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Evaluation of Striped Bass Stocks in Virginia: Monitoring and Tagging Studies, 2022 Progress Report

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Progress Report

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Preface

This report presents the results of striped bass (*Morone saxatilis*) tagging and monitoring activities in Virginia during the period 1 December 2020 through 30 November 2021. It includes an assessment of the biological characteristics of striped bass taken from the 2021 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 calculated 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. Beginning in 2018 monitoring has been accomplished using multi-panel anchor gill nets and tagging was conducted via electrofishing. Methodologies are fully described later in this report.

List of Tables

I. Spawning Stock Monitoring

II. Tagging

List of Figures

I. Spawning Stock Monitoring

II. Tagging

Spawning Stock Monitoring
Spring 2021

Introduction

Every year, striped bass migrate along the continental shelf waters of the US east coast 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 maintaining the productivity of 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 upper 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 25 February and 11 May, 2021 by the VIMS Multispecies Research Group (MRG). Following shortened sampling in 2020 due to COVID-19, mitigation protocols allowed sampling to occur over the complete spawning season in 2021.

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 and retrieved approximately 24 hours later. All specimens were brought back to VIMS for processing (lengths, weight, sex and maturity, with scales, otoliths and spleens 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 an 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 measures to the nearest 10g. Both are integrated into the FEED (Fisheries Environment for Electronic Data) software system which also allows manual input of sex and gonad maturity into a data base file for subsequent analysis. Otoliths were extracted from the striped bass and subsequently processed for aging (as described below). Scales were collected from between the spinous and soft dorsal fins above the lateral line for subsequent aging. As otoliths are considered to be a superior structure to determine age, especially in the older age classes associated with spawning activity, only a subsample of approximately 25% of scale samples are processed using the method established by Merriman (1941) (except that impressions made in acetate sheets replaced the glass slide and acetone) and compared to otolith-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). Final ages were 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 for the 25% subsample by just a single reader, with a selection of samples then also 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= 525) were collected from gill nets in the Rappahannock River while 610 fish were sampled from the James between 25 February and 11 May, 2021. This compares to a total of 1,082 total captures (RA=836, JA=247) in the shortened 2020 sampling season, 456 (RA=379, JA=77) in 2019 and 1,157 (RA=942, JA=215) in 2018.

In the Rappahannock, total daily catches varied from 3-168 striped bass, with the peak catch on 20 April. In the James, daily catches were between 9 and 135 fish with the maximum falling on 13 April. Surface water temperatures in the James hovered between 8-9℃ for the first three weeks of sampling (through 9 March) then rose quickly to 12.5℃ by 24 March, rose again to about 16℃ by 30 March and jumped again to 21℃ by the termination of sampling on 11 May. Water temperatures in the Rappahannock followed a very similar pattern being generally within 1℃-2℃ of those in the James. Typically, peak spawning in the Rappahannock occurs once the temperature rises above 16℃. In both rivers, catch rates started rising during the week of 30 March when surface temperatures reached the 16℃ level (Table 1, Figure 2). Salinities in both rivers were very low (0.03 – 0.09) during the entire sampling period (Table 1, Figure 2).

Males dominated the catch in both rivers (Rapp-495M:29F, James-520M:90F) though the proportions varied between rivers (Rapp – 94.5%, James – 85.2% / Table 2, Figure 3).

In the Rappahannock, males ranged in age from 2 to 20 years. Males captured in the Rappahannock were predominantly ages 3-6 (2015-2018 year classes) with the 2018 (age-3) fish being predominant followed by fish from the 2015 year class (age-6). In the James the age range of male fish was 2 through 10. Similar to previous years, males 3 to 5 (2016-2018 yc) were the most abundant in the James.

Females in the Rappahannock aged between 5 and 26 years (1995-2016 yc) with fish from the 2011 yc (age-10) and 2015 yc (age-6) being somewhat more abundant than others. James females ranged between 3 and 17 years (2004-2018 yc) dominated by fish between ages-3 to 7 years (2014 yc through 2018 yc (Table 3, Figures 4a,4b).

In both rivers, biomass (kg/set) and numerical (number/set) catch rates followed similar general patterns, beginning at low values in February and starting to climb by late-March, peaking in mid-April then declining into late-April and early-May. Specifically, in the Rappahannock, abundance of males rose swiftly and steadily between 25 March and 13 April then followed a similar but downward trajectory over the next three weeks. The trend of female abundance was similar but offset by about two weeks and fell more rapidly than did that of males. Both numbers and biomass of males in the James followed a nearly identical rise as in the Rappahannock but the subsequent decline was more gradual. James River females were most abundant one week later than those in the Rapphannock (Table 4, Figure

5a, Figure 5b).

The ratio of males:females (based on numbers) varied significantly week-to-week, between 0.5:1 – 29.3:1 in the Rappahannock and between 1.6:1 – 22.5:1 in the James, excluding several weeks in which no females were captured. Over the entire season the sex ratio in the Rappahannock was 17.1:1 and in the James was 5.8:1 (Table 4).

Considering the four years of the current monitoring protocol (2018 through 2021), it's unclear whether or not the upstream or downstream position of the two nets fished at each location has an effect on the catch rate. Over that four-year period in the Rappahannock, the average catch of whichever net was set in the downstream position was 46.8 kg (30.3 fish) compared to the upstream net which averaged 62.7 kg (43.7 fish). In the James however, the downstream net averaged a higher biomass and more fish (35.1 kg / 17.8 fish) than the upstream net (24.5 kg / 13.2 fish). For the Rappahannock, these averages are influenced by a relatively small number of sets in which considerably more fish were captured in the upstream net than in its paired downstream net (Figure 6a). A paired t-test using data for both rivers combined found no significant difference due to the relative net position ($p = 0.77$ – biomass / $p = 0.54$ - count / $df = 77$). Considering only those sets in the Rappahannock river a t-test found no difference between upper and lower net position either in count ($p = 0.32$ – biomass / $p = 0.32$ – count / $df = 38$). In the James however, significant differences were indeed present ($p = 0.02$ – biomass / $p = 0.02$ – Count / $df = 38$). The reasons why any possible differences might occur can currently only be the subject of speculation. Possible factors might be the differing topography of the two rivers (the Rappahannock is considerably narrower at the sampling locations than is the James), tidal flows during the specific times when sampling occurs, or the presence of non-target species in the net. This last factor was briefly explored by plotting similar data (counts only) as described above but for all species combined (Figure 6b). Visual comparison appears to show no differences between upstream and downstream nets using these data.

In the Rappahannock, 495 male striped bass sampled in 2021 averaged 464.3mm (TL), 1.373kg and 4.3 years which were all similar to the respective values from 2020 (458.6 mm, 1.229 kg, 4.3 yr). Rappahannock females (29 specimens) had a mean length of 880.7mm, a mean weight of 9.699kg and on average were 10.0 years old which represented a second straight year of decreases (2020 values were 930.0mm, 11.689kg, 10.3yr). In the James River, 520 male specimens averaged 490.1mm in length, 1.450kg and 4.1 years (all values were similar to 2020 fish: 475.2mm, 1.555kg, 4.0yr). Average values for the 90 sampled females were 632.6.6mm, 4.080kg and 5.9 years again representing a 2-year decrease in size and age (2020 values: 748.6mm, 7.5810kg, 8.6yr – Table 5, Figure 7).

Rappahannock male fish displayed peak abundances between 340-360 mm, 400-420mm with a smaller peak between 500-580mm and a scattering of individuals up to 1100mm total lengths. The smaller number Rappahannock females in the samples displayed modes of abundance between 560-750mm, 940-1080mm and three larger specimens up to 1220mm TL. The James River typically produces fewer fish but in 2021 both males and females were more abundant than in the Rappahannock. Males in the James River were distributed over a slightly smaller size range, nearly all ranging between 320-660mm with just a single peak between

470-560mm and a few individuals up to 890mm TL. Females in the James were similarly more abundant than those in the Rappahannock, with a broad size group ranging between 320 to 640mm TL and another between 950 and 1130mm TL (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 38.0 kg/day (confidence interval (CI) = 15.8-60.1) and 47.6 kg/day (CI = 30.4-64.8) respectively, representing 20.6 (Rappahannock, CI = 6.5-34.7) and 25.9 (James, CI = 17.3-25.9) fish per day on average.

For females the average catch was 16.8 kg/day (CI = 7.1 – 26.6) in the Rappahannock and 18.7 (CI = 11.9-25.6) in the James. The average daily catch for Rappahannock males was 22.8 kg/day (CI = 10.5-35.0) and in the James was 29.8 kg/day (CI = 19.2 – 40.4 / Table 8). Comparing these estimates with those from 2020 must be done with extreme caution due to the pandemic-truncated sampling season in that year.

Considering catch by number in the Rappahannock, most fish were captured in the smaller mesh panels (<=5.25”) though in biomass units CPUE was fairly evenly distributed over the entire range of mesh panels. In the James both by number and biomass units, most fish were caught in the same smaller range of meshes with a small peak in the 9” panels. (Table 9, Figure 10).

Female fish in the Rappahannock were primarily captured in the larger mesh panels (6” and greater) while males were captured across multiple mesh sizes. In the James, most females were captured in the 5.25” and 9.0” meshes but were spread among all but the smallest size net. Most males were captured in the 3.75”, 4.5” and 5.25” panels with another small peak in the 9.’) mesh (Table 10, Figure 11).

Age Determinations using Scales and Otoliths

Each of the 1135 striped bass captured in the gill net monitoring project were subjected to age determination via otolith extraction and of these 282 were also aged using scales. Until 2020 scale-otolith comparison were performed on virtually all fish. However, MRG determined that after many years of scale-otolith comparison data the relationship was well established and the paired sample rate could be decreased. Still, 25% of the fish were aged via both methods. Compared to otolith ages (considered to be the more accurate and preferred method), mean scale age is lower at all but the lowest ages and the gap between methods generally increases with increasing age (Table 11, Figure 12).

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Table 1. Number and biomass of striped bass captured, water temperature, and salinity by week in the Rappahannock and James Rivers, spring 2021.

River	Week-of-Year	Sample Date	NumberCaught	Biomass Caught (kg)	Water Temp (C)	Salinity (ppt)
Rappahannock	8	25-Feb-21	3	4.76	5.2	0.05
	9	03-Mar-21	18	21.05	7.9	0.04
	10	09-Mar-21	18	18.35	9.2	0.04
	11	17-Mar-21	10	8.27	10.3	0.04
	12	24-Mar-21	7	8.57	11.8	0.04
	13	30-Mar-21	30	109.89	14.5	0.04
	14	06-Apr-21	91	159.11	15.2	0.04
	15	13-Apr-21	143	251.71		
	16	20-Apr-21	168	294.84	18.6	0.04
	17	27-Apr-21	31	69.91	17.8	0.04
	18	06-May-21	3	21.04	22.8	0.04
	19	11-May-21	3	7.57	19.1	0.05
James	8	25-Feb-21	24	27.5	6.0	0.06
	9	03-Mar-21	25	36.62	8.1	0.05
	10	09-Mar-21	21	28.4	8.9	0.05
	11	17-Mar-21	31	48.83	11.0	0.07
	12	24-Mar-21	9	15.06	12.5	0.07
	13	30-Mar-21	57	121.3	16.2	0.07
	14	06-Apr-21	47	80.76	15.2	0.06
	15	13-Apr-21	135	229.75		
	16	20-Apr-21	62	143.79	14.1	0.06
	17	27-Apr-21	87	200.8	16.5	0.07
	18	06-May-21	99	175.05	21.6	0.08
	19	11-May-21	13	13.16	21.1	0.09

Table 2. Catch rates by week and sex for the Rappahannock and James Rivers, spring 2021.

River	Week-of-Year	Sample Date	Males		Females		Ratio Males:Females (Number)
			Number	Biomass	Number	Biomass	
Rappahannock	8	25-Feb-21	2	2.15	1	2.61	2:1
	9	03-Mar-21	17	17.96	1	3.09	17:1
	10	09-Mar-21	18	18.35	0	0.00	n/a
	11	17-Mar-21	10	8.27	0	0.00	n/a
	12	24-Mar-21	7	8.57	0	0.00	n/a
	13	30-Mar-21	26	69.47	4	40.42	6.5:1
	14	06-Apr-21	88	118.02	3	41.09	29.3:1
	15	13-Apr-21	138	213.22	5	38.49	27.6:1
	16	20-Apr-21	158	169.67	9	110.84	17.6:1
	17	27-Apr-21	28	50.02	3	19.89	9.3:1
	18	06-May-21	2	2.85	1	18.19	2:1
	19	11-May-21	1	0.92	2	6.65	0.5:1
	Overall		495	679.47	29	281.27	17.1:1
James	8	25-Feb-21	22	25.44	2	2.06	11:1
	9	03-Mar-21	19	28.73	6	7.89	3.2:1
	10	09-Mar-21	13	14.75	8	13.65	1.6:1
	11	17-Mar-21	21	31.19	10	17.64	2.1:1
	12	24-Mar-21	9	15.06	0	0.00	n/a
	13	30-Mar-21	53	80.44	4	40.86	13.3:1
	14	06-Apr-21	45	60.14	2	20.62	22.5:1
	15	13-Apr-21	128	180.2	7	49.55	18.3:1
	16	20-Apr-21	47	76.14	15	67.65	3.1:1
	17	27-Apr-21	69	115.7	18	85.10	3.8:1
	18	06-May-21	84	115.45	15	59.60	5.6:1
	19	11-May-21	10	10.59	3	2.57	3.3:1
	Overall		520	753.83	90	367.19	5.8:1

Table 3. Otolith age frequencies by river and sex, spring 2021.

Otolith Age	Rappahannock		James	
	Females	Males	Females	Males
1	0	0	0	0
2	0	2	9	50
3	0	288	13	151
4	0	37	17	158
5	2	12	5	73
6	8	115	10	51
7	2	22	19	30
8	1	4	5	4
9	1	0	4	0
10	8	10	2	3
11	0	1	0	0
12	1	0	0	0
13	1	1	0	0
14	0	0	0	0
15	0	0	3	0
16	0	1	0	0
17	2	0	3	0
18	2	1	0	0
19	0	0	0	0
20	0	1	0	0
21	0	0	0	0
22	0	0	0	0
23	0	0	0	0
24	0	0	0	0
25	0	0	0	0
26	1	0	0	0

Table 4. Weekly total biomass, by sex, of striped bass captured in the Rappahannock and James Rivers, spring 2021.

