	0.49	0.39	0.25	0.32	0.17
1992	0.41	0.33	0.36	0.44	-0.04
1992	0.24	0.22	0.37	0.41	-0.17
1993	0.02	0.02	0.37	0.37	-0.35
1994	0.75	0.53	0.25	0.36	0.38
1995	0.07	0.07	0.41	0.43	-0.36
1996	0.60	0.45	0.18	0.23	0.36
1997	0.76	0.53	0.38	0.54	0.22
1998	0.17	0.15	0.45	0.49	-0.33
1999	0.78	0.54	0.30	0.43	0.36
2000	0.19	0.17	0.25	0.27	-0.09
2001	0.65	0.48	0.21	0.28	0.37
2002	0.33	0.28	0.28	0.33	0.00
2003	0.05	0.05	0.23	0.24	-0.19
2004	0.97	0.62	0.13	0.20	0.77
2005	0.52	0.40	0.19	0.25	0.27
2006	0.26	0.23	0.25	0.29	-0.03
2007	0.40	0.33	0.17	0.21	0.19
2008	0.05	0.05	0.18	0.19	-0.14
2009	0.68	0.50	0.09	0.12	0.57
2010	0.95	0.61	0.09	0.14	0.81
2011	0.74	0.52	0.09	0.13	0.61
2012	1.01	0.64	0.08	0.13	0.88
2013	0.82	0.56	0.06	0.09	0.73
2014	0.48	0.38	0.04	0.05	0.43

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 and Rappahannock rivers, springs, 1990-2014.

Year	Z	A	U	F	M
1990	0.05	0.05	0.17	0.18	-0.13
1992	1.20	0.70	0.14	0.24	0.96
1992	0.06	0.06	0.31	0.32	-0.25
1993	0.39	0.32	0.23	0.28	0.12
1994	0.47	0.38	0.25	0.31	0.16
1995	0.32	0.28	0.19	0.22	0.10
1996	0.41	0.33	0.15	0.18	0.23
1997	0.51	0.40	0.20	0.25	0.26
1998	0.83	0.56	0.15	0.22	0.61
1999	0.92	0.60	0.13	0.20	0.72
2000	0.77	0.54	0.12	0.17	0.60
2001	0.70	0.50	0.16	0.22	0.48
2002	0.43	0.35	0.15	0.18	0.25
2003	0.12	0.11	0.16	0.17	-0.04
2004	1.02	0.64	0.10	0.16	0.86
2005	0.75	0.53	0.12	0.17	0.58
2006	0.57	0.44	0.14	0.19	0.39
2007	0.50	0.40	0.12	0.16	0.35
2008	0.53	0.41	0.09	0.11	0.42
2009	0.26	0.23	0.09	0.11	0.16
2010	1.75	0.83	0.05	0.10	1.66
2011	0.89	0.59	0.08	0.12	0.77
2012	1.15	0.68	0.08	0.13	1.01
2013	0.71	0.51	0.08	0.11	0.60
2014	0.78	0.54	0.06	0.09	0.69

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 and Rappahannock rivers, springs, 1990-2014.

Year	Z	A	U	F	M
1990	0.49	0.39	0.25	0.32	0.18
1992	0.41	0.33	0.36	0.44	-0.04
1992	0.24	0.22	0.37	0.41	-0.17
1993	0.02	0.02	0.37	0.37	-0.35
1994	0.76	0.53	0.25	0.36	0.39
1995	0.06	0.06	0.41	0.42	-0.36
1996	0.60	0.45	0.18	0.23	0.36
1997	0.76	0.53	0.38	0.54	0.22
1998	0.16	0.15	0.45	0.49	-0.33
1999	0.79	0.55	0.30	0.43	0.36
2000	0.18	0.17	0.25	0.27	-0.09
2001	0.66	0.48	0.21	0.28	0.38
2002	0.33	0.28	0.28	0.33	0.00
2003	0.04	0.04	0.23	0.23	-0.19
2004	0.98	0.62	0.13	0.20	0.78
2005	0.52	0.40	0.19	0.25	0.27
2006	0.25	0.22	0.25	0.29	-0.03
2007	0.40	0.33	0.17	0.21	0.19
2008	0.05	0.05	0.18	0.19	-0.14
2009	0.69	0.50	0.09	0.12	0.57
2010	0.96	0.62	0.09	0.14	0.82
2011	0.74	0.52	0.09	0.13	0.61
2012	1.02	0.64	0.08	0.13	0.89
2013	0.79	0.55	0.06	0.09	0.70
2014	0.50	0.39	0.03	0.04	0.45

Table 22a.   Input recapture matrix for IRCR analysis: from striped bass (>457 mm TL) tagged and released in the Rappahannock River, springs 1990-2014. Harvested recaptures only.

Release No.	Year	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14
1,464	1990	21	20	24	10	8	9	2	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
2,481	1991		48	38	22	14	3	1	2	1	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
130	1992			7	4	1	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
621	1993				18	17	12	5	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
195	1994					6	7	4	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
698	1995						24	12	9	4	1	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0
376	1996							3	10	3	2	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0
712	1997								26	17	10	2	0	1	1	1	0	0	0	0	0	0	0	0	0	0
784	1998									28	16	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0
853	1999										30	7	4	2	2	0	0	0	0	0	0	0	0	0	0	0
1,765	2000											44	23	11	7	4	5	1	1	0	0	0	0	0	0	0
797	2001												31	14	5	7	1	0	0	0	0	0	0	0	0	0
315	2002													10	4	6	1	1	1	1	0	0	0	0	0	0
852	2003														32	20	5	3	3	2	1	2	0	0	0	0
1,477	2004															45	14	8	4	3	1	1	0	0	0	0
921	2005																27	17	6	1	4	1	0	0	0	0
668	2006																	27	4	5	5	3	4	0	0	0
1,961	2007																		63	34	16	3	5	0	1	1
523	2008																			17	4	0	0	0	0	1
867	2009																				26	7	2	2	0	1
2050	2010																					29	7	8	2	0
416	2011																						13	4	0	0
1,222	2012																							34	11	5
760	2013																								23	8
454	2014																									8

Table 22b. Input recapture matrix for IRCR analysis: from striped bass (>457 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2014. Recaptures released with streamers cut off only.

Release No.	Year	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14
1,464	1990	77	28	18	9	1	1	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,481	1991		93	33	24	10	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130	1992			6	3	3	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
621	1993				26	16	3	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
195	1994					6	1	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
698	1995						20	7	8	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
376	1996							10	7	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
712	1997								14	6	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
784	1998									21	7	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
853	1999										22	12	1	2	0	0	0	0	0	0	0	0	0	0	0	0
1,765	2000											49	23	7	3	0	0	0	0	0	0	0	0	0	0	0
797	2001												20	6	7	0	1	0	1	0	0	0	0	0	0	0
315	2002													7	3	2	0	0	1	0	0	0	0	0	0	0
852	2003														12	11	3	1	1	0	0	0	0	0	0	0
1,477	2004															25	5	5	1	0	1	0	0	0	0	0
921	2005																14	8	2	1	0	1	0	0	0	0
668	2006																	19	6	1	1	0	0	0	0	0
1,961	2007																		34	10	1	1	0	1	0	1
523	2008																			7	2	2	0	0	0	0
867	2009																				16	2	0	0	0	0
2050	2010																					14	2	0	0	1
416	2011																						5	0	0	0
1,222	2012																							18	2	0
760	2013																								7	1
454	2914																									6

Table 23a. Input recapture matrix for IRCR analysis: from striped bass (>710 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2014. Harvested recaptures only.

Release No.	Year	Recapture year 90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14
301	1990	10	1	6	1	3	5	1	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
390	1991		19	10	12	9	2	1	2	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
40	1992			2	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
212	1993				11	11	5	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
123	1994					4	4	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
210	1995						18	6	5	2	1	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0
67	1996							0	3	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
212	1997								11	12	6	2	0	1	1	1	0	0	0	0	0	0	0	0	0	0
158	1998									16	9	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0
162	1999										13	2	1	2	1	0	0	0	0	0	0	1	0	0	0	0
365	2000											13	11	6	5	3	3	0	1	0	0	0	0	0	0	0
269	2001												9	8	2	6	1	0	0	0	0	0	0	0	0	0
122	2002													7	3	5	1	0	1	1	0	0	0	0	0	0
400	2003														23	13	3	1	2	2	1	2	0	0	0	0
686	2004															21	8	8	3	3	1	1	0	0	0	0
284	2005																12	7	5	1	3	0	0	0	0	0
175	2006																	10	3	3	2	1	4	0	0	0
840	2007																		33	22	11	2	4	0	1	1
75	2008																			5	1	0	0	0	0	1
241	2009																				5	3	0	1	0	1
483	2010																					11	5	4	2	0
190	2011																						7	2	0	0
325	2012																							9	4	1
243	2013																								5	3
247	2014																									5

Table 23b.   Input recapture matrix for IRCR analysis: from striped bass (>710 mm TL) that were tagged and released in the Rappahannock River, springs 1990-2014. Recaptures released with streamers cut off only.

Release No.	Year	Recapture year 90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14
301	1990	15	8	8	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
390	1991		20	13	4	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	1992			2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
212	1993				10	7	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
123	1994					4	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
210	1995						7	2	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67	1996							1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
212	1997								2	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
158	1998									6	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
162	1999										3	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0
365	2000											9	7	4	2	0	0	0	0	0	0	0	0	0	0	0
269	2001												7	4	2	0	1	0	1	0	0	0	0	0	0	0
122	2002													2	2	0	0	0	1	0	0	0	0	0	0	0
400	2003														8	8	3	0	0	0	0	0	0	0	0	0
686	2004															16	2	5	1	0	1	0	0	0	0	0
284	2005																4	4	1	0	0	1	0	0	0	0
175	2006																	2	1	1	1	0	0	0	0	0
840	2007																		12	7	1	1	0	1	0	0
75	2008																			0	0	0	0	0	0	0
241	2009																				1	1	0	0	0	0
483	2010																					5	1	0	0	0
190	2011																						1	0	0	0
325	2012																							2	0	0
243	2013																								1	0
247	2014																									3

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 (5p- 1990-1994, 1995-1999, 2000-2002 and 2003-2006 and 2007-2014; d- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2013 and 2014; v- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2012 and 2013-2014).

2M (1990-1997, 1998-2013)			
model	QAIC$_c$	weight	parameters
F(t), F'(5p)	13,883.8	0.989	32
F(v),F'(v)	13,893.9	0.007	14
F(5p), F'(5p)	13,895.5	0.003	12
F(d), F'(d)	13,897.0	0.001	14
F(t), F'(t)	13,900.2	0.000	52
F(5p), F'(t)	13,911.1	0.000	32

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, 1990-2014.

Year	2M			
	S	M	F	SE
1990	0.641	0.393	0.042	0.013
1991	0.627	0.393	0.065	0.010
1992	0.600	0.393	0.110	0.019
1993	0.607	0.393	0.098	0.018
1994	0.590	0.393	0.125	0.026
1995	0.587	0.393	0.134	0.024
1996	0.625	0.393	0.072	0.019
1997	0.599	0.393	0.115	0.022
1998	0.482	0.626	0.099	0.018
1999	0.474	0.626	0.116	0.019
2000	0.497	0.626	0.069	0.012
2001	0.483	0.626	0.096	0.016
2002	0.486	0.626	0.090	0.019
2003	0.481	0.626	0.102	0.019
2004	0.479	0.626	0.107	0.016
2005	0.492	0.626	0.080	0.015
2006	0.480	0.626	0.104	0.019
2007	0.489	0.626	0.088	0.013
2008	0.483	0.626	0.100	0.018
2009	0.485	0.626	0.095	0.018
2010	0.510	0.626	0.045	0.009
2011	0.511	0.626	0.043	0.011
2012	0.504	0.626	0.057	0.011
2013	0.507	0.626	0.052	0.011
2014	0.510	0.626	0.044	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 (5p- 1990-1994, 1995-1999, 2000-2002, 2003-2006 and 2007-2014; d- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2013 and 2014; v- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2012 and 2013-2014).

2M (1990-2003, 2004-2013)			
model	**QAIC$_c$**	**weight**	**parameters**
F(v), F'(v)	9,054.3	0.957	14
F(t),F'(5p)	9,061.0	0.029	32
F(d), F'(d)	9,063.7	0.008	14
F(5p), F'(5p)	9,064.6	0.006	12
F(t), F'(t)	9,078.1	0.000	52
F(5p), F'(t)	9,083.5	0.000	32

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, 1990-2014.

