1-2024

Evaluation of Striped Bass Stocks in Virginia: Monitoring and Tagging Studies, 2023 Progress Report

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Progress Report

Contract Number: F-77-R-36

Project Period: 1 December 2022 - 30 November 2023

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Submitted To:

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P.O. Box 756
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31 January 2024

Table of Contents

Preface

This report presents the results of striped bass (*Morone saxatilis*) tagging and monitoring activities in Virginia during the period 1 December 2022 through 30 November 2023. It includes an assessment of the biological characteristics of striped bass taken from the 2023 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.

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. Thus, to comply with the plan, coastal states have imposed restrictions on their commercial and recreational striped bass fisheries, including 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. 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 monitoring 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 September 2017, the ASMFC Striped Bass Technical Committee concluded that the Virginia pound net spawning stock monitoring program had inherent shortcomings that 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 has been conducted via electrofishing.

Introduction

Striped bass (*Morone saxatilis*) 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 (Pearson, 1938; Merriman, 1941).

Concern about the decline in striped bass landings along the Atlantic coast in the mid-1970's prompted the development of an interstate fisheries management plan (FMP) under the auspices of the Atlantic States Marine Fisheries Commission (ASMFC) as part of their Interstate Fisheries Management Program (ASMFC (Atlantic States Marine Fisheries Commission), 1981). Federal legislation was enacted in 1984 (Public Law 98-613, The Atlantic Striped Bass Conservation Act), which enabled Federal imposition of a moratorium for an indefinite period in those states that failed to comply with the coastwide plan. To comply with the plan, coastal states have imposed restrictions on their commercial and recreational striped bass fisheries, including combinations of catch quotas, size limits, and time-limited moratoriums to year-round moratoriums.

Since 1990, the ASMFC has mandated that all coastal states participating in the striped bass harvest should maintain rates of fishing mortality (F) at designated target levels. The target fishing mortality rates varied, depending on the estimated stock size and whether the management objective was to rebuild the stock or increase yield. The coast-wide stock status improved by the early 2000s, and target levels of F were subsequently adjusted as new information on stock status became available. Further declines, such as those documented in the 2013 and 2017 stock assessments, triggered additional changes to the target levels of F. The most recent stock assessment (2022) indicated that the striped bass stock was overfished but was not experiencing overfishing. In May 2023, emergency action was approved to change the recreational size limit in response to the extremely high recreational harvest documented in 2022.

Given the reliance on target levels of F, the various states have been required to estimate mortality rates each year to ensure compliance with the coast-wide regulations. These estimates have been derived from mark-recovery studies (Rugolo et al., 1994; Schaefer and Rugolo, 1996; Herbert et al., 1997). The analysis of the tagging data for the provision of estimates of mortality rates to managers continues to evolve. Historically, estimates of total mortality would be obtained using the tag-recapture data and fishing mortality would be estimated by subtracting an assumed, constant value for natural mortality. The Striped Bass Tagging Subcommittee has explored alternative ways to estimate fishing and natural mortality rates, including obtaining year-specific or period-specific natural mortality rates. This is an important issue because there are indications that the natural mortality rate has risen since approximately 1998, coinciding roughly with the onset of an epizootic of the bacterial disease mycobacteriosis (Cardinal, 2001; Crecco, 2003; Jiang et al., 2007a, 2007b; Gauthier et al., 2008).

To document continued compliance with Federal law, the Virginia Institute of Marine Science (VIMS) has relied on the migratory patterns of spawning striped bass to 1) monitor the Virginia spawning stock and 2) tag and release up to 1,000 individual fish each year.

Materials and Methods

Striped bass migrate along the continental shelf waters of the US east coast and then enter brackish or fresh water to spawn (Pearson, 1938). In the Virginia tributaries of Chesapeake Bay, 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). 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). Thus, as in previous years, sampling in 2023 occurred in late-winter and into spring.

Spawning stock monitoring

Sampling protocols

Samples of striped bass for biological characterization of the spring spawning stocks were obtained from the VMRC-defined striped bass spawning areas in the Rappahannock and James rivers (Figure 1); these two rivers are the major contributors to the Chesapeake Bay stocks that originate from Virginia waters. All samples were obtained using multi-panel anchor gill nets consisting of 10 panels; each panel was 9.14 m in length and 3.05 m in depth. The ten stretched mesh sizes, 7.62, 9.52, 11.43, 13.34, 15.24, 16.51, 17.78, 20.32, 22.86, and 25.40 cm, 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. Once per week, two nets were set ~ 0.4 km apart, with the relative locations (upriver/downriver) of the two nets randomly assigned each week. The gear was fished for approximately 24 hours during each sampling event.

All striped bass collected from the monitoring sites were brought to VIMS for processing. Specimens were measured on an electronic fish measuring board interfaced with an electronic balance. The board records lengths (fork length, FL and total length, TL) to the nearest 1 mm, while the balance records whole weight to the nearest 10 g. Both are integrated into the Fisheries Environment for Electronic Data (FEED) software, which also allows for manual input of the sex and gonad maturity into a database for subsequent analysis. Both sagittal otoliths were extracted; scales were collected from between the two dorsal fins above the lateral line.

Otoliths were cleansed of external tissue material by successive rinses in water immediately after extraction. In preparation for ageing, the right sagitta were 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 with a thin layer of crystal bond. The sections were 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.

Although otoliths are considered to be a superior structure to determine age, especially in the older age classes associated with spawning activity, ageing via scales is needed for comparison with the specimens collected for tagging, which cannot be aged via otoliths. Therefore, a subsample of approximately 25% of scale samples were processed using the method established by Merriman (1941), except that impressions that were made in acetate sheets replaced glass slide and acetone. The impressions were made utilizing a Carver hydraulic press at 75 C and 20000 psi for 2.5 minutes. Impressions of multiple scales of each specimen were made. Ages were assigned for the 25% subsample by just a single reader, with a selection of samples then also read by a second, experienced, reader. Agreement between the two readers was greater than 80%. The annual birthdate was assumed to be 1 January of each year.

Analysis protocols

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. As each net contained the same selection of mesh sizes and equal panel dimensions, the net measurements were dropped from the calculations.

Tagging

Capture and tagging protocols

From 1991 to 2017, VIMS scientists obtained samples of mature striped bass on the spawning grounds of the Rappahannock River during the months of March, April, and May. 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 (1.2 m x 2.4 m x 1.2 m deep, with 25.4 mm 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 (available at W&M Scholarworks: https://scholarworks.wm.edu/, or by request).

In 2018, in an effort to increase sampling efficiency and decrease costs, VIMS 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, VIMS acquired its own specialized vessel and electrofishing rig, sent personnel to training, and beginning in 2019, all sampling was completed 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 scooped specimens from the water using dip nets and performed 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 and tributaries, as well as in the York River tributaries (the Pamunkey and Mattaponi rivers). In 2023, electrofishing occurred in the James, Mattaponi, and Rappahannock rivers (Figure 1).

Once onboard, fork length (FL) and total length (TL) measurements were recorded and, whenever possible, the sex of each fish was determined. Striped bass not previously marked and > 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 supplied with fresh aerated water.

Analysis protocols

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:

$$R = \begin{bmatrix} r_{1,1} & r_{1,2} & \cdots & r_{1,j} \\ -1 & r_{2,2} & \cdots & x_{2,j} \\ \vdots & \vdots & \ddots & \vdots \\ -1 & -1 & \cdots & x_{i,j} \end{bmatrix} \qquad (1)$$

where $r_{i,j}$ is the number of tags recovered in year *j* that were released in year *i*. 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 the application of tagging models, including programs SURVIV (White, 1983) and MARK (White and Burnham, 1999).

Hoenig et al. (1998) modified the Brownie (1985) tag-recovery 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:

$$E(R) = \begin{bmatrix} N_1\phi\lambda\mu_1(F_1,M) & N_1\phi\lambda\mu_2(F_2,M)e^{(-(F_1+M))} & \cdots & N_1\phi\lambda\mu_j(F_j,M)e^{\left(-\sum_{k=1}^{j-1}F_k+(j-1)M\right)} \\ -1 & N_2\phi\lambda\mu_2(F_2,M) & \cdots & N_2\phi\lambda\mu_j(F_j,M)e^{\left(-\sum_{k=2}^{j-1}F_k+(j-2)M\right)} \\ \vdots & \vdots & \ddots & \vdots \\ -1 & -1 & \cdots & N_i\phi\lambda\mu_j(F_j,M) \end{bmatrix} \quad (2)$$

where ϕ is the probability of surviving being tagged and retaining the tag in the short-term, λ is the tag-reporting rate, and $\mu_k(F_k, M)$ is the exploitation rate in year *k*, which 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.

Since 2018, the tagging data have been analyzed using the instantaneous rates method. 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 as changes in tagging mortality. Consistent with these analyses, eleven models with varying time periods (corresponding to past management actions) for estimates of fishing mortality (F) and tagging mortality (F-tag) were included. All models included two natural mortality periods, 1990-1997 and 1998-2020 (Table 1). These models were not updated for management actions initiated in 2019.

All analytical approaches were applied separately to striped bass < 457 mm total length (minimum legal size) and to striped bass < 710 mm TL (coastal migrants). Model fit was evaluated using Akaike’s Information Criterion (AIC) (Akaike, 1973; KP and DR, 1985), quasi-likelihood AIC (QAIC) (Akaike, 1985), and goodness-of-fit (GOF) diagnostics were used to evaluate their fit (Burnham et al., 1995).

Results

Spawning stock monitoring

Catch summary

Between 21 February and 2 May 2023, 441 striped bass were collected from gill nets set in the James River, while 241 were collected from those set in the Rappahannock

River, as compared to captures in previous years (Table 2). In the James River, total daily catches ranged from 4-175 striped bass, while in the Rappahannock River, daily catches varied from 1-139 fish. 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 early- to mid-April, and declining by late-April and early May (Table 3, Figure 2). Typically, peak spawning in the Rappahannock River occurs once the water temperature rises above 16 °C, and the weekly catches exhibited the expected temperature-dependent pattern; catches were low early in the season when temperatures were less than 12 °C, peaked rapidly as temperatures approached 16 °C, and declined as temperatures approached 20 °C at the end of the season (Figure 3). Catches in the James River did not follow this same pattern; highest catches occurred at 18.3 and 23.0 °C (Figure 3).

As has been typical during spring sampling in these rivers, males dominated the catches by number, with 359 males and 82 females captured in the James River and 206 males and 34 females captured in the Rappahannock River. As a result, the overall sex ratios (based on numbers) in the two rivers were similar: 4.4 in the James River and 6.1 in the Rappahannock River. However, the percentage of the catches represented by males varied between the rivers and throughout the season (Table 4, Figure 4). Weekly catches of male and female striped bass generally follow similar patterns (Figure 5), though as indicated above, fewer females (by number) were caught throughout the season.

The current monitoring protocols have not documented any consistent effect of the positioning (upstream, downstream) of the two nets fished at each location on the catch rate. Since 2018 in the James River, the catch rate in the downstream net was slightly higher than that in the upstream net, with an average of 32.6 kg (16.4 fish) as compared to 30.5 kg (15 fish) in the upstream net. In contrast, in the Rappahannock River, the catch rate in the downstream net was lower than that in the upstream net, with an average of 43.9 kg (25.5 fish) as compared to 53.1 kg (31.4 fish) in the upstream net. Annual catches in the upstream and downstream nets were quite variable (Table 5) and in some years (e.g., 2023), the upstream net appeared to outperform the downstream net (Figure 6).

Spawning stock indexes

In 2023, the overall (all data pooled) mean biomass index (catch per unit effort, or CPUE, per 24 hours) for the James River was 44.1 kg/day and the respective index for the Rappahannock River was 36.6 kg/day, representing 21.2 and 11 fish per day on average, respectively. The mean biomass index was higher for males than females in the James River; in contrast, this index was higher for females than males in the Rappahannock River. In both rivers, the mean index by number was higher for males than females (Table 6).

The mean index by number was higher in the smaller mesh panels (i.e., those leq 13.3 cm) in both the James and Rappahannock rivers; in contrast, the mean biomass index was higher in smaller mesh panels in the James River and more evenly distributed in the Rappahannock River (Table 7). Sex-specific indices were variable across the various mesh panels in both rivers, and depended on whether the nominal (i.e., count or number) or biomass CPUE was considered. In general, however, the smaller mesh panels had higher nominal CPUE for males and females, and higher biomass CPUE for males, while the biomass CPUE for females was higher in larger mesh panels (Figure 7).

Although the time series under the current sampling regime remains short, particularly with the curtailed monitoring season during 2020 due to COVID-19 restrictions, some trends in the spawning stock indexes can be discerned. Overall CPUE (female and male combined) was particularly low in 2019 in both rivers for both the nominal (count/day) and biomass (kg/day) indices (Figure 8); however, the indexes in the James River appear to be increasing slightly through time, while the indexes in the Rappahannock River are decreasing slightly, particularly since the most recent peak in 2020. In the James River, sex-specific count and biomass indices are displaying similar trends, though at different scales (Figure 9). In contrast, the indexes for male striped bass in the Rappahannock River appear to be driving the declining trends in the overall indexes, with the indexes for females remaining fairly constant over the time series (Figure 10).

