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Evaluation of Striped Bass Stocks in Virginia: Monitoring and Tagging Studies, 2019 Progress Report 1 December 2018 - 31 November 2019

Robert J. Latour
Virginia Institute of Marine Science

Christopher F. Bonzek
Virginia Institute of Marine Science

James Gartland
Virginia Institute of Marine Science

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Evaluation of Striped Bass Stocks in Virginia: Monitoring and Tagging Studies, 2019

Progress Report

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Principal Investigator: Robert J. Latour

Prepared by:

Robert J. Latour, Christopher F. Bonzek, James Gartland

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

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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 December 2018 through 31 November 2019. It includes an assessment of the biological characteristics of striped bass taken from the 2019 spring spawning run and estimates of annual survival and fishing mortality based on annual spring tagging. 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 declines 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). Federal legislation was enacted in 1984 (Public Law 98-613, the Atlantic Striped Bass Conservation Act) which enables Federal imposition of a moratorium for an indefinite period in those states that fail to comply with the coast-wide plan. To be in compliance with the plan, coastal states have imposed restrictions on their commercial and recreational striped bass fisheries ranging from combinations of catch quotas, size limits, closed periods and year-round moratoriums. Due to an improvement in spawning success, as judged by increases in annual values of the Maryland juvenile index, a limited fishery was established in fall, 1990. This transitional fishery existed until 1995 when spawning stock biomass reached sufficiently healthy levels (Field 1997). ASMFC subsequently declared Chesapeake Bay stocks to have reached benchmark levels and adopted Amendment 5 to the original FMP that allowed expanded state fisheries.

To document continued compliance with Federal law, the Virginia Institute of Marine Science (VIMS) has monitored the size and age composition, sex ratio and maturity schedules of the spawning striped bass stock in the Rappahannock River since December 1981 utilizing commercial pound nets and, from 1991-2014, variable-mesh experimental gill nets. Spawning stock assessment was expanded to include the James River in 1994, utilizing commercial fyke nets and variable-mesh experimental gill nets. An experimental fyke net was established in the James River to assess its potential as a source for tagging striped bass. The use of fyke nets was discontinued after 1997. In conjunction with the monitoring studies, tagging programs have been conducted in the James and Rappahannock rivers since 1987. These studies were established to document the migration and relative contribution of these Chesapeake Bay stocks to the coastal population and to provide a means to estimate annual survival rates (S). With the re- establishment of fall recreational fisheries in 1993, the tagging studies were expanded to include the York River and western Chesapeake Bay to provide a direct estimation of the resultant fishing mortality (F). Commencing in 2005, these estimates of F were estimated from the striped bass tagged during the spring in the Rappahannock River. In 2015, tagging and monitoring activities were expanded to encompass three rivers – the James, York and Rappahannock Rivers. In a meeting in September 2017 the ASMFC Striped Bass Technical Committee concluded that the Virginia pound net spawning stock monitoring program had inherent shortcomings which rendered the resulting CPUE indices unsuitable for inclusion in future stock assessments. That action, combined with budget cuts necessitated by VMRC resulted in a major change in methodology to both the spawning stock monitoring and tagging portions of the program. In 2018 monitoring was accomplished using multi-panel anchor gill nets and tagging was conducted via electrofishing. Methodologies are fully described later in this report.

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I. Spawning Stock Monitoring

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Spawning Stock Monitoring
Spring 2019

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 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 and James Rivers between 19 February and 7 May, 2019 by the VIMS Multispecies Research Group (MRG). All samples were obtained using two 300-foot multi-panel anchor gill nets consisting of 10 panels each set once per week in approximately the same locations each time. Each panel was 30ft. (18.28m) in length and 10ft. (3.05m) in depth. The ten stretched mesh sizes (in inches) are 3, 3.75, 4.5, 5.25, 6, 6.5, 7, 8, 9, and 10. These mesh sizes correspond to those used by the Maryland Department of Natural Resources spawning stock monitoring program. The order of the panels in each net was determined randomly prior to net construction. Two nets were set in close proximity (~1/4 mile apart) for each sampling event. The relative locations of the two nets were randomly assigned each week. The gear was set by MRG scientists (a change from past practice when commercial fishermen handled the fishing gear) and retrieved 24 hours later. All specimens were brought back to VIMS for processing (lengths, weight, sex and maturity, with scales, otoliths and stomachs preserved for later analysis) and disposal. The fishing locations were within the striped bass spawning areas as defined by VMRC (Figure 1).

Striped bass collected from the monitoring sites were measured on a MRG-made "Ichthystick" electronic fish measuring board and weighed using a Mettler PM 30000-K electronic balance. The board records lengths (FL and TL) to the nearest 1mm, and the scale to the nearest 10g. Both are integrated into the FEED (Fisheries Environment for Electronic Data) software system which allows manual input of sex and gonad maturity into a data base 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 scale-derived ages.

Otoliths were cleansed of external tissue material by successive rinses in water immediately after extraction. The right sagitta were prepared for ageing by being placed on melted crystal bond and sectioned to a one millimeter thickness on a Buehler Isomet saw. These transverse sections were then polished using 320-400 grit wet sandpaper. The polished sections were then covered over with a thin layer of crystal bond. The sections are read using a Motic stereo dissecting microscope under 25x magnification.

Each otolith was aged by each of three readers using the methods described by Wischniowski and Bobko (1998). Similarly, all readable scales from the monitoring specimens were aged by three readers. For otoliths, final ages assigned if at least two readers agreed. In cases in which all three readers disagreed the structure was re-analyzed by each reader and if agreement was still not found then the readers would conference together until consensus was reached. As scales are considered a secondary source for this part of the program, ages were assigned by just a single reader, with a selection of samples then read by a senior scientist. Agreement between the two readers was greater than 80%. The annual birthdate is assumed to be 1 January of each year.

River-specific spawning stock catch-per-unit-effort (CPUE) indices were calculated for all mature specimens captured and for several subgroups of fish (e.g. by sex). The unit of effort used was a standardized 24-hour set (the actual number of hours fished divided by 24). Data from the two nets in each location were treated as independent samples. The assumption of independence will be tested as more data are collected in future years. As each net contained the same selection of mesh sizes and equal panel dimensions, the net measurements were dropped from the calculations. This may also have to be amended in future years if individual nets or net panels are rendered inoperable during a sampling day.

Results

Catch Summary

Striped bass (n= 379) were sampled from gill nets in the Rappahannock River while 77 fish were sampled from the James between 19 February and 7 May, 2019. These numbers were considerably lower than those from 2018 (Rapp: 942, James: 215) which was the first year in which gill nets were used as the primary sampling gear. However, total catch numbers were comparable to those of recent years using pound nets in the Rappahannock.

In the Rappahannock, total daily catches varied from 1-186 striped bass, with the peak catch on 9 April. In the James, daily catches were between 1 and 16 fish with the maximum falling on 28 March. Surface water temperatures in the James hovered near 8℃ for the first four weeks of sampling (through mid-March) then rose quickly to 12℃-13℃ during mid-March to early-April, rose again by another 4℃ by 9 April then increased steadily during the rest of the season to about 23.5℃ by early May. Water temperatures in the Rappahannock followed a similar pattern but were generally 1℃-2℃ cooler than those in the James. As is typical, peak spawning in the Rappahannock occurred once the temperature rose above 16℃ but in the James no particular temperature related pattern of catch was observed in 2019 (Table 1, Figure 2). Salinities in both rivers were very low (0.02 – 0.07) during the entire sampling period (Table 1, Figure 2).

Males dominated the catch in both rivers (Rapp-356M:23F, James-61M:15F) though the proportions varied between rivers (Rapp - 93.9%, James – 80.3% / Table 2, Figure 3). Catches of female striped bass in both rivers peaked during the second and third weeks of April though the numbers were small.

In the Rappahannock males ranged in age from 2 (6 specimens, all either mature or running ripe) to 9 (1 specimen). Rappahannock females were between ages 5 to 23. In the James the youngest males were age-2 (7 fish, all either mature or maturing) and the oldest was age-9 (1 fish). James females ranged between age-2 (1 fish, maturing) and age-14. Males captured in the Rappahannock were predominantly ages 4-6 (2013-2015 year classes) though there were also a large number of age-8 males (2010 yc). These were the same year classes which were most abundant in 2018. In the James, males 3 to 5 (2014-2016 yc) were most abundant. Females in both rivers were far fewer in number (maximum catch/age = 4) so detecting peak age classes was not possible. In the Rappahannock females ranged between 5 and 23 years (1996-2014 yc) while in the James captured females were between 2 and 4 years old (2017-2005 yc - Table 3, Figures 4a,4b).

Biomass catch rate (kg/set) followed a similar weekly pattern as catch in numbers, beginning at low values in February, reaching a peak in mid-April then steadily declining over a two-to-three-week period and falling to near zero by 7 May, though the pattern was somewhat more pronounced in the Rappahannock than in the James (Table 4, Figure 5).

The ratio of males:females varied weekly, between 3.3:1 – 53.0:1 in the Rappahannock and between 0.0:1 – 15.0:1 in the James, excluding several weeks in which no females were captured. Over the entire season the sex ratio in the Rappahannock was 15.5:1 and in the James was 4.1:1 (Table 4).

The upstream or downstream position of the two nets fished at each location did not appear to have an effect on the catch rate, though sample sizes are relatively small. For 2019, in the Rappahannock, the average catch of whichever net was set in the downstream position was 306.3 kg (148.8 fish) compared to the upstream net which averaged 473.2 kg (238.8 fish). In the James however, the downstream net averaged more biomass and more fish (102.2 kg / 42.6 fish) than the upstream net (70.7 kg / 32.4 fish). This was the same pattern as was observed in 2018 and will bear investigation if the pattern continues in future years. A paired t-test with all data combined found no significant difference due to the relative net position ($p = 0.44$ – biomass / $p = 0.38$ count / $df = 20$). These patterns are generally apparent with data from both years plotted together (Figure 6).

In the Rappahannock, the 356 male striped bass sampled in 2019 averaged 471.5mm (TL), 1.218kg and 4.4 years which were all moderate increases compared to 2018 (434.1 mm, 0.986 kg, 3.9 yr). Rappahannock females (23 specimens) had a mean length of 926.9mm, a mean weight of 14.110kg and on average were 11.7 years old which also were all moderate increases compared to the spring of 2018. In the James River, 62 male specimens averaged 455.6mm in length, 1.205kg and 4.2 years (somewhat smaller than 2018 fish but also 0.3 years younger on average) while averages for the 15 sampled females were 725.7mm, 6.252kg and 7.2 years (both larger and older than averaged fish from 2018 – Table 5, Figure 7).

Rappahannock male fish displayed a broad peak in abundance between 410-550 mm total lengths. Rappahannock females fell into two general groups from 600mm-830mm and 950mm-1130mm. While smaller in number and with a narrower size range, males in the James River showed peak abundance somewhat smaller than their Rappahannock counterparts with the largest cohort ranging between 370mm and 530mm. Females in the James were also smaller than their Rappahannock counterparts with groups between 460mm and 620mm and 740mm-800mm (Table 6, Figure 8). Within each year class, females on average were slightly larger and heavier than males (Table 7, Figure 9).

Spawning Stock Biomass Indexes

The overall (all data pooled) mean biomass index for the Rappahannock and James rivers were 30.1 kg/day (confidence interval (CI) = 9.8-50.5) and 6.5 kg/day (CI = 3.2-9.9) respectively, representing 15.1 (Rappahannock, CI = 4.6-25.6) and 30 (James, CI = 1.8-4.2) fish per day on average. For females the average catch was 23.9 kg/day (CI = 10.1 – 37.6) in the Rappahannock and 5.1 (CI = 1.5-8.7) in the James. In contrast to 2018, the average daily catch for males was lower than that for females in the Rappahannock at 14.8 kg/day (CI = 6.1-23.5) as well as in the James at 3.7 kg/day (CI = 2.4 – 4.9 / Table 8).

In both rivers, most fish were captured in the smaller mesh panels (<=4.5”) and in the largest meshes (9” and 10” - Table 9, Figure 10). Female fish in the Rappahannock were primarily captured in the largest mesh panels (8”, 9”, 10”) while males were captured across multiple mesh sizes with peaks at the smallest and largest meshes. In the James, the pattern of catch rates across mesh sizes was similar for both sexes with maximum captures between 3.75” to 6” and at the larger mesh panels, 8”, 9”, 10” (Table 10, Figure 11).

Age Determinations using Scales and Otoliths

With a small number of exceptions all specimens (447 out of 456) were aged using both scales and otoliths. Compared to otolith ages, mean scale ages at all age classes were lower, with the exception of age-3 otolith-aged fish where the average scale age was 3.25. underestimate at age 8 and older (Table 10, Figure 11). Between ages-2 and 4 both methods, on average, produced very similar results. Beginning with age-5 however they started to diverge and the discrepancy increased at older ages. There was significant variability within any given age-class, best exemplified by the otolith age-8 fish. Scale age for these specimens averaged 6.79 years but ranged between 4 and 9 years (Figure 12).

Otolith and scale ages were in agreement in 333 of 447 paired samples (74.5%), within one year on 94.4% (422/447) of the time and within two years for 97.5% (436/447) of specimens. A total of 11 fish differed in age by three or more years with the maximum difference being 9 years (otolith age 14 v. scale age 5 – Figure 13). Readers were unanimous on 412 of 450 otoliths (91.6%) with two of three readers were in agreement on the other 38 (8.4%) of otoliths.

Literature Cited

Berggren, T.J. and J.T. Lieberman. 1978. Relative contribution of Hudson, Chesapeake and Roanoke striped bass, *Morone saxatilis,* stocks to the Atlantic coast fishery. U. S. Fish. Bull. 76(2): 335-345.

Chapoton, R.B. and J.E. Sykes. 1961. Atlantic coast migration of large striped bass as evidenced by fisheries and tagging. Trans. Amer. Fish. Soc. 90(1):13-20.

Dorazio, R.M., K.A. Hattala, C.B. McCollough and J.E. Skjeveland. 1994. Tag recovery estimates of migration of striped bass from spawning areas of the Chesapeake Bay. Trans. Amer. Fish. Soc. 123: 950-963.

Field, J.D. 1997. Atlantic striped bass management: where did we go right? Fisheries 22(7): 6-8.

Grant, G.C. and J.E. Olney. 1991. Distribution of striped bass *Morone saxatilis* (Walbaum) eggs and larvae in major Virginia rivers. U. S. Fish. Bull. 89:187-193.

Hardy, J.D. Jr. 1978. Development of fishes of the mid-Atlantic bight. Vol. III, Aphrederidae through Rachycentridae. U. S. Fish Wildl. Serv. FWS/OBS-78/12.

Lewis, R.M. 1957. Comparative study of populations of the striped bass. U. S. Fish and Wildlife Service Spec. Rep. Fisheries 204:1-54.

McGovern, J.C. and J.E. Olney. 1996. Factors affecting survival of early life stages and subsequent recruitment of striped bass on the Pamunkey River, Virginia. Can. J. Fish. Aquat. Sci. 53: 1713-1726.

Merriman, D. 1941. Studies on the striped bass (*Roccus saxatilis*) of the Atlantic Coast. Fish. Bull. U.S. Fish Wildl. Serv. 50(35):1-77.

Olney, J.E., J.D. Field, and J.C. McGovern. 1991. Striped bass egg mortality, production and female biomass in Virginia rivers, 1980-1989. Trans. Amer. Fish. Soc. 120: 354-367.

Pearson, J.C. 1938. The life history of the striped bass, or rockfish, *Roccus saxatilis* (Walbaum). U. S. Fish. Bull. 49: 825-851.

Raney, E.C. 1957. Subpopulations of the striped bass *Roccus saxatilis* (Walbaum), in tributaries in Chesapeake Bay. U. S. Fish Wildl. Serv., Spec. Sci. Fish. 208: 85-107.

Literature Cited (cont.)

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Bd. Can. Bull. 191: 382 p.

Rugolo, L.J., P.W. Jones, R.K. Schaefer, K.S. Knotts, H.T. Hornick and J.L. Markham. 1994. Estimation of Chesapeake Bay-wide exploitation rate and population abundance for the 1993 striped bass stock. Manuscript, Maryland Department of Natural Resources, Annapolis, Md.

Secor, D.H. 1999. Specifying divergent migrations in the concept of stock: the contingent hypothesis. Fisheries research 43: 13-34.

Secor, D.H., T.M. Trice and H.T. Hornick. 1995. Validation of otolith-based ageing and a comparison of otolith and scale-based ageing in mark-recaptured Chesapeake Bay striped bass, *Morone saxatilis.* Fish. Bull. 93:186-190.

Van Winkle, W., K.D. Kumar, and D.S. Vaughan. 1988. Relative contributions of Hudson River and Chesapeake Bay striped bass stocks to the Atlantic Coast population. Amer. Fish. Soc. Mono. 4: 255-266.

Wischniowski, W. and S. Bobko. 1998. Age and growth laboratory manual. Final report Old Dominion Univ. Center for Quantitive Fisheries Ecology.