Year	2M			
	S	M	F	SE
1990	0.669	0.252	0.140	0.018
1991	0.669	0.252	0.140	0.017
1992	0.668	0.252	0.141	0.016
1993	0.668	0.252	0.142	0.017
1994	0.666	0.252	0.144	0.022
1995	0.623	0.252	0.216	0.024
1996	0.625	0.252	0.213	0.026
1997	0.624	0.252	0.215	0.023
1998	0.624	0.252	0.216	0.023
1999	0.623	0.252	0.217	0.025
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	0.701	0.252	0.101	0.010
2004	0.701	0.478	0.100	0.010
2005	0.560	0.478	0.100	0.010
2006	0.560	0.478	0.100	0.010
2007	0.567	0.478	0.089	0.010
2008	0.566	0.478	0.089	0.012
2009	0.567	0.478	0.088	0.010
2010	0.567	0.478	0.087	0.010
2011	0.567	0.478	0.088	0.010
2012	0.567	0.478	0.087	0.011
2013	0.593	0.478	0.044	0.011
2914	0.593	0.478	0.044	0.010

Table 28a.   Input recapture matrix for IRCR analysis: from striped bass (>457 mm TL) tagged and released in the James and Rappahannock rivers, springs 1990-2014. Harvested recaptures only.

Release No.	Year	Recapture year 90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14
1,464	1990	21	20	24	10	8	9	2	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
2,481	1991		48	38	22	14	3	1	2	1	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
130	1992			7	4	1	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
621	1993				18	17	12	5	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
195	1994					6	7	4	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
698	1995						24	12	9	4	1	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0
376	1996							3	10	3	2	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0
712	1997								26	17	10	2	0	1	1	1	0	0	0	0	0	0	0	0	0	0
784	1998									28	16	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0
853	1999										30	7	4	2	2	0	0	0	0	0	0	1	0	0	0	0
1,765	2000											44	23	11	7	4	5	1	1	0	0	0	0	0	0	0
797	2001												31	14	5	7	1	0	0	0	0	0	0	0	0	0
315	2002													10	4	6	1	1	1	1	0	0	0	0	0	0
852	2003														32	20	5	3	3	2	1	2	0	0	0	0
1,477	2004															45	14	8	4	3	1	1	0	0	0	0
921	2005																27	17	6	1	4	1	0	0	0	0
668	2006																	27	4	5	5	3	4	0	0	0
1,961	2007																		64	34	16	3	5	0	1	1
523	2008																			17	4	0	0	0	0	1
867	2009																				26	7	2	2	0	1
2050	2010																					29	7	8	2	0
416	2011																						13	4	0	0
1,222	2012																							34	11	5
760	2013																								23	8
614	2014																									8

Table 28b. Input recapture matrix for IRCR analysis: from striped bass (>457 mm TL) that were tagged and released in the James and Rappahannock rivers, springs 1990-2014. Recaptures released with streamers cut off only.

Release No.	Year	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14
1,464	1990	77	28	18	9	1	1	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,481	1991		93	33	24	10	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130	1992			6	3	3	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
621	1993				26	16	3	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
195	1994					6	1	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
698	1995						20	7	8	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
376	1996							10	7	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
712	1997								14	6	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
784	1998									21	7	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
853	1999										22	12	1	2	0	0	0	0	0	0	0	0	0	0	0	0
1,765	2000											50	23	7	3	0	0	0	0	0	0	0	0	0	0	0
797	2001												20	6	7	0	1	0	1	0	0	0	0	0	0	0
315	2002													7	3	2	0	0	1	0	0	0	0	0	0	0
852	2003														12	11	3	1	1	0	0	0	0	0	0	0
1,477	2004															25	5	5	1	0	1	0	0	0	0	0
921	2005																14	8	2	1	0	1	0	0	0	0
668	2006																	19	6	1	1	0	0	0	0	0
1,961	2007																		34	10	1	1	0	1	0	1
523	2008																			7	2	2	0	0	0	0
867	2009																				16	2	0	0	0	0
2050	2010																					14	2	0	0	1
416	2011																						5	0	0	0
1,222	2012																							18	2	0
760	2013																								7	1
614	2914																									8

110

Table 29a. Input recapture matrix for IRCR analysis: from striped bass (>710 mm TL) that were tagged and released in the James and Rappahannock rivers, springs 1990-2014. Harvested recaptures only.

Release No.	Year	Recapture year 90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14
301	1990	10	1	6	1	3	5	1	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
390	1991		19	10	12	9	2	1	2	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
40	1992			2	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
212	1993				11	11	5	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
123	1994					4	4	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
210	1995						18	6	5	2	1	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0
67	1996							0	3	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
212	1997								11	12	6	2	0	1	1	1	0	0	0	0	0	0	0	0	0	0
158	1998									16	9	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0
162	1999										13	2	1	2	1	0	0	0	0	0	0	1	0	0	0	0
365	2000											13	11	6	5	3	3	0	1	0	0	0	0	0	0	0
269	2001												9	8	2	6	1	0	0	0	0	0	0	0	0	0
122	2002													7	3	5	1	0	1	1	0	0	0	0	0	0
400	2003														23	13	3	1	2	2	1	2	0	0	0	0
686	2004															21	8	8	3	3	1	1	0	0	0	0
284	2005																12	7	5	1	3	0	0	0	0	0
175	2006																	10	3	3	2	1	4	0	0	0
840	2007																		33	22	11	2	4	0	1	1
75	2008																			5	1	0	0	0	0	1
241	2009																				5	3	0	1	0	1
483	2010																					11	5	4	2	0
190	2011																						7	2	0	0
325	2012																							9	4	1
243	2013																								5	3
285	2014																									5

Table 29b. Input recapture matrix for IRCR analysis: from striped bass (>710 mm TL) that were tagged and released in the James and Rappahannock rivers, springs 1990-2014. Recaptures released with streamers cut off only.

Release No.	Year	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14
301	1990	15	8	8	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
390	1991		20	13	4	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	1992			2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
212	1993				10	7	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
123	1994					4	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
210	1995						7	2	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67	1996							1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
212	1997								2	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
158	1998									6	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
162	1999										3	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0
365	2000											9	7	4	2	0	0	0	0	0	0	0	0	0	0	0
269	2001												7	4	2	0	1	0	1	0	0	0	0	0	0	0
122	2002													2	2	0	0	0	1	0	0	0	0	0	0	0
400	2003														8	8	3	0	0	0	0	0	0	0	0	0
686	2004															16	2	5	1	0	1	0	0	0	0	0
284	2005																4	4	1	0	0	1	0	0	0	0
175	2006																	2	1	1	1	0	0	0	0	0
840	2007																		12	7	1	1	0	1	0	0
75	2008																			0	0	0	0	0	0	0
241	2009																				1	1	0	0	0	0
483	2010																					5	1	0	0	0
190	2011																						1	0	0	0
325	2012																							2	0	0
243	2013																								1	0
285	2014																									3

Table 30. Model Akaike weighting results (striped bass ≥ 457 mm TL) for the 2M IRCR analyses for James and Rappahannock river releases. Model notations: Fishing mortality (F), release mortality (F') and natural mortality (M), annual estimates (t) and period estimates (5p- 1990-1994, 1995-1999, 2000-2002 and 2003-2006 and 2007-2014; d- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2013 and 2014; v- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2012 and 2013-2014).

2M (1990-1997, 1998-2013)			
model	QAIC$_c$	weight	parameters
F(t), F'(5p)	13,496.4	0.985	32
F(v),F'(v)	13,505.9	0.009	14
F(5p), F'(5p)	13,508.3	0.003	12
F(d), F'(d)	13,508.3	0.003	14
F(t), F'(t)	13,514.8	0.000	52
F(5p), F'(t)	13,524.8	0.000	32

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 and Rappahannock River releases, 1990-2014.

Year	2M			
	S	M	F	SE
1990	0.641	0.393	0.043	0.013
1991	0.627	0.393	0.065	0.011
1992	0.600	0.393	0.109	0.018
1993	0.607	0.393	0.098	0.018
1994	0.590	0.393	0.125	0.026
1995	0.587	0.393	0.134	0.025
1996	0.625	0.393	0.072	0.019
1997	0.599	0.393	0.115	0.022
1998	0.483	0.625	0.099	0.018
1999	0.475	0.625	0.116	0.020
2000	0.497	0.625	0.069	0.012
2001	0.484	0.625	0.096	0.017
2002	0.487	0.625	0.090	0.019
2003	0.482	0.625	0.101	0.019
2004	0.479	0.625	0.107	0.016
2005	0.492	0.625	0.080	0.015
2006	0.481	0.625	0.103	0.019
2007	0.490	0.625	0.087	0.013
2008	0.484	0.625	0.100	0.018
2009	0.486	0.625	0.095	0.018
2010	0.511	0.625	0.045	0.008
2011	0.512	0.625	0.043	0.011
2012	0.505	0.625	0.057	0.011
2013	0.507	0.625	0.051	0.011
2014	0.513	0.625	0.040	0.011

Table 32. Model Akaike weighting results (striped bass ≥ 711 mm TL) for the 2M IRCR analyses of James and Rappahannock River releases. Model notations: Fishing mortality (F), release mortality (F') and natural mortality (M), annual estimates (t) and period estimates (5p- 1990-1994, 1995-1999, 2000-2002, 2003-2006 and 2007-2014; d- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2013 and 2014; v- 1990-1994, 1995-1999, 2000-2002, 2003-2006, 2007-2012 and 2013-2014).

model	QAIC$_c$	weight	parameters
2M (1990-2003, 2004-2013)			
F(v), F'(v)	9,056.0	0.963	14
F(t),F'(5p)	9,062.9	0.027	32
F(d), F'(d)	9,065.7	0.008	14
F(5p), F'(5p)	9,067.7	0.003	12
F(t), F'(t)	9,080.8	0.000	52
F(5p), F'(t)	9,086.4	0.000	32

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 and Rappahannock River releases, 1990-2014.

Year	2M			
	S	M	F	SE
1990	0.669	0.252	0.140	0.017
1991	0.669	0.252	0.140	0.017
1992	0.668	0.252	0.141	0.016
1993	0.668	0.252	0.142	0.017
1994	0.667	0.252	0.143	0.022
1995	0.623	0.252	0.216	0.024
1996	0.625	0.252	0.213	0.026
1997	0.624	0.252	0.215	0.023
1998	0.624	0.252	0.216	0.023
1999	0.623	0.252	0.217	0.025
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	0.701	0.252	0.100	0.010
2004	0.560	0.476	0.100	0.010
2005	0.561	0.476	0.099	0.010
2006	0.560	0.476	0.100	0.010
2007	0.568	0.476	0.088	0.009
2008	0.567	0.476	0.089	0.012
2009	0.568	0.476	0.088	0.010
2010	0.568	0.476	0.087	0.010
2011	0.568	0.476	0.087	0.010
2012	0.568	0.476	0.087	0.011
2013	0.595	0.476	0.043	0.010
2014	0.595	0.476	0.042	0.010

III. Alternative procedures for estimating age composition

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

Introduction

In studies of age composition, it is common to measure the length of a large number of fish and age a sample of fish from each length class. The aged sample is known as an age-length key. There are two approaches to using age-length key: the classic age length key as described by Kimura (1977) and Westrheim and Ricker (1978) and inverse key as described by Hoenig and Heisey (1987). It is possible to combine the two approaches (Hoenig et al. 2002) though this has never been tried in practice.

Materials and Methods

The classic age-length key looks at the distribution of age within each length class. This implies that a separate key must be derived each year because the age composition changes from year to year. For example, the first length class might contain mostly one year olds but also a few two year olds. If, the next year, there is a complete recruitment failure then the first length class will contain only two year olds, there being no recruiting one year olds.

The inverse age-length key looks at the distribution of length for each of the age classes. If we assume that growth does not vary from year to year (more about this later), then the distribution of length at age will remain constant from year to year. Consequently, an inverse key derived in one year can be used to analyze length frequencies from another year. The results of using an inverse age-length key are generally less precise than using a classic key.