Age and length composition

Ageing via otoliths was completed for 680 of the 682 striped bass captured in the gill net monitoring project. As the scale-otolith age relationship is well established, in 2020 the paired sample rate was decreased, and 165 (24.3%) individuals were aged via both methods in 2023 (Table 8). In 2023, there was 85.5% agreement between the two methods and discrepancies in the ages were > 1 for only 2 specimens. For nearly every year class, the average ages fell very close to the 1:1 line (Figure 11).

In 2023, male fish ranged from 2 to 10 years in the James River. Most males were between age 3 and age 6 years (2017-2020 year classes), with age-4 fish being predominant. Patterns were similar in the Rappahannock River, with males ranging from 3 to 8 years. Most males were between age 3 and age 5 (2018-2020 year classes), with age-5 fish (2018 year class) being predominant (Figure 12). Although less frequently encountered than males, females in both rivers exhibited a wider age distribution; females ranged from 3 to 21 years in the James River, and from 4 to 21 years in the Rappahannock River (Figure 12).

In the James River, male fish were 311 to 921 mm total length (TL), with peak abundances at about 450-550 mm TL (Figure 13). The size distribution of males from the Rappahannock River was generally similar to that of James River males, but with fewer individuals caught. The overall size range was 363 to 897 mm TL, though the peak abundance was at a slightly larger size than in the James River, at around 500-600 mm. Females in both rivers displayed a wider size distribution than males in the same river, with two modal size groups (Figure 13). In the James River, female fish measured 381 to 1200 mm TL, while those from the Rappahannock River measured 448 to 1224 mm TL; in both rivers, peaks in abundance at around 500-600 and 1000 mm TL were evident. Within each year class, females were, on average, slightly larger and heavier than males (Figure 14).

In the James River, the 359 male striped bass sampled in spring 2023 averaged 487.8 mm TL, 1.5 kg, and 4.5 years, which were all similar to the respective mean values from 2022 (477.9 mm TL, 1.4 kg, and 4.2 years). James River females (82 individuals) averaged 647.2 mm TL, 4.6 kg, and 6.4 years; while this represents moderate decreases in length and weight, the average age was slightly higher in 2023 relative to 2022 (700.5 mm TL, 6.2 kg, and 4.5 years). In the Rappahannock River, the 206 male striped bass sampled in spring 2023 averaged 539 mm TL, 2 kg, and 5.1 years, which were all slightly higher than the respective mean values from 2022 (484.4 mm TL, 1.5 kg, and 4.9 years). As in the James River, Rappahannock River females (34 individuals) were older, but slightly smaller in size and weight in 2023 relative to 2022 (averaging 907.2 mm TL, 11.2 kg, and 9.6 years in 2023, and 957.1 mm TL, 12.1 kg, and 4.5 years in 2022).

Tagging

Tag release summary

Electrofishing tagging events (24 total) occurred between 1 March and 25 April 2023, in the James (15), Mattaponi (3), and Rappahannock (6) rivers. An additional sampling event via trammel net occurred in the Mattaponi River on 22 March. No striped bass were caught during 4 tagging events; during the remaining tagging events, 1 to 99 fish were tagged. A total of 682 fish were tagged and released, which is fewer than the target of 1,000.

In the James River, the 15 electrofishing events were conducted between 1 March and 25 April, which resulted in 351 fish tagged and released (Table 9). In total, 311 resident striped bass (457 - 710 mm TL) were tagged and released; 258 were identified as male and none were identified as female, though many of the specimens recorded as sex-unknown may have been female. Similarly, while only 1 of the 39 tagged coastal migrants (> 710 mm TL) was female, the majority were recorded as sex-unknown and may have been female. Note that an additional resident male was recaptured in 2023 (originally tagged and released in the James River in 2021) was excluded from the data reported here.

Sampling in the Mattaponi River (a tributary of the York River) occurred over 4 days, including 3 days of electrofishing and 1 day using a trammel net. All 13 specimens (8 resident fish and 5 coastal migrants) from the Mattaponi River were taken via electrofishing on 14 April.

In the Rappahannock River, resident fish accounted for 264 out of 317 total striped bass tagged and released between 28 March and 17 April, 2023 (6 sampling events). An additional 52 coastal migrants were tagged and released (Table 9).

Tag recapture summary

Coast-wide, 19 VIMS-tagged striped bass > 457 mm TL were recaptured between 1 January and 31 December 2023. The largest source of recaptures (16 reported, 84.2%) was Virginia; 2 recaptured specimens were from New Jersey and the remaining individual was reported without a recapture locality but was likely taken in Chesapeake

Bay (Table 10). Recaptures occurred in relatively low numbers throughout the cooler months of the year, with a peak of 5 individuals in March and no recaptures in the hottest months of July, August, and September.

Mortality estimates

For striped bass > 457 mm TL, model 11 received the most support, though 2 additional models had weights of > 0.15 (Table 15). All models estimated similar values of annual survival (S), averaging about 0.63 (range: 0.60-0.66) during the period 1990-1997 and 0.46-0.52 during 1998-2022 (Figure 16). Similarly, all models resulted in natural mortality (M) estimates averaging 0.38 during 1990-1997 and 0.61-0.63 during 1998-2022. 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; average F ranged from 0.04-0.13 during 1990-1997 and 0.03-0.14 during 1998-2022. Tagging mortality (F-tag) estimates followed a general downward trend for all models, with very low (< 0.1) values since 1998.

For migratory striped bass (those > 710 mm TL at tagging), model 8 received the most support; only 1 additional model had a weight of > 0.15 (Table 15). All models estimated similar values of annual survival (S), averaging about 0.68 (range: 0.63-0.72) during the period 1990-1997 and 0.51-0.67 during 1998-2022 (Figure 16). Similarly, all models resulted in natural mortality (M) estimates averaging 0.22 during 1990-1997 and 0.39-0.42 during 1998-2022. 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; average F ranged from 0.10-0.24 during 1990-1997 and 0.00-0.27 during 1998-2022. Tagging mortality (F-tag) estimates followed a general downward trend for all models, with very low (< 0.1) values since 1998.

Considering only the best model for each size-based analysis, annual survival (S) was higher for the coastal migrant fish (those > 710 mm TL) than for all fish > 457 mm TL, with a larger difference in more recent years relative to 1990-1997 (Figure 17). This appears to be related to contrasting trends in fishing mortality (F) and natural mortality (M). Early in the time-series, coastal migrants experienced a higher F than all fish combined, while in more recent years, F has declined faster in the coastal migrants. In contrast, M increased in both groups after 1997, but the magnitude of the increase was smaller for the coastal migrants.

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Tables

Table 1: Description of Instantaneous Rates Catch/Release (IRCR) models with varying time periods for fishing mortality and tagging mortality; all models included two time periods for natural mortality (1990-1997 and 1998-2022).

Model	Fishing Mortality	Tagging Mortality
1	Year-specific	Year-specific
2	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 - 2022	Year-specific
3	Year-specific	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 - 2022
4	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 - 2022	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 - 2022
5	7 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 - 2016 / 2017 - 2022	7 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 - 2016 / 2017 - 2022
6	7 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 / 2016 - 2022	7 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2014 / 2015 / 2016 - 2022
7	5 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2022	Year-specific
8	Year-specific	5 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2022
9	5 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2022	5 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2022
10	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2016 / 2017 - 2022	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2016 / 2017 - 2022
11	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2015 / 2016 - 2022	6 periods: 1990 - 1994 / 1995 - 1999 / 2000 - 2002 / 2003 - 2006 / 2007 - 2015 / 2016 - 2022

Table 2: Number of striped bass caught during the spring spawning stock monitoring in the James and Rappahannock rivers, 2018-2023.

Year	James	Rappahannock
2018	215	942
2019	77	379
2020	247	835
2021	610	525
2022	384	611
2023	441	241

Table 3: Number and biomass of striped bass captured, water temperature, and salinity, by week in the James and Rappahannock rivers, spring 2023.

River	Week-of-Year	Sample Date	Number Caught	Biomass Caught (kg)	Water Temp (C)	Salinity
James	8	2023-02-21	31	89.08	10.74	0.06
James	9	2023-03-01	12	15.77	11.92	0.06
James	10	2023-03-09	28	35.20	11.82	0.08
James	12	2023-03-20	29	56.11	11.64	0.08
James	13	2023-03-27	28	50.63	15.45	0.08
James	14	2023-04-04	118	277.13	18.32	0.09
James	15	2023-04-10	9	29.30	17.64	0.09
James	16	2023-04-19	175	323.12	22.97	0.10
James	17	2023-04-25	7	24.74	19.61	0.10
James	18	2023-05-02	4	11.98	16.55	0.04
Rappahannock	8	2023-02-21	16	23.91	9.46	0.05
Rappahannock	9	2023-03-01	24	41.22	10.41	0.13
Rappahannock	10	2023-03-06	18	32.86	11.30	0.04
Rappahannock	11	2023-03-16	2	3.29	8.15	0.53
Rappahannock	12	2023-03-20	4	7.88	8.91	0.26
Rappahannock	13	2023-03-27	6	51.86	12.23	0.50
Rappahannock	14	2023-04-04	139	467.23	16.31	0.86
Rappahannock	15	2023-04-10	28	150.22	15.79	0.93
Rappahannock	16	2023-04-19	1	1.44	19.19	0.77
Rappahannock	17	2023-04-25	3	9.28	20.04	0.93

Table 4: Weekly total number and biomass, by sex, of striped bass captured in the James and Rappahannock rivers, spring 2023.

			Number Caught		Biomass Caught (kg)		
River	Week-of-Year	Sample Date	Females	Males	Females	Males	Percent Males
James	8	2023-02-21	8	23	52.2	36.9	74.2
James	9	2023-03-01	0	12	0.0	15.8	100.0
James	10	2023-03-09	0	28	0.0	35.2	100.0
James	12	2023-03-20	7	22	29.4	26.8	75.9
James	13	2023-03-27	7	21	23.4	27.3	75.0
James	14	2023-04-04	18	100	109.6	167.6	84.8
James	15	2023-04-10	7	2	24.4	4.9	22.2
James	16	2023-04-19	28	147	114.8	208.3	84.0
James	17	2023-04-25	4	3	14.6	10.1	42.9
James	18	2023-05-02	3	1	11.5	0.5	25.0
Rappahannock	8	2023-02-21	0	16	0.0	23.9	100.0
Rappahannock	9	2023-03-01	1	23	3.0	38.2	95.8
Rappahannock	10	2023-03-06	0	18	0.0	32.9	100.0
Rappahannock	11	2023-03-16	0	1	0.0	1.5	100.0
Rappahannock	12	2023-03-20	1	3	2.0	5.9	75.0
Rappahannock	13	2023-03-27	4	2	48.5	3.3	33.3
Rappahannock	14	2023-04-04	18	121	213.8	253.4	87.0
Rappahannock	15	2023-04-10	8	20	107.1	43.1	71.4
Rappahannock	16	2023-04-19	0	1	0.0	1.4	100.0
Rappahannock	17	2023-04-25	2	1	7.9	1.4	33.3

Table 5: Average catch, by number and biomass, of striped bass in the upstream and downstream nets in the James and Rappahannock rivers, 2018-2023.

		Number Caught		Biomass Caught (kg)	
River	**Year**	**Downstream**	**Upstream**	**Downstream**	**Upstream**
James	2018	13.3	8.2	28.0	12.9
James	2019	3.6	2.8	8.1	6.0
James	2020	17.6	17.7	39.7	36.7
James	2021	29.9	20.9	54.5	38.9
James	2022	14.2	17.8	29.7	39.3
James	2023	20.3	23.8	38.7	52.6
Rappahannock	2018	31.9	72.8	32.7	98.2
Rappahannock	2019	12.8	18.8	26.1	37.0
Rappahannock	2020	70.1	49.1	101.9	58.1
Rappahannock	2021	12.8	30.9	32.8	48.5
Rappahannock	2022	34.9	16.0	60.1	39.1
Rappahannock	2023	8.0	16.1	28.4	50.5

Table 6: Average catch per unit effort (CPUE, per 24 hours) by river and sex, in count and biomass, with lower (LCL) and upper (UCL) confidence limits, spring 2023.

		Nominal CPUE (count/day)			Biomass CPUE (kg/day)		
River	**Sex**	**LCL**	**Mean**	**UCL**	**LCL**	**Mean**	**UCL**
James	Combined	9.8	21.2	32.7	20.9	44.1	67.2
James	Female	3.0	4.9	6.8	12.3	23.0	33.8
James	Male	8.6	19.2	29.8	12.9	28.5	44.1
Rappahannock	Combined	2.3	11.0	19.6	8.6	36.6	64.5
Rappahannock	Female	1.7	3.6	5.5	14.8	40.5	66.2
Rappahannock	Male	2.3	12.4	22.4	3.5	24.3	45.2

Table 7: Average catch per unit effort (CPUE, per 24 hours) by river and mesh size, in count and biomass, with lower (LCL) and upper (UCL) confidence limits, spring 2023.

