A REVIEW OF THE 2018 ROANOKE RIVER STRIPED BASS SPAWNING STOCK CHARACTERISTICS

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Abstract.—North Carolina Wildlife Resources Commission (NCWRC) staff conducted an electrofishing survey for spawning Striped Bass *Morone saxatilis* near Weldon, NC, in the spring of 2018. Weekly surveys collected 1,280 Striped Bass. Males represented 88.4% of the catch, while females represented 5.5%; fish of unknown sex made up the remaining 6.1% of the catch. Overall relative abundance of Striped Bass was 105.3 fish/h. The low CPUE in 2018 continued a decreasing trend in relative abundance that has been seen since 2006. Age analysis indicated that the 2018 population was comprised primarily of age-3 (2015 cohort; 42.8%) and age-4 (2014 cohort; 28.9%) fish. The spawning population continued to exhibit a right-truncated length and age distribution, as age-9 or older fish were not captured in 2018. This constriction of length and age distributions suggests recruitment overfishing may be occurring. Catch curve analysis indicated a high fishing mortality (F = 0.88). An increasing trend in cohort mortality was observed; more recent cohorts (2001–2010) continued to have mortality rates greater than 50%. High mortality rates experienced by recent cohorts are likely responsible for the reduction in relative abundance of fish older than age 9. Spawning potential ratio (SPR) was estimated to be approximately 0.03. This value is well under the SPR_{Target} of 0.45 as defined by the North Carolina Estuarine Striped Bass Fisheries Management Plan. This low SPR is another indication that recruitment overfishing may be occurring. Regulations that reduce mortality and expand the age distribution must be implemented to end recruitment overfishing. Population improvements as defined by expanded size and age distributions are likely if conservative regulations are implemented as part of a collaborative management approach between the NCWRC and North Carolina Division of Marine Fisheries.

Striped Bass *Morone saxatilis* are long lived (approximately 30 years) finfish found along the eastern coast of the United States from Florida to Maine. Striped Bass are anadromous, primarily residing in saltwater but migrating to freshwater to spawn. The degree of anadromy in Striped Bass varies by latitude. Populations found south of Albemarle Sound exhibit little ocean migration (Dudley et al. 1977), while populations north of Albemarle Sound are known to exhibit yearly spawning migrations from the Atlantic Ocean to their natal rivers (Waldman et al. 1997; Abel et al. 2012; Callihan et al. 2014; Callihan et al. 2015). Striped Bass populations along the East Coast support important commercial and recreational fisheries. Declines in coastwide populations were seen in the late 1970s and early 1980s due to overfishing and poor environmental conditions. This decline was also seen in the Albemarle/Roanoke (A/R) stock of Striped Bass. To protect the stock, the state of North Carolina and the Atlantic States Marine Fisheries Commission (ASMFC) implemented strict harvest regulations in the late 1980s and early 1990s. In 1997, the A/R stock of Striped Bass was declared recovered (NCDENR 2004) and according to the latest stock assessment by North Carolina Division of Marine Fisheries (NCDMF) currently is not overfished (Flowers et al. 2016).

The A/R stock of Striped Bass is jointly managed by the North Carolina Wildlife Resources Commission (NCWRC) and NCDMF. The NCWRC is responsible for Striped Bass management in the Roanoke River Management Area (RRMA), while NCDMF manages Striped Bass in the Albemarle Sound Management Area (ASMA). As a requirement of the interstate fisheries management plan for Striped Bass (ASMFC 1981) and its associated amendment (ASMFC 2003) and addendum (ASMFC 2014), data from both agencies are combined to produce North Carolina's annual Striped Bass stock status report to the ASMFC. These data are combined with long term population trends to calculate benchmark values for fishing mortality (F) and spawning stock biomass (SSB). In cooperation with the ASMFC Striped Bass Technical Committee and Management Board, approved benchmark values are incorporated into the North Carolina Estuarine Striped Bass Fisheries Management Plan for the A/R Striped Bass stock (NCDENR 2014). Total allowable landings (TAL) along with length, season, and creel limits may be adjusted to comply with the approved benchmark values. The 2018 TAL for the A/R stock was 275,000 pounds, of which 68,750 pounds was allocated to recreational harvest in the RRMA. Striped Bass harvest in the RRMA was managed through a set harvest season established from March 1 through April 30. Size regulations in the RRMA included an 18-inch minimum size limit and a 22–27-inch protective slot that is intended to protect females ages 5–8. The daily creel limit was 2 fish per day of which only one fish above 27 inches was allowed to be harvested.

The NCWRC annually conducts a spawning stock assessment of Striped Bass on the spawning grounds near Weldon, NC, and a creel survey to evaluate the recreational harvest of Striped Bass throughout the RRMA. This report characterizes the spawning portion of the A/R stock in the RRMA by estimating relative abundance, mortality, age-structure, and size-structure of Striped Bass collected using boat electrofishing on the spawning grounds in 2018.

Methods

Spawning Stock Assessment.—NCWRC sampled Striped Bass weekly from April 9 to May 14, 2018. Sampling started once water temperatures approached 15°C and continued through the range of optimal spawning temperatures until water temperatures surpassed 22°C. A boat mounted electrofishing unit (Smith-Root 7.5 GPP, 1 netter) was used to collect Striped Bass from their historic spawning grounds near Weldon, NC (Figure 1). Sampling stations were located on main and secondary river channel habitats. Three strata were sampled each day, and strata selection was dependent on flow conditions. Flows of approximately 7,000 ft^3/s (cfs) or less restricted access to strata above the rapids in proximity to the Weldon boating access area (Figure 1). Two sites were selected within each stratum, for a total of six sampling sites per day.

At each site, all Striped Bass were netted and placed into an oxygenated holding tank until they could be transported to a nearby work-up boat. All Striped Bass transferred to the work-up boat were measured for total length (TL, mm), and sex was determined by assessing the presence of eggs or milt when pressure was applied to the fish's abdomen. Weight (kg) and scales were obtained from a subsample of up to five fish in each 25-mm size group per sex per sampling date. Scales and weights were collected from all fish greater than 700 mm. Scales were removed from the left side of the fish between the lateral line and dorsal fin and stored in numbered envelopes. Striped Bass scales were pressed and aged following standard protocol (NCWRC and NCDMF 2011). Scales were aged using an EyeCom 3000 microfiche reader at 24X and 36X magnification. The primary reader aged up to 15 individuals per 25-mm length group per sex, and a subsample (20% of aged scales) was aged by a secondary reader for age verification. Age discrepancies between the readers were reconciled in concert.

Relative abundance of Striped Bass was indexed by catch-per unit-effort (CPUE) and was expressed as the number of fish captured per hour of electrofishing (fish/h). Overall CPUE (total fish collected/hours of electrofishing effort) for all sample sites and daily CPUE were calculated. Additionally, a 3-week mean of CPUE (peak CPUE ± 1 week) was calculated and compared to previous years. An age-length key created from scale age data was applied to any unaged fish to complete age distributions for male and female Striped Bass. Mean length at age was then calculated for males and females of the entire 2018 sample using methods described by Bettoli and Miranda (2001). Mean daily water temperature (°C) was calculated from temperature values collected at each sampling site and mean daily discharge (cfs) was recorded from the U.S. Geological Survey gaging station (02080500) at Roanoke Rapids, NC.

Mortality.—Instantaneous total (Z) and annual (A) mortality for 2015–2018 was estimated using the Chapman-Robson mortality estimator and variance inflation factor, where the age of full recruitment is the age of maximum catch plus 1 year (peak plus method; Smith et al. 2012). Instantaneous fishing mortality (F) and exploitation rate (u) were calculated using an instantaneous natural mortality (M) of 0.15 (NCDENR 2014).

Annual mortality (A) was estimated for each Striped Bass cohort from 1992 to 2012 using the Chapman-Robson mortality estimator and variance inflation factor as described by Smith et al. (2012). Using this method, age of full recruitment is the age of maximum catch plus 1 year (peak plus method), and at least three years of data are needed following the age of full recruitment. Thus, 2013–2017 cohorts were excluded from the analysis. Scale age data collected during the NCWRC annual electrofishing surveys from 1993 to 2018 were used for the cohort mortality analysis.

Population Modeling.—Yield-per-recruit (YPR) was modeled using FAMS v1.64 (Fisheries Analysis and Modeling Simulator; Slipke and Maceina 2014). Growth parameters were obtained from a von Bertalanffy growth equation and a weight-length equation generated using the

1,202 individuals (1,131 males and 71 females) collected during the 2018 spawning stock assessment. The fecundity at length equation and maturation schedule were obtained from Olsen and Rulifson (1992) and Boyd (2011), respectively. Egg production per recruit (number of eggs), yield-per-recruit (kg), number of fish at 749 mm (approximate age-9 fish) and spawning potential ratio (SPR; Goodyear 1993) were estimated using a combination of conditional fishing mortality (*cf*) ranging 0.1–0.8 (increments of 0.1), various length regulations, and an assumed conditional natural mortality of 0.15.

