River Herring Monitoring in Tributaries of the Cape Fear River, North Carolina, 2018–2020

Federal Aid in Sport Fish Restoration
Project F-108

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Raleigh

2020

Keywords: Blueback Herring, Town Creek, Rice's Creek, electrofishing

Recommended Citation

Boggs, A. D., and K. T. Rachels. 2020. River herring monitoring in tributaries of the Cape Fear River, North Carolina, 2018–2020. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-108, Final Report, Raleigh.

This project was funded under the Federal Aid in Sport Fish Restoration Program utilizing state fishing license money and federal grant funds derived from federal excise taxes on fishing tackle and other fishing related expenditures. Funds from the Sport Fish Restoration Program are used for fisheries management and research, aquatic education, and boating access facilities. The program is administered cooperatively by the N.C. Wildlife Resources Commission and the U.S. Fish and Wildlife Service.

Abstract. River herring populations have been monitored annually by the North Carolina Wildlife Resources Commission since 2006 when a harvest moratorium was enacted in Inland Fishing Waters. In the Cape Fear River basin, river herring in Town Creek and Rice's Creek have been monitored annually using boat electrofishing. Alewife have not been observed during the time period. Blueback Herring mean (SE) weekly catch per unit effort ranged from 1.6 (0.5) to 21.5 (5.8) fish/h and has varied without trend since 2009. Males were encountered more frequently than females. Female Blueback Herring consistently had greater mean total lengths than males. Additionally, females displayed a broader age structure than male Blueback Herring, with females attaining age 7 while no males were observed older than age 5. Discrete annual mortality was 84.9% in 2019 and 65.7% in 2020. Though captures of Blueback Herring have appeared to increase slightly compared to the first several years of monitoring in Town and Rice's creeks, Blueback Herring population recovery remains incomplete.

Blueback Herring *Alosa aestivalis* and Alewife *A. pseudoharengus*, collectively managed as river herring, are anadromous species found in North Carolina and other portions of North America along the Atlantic coast. River herring spend most of their life in the ocean but return to their natal river to spawn in late winter and spring. River herring populations are depleted throughout their range, primarily due to overfishing and dam construction (ASMFC 2009). The North Carolina Wildlife Resources Commission (NCWRC) enacted a harvest moratorium in Inland Fishing Waters in 2006, and the North Carolina Marine Fisheries Commission followed with a moratorium in Joint and Coastal Fishing Waters in 2007 (White and McCargo 2020). Currently, only states that can demonstrate a sustainable fishery through a management plan approved by the Atlantic States Marine Fisheries Commission (ASMFC) are permitted to harvest river herring (ASMFC 2009).

Since 2006, NCWRC has surveyed river herring to monitor spawning stock recovery and the efficacy of the harvest moratorium. The objectives of this report are to describe river herring relative abundance, size-structure, and age-structure in Town and Rice's creeks in 2018–2020 and to examine overall trends in the full time series.

Methods

Study site. Town Creek and Rice's Creek are tributaries of the Cape Fear River in southeastern North Carolina. Sampling has been conducted in Town Creek since 2006 and Rice's Creek since 2008. Three fixed study sites in Town Creek and one fixed site in Rice's Creek were established in areas utilized by spawning river herring (Figure 1). The map of study sites was created using site coordinates, ArcMap (version 10.7), and data from NC OneMap, North Carolina Center for Geographic Information and Analysis, North Carolina Department of Transportation, and Esri.

Field Collection. River herring sampling commenced when water temperatures approached 12°C, generally during week 8 or 9 of the year, and continued until spawning appeared complete (generally water temperature >22°C). The survey was curtailed after week 12 in 2020 due to the public health safety response to COVID-19. River herring were collected using boat-mounted electrofishing (Smith-Root 7.5 GPP; 120 Hz; 5000–7000 W) and one dip netter. Collected river herring were identified to species and measured for total length (mm) and weight (g). Each fish was sexed by applying directional pressure on the abdomen of the fish toward the vent and observing either milt (male) or eggs (female). Water temperature (°C), conductivity (µS/cm), dissolved oxygen (mg/L), and salinity (ppt) were measured using a YSI Pro2300 or a YSI 85 meter. Electrofishing unit settings and effort (measured in seconds) were recorded for each sampling event. A Trimble Yuma field computer was used to record data during sampling events.