Thus, the two approaches can be summarized as follows:

Classic key	Inverse key
Uses age-at-length matrix	Uses length-at-age matrix
Requires annual sample	Can use data from previous years
Precise (relatively) results	Generally not as precise as classic key

The generalized or combined age-length key uses length frequency data from every year and aged samples from some or all years; it estimates the age composition for all years simultaneously. In theory, the combined key should provide an improvement over the classic key for each year with a length frequency sample and an age-length key. This is because the combined key augments the data for the specific year with information from other years. The procedure is described fully in Hoenig et al. (2002) and can be illustrated by:

Expectation-maximization (EM) algorithm

1. Find initial age composition for each year (by Classic ALK)
2. Calculate length-at-age probabilities (using all years)
   - Uses estimated <u>age composition</u>
3. Calculate age-at-length probabilities each year (Bayes' Theorem)
   - ALKs now imply single length-at-age relationship, all years

Length-at-age (step 2) (Inverse)

Age-composition (step 1)

Length-composition (data collected)

Age-at-length (Classic)

$$P(i \mid j) = \frac{P(j \mid i)\,P(i)}{\sum_i P(j \mid i)\,P(i)}$$

i = age, j = length

4. Calculate <u>age composition</u> each year using Step 3 ALKs
5. Repeat until convergence

where, i refers to age, j to length, ALK is an abbreviation for age length key, and P( ) denotes a probability.

We evaluated the use of the combined key to estimate the age composition of striped bass for several years simultaneously. The procedure was as follows. All striped bass examined by the VIMS striped bass monitoring and assessment program have been measured and aged. We combined the data for all years so as to have a very large number of ages and associated length measurements. We then randomly assigned the data pairs to six "years" to create a simulated dataset. For each simulated dataset we analyzed the data three ways: using a classic age-length key for each of the six years, using the combined age-length key to analyze all six years simultaneously, and by pretending that an aged sample was only available for five of the six years so that the sixth year age composition had to be estimated using just length frequencies from that year (and age-length key data from the other five years). This last case was considered because sometimes fisheries agencies find that they have to determine age composition for a year in which no aging data are available.

Results

The results show that the classic age-length key produces unbiased estimates (as expected) but with large variances (Figure 1.). The generalized method produced biased estimates for some ages but had lower variance. The generalized method when applied to a dataset with a missing aged sample for one year performed almost as well as the generalized method applied to complete data.

The generalized or combined key is predicated on the assumption that growth does not change over time. For striped bass, this assumption is testable because we have extensive

samples collected over many years. It appears that mean length has declined rather steadily over time for all age groups examined (Figure 2.).

Discussion

The Assumption of consistent length-at-age over time allows for the estimation of age composition in years with no aging. This can be very important in fisheries assessment work, though this problem has not arisen in the striped bass monitoring program. The generalized model provides a more stable age distribution than the classic key, but it introduces bias in the estimates. The generalized model may or may not work well when the age distribution changes over time. The generalized method relies on the assumption that growth rate does not change over time. The available evidence indicates that striped bass growth is changing over time. Thus, the generalized key does not appear to be a viable way to improve the precision of the estimated age composition of striped bass.

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Hoenig, J.M. and D.M. Heisey. 1987. Use of a Loglinear Model with the EM Algorithm for Correcting Estimates of Stock Composition and Converting Length to Age. Trans. Amer. Fish. Soc. 116:232-243.

Kimura, D. 1977. Statistical assessment of the age-length key. J. Fish. Res. Bd. Can. 34:317-324.

Westrheim, S.J. and W.E. Ricker. 1978. Bias in using an age-length key to estimate age-frequency distributions. J. Fish. Res. Bd. Can. 35:184-189.

Figure 1. Results of simulations comparing the classic age-length key with the combined or the generalized key. The combined key is applied to the complete data sets analyzed with the classis keys and also to data sets in which the aged sample is missing for one of the years. SSE = sum of squared errors (predicted minus actual age frequencies.
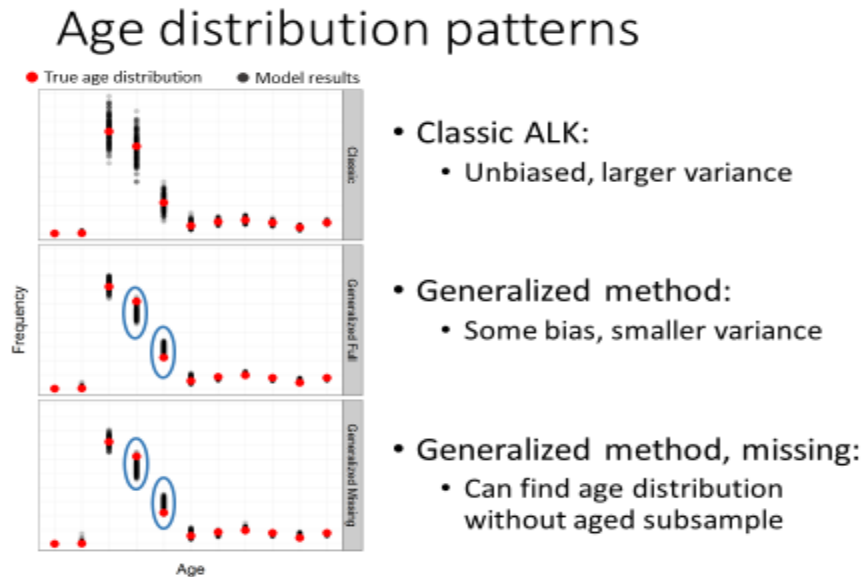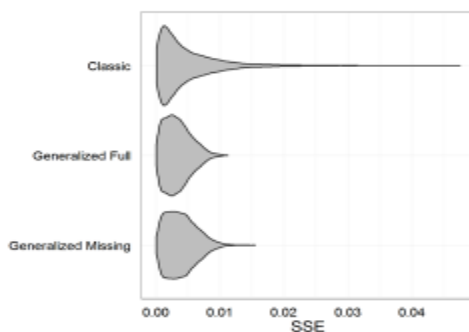
Figure 2a. Annual changes in mean lengths (TL in inches) of striped bass age classes in the
Rappahannock River, 1991-2015.

age 3

$y = -0.0847x + 17.521$
$R^2 = 0.6719$

age 4

$y = -0.0886x + 20.588$
$R^2 = 0.6372$

age 5

$y = -0.0785x + 23.359$
$R^2 = 0.5403$
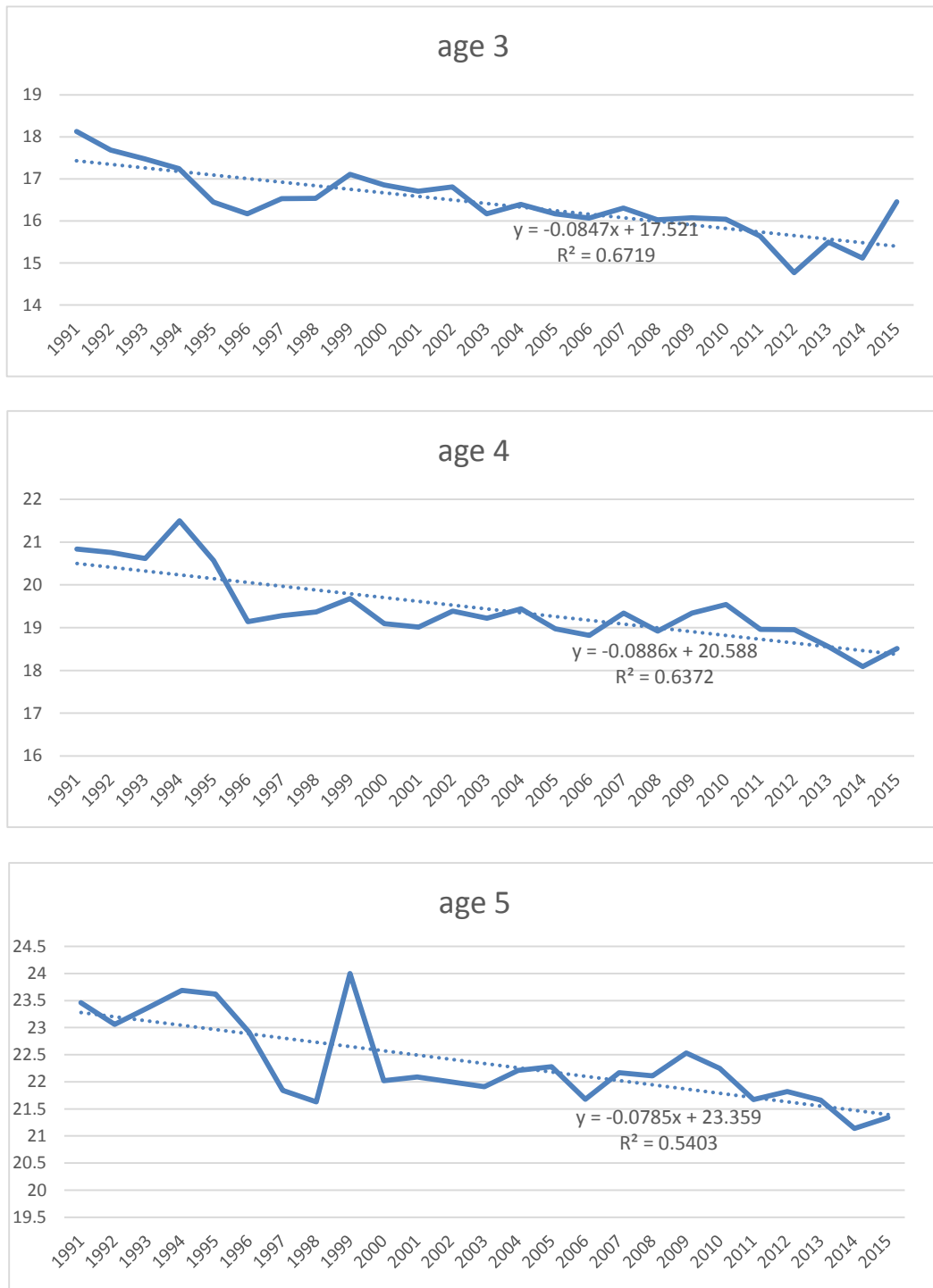
Figure 2b. Annual changes in mean lengths (TL in inches) of striped bass age classes in the Rappahannock River, 1991-2015.

age 6

$y = -0.1374x + 26.964$
$R^2 = 0.5177$

age 7

age 8

$y = -0.1721x + 33.863$
$R^2 = 0.4931$
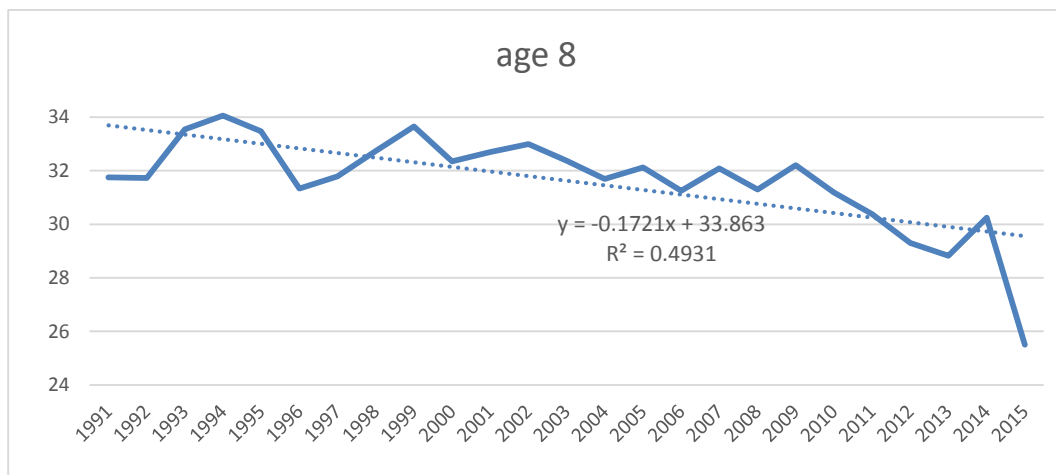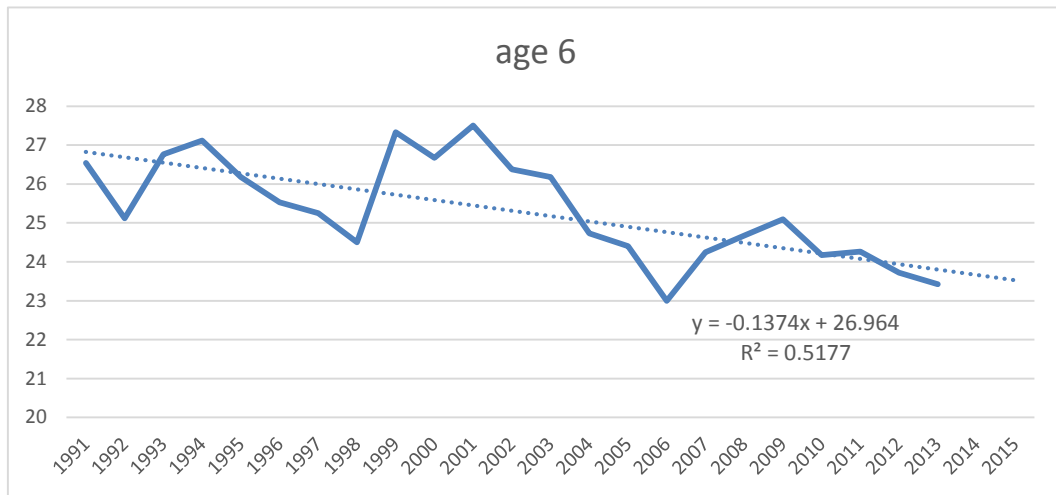
Figure 2c. Annual changes in mean lengths (TL in inches) of striped bass age classes in the Rappahannock River, 1991-2015.