Results

2018 Spawning Stock Assessment.—Boat electrofishing in the spring yielded 1,280 Striped Bass in 12.16 h of electrical output. Males made up 88.4% of the sample (n = 1,131), while females accounted for 5.5% (n = 71). Individuals of unknown length and sex (n = 78) made up the remaining 6.1%. Overall relative abundance of Striped Bass was 105.3 fish/h (1,280 fish/12.16 h; Figure 2). The peak in daily pooled CPUE was 261.9 fish/h and occurred on May 7, when average water temperature was approximately 18.5°C (Table 1). Mean peak CPUE ± 1 week was 172.9 fish/h (SE = 27.4). Flows in the Roanoke River remained below 20,000 cfs for all sampling dates except April 30 (Table 1). Sampling activities during the last two weeks of May were cancelled due to flow conditions that exceeded 30,000 cfs.

Striped Bass scales (n = 245) were aged by the primary reader, and 67 scales were aged in a subsample by a secondary reader. Exact agreement between the two readers was 74%, while initial agreement ± 1 year was 92%. Age discrepancies were rectified in concert, and 100% agreement was achieved for the subsample. Final ages from the subsample (double reads) were similar to the full sample (single reads; Figure 3), indicating adequate precision of the primary reader's ages. Analysis of the 2018 age data indicated eight cohorts of Striped Bass were present during the spawning stock assessment. The age distribution ranged between 1 and 8 years (Figure 4). The 2015 (age-3) cohort made up the majority (42.8%) of fish collected in 2018 and was the main contributor to overall relative abundance with a CPUE of 42.3 fish/h (Table 2). The 2014 cohort made up 28.9% of the catch, while the 2013 (age-5) cohort continued to contribute minimally (7.0%) to the overall catch. Female Striped Bass were represented by seven cohorts (ages 2–8), while males were represented by eight cohorts (ages 1–8). The female catch was dominated by age-6 fish (2012 cohort), which represented 39.4% of all females (Table 3). No females older than age 8 were captured in 2018. Male Striped Bass were mainly represented by the 2015 (age-3) and 2014 (age-4) cohorts, which accounted for 45.3% and 28.3% of the male catch, respectively. Fish older than age 4 represented 10.2% of the total male catch (Table 3). No fish (male or female) older than age 9 were captured in 2018 (Figure 5).

The length distributions for males and females were both unimodal. The length distribution for the overall spawning population was severely truncated to the left as few fish above 700 mm were collected in 2018. The peak in the male length distribution was 400 mm (Figure 6). Approximately 6% of fish within the protective slot (22–27 inches) were males, and less than 1% of males were above the protective slot limit. The peak in the female length distribution occurred at 500 mm. The majority of the female catch consisted of individuals within the protective slot, with approximately 9% of females larger than the upper end of the protective slot limit.

Mortality.—The catch curve regression based on 2015–2018 age data estimated total instantaneous mortality rates (*Z*) to range from 0.56 (2017) to 1.77 (2016; Table 4). Using the natural mortality rate (*M*) of 0.15, fishing mortality (*F*) ranged from 0.38 (2017) to 1.62 (2016; Figure 7). The 2018 fishing mortality rate was 0.88, which exceeds both the F_{Target} of 0.33 and $F_{Threshold}$ of 0.41 established in the 2016 stock assessment.

Annual mortality estimates and 90% confidence intervals were calculated for the 1992–2012 cohorts (Figure 8). Age of full recruitment ranged from age 3 to age 5, with age 4 being the fully recruited age in 81% of the cohorts (Table 5). The number of ages used for each cohort varied from three to twelve, with the more recent cohorts having fewer age classes available for inclusion in the analyses (Table 5). Mortality ranged from 30.2% (1995 cohort) to 74.3% (2011 cohort). The 1992 to 2000 cohort mortalities were low and ranged from 30.2% to 45.1% However, the 2001 to 2010 cohorts experienced overall higher mortality rates ranging from 44.9% to 79.0%, with all but one cohort experiencing mortalities of 50% or greater.

Population Modeling.—Yield-per-recruit analysis of the 2018 spawning population estimated SPR = 0.03. This SPR is well below the SPR_{Target} of 0.45. A 30-in MLL would be required to reach the SPR_{Target} at the F_{2018} and F_{Target} mortality rates (Figure 9). If mortality was decreased to a stock restoration level (*F*=0.25; Richards and Rago 1999), a 26-in MLL would be needed to reach SPR_{Target} (Figure 9). At the current mortality rate, the 30-in MLL increases both egg production (Figure 10) and number of fish at age 9 (Figure 11) by 1,247% and 3,564%, respectively (Table 6), while decreasing harvest by 57%. The 30-in MLL maximizes YPR at F_{2018} and slightly outperforms the 26-in MLL at F_{Target} (Figure 12).

Management Implications

The catch curve analysis estimated high mortality over the past four years on the Roanoke River Striped Bass spawning stock. Fishing mortality during 2015–2018 has exceeded both F_{Target} (F = 0.33) and $F_{Threshold}$ (F = 0.41), which were established within the framework of the NC Estuarine Striped Bass Fisheries Management Plan (NCDENR 2014). The fishing mortality levels in 2016 and 2018 have approached or exceeded fishing mortality levels in 1984 (F = 1.01) when the A/R stock was declared collapsed. The fishing mortality rate in 2018 exceeded mortality rates seen in the Neuse River in 2014 (Rachels and Ricks 2015) and was similar to fishing mortality rates that lead to the collapse of the Chesapeake Bay stock during the mid-1970s (Richards and Rago 1999). The high mortality rates and the likely overharvest of fish less than 558 mm (22 in) are driving the decreasing abundance of fish age 9+.

Severe truncation of the length and age distributions continued in 2018. The population was primarily composed of individuals smaller than the upper end of the protective slot limit (685 mm; 27 in) and younger than 5 years old. The failed 2013 cohort is still evident as the contribution of age-5 fish was lower than previous years. Most notable was the low abundance of age-7 and age-8 individuals and the absence of any fish age-9 or older. The decrease in abundance of older fish (age 9 and older) has been observed since 2006; however, 2018 was the first year (including pre-recovery years) that age-9+ fish were not collected. The lack of older fish continues to limit egg production to younger fish, which are known to produce fewer and lower quality eggs (Boyd 2011). The length and age distributions seen in the Roanoke River were similar to those found in the Neuse River in 2014 (Rachels and Ricks 2015). The Roanoke River length and age distributions were also similar to distributions in the Chesapeake Bay during the mid-1970s and 1980s when overfishing led to a stock collapse (Richards and Rago 1999). The truncation seen in all three systems (the Chesapeake Bay in the mid-1980s, the Neuse River in 2014, and the Roanoke River in 2018) is a classic indicator of recruitment overfishing and potential stock collapse. The 2018 SPR was 0.03, well below the SPR_{Target} of 0.45. The 2018 SPR was also well below the SPR of 0.30 for the Neuse River in 2014 (Rachels and Ricks 2015). This low SPR indicates that at current mortality rates, egg production in the population is severely depressed. The low egg production is another indication that recruitment overfishing is occurring on the A/R stock of Striped Bass. At F_{2018} and F_{Target}, a 30-in MLL is needed to reach the SPR_{Target} of 0.45. However, at $F_{Restoration}$ (F = 0.25) , a 26-in MLL is needed to reach SPR_{Target}.

The relative abundance of Roanoke River Striped Bass in 2018 (105.3 fish/h) increased from previous years (2016 and 2017). However, relative abundance in 2018 was significantly depressed compared to levels in the mid-2000s. Similar relative abundance values were seen in the mid-1990s before the A/R stock had recovered from overfishing. Female relative abundance also continued to decline to pre-recovery levels. Streamflow was adequate for effective sampling throughout most of the spawning period. Streamflow during the last two weeks (week 21 and 22) of May exceeded 30,000 cfs, resulting in the cancellation of sampling activities. Data (NCWRC, unreported) suggest that female relative abundance usually peaks between week 19 and 20 (the second and third weeks in May). It is likely that the Striped Bass missed over the last two weeks would have only marginally increased overall and female relative abundance.