Blueback Herring aging. Scales were collected from up to 10 Blueback Herring of each sex within each 10-mm size-class. Scales were collected from the left side of each fish between the lateral line and the top of the fish, just posterior of the dorsal fin. Aging methods followed Kornegay (1978) and ASMFC (2014). For the 2018 scales, one reader aged all scales once and aged approximately 10% of the scales a second time. For the 2019 and 2020 scales, each fish was aged in two independent reads with discrepancies resolved through a concert read. Spawning marks were identified to assess repeat spawners. Sex-specific age-length keys were

developed using aged fish and a multinomial regression model (Venables and Ripley 2002; Gerritsen et al. 2006; Ogle 2015; Ogle et al. 2020) for each year. The sex-specific age-length keys were used to assign individual ages to unaged fish (Isermann and Knight 2005; Ogle 2015).

Data analyses. Data were uploaded into the NCWRC BIODE database for data storage. Relative abundance was indexed as catch per unit effort (CPUE; fish/h). Size structure was evaluated using sex-specific length frequency histograms (Ogle 2015; Wickham 2016). Sex-specific box plots were used to assess length-at-age (Wickham 2016). The Chapman-Robson method was used to estimate instantaneous total mortality (Robson and Chapman 1961; Smith et al. 2012; Nelson 2019a, 2019b). The age at recruitment to the catch-curve was the modal age plus one year (Peak +1), data were not right truncated, and the standard error of the estimates was corrected for overdispersion (Smith et al. 2012). The dplyr package in R was used to manipulate the data (Wickham et al. 2020). All analyses were performed using R 3.6.3 (R Core Team 2019) and RStudio (version 1.2.5033; RStudio Team 2020).

Results

No Alewife were observed. Blueback Herring catch varied without trend among years (Table 1; Figure 2). Mean (SE) weekly CPUE ranged from 6.0 (2.0) fish/h in 2018 to 22.4 (7.5) fish/h in 2019. Peak weekly CPUE occurred during weeks 12–15 (Figure 3). The largest individual fish each year were female, and female mean total length was always greater than male mean total length (Table 1). The modal size class of male Blueback Herring was 270–280 mm in 2018 and 2020 and 250–260 mm for 2019, while the modal size class of females was 290–300 mm in 2018, 270–280 mm in 2019, and 280–290 mm in 2020 (Figures 4–6).

Forty-six fish were aged in 2018, six (13%) of which were repeat spawners based on the presence of at least one spawning mark. In 2019, 87 fish were aged, and 10 (11.5%) were repeat spawners. In 2020, 62 fish were aged, 14 (22.6%) of which were determined to be repeat spawners. Between-reader agreement was 82% in 2019 and 77% in 2020. Agreement was 100% for the scales aged twice in 2018. Females had a broader age distribution (ages 3 to 7) than males (ages 3 to 5), and captured males were frequently younger (modal age of 3 or 4 years old) compared to females (modal age of 4 or 5 years old; Figure 7). Females demonstrated greater length-at-age than males (Figures 8–10).

Instantaneous total mortality (Z) could not be estimated for the 2018 spawning stock because the age at recruitment to the catch-curve was also the oldest age-class observed. Instantaneous total mortality was 1.87 (SE = 0.34) in 2019, equating with a discrete annual mortality of 84.6% (95% CI = 71.6–92.4%). For 2020, Z was 1.07 (SE = 0.28), equating with an annual mortality rate of 65.7% (95% CI = 44.4–81.7%).

Discussion

After an initial increase following the first few years of the survey, the Blueback Herring population abundance in Town and Rice's creek has varied without trend over time. The increase in CPUE compared to the first few years after the harvest moratorium, however, could be due to an increase in knowledge of their spawning habits and refinement of sampling methods. Consistently positive trends in Blueback Herring CPUE have not been documented in

NCWRC monitoring efforts in other spawning areas of North Carolina (Potoka 2016; Buckley and Ricks 2018). Blueback Herring still face many challenges to population recovery, including a high annual mortality rate. Estimates of annual mortality of Blueback Herring in North Carolina in 2019 ranged from 36.6% based on the North Carolina Division of Marine Fisheries (NCDMF) independent gill net survey in Albemarle Sound (White and McCargo 2020) to 84.6% in the Cape Fear River in this study. Causes of high mortality for Blueback Herring may include bycatch from oceanic commercial fisheries (ASFMC 2012; Hasselman et al. 2016).