Table 1. Number and biomass of striped bass captured, water temperature, and salinity by week in the Rappahannock and James Rivers, spring 2019.

River	Week-of-Year	Sample Date	Number Caught	Biomass Caught (kg)	Water Temp. (C)	Salinity (ppt)
Rappahannock	8	19-Feb-19	8	11.83	6.6	0.03
	9	28-Feb-19	14	17.14	6.7	0.03
	10	08-Mar-19	7	8.07	5.9	0.03
	11	12-Mar-19	4	4.99	6.3	0.03
	12	19-Mar-19	9	9.41	10.5	0.03
	13	28-Mar-19	8	28.1	9.4	0.02
	14	04-Apr-19	13	80.31	12.4	0.02
	15	09-Apr-19	186	359.4	15.7	0.03
	16	17-Apr-19	68	144.7	18.7	0.03
	17	23-Apr-19	54	81.5	20.8	0.03
	18	30-Apr-19	7	9.93	19.5	0.03
	19	07-May-19	1	2.76	22.7	0.03
James	8	19-Feb-19	1	2.2	7.7	0.07
	9	28-Feb-19	11	14.75	8.8	0.04
	10	07-Mar-19	4	3.75	7.8	0.05
	11	12-Mar-19	3	7.61	8.2	0.05
	12	19-Mar-19	3	18.09	12.9	0.06
	13	28-Mar-19	16	31.14	11.8	0.04
	14	04-Apr-19	10	12.23	13.4	0.06
	15	09-Apr-19	9	45.33	17.0	0.06
	16	17-Apr-19	5	3.47	17.6	0.05
	17	23-Apr-19	10	17.77	19.2	0.05
	18	30-Apr-19	4	10.71	20.1	0.05
	19	07-May-19	1	1.43	23.7	0.07

Table 2. Catch rates by week and sex for the Rappahannock and James Rivers, spring 2019.

River	Week-of-Year	Sample Date	Males	Females	Percent Males
Rappahannock	8	19-Feb-19	7	1	88%
	9	28-Feb-19	14	0	100%
	10	08-Mar-19	6	1	86%
	11	12-Mar-19	4	0	100%
	12	19-Mar-19	9	0	100%
	13	28-Mar-19	7	1	88%
	14	04-Apr-19	10	3	77%
	15	09-Apr-19	178	8	96%
	16	17-Apr-19	61	7	90%
	17	23-Apr-19	53	1	98%
	18	30-Apr-19	6	1	86%
	19	07-May-19	1	0	100%
James	8	18-Feb-09	0	1	0%
	9	28-Feb-19	11	0	100%
	10	07-Mar-19	3	1	75%
	11	12-Mar-19	2	0	100%
	12	19-Mar-19	2	0	100%
	13	28-Mar-19	15	1	94%
	14	04-Apr-19	9	1	90%
	15	09-Apr-19	5	4	56%
	16	17-Apr-19	4	1	80%
	17	23-Apr-19	8	2	80%
	18	30-Apr-19	2	2	50%
	19	07-May-19	1	0	100%

Table 3. Otolith age frequencies by river and sex, spring 2019.

Otolith Age	Rappahannock		James	
	Females	Males	Females	Males
1	0	0	0	0
2	0	6	1	8
3	0	8	0	14
4	0	231	2	12
5	4	77	4	20
6	2	20	1	5
7	1	1	0	1
8	1	10	2	1
9	2	1	0	1
10	1	0	2	0
11	0	0	2	0
12	1	0	0	0
13	1	0	0	0
14	2	0	1	0
15	2	0	0	0
16	2	0	0	0
17	1	0	0	0
18	0	0	0	0
19	2	0	0	0
20	0	0	0	0
21	0	0	0	0
22	0	0	0	0
23	1	0	0	0
24	0	0	0	0
25	0	0	0	0

Table 4. Weekly total biomass, by sex, of striped bass captured in the Rappahannock and James Rivers, spring 2019.

River	Week-of-Year	Sample Date	Males	Females	Ratio Males:Females
Rappahannock	10	10-Mar-18	13.26	0.00	n/a
	11				n/a
	12	19-Mar-18	15.44	0.00	n/a
	13	26-Mar-18	13.38	16.74	0.8:1
	14	02-Apr-18	72.33	35.10	2.06:1
	15	12-Apr-18	126.12	35.40	3.56:1
	16	18-Apr-18	35.05	109.62	0.32:1
	17	26-Apr-18	226.37	18.53	12.22:1
	18	03-May-18	398.97	62.06	6.43:1
	19	10-May-18	0	1.47	0:1
James	10	09-Mar-18	3.59	11.14	0.32:1
	11	14-Mar-18	6.92	14.36	0.48:1
	12	23-Mar-18	0	3.20	0:1
	13	28-Mar-18	5.91	1.17	5.05:1
	14	05-Apr-18	12.16	0.00	n/a
	15	09-Apr-18	7.8	15.81	0.49:1
	16	16-Apr-18	114.39	35.31	3.24:1
	17	23-Apr-18	2.77	27.13	0.1:1
	18	01-May-18	84.27	42.18	2:1
	19	09-May-18	3.28	3.19	1.03:1

Table 5. Average length (mm), weight (g) and age of striped bass by year, river and sex, spring 2019. Double lines indicate changes in sampling methods and/or locations.

	Rappahannock River								James River								Overall							
	Males				Females				Males				Females				Males				Females			
Year	n	Mean TL (mm)	Mean Wt (g)	Mean Age	n	Mean TL (mm)	Mean Wt (g)	Mean Age	n	Mean TL (mm)	Mean Wt (g)	Mean Age	n	Mean TL (mm)	Mean Wt (g)	Mean Age	n	Mean TL (mm)	Mean Wt (g)	Mean Age	n	Mean TL (mm)	Mean Wt (g)	Mean Age
1990	595	476.5	1352	4.3	176	528.1	2330	5.1	15	493.9	1595		27	549.9	2157		625	478.7	1373	4.3	210	532.2	2297	5.1
1991	1549	524.5	1695	3.6	569	549.6	2059	3.7	0		1070		1	846.0	3404		1687	527.3	1728	3.6	602	550.0	2058	3.7
1992	694	521.8	1620	3.6	332	595.8	2865	4.8									709	523.0	1639	3.6	341	600.8	2944	4.8
1993	1229	515.8	1762	3.8	561	610.4	3425	4.9									1229	515.8	1762	3.8	561	610.4	3425	4.9
1994	936	536.7	1864	4.0	342	702.9	4749	6.0	171	537.1	1868	4.2	66	709.7	4822	6.4	1107	536.8	1864	4.0	408	704.0	4760	6.1
1995	1327	445.3	1224	3.3	405	589.6	3583	5.1	1143	512.7	1743	3.9	423	687.4	4600	6.1	2470	476.5	1464	3.6	828	639.6	4102	5.6
1996	647	467.3	1221	3.5	136	578.6	2715	4.8									647	467.3	1221	3.5	136	578.6	2715	4.8
1997	522	482.1	1401	3.9	133	862.3	8408	9.1									522	482.1	1401	3.9	133	862.3	8408	9.1
1998	697	471.6	1192	3.7	119	897.0	8498	9.3									697	471.6	1192	3.7	119	897.0	8498	9.3
1999	1103	447.3	1029	3.5	51	825.6	7186	8.6									1103	447.3	1029	3.5	51	825.6	7186	8.6
2000	1937	471.0	1113	2.7	80	853.5	7408	7.7									1937	471.0	1113	2.7	80	853.5	7408	7.7
2001	472	511.9	1571	3.3	105	875.4	7339	8.1									472	511.9	1571	3.3	105	875.4	7339	8.1
2002	111	534.3	1938	3.5	41	781.2	5833	6.5									111	534.3	1938	3.5	41	781.2	5833	6.5
2003	283	585.0	2413	4.2	186	893.2	8306	8.5									283	585.0	2413	4.2	186	893.2	8306	8.5
2004	631	585.8	2529	4.3	236	877.8	8014	8.4									631	585.8	2529	4.3	236	877.8	8014	8.4
2005	446	550.7	2104	3.9	171	875.3	7996	8.6									446	550.7	2104	3.9	171	875.3	7996	8.6
2006	623	479.8	1370	3.5	119	828.0	6876	5.6									623	479.8	1370	3.5	119	828.0	6876	5.6
2007	748	561.5	2233	5.0	356	896.9	8427	10.5									748	561.5	2233	5.0	356	896.9	8427	10.5
2008	413	504.5	1594	4.3	74	801.7	6632	8.6									413	504.5	1594	4.3	74	801.7	6632	8.6
2009	437	573.5	1821	5.1	183	786.0	5037	8.3									437	573.5	1821	5.1	183	786.0	5037	8.3
2010	828	568.4	1040	5.2	219	871.3	5481	10.1									828	568.4	1040	5.2	219	871.3	5481	10.1
2011	131	625.9	1140	6.1	84	851.3	7123	9.5									131	625.9	1140	6.1	84	851.3	7123	9.5
2012	321	577.1	2390	5.5	117	859.5	8405	9.8									321	577.1	2390	5.5	117	859.5	8405	9.8
2013	152	556.6	745	5.3	94	855.4	5514	10.1									152	556.6	745	5.3	94	855.4	5514	10.1
2014	126	507.9	1958	4.8	95	925.0	9910	11.1									126	507.9	1958	4.8	95	925.0	9910	11.1
2015	108	508.9	1565	4.5	44	917.2	9795	11.4									108	508.9	1565	4.5	44	917.2	9795	11.4
2016	305	480.3	1260	4.1	57	906.3	9830	10.8									305	480.3	1260	4.1	57	906.3	9830	10.8
2017	204	453.8	1138	4.0	17	746.6	6475	8.4									204	453.8	1138	4.0	17	746.6	6475	8.4
2018	916	434.1	986	3.9	25	912.0	10997	10.4	179	483.7	1347	3.9	36	669.7	4664	5.2	1095	442.2	1045	3.9	61	769.0	7259	7.3
2019	356	471.5	1218	4.4	23	926.9	14110	11.7	62	455.6	1205	4.2	15	725.7	6252	7.2	418	469.1	1216	4.4	38	847.4	11008	9.9

Table 6. Length frequencies (mm TL) of striped bass sampled from the gill nets, spring 2019.

Length	Rapp-males	Rapp-females	James-males	James-females	Length	Rapp-males	Rapp-females	James-males	James-females
300	1	0	1	0	800	0	0	0	1
310	2	0	1	0	810	0	0	0	0
320	1	0	3	0	820	0	0	0	0
330	0	0	0	0	830	0	1	0	0
340	3	0	3	0	840	0	0	0	0
350	0	0	0	0	850	0	0	0	0
360	1	0	0	0	860	0	0	0	0
370	0	0	1	0	870	0	0	0	0
380	1	0	1	0	880	0	0	0	0
390	4	0	1	0	890	0	0	0	0
400	7	0	3	0	900	0	0	0	0
410	13	0	0	0	910	0	0	0	0
420	19	0	3	0	920	0	0	0	0
430	14	0	2	0	930	0	0	0	0
440	28	0	5	0	940	0	0	0	0
450	18	0	3	0	950	0	1	0	0
460	52	0	5	1	960	0	1	0	0
470	44	0	4	0	970	0	0	0	0
480	28	0	4	0	980	0	0	0	0
490	21	0	3	0	990	0	0	0	0
500	22	0	6	1	1000	0	1	0	1
510	15	0	3	0	1010	0	0	0	0
520	17	0	2	0	1020	0	0	0	0
530	10	0	3	1	1030	0	0	0	0
540	8	0	1	1	1040	0	0	0	0
550	5	0	0	0	1050	0	0	0	0
560	2	0	1	0	1060	0	1	0	3
570	7	0	0	0	1070	0	2	0	0
580	3	0	0	1	1080	0	1	0	0
590	1	0	1	2	1090	0	0	0	0
600	2	1	0	0	1100	0	2	0	0
610	2	0	1	0	1110	0	0	0	0
620	1	1	1	1	1120	0	1	0	0
630	1	2	0	0	1130	0	2	0	0
640	0	1	0	0	1140	0	0	0	0
650	0	1	0	0	1150	0	0	0	0
660	1	0	0	0	1160	0	0	0	0
670	0	0	0	0	1170	0	0	0	0
680	0	0	0	0	1180	0	0	0	0
690	0	0	0	0	1190	0	0	0	0
700	1	0	0	0	1200	0	0	0	0
710	0	0	0	0	1210	0	0	0	0
720	0	0	0	0	1220	0	2	0	0
730	0	1	0	0	1230	0	0	0	0
740	0	0	0	1	1240	0	0	0	0
750	0	0	0	0	1250	0	0	0	0
760	0	0	0	0	1260	0	0	0	0
770	0	0	0	1	1270	0	0	0	0
780	0	1	0	0	1280	0	0	0	0
790	0	0	0	0	1290	0	0	0	0
					1300	0	0	0	0

Table 7. Average length (mm) and weight (g), with standard deviations (Std Dev) of striped bass by year class, spring 2019.

Year Class	Females					Males				
	n	Mean TL (mm)	Std Dev	Mean Wt. (g)	Std Dev	n	Mean TL (mm)	Std Dev	Mean Wt. (g)	Std Dev
2017	1	502.0		1,450		14	349.6	65.5	508	404.5
2016						22	413.4	49.9	857	385.7
2015	2	491.5	50.2	1,325	148.5	243	461.2	36.2	1,104	280.6
2014	8	606.4	37.6	2,819	529.0	97	490.2	60.0	1,421	379.0
2013	3	614.7	23.9	2,467	275.4	25	517.8	48.1	1,604	413.0
2012	1	778.0		5,480		2	590.5	30.4	2,265	544.5
2011	3	781.7	47.9	5,987	1,154.0	11	578.7	68.3	2,319	781.3
2010	2	840.5	154.9	9,565	5,989.2	2	557.0	66.5	2,000	707.1
2009	3	1,026.3	61.8	14,677	1,171.6					
2008	2	1,028.0	41.0	14,505	1,251.6					
2007	1	1,070.0		17,490						
2006	1	1,075.0		14,550						
2005	3	1,043.7	220.8	19,613	11,126.6					
2004	2	1,114.5	20.5	23,020	1,640.5					
2003	2	1,080.0	28.3	21,045	445.5					
2002	1	1,001.0		18,640						
2000	2	1,146.0	107.5	26,165	7,856.0					
1996	1	1,126.0		18,680						

Table 8. Average catch per day by river and sex, in numbers and biomass with lower (LCL) and upper (UCL) confidence limits, spring 2019.

River	Sex	LCL	Number per Day	UCL	LCL	KG per day	UCL
Rapp	Combined	4.6	15.1	25.6	9.8	30.1	50.5
	F	0.9	1.7	2.5	10.1	23.9	37.6
	M	4.6	11.7	18.8	6.1	14.8	23.5
James	Combined	1.8	3.0	4.2	3.2	6.5	9.9
	F	0.4	0.8	1.1	1.5	5.1	8.7
	M	1.9	2.8	3.7	2.4	3.7	4.9

Table 9. Average catch per day by river and mesh size, in numbers and biomass with lower (LCL) and upper (UCL) confidence limits, spring 2019.

River	Mesh (in)	LCL	Number per Day	UCL	LCL	KG per Day	UCL
Rapp	3.00	0.34	2.52	4.71	0.41	2.43	4.46
	3.75	0.66	2.22	3.77	0.57	1.90	3.24
	4.50	0.27	8.51	16.75	0.22	10.99	21.76
	5.25	0.35	0.69	1.03	0.71	1.42	2.13
	6.00	0.00	0.32	0.67	0.00	0.90	1.91
	6.50	0.00	0.16	0.36	0.00	1.34	3.64
	7.00	0.00	0.20	0.40	0.00	2.58	5.37
	8.00	0.00	0.04	0.12	0.00	0.06	0.19
	9.00	0.04	0.28	0.52	0.67	5.59	10.52
	10.00	0.00	0.12	0.29	0.00	2.88	7.07
James	3.00	0.22	0.48	0.74	0.11	0.28	0.45
	3.75	0.06	0.32	0.57	0.08	0.30	0.52
	4.50	0.43	1.30	2.17	0.46	1.80	3.15
	5.25	0.17	0.48	0.80	0.28	0.90	1.51
	6.00	0.00	0.08	0.18	0.00	0.26	0.62
	6.50	0.00	0.08	0.18	0.00	0.17	0.43
	7.00	0.00	0.04	0.13	0.00	0.30	0.91
	8.00	0.00	0.04	0.12	0.00	0.26	0.79
	9.00	0.00	0.11	0.27	0.00	1.65	4.04
	10.00	0.00	0.04	0.13	0.00	0.62	1.85

Table 10. Average catch per day by river, sex and mesh size, in biomass with lower (LCL) and upper (UCL) confidence limits, spring 2019.