It is highly likely that recruitment overfishing is occurring on the A/R stock of Striped Bass given the truncated age distribution, scarcity of large fish, high mortality rates in 2015–2018, extremely low SPR in 2018, and suspected depressed egg production. Recruitment overfishing is the main driver in Striped Bass stock collapse as it can severely reduce spawning stock biomass to the point where strong cohorts cannot be produced (Goodyear et al. 1985; Richards and Deuel 1987; Richards and Rago 1999). Reduced egg production likely causes Striped Bass eggs and larvae to be more susceptible to environmental conditions (Richards and Rago 1999). Three of the last six cohorts of A/R Striped Bass have either been weak or have failed (NCDENR 2018) indicating that egg production may be critically low.

To improve the management of the A/R Striped Bass stock, the goals and associated objectives in the NC Estuarine Striped Bass Fishery Management Plan must be more clearly defined. The goals of Amendment 1 of the FMP include preserving adequate spawning stock, providing and maintaining a broad age distribution, and protecting the integrity of critical habitat. However, the amendment does not provide definitions or specific expectations regarding adequate spawning stock or a broad age distribution. Changes to harvest practices throughout the A/R are necessary to reduce mortality, expand the age distribution, and increase Striped Bass egg production on the spawning grounds. The continued absence of Striped Bass within the protective slot limit, despite this regulation being in place for over 30 years on the spawning grounds, suggests that population improvements will not occur without collaborative management efforts in both the RRMA and ASMA.

Management Recommendations

1. To facilitate population recovery, reduce the TAL as necessary to lower fishing mortality to $F = 0.25$. Consider removing the protective slot limit in the RRMA and establishing a 26-inch MLL in both the RRMA and ASMA.
2. Maintain the current harvest season for Striped Bass in the RRMA as established (1 March–30 April).
3. Conduct meetings with stakeholders to discuss the future management of the Albemarle/Roanoke Striped Bass stock.
4. To reduce recreational discard mortality in both the ASMA and RRMA, propose a regulation that would require anglers to use barbless circle hooks when fishing with natural bait. Address management measures to reduce commercial discard mortality as a part of the current FMP update.
5. Continue coordination efforts with U.S. Army Corps of Engineers and other Roanoke River stakeholders to provide flow conditions that will be favorable for successful Striped Bass cohort production.
6. Review relationships between spring spawning flows, juvenile abundance monitoring in Albemarle Sound, and age-3 abundance on the spawning grounds to develop predictive models regarding Striped Bass cohort strength.

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TABLE 1.—Daily pooled CPUE (daily catch/daily effort) of Striped Bass collected by electrofishing on the Roanoke River spawning grounds during 2018. Mean daily discharge was reported from the US Geological Survey gaging station (02080500) at Roanoke Rapids, NC.

Date	Effort (h)	Catch	Pooled CPUE	Average Discharge (cfs)	Water Temp (^{o}C)
04/09/2018	1.75	22	12.6	11,600	11.7
04/16/2018	2.00	86	43.1	5,600	14.9
04/23/2018	2.41	140	58.2	9,500	15.1
04/30/2018	1.93	345	178.8	20,600	16.8
05/07/2018	1.99	431	217.0	15,600	18.6
05/14/2018	2.09	256	122.7	6,670	21.3
Total	12.16	1280			

TABLE 2.—Striped Bass age distributions (percent composition) and relative abundance (CPUE; fish/h) of seven male cohorts and nine female cohorts collected by electrofishing on the Roanoke River spawning grounds, 2018. Overall totals exclude 78 individuals of unknown length and sex.

		Percent Composition			CPUE (fish/h)		
Cohort	Age	Male	Female	Overall	Male	Female	Overall
2017	1	0.9	0.0	0.9	0.9	0.0	0.9
2016	2	14.2	0.1	14.3	14.0	0.1	14.1
2015	3	42.6	0.5	43.1	42.1	0.5	42.6
2014	4	26.7	0.8	27.5	26.3	0.8	27.1
2013	5	5.5	1.5	7.0	5.4	1.4	6.9
2012	6	3.7	2.3	6.0	3.7	2.3	6.0
2011	7	0.4	0.7	1.0	0.4	0.7	1.0
2010	8	0.1	0.1	0.2	0.1	0.1	0.2
Totals		94.0	6.0	100	92.9	5.8	98.7

TABLE 3.—Age composition and mean total length (mm) of eight cohorts of male Striped Bass and seven cohorts of female Striped Bass collected by electrofishing on the Roanoke River spawning grounds in 2018.

Males

Cohort	Age	N Aged	N Estimated	N Total	Percent Composition	Total Length (mm) Mean	SD	Min.	Max.
2017	1	6	5	11	1.0	261	20	245	287
2016	2	41	129	170	15.1	349	34	257	392
2015	3	47	464	511	45.3	414	36	308	492
2014	4	36	284	320	28.3	455	30	373	545
2013	5	25	41	66	5.9	538	29	503	612
2012	6	24	21	45	3.9	599	33	565	707
2011	7	3	2	5	0.4	684	25	669	715
2010	8	1	0	1	0.1	787	0	782	782
Totals		183	946	1,129	100				

Females

Cohort	Age	N Aged	N Estimated	N Total	Percent Composition	Total Length (mm) Mean	SD	Min.	Max.
2016	2	1	0	1	1.4	312	0	319	319
2015	3	6	0	6	8.5	420	38	375	485
2014	4	8	2	10	13.4	491	40	423	543
2013	5	15	3	18	24.7	555	39	518	650
2012	6	23	5	28	39.4	623	33	540	660
2011	7	8	0	8	11.3	706	12	687	721
2010	8	1	0	1	1.4	787	0	798	798
Totals		62	9	71	100				

TABLE 4.—Mortality rate estimates 2015–2018. Instantaneous fishing mortality (*F*) was calculated using an instantaneous natural mortality of 0.15.

	2015	2016	2017	2018
Z (± SE)	0.72 (0.058)	1.77 (0.647)	0.56 (0.124)	1.03 (0.144)
Lower 90% CI	0.62	0.71	0.36	0.79
Upper 90% CI	0.82	2.83	0.76	1.27
F	0.57	1.62	0.41	0.88
u	0.406	0.759	0.314	0.549

TABLE 5.—Cohort mortality estimates from 1992 to 2012. Age of full recruitment (peak plus) is described by Smith et al. 2012.

Cohort	Age of full recruitment	Number of ages used	Annual mortality (*A*)	Lower 90% CI	Upper 90% CI
1992	Age 5	12	38.1	31.6	44.0
1993	Age 4	13	34.3	28.7	39.5
1994	Age 4	13	37.5	30.6	43.7
1995	Age 4	14	30.2	25.1	30.0
1996	Age 4	13	33.0	28.3	37.3
1997	Age 5	12	45.1	37.9	51.5
1998	Age 4	12	45.1	38.7	50.8
1999	Age 5	10	34.3	27.4	40.6
2000	Age 4	10	36.9	25.7	46.4
2001	Age 4	10	57.3	52.0	61.9
2002	Age 4	9	66.7	60.8	71.8
2003	Age 4	9	65.4	56.9	72.2
2004	Age 4	8	44.9	30.9	55.5
2005	Age 4	9	51.3	43.2	58.3
2006	Age 3	8	65.4	61.8	68.6
2007	Age 4	7	61.7	57.2	65.8
2008	Age 4	6	74.3	64.4	81.5
2009	Age 4	5	63.2	52.0	71.8
2010	Age 4	5	65.4	54.0	73.9
2011	Age 4	4	79.0	68.2	86.1
2012	Age 4	3	51.3	4.0	75.3

TABLE 6.—Change in population parameters in response to current and target instantaneous fishing mortality rates (*F*). Spawning potential ratio is not expressed in percent change.