age 9

$y = -0.1275x + 35.685$
$R^2 = 0.7364$

age 10

$y = -0.1276x + 37.749$
$R^2 = 0.7283$

age 11

$y = -0.1726x + 40.087$
$R^2 = 0.7807$
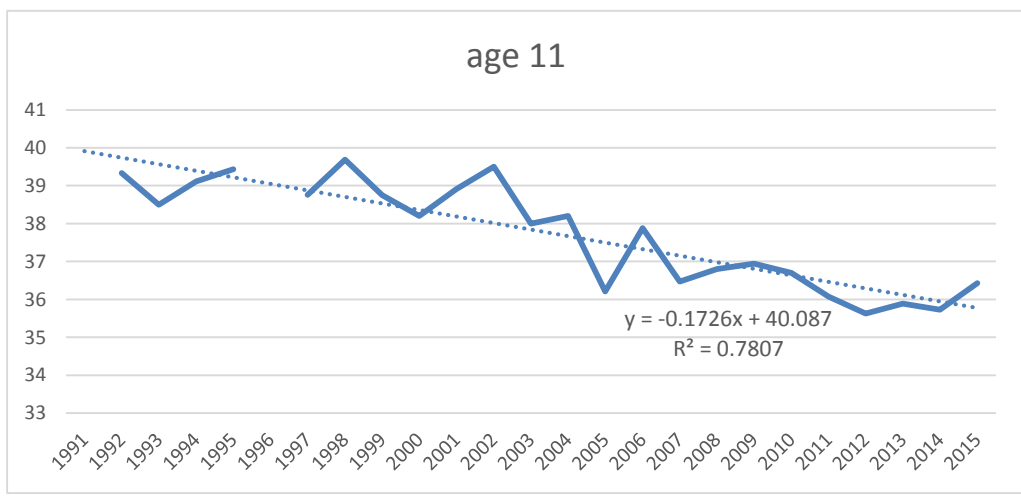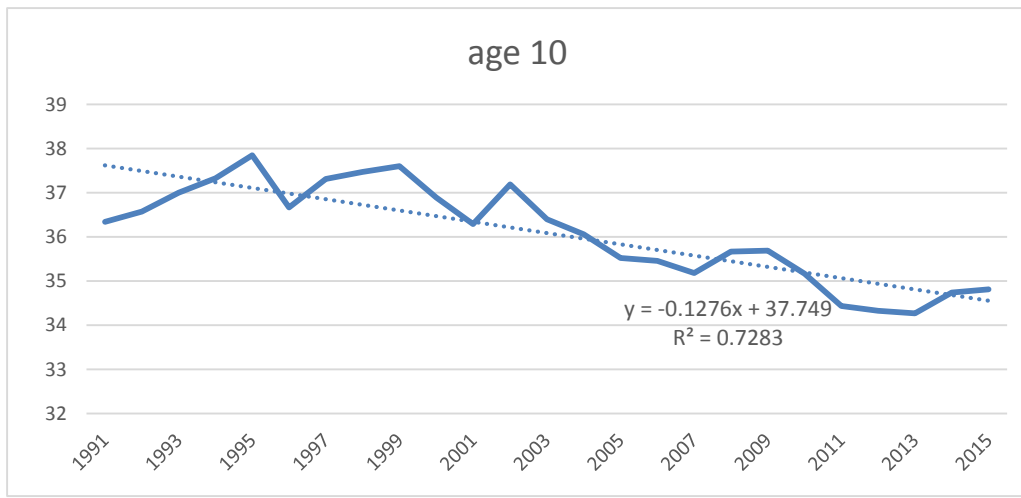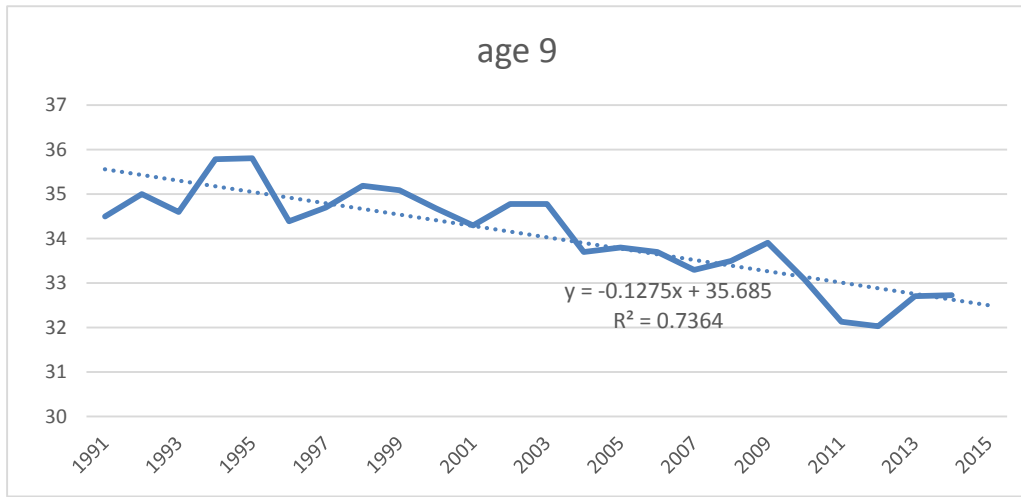
Appendix A. Daily flow rates of the Rappahannock River,
30 March – 3 May, 1985-2014.

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Department of Fisheries Science