River	Week-of-Year	Sample Date	Males	Females	Ratio Males:Females
Rappahannock	8	25-Feb-21	2.15	2.61	0.8:1
	9	03-Mar-21	17.96	3.09	5.8:1
	10	09-Mar-21	18.35	0.00	n/a
	11	17-Mar-21	8.27	0.00	n/a
	12	24-Mar-21	8.57	0.00	n/a
	13	30-Mar-21	69.47	40.42	1.7:1
	14	06-Apr-21	118.02	41.09	2.9:1
	15	13-Apr-21	213.22	38.49	5.5:1
	16	20-Apr-21	169.67	110.84	1.5:1
	17	27-Apr-21	50.02	19.89	2.5:1
	18	06-May-21	2.85	18.19	0.2:1
	19	11-May-21	0.92	6.65	0.1:1
	Overall		679.47	281.27	2.4:1
James	8	25-Feb-21	25.44	2.06	12.3:1
	9	03-Mar-21	28.73	7.89	3.6:1
	10	09-Mar-21	14.75	13.65	1.1:1
	11	17-Mar-21	31.19	17.64	1.8:1
	12	24-Mar-21	15.06	0.00	n/a
	13	30-Mar-21	80.44	40.86	2:1
	14	06-Apr-21	60.14	20.62	2.9:1
	15	13-Apr-21	180.2	49.55	3.6:1
	16	20-Apr-21	76.14	67.65	1.1:1
	17	27-Apr-21	115.7	85.10	1.4:1
	18	06-May-21	115.45	59.60	1.9:1
	19	11-May-21	10.59	2.57	4.1:1
	Overall		753.83	367.19	2.1:1

Table 5. Average length (mm), weight (g) and age of striped bass by year, river and sex, spring 2021. 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	####	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
2020	826	458.6	1229	4.3	9	930.0	11689	10.3	221	475.2	1555	4.0	25	748.6	7580	8.6	1047	462.1	1298	4.2	34	796.6	8668	9.0
2021	495	464.3	1373	4.3	29	880.7	9699	10.0	520	490.1	1450	4.1	90	632.6	4080	5.9	1015	477.5	1412	4.2	119	693.1	5449	6.9

Table 6. Length frequencies (mm TL) of striped bass sampled from the gill nets, spring 2021.

Length	Rapp-males	Rapp-females	James-males	James-females	Length	Rapp-males	Rapp-females	James-males	James-females
300	0	0	0	0	800	0	0	0	2
310	0	0	0	0	810	0	0	0	0
320	3	0	2	1	820	0	0	0	0
330	7	0	3	1	830	1	0	0	0
340	19	0	6	0	840	0	1	0	0
350	32	0	5	1	850	0	0	0	0
360	31	0	7	0	860	0	0	0	0
370	20	0	7	2	870	0	0	0	0
380	19	0	8	2	880	0	0	0	0
390	17	0	7	1	890	0	0	1	0
400	30	0	10	0	900	0	0	0	2
410	28	0	9	1	910	0	0	0	0
420	23	0	10	1	920	0	0	0	0
430	20	0	16	1	930	0	0	0	0
440	22	0	21	3	940	1	1	0	0
450	6	0	18	0	950	0	0	0	2
460	16	0	18	1	960	0	0	0	0
470	12	0	35	2	970	1	1	0	2
480	9	0	47	0	980	0	3	0	0
490	5	0	32	1	990	0	3	0	0
500	14	0	48	1	1000	0	1	0	1
510	19	0	37	3	1010	0	0	0	0
520	13	0	32	1	1020	0	0	0	1
530	11	0	26	2	1030	0	0	0	0
540	17	0	36	4	1040	1	1	0	0
550	11	0	18	1	1050	1	1	0	0
560	14	1	20	6	1060	0	2	0	2
570	14	0	11	5	1070	0	0	0	0
580	11	1	7	4	1080	1	1	0	1
590	8	0	5	2	1090	0	0	0	0
600	5	1	4	2	1100	1	0	0	0
610	5	0	4	3	1110	0	0	0	0
620	4	2	2	3	1120	0	0	0	0
630	2	0	2	3	1130	0	1	0	3
640	4	0	2	2	1140	0	0	0	0
650	2	2	0	0	1150	0	1	0	0
660	2	1	1	3	1160	0	0	0	0
670	1	0	0	2	1170	0	0	0	0
680	3	1	0	4	1180	0	0	0	0
690	2	0	0	0	1190	0	0	0	0
700	2	0	0	1	1200	0	0	0	0
710	1	0	0	0	1210	0	0	0	0
720	1	0	2	1	1220	0	1	0	0
730	1	1	1	2	1230	0	0	0	0
740	1	0	0	1	1240	0	0	0	0
750	0	1	0	0	1250	0	0	0	0
760	0	0	0	0	1260	0	0	0	0
770	0	0	0	0	1270	0	0	0	0
780	0	0	0	0	1280	0	0	0	0
790	1	0	0	0	1290	0	0	0	0
					1300	0	0	0	0
					Total	495	29	520	90

Table 7. Average length (mm) and weight (g), with standard deviations (Std Dev) of striped bass by year class, spring 2021.

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
2019	9	380.6	34.3	651	213.2	52	376.8	34.3	628	188.6
2018	13	458.2	54.1	1,157	349.1	439	415.1	47.9	834	322.6
2017	17	558.7	24.8	1,976	283.8	195	497.7	37.3	1,453	363.5
2016	7	588.7	21.0	2,416	657.5	85	524.3	25.6	1,691	276.7
2015	18	659.8	91.3	3,772	1,917.6	166	555.9	49.8	2,065	596.8
2014	21	655.9	79.1	3,715	1,498.4	52	571.2	62.9	2,240	783.8
2013	6	801.5	108.4	6,497	2,640.1	8	643.1	118.9	3,374	1,871.5
2012	5	1,001.6	51.6	12,462	1,942.2					
2011	10	993.9	34.7	12,050	1,730.7	13	709.9	142.2	4,734	3,011.4
2010						1	624.0		2,850	
2009	1	1,049.0		11,570						
2008	1	982.0		13,660		1	1,053.0		14,420	
2006	3	1,030.0	120.0	13,703	4,575.2					
2005						1	1,045.0		12,980	
2004	5	1,101.2	40.0	18,142	1,150.3					
2003	2	1,113.5	46.0	16,465	2,439.5	1	1,080.0		14,610	
2001						1	1,100.0		14,900	
1995	1	1,218.0		19,380						

Table 8. Average catch per day by river and sex, in numbers and biomass with lower (LCL) and upper (UCL) confidence limits, spring 2021.

River	Sex	LCL	Number per Day	UCL	LCL	KG per day	UCL
Rapp	Combined	6.5	20.6	34.7	15.9	38.0	60.1
	F	1.0	1.7	2.5	7.1	16.8	26.6
	M	6.1	16.4	26.7	10.5	22.8	35.0
James	Combined	17.3	25.9	34.5	30.4	47.6	64.8
	F	3.3	4.6	5.9	11.9	18.7	25.6
	M	13.5	20.6	27.8	19.2	29.8	40.4

Table 9. Average catch per day by river and mesh size, in numbers and biomass with lower (LCL) and upper (UCL) confidence limits, spring 2021.

River	Mesh (in)	LCL	Number per Day	UCL	LCL	KG per Day	UCL
Rapp	3.00	0.00	5.63	14.59	0.00	3.12	7.76
	3.75	1.95	7.53	13.10	1.96	7.46	12.96
	4.50	0.79	2.37	3.94	1.20	3.79	6.38
	5.25	0.85	2.70	4.56	1.94	5.87	9.80
	6.00	0.34	0.88	1.42	1.08	2.81	4.54
	6.50	0.16	0.52	0.89	0.71	2.35	3.99
	7.00	0.02	0.31	0.60	0.34	2.93	5.53
	8.00	0.07	0.24	0.41	0.85	3.50	6.14
	9.00	0.00	0.20	0.41	0.08	2.52	4.97
	10.00	0.00	0.24	0.48	0.03	3.63	7.23
James	3.00	0.75	1.85	2.94	0.66	1.52	2.38
	3.75	5.03	8.04	11.05	5.48	8.97	12.46
	4.50	4.94	9.84	14.75	7.75	15.53	23.31
	5.25	3.15	4.42	5.69	6.42	9.66	12.90
	6.00	0.19	0.51	0.84	0.58	1.64	2.71
	6.50	0.17	0.47	0.78	0.72	2.10	3.47
	7.00	0.04	0.22	0.40	0.09	1.08	2.06
	8.00	0.04	0.21	0.38	0.23	1.91	3.59
	9.00	0.07	0.29	0.52	0.95	4.52	8.09
	10.00	0.00	0.04	0.13	0.00	0.67	2.01

Table 10. Average catch per day by river, sex and mesh size, in biomass with lower (LCL) and upper (UCL) confidence limits, spring 2021.

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	0.07	0.21	0.00	0.24	0.71
		5.25	0.00	0.09	0.26	0.00	0.22	0.67
		6.00	0.06	0.33	0.59	0.14	0.94	1.75
		6.50	0.02	0.21	0.40	0.00	1.43	2.94
		7.00	0.00	0.17	0.37	0.00	1.89	4.01
		8.00	0.04	0.20	0.37	0.44	3.00	5.57
		9.00	0.00	0.17	0.37	0.00	2.11	4.52
		10.00	0.00	0.17	0.37	0.00	2.62	5.72
	Male	3.00	0.00	8.44	17.74	0.00	4.68	9.48
		3.75	4.49	9.03	13.57	4.48	8.95	13.43
		4.50	1.81	3.25	4.70	2.71	5.10	7.50
		5.25	1.88	3.48	5.08	4.17	7.55	10.93
		6.00	0.57	0.96	1.35	1.85	3.17	4.49
		6.50	0.34	0.73	1.12	1.36	2.96	4.56
		7.00	0.09	0.25	0.42	0.56	2.33	4.09
		8.00	0.09	0.27	0.44	1.25	3.95	6.64
		9.00	0.03	0.24	0.44	0.44	2.90	5.37
		10.00	0.02	0.23	0.43	0.39	3.46	6.54
James	Female	3.00	0.00	0.27	0.57	0.00	0.12	0.25
		3.75	1.03	1.35	1.67	0.81	1.43	2.04
		4.50	0.95	1.54	2.14	1.47	2.89	4.31
		5.25	1.05	1.53	2.02	2.41	4.42	6.42
		6.00	0.02	0.35	0.69	0.02	1.11	2.20
		6.50	0.15	0.43	0.71	0.65	1.88	3.11
		7.00	0.01	0.18	0.35	0.01	1.04	2.07
		8.00	0.04	0.21	0.38	0.23	1.91	3.59
		9.00	0.07	0.29	0.52	0.95	4.52	8.09
		10.00	0.00	0.04	0.13	0.00	0.67	2.01
	Males	3.00	1.19	2.16	3.14	1.18	1.97	2.77
		3.75	5.32	7.81	10.29	5.90	8.73	11.57
		4.50	5.18	9.55	13.91	7.92	14.73	21.55
		5.25	2.64	3.47	4.30	5.14	6.80	8.45
		6.00	0.32	0.63	0.93	1.02	2.02	3.03
		6.50	0.15	0.43	0.71	0.67	1.91	3.15
		7.00	0.07	0.25	0.43	0.16	1.11	2.06
		8.00	0.04	0.21	0.38	0.23	1.91	3.59
		9.00	0.07	0.29	0.52	0.95	4.52	8.09
		10.00	0.00	0.04	0.13	0.00	0.67	2.01

Table 11. Average, minimum and maximum scale ages for each otolith age class from ages derived from the same specimen, spring 2021.

Otolith Age	n	Minimum Scale Age	Mean Scale Age	Maximum Scale Age
2	25	2	2.2	4
3	103	2	3.0	4
4	59	3	3.7	6
5	21	3	4.4	5
6	41	4	5.2	7
7	14	4	5.6	7
8	4	5	6.5	8
9	3	8	8.3	9
10	4	9	9.3	10
11	1	8	8.0	8
12	1	10	10.0	10
13	0			
14				
15	2	11	11.5	12
16	0			
17	1	13	13.0	13
18	2	12	13.0	14
19				
20	1	13	13.0	13
21				
22				
23				
24				
25				
26	0			

Figure 1. Locations of gill nets sampled in spring spawning stock assessments of striped bass in the Rappahannock and James Rivers, spring 2021.

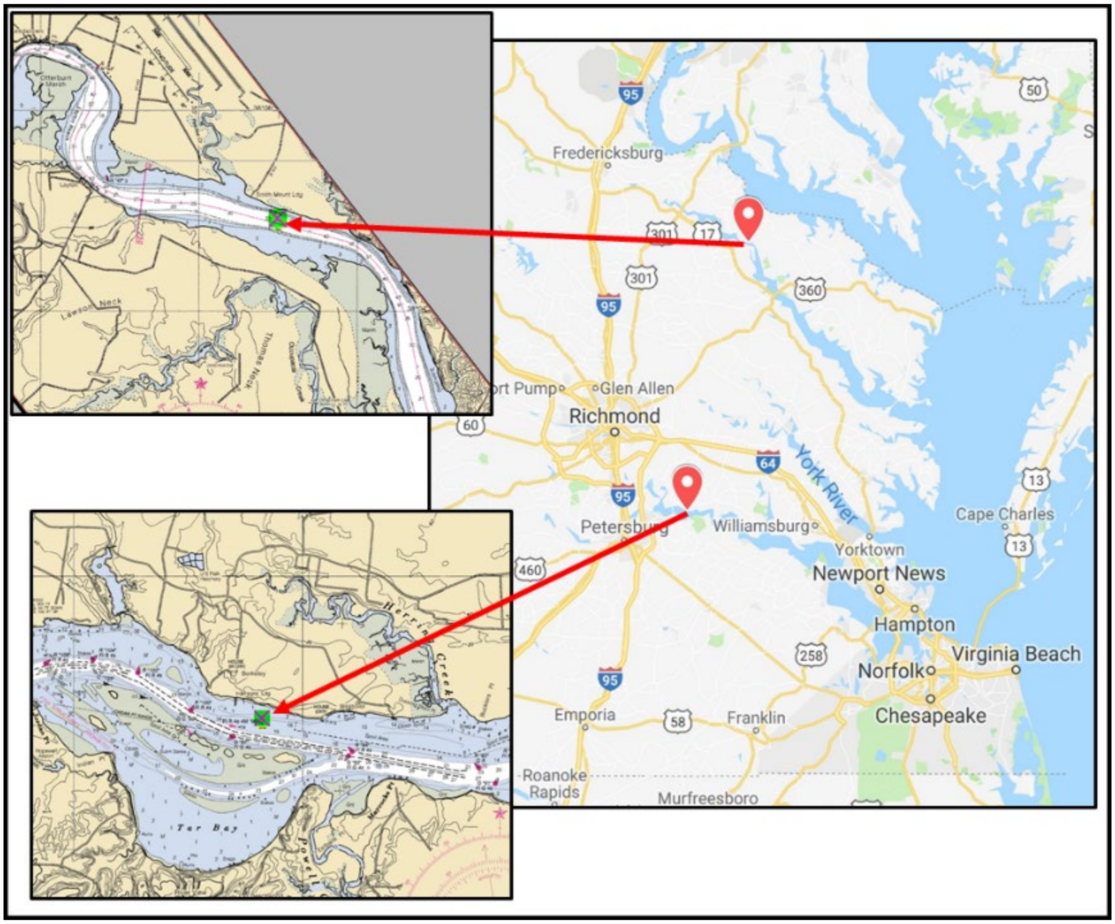


Figure 2. Number of striped bass captured and water temperature by week in the Rappahannock and James Rivers, spring 2021.