Although multiple fisheries interact with Blueback Herring, midwater trawls and small mesh bottom trawls in the Atlantic Ocean comprise the majority of Blueback Herring bycatch (ASMFC 2017a). Blueback Herring are especially susceptible to being captured in New England fisheries targeting Atlantic Herring *Clupea harengus* and Atlantic Mackerel *Scomber scombrus* (Bethoney et al. 2017), but the South Atlantic Stock of Blueback Herring, to which the Cape Fear River population belongs (Palkovacs et al. 2014) is less affected by the New England fisheries than other, more northern stocks (Hasselman et al. 2016). Thus, sources of mortality other than Atlantic Ocean commercial fisheries bycatch may also be impacting Cape Fear River Blueback Herring.

Predation by other fish, such as Striped Bass *Morone saxatilis*, is also a concern (Davis et al. 2012). In the Cape Fear River basin, predation by Striped Bass may be less important than in other areas as the Striped Bass population is depressed and currently not self-sustaining (Rachels and Morgeson 2018). However, Flathead Catfish *Pylodictis olivaris* and Blue Catfish *Ictalurus furcatus*, which are abundant in the Cape Fear River basin, have the potential to negatively impact Blueback Herring populations (Schmitt et al. 2017).

Along with spawning stock mortality, poor recruitment could explain the lack of recovery (ASMFC 2017a, 2017b; NCDMF 2019). Recruitment of Blueback Herring has been hindered by factors such as river flows, predation, low spawning stock abundance, truncated age distribution of spawning individuals, loss of spawning habitat or access to spawning habitat, pollution, and environmental factors (Limburg and Waldman 2009; Riley 2012; ASMFC 2017a, 2017b). The impacts of climate change are unknown; however, climate change may also play a role in either depressing or increasing populations of Blueback Herring through decreased survival of adults or juveniles, changes in behavior, or potential increases in spawning habitat (NMFS 2012). The presence of repeat spawners is a positive observation, and the male to female ratio appears to have improved, or at least to have decreased in variability, over time, decreasing from 77 to 1 at the highest to approximately 2 to 1 at the lowest. The age structure expanded in 2019 and 2020, with Blueback Herring ages ranging from 3 to 7, compared to 2018, with Blueback Herring ages ranging from 3 to 5. However, few age-5 males were encountered, and no male Blueback Herring older than age 5 were observed between 2018 and 2020. Blueback Herring can reach age 9 or 10; however, the maximum age of observed Blueback Herring has decreased over time in some rivers, including the Chowan River (ASMFC 2017a). With such high rates of mortality and truncated age distributions, Blueback Herring population recovery remains incomplete in Town and Rice's creeks.

Management Recommendations

1. Maintain the harvest moratorium on river herring.
2. Continue monitoring the river herring spawning stock in Town and Rice's creeks.
3. Evaluate river herring recruitment in the Cape Fear River.
4. Conduct exploratory sampling to determine if river herring are utilizing other tributaries of the Cape Fear River for spawning.
5. Continue collecting scales from a subsample of river herring to monitor the age distribution, percentage of repeat spawners, and mortality rates.

Acknowledgments

We appreciate suggestions and comments from Kevin Dockendorf, Jeremy McCargo, and Chad Thomas to previous drafts of this report. Thank you to Pete Kornegay for aging the 2018 Blueback Herring scales.

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TABLE 1. Summary statistics for Blueback Herring sampling, 2006–2020.

Year	Effort (h)	Catch Males	Catch Females	M:F Ratio	Total CPUE	Peak Weekly CPUE	Mean CPUE	Mean CPUE SE	Mean Male TL	Female Mean TL	Max TL
2006	16.0	33	7	4.7:1	2.5	10.5	2.5	1.1	262.4	272.0	296
2007	16.0	22	3	7.3:1	1.6	4.5	1.6	0.5	244.7	269.3	282
2008	17.0	97	12	8.1:1	6.4	24.0	6.4	2.3	255.2	262.4	276
2009	13.8	154	2	77.0:1	11.3	61.3	11.3	3.6	250.3	278.0	284
2010	11.3	157	29	5.4:1	16.5	37.6	16.7	3.7	256.8	269.5	292
2011	11.9	139	32	4.3:1	14.4	29.9	13.7	3.4	250.8	272.4	304
2012	15.2	242	28	8.6:1	13.0	46.1	17.3	4.0	253.6	277.8	308
2013	9.9	168	30	5.6:1	20.0	57.2	18.5	5.5	254.4	269.7	298
2014	7.8	38	17	2.2:1	7.1	30.2	7.6	3.2	258.9	281.5	295
2015	11.0	113	30	3.8:1	13.6	28.0	15.4	4.0	255.2	274.6	318
2016	-	-	-	-	-	-	-	-	-	-	-
2017	10.4	117	60	2.0:1	17.1	60.3	17.1	4.3	264.7	281.6	320
2018	12.1	55	17	3.2:1	5.9	19.7	6.0	2.0	265.9	290.4	323
2019	8.2	152	40	3.8:1	23.2	54.1	22.4	7.5	262.9	279.2	314
2020	4.3	57	27	2.1:1	19.7	44.8	18.1	5.1	268.8	286.4	318