River	Sex	Mesh (in)	LCL	Number per Day	UCL	LCL	KG per Day	UCL
Rapp	Female	3.00	0.00	0.00	0.00	0.00	0.00	0.00
		3.75	0.00	0.00	0.00	0.00	0.00	0.00
		4.50	0.00	0.00	0.00	0.00	0.00	0.00
		5.25	0.00	0.14	0.33	0.00	0.38	0.91
		6.00	0.00	0.13	0.27	0.00	0.38	0.80
		6.50	0.00	0.13	0.31	0.00	1.34	3.74
		7.00	0.00	0.20	0.40	0.00	2.58	5.37
		8.00	0.00	0.00	0.00	0.00	0.00	0.00
		9.00	0.04	0.28	0.52	0.67	5.59	10.52
		10.00	0.00	0.12	0.29	0.00	2.88	7.07
	Male	3.00	1.40	3.37	5.33	1.43	3.24	5.06
		3.75	1.54	2.87	4.21	1.32	2.47	3.62
		4.50	3.22	9.73	16.23	4.05	12.56	21.07
		5.25	0.58	0.86	1.15	1.15	1.71	2.27
		6.00	0.02	0.27	0.53	0.03	0.74	1.44
		6.50	0.00	0.19	0.39	0.00	1.34	3.54
		7.00	0.00	0.20	0.40	0.00	2.58	5.37
		8.00	0.00	0.08	0.19	0.00	0.12	0.29
		9.00	0.04	0.28	0.52	0.67	5.59	10.52
		10.00	0.00	0.12	0.29	0.00	2.88	7.07
James	Female	3.00	0.00	0.00	0.00	0.00	0.00	0.00
		3.75	0.00	0.00	0.00	0.00	0.00	0.00
		4.50	0.00	0.29	0.58	0.00	0.65	1.39
		5.25	0.00	0.06	0.19	0.00	0.09	0.28
		6.00	0.00	0.08	0.18	0.00	0.26	0.62
		6.50	0.00	0.00	0.00	0.00	0.00	0.00
		7.00	0.00	0.04	0.13	0.00	0.30	0.91
		8.00	0.00	0.04	0.12	0.00	0.26	0.79
		9.00	0.00	0.11	0.27	0.00	1.65	4.04
		10.00	0.00	0.04	0.13	0.00	0.62	1.85
	Males	3.00	0.45	0.68	0.91	0.25	0.40	0.55
		3.75	0.25	0.51	0.77	0.25	0.48	0.70
		4.50	0.84	1.46	2.08	1.04	1.83	2.61
		5.25	0.39	0.69	0.99	0.71	1.30	1.89
		6.00	0.00	0.08	0.18	0.00	0.26	0.62
		6.50	0.01	0.14	0.27	0.00	0.32	0.65
		7.00	0.00	0.04	0.13	0.00	0.30	0.91
		8.00	0.00	0.04	0.12	0.00	0.26	0.79
		9.00	0.00	0.11	0.27	0.00	1.65	4.04
		10.00	0.00	0.04	0.13	0.00	0.62	1.85

Table 11. Average, standard error, minimum and maximum scale ages for each otolith age class from ages derived from the same specimen, spring 2019.

n	Otolith Age	Scale Age			
		MeanScaleAge	SE_ScaleAge	MinScaleAge	MaxScaleAge
15	2	2.33	0.16	2	4
20	3	3.25	0.16	3	6
242	4	4.00	0.01	2	5
103	5	4.63	0.05	4	6
28	6	5.14	0.15	4	8
3	7	6.33	0.67	5	7
14	8	6.79	0.38	4	9
4	9	7.75	0.25	7	8
3	10	10.00	1.15	8	12
2	11	11.00	1.00	10	12
1	12	11.00		11	11
1	13	13.00		13	13
3	14	10.67	2.85	5	14
2	15	13.00	1.00	12	14
2	16	11.50	1.50	10	13
1	17	15.00		15	15
2	19	12.50	0.50	12	13
1	23	18.00		18	18

Figure 1. Locations of gill nets sampled in spring spawning stock assessments of striped bass in the Rappahannock and James Rivers, spring 2019.

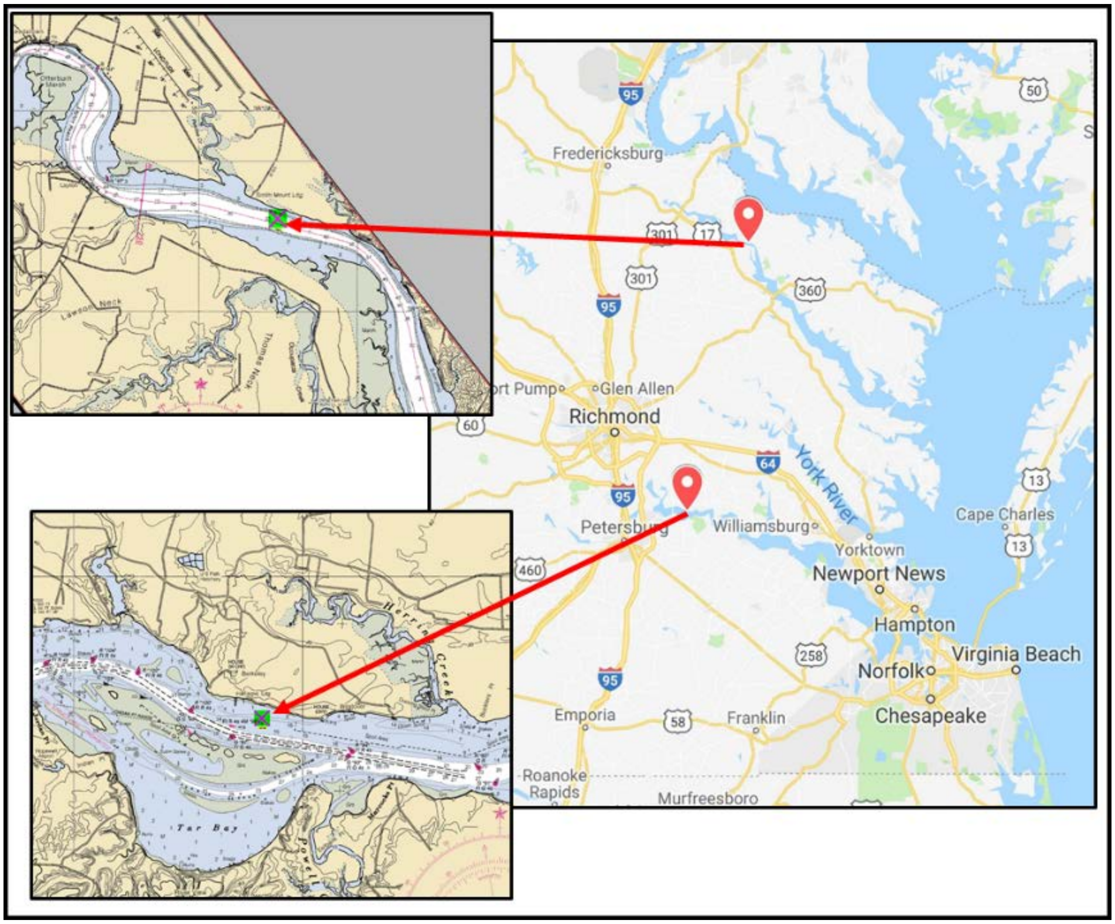


Figure 2. Number of striped bass captured and water temperature by week in the Rappahannock and James Rivers, spring 2019.

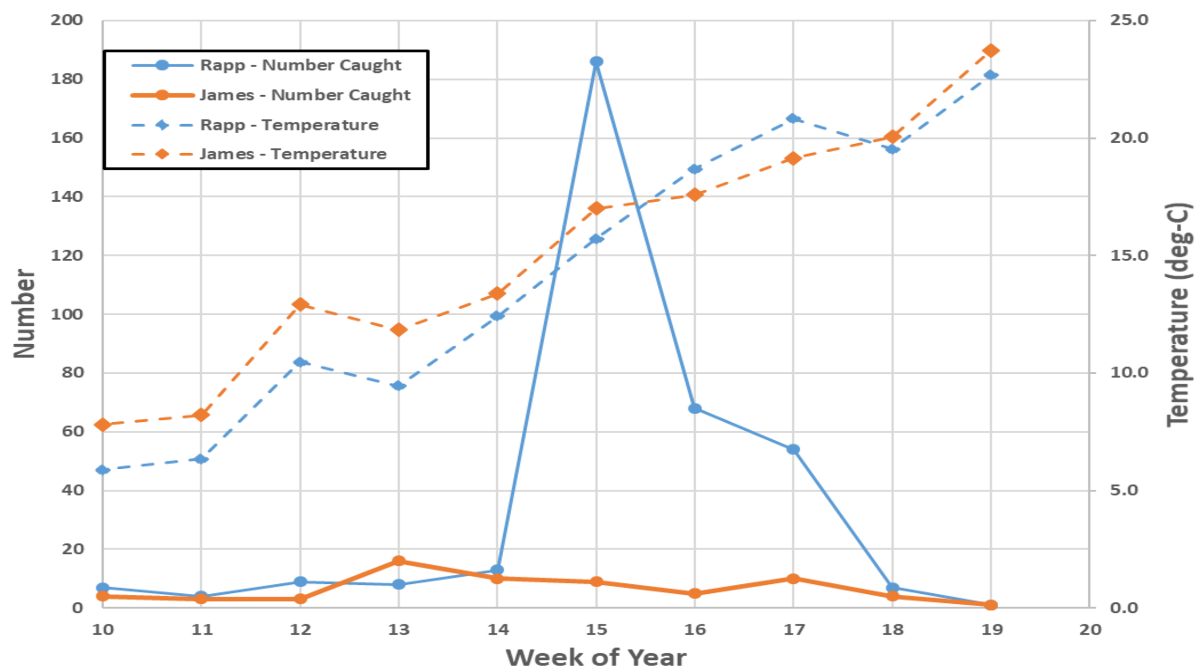
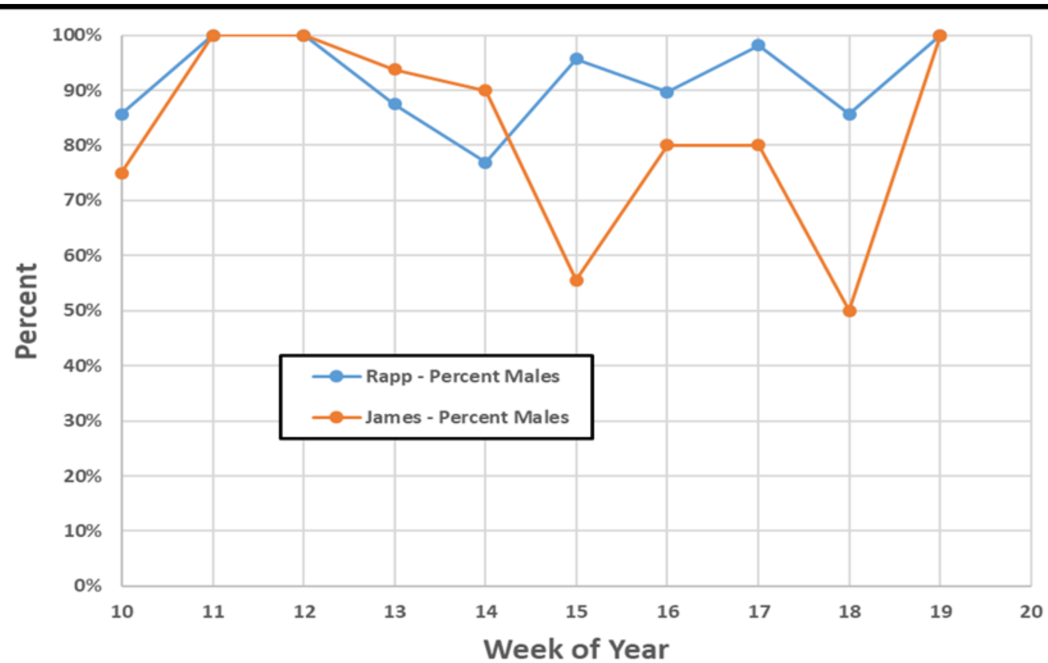


Figure 3. Percent of males by week in the Rappahannock and James rivers samples, spring 2019.



Rapp - Males	7	14	6	4	9	7	10	178	61	53	6	1
Rapp - Females	1	0	1	0	0	1	3	8	7	1	1	0
James - Males	0	11	3	2	2	15	9	5	4	8	2	1
James - Females	1	0	1	0	0	1	1	4	1	2	2	0

Figure 4a. Otolith age frequencies by river, spring 2019 females.

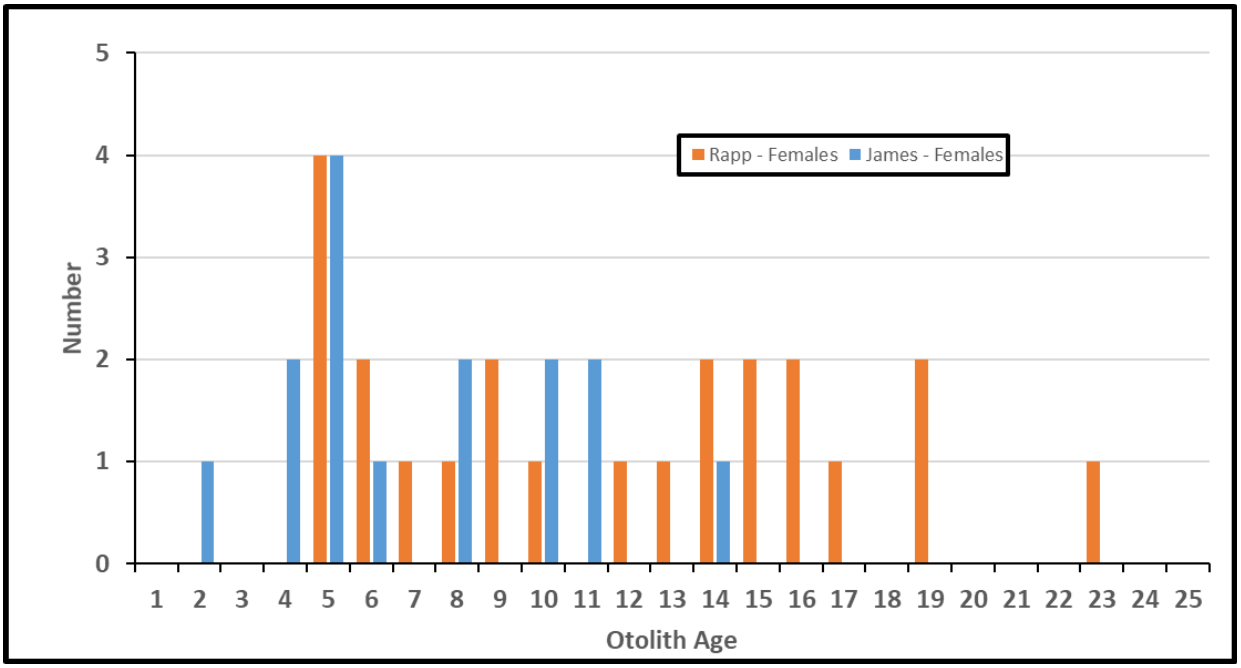


Figure 4b. Otolith age frequencies by river, spring 2019 males.

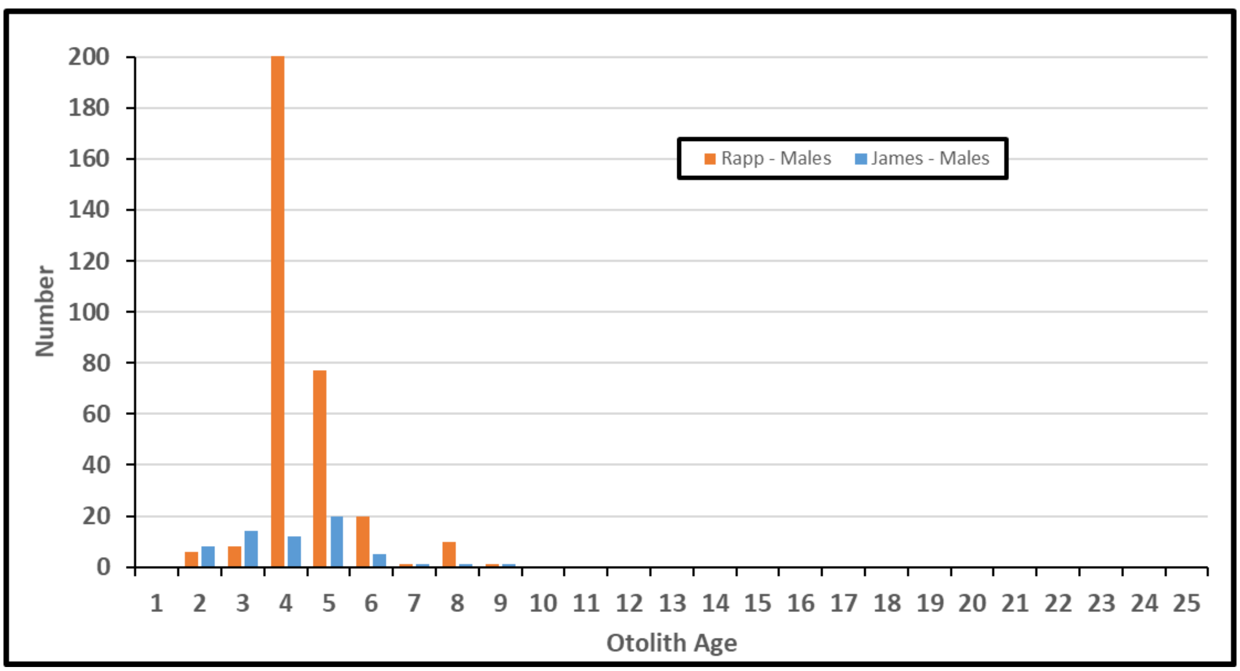


Figure 5. Weekly total biomass, by sex, of striped bass captured in the Rappahannock and James Rivers, spring 2019.