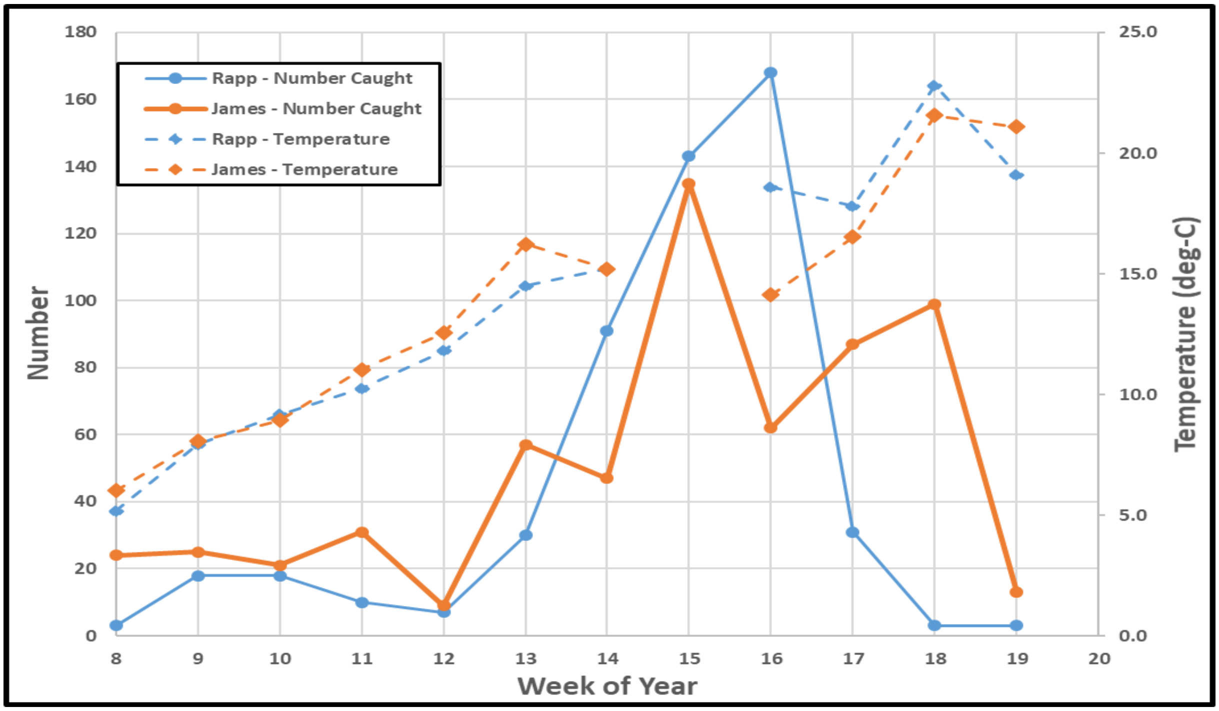
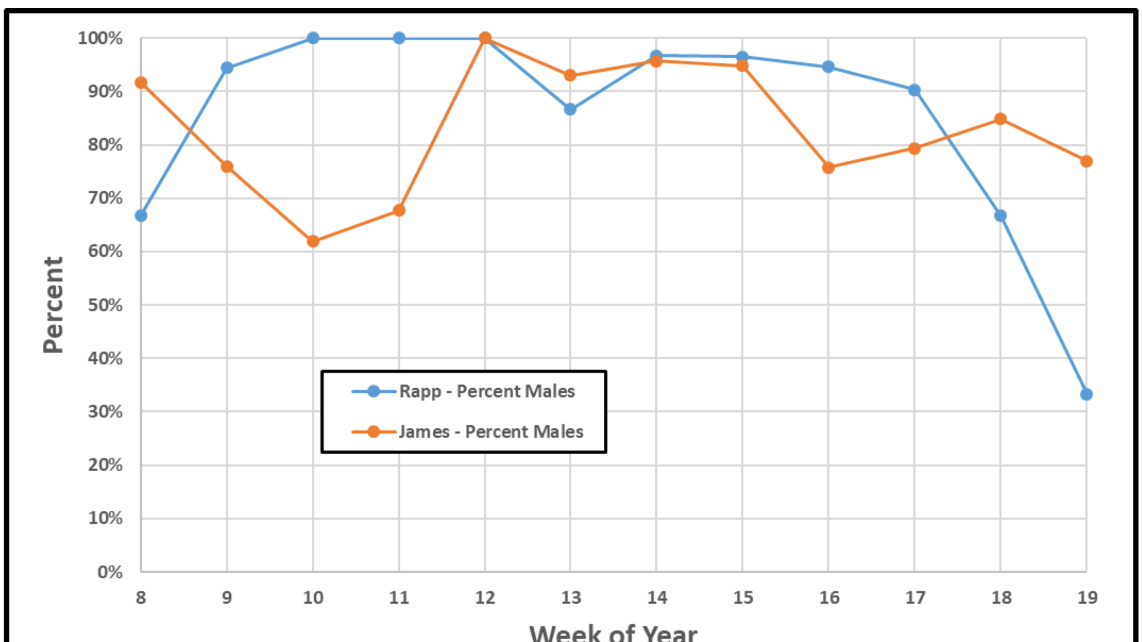


Figure 3. Catch by week and sex in the Rappahannock and James rivers, spring 2021.



Rapp - Males	2	17	18	10	7	26	88	138	158		2	1
Rapp - Females	1	1	0	0	0	4	3	5	9	3	1	2
James - Males	22	19	13	21	9	53	45	128	47	69	84	10
James - Females	2	6	8	10	0	4	2	7	15	18	15	3

Figure 4a. Otolith age frequencies by river, spring 2021 females.

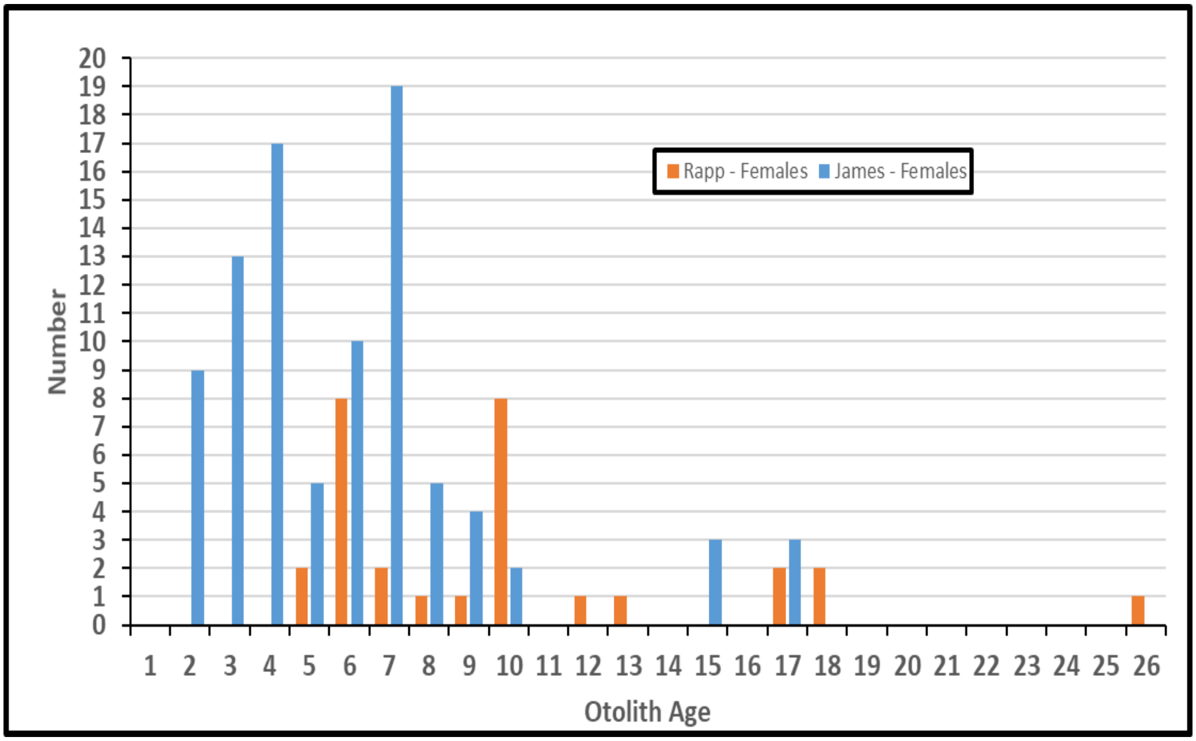


Figure 4b. Otolith age frequencies by river, spring 2021 males.

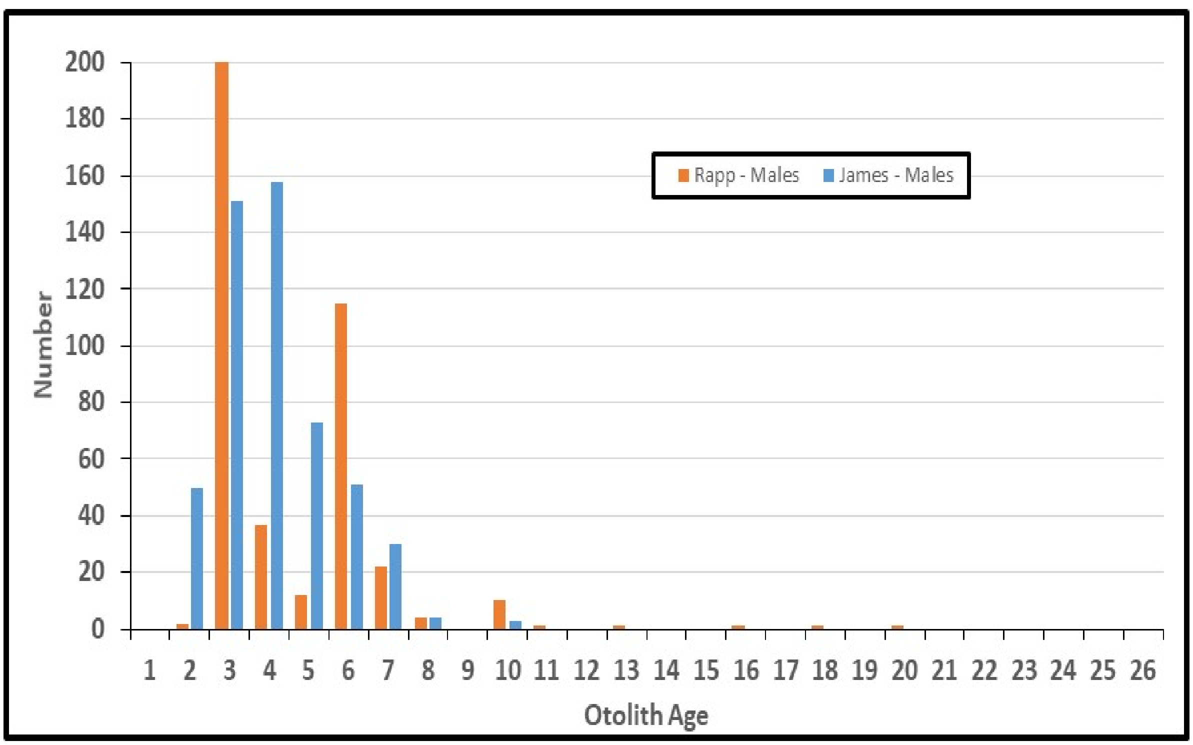


Figure 5a. Weekly total catch by number, by sex, of striped bass captured in the Rappahannock and James Rivers, spring 2021 (Note that the axis scales for males and females differ).

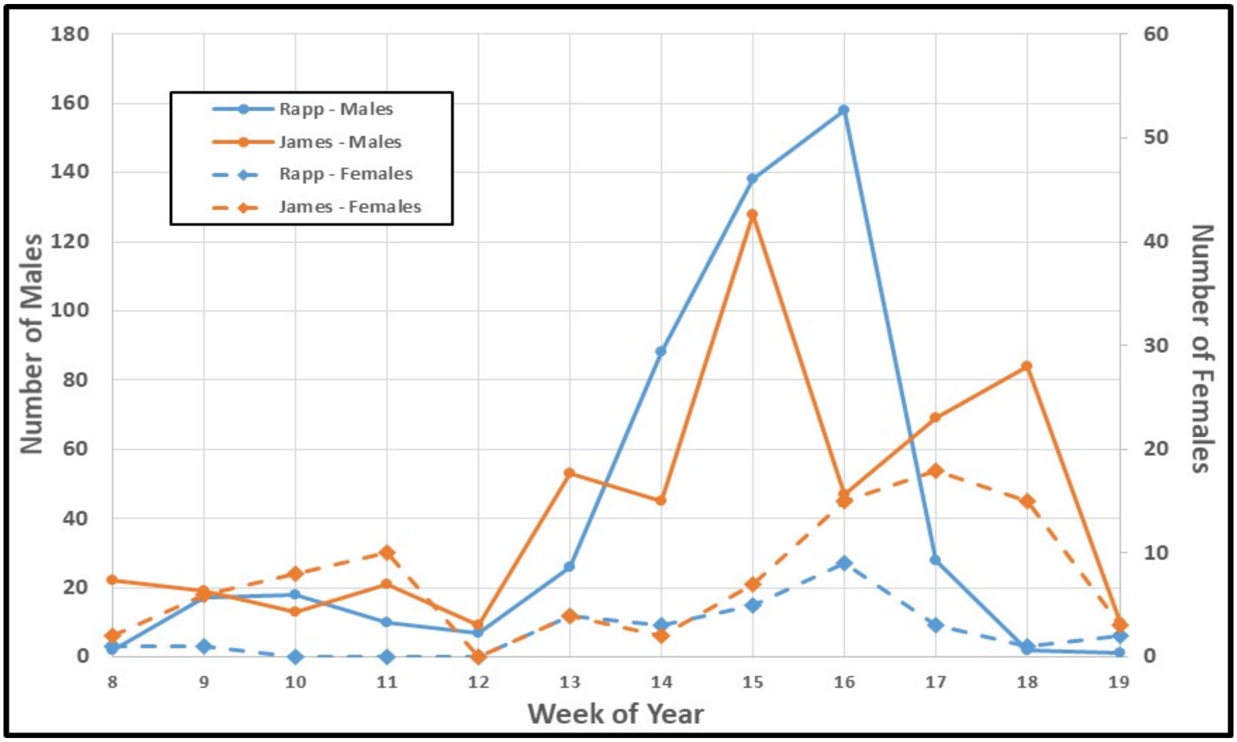


Figure 5b. Weekly total catch by biomass, by sex, of striped bass captured in the Rappahannock and James Rivers, spring 2021.