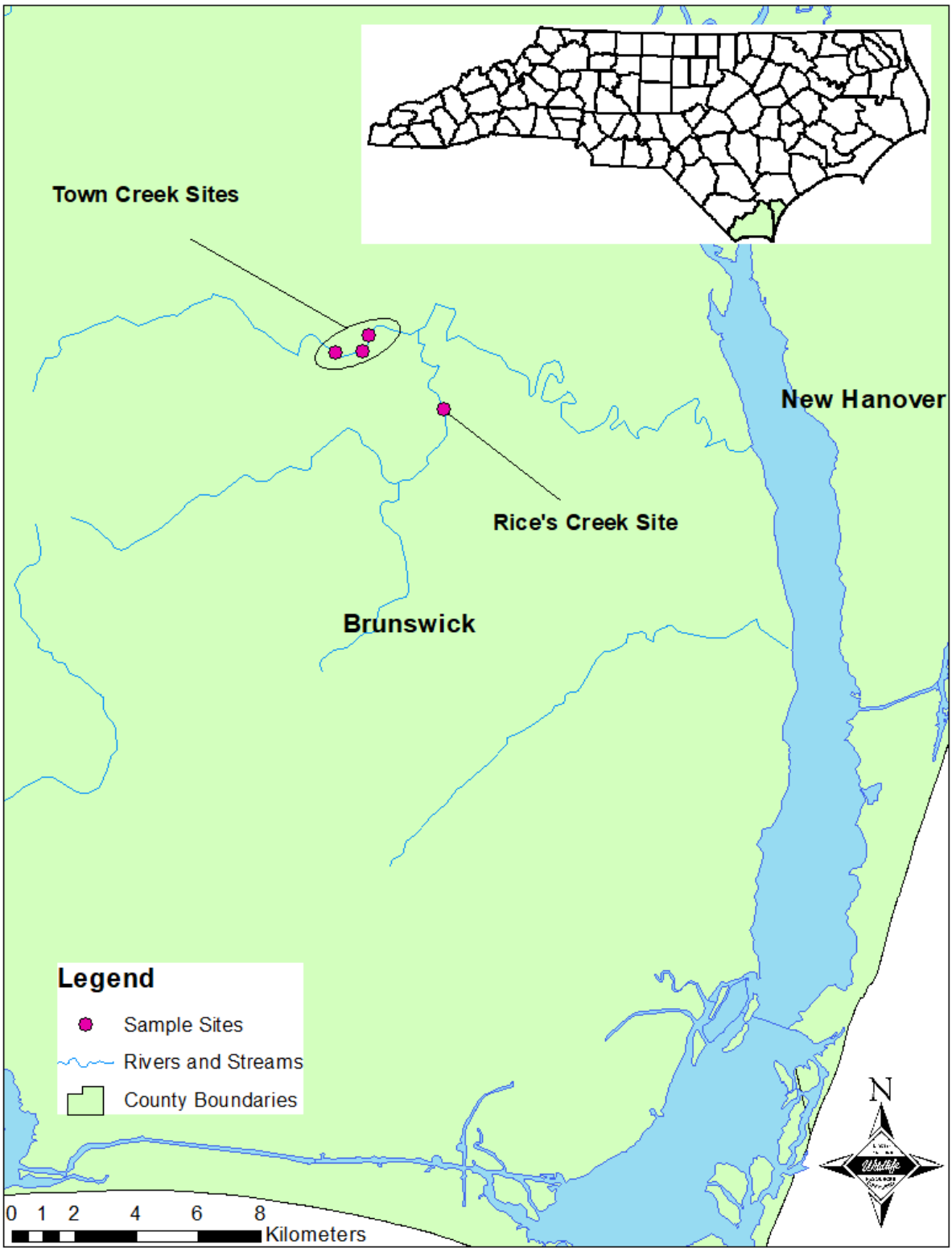

FIGURE 1. Locations of the sampling sites on Town Creek and Rice's Creek for 2018–2020.