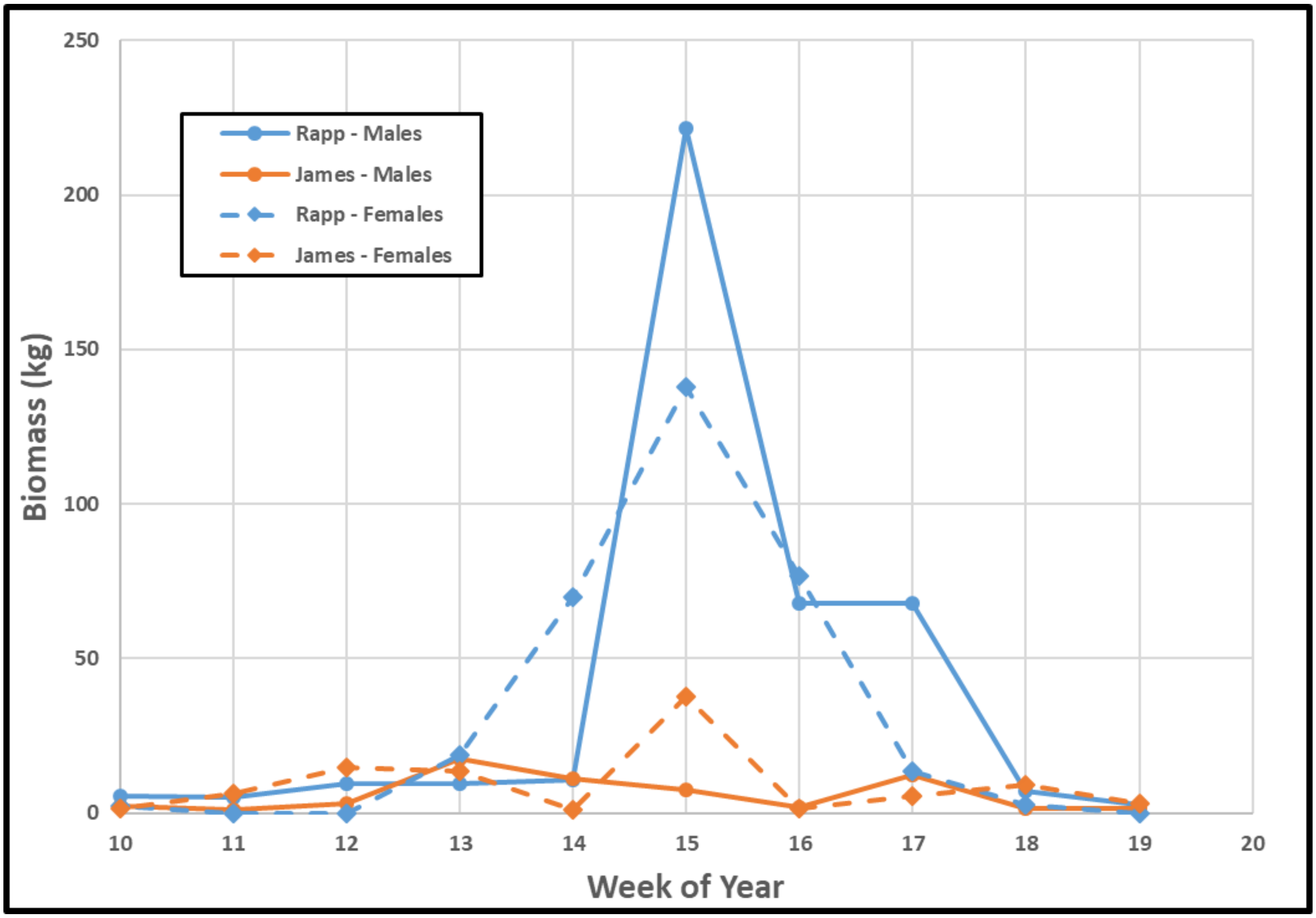
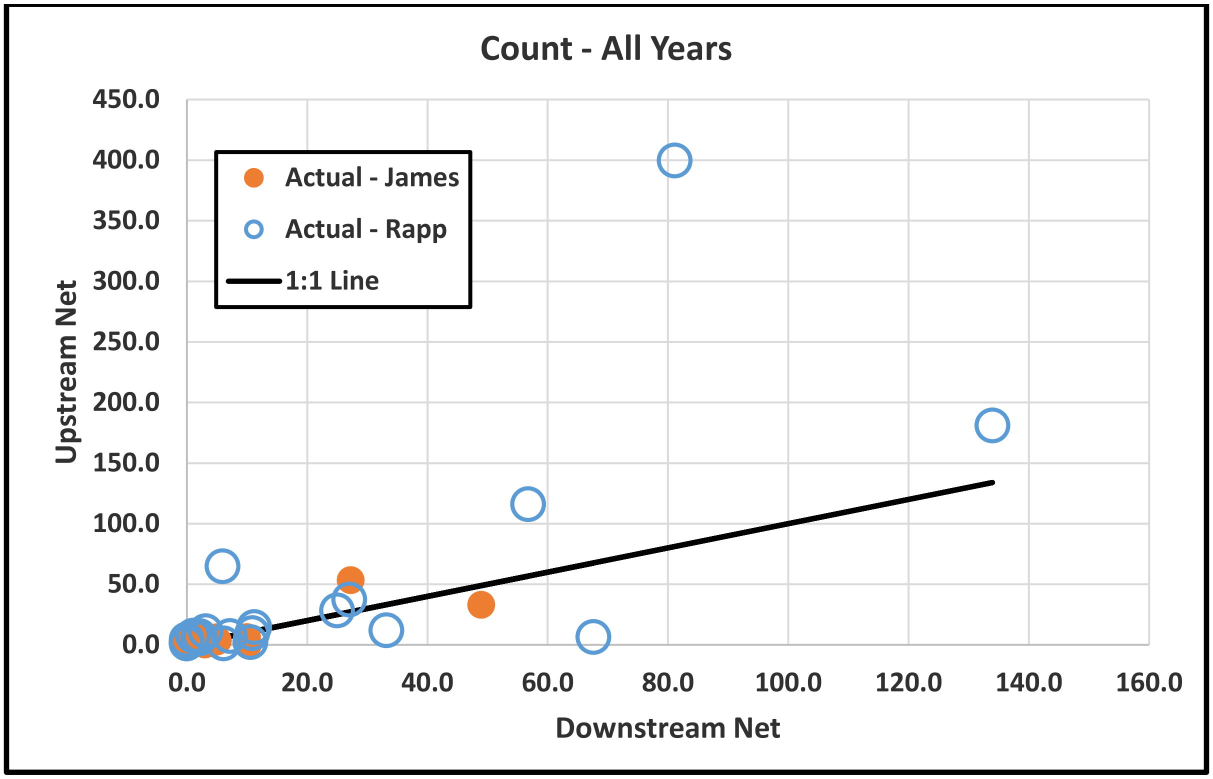


Figure 6. Comparison of catch rates, in biomass and numbers, between two nets in each river, 2018 and 2019.



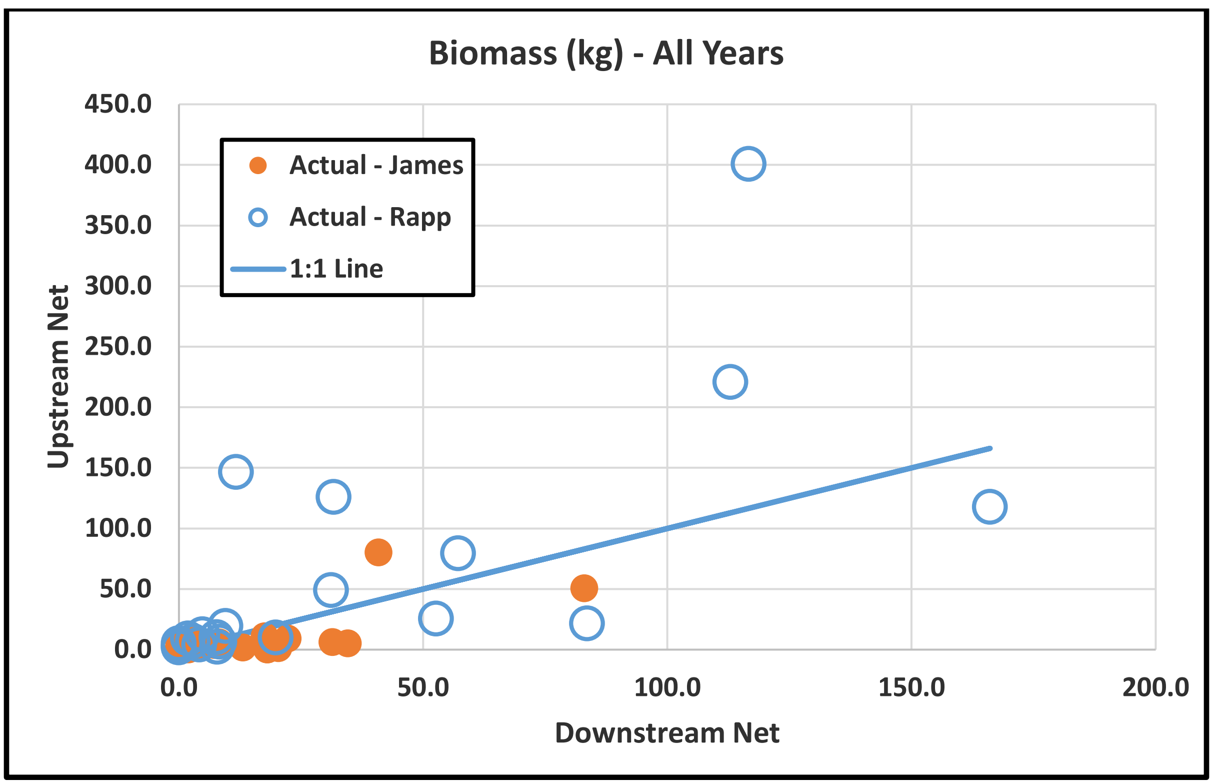
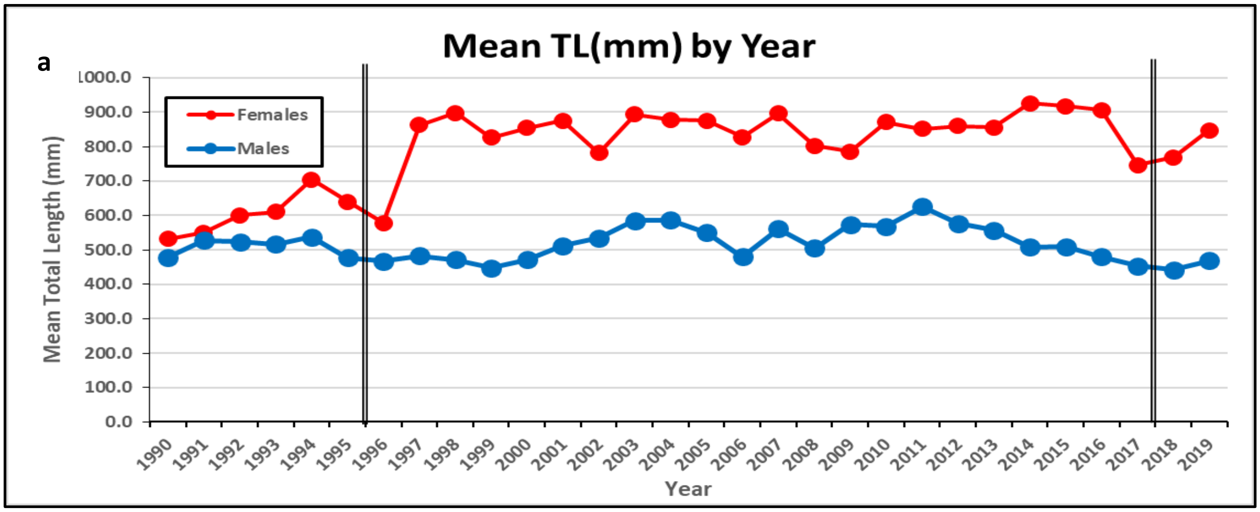
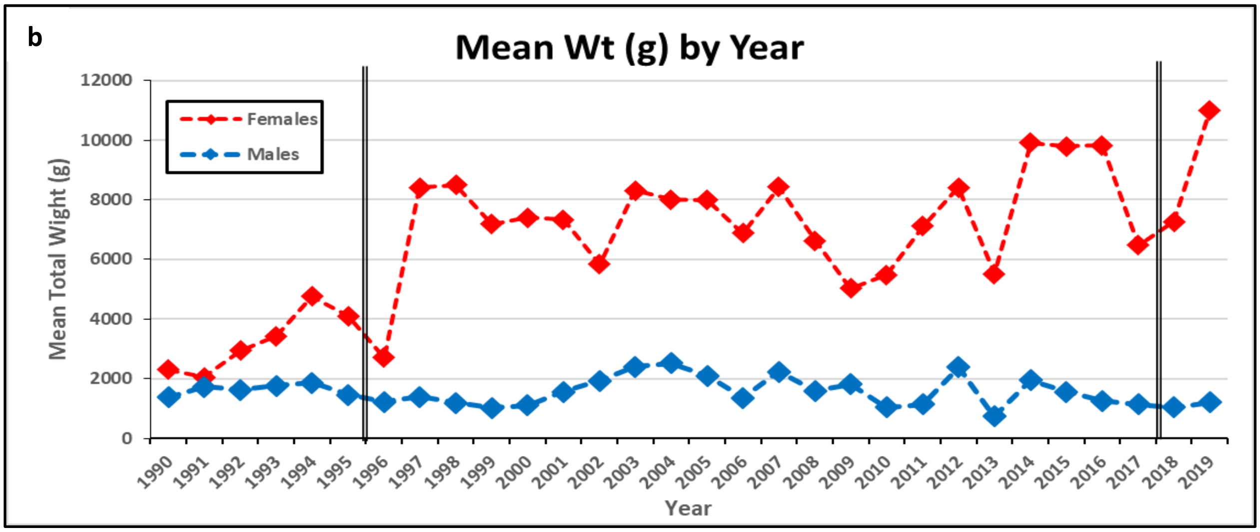


Figure 7. Average length (mm, a), weight (g, b) and age © of striped bass by year, river and sex, spring 2019. Double lines indicate changes in sampling methods and/or locations.





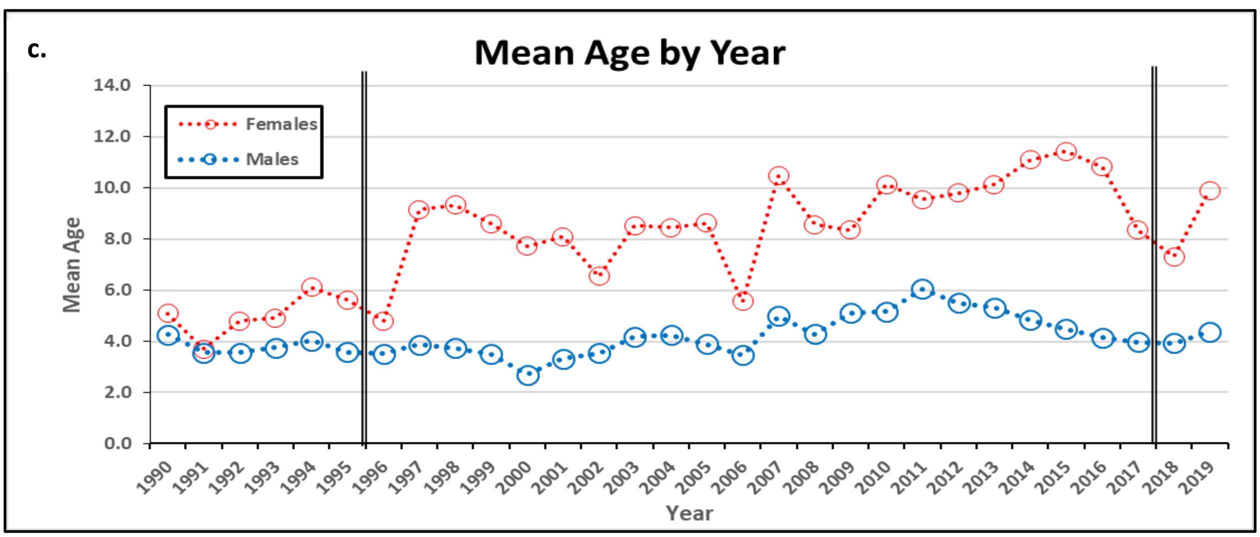


Figure 8. Length frequencies of striped bass captured in gill nets, spring 2019.