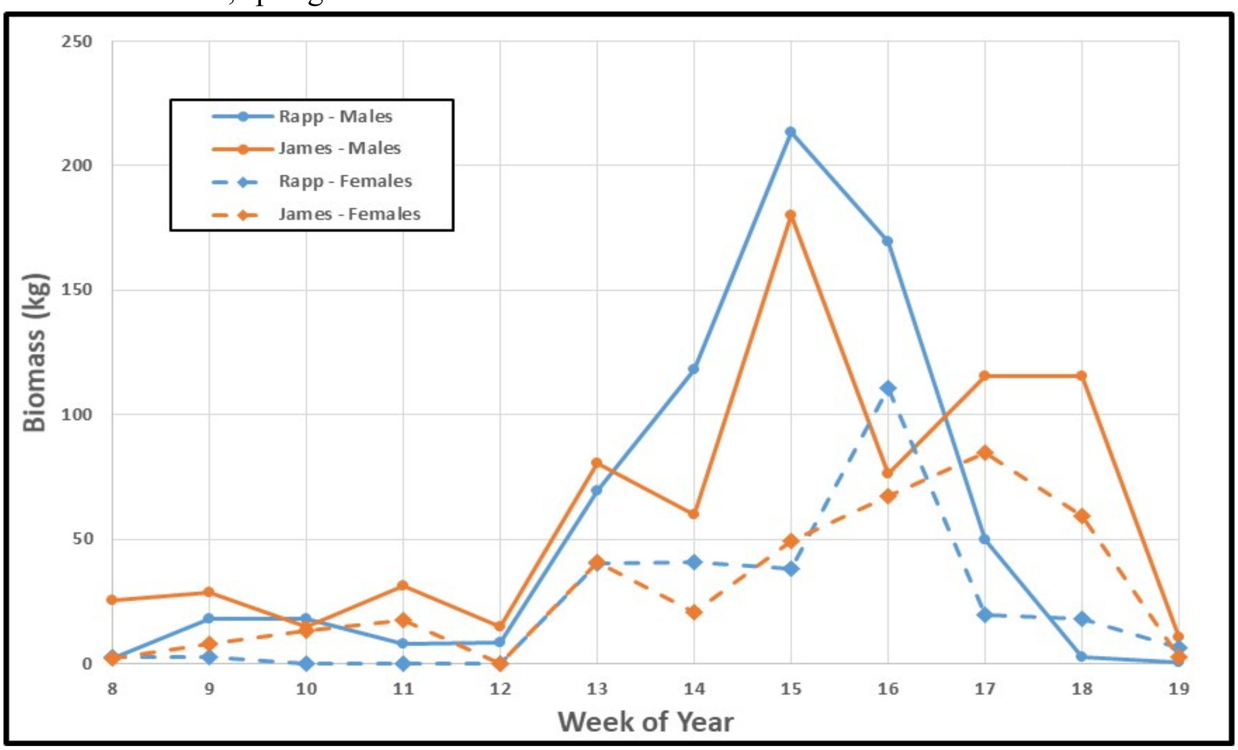
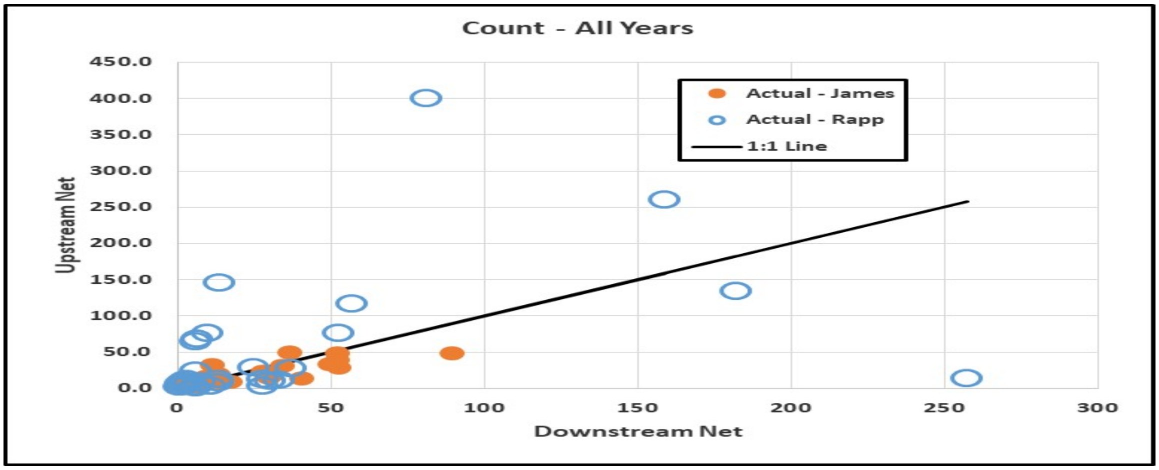


Figure 6a. Comparison of catch rates (numbers and biomass) of Striped Bass between upstream and downstream paired nets in each river, 2018 through 2021.



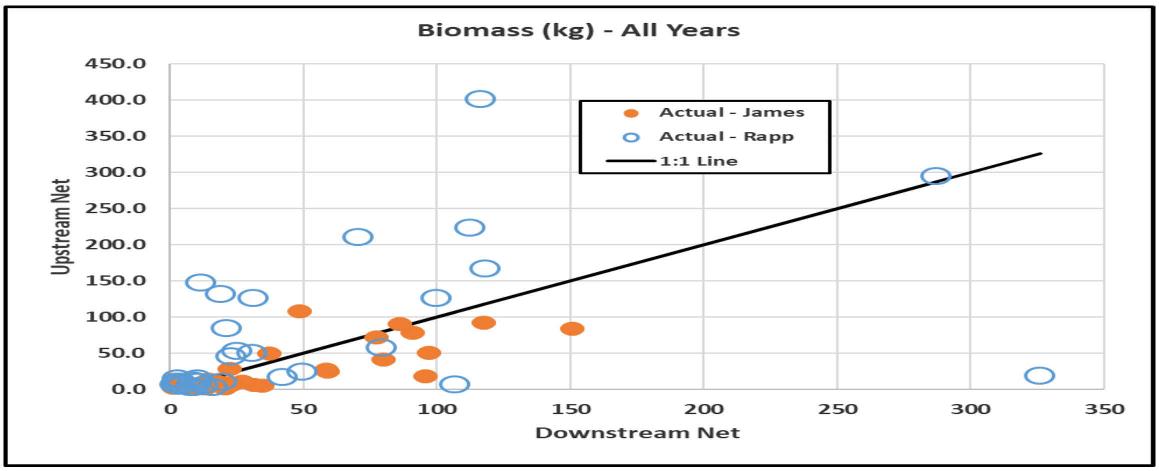


Figure 6b. Comparison of catch rates (numbers only) of all species combined between upstream and downstream paired nets in each river, 2018 through 2021.

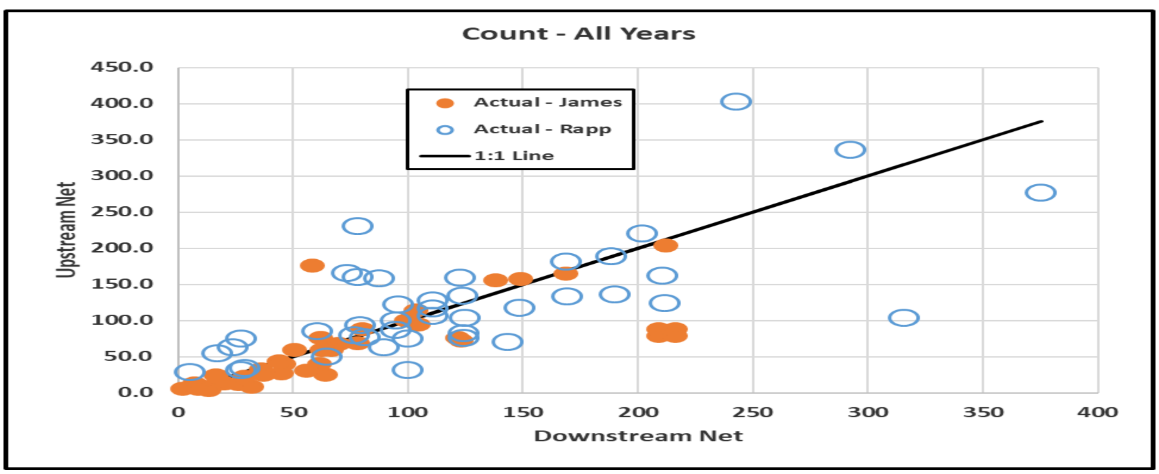


Figure 7. Average length (mm, a), weight (g, b) and age of striped bass by year and sex, 1990 - 2021. Double lines indicate changes in sampling methods and/or locations.

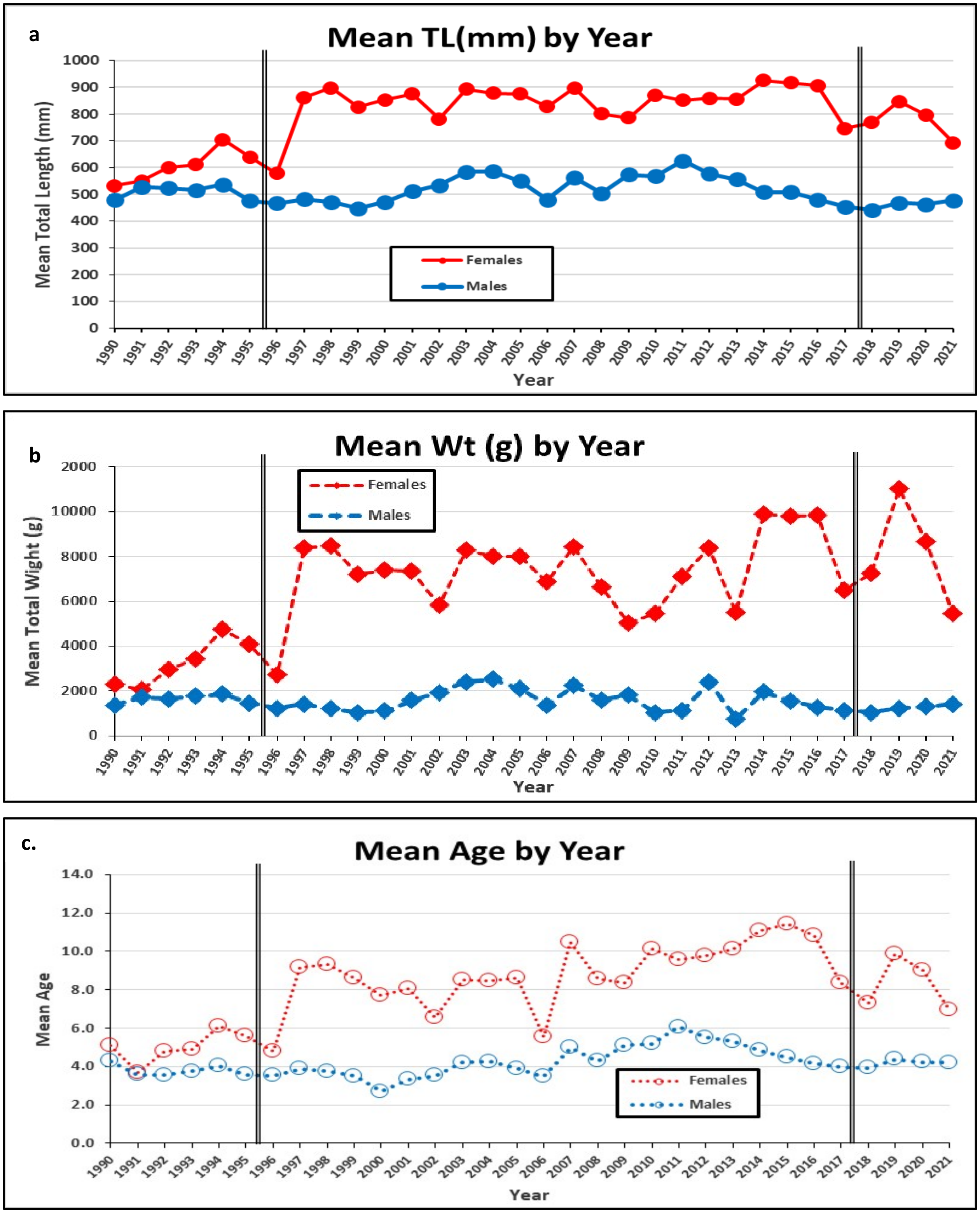


Figure 8. Length frequencies of striped bass captured in gill nets, spring 2021.

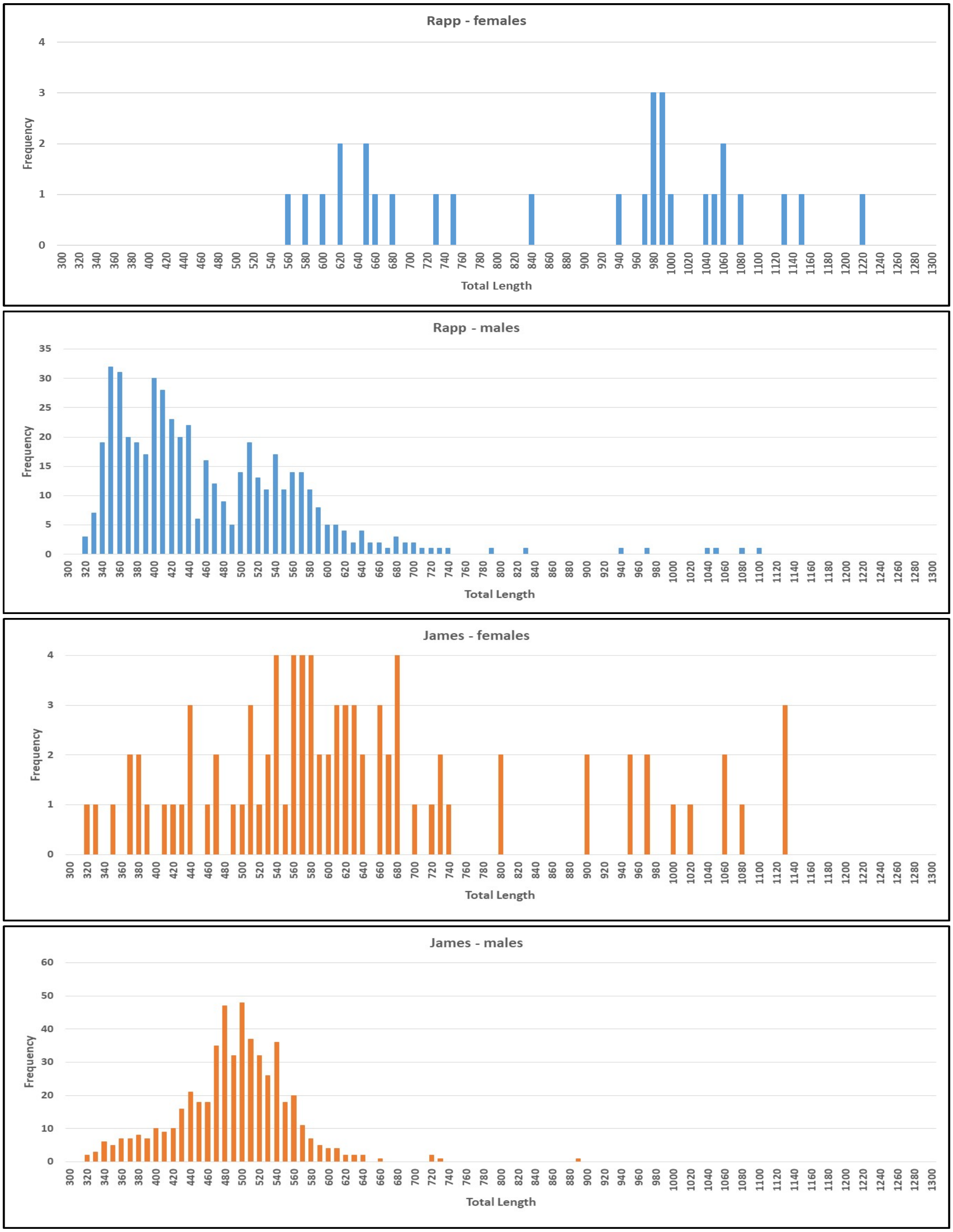
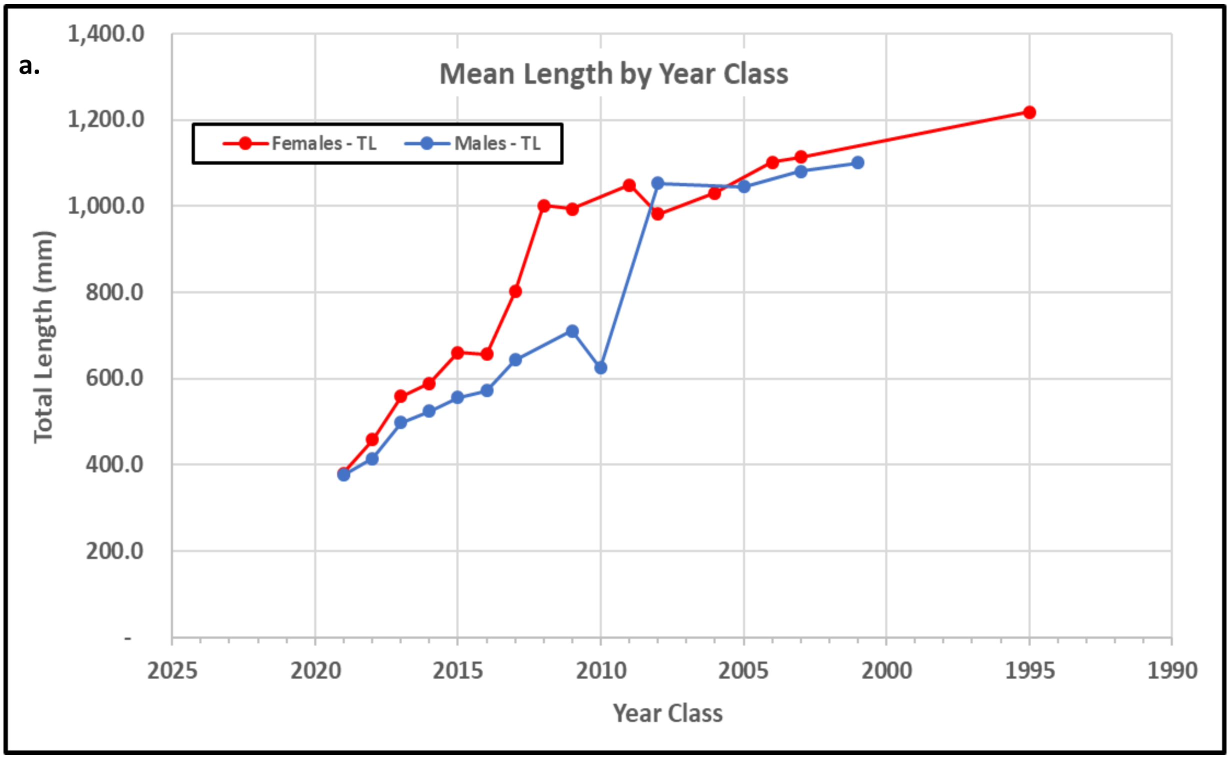