School of Marine Science

Virginia Institute of Marine Science

The College of William and Mary

Gloucester Point, VA. 23062-1346

Figure 1. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, spring 2014.
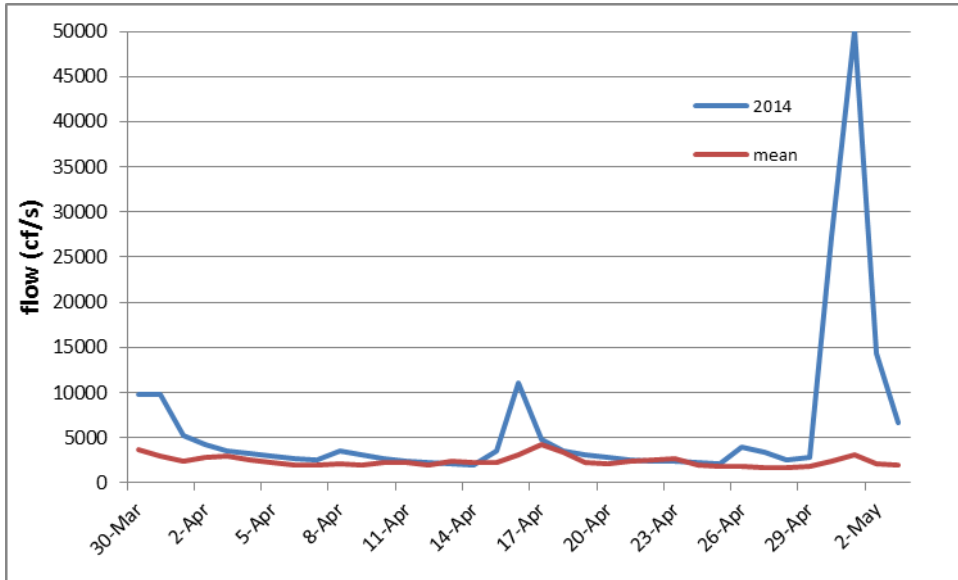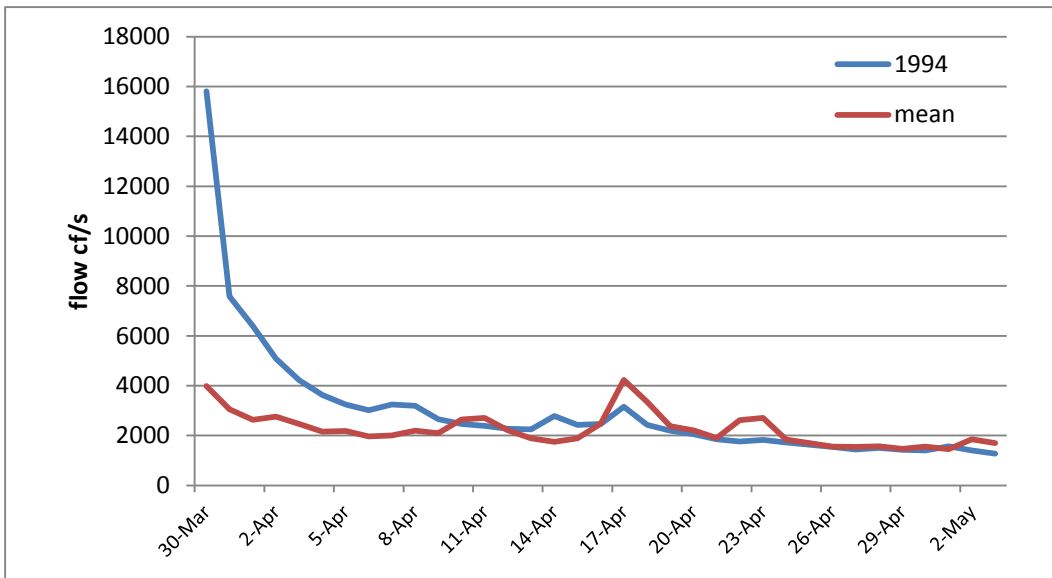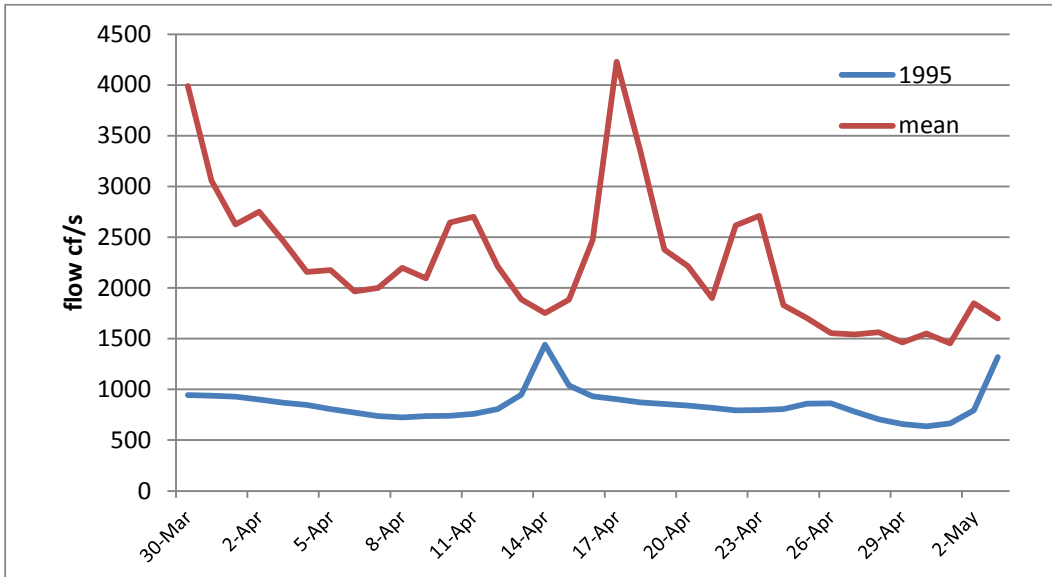
Figure 2. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, spring 2012-2013.
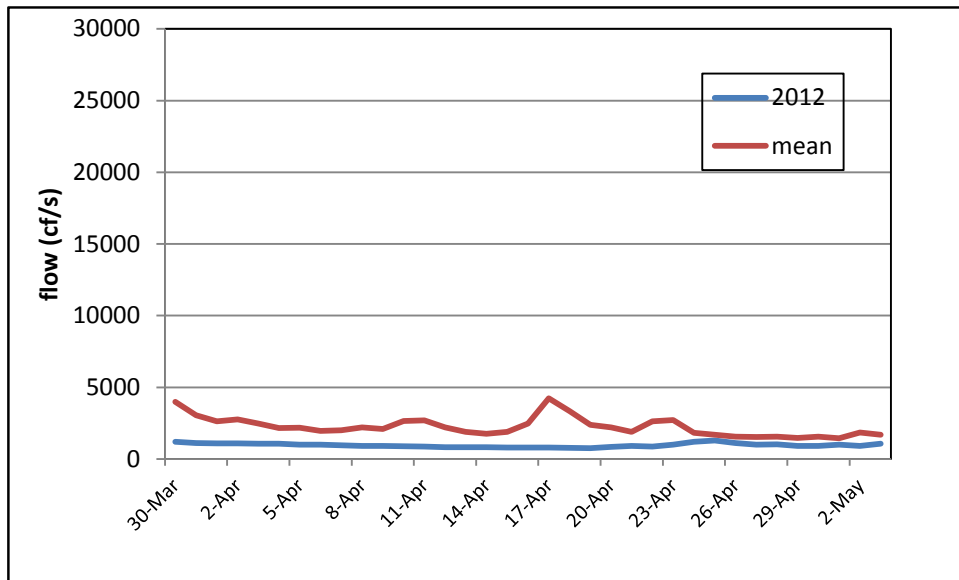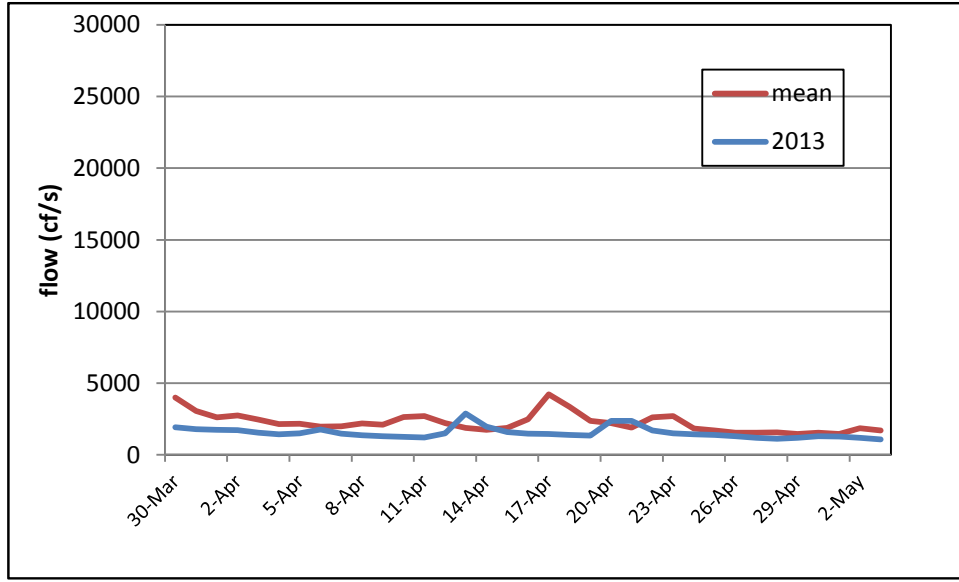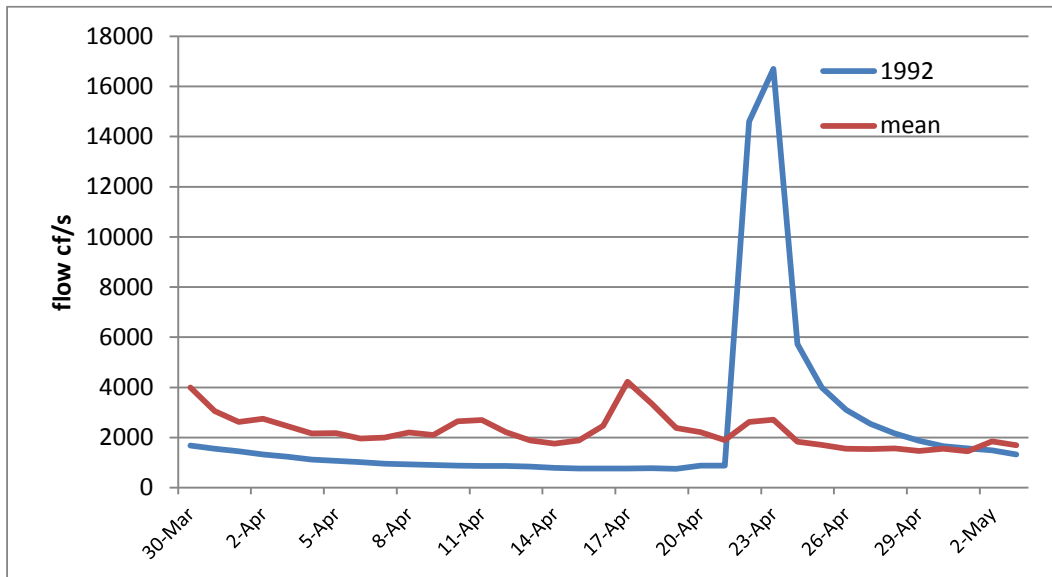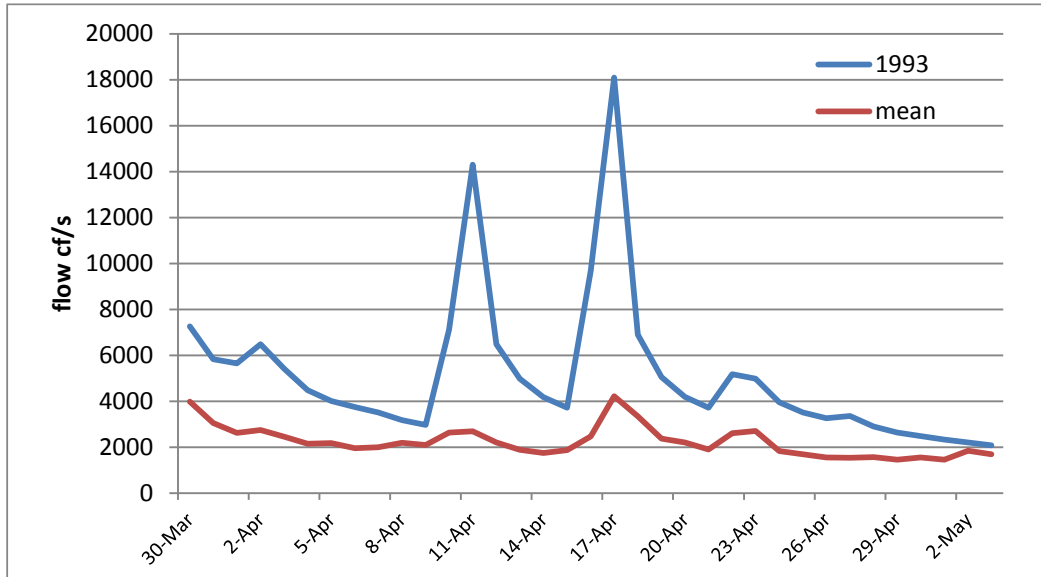
Figure 3. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2010-2011.
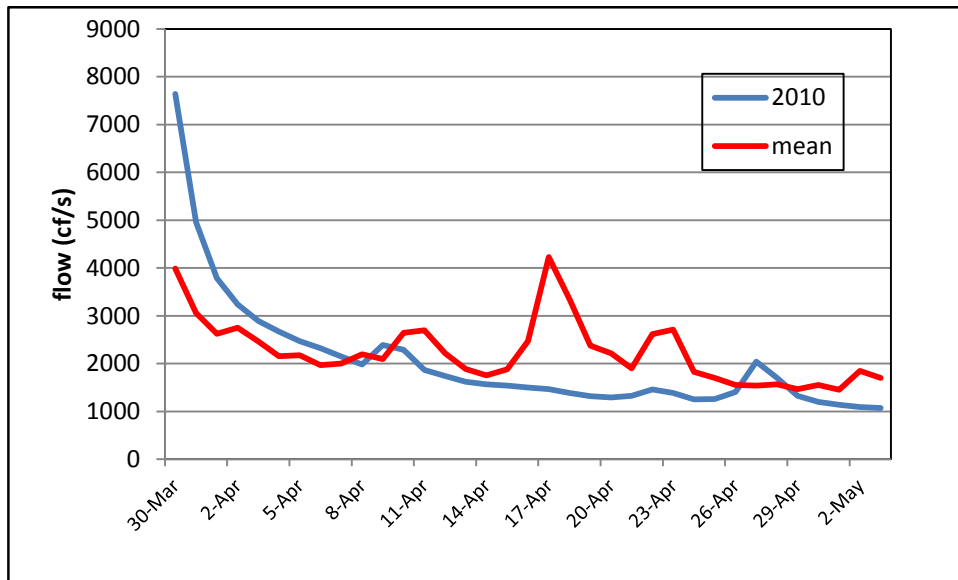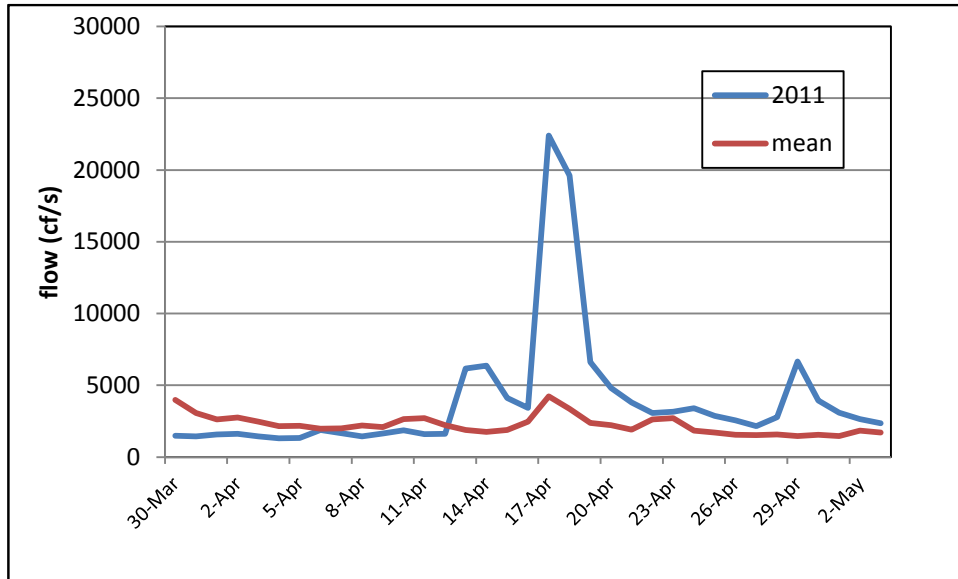