Current fishing mortality (*F*=0.91)

Regulation	SPR	Percent Change			
		Yield	Egg Production	Number Harvested	Number at Age 9
18-in MLL	0.03	0	0	0	0
18-in MLL, 22 to 27-in Protective Slot	0.12	2	289	-11	919
22-in MLL	0.10	32	217	-21	159
23-in MLL	0.13	41	314	-25	273
23-in MLL with 27-in Max	0.19	35	502	-31	891
26-in MLL	0.27	59	695	-40	1092
30-in MLL	0.50	67	1246	-57	3564

Target fishing mortality (*F*=0.33)

Regulation	SPR	Percent Change			
		Yield	Egg Production	Number Harvested	Number at Age 9
18-in MLL	0.17	29	420	-22	1107
18-in MLL, 22 to 27-in Protective Slot	0.27	18	702	-34	2197
22-in MLL	0.26	46	746	-38	1753
23-in MLL	0.29	60	808	-42	1969
23-in MLL with 27-in Max	0.37	40	1009	-47	2443
26-in MLL	0.41	58	1122	-53	3075
30-in MLL	0.55	59	1598	-65	4756

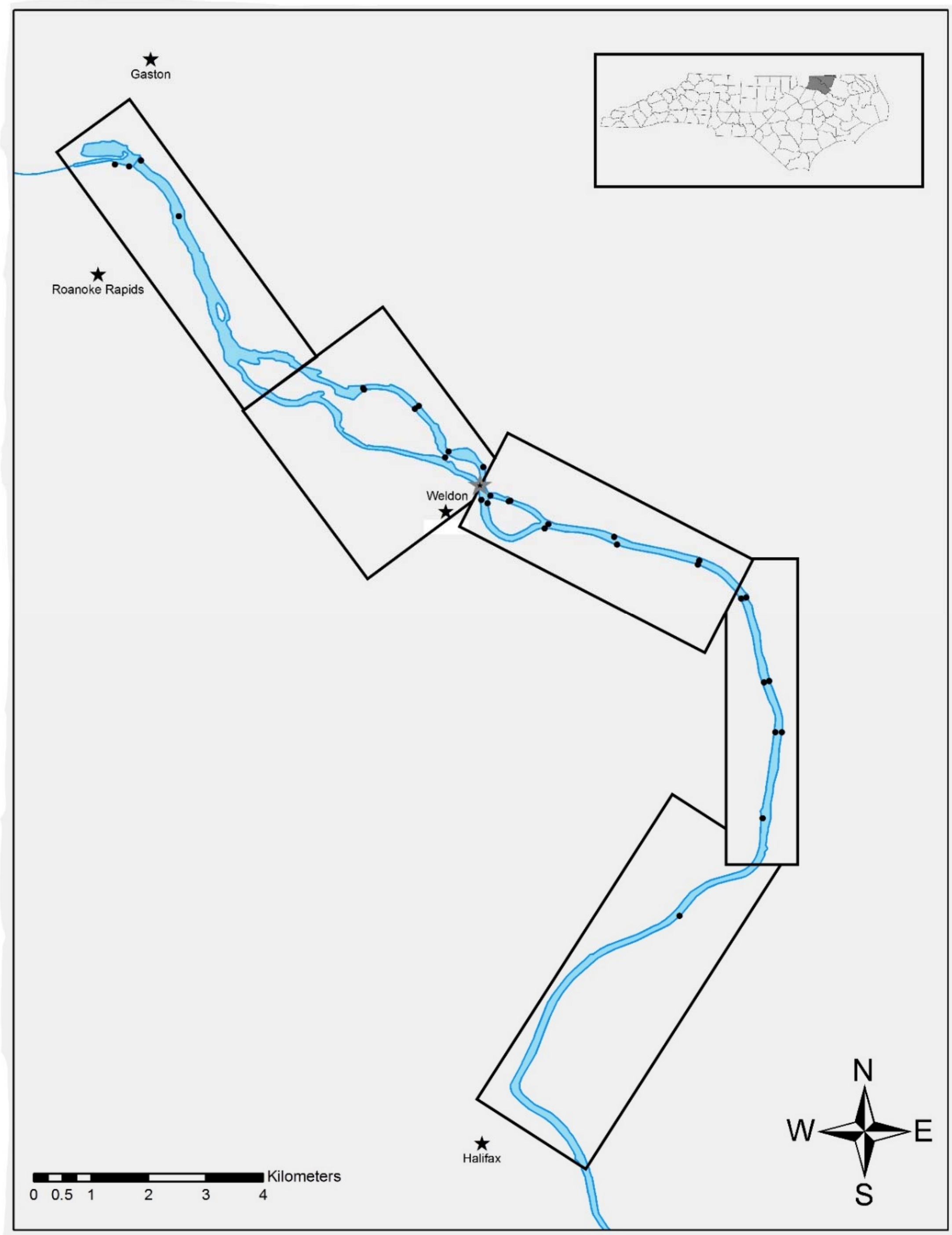

FIGURE 1.—Striped Bass spawning grounds on the Roanoke River, near the vicinity of Weldon, NC. Black boxes represent relative locations of river strata while black dots indicate sampling site locations. The gray star indicates location of rapids near the Weldon boating access area; flows less than 7,000 cfs restrict access to the strata above this location.

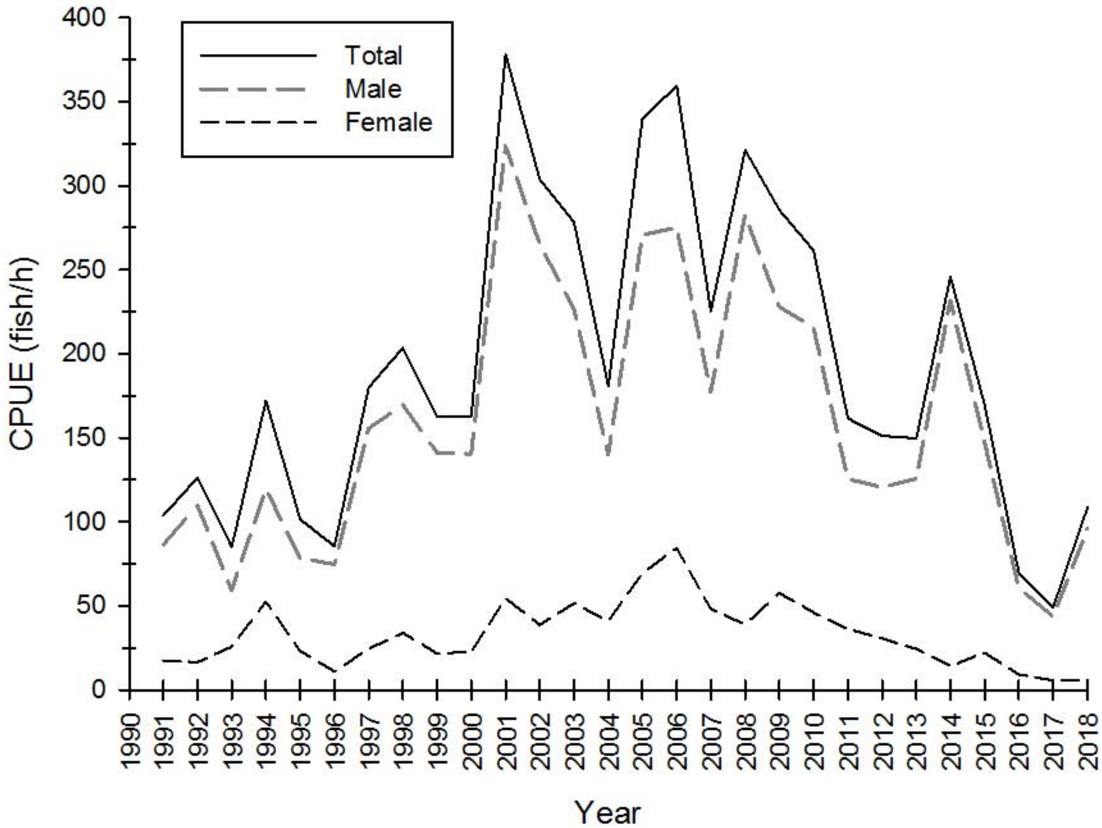

FIGURE 2.—Relative abundance (CPUE; fish/h) of male and female Striped Bass from the Roanoke River, North Carolina from 1991 to 2018.