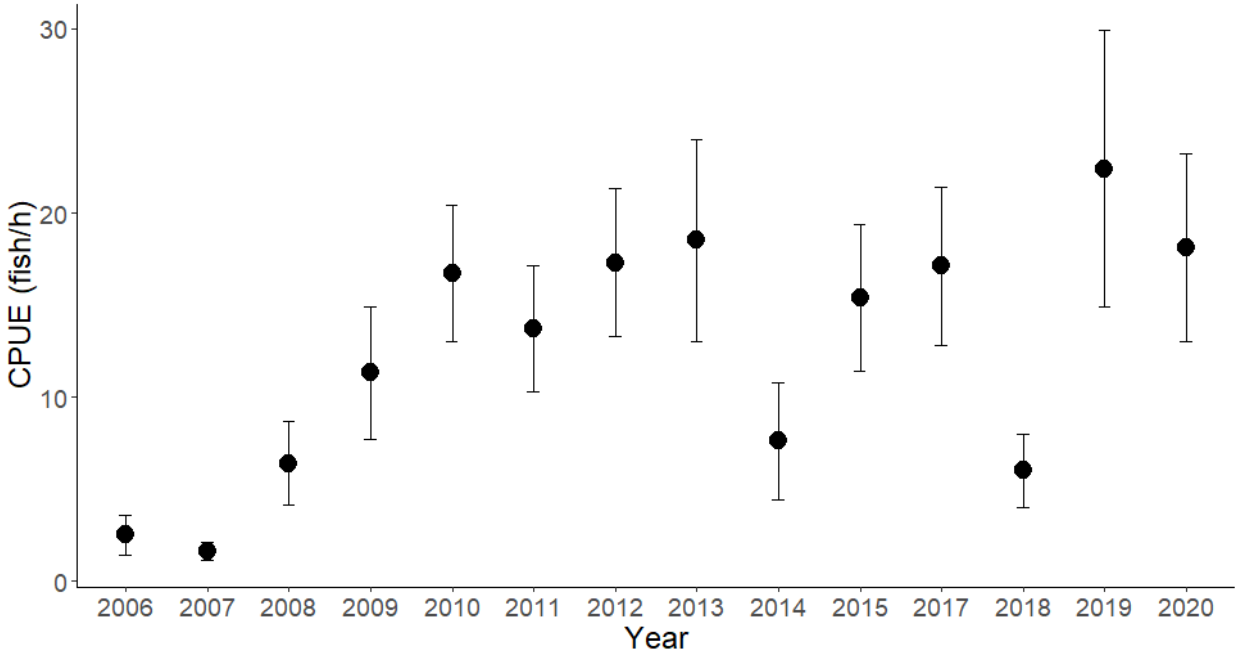

FIGURE 2. Mean catch per unit effort (CPUE) of Blueback Herring for 2006–2020. Error bars denote standard error.