Figure 4. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2008-2009.
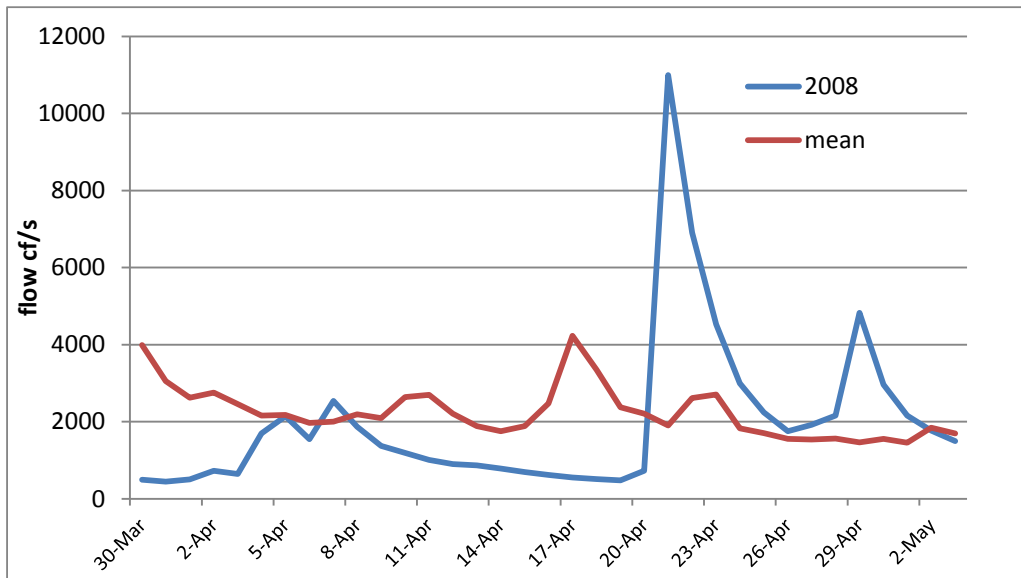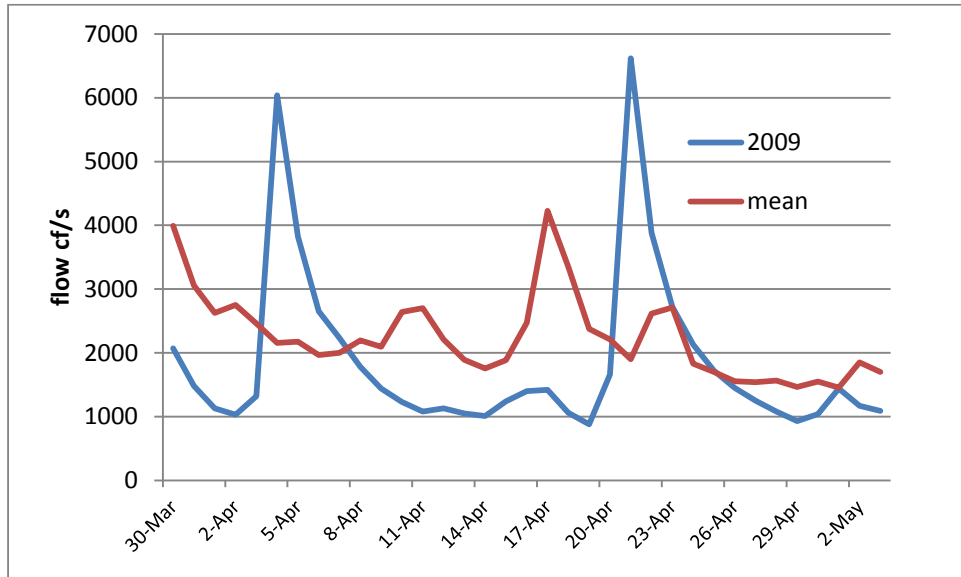
Figure 5. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2006-2007.
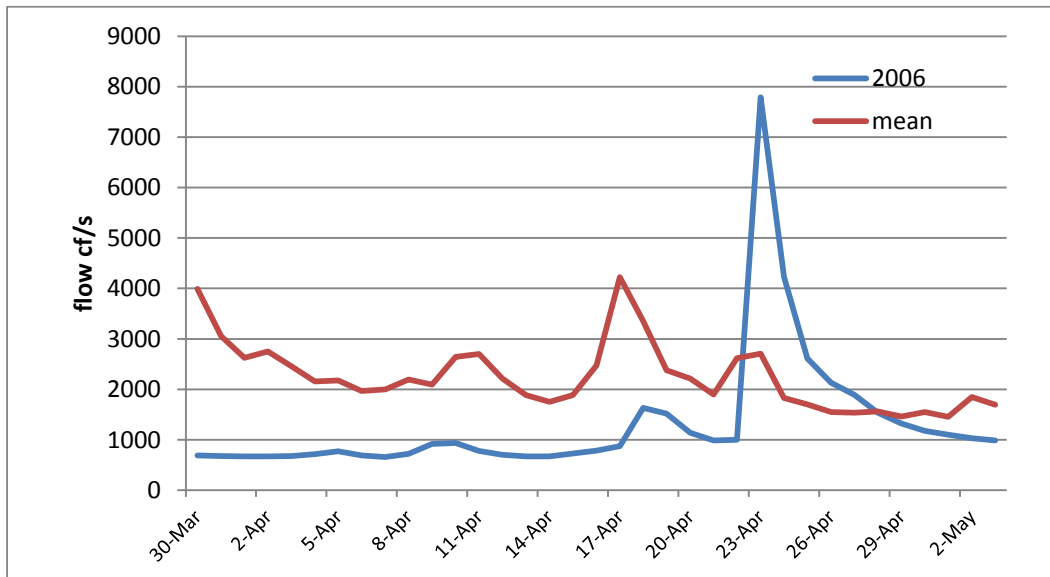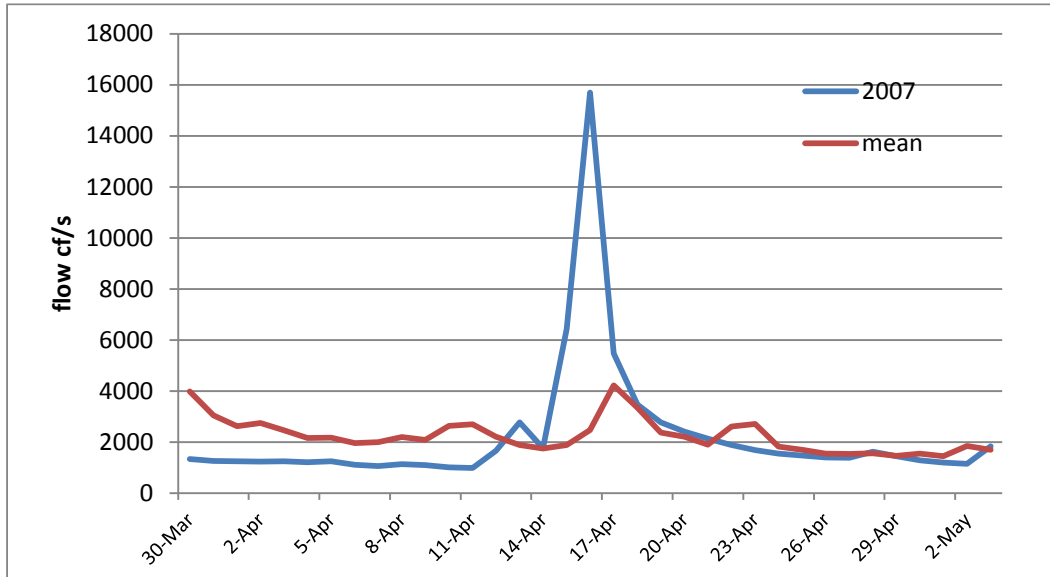
Figure 6. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2004-2005.
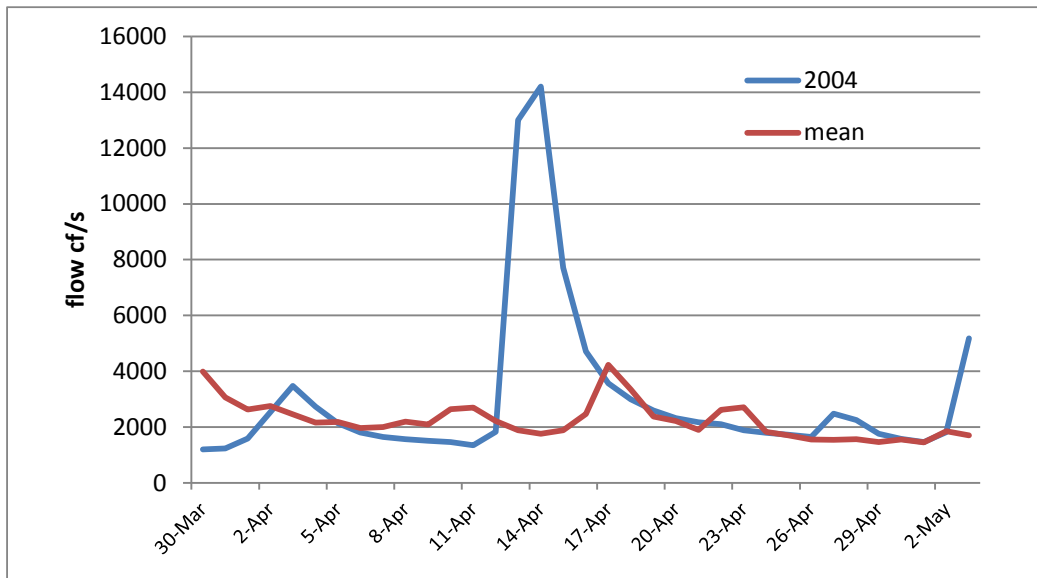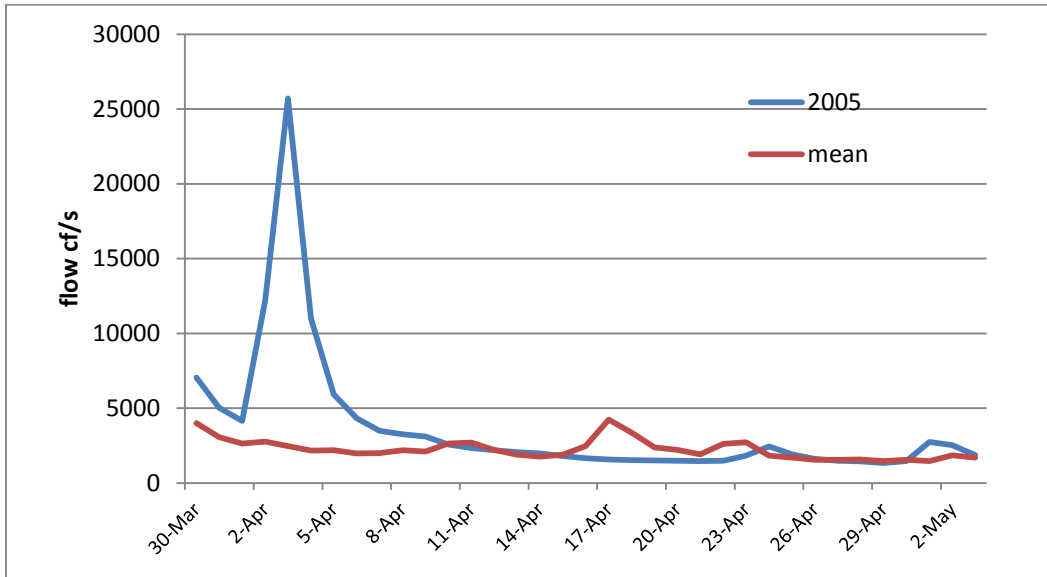
Figure 7. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2002-2003.
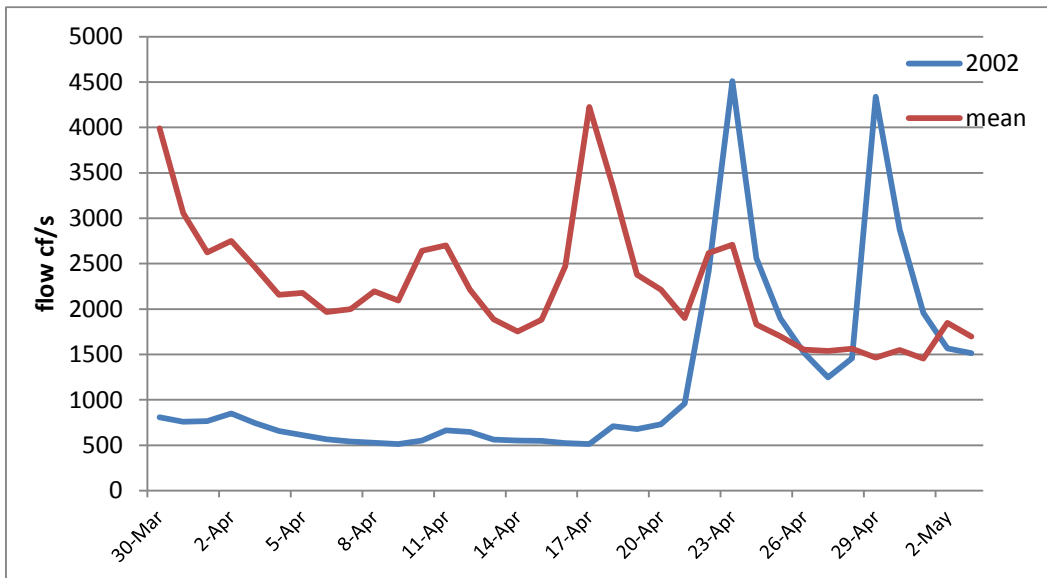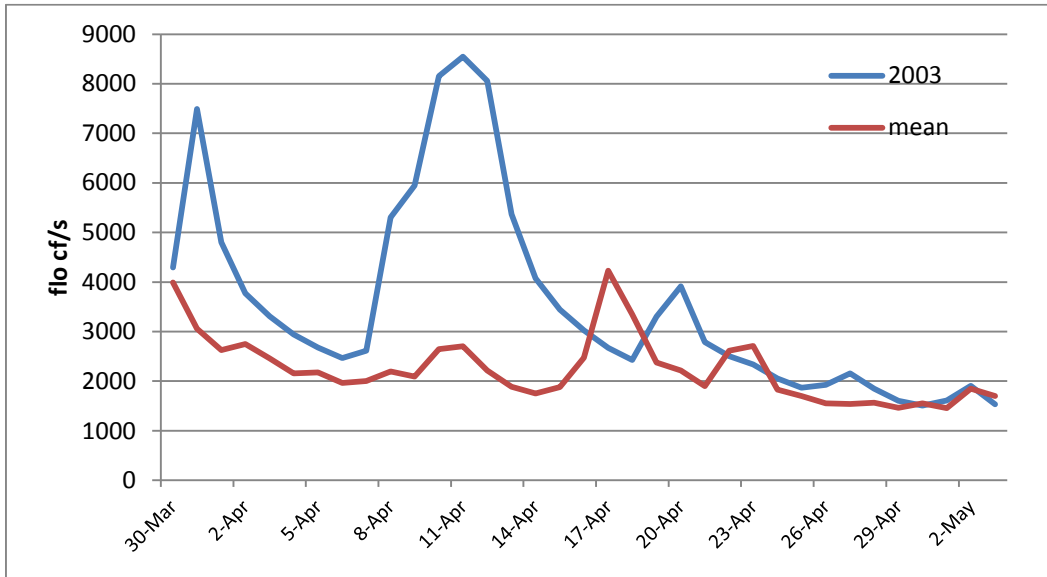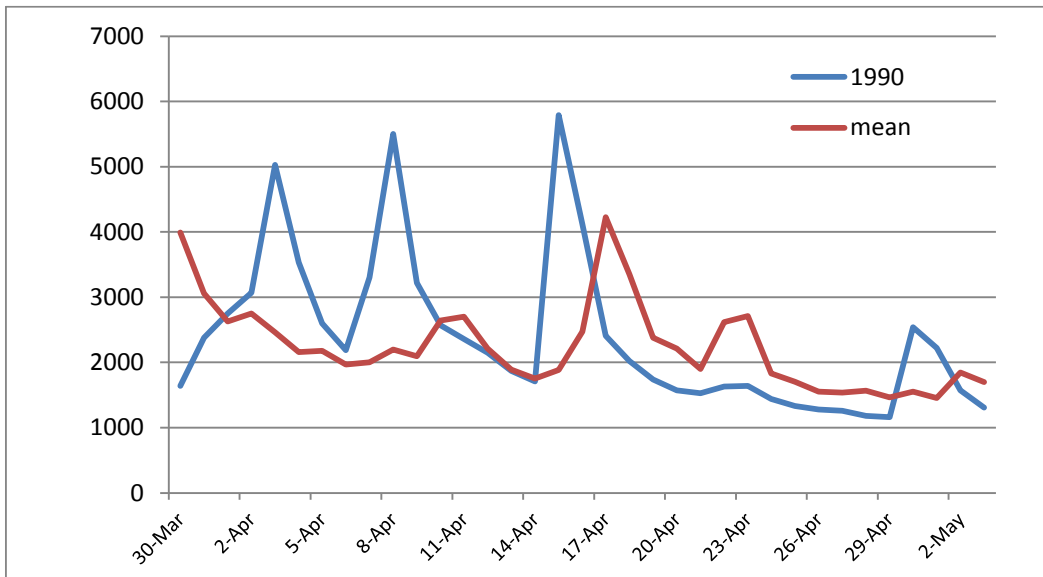