Figure 9. Average length (mm) and weight (g), by sex of striped bass by year class, spring 2021, Rappahannock and James Rivers combined.



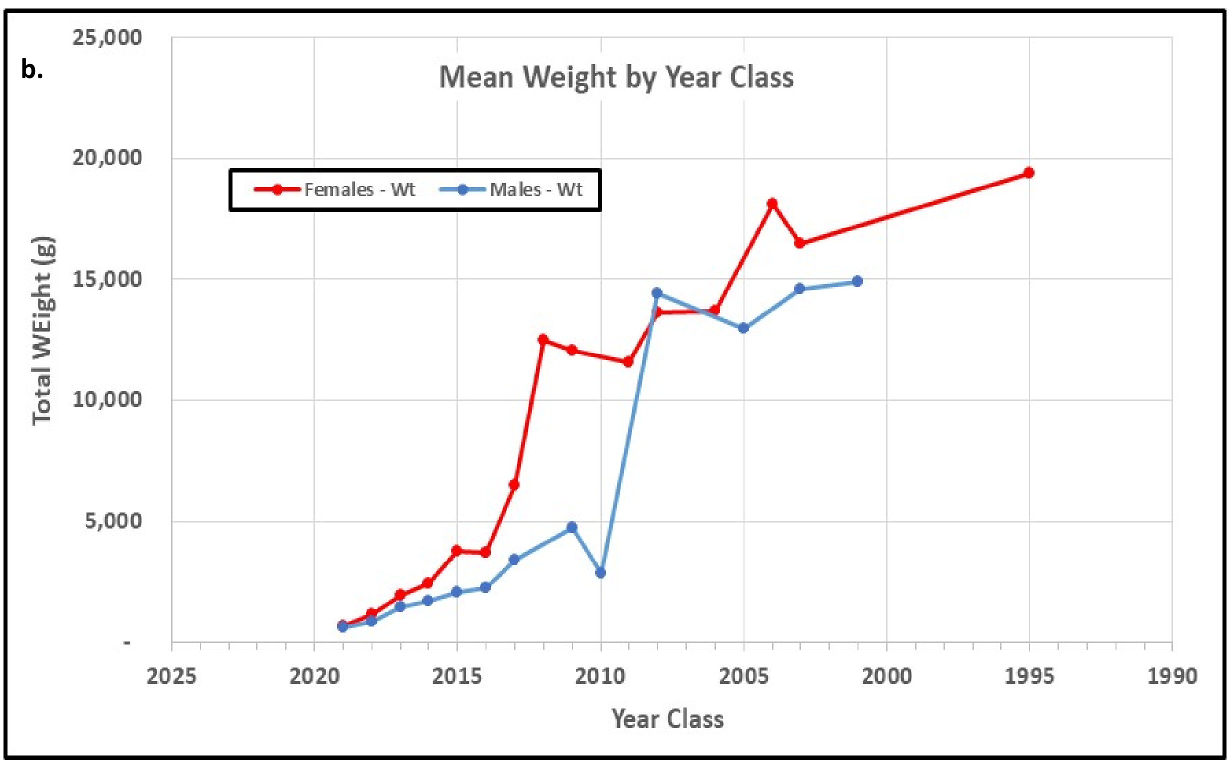
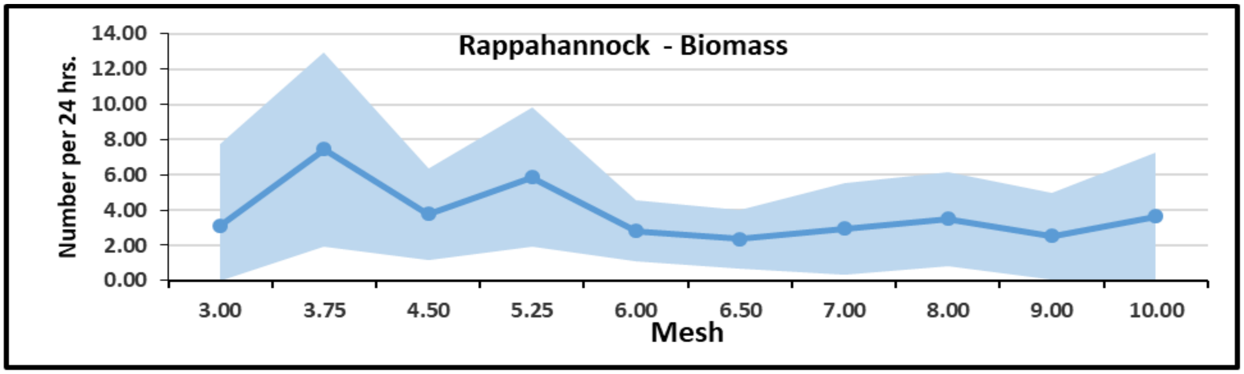
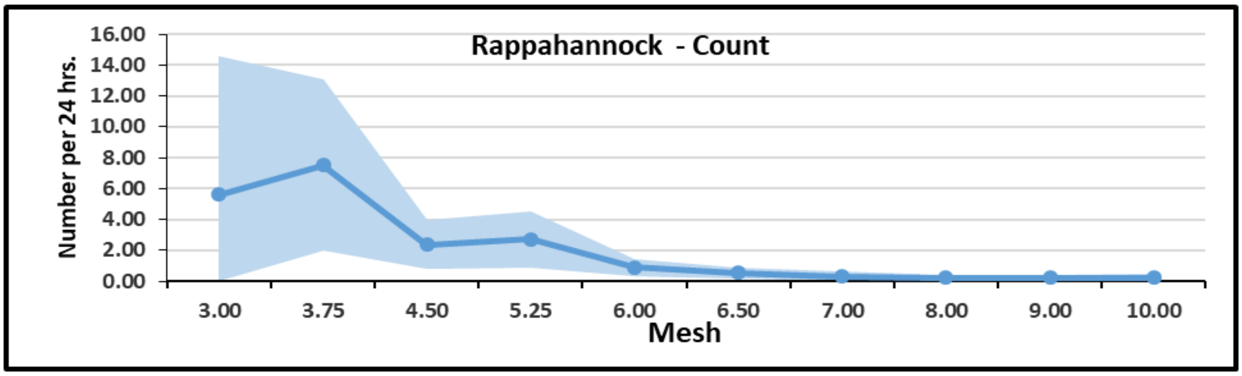
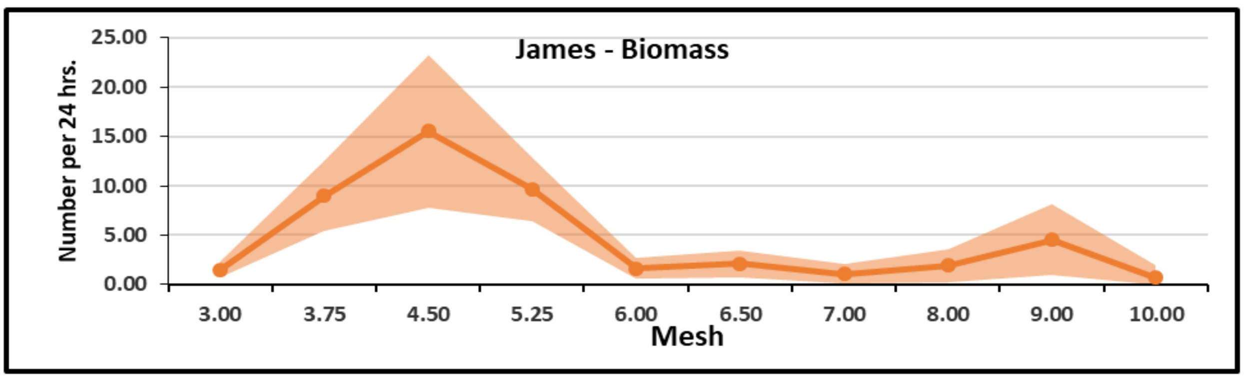


Figure 10. Average catch per day by river and mesh size, in biomass and numbers, spring 2021.







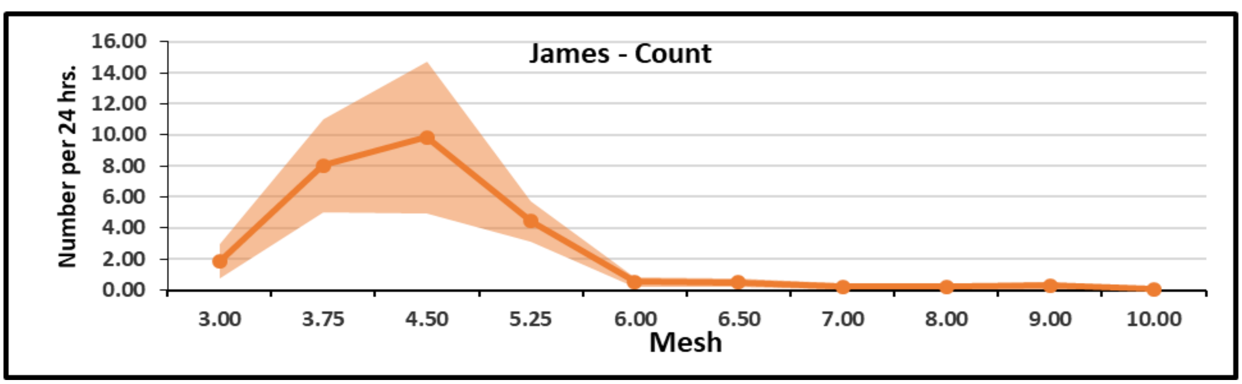


Figure 11. Average catch per day by river, sex and mesh size, in biomass, spring 2021.