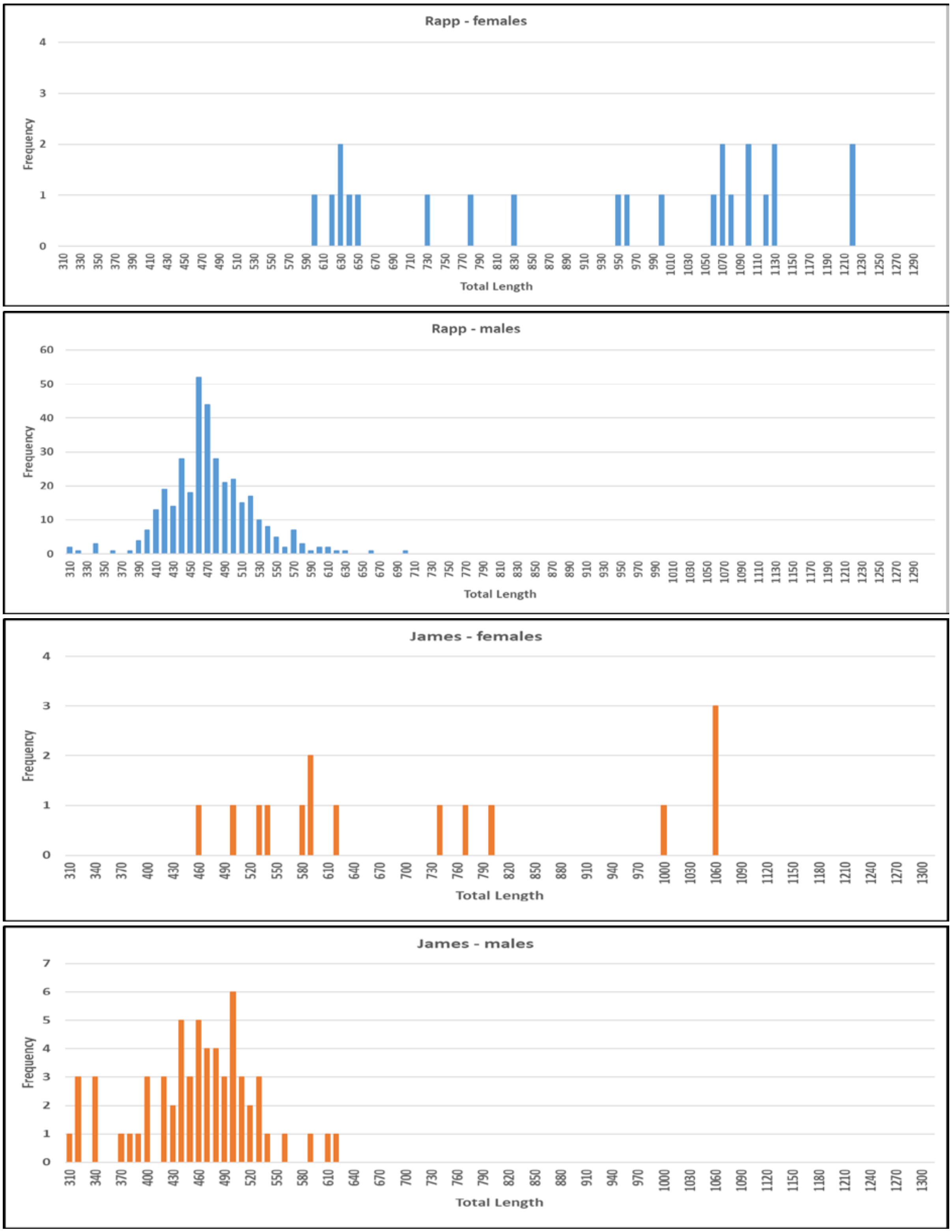
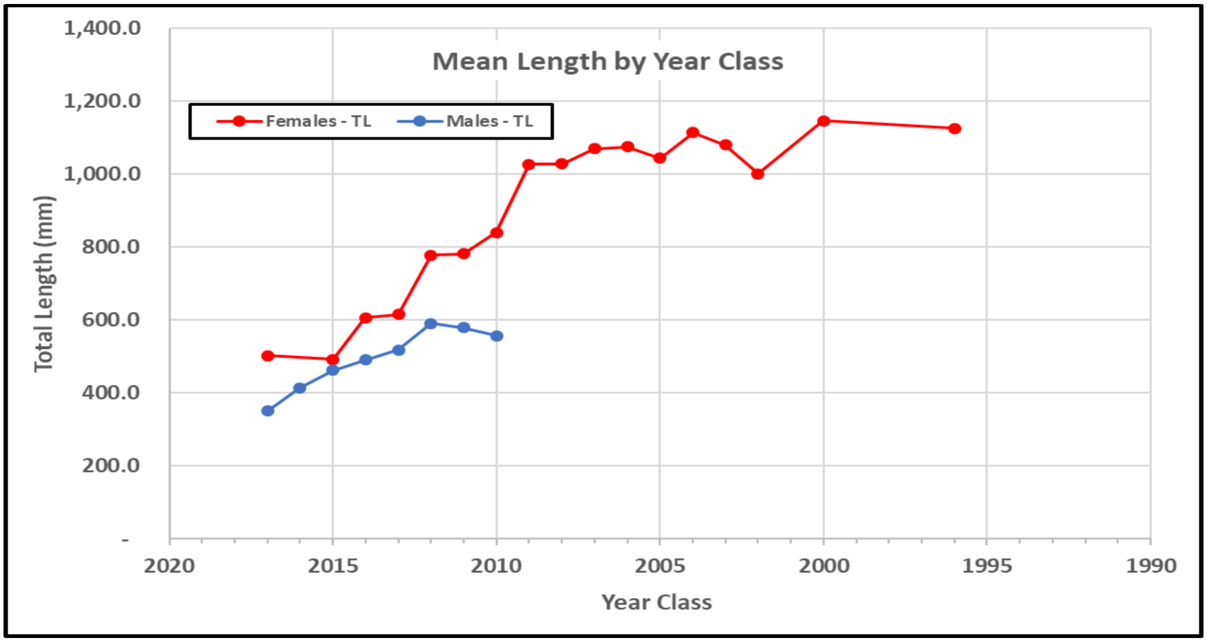


Figure 9. Average length (mm) and weight (g), by sex of striped bass by year class, spring 2019, Rappahannock and James Rivers combined.



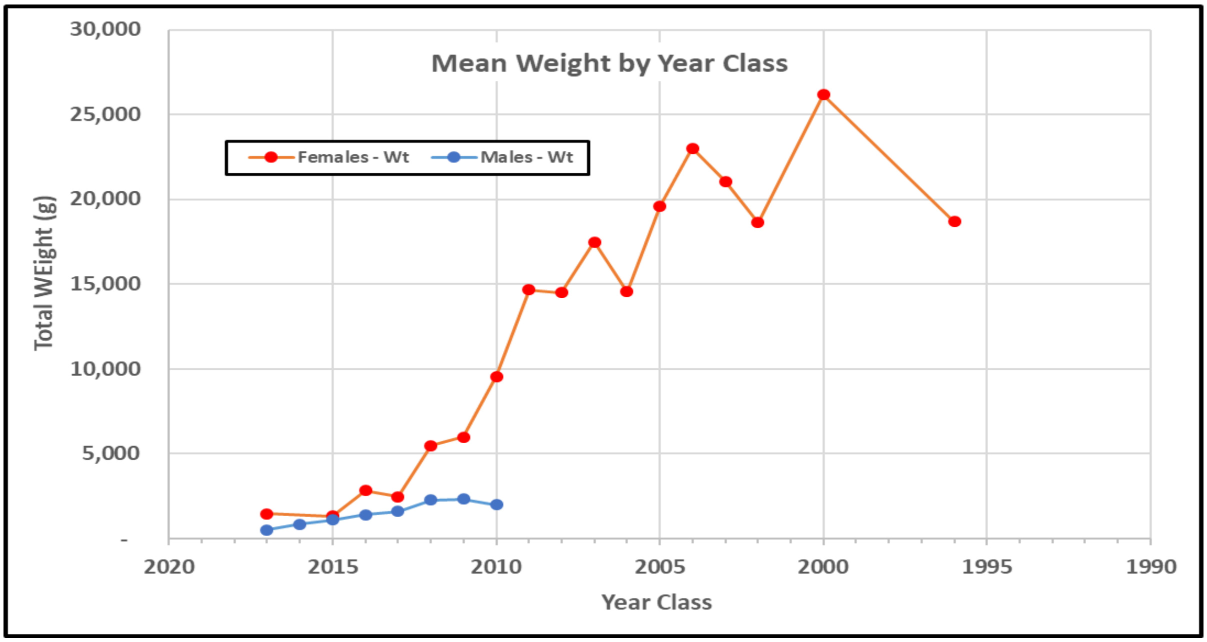


Figure 10. Average catch per day by river and mesh size, in biomass and numbers, spring 2019.

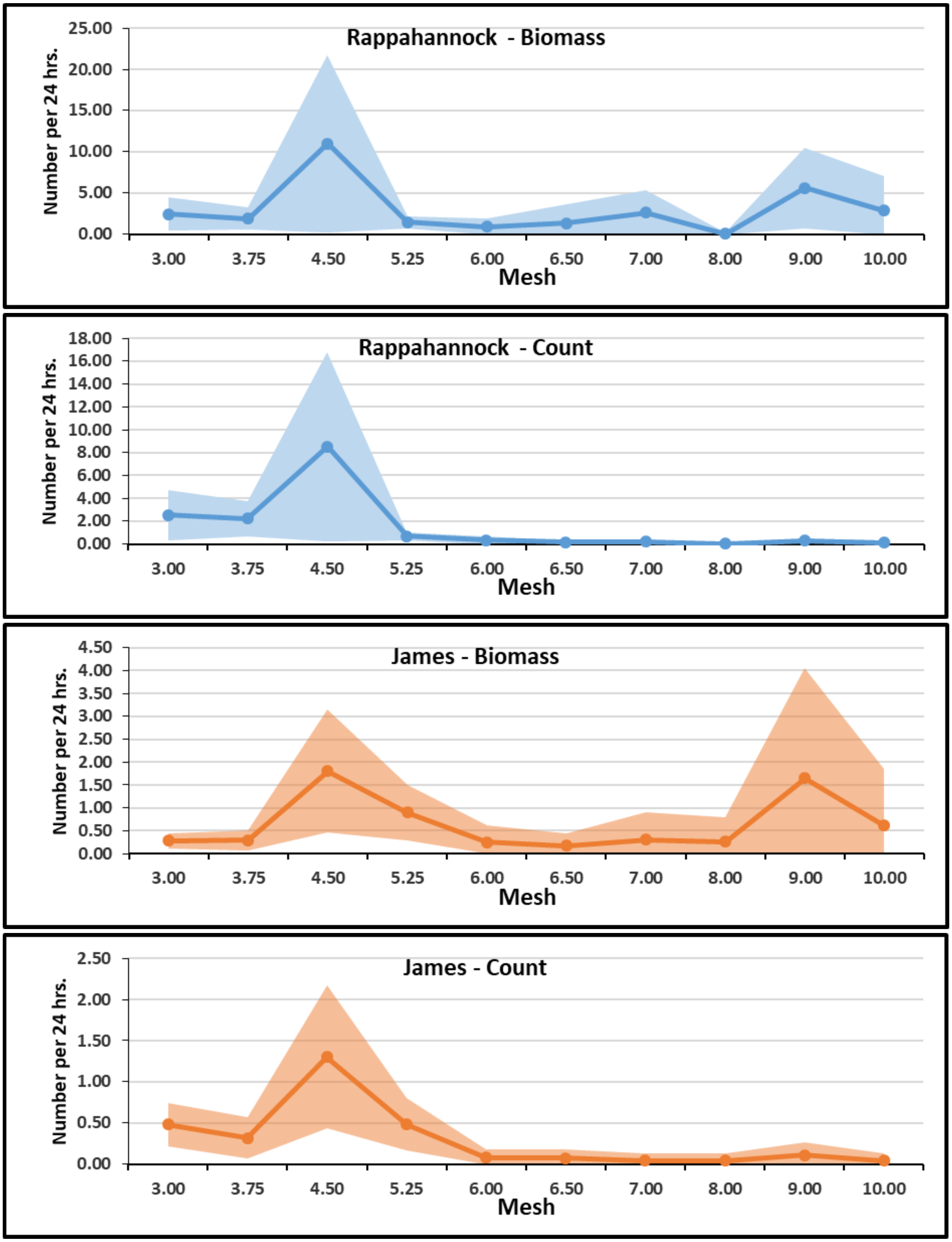


Figure 11. Average catch per day by river, sex and mesh size, in biomass, spring 2019.

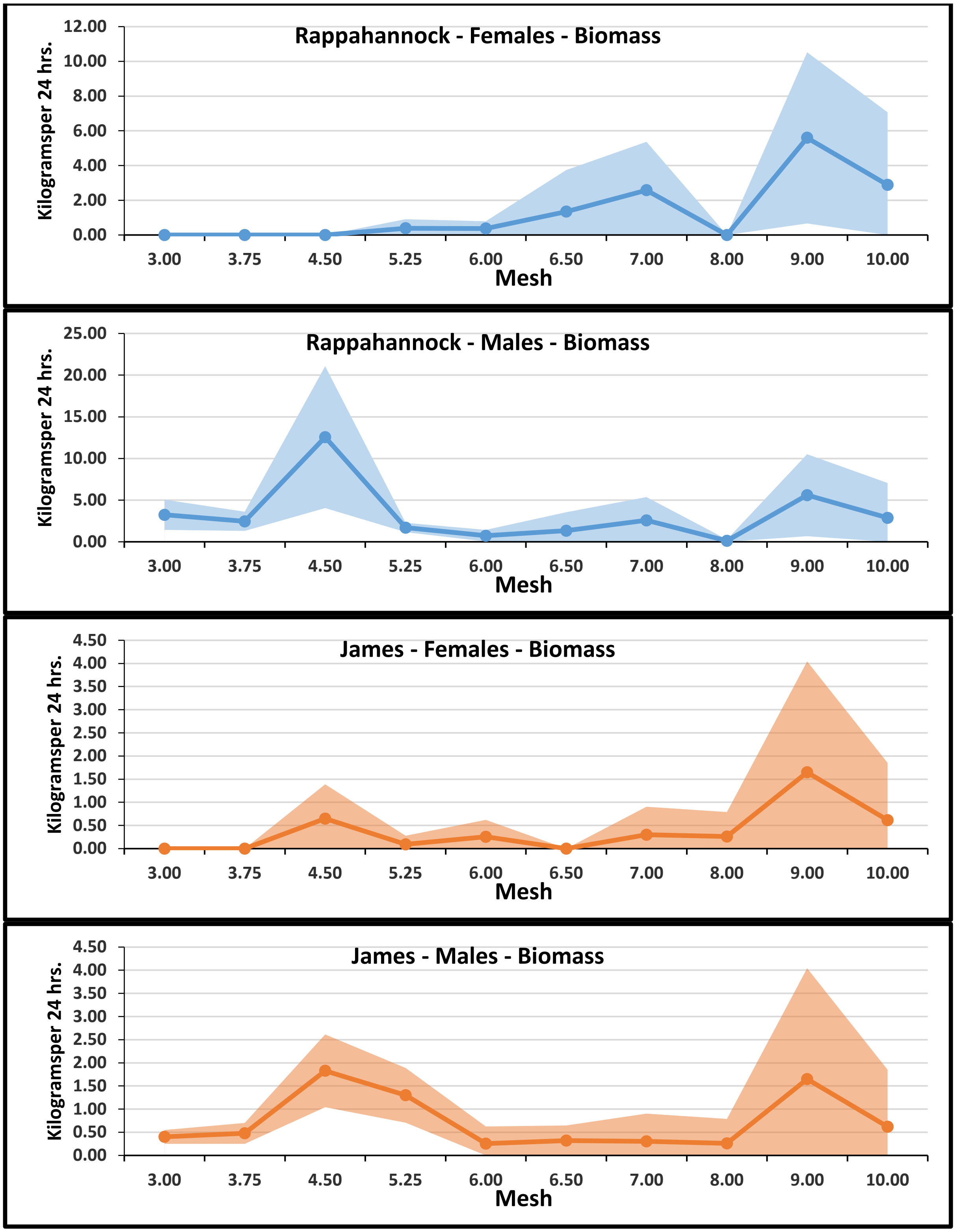


Figure 12. Comparison of otolith age to mean scale age for samples derived from the same specimen, spring 2019.