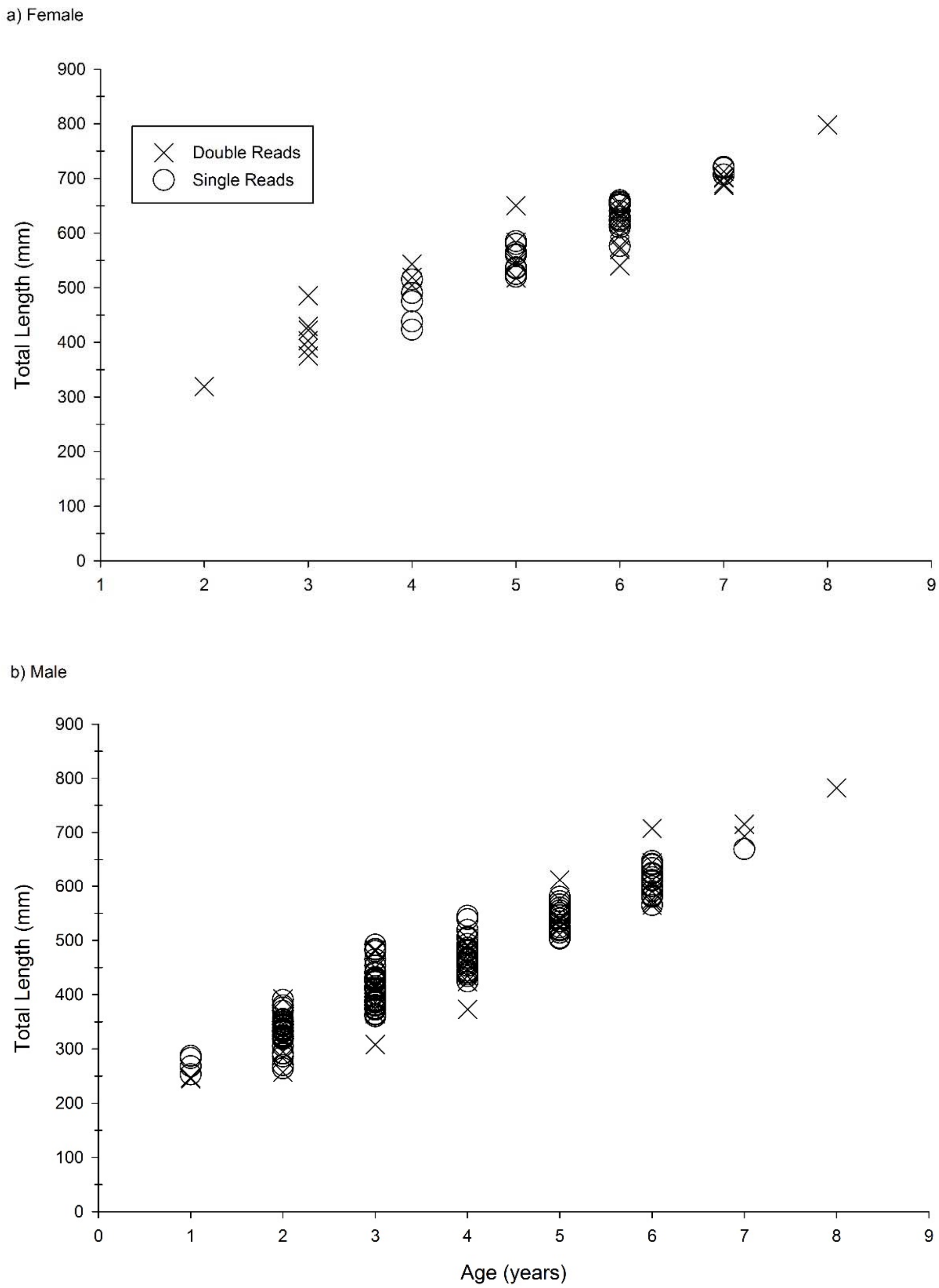

FIGURE 3.—Comparison of single and double-read scale ages for female (a) and male (b) Striped Bass collected from the Roanoke River during spring 2018.

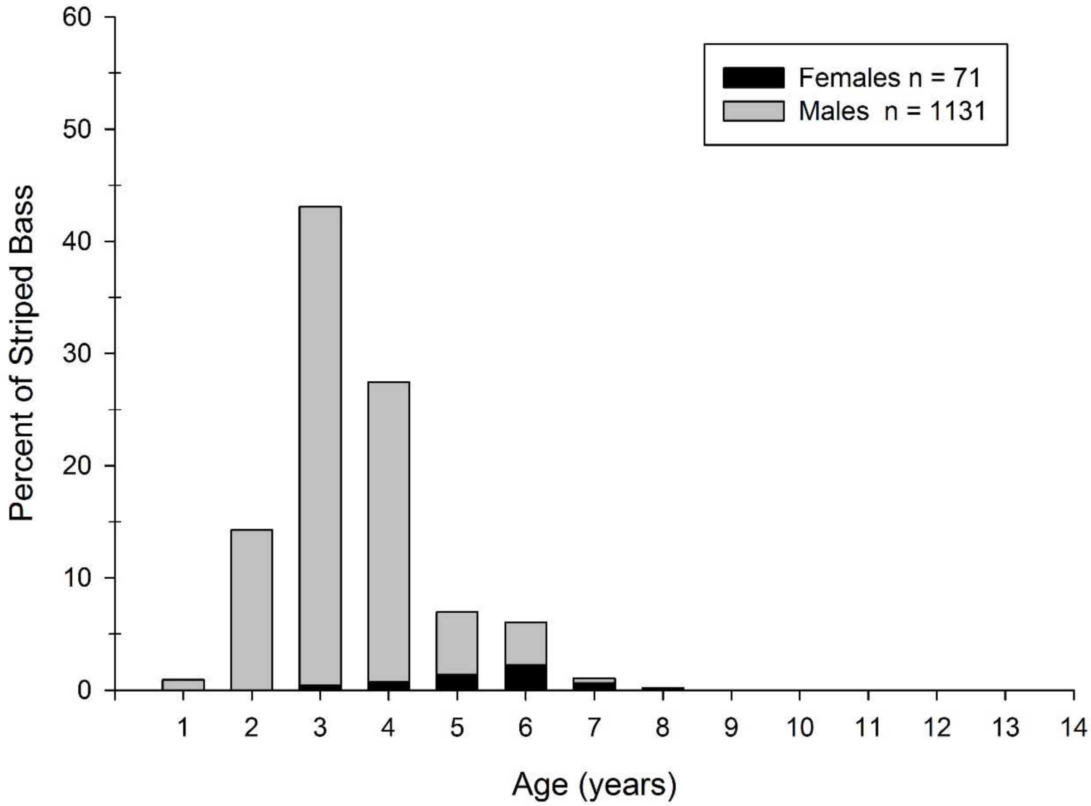

FIGURE 4.—Age distribution for Striped Bass collected from the Roanoke River, spring 2018.

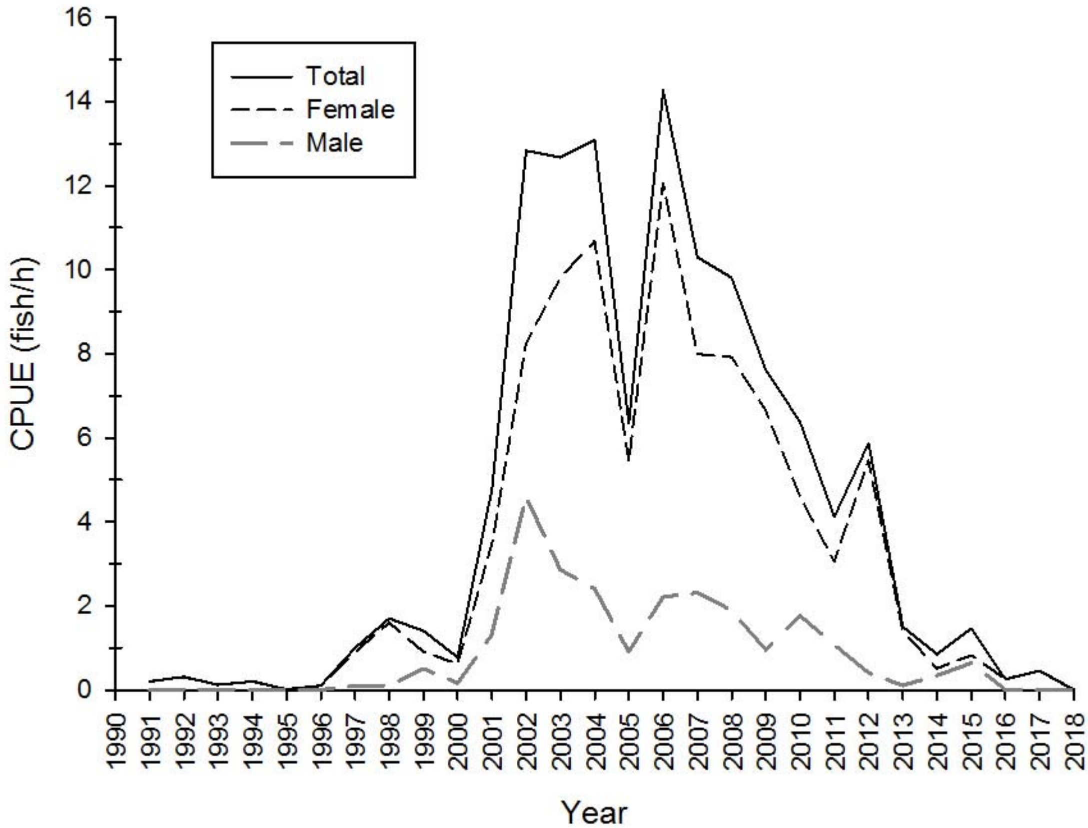

FIGURE 5.—Relative abundance (CPUE; fish/h) of Roanoke River Striped Bass ≥ age 9 collected by electrofishing during spawning stock surveys at Weldon, NC; 1991–2018.