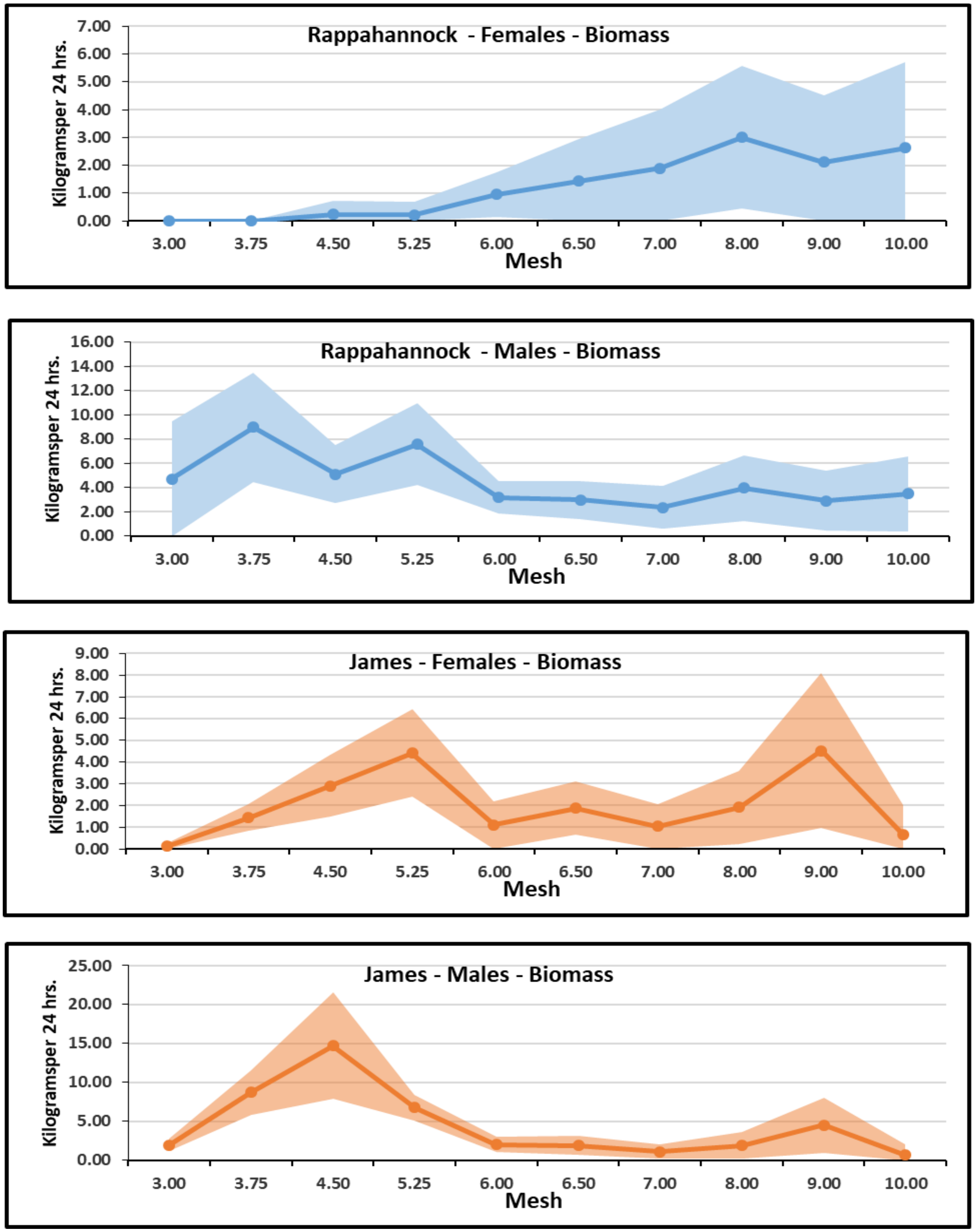
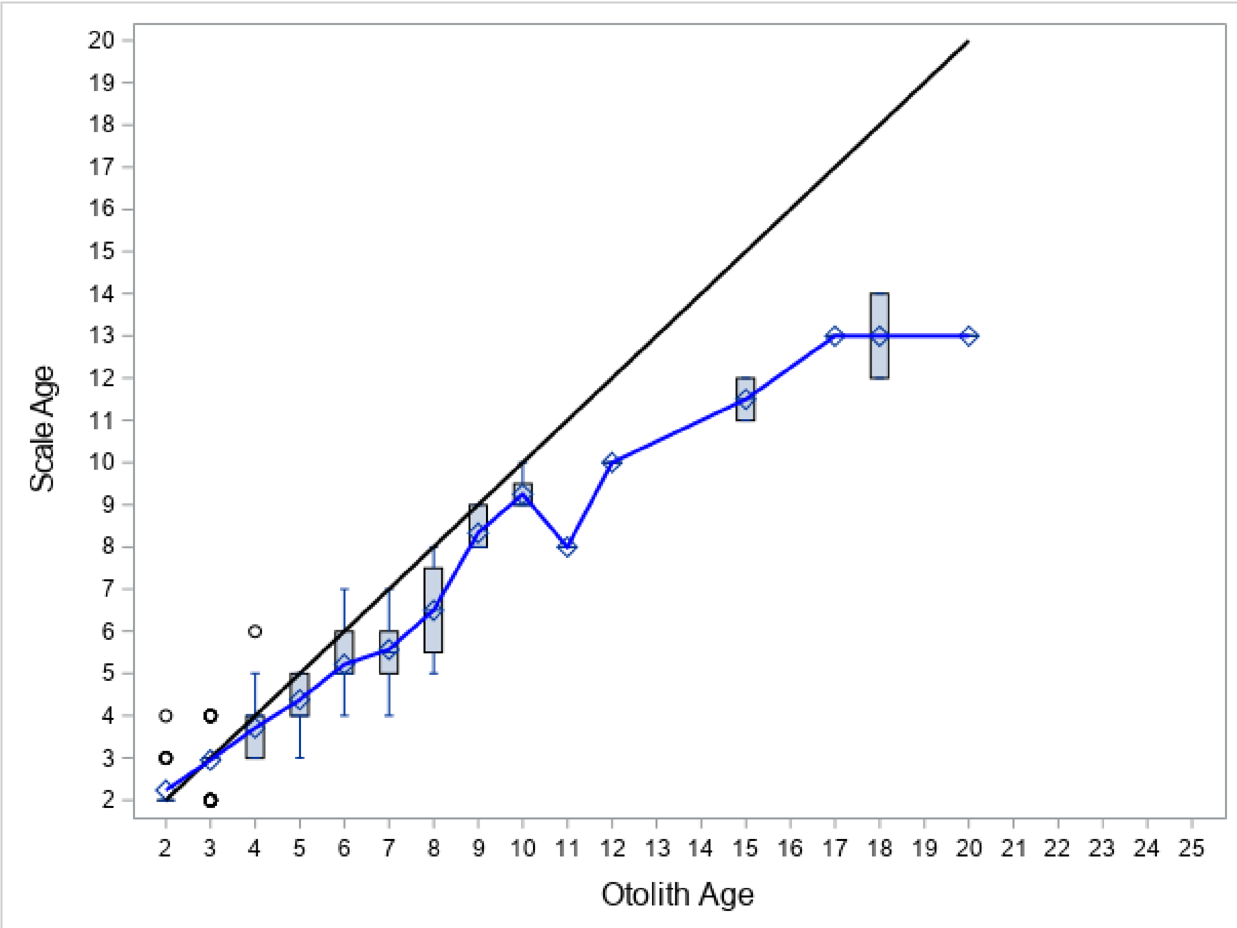


Figure 12. Comparison of otolith age to scale age for samples derived from the same specimen, spring 2021. Boxes represent 25% and 75% quartiles, diamond symbols are the mean, horizontal lines are the median, circles are outliers, the solid black line is the 1:1 line.



Tagging

Spring, 2021

Introduction

The Striped Bass Program, a component of the Multispecies Research Group at 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 are generally represented by constructing an upper triangular matrix of tag recoveries, where each cell of the matrix contains the number of tag returns from a particular year of tagging and recovery. For example, a study with I years of tagging and J years of recovery would yield the following data matrix

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

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

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

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

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

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

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

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

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

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

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

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

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 VIMS 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. 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 457 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 (Table 1).

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 are published in the 2019 benchmark assessment (National Marine Fisheries Service, 2019). 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 2021 Tag Release summary

Electrofishing tagging events (18 of them) occurred between 11 March and 27 April 2021 in the Rappahannock (6), James (10), Mattaponi (2) Rivers. During each event fishing occurred nearly continuously, generally in a grid pattern covering the location thoroughly. Between 0 (1 event in early March) and 126 fish were tagged on a given day.

A total of 1,034 fish were tagged and released, which exceeded the target of 1,000 and which compared to 1,023 in 2020, just 119 in 2019 and 859 in 2018. The median date of release for both rivers combined was 14 April 2021.

In the Rappahannock River, the 6 electrofishing events were conducted between 29 March and 22 April, 2021 which resulted in 335 fish being tagged and released (Table 1). There were 293 resident striped bass (457-710 mm TL) tagged and released, none were identified as females, though it can be presumed that most specimens recorded as sex-unknown were likely females. Zero coastal migrant fish (>710mm) were tagged in the Rappahannock in 2021.

In the James River, resident fish (457-710mm TL) accounted for 658 out of the total of 697 striped bass which were tagged and released between 17 March and 27 April, 2021 (10 sampling dates). An additional 39 coastal migrants (457-710 mm TL) were tagged and released (Table 2).

In the Mattaponi River (a tributary to the York River), one additional resident fish was tagged and released on 2 April 2021 (Table 3). Another electrofishing effort on 11 March yielded no tagged fish.

Mortality Estimates

Tag recapture summary: Coastwide, a total of 68 Virginia-tagged striped bass >457 mm TL were recaptured between 1 January and 31 December 2021. The largest source of recaptures (53 / 77.9%) was from Virginia followed by New York (5 / 7.3%), Maryland and Massachusetts (3 each / 4.4%), Rhode Island (2 / 2.9%), and finally Connecticut and North Carolina (1 each / 1.5%). The peak months for recaptures was May (25 / 36.8%), with all other months at 9 (December, all from Virginia) or fewer (Table 4).

From the 68 total recoveries, 4 were migratory striped bass (>710 mm TL at time of tagging) recaptured between 1 January and 31 December, 2021 (Table 5). These fish were recaptured in Rhode Island (2), Connecticut (1) and Virginia (1). Recapture events for the coastal migrants occurred in June (2 / both in Rhode Island), August (1 / Connecticut) and December (1 / Virginia).

The small number of recaptured fish may be due to decreased recreational fishing effort caused by the combination of lower bag limits imposed by ASMFC and Covid-19 restrictions.

Instantaneous rates model estimates of survival, fishing and natural mortality

Consistent with the analyses performed as part of the 2019 benchmark assessment, eleven models with varying time periods (corresponding to past management actions) for estimates of fishing mortality (F) and tagging mortality (Ftag) were included. All models included two natural mortality periods 1990-1997 and 1998-2020 (Table 6). These models were not updated for management actions initiated in 2019.

Virginia releases: In 2020, resident striped bass (≥ 457 mm TL) from just three tagging years were recaptured and harvested (3 from 2018, 0 from 2019, 20 from 2020 - Table 7a). An additional 15 resident fish from the previous four tagging years (2 from 2017, 2 from 2018, 0 from 2019, 11 from 2020) were recaptured and returned to the water (Table 7b). These were added to their respective input matrixes for estimating survival and mortality parameters using the instantaneous rates model.

Likewise, there were 0 harvested and 5 (2 from 2017, 1 from 2018, 0 from 2019, 2 from 2020) re-released migratory striped bass (≥ 711 mm TL) tagged recaptured in 2020. These data were also used to complete their respective instantaneous rate model input matrixes (Tables 8a,b).

For striped bass ≥ 457 mm TL, Model 9 received the most support, with Models 11, 10, 4, 5 and 6 also receiving a measure of support. All models estimated similar values of annual survival, averaging about 0.62 during the period 1990-1997 and 0.48-0.52 during 1998-2020 (Figure 1a). Similarly, all models resulted in natural mortality (M) estimates averaging 0.35 during 1990-1997 and 0.60-0.61 during 1998-2020 (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 0.04-0.05 (Figure 1c). F-tag estimates followed a general downward trend for nearly all models, with very low 0.01-0.02 values in recent years (Figure 1d).

For migratory striped bass (≥ 711 mm TL at tagging), Model 8 received the most support, with models 3, 9, 10 and 11 also receiving a measure of support. All models estimated similar values of annual survival, averaging about 0.69 during the period 1990-1997 and 0.60-0.63 during 1998-2020 (Figure 2a). All models resulted in natural mortality (M) estimates averaging 0.21-0.22 during 1990-1997 and 0.39-0.40 during 1998-2019 (Figure 2b). Estimates of fishing mortality (F) were somewhat more variable, with those models which allow year-specific estimates of F differing from those allowing only periodic changes. Considering only Model 8, F estimates generally increased between 1990 (0.09) and 1999 (0.26) then ranged between 0.08 and 0.11 until 2008 and have remained near 0.06 since (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).

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Table 1. Summary data of striped bass tagged and released in the Rappahannock River, spring 2021.

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
3/29/2021									84	533.4			4	1070.8	2	896.0			90
4/6/2021							1	637.0	56	524.5			6	1132.0					63
4/8/2021							1	528.0	18	534.1			12	1112.3					31
4/12/2021									66	527.0			13	1074.6					79
4/13/2021							1	458.0	38	534.4			2	1170.5					41
4/22/2021									31	557.7									31
																			0
																			0
																			0
																			0
																			0
																			0
																			0
																			0
																			0
																			0
																			0
																			0
Total	0		0		0		3		293		0		37		2		0		335

Table 2. Summary data of striped bass tagged and released James River, spring 2021.

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
3/17/2021							4	522.8	13	536.2									17
3/25/2021							3	574.7	11	518.3									14
4/5/2021							3	536.3	54	539.2			2	1176.0					59
4/7/2021									87	505.8									87
4/15/2021							15	579.5	110	518.5			1	1178.0					126
4/16/2021							14	581.6	101	517.1			5	1094.2	3	751.3			123
4/21/2021							3	567.3	75	500.6			3	1119.3	2	842.0			83
4/23/2021							9	539.9	28	491.8	1	569	5	1007.8	1	1029.0			44
4/26/2021			1	454.0			18	558.3	46	515.9			8	1008.1					73
4/27/2021							8	558.5	54	530.7			8	901.6	1	1025.0			71
Total	0		1		0		77		579		1		32		7		0		697

Table 3. Summary data of striped bass tagged and released Mattaponi River, spring 2021.

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
4/2/2021							1	510.0											1
																			0
																			0
Total	0		0		0		1		0		0		0		0		0		1

Table 4. Location of striped bass (≥ 457 mm TL), recaptured in 2021, that were originally tagged and released in Virginia during springs 1990-2020.

	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	0	0	0	0	0	0
Rhode Island	0	0	0	0	0	2	0	0	0	0	0	0	2
Connecticut	0	0	0	0	0	0	0	1	0	0	0	0	1
New York	0	0	0	0	0	0	0	0	0	0	0	0	0
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	1	0	0	0	0	0	0	0	1
Maryland	0	0	0	0	0	2	0	2	0	0	2	0	6
District of Columbia	0	0	0	0	0	0	0	0	0	0	0	0	0
Virginia	1	0	3	2	14	9	3	2	2	7	6	9	58
North Carolina	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1	0	3	2	15	13	3	5	2	7	8	9	68

Table 5. Location of migratory striped bass (≥ 710 mm TL), recaptured in 2021, that were originally tagged and released in Virginia during springs 1990-2020.

	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	0	0	0	0	0	0
Rhode Island	0	0	0	0	0	2	0	0	0	0	0	0	2
Connecticut	0	0	0	0	0	0	0	1	0	0	0	0	1
New York	0	0	0	0	0	0	0	0	0	0	0	0	0
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	0	0	0	0	0	0	0	0
District of Columbia	0	0	0	0	0	0	0	0	0	0	0	0	0
Virginia	0	0	0	0	0	0	0	0	0	0	0	1	1
North Carolina	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	2	0	1	0	0	0	1	4

Table 6. Description of IRCR models with varying time periods for fishing mortality, tagging mortality and natural mortality.

	Fishing Mortality	Tagging Mortality	Natural Mortality
Model 1:	Year-specific	Year-specific	2 periods: 1990 - 1997 / 1998 - 2020
Model 2:	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 - 2020	Year-specific	2 periods: 1990 - 1997 / 1998 - 2020
Model 3:	Year-specific	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 - 2020	2 periods: 1990 - 1997 / 1998 - 2020
Model 4:	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 - 2020	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 - 2020	2 periods: 1990 - 1997 / 1998 - 2020
Model 5:	7 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 - 2016 / 2017 - 2020	7 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 - 2016 / 2017 - 2020	2 periods: 1990 - 1997 / 1998 - 2020
Model 6:	7 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 / 2016 - 2020	7 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 / 2016 - 2020	2 periods: 1990 - 1997 / 1998 - 2020
Model 7:	5 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2020	Year-specific	2 periods: 1990 - 1997 / 1998 - 2020
Model 8:	Year-specific	5 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2020	2 periods: 1990 - 1997 / 1998 - 2020
Model 9:	5 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2020	5 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2020	2 periods: 1990 - 1997 / 1998 - 2020
Model 10:	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2016 / 2017 - 2020	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2016 / 2017 - 2020	2 periods: 1990 - 1997 / 1998 - 2020
Model 11:	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2015 / 2016 - 2020	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2015 / 2016 - 2020	2 periods: 1990 - 1997 / 1998 - 2020

Table 7a. Input recapture matrix for IRCR analysis: from striped bass (>457 mm TL) tagged and released in the springs of 1990-2020 (Rappahannock River only 1990-2017, all Virginia waters 2018-2020). 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	2019	2020	Total
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	0	0	97
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	0	0	133
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	0	0	16
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	0	0	57
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	0	0	20
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	0	0	54
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	0	0	22
1997	712								26	17	10	2	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	58
1998	784									28	16	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49
1999	853										30	7	4	2	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	46
2000	1767											42	25	11	7	3	7	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	97
2001	797												31	13	6	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	58
2002	315													10	3	6	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	24
2003	852														31	20	4	5	3	2	1	2	0	0	0	0	1	0	0	0	0	0	69
2004	1477															45	14	6	6	3	1	1	0	0	0	0	0	0	0	0	0	0	76
2005	921																25	18	7	1	4	0	1	0	0	0	0	0	0	0	0	0	56
2006	668																	26	4	6	5	3	4	0	0	0	0	0	0	0	0	0	48
2007	1961																		62	35	16	4	5	0	1	1	1	0	0	0	0	0	125
2008	523																			15	6	0	0	0	0	1	0	0	0	0	0	0	22
2009	867																				26	7	2	2	0	1	0	0	0	0	0	0	38
2010	2050																					28	7	9	2	0	1	0	1	0	0	0	48
2011	416																						12	4	0	0	1	0	0	0	0	0	17
2012	1222																							33	12	5	2	0	0	0	0	0	52
2013	760																								23	8	7	1	0	0	0	0	39
2014	454																									8	3	4	0	1	2	0	18
2015	313																										8	4	2	2	0	0	16
2016	798																											11	5	1	1	0	18
2017	307																												5	1	1	0	7
2018	849																													21	7	3	31
2019	101																														2	0	2
2020	1023																															20	20
Total	26759	21	66	70	54	46	58	25	54	56	65	55	66	39	53	82	54	57	84	63	59	46	31	48	38	24	24	20	13	26	13	23	