		Nominal CPUE (fish/day)			Biomass CPUE (kg/day)		
River	**Mesh (cm)**	**LCL**	**Mean**	**UCL**	**LCL**	**Mean**	**UCL**
James	7.6	0.7	1.7	2.7	0.8	1.8	2.9
James	9.5	2.1	6.5	11.0	2.4	7.0	11.7
James	11.4	3.4	6.7	10.0	5.1	10.2	15.4
James	13.3	1.6	3.6	5.5	3.2	7.5	11.8
James	15.2	0.4	1.1	1.7	1.0	3.0	5.1
James	16.5	0.2	0.5	0.9	0.9	3.4	6.0
James	17.8	0.2	0.6	1.1	1.0	3.4	5.9
James	20.3	0.0	0.2	0.4	0.0	1.8	3.6
James	22.9	0.0	0.2	0.4	0.2	2.7	5.3
James	25.4	0.0	0.1	0.3	0.0	3.0	6.3
Rappahannock	7.6	0.0	0.5	1.1	0.0	0.8	1.9
Rappahannock	9.5	0.1	0.9	1.6	0.0	1.1	2.2
Rappahannock	11.4	0.9	2.0	3.0	1.4	3.0	4.6
Rappahannock	13.3	0.0	4.5	9.6	0.0	8.7	19.0
Rappahannock	15.2	0.1	1.7	3.4	0.0	4.9	10.1
Rappahannock	16.5	0.0	0.2	0.4	0.0	0.6	1.2
Rappahannock	17.8	0.0	0.2	0.3	0.0	1.3	2.9
Rappahannock	20.3	0.0	0.3	0.7	0.0	5.1	11.2
Rappahannock	22.9	0.0	0.4	0.7	0.0	4.2	8.4
Rappahannock	25.4	0.0	0.4	0.9	0.0	6.8	14.9

Table 8: Scale-age distribution (minimum, mean, median, maximum) for each otolith age class from ages derived from the same specimen, spring 2023.

Otolith Age	n	Minimum Scale Age	Mean Scale Age	Median Scale Age	Maximum Scale Age
2	0				
3	9	3	3.1	3	4
4	63	4	4	4	5
5	73	4	5	5	6
6	5	6	6.8	6	9
7	4	6	6.8	7	7
8	6	7	7.3	7	8
9	2	8	8.5	8.5	9
10	2	9	9.5	9.5	10
11	0				
12	0				
13	0				
14	0				
15	0				
16	0				
17	0				
18	1	14	14	14	14

Table 9: Summary data for striped bass that were tagged and released, spring 2023. Note that an additional male fish, initially tagged and released in the James River on 15 April 2021, was recaptured in the James River on 10 April 2023 and length was not recorded for two specimens; these individuals are not included in the totals reported here.

Date	457 - 710 mm TL						> 710 mm TL					
	Unknown		Males		Females		Unknown		Males		Females	
	n	Avg TL	n	Avg TL	n	Avg TL	n	Avg TL	n	Avg TL	n	Avg TL
James												
2023-03-01			1	581.0								
2023-03-09			4	532.2								
2023-03-16	3	526.0	21	532.2								
2023-03-20			10	518.0								
2023-03-21			5	524.2			1	780.0				
2023-03-27	1	470.0	11	581.3			1	738.0				
2023-04-03	4	513.0	16	546.5			6	1,013.7	1	714.0		
2023-04-06	4	471.5	27	533.0			3	899.3				
2023-04-10	6	498.8	40	507.7			4	1,049.5	2	792.0		
2023-04-18	8	502.5	20	509.0			3	1,099.7	1	956.0	1	1,010.0
2023-04-19	9	561.9	35	500.4			8	1,047.9	1	756.0		
2023-04-20	14	555.7	38	516.5			2	1,002.5	1	1,035.0		
2023-04-21	2	589.0	27	498.0			3	962.3				
2023-04-25	2	624.0	3	578.7					1	750.0		
Mattaponi												
2023-04-14	1	516.0	7	565.1			5	1,080.4				
Rappahannock												
2023-03-28	1	572.0	11	518.7			5	1,148.0	1	1,040.0		
2023-03-29			97	518.9			1	1,216.0	1	915.0		
2023-03-30			83	514.0			3	1,096.7	1	976.0		
2023-04-04	1	548.0	24	541.5			21	1,111.7				
2023-04-05	1	499.0	2	513.0			8	1,110.0	3	797.7		
2023-04-17	7	572.9	37	530.8			4	963.5	4	874.0		

Table 10: Summary data for striped bass that were tagged and released, spring 2023. Note that an additional male fish, initially tagged and released in the James River on 15 April 2021, was recaptured in the James River on 10 April 2023 and length was not recorded for two specimens; these individuals are not included in the totals reported here.

	Month												
State	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**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	0	0	0	0	0	0	0	0
Connecticut	0	0	0	0	0	0	0	0	0	0	0	0	0
New York	0	0	0	0	0	0	0	0	0	0	0	0	0
New Jersey	0	0	0	0	0	1	0	0	0	1	0	0	2
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	1	2	5	2	1	2	0	0	0	1	1	1	16
North Carolina	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1	2	5	2	1	3	0	0	0	2	1	1	18

Table 11: Input recapture matrix for the Instantaneous Rates Catch/Release (IRCR) analysis for harvested striped bass (> 457 mm TL) tagged and released in the springs of 1990-2022 (Rappahannock River only 1990-2017, all Virginia waters 2018-2022).

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	2021	2022
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	0	0
1991	2482	-	47	38	22	14	3	1	2	1	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	130	-	-	7	4	1	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	621	-	-	-	18	17	12	3	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	195	-	-	-	-	6	7	4	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	698	-	-	-	-	-	24	12	9	4	1	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	377	-	-	-	-	-	-	3	10	3	2	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1997	712	-	-	-	-	-	-	-	26	17	10	2	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	784	-	-	-	-	-	-	-	-	28	16	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	853	-	-	-	-	-	-	-	-	-	30	7	4	2	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
2000	1767	-	-	-	-	-	-	-	-	-	-	42	25	11	7	3	7	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	797	-	-	-	-	-	-	-	-	-	-	-	31	13	6	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	315	-	-	-	-	-	-	-	-	-	-	-	-	10	3	6	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2003	852	-	-	-	-	-	-	-	-	-	-	-	-	-	31	20	4	5	3	2	1	2	0	0	0	0	1	0	0	0	0	0	0	0
2004	1477	-	-	-	-	-	-	-	-	-	-	-	-	-	-	45	14	6	6	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0
2005	921	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	25	18	7	1	4	0	1	0	0	0	0	0	0	0	0	0	0	0
2006	668	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26	4	6	5	3	4	0	0	0	0	0	0	0	0	0	0	0
2007	1961	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	62	35	16	4	5	0	1	1	1	0	0	0	0	0	0	0
2008	523	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15	6	0	0	0	0	1	0	0	0	0	0	0	0	0
2009	867	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26	7	2	2	0	1	0	0	0	0	0	0	0	0
2010	2050	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	28	7	9	2	0	1	0	1	0	0	0	0	0
2011	416	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	4	0	0	1	0	0	0	0	0	0	0
2012	1222	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	33	12	5	2	0	0	0	0	0	0	0
2013	760	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23	8	7	1	0	0	0	0	0	0
2014	454	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	3	4	0	1	2	0	0	0
2015	313	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	4	2	2	0	0	0	0
2016	798	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	5	1	1	0	0	0
2017	307	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	1	1	0	0	0
2018	849	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21	7	3	0	0
2019	101	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	0	0	0
2020	1023	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20	6	4
2021	1032	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21	6
2022	683	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7

Table 12: Input recapture matrix for the Instantaneous Rates Catch/Release (IRCR) analysis for re-released striped bass (> 457 mm TL) tagged and released in the springs of 1990-2022 (Rappahannock River only 1990-2017, all Virginia waters 2018-2022). Recaptured fish were released with tag streamers cut off.

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	2021	2022
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	0	0
1991	2482	-	82	42	28	13	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	130	-	-	5	4	3	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	621	-	-	-	22	20	3	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	195	-	-	-	-	6	1	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	698	-	-	-	-	-	21	8	8	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	377	-	-	-	-	-	-	10	6	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1997	712	-	-	-	-	-	-	-	12	8	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	784	-	-	-	-	-	-	-	-	21	7	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	853	-	-	-	-	-	-	-	-	-	19	15	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	1767	-	-	-	-	-	-	-	-	-	-	50	23	8	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	797	-	-	-	-	-	-	-	-	-	-	-	16	10	7	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	315	-	-	-	-	-	-	-	-	-	-	-	-	6	3	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2003	852	-	-	-	-	-	-	-	-	-	-	-	-	-	12	6	8	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
2004	1477	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23	6	6	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	921	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13	9	2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
2006	668	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18	7	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
2007	1961	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	33	11	1	1	0	1	0	1	0	0	0	0	0	2	0	0
2008	523	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	3	2	0	0	0	0	0	0	0	0	0	0	0	0
2009	867	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14	4	0	0	0	0	0	0	0	0	0	0	0	0
2010	2050	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14	1	1	0	1	0	0	0	0	0	0	0	0
2011	416	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	0	0	0	0	1	0	0	0	0	0	0
2012	1222	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16	4	0	0	0	0	0	0	0	0	0
2013	760	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	2	1	0	0	0	0	0	0	0
2014	454	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	2	0	3	0	0	0	0	0
2015	313	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	0	0	0	0	0	0	0
2016	798	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	0	1	0	0	0	0
2017	307	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	0	0	2	0	0
2018	849	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	22	6	2	0	0
2019	101	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	0	0	0
2020	1023	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15	8	1
2021	1032	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	27	6
2022	683	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9

Table 13: Input recapture matrix for the Instantaneous Rates Catch/Release (IRCR) analysis for harvested striped bass (> 710 mm TL) tagged and released in the springs of 1990-2022 (Rappahannock River only 1990-2017, all Virginia waters 2018-2022).

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	2021	2022
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	0	0
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	0	0
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	0	0
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	0	0
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	0	0
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	0	0
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	0	0
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	0	0
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	0	0
1999	162	-	-	-	-	-	-	-	-	-	13	2	1	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
2000	365	-	-	-	-	-	-	-	-	-	-	13	11	6	5	3	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	269	-	-	-	-	-	-	-	-	-	-	-	9	8	2	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	122	-	-	-	-	-	-	-	-	-	-	-	-	7	3	5	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2003	400	-	-	-	-	-	-	-	-	-	-	-	-	-	23	13	3	1	2	2	1	2	0	0	0	0	1	0	0	0	0	0	0	0
2004	688	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21	8	8	3	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0
2005	284	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	7	5	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	175	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	2	4	2	1	4	0	0	0	0	0	0	0	0	0	0	0
2007	840	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	33	22	11	2	4	0	1	1	1	0	0	0	0	0	0	0
2008	75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	1	0	0	0	0	1	0	0	0	0	0	0	0	0
2009	242	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	3	0	1	0	1	0	0	0	0	0	0	0	0
2010	483	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	5	4	2	0	1	0	1	0	0	0	0	0
2011	191	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	2	0	0	1	0	0	0	0	0	0	0
2012	325	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	4	1	1	0	0	0	0	0	0	0
2013	244	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	3	3	0	0	0	0	0	0	0
2014	247	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	2	3	0	1	2	0	0	0
2015	75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	0	1	0	0	0	0
2016	99	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	1	0	1	0	0	0
2017	33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	0	0	0
2018	82	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	1	0	0	0
2019	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
2020	70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
2021	78	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0
2022	47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0

Table 14: Input recapture matrix for the Instantaneous Rates Catch/Release (IRCR) analysis for re-released striped bass (> 710 mm TL) tagged and released in the springs of 1990-2022 (Rappahannock River only 1990-2017, all Virginia waters 2018-2022). Recaptured fish were released with tag streamers cut off.

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	2021	2022
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	0	0
1991	391	-	20	11	6	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	40	-	-	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	213	-	-	-	10	7	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	123	-	-	-	-	4	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	211	-	-	-	-	-	7	2	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	67	-	-	-	-	-	-	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1997	212	-	-	-	-	-	-	-	2	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	157	-	-	-	-	-	-	-	-	6	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	162	-	-	-	-	-	-	-	-	-	2	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	365	-	-	-	-	-	-	-	-	-	-	9	7	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	269	-	-	-	-	-	-	-	-	-	-	-	7	4	2	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	122	-	-	-	-	-	-	-	-	-	-	-	-	2	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2003	400	-	-	-	-	-	-	-	-	-	-	-	-	-	8	5	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	688	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15	2	6	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	284	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	4	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
2006	175	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	840	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	7	1	1	0	1	0	0	0	0	0	0	0	0	0	0
2008	75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	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	0	0
2010	483	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	1	0	0	0	0	0	0	0	0	0	0	0
2011	191	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	0	0	0	1	0	0	0	0	0	0
2012	325	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	0	0	0	0	0	0	0	0	0	0
2013	244	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	0	0	0	0	0	0	0	0
2014	247	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	2	0	2	0	0	0	0	0
2015	75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	0	0	0	0	0	0
2016	99	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	1	0	0	0	0
2017	33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	2	0	0
2018	82	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	1	0	0
2019	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
2020	70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	0	1
2021	78	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	0
2022	47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2

Table 15: Model selection criteria from the Instantaneous Rates Catch/Release (IRCR) analysis (separately for fish > 467 mm TL and those > 710 mm TL) for re-released striped bass tagged and released in the springs of 1990-2022 (Rappahannock River only 1990-2017, all Virginia waters 2018-2022). N = number of parameters, Log-lik = model log-likelihood, QAICc = quasi-AIC corrected for small sample size, Weight = model weight associated with the QAICc.