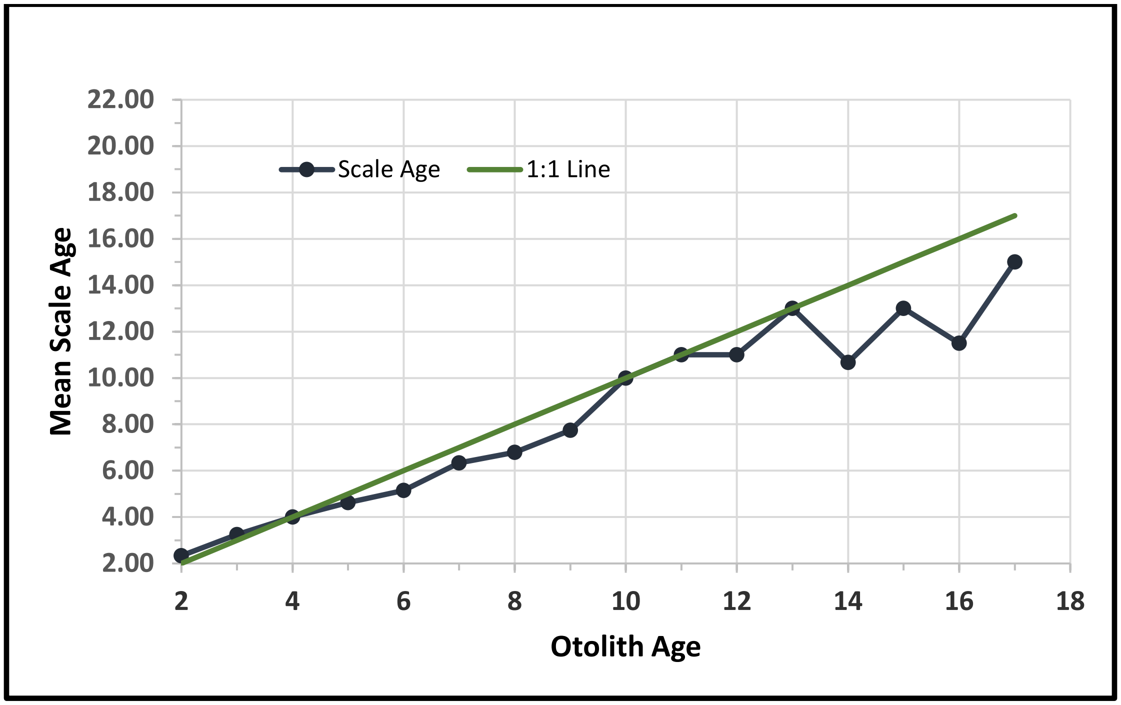
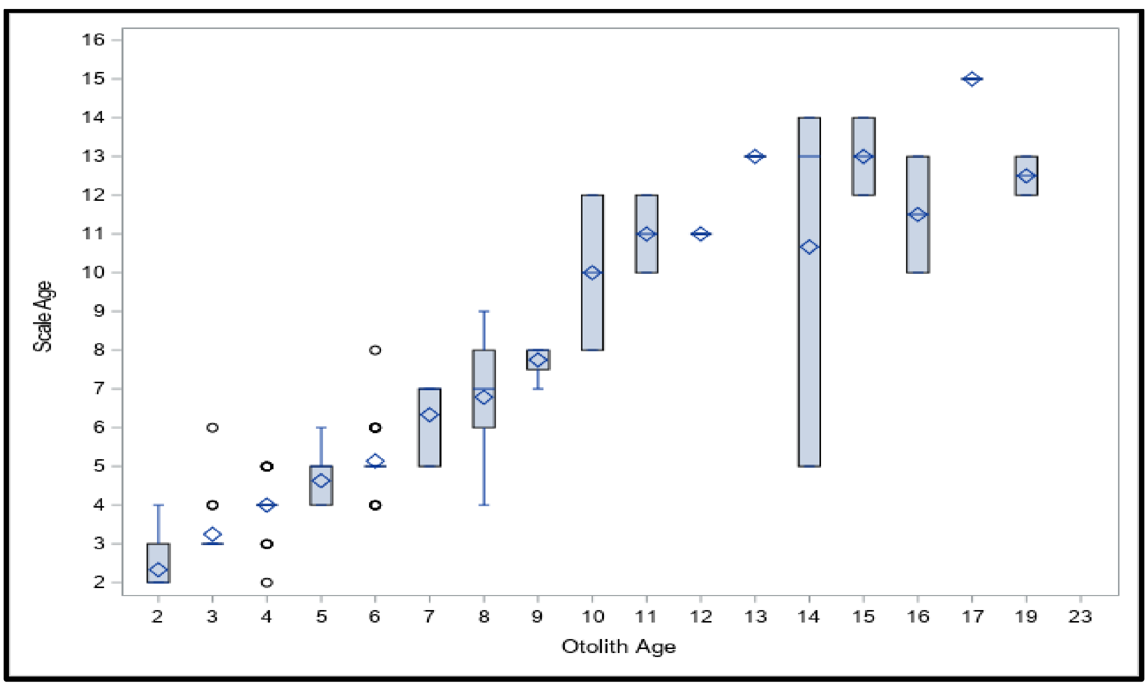


Figure 13. Variability of otolith age compared to scale age for samples derived from the same specimen, spring 2019. Boxes represent 25% and 75% quartiles, diamond symbols are the mean, horizontal lines are the median, circles are outliers.



Tagging

Spring, 2019

Introduction

The Striped Bass Program, now a component of the Multispecies Research Group, 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.

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

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

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

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

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

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

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

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

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

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

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

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

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

Materials and Methods

Capture and Tagging Protocol

1991 – 2017

Each year in the Rappahannock River 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 were 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.

In order to diversify the tagging locations of striped bass and to increase the number of fish tagged each year, in some years specimens from the James and York River systems were captured in multi-mesh gill nets, then tagged and released similarly as described above. Full descriptions of the gear and methods are described in earlier project reports.

2018 - present

In an effort to increase sampling efficiency and decrease costs, in 2018 MRG commenced capturing striped bass to be tagged using electrofishing gear rather than the pound nets and gill nets used in earlier years. In 2018 this was accomplished in cooperation with the Virginia Department of Game and Inland Fisheries (VDGIF) which possessed the requisite vessels, equipment and expertise and which regularly conducts such investigations at approximately the same locations and time of year. Subsequent to the 2018 tagging season, having demonstrated that this gear could be an effective method for this program in Virginia waters, MRG acquired its own specialized vessel and electrofishing rig, sent personnel to training, and in 2019 we performed all sampling using only VIMS equipment and personnel.

During most sampling events, all operations were performed on the single vessel described above. Trained VIMS personnel piloted the vessel and operated the apparatus while other biologists would scoop specimens from the water using dip nets and perform the tagging operation described below. Depending upon the sampling schedule on any given day, during some tagging events the specimen processing could be done on a second, following vessel. Due to the small numbers of fish which were being captured during the first several weeks of effort, we also attempted to capture specimens for tagging by using gill nets on four occasions in early April 2019 but this effort also resulted in very few fish being captured. Tagging was done at several locations in the Rappahannock River, in the James River main stem as well as in the James River tributaries as well as in the York River tributaries the Pamunkey River and the Mattaponi River.

Once onboard, 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 450 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 or after a short recovery period spent in an onboard holding tank which was supplied with fresh aerated water.

Analysis Protocol

For each striped bass assessment through 2016 several different approaches were used to analyze the tagging data. These were, the program MARK, the exploitation rate (R/M) method, the catch equation method, and the instantaneous rates method. Each is fully described in earlier project annual reports (e.g. Sadler, 2016).

For the 2018 Benchmark Assessment only the instantaneous rates method was used. This method allows the estimate of natural mortality to be constant, or to vary by periods and allows for varying fishing mortality under different regulatory periods as well changes in tagging mortality. Virginia data were included under 11 sets of test assumptions regarding changes in fishing mortality, tagging mortality, and natural mortality. These 11 models were:

	Fishing Mortality	Tagging Mortality	Natural Mortality
Model 1:	Year-specific	Year-specific	2 periods: 1990 - 1997 / 1998 - 2017
Model 2:	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 - 2017	Year-specific	2 periods: 1990 - 1997 / 1998 - 2017
Model 3:	Year-specific	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 - 2017	2 periods: 1990 - 1997 / 1998 - 2017
Model 4:	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 - 2017	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 - 2017	2 periods: 1990 - 1997 / 1998 - 2017
Model 5:	7 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 - 2016 / 2017	7 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 - 2016 / 2017	2 periods: 1990 - 1997 / 1998 - 2017
Model 6:	7 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 / 2016 - 2017	7 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 / 2016 - 2017	2 periods: 1990 - 1997 / 1998 - 2017
Model 7:	5 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2017	Year-specific	2 periods: 1990 - 1997 / 1998 - 2017
Model 8:	Year-specific	5 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2017	2 periods: 1990 - 1997 / 1998 - 2017
Model 9:	5 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2017	5 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2017	2 periods: 1990 - 1997 / 1998 - 2017
Model 10:	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2016 / 2017	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2016 / 2017	2 periods: 1990 - 1997 / 1998 - 2017
Model 11:	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2015 / 2016 - 2017	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2015 / 2016 - 2017	2 periods: 1990 - 1997 / 1998 - 2017

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). Coast wide model results and selection will be available in the 2018 benchmark assessment, when published. Model fit was evaluated using Akaike's Information Criterion (AOC) (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).

Results

Spring 2019 Tag Release summary

Electrofishing tagging events (18 of them) occurred between 29 March and 2 May 2019 in the Rappahannock (10), James (3), Mattaponi (3), Pamunkey (1) and Chickahominy (1) Rivers. Each event lasted between 0.3 and 2.7 hours and fishing occurred nearly continuously, generally in a grid pattern covering the location thoroughly. During each event between 0 (8 events) and 27 fish were tagged.

Drift gill nets were employed on five fishing days between 8 March and 11 April. Early in the season (8 March) this gear was used because a malfunctioning component on the electrofishing vessel caused it to be unavailable and it was considered important to begin our tagging operations. Later (4 days between 3-11 April), we attempted to supplement the low numbers of fish tagged via electrofishing with additional gill net efforts (4 days in the Rappahannock, 1 in the James, with nets set for between 1.2 and 10.1 hours). On two of these sampling days, no fish were tagged, on three days 2 fish were tagged and on one day 11 tags were deployed.

A total of only 102 fish were tagged and released which was disappointingly lower than the 859 fish in 2018 and well short of the target of 1,000 striped bass. The median date of released for both rivers combined was 17 April 2019.

In the Rappahannock River a total of 53 striped bass were tagged and released between 4 April and 24 April, 2019 (Table 1). There were 45 resident striped bass (457-710 mm TL) tagged and released. One additional fish measured at 448mm was also tagged and released. Coastal migrant fish (>710mm) tagged totaled 8 specimens with the largest measured at 1,121mm.

In the James River, just 8 striped bass were tagged and released between 3 April and 29 April, 2019 (Table 2). All fish were resident striped bass (457-710 mm TL).

In the Mattaponi River (a tributary to the York River), an additional 41 fish were tagged and released on 17 April and 25 April 2019 (Table 3). Of these 41, 35 were residents (457-710mm TL) and 6 were coastal migrants (>710mm TL).

Mortality Estimates, 2017-2018

Tag recapture summary: A total of 68 striped bass >457 mm TL were recaptured between 1 January and 31 December 2018. The largest source of recaptures (56 / 82.3%) was from Chesapeake Bay (53 / 77.9% in Virginia, and 3 / 4.4% in Maryland, Table 4). Other recaptures occurred in Massachusetts (3), and Rhode Island (2), Connecticut (1), New York (5) and North Carolina (1). The peak month for recaptures was in May (25) with another much smaller peak in December (9). In both of those months all or nearly all of the recaptures occurred in Virginia. All other months had between 1 and 6 recaptured fish.

From the 68 total recoveries, 14 were migratory striped bass (>710 mm total length) recaptured between 1 January and 31 December, 2018 (Table 5). These fish were recaptured in Massachusetts (3), Rhode Island (2), Connecticut (1), New York (5), Maryland (1), and Virginia (2). Recapture events for the coastal migrants occurred in March (1), April (1), May (1), June (1), July (3), August (3), November (2) and December (1).

Instantaneous rates model estimates of survival, fishing and natural mortality

All models included two natural mortality period scenarios 1990-1997 and 1998-2017 M periods for striped bass ≥ 457 mm TL and 1990-2003 and 2004-2017 M periods for striped bass ≥ 711 mm TL.

Virginia releases: Five striped bass (≥ 457 mm TL) tagged in spring 2017 and an additional eight tagged in previous springs were harvested during the 2017-2018 recapture interval. In addition, there were two 2017-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 6a,b) for estimating survival and mortality parameters using the instantaneous rates model.

Likewise, there were three harvested (one from 2017 releases) and one released striped bass from striped bass ≥ 711 mm TL tagged in spring 2017 and recaptured during the 2017-2018 recapture interval and used to complete their respective instantaneous rate model input matrixes (Tables a,b).

For striped bass ≥ 457 mm TL, Model 9 received the most support, with Models 11, 10, and 4 also receiving a measure of support. All models estimated similar values of annual survival, averaging about 0.62 during the period 1990-1997 and 0.51 during 1998-2017 (Figure 1a). Similarly, all models resulted in natural mortality (M) estimates averaging 0.36 during 1990-1997 and 0.59 during 1998-2007 (Figure 1b). Estimates of fishing mortality (F) were more variable, with those models which allow year-specific estimates of F differing from those allowing only periodic changes. Considering only Model 9, F estimates ranged between 0.05 and 0.11, with recent years estimated at 0.05 (Figure 1c). F-tag estimates followed a general downward trend for all models, with very low 0.01-0.02 values in recent years (Figure 1d).

For migratory striped bass (≥ 711 mm TL), Model 9 again received the most support, with models 11, 10, and 4 also receiving a measure of support. All models except Model 1 estimated similar values of annual survival, averaging about 0.68 during the period 1990-1997 and 0.63 during 1998-2017 (Figure 2a). Similarly, all models except Model 1 resulted in natural mortality (M) estimates averaging 0.22 during 1990-1997 and 0.39 during 1998-2007 (Figure 2b). Estimates of fishing mortality (F) were more variable, with those models which allow year-specific estimates of F differing from those allowing only periodic changes. Considering only Model 9, F estimates ranged between 0.06 and 0.20, with recent years estimated at 0.06 (Figure 2c). F-tag estimates followed a general downward trend for all models, with very low 0.01-0.02 values in recent years (Figure 2d).

Literature Cited

Akaike, H. 1973. Information theory as an extension of the maximum likelihood principle. In Second International Symposium on Information Theory. Edited by B. N. Petrov and F. Csaki. Budapest. Academiai Kiado.

Akaike, H. 1985. Prediction and entropy. In A Celebration of Statistics. Edited by A.C. Atkinson and S.E. Fienberg. New York: Springer.

Brownie, C., D.R. Anderson, K.P. Burhnam, and D.R. Robson. 1985. Statistical inference from band recovery data: a handbook, 2nd ed., U.S. Fish and Wildl. Serv. Resour. Publ. No. 156.

Burnham, K.P., G.C. White, and D.R. Anderson. 1995. Model selection strategy in the analysis of capture-recapture data. Biometrics 51:888-898.

Hoenig, J.M., N.J. Barrowman, W.S. Hearn, and K.H. Pollock. 1998a. Multiyear tagging studies incorporating fishing effort data. Can. J. Fish. Aquat. Sci. 55:1466-1476.

Ricker, W.E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations.Bull. Fish. Res. Board Can. No 191.

Seber, G.A.F. 1970. Estimating time-specific survival and reporting rates for adult birds from band returns. Biometrika, 57: 313-318.

Sadler, P.W., Hoenig, J.M., Michaelson, S., Goins, L. M. and R.E. Harris. 2016. Evaluation of striped bass stocks in Virginia: monitoring and tagging studies, 2015-2019. Annual report, Virginia Institute of Marine Science: 141pp.

Smith, D.R., K.P. Burnham, D.M. Kahn, X. He, C.J. Goshorn, K.A. Hattala, and A.W. Kahnle. 2000. Bias in survival estimates from tag-recovery models where catch-and-release is common, with an example from Atlantic striped bass (Morone saxatilis). Can. J. Fish. Aquat. Sci. 57:886-897.

White, G.C. 1983. Numerical estimation of survival rates from band-recovery and biotelemetry data. J. Wildl. Manage. 47:716-728.

White, G.C. and K. P. Burnham. 1999. Program MARKBsurvival estimation from populations of marked animals. Bird Study 46:120-138.

Wooley, C.M., N.C. Parker, B.M. Florence and R.W. Miller. 1990. Striped bass restoration along the Atlantic Coast: a multistate and federal cooperative hatchery and tagging program.

Table 1. Summary data of striped bass tagged and released in the Rappahannock River, spring 2019.

Date	<457mm TL						457mm - 710mm TL						> 710mm TL						Total
	Unknown		Males		Females		Unknown		Males		Females		Unknown		Males		Females		
	n	Avg TL	n	Avg TL	n	Avg TL	n	Avg TL	n	Avg TL	n	Avg TL	n	Avg TL	n	Avg TL	n	Avg TL	n
4/17/2019									23	510.9			3	957.7	1	734.0			27
4/25/2019							1	552.0	11	550.7					2	795.0			14
Total	0		0		0		1		34		0		3		3		0		41

Table 2. Summary data of striped bass tagged and released James River, spring 2019.