Figure 8. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 2000-2001.
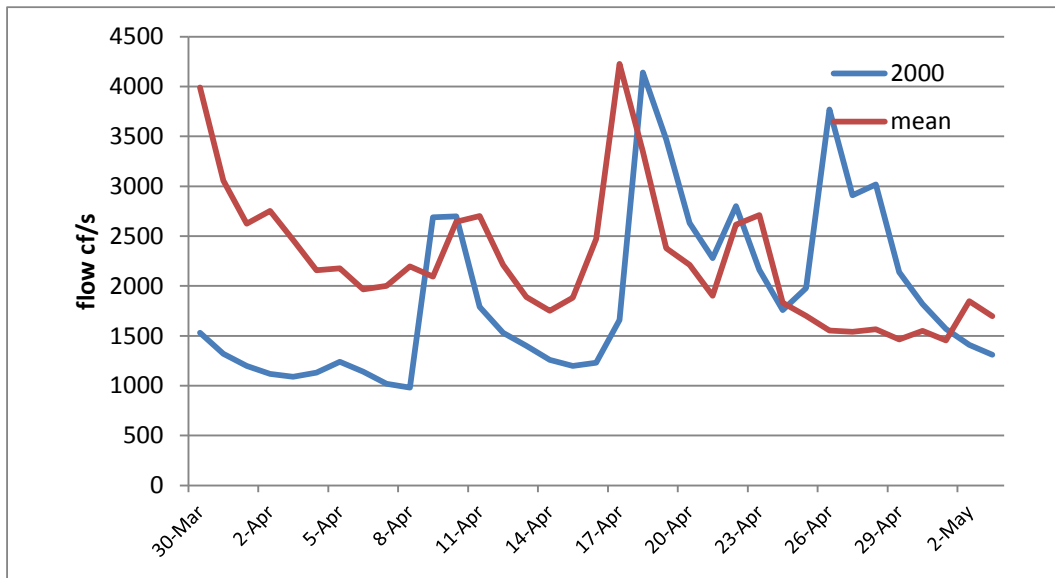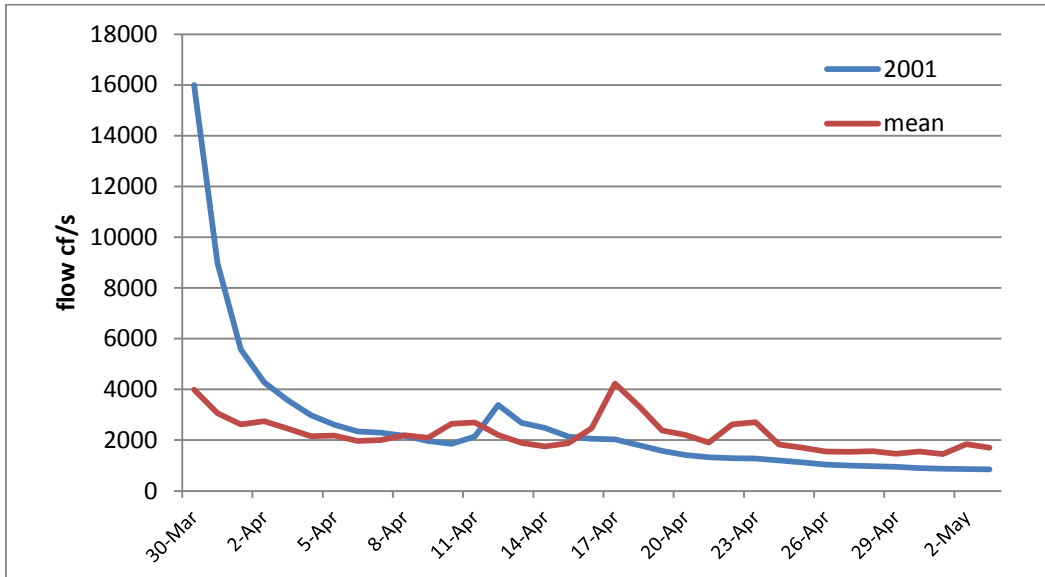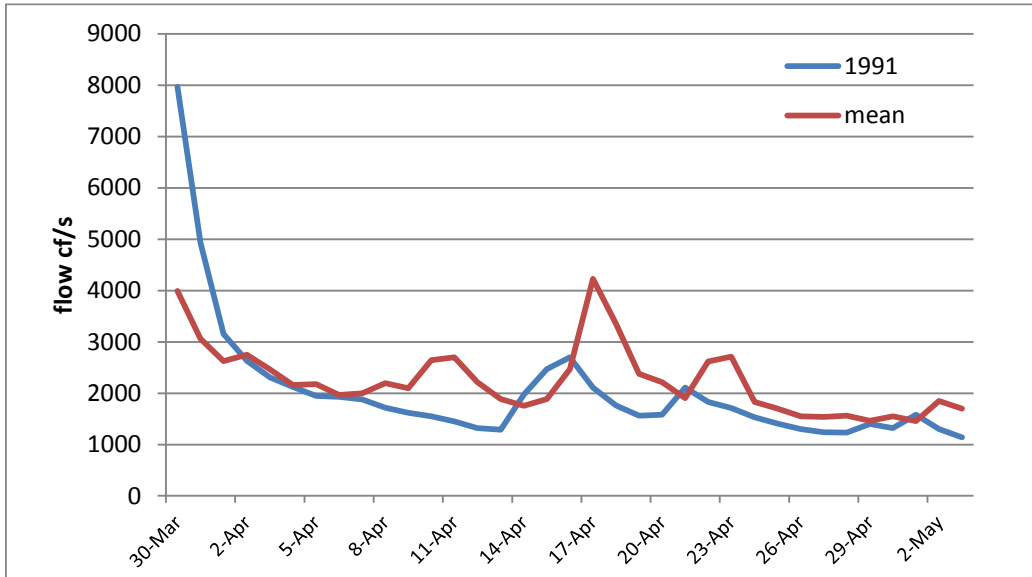
Figure 9. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1998-1999.
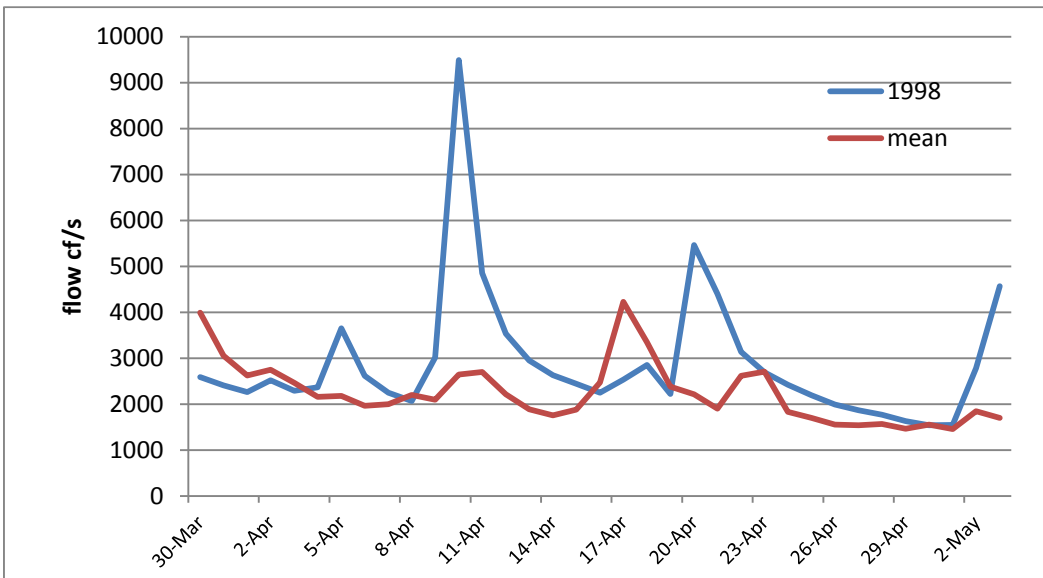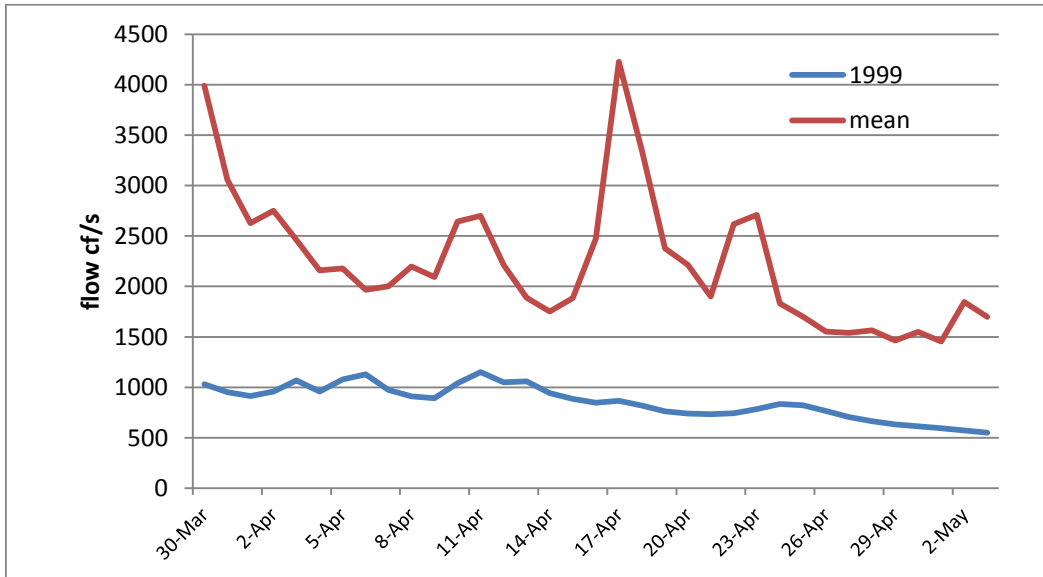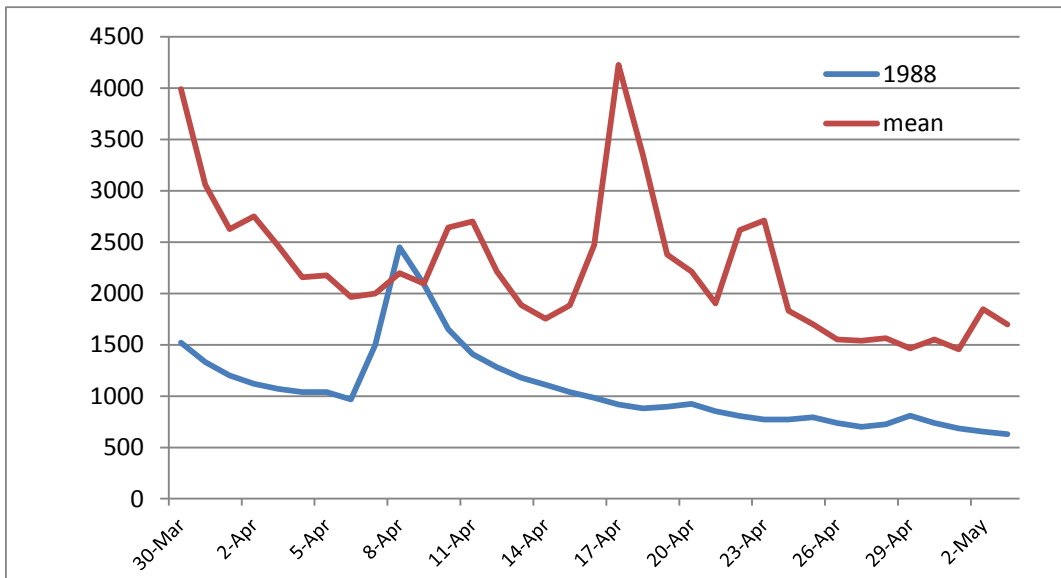
Figure 10. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1996-1997.
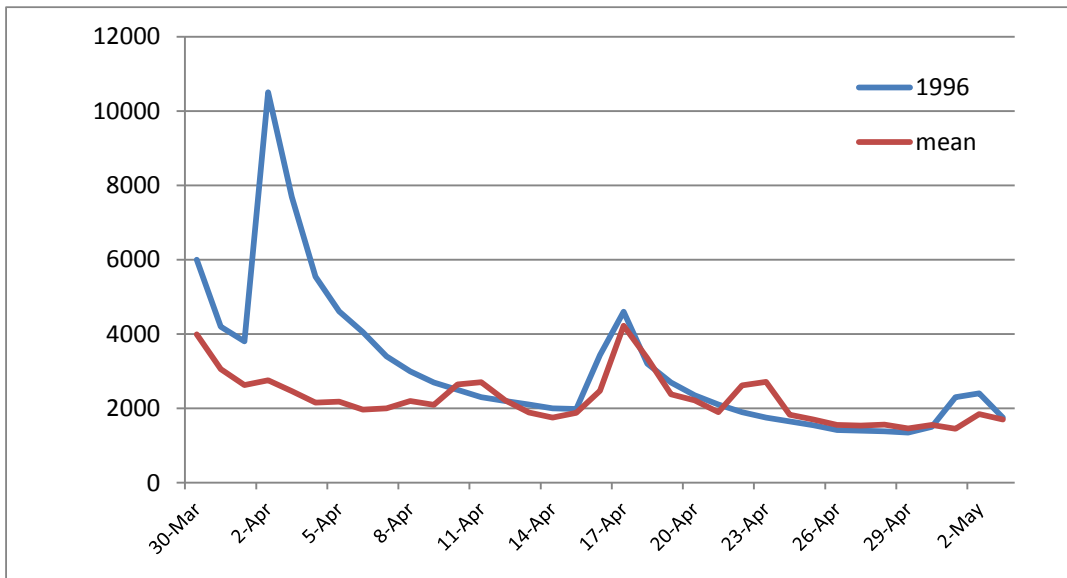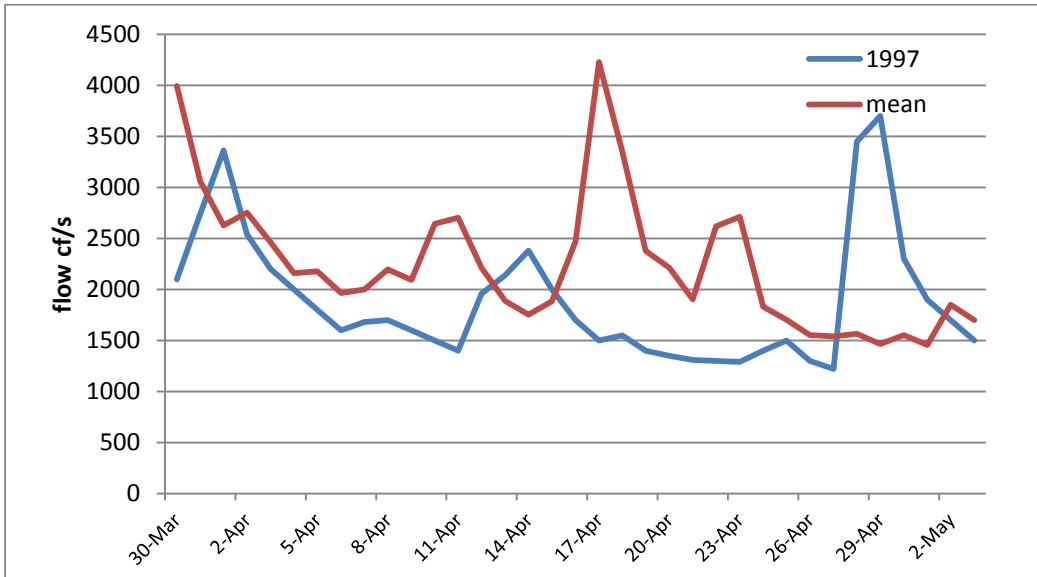
Figure 11. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1994-1995.
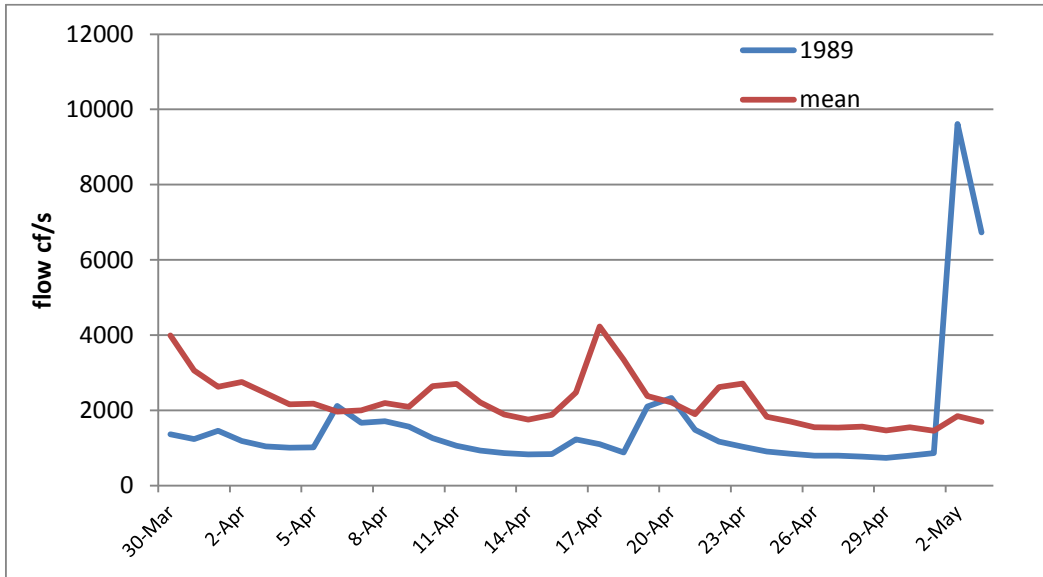
Figure 12. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1992-1993.