		> 457 mm TL			> 710 mm TL		
Model	**N**	**Log-lik**	**QAICc**	**Weight**	**Log-lik**	**QAICc**	**Weight**
1	68	-13325.10	6668.25	0.00	-4836.93	9813.19	0.00
2	41	-13359.80	6631.04	0.00	-4863.77	9812.04	0.00
3	41	-13340.60	6621.63	0.00	-4848.97	9782.44	0.28
4	14	-13387.20	6590.36	0.15	-4880.44	9790.95	0.00
5	16	-13384.10	6592.85	0.04	-4877.36	9788.80	0.01
6	16	-13383.80	6592.70	0.05	-4878.94	9791.96	0.00
7	40	-13365.00	6631.59	0.00	-4868.09	9818.65	0.00
8	40	-13342.40	6620.51	0.00	-4849.09	9780.65	0.67
9	12	-13394.60	6589.98	0.18	-4885.08	9796.21	0.00
10	14	-13384.50	6589.04	0.28	-4878.86	9787.79	0.02
11	14	-13384.20	6588.89	0.31	-4879.20	9788.47	0.01

Figures

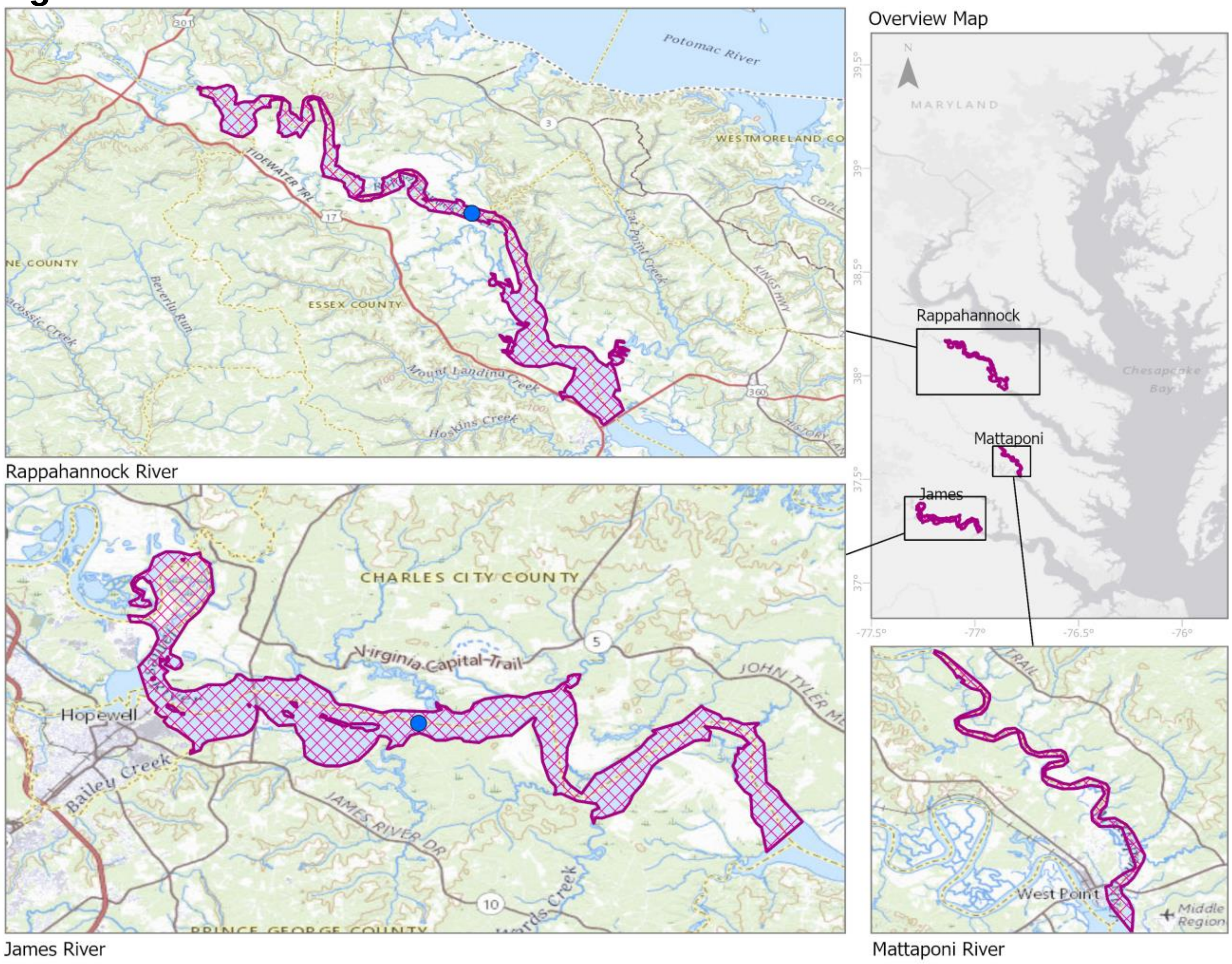

Figure 1: Locations of gill nets sampled (blue dots) and spatial extent of electrofishing coverage (crosshatched polygons), spring 2023. Map credits include: Esri, HERE, Garmin, USGS, EPA, NPS, USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road Data; Natural Earth Data; U.S. Department of State Humanitarian Information Unit; and NOAA National Centers for Environmental Information, U.S. Coastal Relief Model. Spatial data refreshed April, 2023.

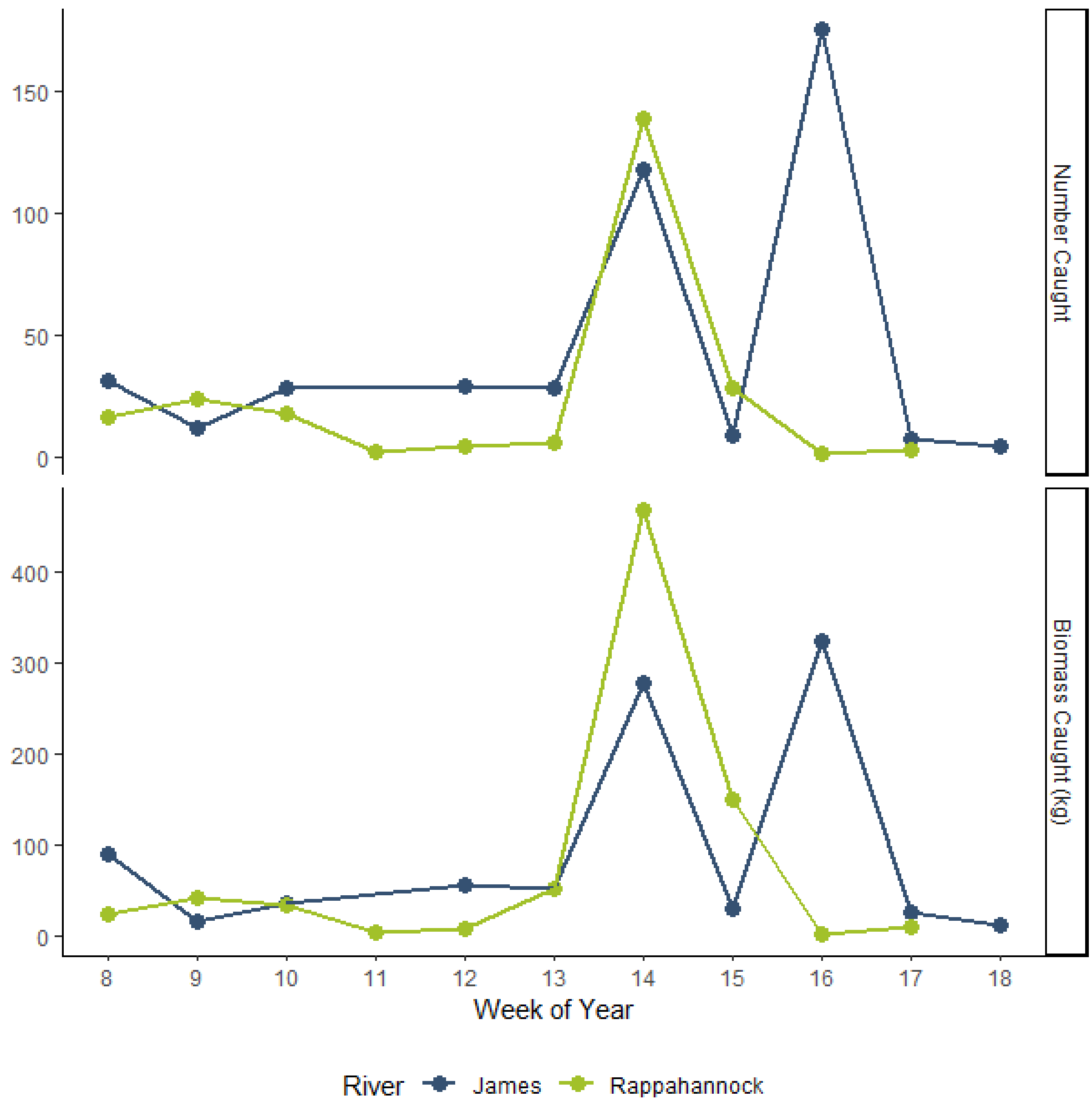

Figure 2: Number and biomass of striped bass captured, by week in the James and Rappahannock rivers, spring 2023.

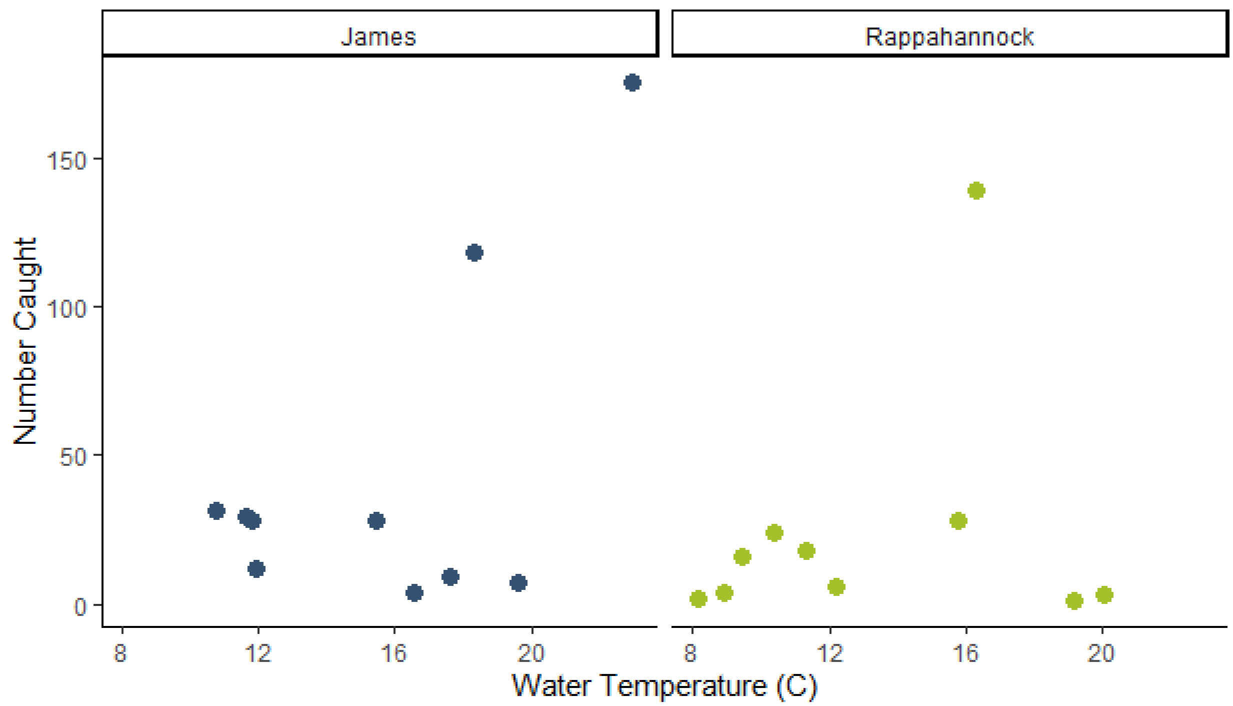

Figure 3: Number of striped bass caught as a function of water temperature in the James and Rappahannock rivers, spring 2023.