Table 7b. Input recapture matrix for IRCR analysis: from striped bass (>457 mm TL) that were tagged and released in the springs of 1990-2020 (Rappahannock River only 1990-2017, all Virginia waters 2018-2020). 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	2019	2020	Total
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	0	0	142
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	0	0	168
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	0	0	14
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	0	0	49
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	0	0	11
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	0	0	39
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	0	0	20
1997	712								12	8	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25
1998	784									21	7	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30
1999	853										19	15	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	38
2000	1767											50	23	8	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	84
2001	797												16	10	7	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	35
2002	315													6	3	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	13
2003	852														12	6	8	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	29
2004	1477															23	6	6	1	0	1	0	0	0	0	0	0	0	0	0	0	0	37
2005	921																13	9	2	0	1	1	0	0	0	0	0	0	0	0	0	0	26
2006	668																	18	7	0	1	1	0	0	0	0	0	0	0	0	0	0	27
2007	1961																		33	11	1	1	0	1	0	1	0	0	0	0	0	2	50
2008	523																			6	3	2	0	0	0	0	0	0	0	0	0	0	11
2009	867																				14	4	0	0	0	0	0	0	0	0	0	0	18
2010	2050																					14	1	1	0	1	0	0	0	0	0	0	17
2011	416																						5	0	0	0	0	1	0	0	0	0	6
2012	1222																							16	4	0	0	0	0	0	0	0	20
2013	760																								6	2	1	0	0	0	0	0	9
2014	454																									6	2	0	3	0	0	0	11
2015	313																										5	0	0	0	0	0	5
2016	798																											11	0	1	0	0	12
2017	307																												3	0	0	2	5
2018	849																													22	6	2	30
2019	101																														2	0	2
2020	1023																															15	15
Total	26759	61	128	64	66	44	28	20	30	41	28	70	40	27	26	33	28	34	45	18	21	23	6	18	10	10	8	13	6	23	8	21	

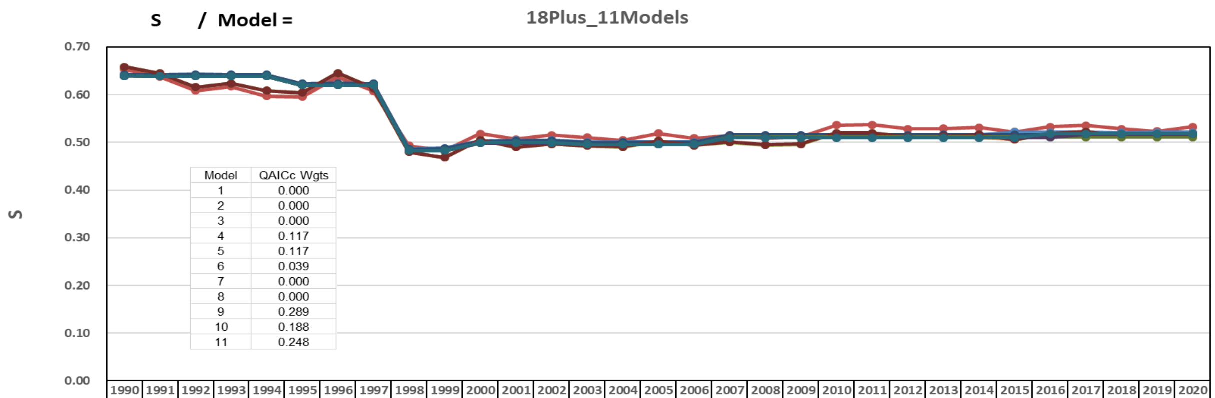
Table 8a. Input recapture matrix for IRCR analysis: from striped bass (>710 mm TL) that were tagged and released in the springs of 1990-2020 (Rappahannock River only 1990-2017, all Virginia waters 2018-2020). Harvested recaptures only.

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	2019	2020	Total
1990	303	10	2	6	1	3	5	1	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31
1991	391		19	10	12	9	2	1	2	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	58
1992	40			2	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
1993	213				11	11	5	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32
1994	123					4	4	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
1995	211						18	6	5	2	1	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36
1996	67							0	3	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
1997	212								11	12	6	2	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34
1998	157									16	9	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30
1999	162										13	2	1	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	20
2000	365											13	11	6	5	3	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	43
2001	269												9	8	2	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26
2002	122													7	3	5	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	18
2003	400														23	13	3	1	2	2	1	2	0	0	0	0	1	0	0	0	0	0	48
2004	688															21	8	8	3	3	1	1	0	0	0	0	0	0	0	0	0	0	45
2005	284																12	7	5	1	3	0	0	0	0	0	0	0	0	0	0	0	28
2006	175																	10	2	4	2	1	4	0	0	0	0	0	0	0	0	0	23
2007	840																		33	22	11	2	4	0	1	1	1	0	0	0	0	0	75
2008	75																			5	1	0	0	0	0	1	0	0	0	0	0	0	7
2009	242																				5	3	0	1	0	1	0	0	0	0	0	0	10
2010	483																					11	5	4	2	0	1	0	1	0	0	0	24
2011	191																						6	2	0	0	1	0	0	0	0	0	9
2012	325																							9	4	1	1	0	0	0	0	0	15
2013	244																								5	3	3	0	0	0	0	0	11
2014	247																									5	2	3	0	1	2	0	13
2015	75																										1	0	0	1	0	0	2
2016	99																											3	1	0	1	0	5
2017	33																												1	1	1	0	3
2018	82																													4	1	0	5
2019	14																														0	0	0
2020	70																															0	0
Total	7202	10	21	18	25	28	35	14	25	31	33	20	27	25	38	49	29	26	47	38	24	21	19	16	12	12	11	6	3	7	5	0	

Table 8b. Input recapture matrix for IRCR analysis: from striped bass (>710 mm TL) that were tagged released in the springs of 1990-2020 (Rappahannock River only 1990-2017, all Virginia waters 2018-2020). 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	2019	2020	Total
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	0	0	34
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	0	0	40
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	0	0	4
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	0	0	20
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	0	0	6
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	0	0	14
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	0	0	1
1997	212								2	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
1998	157									6	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11
1999	162										2	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
2000	365											9	7	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22
2001	269												7	4	2	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	15
2002	122													2	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	5
2003	400														8	5	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19
2004	688															15	2	6	1	0	1	0	0	0	0	0	0	0	0	0	0	0	25
2005	284																4	4	1	0	0	1	0	0	0	0	0	0	0	0	0	0	10
2006	175																	2	1	0	2	0	0	0	0	0	0	0	0	0	0	0	5
2007	840																		12	7	1	1	0	1	0	0	0	0	0	0	0	0	22
2008	75																			0	0	0	0	0	0	0	0	0	0	0	0	0	0
2009	242																				1	1	0	0	0	0	0	0	0	0	0	0	2
2010	483																					5	1	0	0	0	0	0	0	0	0	0	6
2011	191																						1	0	0	0	0	1	0	0	0	0	2
2012	325																							2	0	0	0	0	0	0	0	0	2
2013	244																								1	0	0	0	0	0	0	0	1
2014	247																									3	2	0	2	0	0	0	7
2015	75																										1	0	0	0	0	0	1
2016	99																											0	0	1	0	0	1
2017	33																												0	0	0	2	2
2018	82																													2	1	1	4
2019	14																														0	0	0
2020	70																															2	2
Total	7202	16	26	22	18	14	11	3	6	10	8	15	15	11	15	20	13	12	17	7	5	8	2	3	1	3	3	1	2	3	1	5	

Figure 1a. IRCR generated estimates of annual survival (S) for striped bass ≥ 457 mm TL tagged in Virginia, 1990-2020.

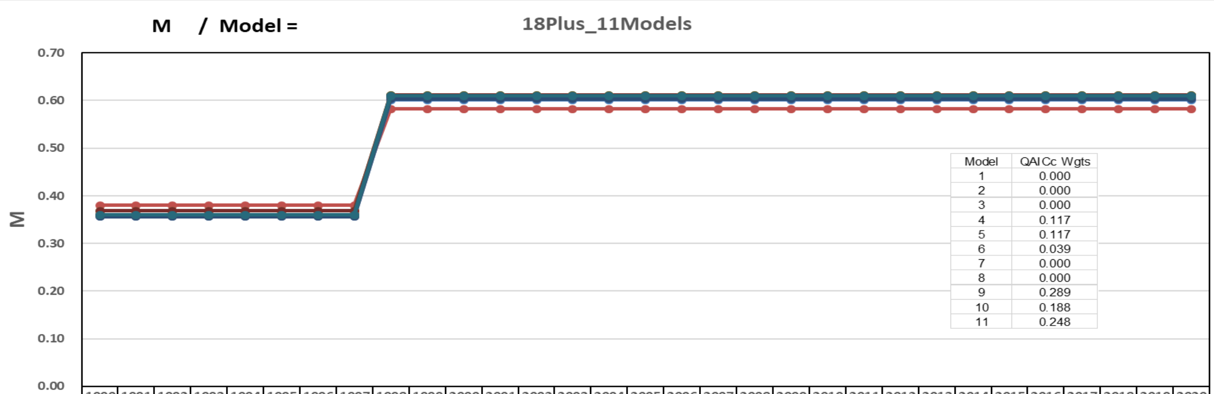


	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Model 1	0.653	0.637	0.608	0.616	0.597	0.595	0.636	0.607	0.492	0.482	0.518	0.506	0.515	0.509	0.504
Model 2	0.641	0.641	0.642	0.641	0.641	0.623	0.623	0.622	0.486	0.487	0.503	0.504	0.504	0.500	0.500
Model 3	0.657	0.644	0.615	0.623	0.608	0.604	0.645	0.613	0.479	0.468	0.504	0.489	0.496	0.492	0.490
Model 4	0.639	0.638	0.638	0.638	0.638	0.620	0.620	0.620	0.483	0.483	0.499	0.499	0.499	0.496	0.496
Model 5	0.639	0.638	0.638	0.638	0.638	0.620	0.620	0.620	0.483	0.483	0.499	0.499	0.499	0.496	0.496
Model 6	0.639	0.638	0.638	0.638	0.638	0.620	0.620	0.620	0.483	0.483	0.499	0.499	0.499	0.496	0.496
Model 7	0.641	0.641	0.642	0.641	0.641	0.623	0.623	0.623	0.485	0.486	0.502	0.503	0.503	0.499	0.499
Model 8	0.657	0.644	0.615	0.623	0.608	0.604	0.645	0.613	0.479	0.468	0.505	0.490	0.496	0.492	0.490
Model 9	0.639	0.638	0.638	0.638	0.638	0.620	0.620	0.620	0.482	0.482	0.498	0.498	0.498	0.495	0.495
Model 10	0.639	0.638	0.638	0.638	0.638	0.620	0.620	0.620	0.482	0.482	0.498	0.498	0.498	0.495	0.495
Model 11	0.639	0.638	0.638	0.638	0.638	0.620	0.620	0.620	0.483	0.483	0.499	0.499	0.499	0.496	0.496

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Model 1	0.519	0.508	0.514	0.508	0.510	0.536	0.536	0.528	0.529	0.531	0.521	0.532	0.535	0.528	0.523	0.532
Model 2	0.501	0.500	0.514	0.514	0.514	0.514	0.515	0.514	0.515	0.514	0.521	0.521	0.521	0.520	0.521	0.520
Model 3	0.502	0.493	0.500	0.494	0.495	0.519	0.519	0.511	0.512	0.515	0.505	0.517	0.521	0.512	0.516	0.517
Model 4	0.496	0.496	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.516	0.516	0.516	0.516	0.516	0.516
Model 5	0.496	0.496	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.516	0.516	0.516	0.516	0.516	0.516
Model 6	0.496	0.496	0.509	0.509	0.509	0.509	0.509	0.509	0.509	0.509	0.506	0.517	0.517	0.517	0.517	0.517
Model 7	0.500	0.499	0.514	0.515	0.515	0.515	0.516	0.515	0.515	0.515	0.515	0.515	0.515	0.514	0.515	0.515
Model 8	0.503	0.493	0.500	0.494	0.496	0.519	0.519	0.511	0.512	0.516	0.506	0.518	0.522	0.513	0.517	0.518
Model 9	0.495	0.495	0.511	0.511	0.511	0.511	0.511	0.511	0.511	0.511	0.511	0.511	0.511	0.511	0.511	0.511
Model 10	0.495	0.495	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.517	0.517	0.517	0.517
Model 11	0.496	0.496	0.509	0.509	0.509	0.509	0.509	0.509	0.509	0.509	0.509	0.517	0.517	0.517	0.517	0.517

Year

Figure 1b. IRCR generated estimates of annual natural mortality (M) for striped bass ≥ 457 mm TL tagged in Virginia, 1990-2020.

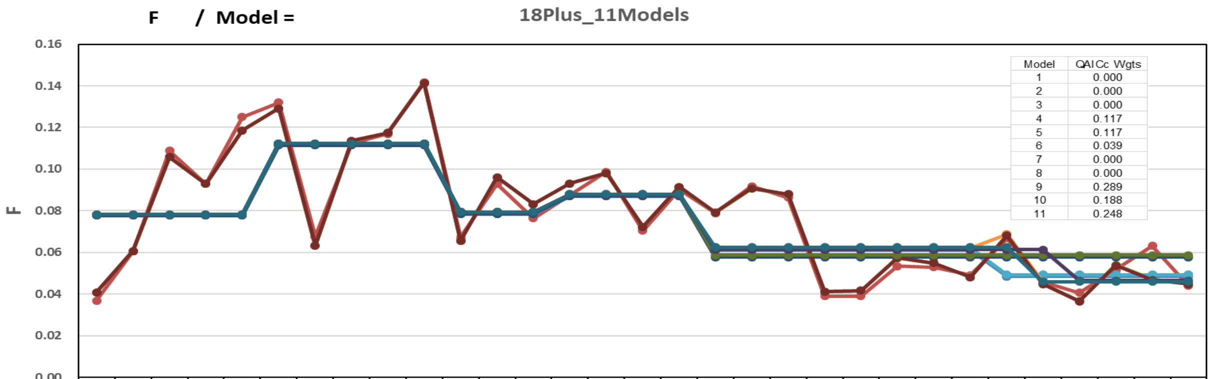


	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
M1	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.58	0.58	0.58	0.58	0.58	0.58	0.58
M2	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.60	0.60	0.60	0.60	0.60	0.60	0.60
M3	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.61	0.61	0.61	0.61	0.61	0.61	0.61
M4	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
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
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
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
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
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
M10	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
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

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
M1	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
M2	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	0.61	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	0.60	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
M5	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	0.60	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	0.60	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	0.61	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	0.61	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	0.60	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
M11	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, 1990-2020.