Date	<457mm TL						457mm - 710mm TL						> 710mm TL						Total
	Unknown		Males		Females		Unknown		Males		Females		Unknown		Males		Females		
	n	Avg TL	n	Avg TL	n	Avg TL	n	Avg TL	n	Avg TL	n	Avg TL	n	Avg TL	n	Avg TL	n	Avg TL	n
4/3/2019							1	633.0	1	490.0									2
4/22/2019							2	565.5	2	509.0									4
4/29/2019							2	583.5											2
Total	0		0		0		5		3		0		0		0		0		8

Table 3. Summary data of striped bass tagged and released York River, spring 2019.

Date	<457mm TL						457mm - 710mm TL						> 710mm TL						Total
	Unknown		Males		Females		Unknown		Males		Females		Unknown		Males		Females		
	n	Avg TL	n	Avg TL	n	Avg TL	n	Avg TL	n	Avg TL	n	Avg TL	n	Avg TL	n	Avg TL	n	Avg TL	n
4/3/2019							1	633.0	1	490.0									2
4/22/2019							2	565.5	2	509.0									4
4/29/2019							2	583.5											2
Total	0		0		0		5		3		0		0		0		0		8

Table 4. Location of striped bass (≥ 457 mm TL), recaptured in 2018, that were originally tagged and released in the Rappahannock River during springs 1990-2017.

	Month												
State	1	2	3	4	5	6	7	8	9	10	11	12	Total
Maine	0	0	0	0	0	0	0	0	0	0	0	0	0
New Hampshire	0	0	0	0	0	0	0	0	0	0	0	0	0
Massachusetts	0	0	0	0	0	0	0	2	1	0	0	0	3
Rhode Island	0	0	0	0	0	0	1	1	0	0	0	0	2
Connecticut	0	0	0	0	0	0	1	0	0	0	0	0	1
New York	0	0	0	1	1	0	1	0	0	0	2	0	5
New Jersey	0	0	0	0	0	0	0	0	0	0	0	0	0
Pennsylvania	0	0	0	0	0	0	0	0	0	0	0	0	0
Delaware	0	0	0	0	0	0	0	0	0	0	0	0	0
Maryland	0	0	0	0	0	3	0	0	0	0	0	0	3
District of Columbia	0	0	0	0	0	0	0	0	0	0	0	0	0
Virginia	1	4	3	1	23	2	1	1	0	6	2	9	53
North Carolina	0	0	0	0	1	0	0	0	0	0	0	0	1
Total	1	4	3	2	25	5	4	4	1	6	4	9	68

Table 5. Location of migratory striped bass (≥ 710 mm TL), recaptured in 2018, that were originally tagged and released in Virginia during springs 1990-2017.

	Month												
State	1	2	3	4	5	6	7	8	9	10	11	12	Total
Maine	0	0	0	0	0	0	0	0	0	0	0	0	0
New Hampshire	0	0	0	0	0	0	0	0	0	0	0	0	0
Massachusetts	0	0	0	0	0	0	0	2	1	0	0	0	3
Rhode Island	0	0	0	0	0	0	1	1	0	0	0	0	2
Connecticut	0	0	0	0	0	0	1	0	0	0	0	0	1
New York	0	0	0	1	1	0	1	0	0	0	2	0	5
New Jersey	0	0	0	0	0	0	0	0	0	0	0	0	0
Pennsylvania	0	0	0	0	0	0	0	0	0	0	0	0	0
Delaware	0	0	0	0	0	0	0	0	0	0	0	0	0
Maryland	0	0	0	0	0	1	0	0	0	0	0	0	1
District of Columbia	0	0	0	0	0	0	0	0	0	0	0	0	0
Virginia	0	0	1	0	0	0	0	0	0	0	0	1	2
North Carolina	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	1	1	1	1	3	3	1	0	2	1	14

Table 6a. Input recapture matrix for IRCR analysis: from striped bass (>457 mm TL) tagged and released in the springs of 1990-2018 (Rappahannock River only 1990-2017, all Virginia waters 2018). Harvested recaptures only.

Releases		Recapture Year																												
Year	n	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1990	1466	21	19	25	10	8	9	2	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	2482		47	38	22	14	3	1	2	1	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	130			7	4	1	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	621				18	17	12	3	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	195					6	7	4	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	698						24	12	9	4	1	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	377							3	10	3	2	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1997	712								26	17	10	2	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	784									28	16	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	853										30	7	4	2	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
2000	1767											42	25	11	7	3	7	1	1	0	0	0	0	0	0	0	0	0	0	0
2001	797												31	13	6	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	315													10	3	6	2	1	1	1	0	0	0	0	0	0	0	0	0	0
2003	852														31	20	4	5	3	2	1	2	0	0	0	0	1	0	0	0
2004	1477															45	14	6	6	3	1	1	0	0	0	0	0	0	0	0
2005	921																25	18	7	1	4	0	1	0	0	0	0	0	0	0
2006	668																	26	4	6	5	3	4	0	0	0	0	0	0	0
2007	1961																		62	35	16	4	5	0	1	1	1	0	0	0
2008	523																			15	6	0	0	0	0	1	0	0	0	0
2009	867																				26	7	2	2	0	1	0	0	0	0
2010	2050																					28	7	9	2	0	1	0	1	0
2011	416																						12	4	0	0	1	0	0	0
2012	1222																							33	12	5	2	0	0	0
2013	760																								23	8	7	1	0	0
2014	454																									8	3	4	0	1
2015	313																										8	4	2	2
2016	798																											11	5	1
2017	307																												5	1
2018	849																													21

Table 6b. Input recapture matrix for IRCR analysis: from striped bass (>457 mm TL) that were tagged and released in the springs of 1990-2018 (Rappahannock River only 1990-2017, all Virginia waters 2018). Recaptures released with streamers cut off only.

Releases		Recapture Year																												
Year	n	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1990	1466	61	46	17	12	2	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	2482		82	42	28	13	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	130			5	4	3	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	621				22	20	3	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	195					6	1	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	698						21	8	8	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	377							10	6	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1997	712								12	8	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	784									21	7	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	853										19	15	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	1767											50	23	8	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	797												16	10	7	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
2002	315													6	3	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0
2003	852														12	6	8	1	0	1	0	0	0	0	0	0	0	1	0	0
2004	1477															23	6	6	1	0	1	0	0	0	0	0	0	0	0	0
2005	921																13	9	2	0	1	1	0	0	0	0	0	0	0	0
2006	668																	18	7	0	1	1	0	0	0	0	0	0	0	0
2007	1961																		33	11	1	1	0	1	0	1	0	0	0	0
2008	523																			6	3	2	0	0	0	0	0	0	0	0
2009	867																				14	4	0	0	0	0	0	0	0	0
2010	2050																					14	1	1	0	1	0	0	0	0
2011	416																						5	0	0	0	0	1	0	0
2012	1222																							16	4	0	0	0	0	0
2013	760																								6	2	1	0	0	0
2014	454																									6	2	0	3	0
2015	313																										5	0	0	0
2016	798																											11	0	1
2017	307																												2	0
2018	849																													22

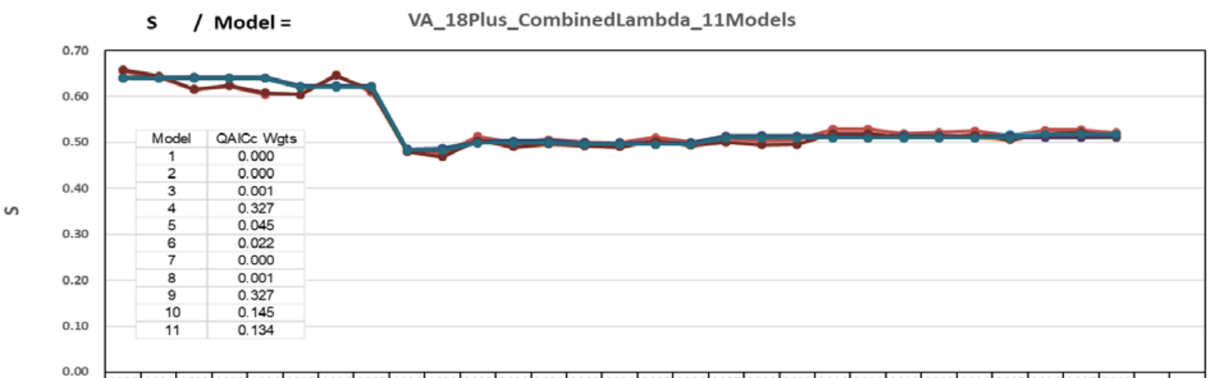
Table 7a. Input recapture matrix for IRCR analysis: from striped bass (>710 mm TL) that were tagged and released in the springs of 1990-2018 (Rappahannock River only 1990-2017, all Virginia waters 2018). Harvested recaptures only.

Releases		Recapture Year																												
Year	n	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1990	1466	61	46	17	12	2	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	2482		82	42	28	13	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	130			5	4	3	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	621				22	20	3	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	195					6	1	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	698						21	8	8	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	377							10	6	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1997	712								12	8	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	784									21	7	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	853										19	15	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	1767											50	23	8	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	797												16	10	7	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
2002	315													6	3	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0
2003	852														12	6	8	1	0	1	0	0	0	0	0	0	0	1	0	0
2004	1477															23	6	6	1	0	1	0	0	0	0	0	0	0	0	0
2005	921																13	9	2	0	1	1	0	0	0	0	0	0	0	0
2006	668																	18	7	0	1	1	0	0	0	0	0	0	0	0
2007	1961																		33	11	1	1	0	1	0	1	0	0	0	0
2008	523																			6	3	2	0	0	0	0	0	0	0	0
2009	867																				14	4	0	0	0	0	0	0	0	0
2010	2050																					14	1	1	0	1	0	0	0	0
2011	416																						5	0	0	0	0	1	0	0
2012	1222																							16	4	0	0	0	0	0
2013	760																								6	2	1	0	0	0
2014	454																									6	2	0	3	0
2015	313																										5	0	0	0
2016	798																											11	0	1
2017	307																												2	0
2018	849																													22

Table 7b. Input recapture matrix for IRCR analysis: from striped bass (>710 mm TL) that were tagged released in the springs of 1990-2018 (Rappahannock River only 1990-2017, all Virginia waters 2018). Recaptures released with streamers cut off only.

Releases		Recapture Year																												
Year	n	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1990	303	16	6	9	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	391		20	11	6	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	40			2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	213				10	7	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	123					4	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	211						7	2	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	67							1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1997	212								2	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	157									6	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	162										2	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	365											9	7	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	269												7	4	2	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
2002	122													2	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
2003	400														8	5	6	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	688															15	2	6	1	0	1	0	0	0	0	0	0	0	0	0
2005	284																4	4	1	0	0	1	0	0	0	0	0	0	0	0
2006	175																	2	1	0	2	0	0	0	0	0	0	0	0	0
2007	840																		12	7	1	1	0	1	0	0	0	0	0	0
2008	75																			0	0	0	0	0	0	0	0	0	0	0
2009	242																				1	1	0	0	0	0	0	0	0	0
2010	483																					5	1	0	0	0	0	0	0	0
2011	191																						1	0	0	0	0	1	0	0
2012	325																							2	0	0	0	0	0	0
2013	244																								1	0	0	0	0	0
2014	247																									3	2	0	2	0
2015	75																										1	0	0	0
2016	99																											0	0	1
2017	33																												0	0
2018	82																													2

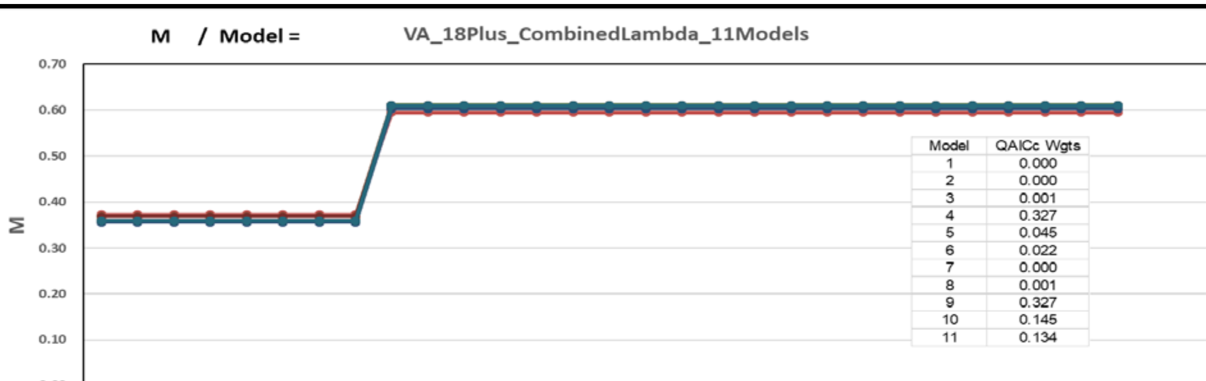
Figure 1a. IRCR generated estimates of annual survival (S) for striped bass ≥ 457 mm TL tagged in Virginia, 1990-2018.



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Model 1	0.65	0.64	0.61	0.62	0.60	0.60	0.64	0.60	0.48	0.47	0.51	0.49	0.50	0.50	0.49	0.51	0.50	0.50	0.50	0.50	0.52	0.52	0.51	0.52	0.52	0.51	0.52	0.52	0.52
Model 2	0.64	0.64	0.64	0.64	0.64	0.62	0.62	0.62	0.48	0.48	0.50	0.50	0.50	0.49	0.49	0.49	0.49	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Model 3	0.65	0.64	0.61	0.62	0.60	0.60	0.64	0.61	0.47	0.46	0.50	0.48	0.49	0.49	0.49	0.50	0.49	0.50	0.49	0.49	0.51	0.51	0.51	0.51	0.51	0.50	0.51	0.52	0.51
Model 4	0.63	0.63	0.63	0.63	0.63	0.62	0.62	0.62	0.48	0.48	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Model 5	0.63	0.63	0.63	0.63	0.63	0.62	0.62	0.62	0.48	0.48	0.50	0.50	0.50	0.49	0.49	0.49	0.49	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Model 6	0.63	0.63	0.63	0.63	0.63	0.62	0.62	0.62	0.48	0.48	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.51	0.51	0.51
Model 7	0.64	0.64	0.64	0.64	0.64	0.62	0.62	0.62	0.48	0.48	0.50	0.50	0.50	0.49	0.49	0.49	0.49	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Model 8	0.65	0.64	0.61	0.62	0.60	0.60	0.64	0.61	0.47	0.46	0.50	0.48	0.49	0.49	0.49	0.50	0.49	0.50	0.49	0.49	0.51	0.51	0.51	0.51	0.51	0.50	0.51	0.52	0.51
Model 9	0.63	0.63	0.63	0.63	0.63	0.62	0.62	0.62	0.48	0.48	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Model 10	0.63	0.63	0.63	0.63	0.63	0.62	0.62	0.62	0.48	0.48	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Model 11	0.63	0.63	0.63	0.63	0.63	0.62	0.62	0.62	0.48	0.48	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.51	0.51	0.51

Year

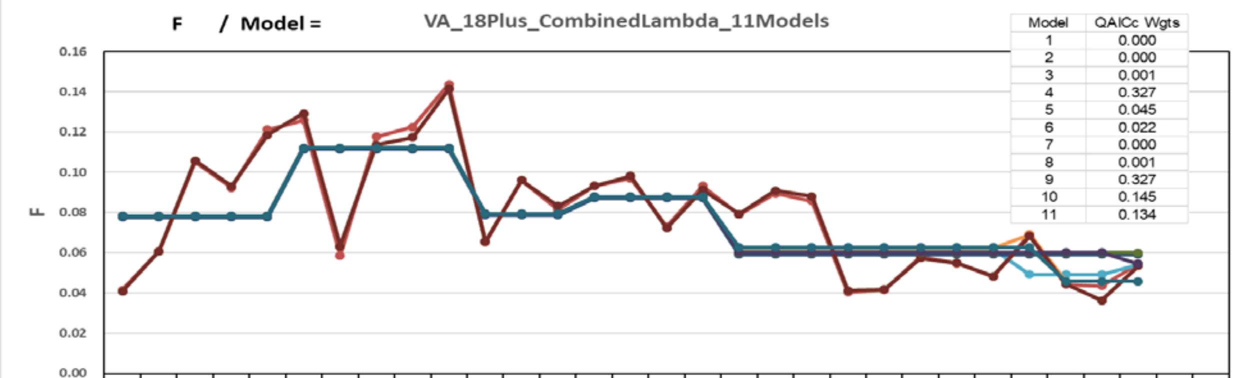
Figure 1b. IRCR generated estimates of annual natural mortality (M) for striped bass ≥ 457 mm TL tagged in Virginia, 1990-2018.