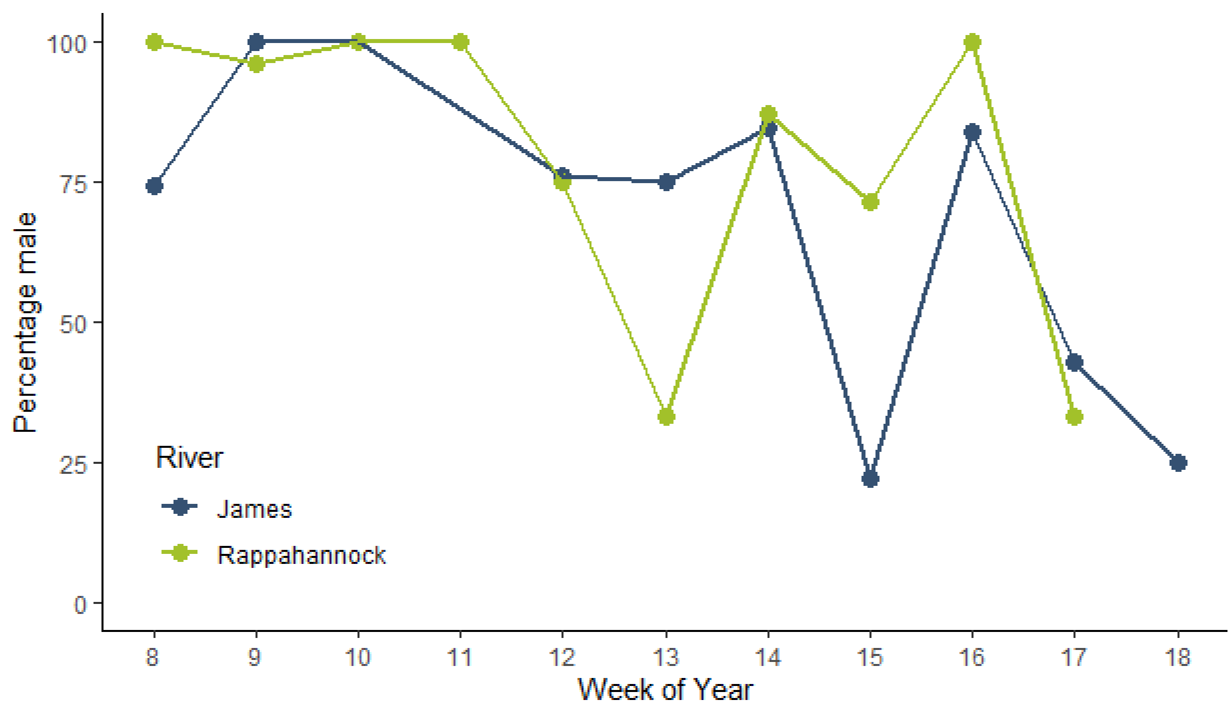

Figure 4: Relative contribution of male fish to the total catch of striped bass in the James and Rappahannock rivers, spring 2023.

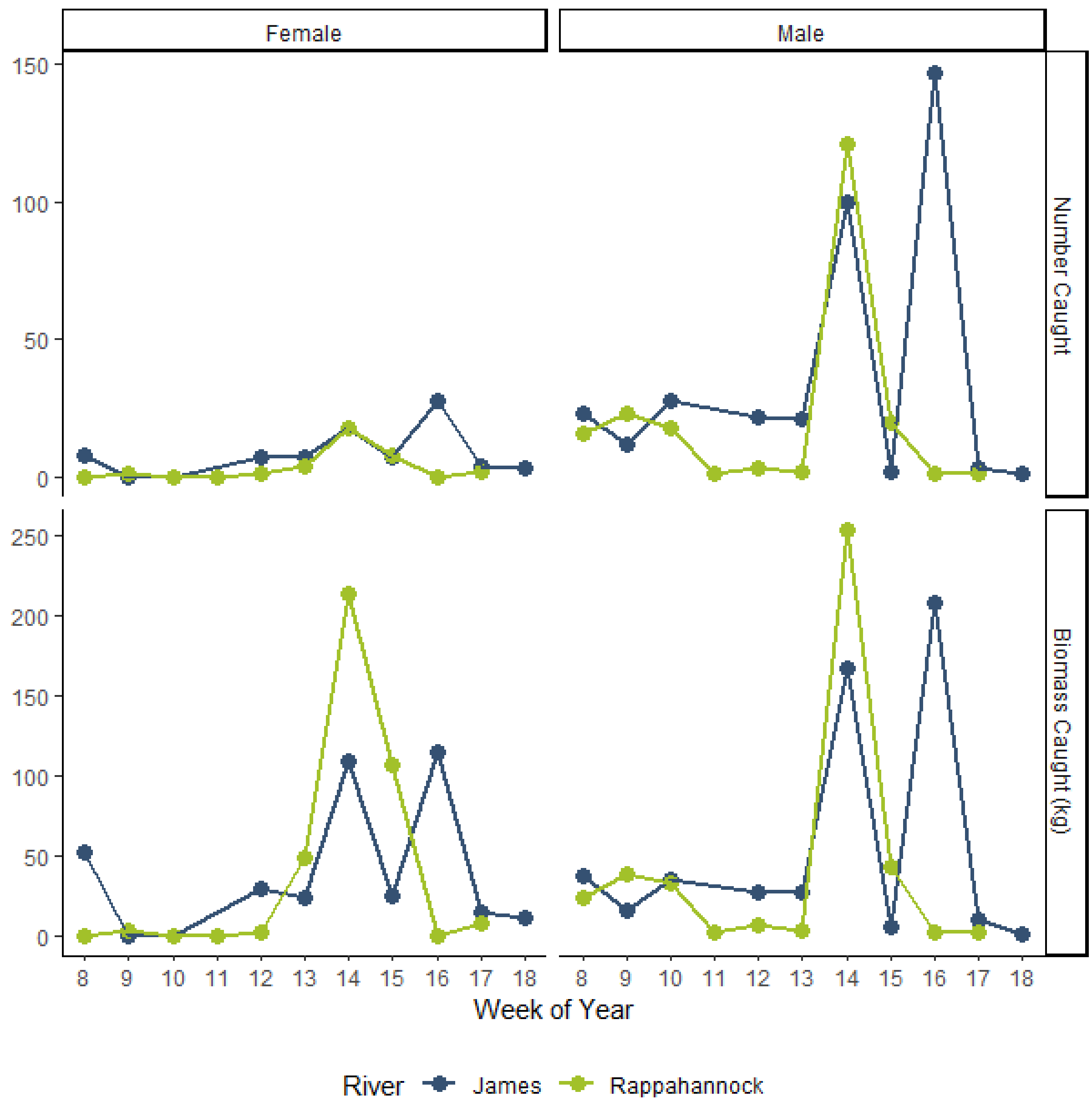

Figure 5: Number and biomass of female and male striped bass caught by week in the James and Rappahannock rivers, spring 2023.

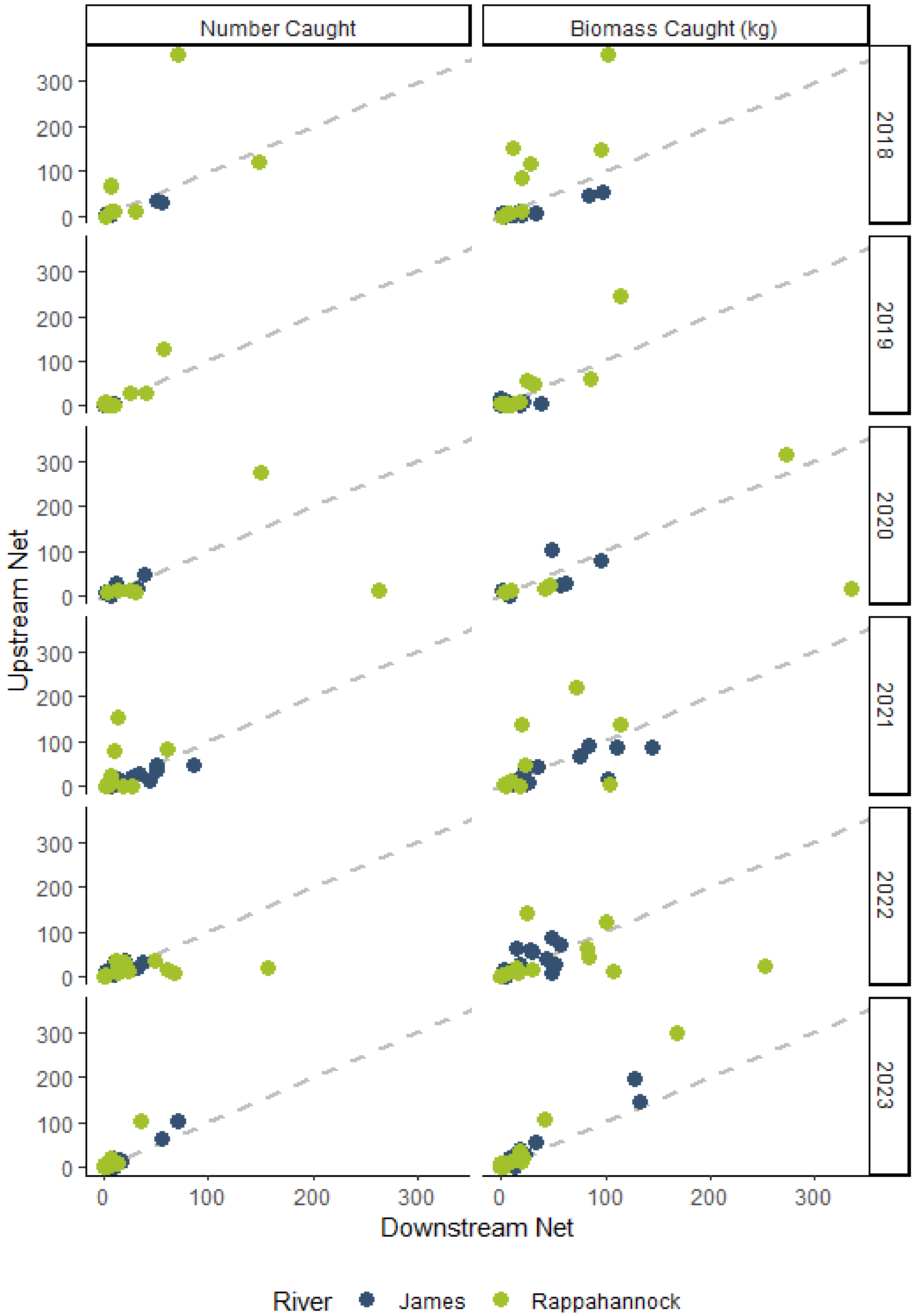

Figure 6: Comparison of catch rates (numbers and biomass) of striped bass between upstream and downstream paired nets in each river, 2018-2023.

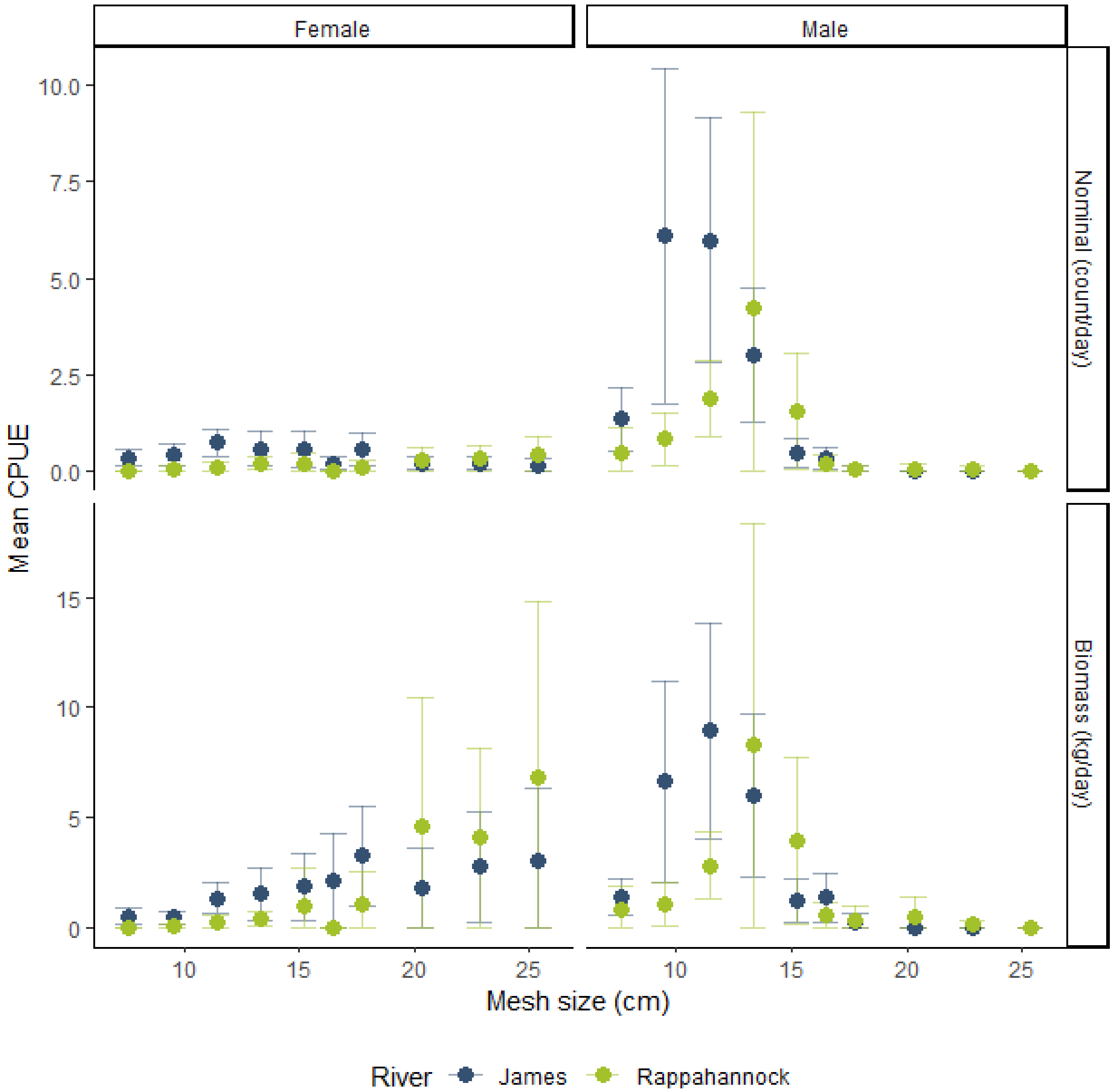

Figure 7: Catch per unit effort (CPUE, per 24 hours) by river, sex, and mesh size, in count and biomass, with lower (LCL) and upper (UCL) confidence limits, spring 2023.