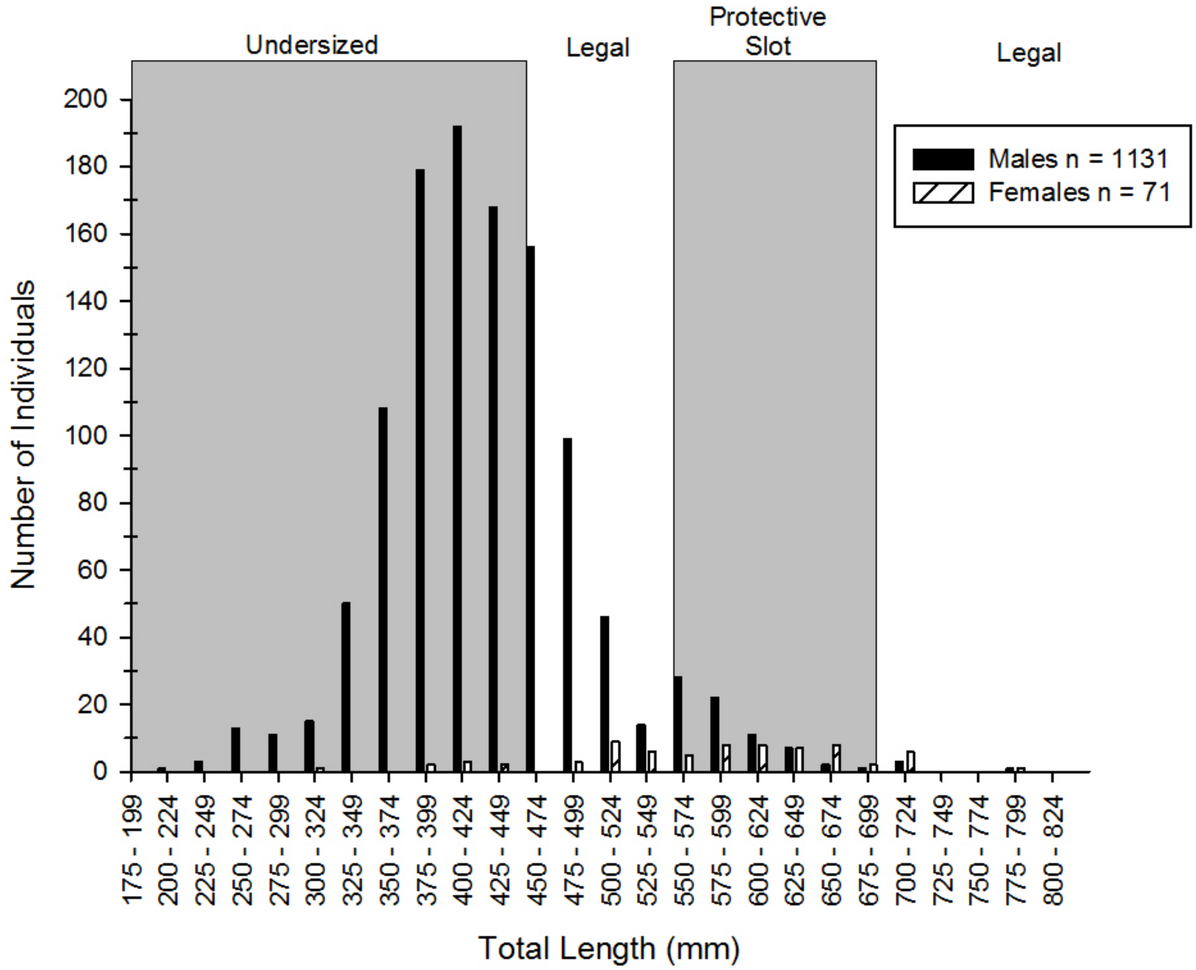

FIGURE 6.—Length frequency histograms for Striped Bass collected from the Roanoke River, spring 2018. Shaded areas indicate sizes protected from legal harvest (< 457 mm and 559–686 mm).

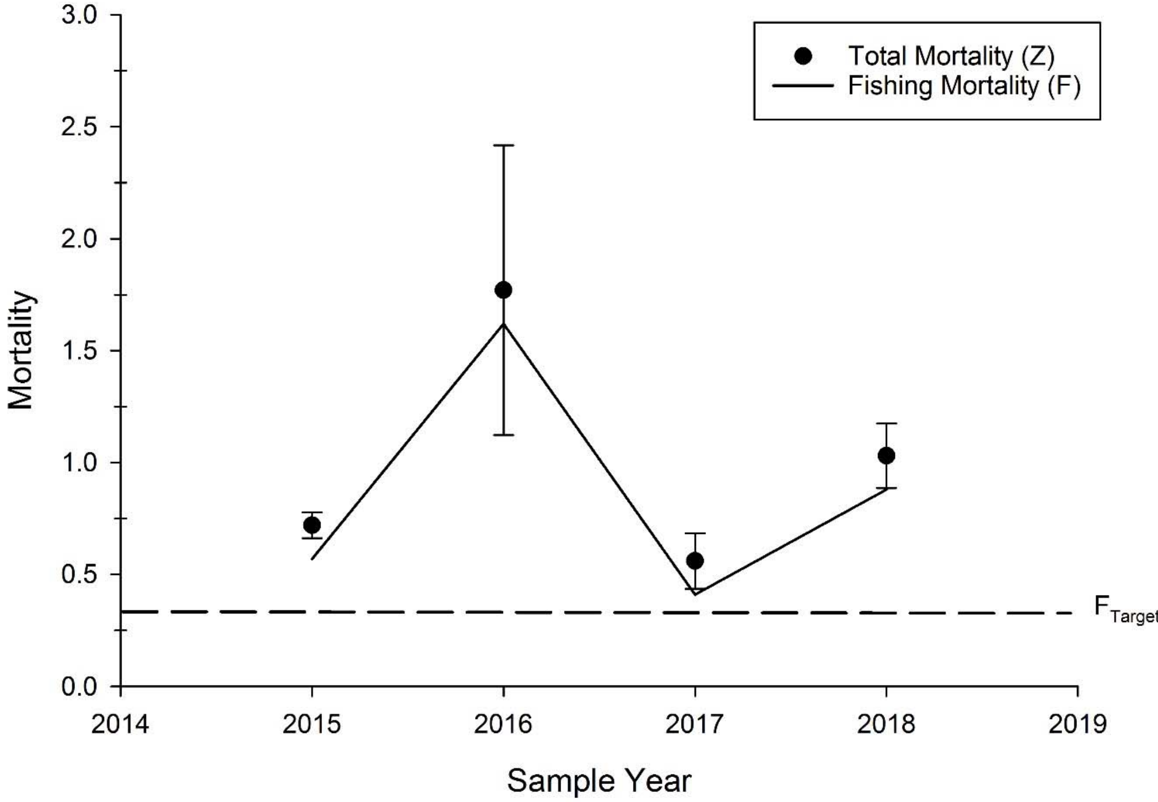

FIGURE 7.—Total (*Z*) and fishing (*F*) mortality estimates from 2015 to 2018. Error bars for *Z* represent standard error (SE). Fishing mortality was calculated using a conditional natural mortality rate of 0.15. Dashed line indicates the F_{Target} value of 0.33 as assigned by the NC Estuarine Striped Bass Fisheries Management Plan.

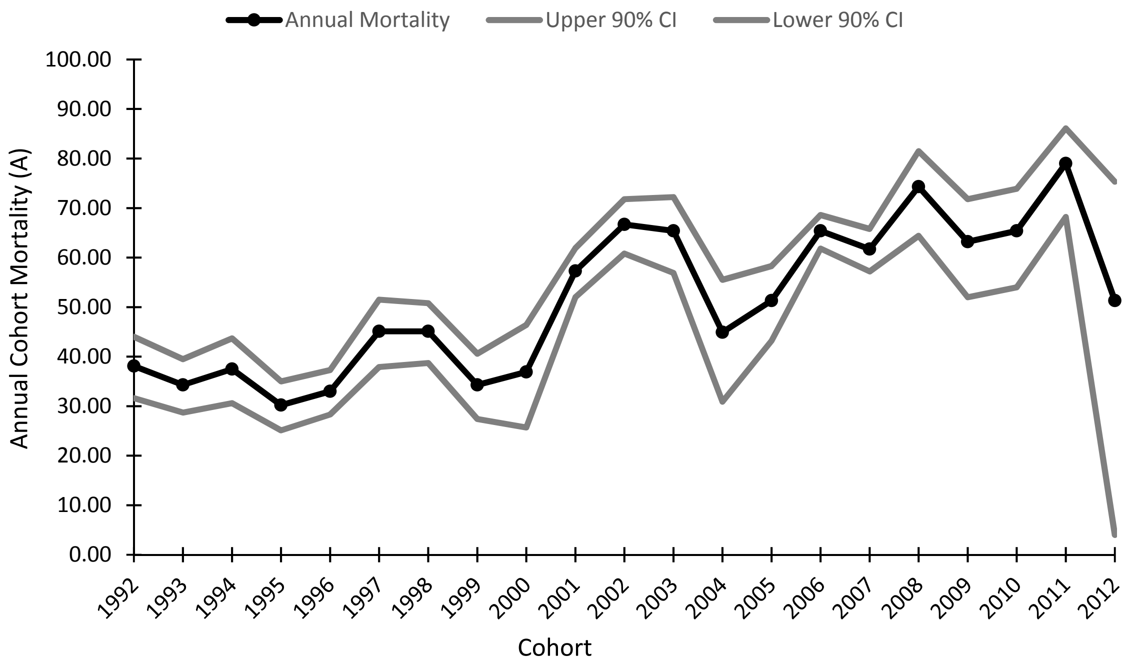

FIGURE 8.—Cohort mortality analysis results for 1992–2012 cohorts of Roanoke River Striped Bass.