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
M1	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59
M2	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
M3	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
M4	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
M5	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
M6	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
M7	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
M8	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
M9	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
M10	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
M11	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60

Year

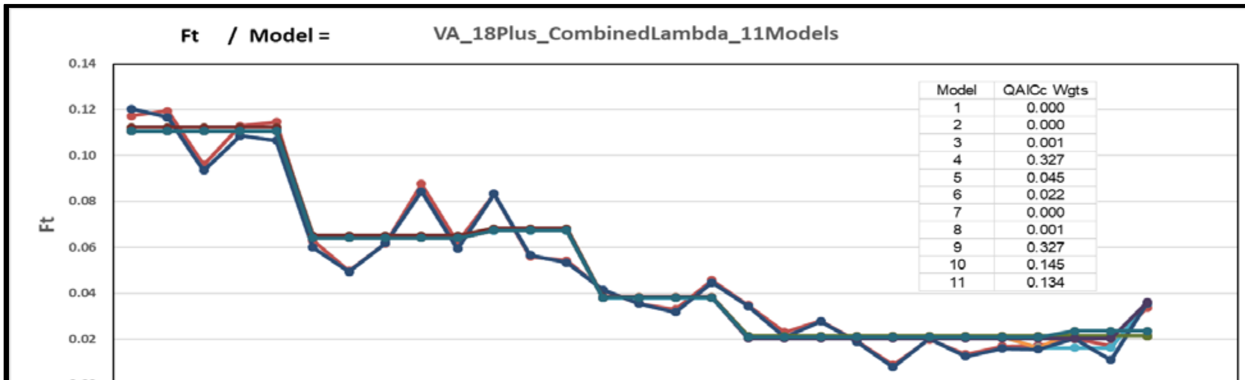
Figure 1c. IRCR generated estimates of annual fishing mortality (F) for striped bass ≥ 457 mm TL tagged in Virginia, 1990-2018.



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
M1	0.04	0.06	0.10	0.09	0.12	0.12	0.05	0.11	0.12	0.14	0.06	0.09	0.08	0.09	0.09	0.07	0.09	0.07	0.08	0.08	0.04	0.04	0.05	0.05	0.04	0.06	0.04	0.04	0.05
M2	0.07	0.07	0.07	0.07	0.07	0.11	0.11	0.11	0.11	0.11	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
M3	0.04	0.06	0.10	0.09	0.11	0.12	0.06	0.11	0.11	0.14	0.06	0.09	0.08	0.09	0.09	0.07	0.09	0.07	0.09	0.08	0.04	0.04	0.05	0.05	0.04	0.06	0.04	0.03	0.05
M4	0.07	0.07	0.07	0.07	0.07	0.11	0.11	0.11	0.11	0.11	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
M5	0.07	0.07	0.07	0.07	0.07	0.11	0.11	0.11	0.11	0.11	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.04	0.04	0.04	0.05
M6	0.07	0.07	0.07	0.07	0.07	0.11	0.11	0.11	0.11	0.11	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.04	0.04	0.04
M7	0.07	0.07	0.07	0.07	0.07	0.11	0.11	0.11	0.11	0.11	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
M8	0.04	0.06	0.10	0.09	0.11	0.12	0.06	0.11	0.11	0.14	0.06	0.09	0.08	0.09	0.09	0.07	0.09	0.07	0.09	0.08	0.04	0.04	0.05	0.05	0.04	0.06	0.04	0.03	0.05
M9	0.07	0.07	0.07	0.07	0.07	0.11	0.11	0.11	0.11	0.11	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
M10	0.07	0.07	0.07	0.07	0.07	0.11	0.11	0.11	0.11	0.11	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05
M11	0.07	0.07	0.07	0.07	0.07	0.11	0.11	0.11	0.11	0.11	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.04	0.04	0.04

Year

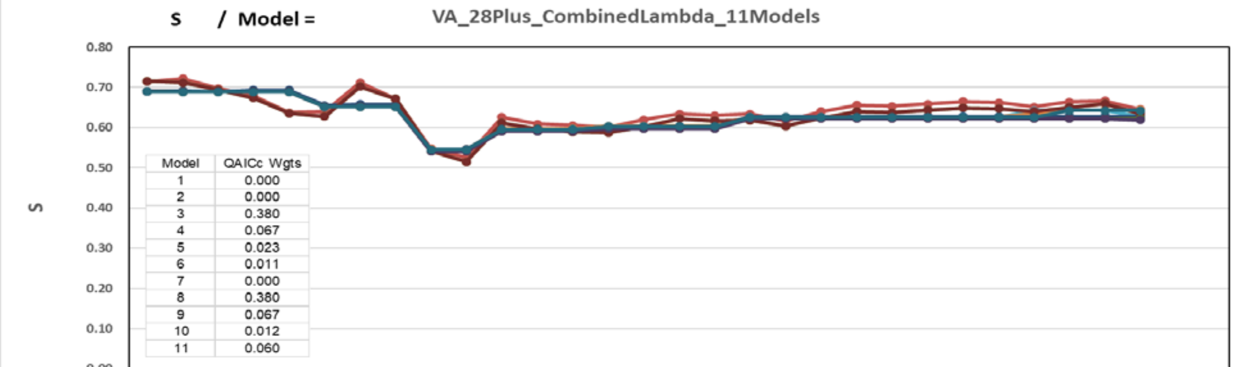
Figure 1d. IRCR generated estimates of annual tagging mortality (F-tag) for striped bass ≥ 457 mm TL tagged in Virginia, 1990-2018.



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
M1	0.11	0.11	0.09	0.11	0.11	0.06	0.04	0.06	0.08	0.06	0.08	0.05	0.05	0.04	0.03	0.03	0.04	0.03	0.02	0.02	0.01	0.00	0.01	0.01	0.01	0.01	0.02	0.01	0.03
M2	0.12	0.11	0.09	0.10	0.10	0.05	0.04	0.06	0.08	0.05	0.08	0.05	0.05	0.04	0.03	0.03	0.04	0.03	0.02	0.02	0.01	0.00	0.02	0.01	0.01	0.01	0.02	0.01	0.03
M3	0.11	0.11	0.11	0.11	0.11	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
M4	0.11	0.11	0.11	0.11	0.11	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
M5	0.11	0.11	0.11	0.11	0.11	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.03
M6	0.11	0.11	0.11	0.11	0.11	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02
M7	0.12	0.11	0.09	0.10	0.10	0.05	0.04	0.06	0.08	0.05	0.08	0.05	0.05	0.04	0.03	0.03	0.04	0.03	0.02	0.02	0.01	0.00	0.02	0.01	0.01	0.01	0.02	0.01	0.03
M8	0.11	0.11	0.11	0.11	0.11	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
M9	0.11	0.11	0.11	0.11	0.11	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
M10	0.11	0.11	0.11	0.11	0.11	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03
M11	0.11	0.11	0.11	0.11	0.11	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

Year

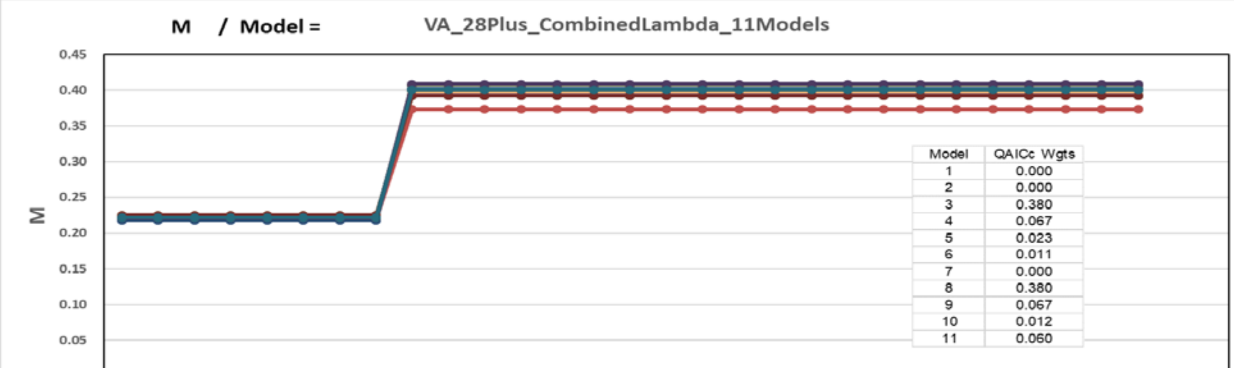
Figure 2a. IRCR generated estimates of annual survival (S) for striped bass ≥ 711 mm TL tagged in Virginia, 1990-2018.



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Model 1	0.71	0.72	0.69	0.67	0.63	0.63	0.71	0.67	0.54	0.52	0.62	0.60	0.60	0.60	0.61	0.63	0.62	0.63	0.61	0.63	0.65	0.65	0.65	0.66	0.66	0.65	0.66	0.66	0.64
Model 2	0.69	0.69	0.68	0.69	0.69	0.65	0.65	0.65	0.54	0.54	0.59	0.59	0.59	0.60	0.60	0.60	0.60	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Model 3	0.71	0.71	0.69	0.67	0.63	0.62	0.70	0.67	0.54	0.51	0.61	0.59	0.58	0.58	0.60	0.62	0.61	0.61	0.60	0.62	0.63	0.63	0.64	0.64	0.64	0.63	0.65	0.65	0.63
Model 4	0.69	0.68	0.68	0.68	0.68	0.65	0.65	0.65	0.54	0.54	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Model 5	0.68	0.68	0.68	0.68	0.68	0.65	0.65	0.65	0.54	0.54	0.59	0.59	0.59	0.60	0.60	0.60	0.60	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.64	0.64	0.64	0.62
Model 6	0.68	0.68	0.68	0.68	0.68	0.65	0.65	0.65	0.54	0.54	0.59	0.59	0.59	0.60	0.60	0.60	0.60	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.63	0.64	0.64	0.64
Model 7	0.69	0.69	0.68	0.69	0.69	0.65	0.65	0.65	0.54	0.54	0.59	0.59	0.59	0.60	0.60	0.60	0.60	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Model 8	0.71	0.71	0.69	0.67	0.63	0.62	0.70	0.67	0.54	0.51	0.61	0.59	0.58	0.58	0.60	0.62	0.61	0.61	0.60	0.62	0.63	0.63	0.64	0.64	0.64	0.63	0.65	0.65	0.63
Model 9	0.69	0.68	0.68	0.68	0.68	0.65	0.65	0.65	0.54	0.54	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Model 10	0.69	0.68	0.68	0.68	0.68	0.65	0.65	0.65	0.54	0.54	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.61
Model 11	0.68	0.68	0.68	0.68	0.68	0.65	0.65	0.65	0.54	0.54	0.59	0.59	0.59	0.60	0.60	0.60	0.60	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.64	0.64	0.64

Year

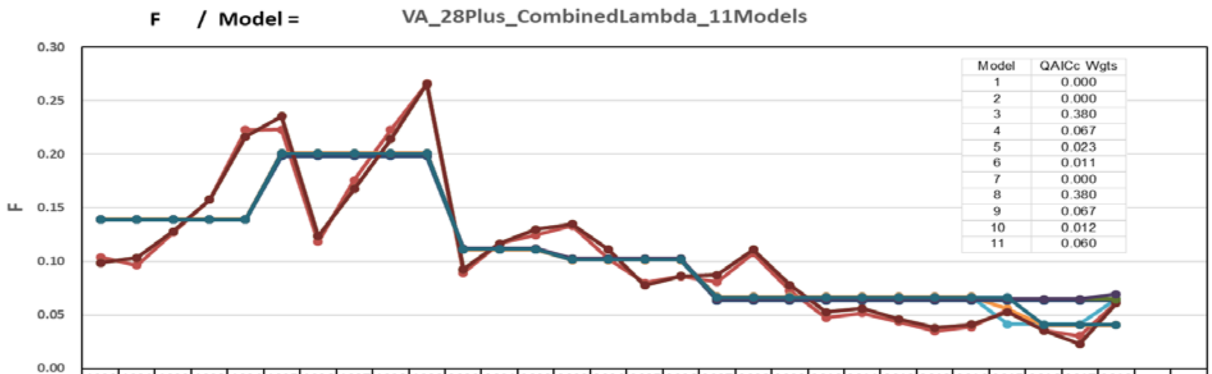
Figure 2b. IRCR generated estimates of annual natural mortality (M) for striped bass ≥ 711 mm TL tagged in Virginia, 1990-2018.



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
M1	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
M2	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
M3	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
M4	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
M5	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
M6	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
M7	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
M8	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
M9	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
M10	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
M11	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40

Year

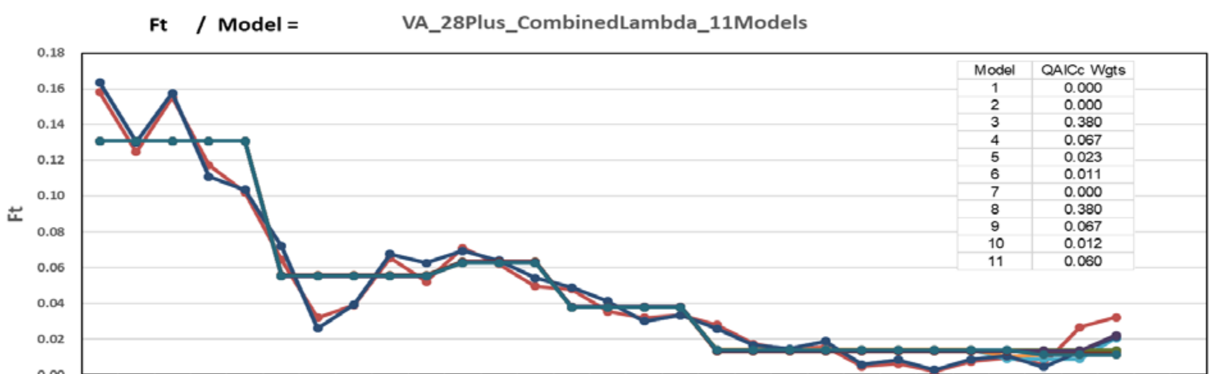
Figure 2c. IRCR generated estimates of annual fishing mortality (F) for striped bass ≥ 711 mm TL tagged in Virginia, 1990-2018.



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
M1	0.10	0.09	0.12	0.15	0.22	0.22	0.11	0.17	0.22	0.26	0.08	0.11	0.12	0.13	0.10	0.07	0.08	0.08	0.10	0.07	0.04	0.05	0.04	0.03	0.03	0.05	0.03	0.03	0.06
M2	0.13	0.13	0.13	0.13	0.13	0.19	0.19	0.19	0.19	0.19	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
M3	0.09	0.10	0.12	0.15	0.21	0.23	0.12	0.16	0.21	0.26	0.09	0.11	0.12	0.13	0.11	0.07	0.08	0.08	0.11	0.07	0.05	0.05	0.04	0.03	0.04	0.05	0.03	0.02	0.06
M4	0.13	0.13	0.13	0.13	0.13	0.20	0.20	0.20	0.20	0.20	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
M5	0.13	0.13	0.13	0.13	0.13	0.20	0.20	0.20	0.20	0.20	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.04	0.04	0.04	0.06
M6	0.13	0.13	0.13	0.13	0.13	0.20	0.20	0.20	0.20	0.20	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.04	0.04	0.04
M7	0.13	0.13	0.13	0.13	0.13	0.19	0.19	0.19	0.19	0.19	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
M8	0.09	0.10	0.12	0.15	0.21	0.23	0.12	0.16	0.21	0.26	0.09	0.11	0.12	0.13	0.11	0.07	0.08	0.08	0.11	0.07	0.05	0.05	0.04	0.03	0.04	0.05	0.03	0.02	0.06
M9	0.13	0.13	0.13	0.13	0.13	0.20	0.20	0.20	0.20	0.20	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
M10	0.13	0.13	0.13	0.13	0.13	0.20	0.20	0.20	0.20	0.20	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
M11	0.13	0.13	0.13	0.13	0.13	0.20	0.20	0.20	0.20	0.20	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.04	0.04	0.04

Year

Figure 2d. IRCR generated estimates of annual tagging mortality (F-tag) for striped bass ≥ 711 mm TL tagged in Virginia, 1990-2018.



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
M1	0.15	0.12	0.15	0.11	0.10	0.06	0.03	0.03	0.06	0.05	0.07	0.06	0.04	0.04	0.03	0.03	0.03	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03
M2	0.16	0.12	0.15	0.11	0.10	0.07	0.02	0.03	0.06	0.06	0.06	0.06	0.05	0.04	0.04	0.02	0.03	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.02
M3	0.13	0.13	0.13	0.13	0.13	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.03	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
M4	0.13	0.13	0.13	0.13	0.13	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.03	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
M5	0.13	0.13	0.13	0.13	0.13	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.03	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.02
M6	0.13	0.13	0.13	0.13	0.13	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.03	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
M7	0.16	0.12	0.15	0.11	0.10	0.07	0.02	0.03	0.06	0.06	0.06	0.06	0.05	0.04	0.04	0.02	0.03	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.02
M8	0.13	0.13	0.13	0.13	0.13	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.03	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
M9	0.13	0.13	0.13	0.13	0.13	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.03	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
M10	0.13	0.13	0.13	0.13	0.13	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.03	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
M11	0.13	0.13	0.13	0.13	0.13	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.03	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Year