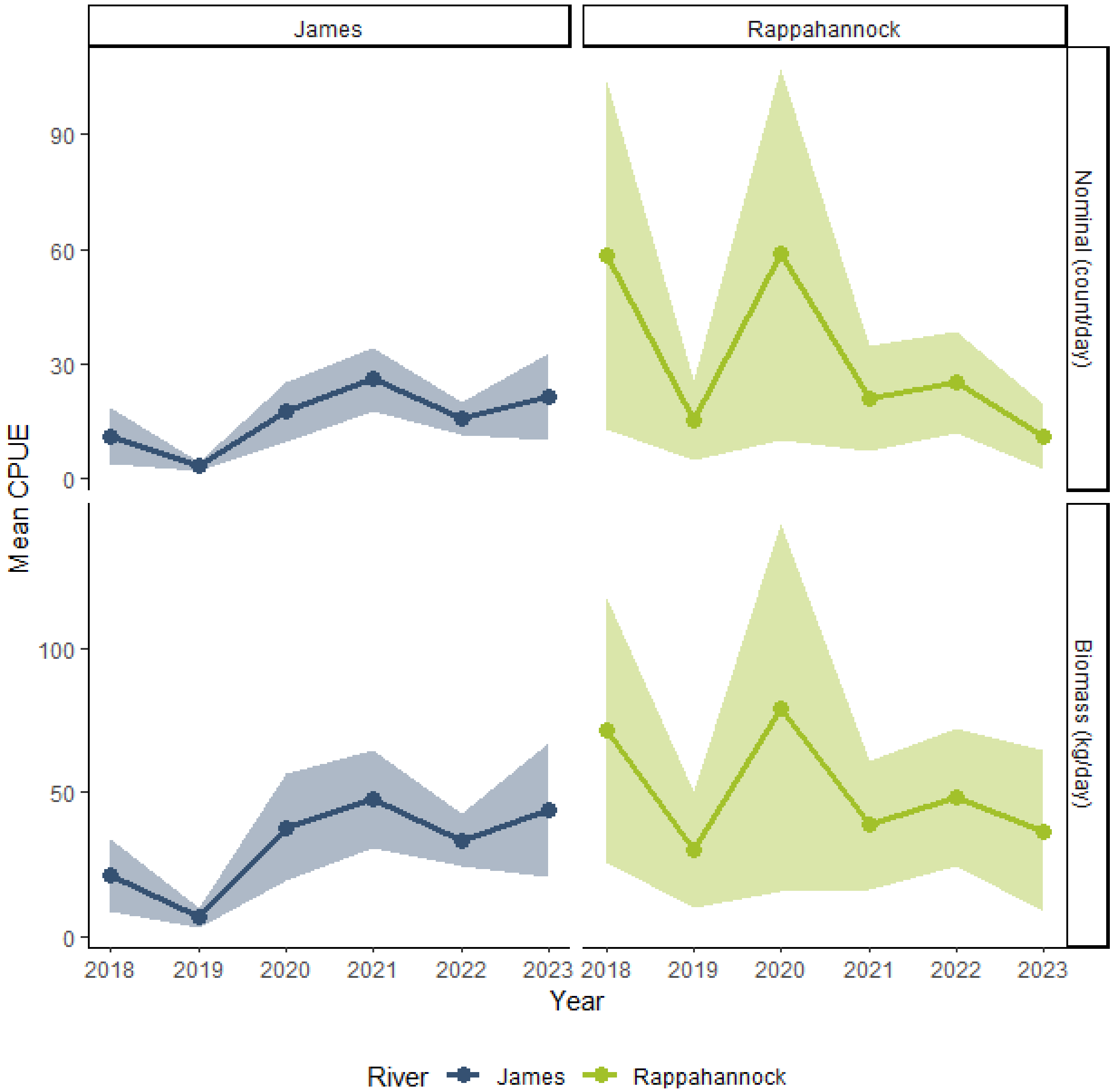

Figure 8: Catch per unit effort (CPUE, per 24 hours) by river, in count and biomass, with lower (LCL) and upper (UCL) confidence limits, 2018 - 2023. Note that sampling in 2020 was curtailed in late March due to COVID-19 restrictions.

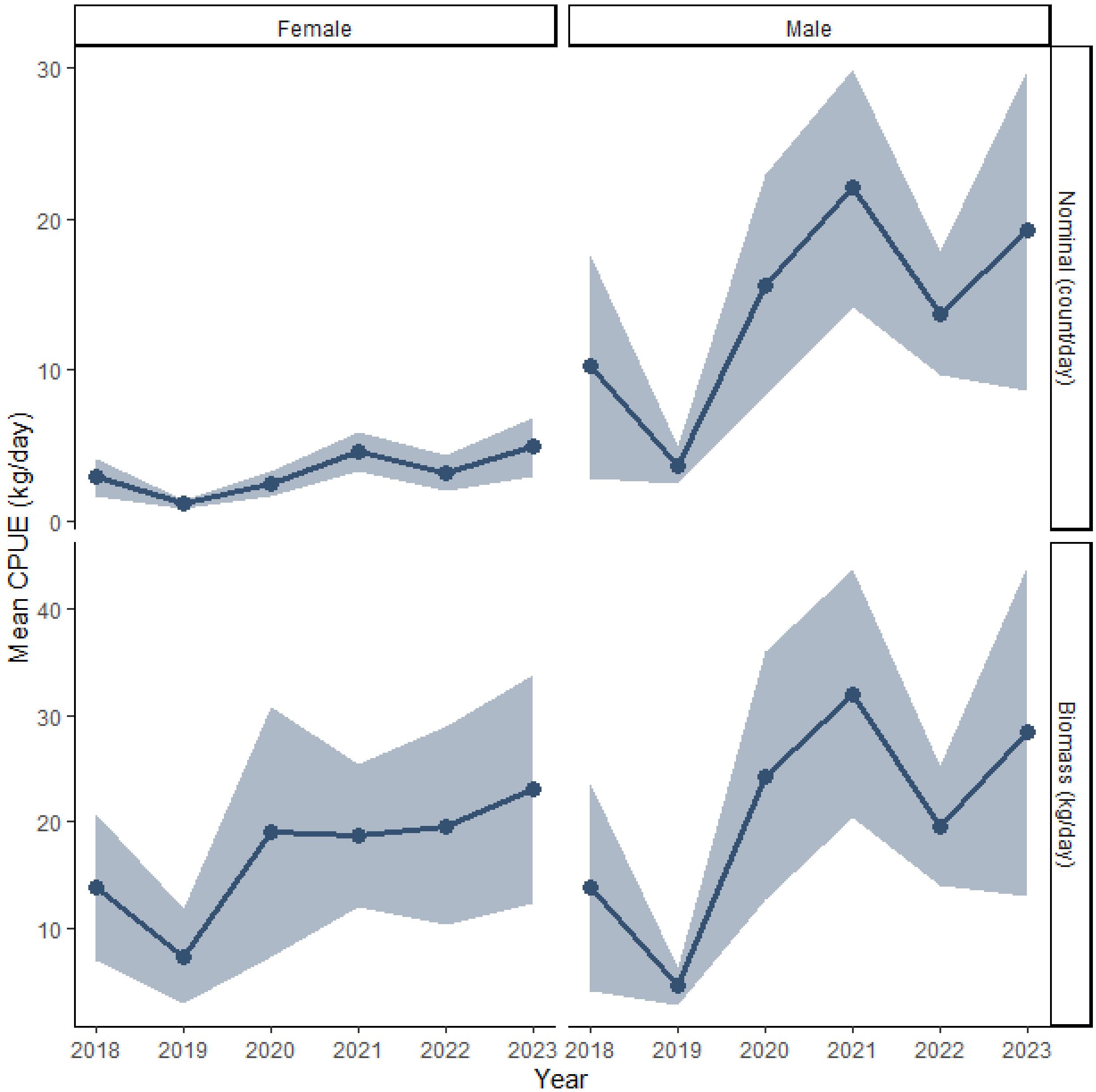

Figure 9: Catch per unit effort (CPUE, per 24 hours) by sex for the James River, in count and biomass, with lower (LCL) and upper (UCL) confidence limits, 2018 - 2023. Note that sampling in 2020 was curtailed in late March due to COVID-19 restrictions.

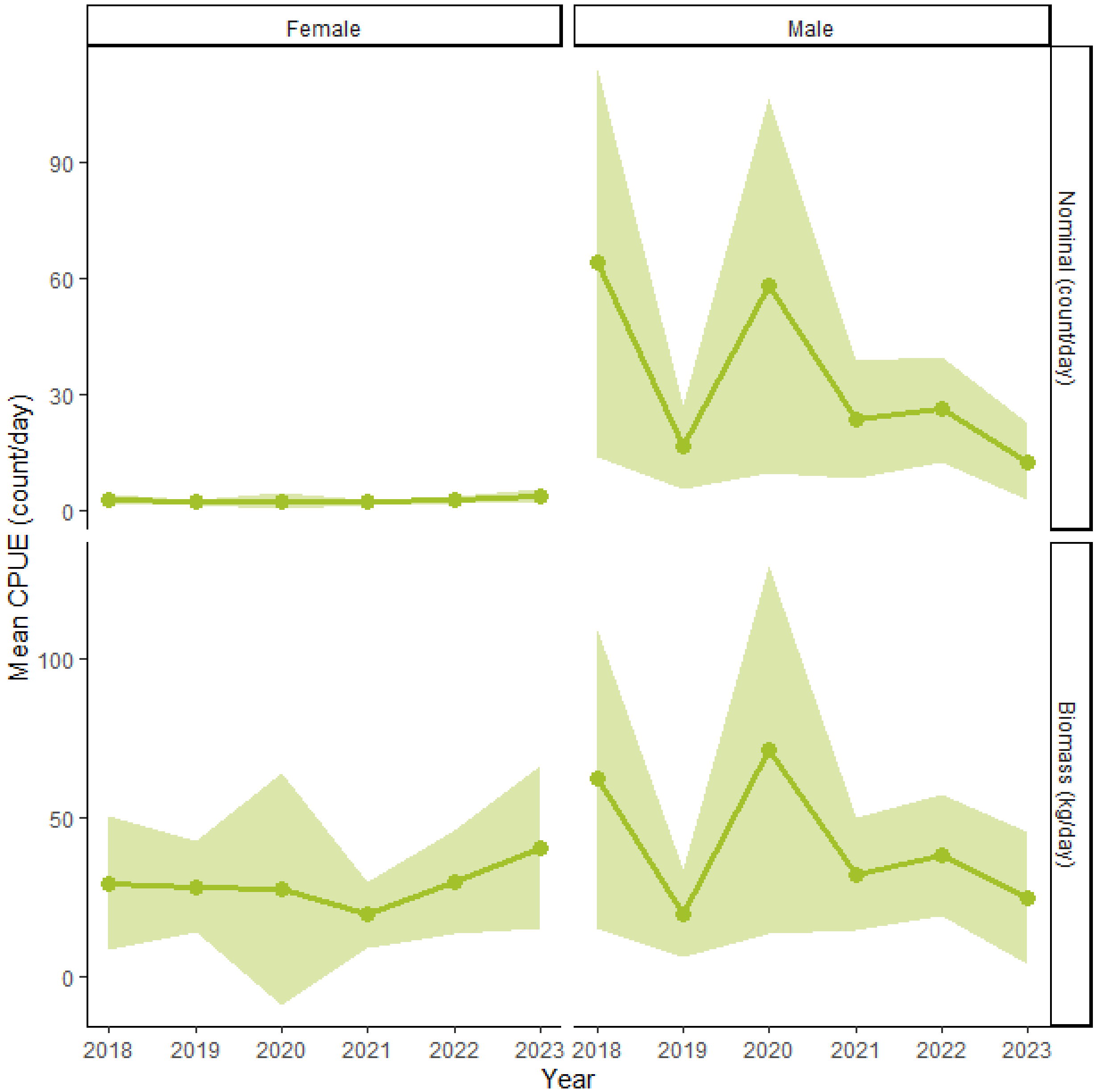

Figure 10: Catch per unit effort (CPUE, per 24 hours) by sex for the Rappahannock River, in count and biomass, with lower (LCL) and upper (UCL) confidence limits, 2018 - 2023. Note that sampling in 2020 was curtailed in late March due to COVID-19 restrictions.