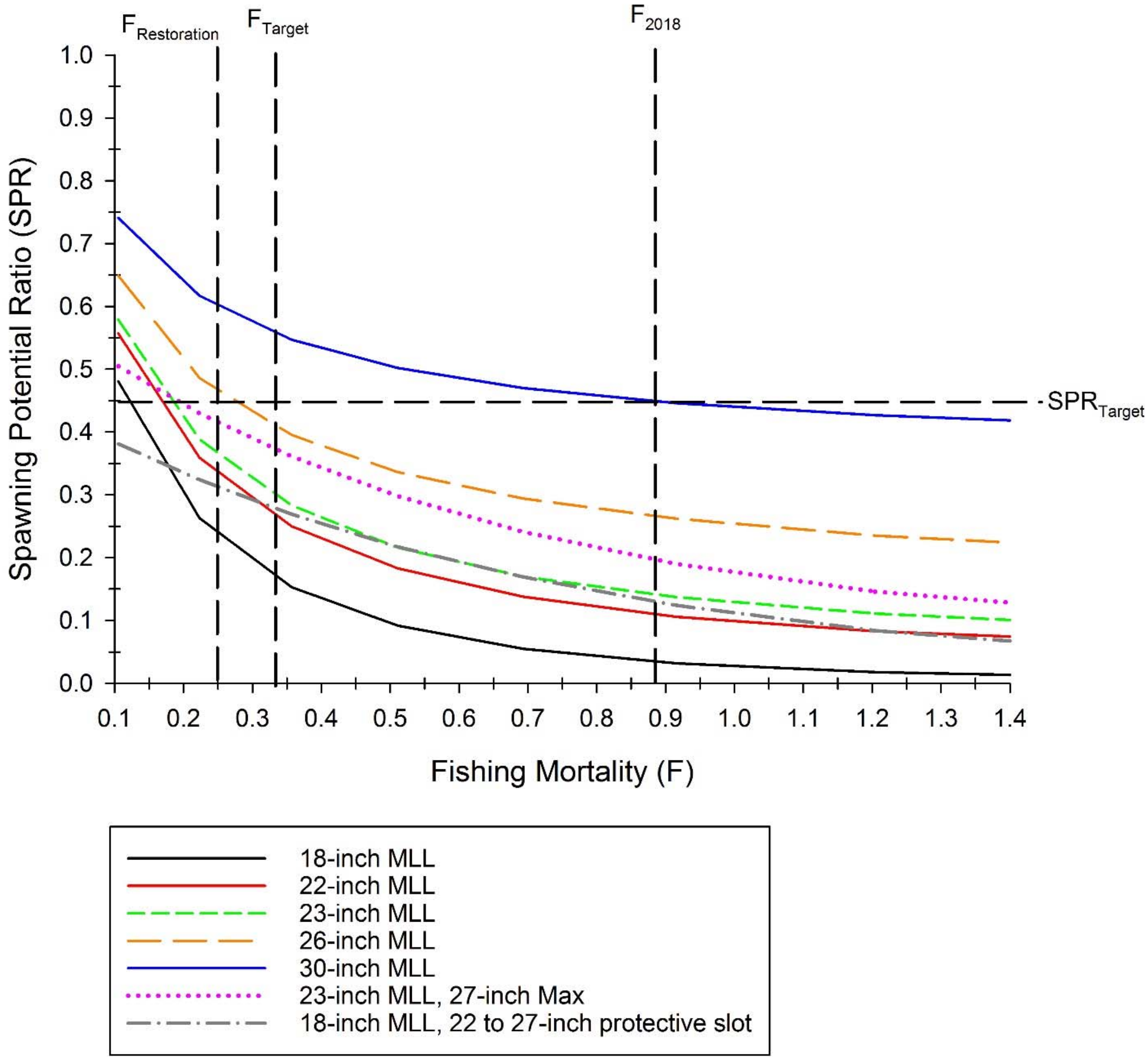

FIGURE 9.—The performance of potential length regulations at maximizing SPR under various exploitation rates. Natural mortality was set at *cm* = 0.15 for each model run.

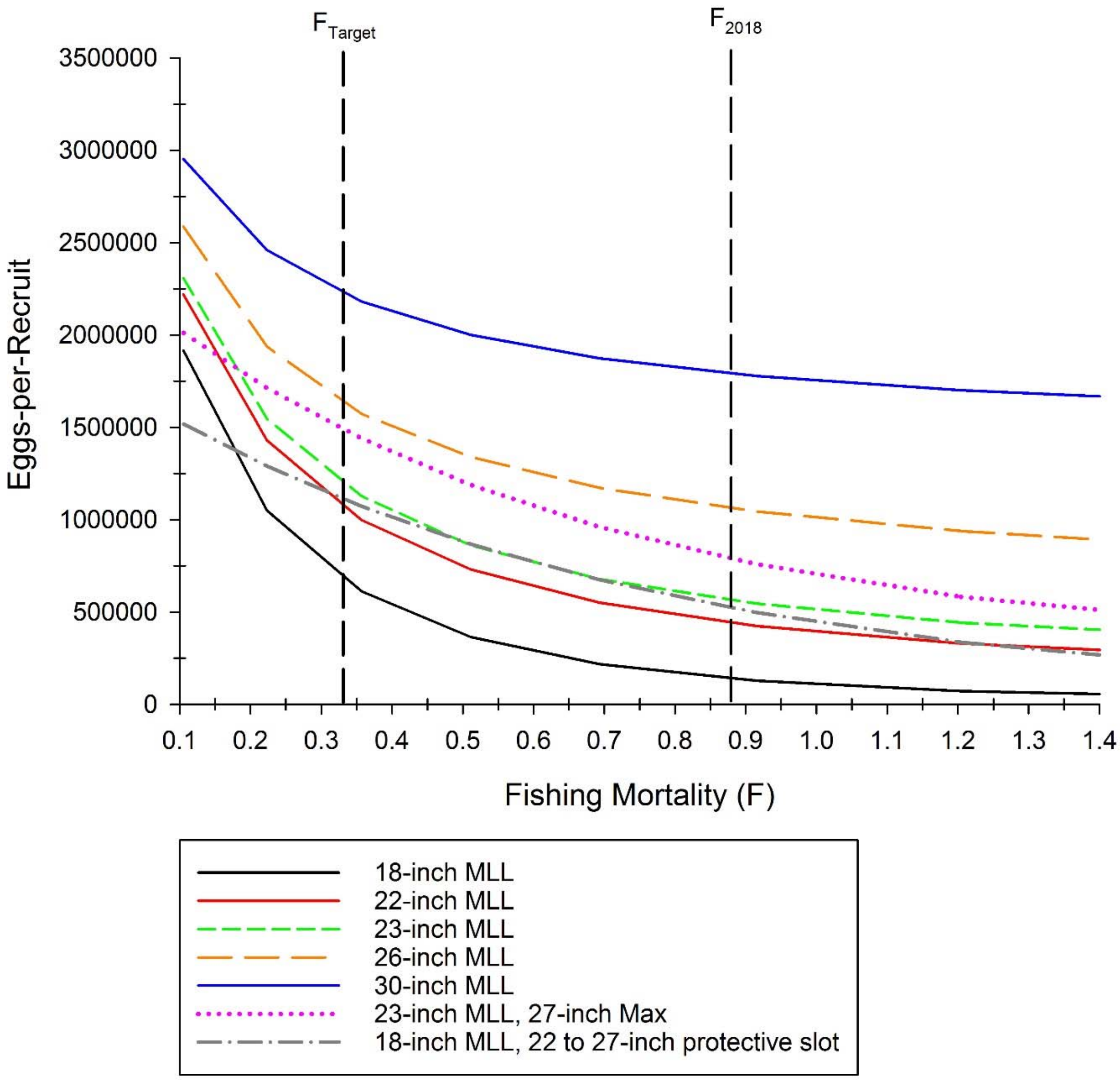

FIGURE 10.—Egg production (in millions of eggs) at several potential length regulations. Natural mortality was set at *cm* = 0.15 for each model run.