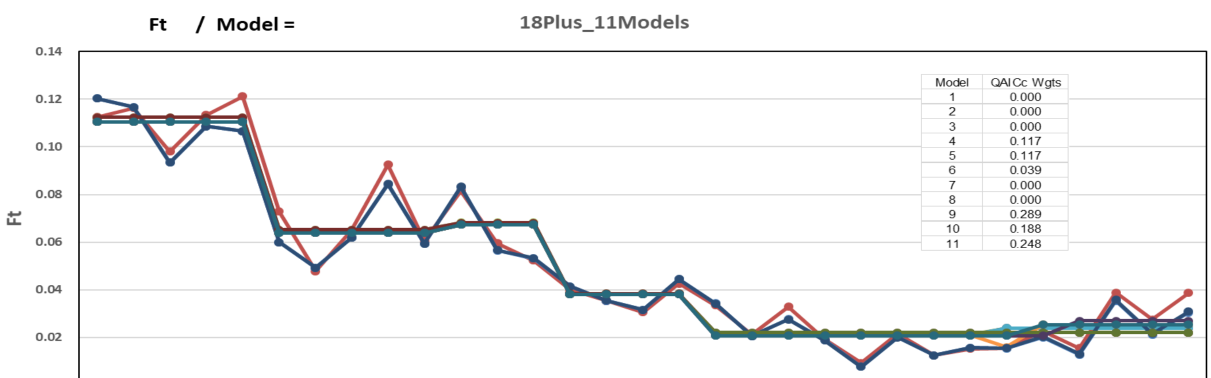


	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
M1	0.03	0.06	0.10	0.09	0.12	0.13	0.06	0.11	0.11	0.14	0.06	0.09	0.07	0.08	0.09
M2	0.07	0.07	0.07	0.07	0.07	0.11	0.11	0.11	0.11	0.11	0.07	0.07	0.07	0.08	0.08
M3	0.04	0.06	0.10	0.09	0.11	0.12	0.06	0.11	0.11	0.14	0.06	0.09	0.08	0.09	0.09
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
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
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
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
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
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
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
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

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
M1	0.07	0.09	0.07	0.09	0.08	0.03	0.03	0.05	0.05	0.04	0.06	0.04	0.04	0.05	0.06	0.04
M2	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	0.04	0.04	0.04
M3	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	0.04	0.04
M4	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	0.04	0.04	0.04
M5	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	0.04	0.04	0.04
M6	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	0.04	0.04
M7	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	0.05	0.05
M8	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	0.04	0.04
M9	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	0.05	0.05
M10	0.08	0.08	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.04	0.04	0.04	0.04
M11	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	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, 1990-2020.

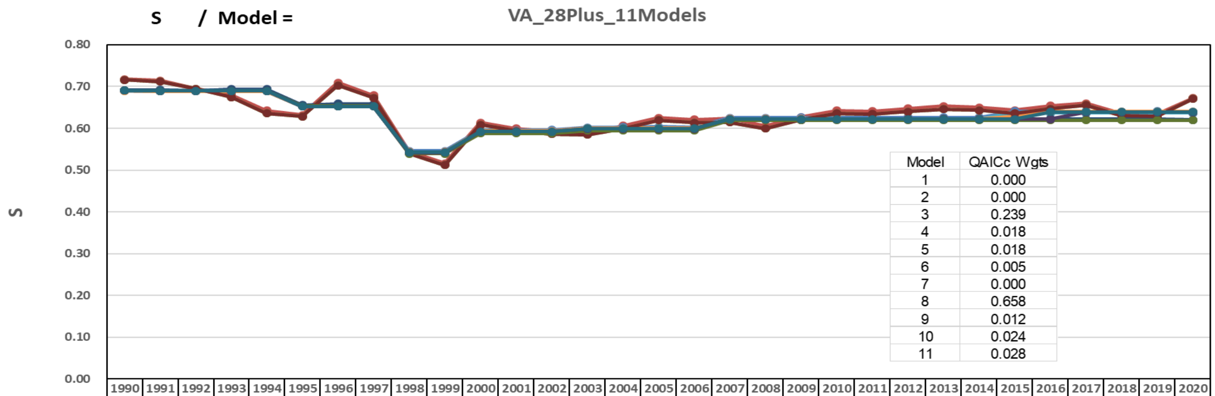


	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
M1	0.11	0.11	0.09	0.11	0.12	0.07	0.04	0.06	0.09	0.06	0.08	0.05	0.05	0.03	0.03
M2	0.12	0.11	0.09	0.10	0.10	0.05	0.04	0.06	0.08	0.05	0.08	0.05	0.05	0.04	0.03
M3	0.11	0.11	0.11	0.11	0.11	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.03	0.03
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
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
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
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
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
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
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
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

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
M1	0.03	0.04	0.03	0.02	0.03	0.01	0.00	0.02	0.01	0.01	0.01	0.02	0.01	0.03	0.02	0.03
M2	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	0.02	0.03
M3	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	0.02	0.02
M4	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	0.02	0.02
M5	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	0.02	0.02
M6	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	0.02	0.02
M7	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	0.02	0.03
M8	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	0.02	0.02
M9	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	0.02	0.02
M10	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	0.02	0.02
M11	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	0.02	0.02

Year

Figure 2a. IRCR generated estimates of annual survival (S) for striped bass ≥ 711 mm TL tagged in Virginia, 1990-2020.

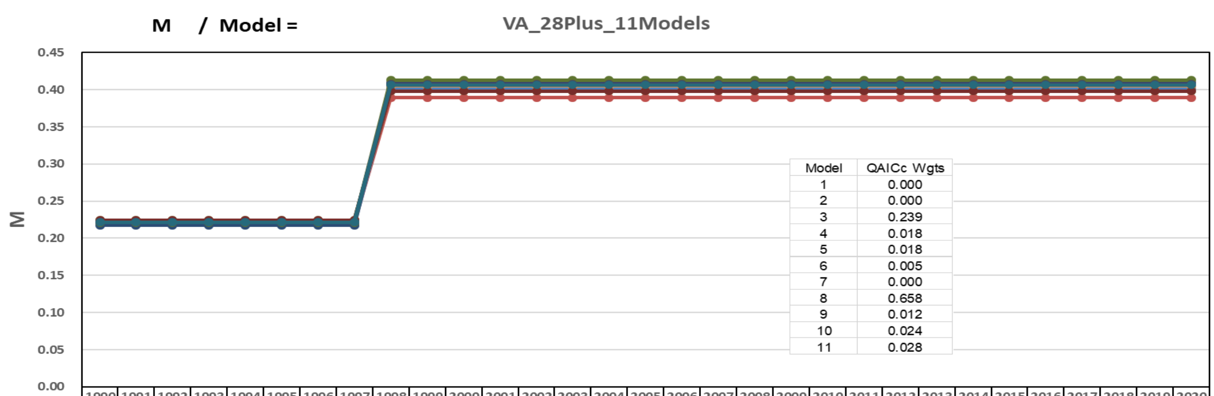


	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Model 1	0.717	0.714	0.694	0.680	0.642	0.631	0.709	0.678	0.544	0.515	0.613	0.599	0.592	0.587	0.605	0.624
Model 2	0.690	0.691	0.689	0.692	0.693	0.655	0.657	0.656	0.545	0.546	0.595	0.595	0.596	0.602	0.602	0.603
Model 3	0.716	0.712	0.694	0.674	0.636	0.628	0.702	0.672	0.539	0.512	0.608	0.594	0.586	0.584	0.598	0.619
Model 4	0.689	0.689	0.689	0.689	0.689	0.652	0.652	0.652	0.542	0.542	0.593	0.593	0.593	0.599	0.599	0.599
Model 5	0.689	0.689	0.689	0.689	0.689	0.652	0.652	0.652	0.542	0.542	0.593	0.593	0.593	0.599	0.599	0.599
Model 6	0.689	0.689	0.689	0.689	0.689	0.652	0.652	0.652	0.543	0.543	0.593	0.593	0.593	0.600	0.600	0.600
Model 7	0.691	0.692	0.690	0.693	0.693	0.656	0.658	0.657	0.541	0.541	0.589	0.590	0.590	0.596	0.596	0.597
Model 8	0.716	0.712	0.694	0.674	0.636	0.628	0.702	0.672	0.539	0.512	0.608	0.594	0.586	0.584	0.598	0.619
Model 9	0.690	0.689	0.689	0.689	0.689	0.653	0.653	0.653	0.538	0.538	0.588	0.588	0.588	0.594	0.594	0.594
Model 10	0.690	0.689	0.689	0.689	0.689	0.652	0.652	0.652	0.541	0.541	0.591	0.591	0.591	0.598	0.598	0.598
Model 11	0.690	0.689	0.689	0.689	0.689	0.652	0.652	0.652	0.542	0.542	0.592	0.592	0.592	0.599	0.599	0.599

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Model 1	0.620	0.623	0.605	0.626	0.642	0.640	0.647	0.652	0.650	0.643	0.654	0.660	0.635	0.633	0.671
Model 2	0.603	0.624	0.625	0.625	0.625	0.626	0.625	0.626	0.625	0.640	0.641	0.640	0.640	0.640	0.638
Model 3	0.613	0.614	0.599	0.619	0.635	0.633	0.640	0.645	0.643	0.635	0.646	0.655	0.630	0.628	0.670
Model 4	0.599	0.622	0.622	0.622	0.622	0.622	0.622	0.622	0.622	0.637	0.637	0.637	0.637	0.637	0.637
Model 5	0.599	0.622	0.622	0.622	0.622	0.622	0.622	0.622	0.622	0.637	0.637	0.637	0.637	0.637	0.637
Model 6	0.600	0.622	0.622	0.622	0.622	0.622	0.622	0.622	0.622	0.629	0.640	0.640	0.640	0.640	0.640
Model 7	0.597	0.621	0.622	0.622	0.621	0.622	0.622	0.622	0.622	0.622	0.622	0.622	0.621	0.622	0.619
Model 8	0.613	0.614	0.599	0.619	0.636	0.633	0.640	0.645	0.643	0.635	0.646	0.655	0.630	0.628	0.670
Model 9	0.594	0.619	0.619	0.619	0.619	0.619	0.619	0.619	0.619	0.619	0.619	0.619	0.619	0.619	0.619
Model 10	0.598	0.621	0.621	0.621	0.621	0.621	0.621	0.621	0.621	0.621	0.621	0.638	0.638	0.638	0.638
Model 11	0.599	0.621	0.621	0.621	0.621	0.621	0.621	0.621	0.621	0.621	0.639	0.639	0.639	0.639	0.639

Year

Figure 2b. IRCR generated estimates of annual natural mortality (M) for striped bass ≥ 711 mm TL tagged in Virginia, 1990-2020.

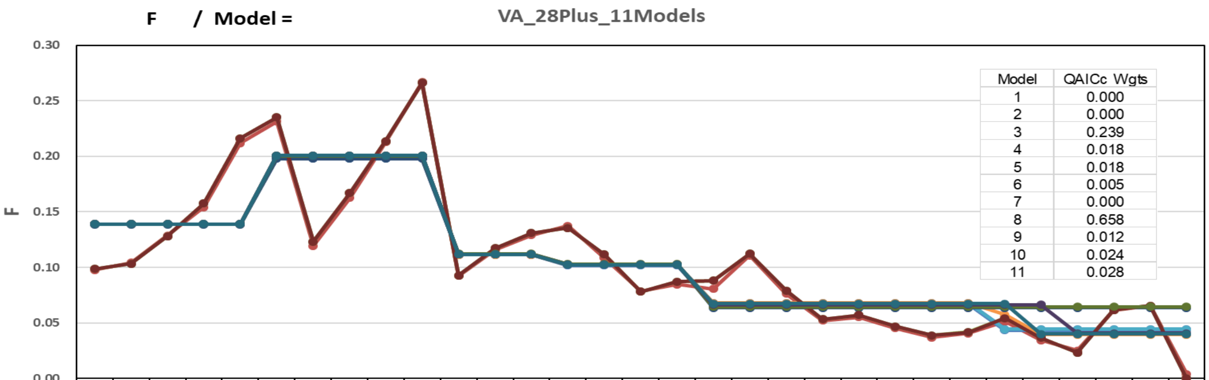


	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
M1	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
M2	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
M3	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
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
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
M6	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
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
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
M9	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
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
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

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
M1	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
M2	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	0.39	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	0.40	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	0.40	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	0.40	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
M7	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	0.39	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	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
M10	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	0.40	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

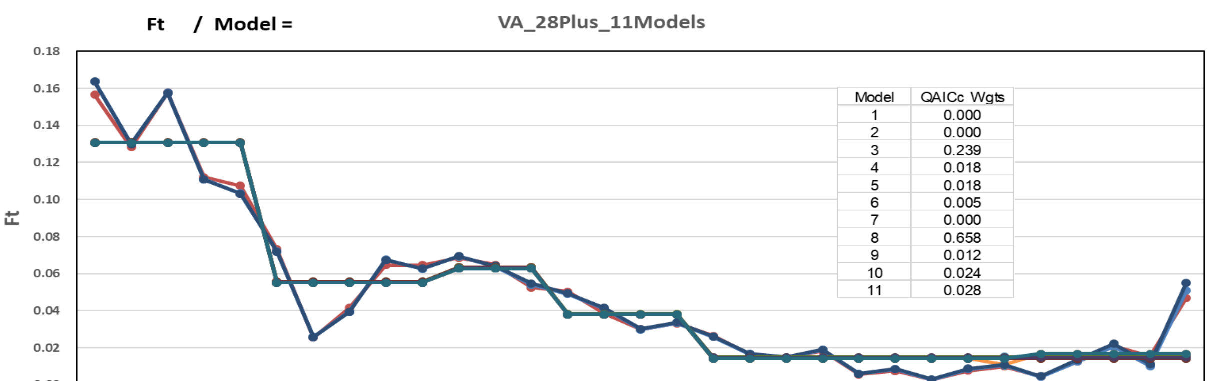
Figure 2c. IRCR generated estimates of annual fishing mortality (F) for striped bass ≥ 711 mm TL tagged in Virginia, 1990-2020.



	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	2019	2020
M1	0.09	0.10	0.12	0.15	0.21	0.23	0.11	0.16	0.21	0.26	0.09	0.11	0.12	0.13	0.10	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	0.06	0.00
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	0.04	0.04	0.04	0.04	0.04	0.04
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	0.13	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	0.06	0.00
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	0.04	0.04	0.04	0.04	0.04	0.04
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	0.04	0.04	0.04
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	0.03	0.03	0.03	0.03	0.03
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	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	0.13	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	0.06	0.00
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	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	0.04	0.04	0.04	0.04
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	0.03	0.03	0.03	0.03	0.03

Year

Figure 2d. IRCR generated estimates of annual tagging mortality (F-tag) for striped bass ≥ 711 mm TL tagged in Virginia, 1990-2020.



	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	2019	2020
M1	0.15	0.12	0.15	0.11	0.10	0.07	0.02	0.04	0.06	0.06	0.06	0.06	0.05	0.05	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	0.01	0.02	0.01	0.04
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	0.01	0.05
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	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	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	0.01	0.01	0.01	0.01	0.01	0.01
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	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	0.03	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	0.01	0.05
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	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	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	0.01	0.01	0.01
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	0.01	0.01

Year