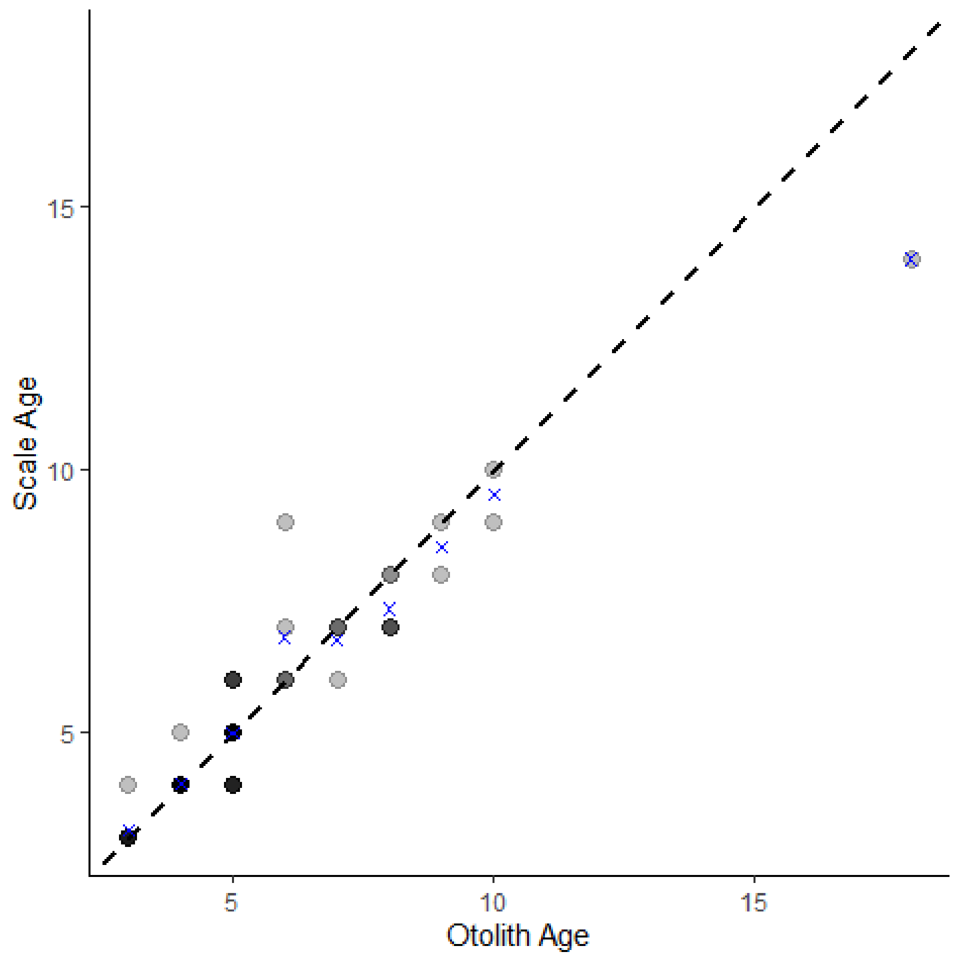

Figure 11: Comparison of otolith age to scale age for samples derived from the same specimen, spring 2023. Blue crosses represent the mean scale age for each otolith year class. For reference, the dashed blue line is the 1:1 line.

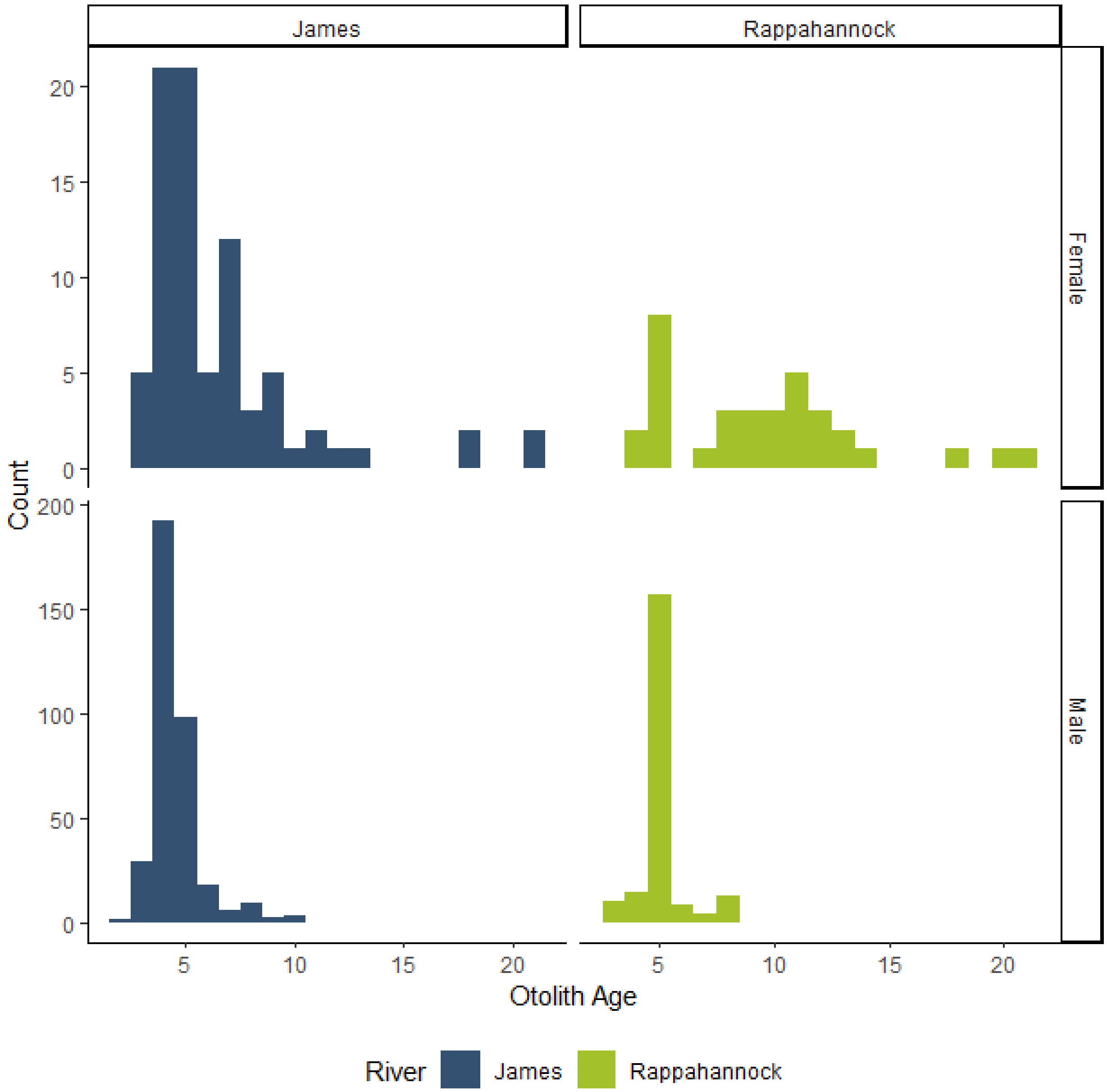

Figure 12: Otolith age-frequency distribution by river and sex, spring 2023.

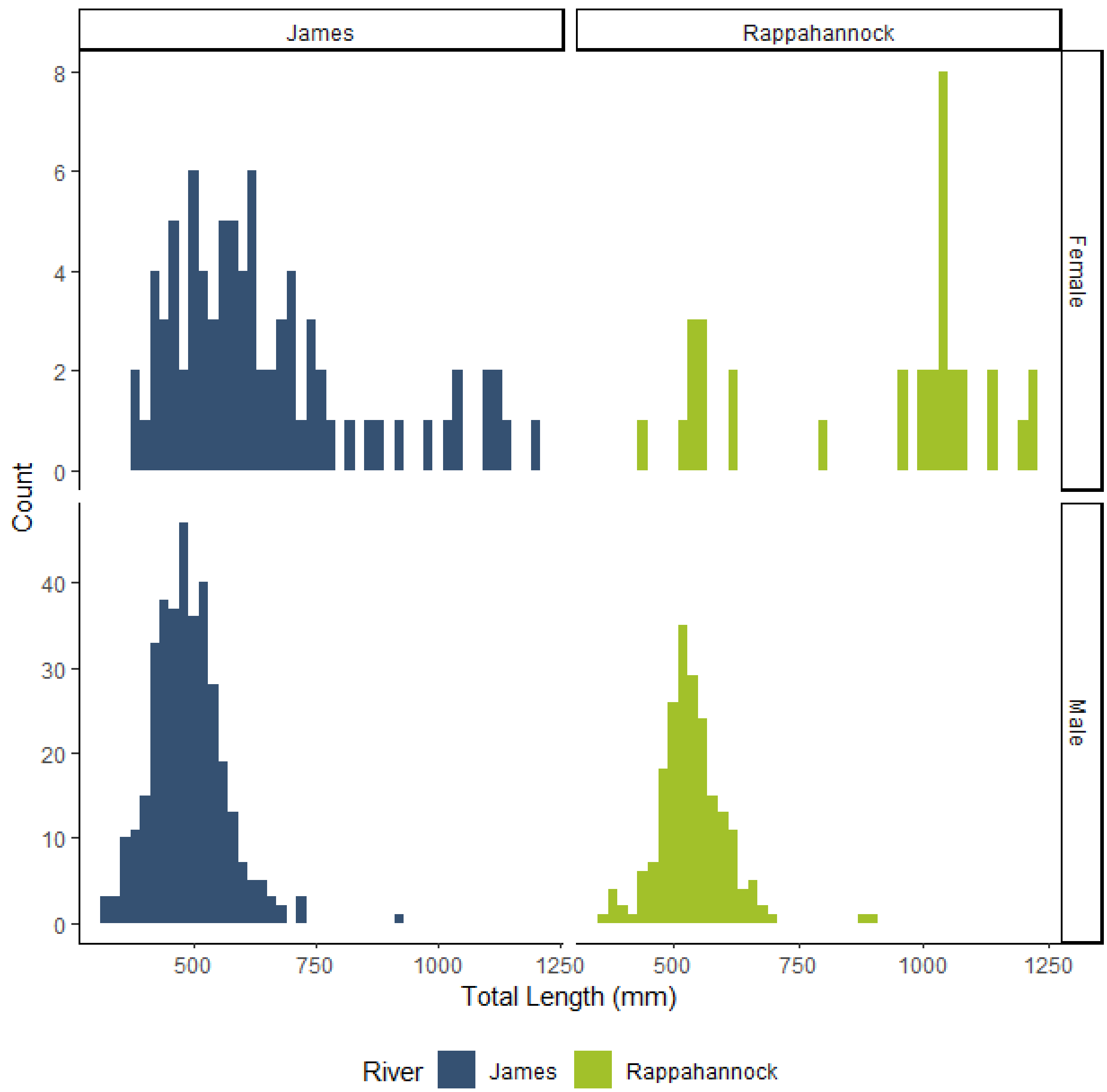

Figure 13: Length-frequency distribution by river and sex, spring 2023.

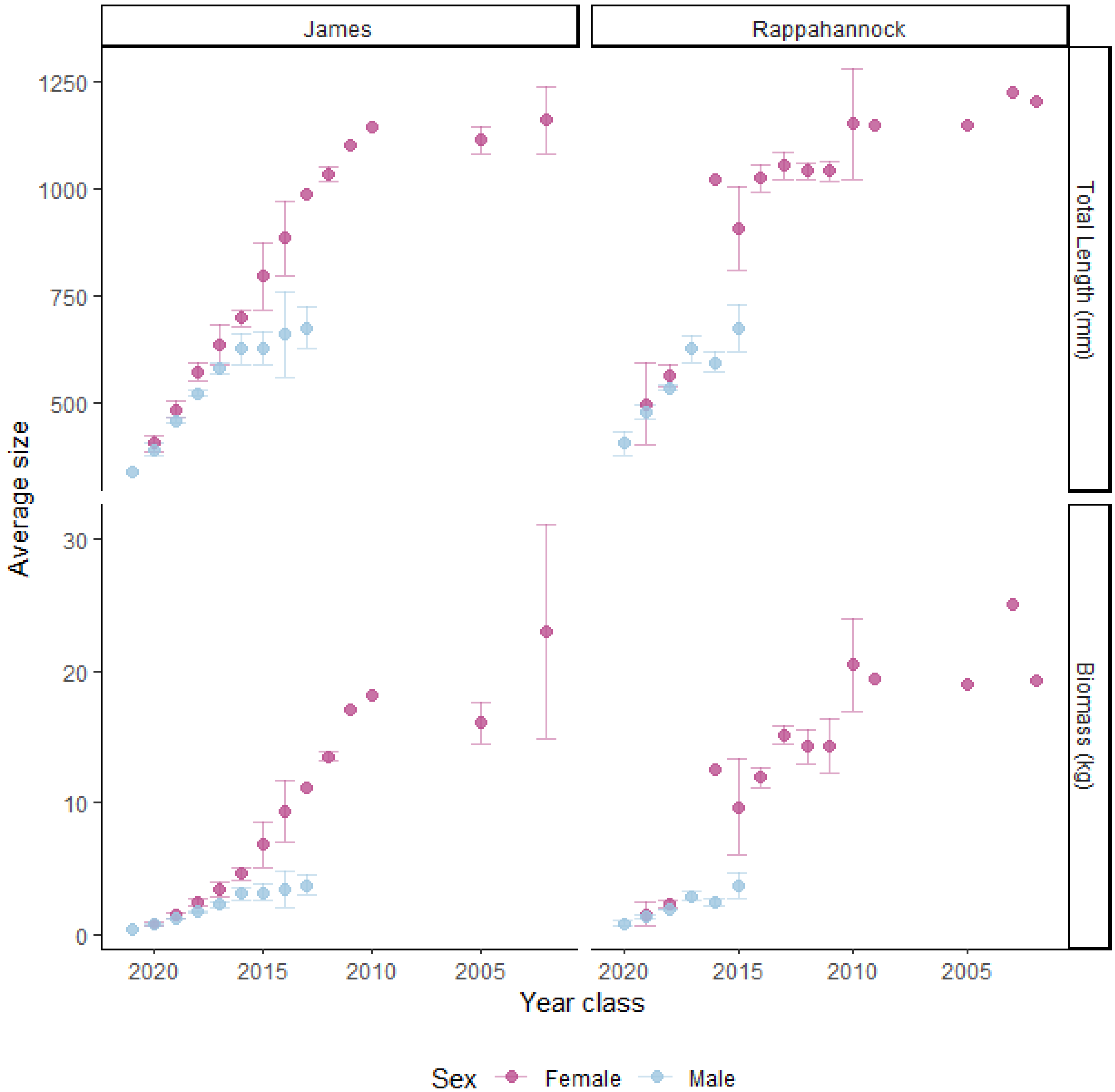

Figure 14: Average length (mm) and weight (kg) of striped bass, by river and sex for each year class, spring 2023.