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

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

Figure 15. Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, springs 1986-1987.
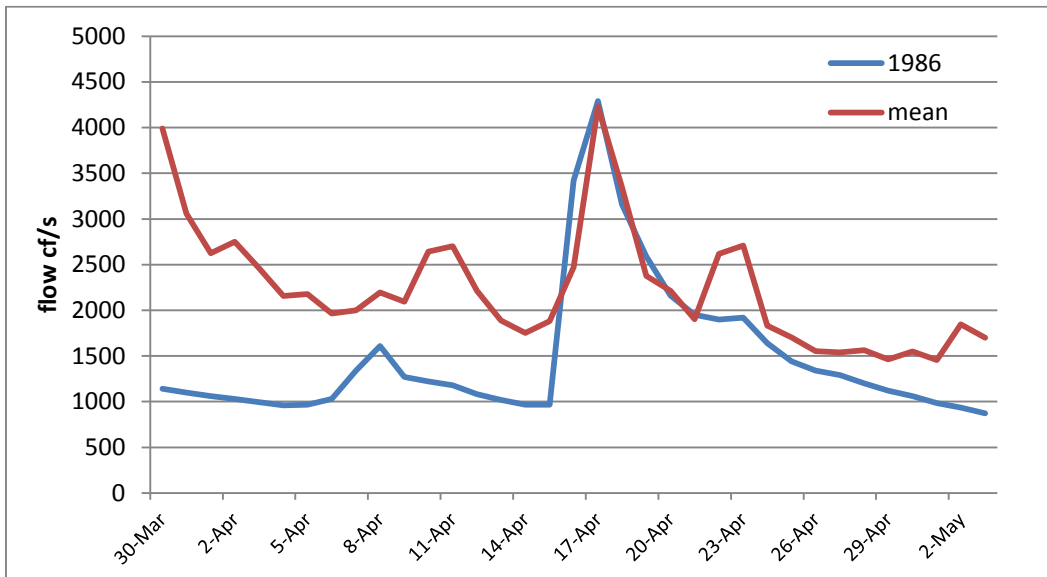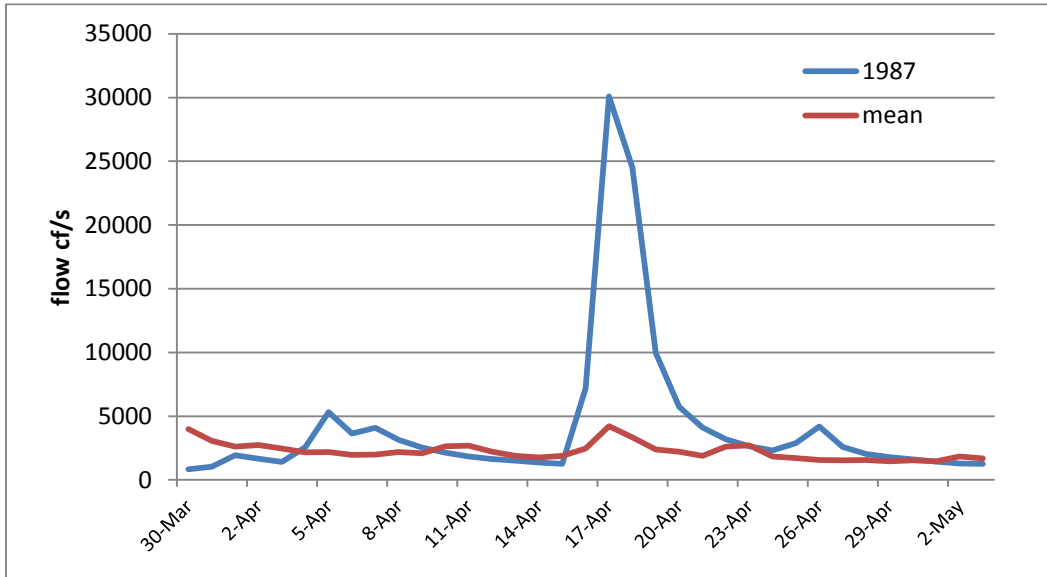
Figure 16.   Daily and historic mean river flows (cf/s) for the Rappahannock River during the spawning stock assessment period, spring 1985.