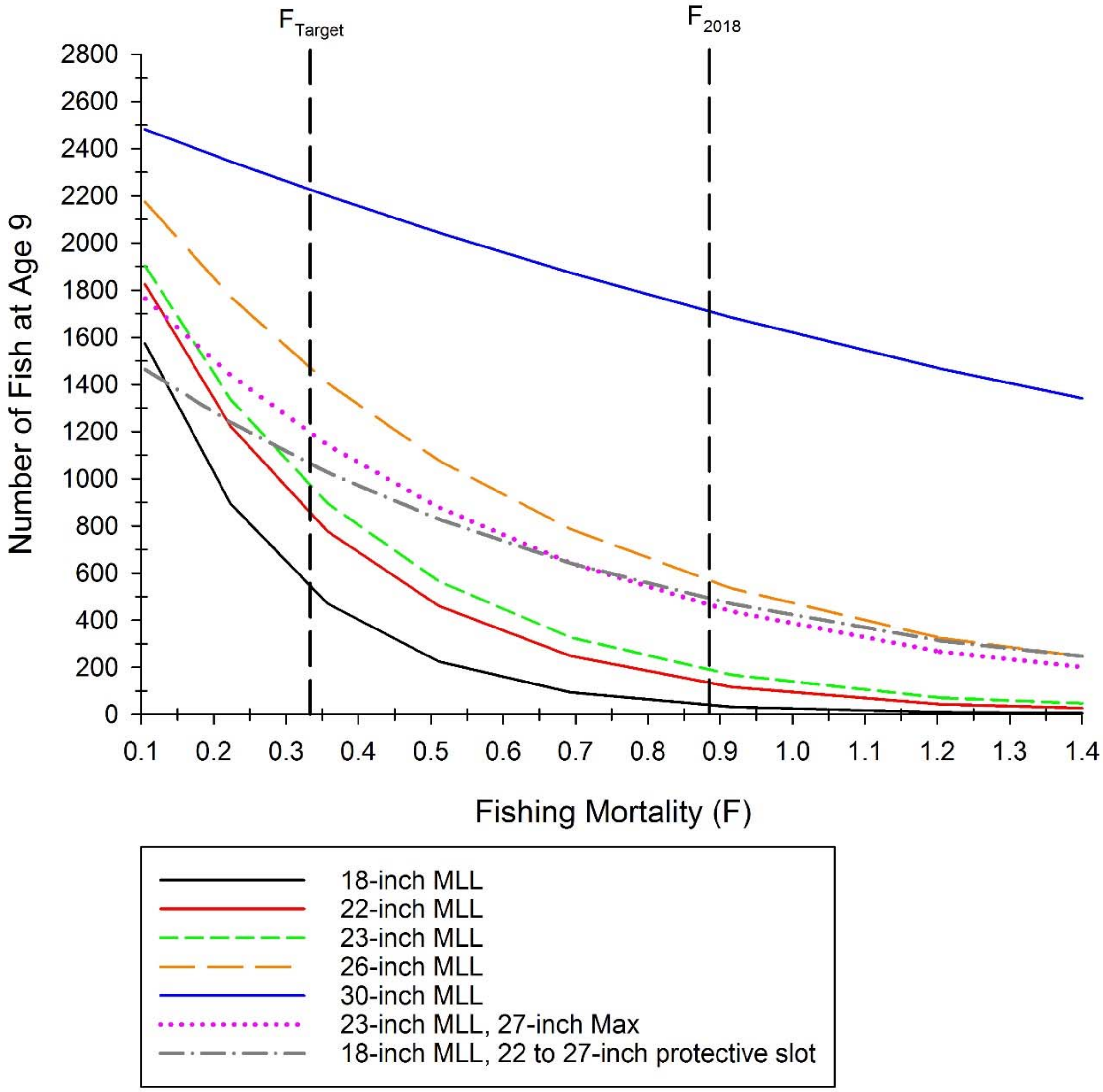

FIGURE 11.—The number of age-9 fish at several potential length regulations. The number of age-9 fish is based on 10,000 recruits and does not reflect the actual number of age-9 individuals in the population. Natural mortality was set at *cm* = 0.15 for each model run.

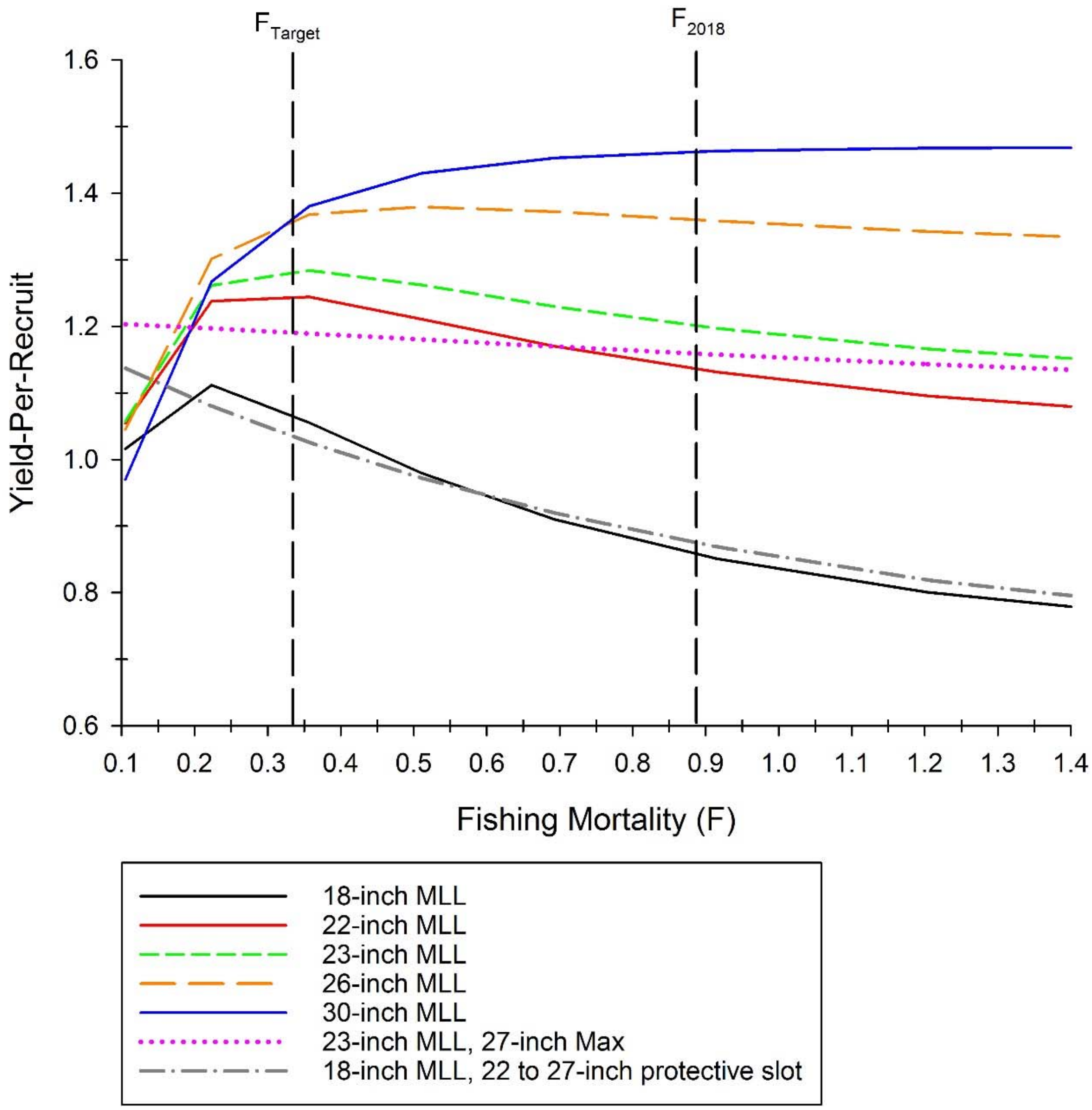

FIGURE 12.—Yield-per-recruit produced by several potential length regulations. Natural mortality was set at *cm* = 0.15 for each model run.