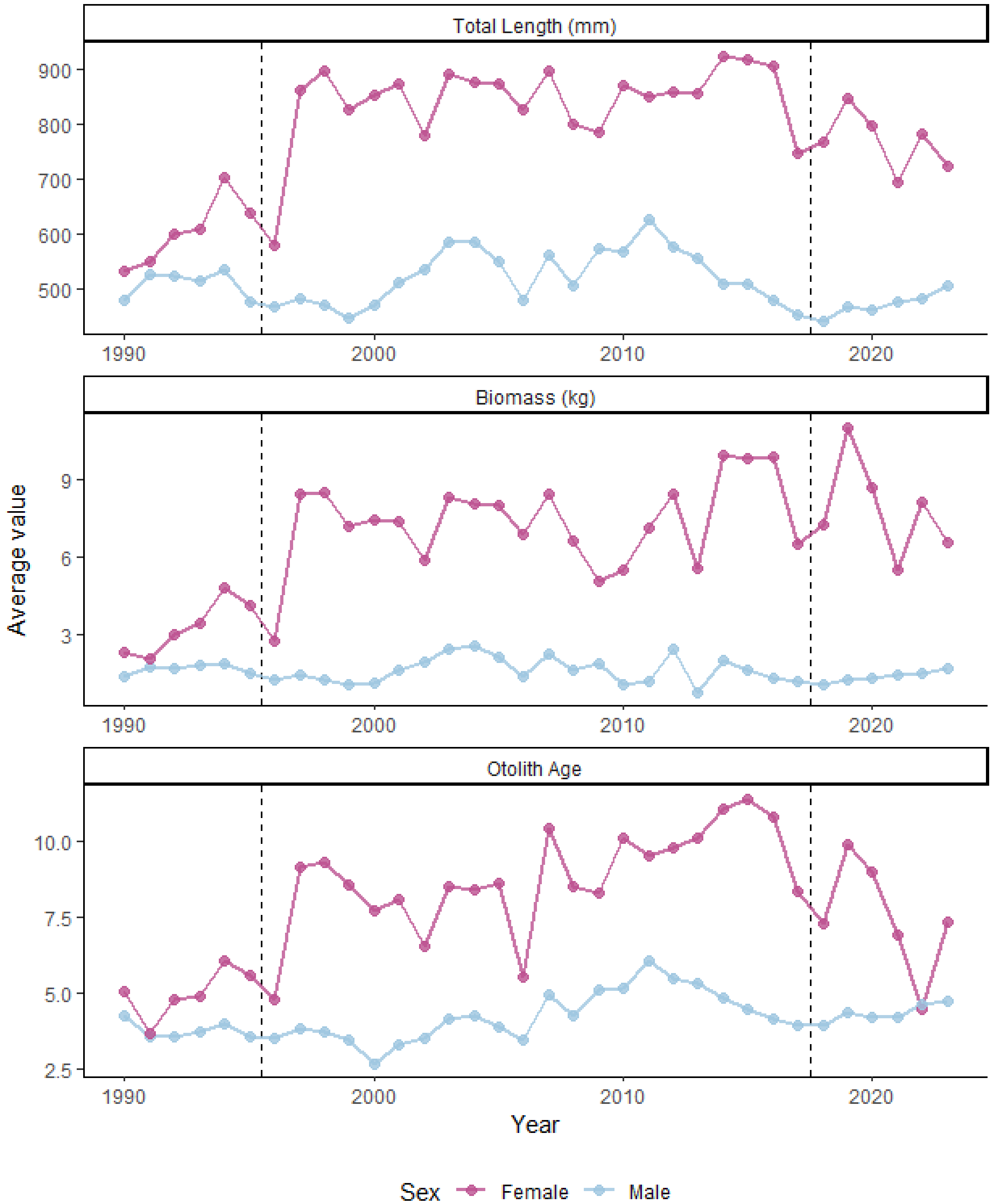

Figure 15: Average length (mm), weight (kg), and age of striped bass, by year and sex, 1990 - 2023. Vertical dashed lines indicate changes in sampling methods and/or locations.

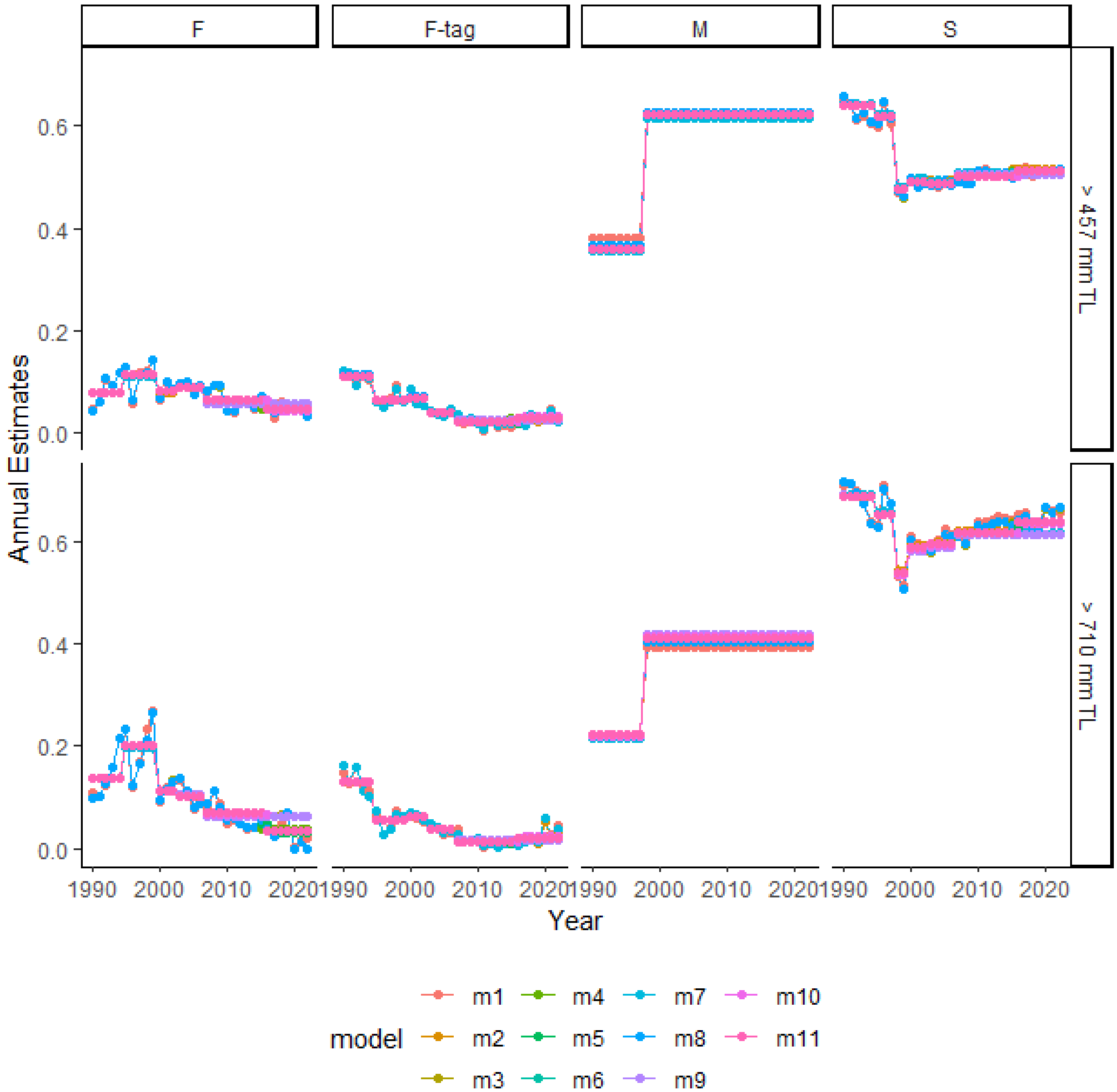

Figure 16: Estimates of annual fishing mortality (F), annual tagging mortality (F-tag), annual natural mortality (M) and annual survival (S) generated from all 11 models included in the Instantaneous Rates Catch/Release (IRCR) analysis for striped bass tagged in Virginia, 1990 - 2022. Analyses were run separately for fish > 457 mm total length (TL) and coastal migrants (those > 710 mm TL).

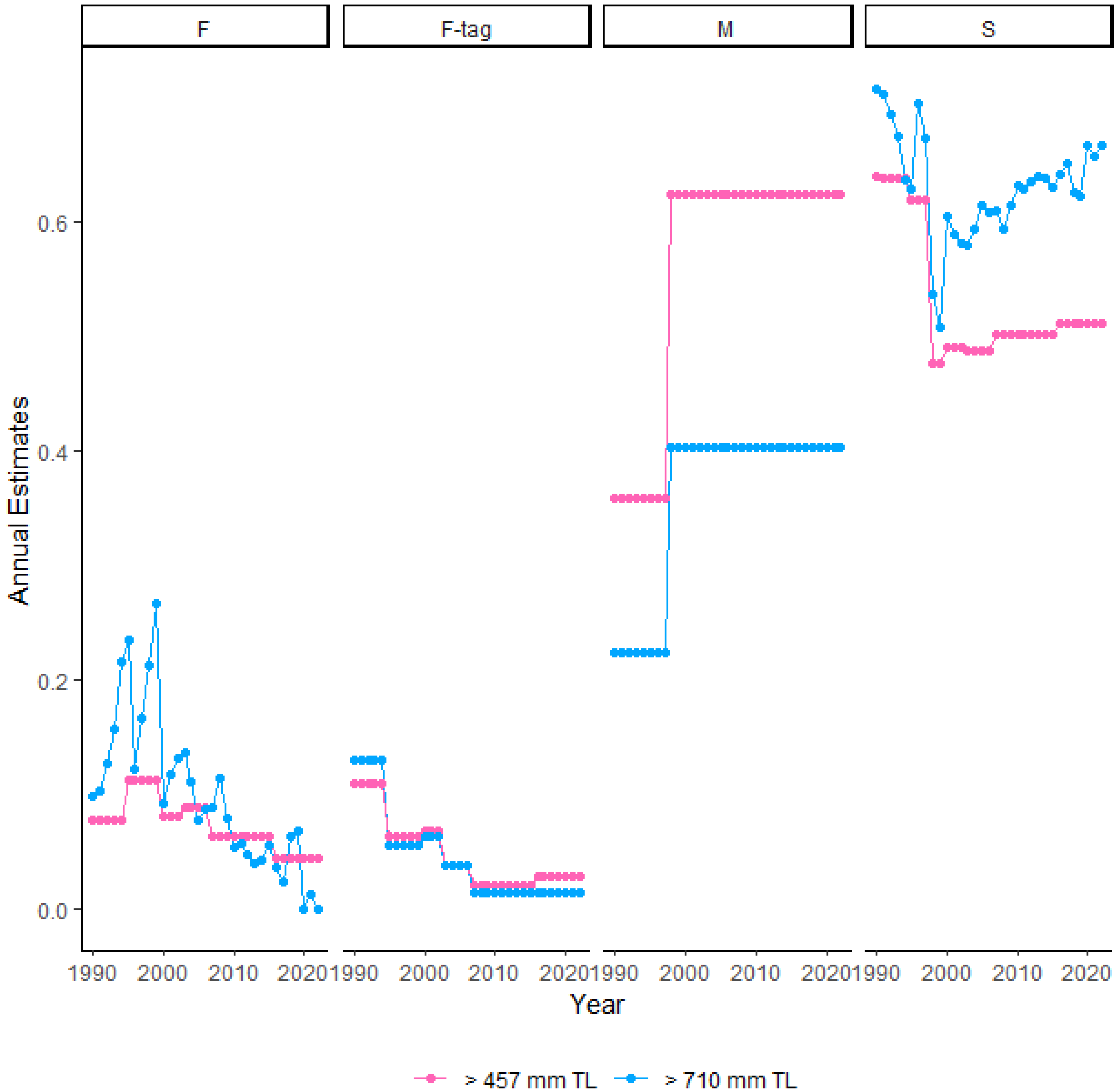

Figure 17: Estimates of annual fishing mortality (F), annual tagging mortality (F-tag), annual natural mortality (M) and annual survival (S) generated from the best of the models (lowest QAICc) included in the Instantaneous Rates Catch/Release (IRCR) analysis for striped bass tagged in Virginia, 1990 - 2022. Analyses were run separately for fish > 457 mm total length (TL) and coastal migrants (those > 710 mm TL); the best model was m11 for fish > 457 mm TL and m8 for fish > 710 mm TL.