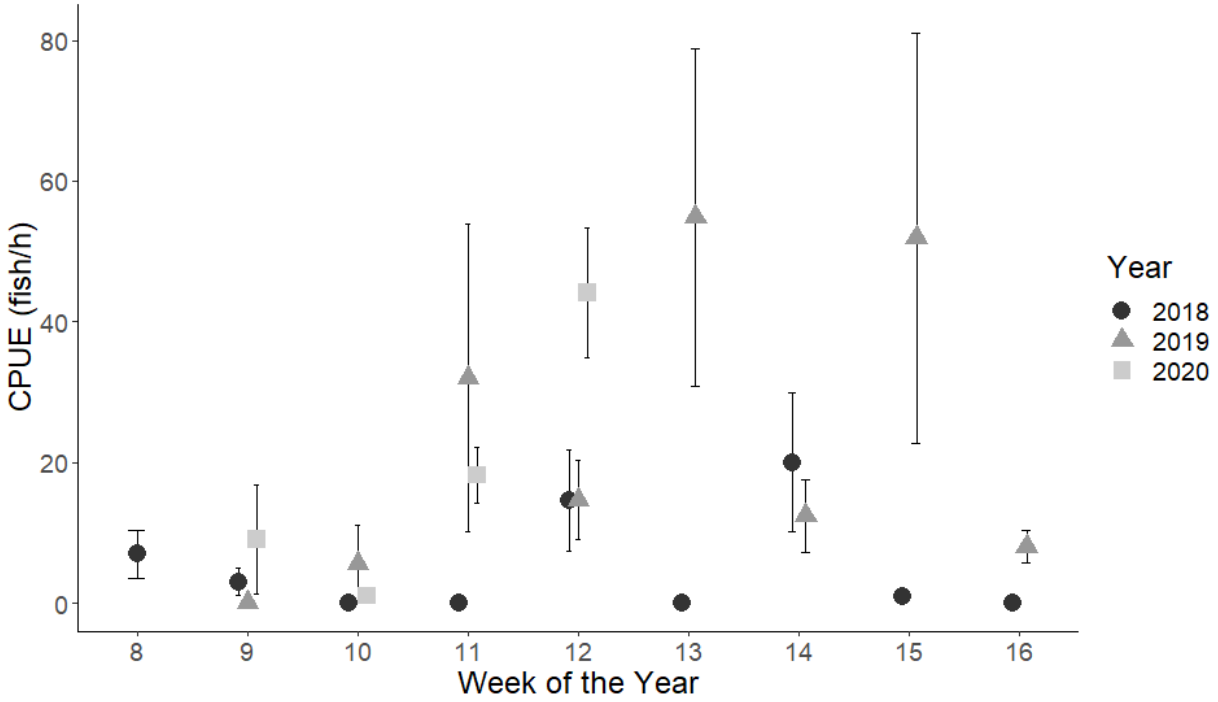

FIGURE 3. Mean weekly catch per unit effort (fish/h) of Blueback Herring by week of the year for 2018–2020. Error bars denote standard error. Sampling in 2020 ended in week 12 due to COVID-19.

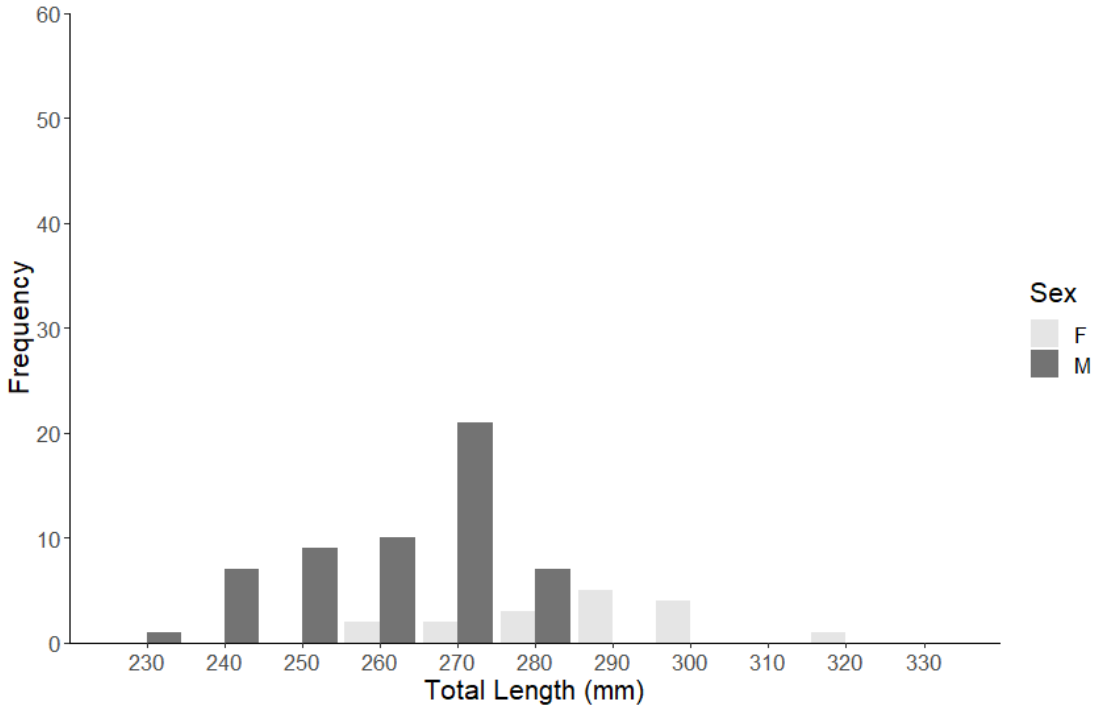

FIGURE 4. Length frequency for male (n = 55) and female (n = 17) Blueback Herring captured in 2018.

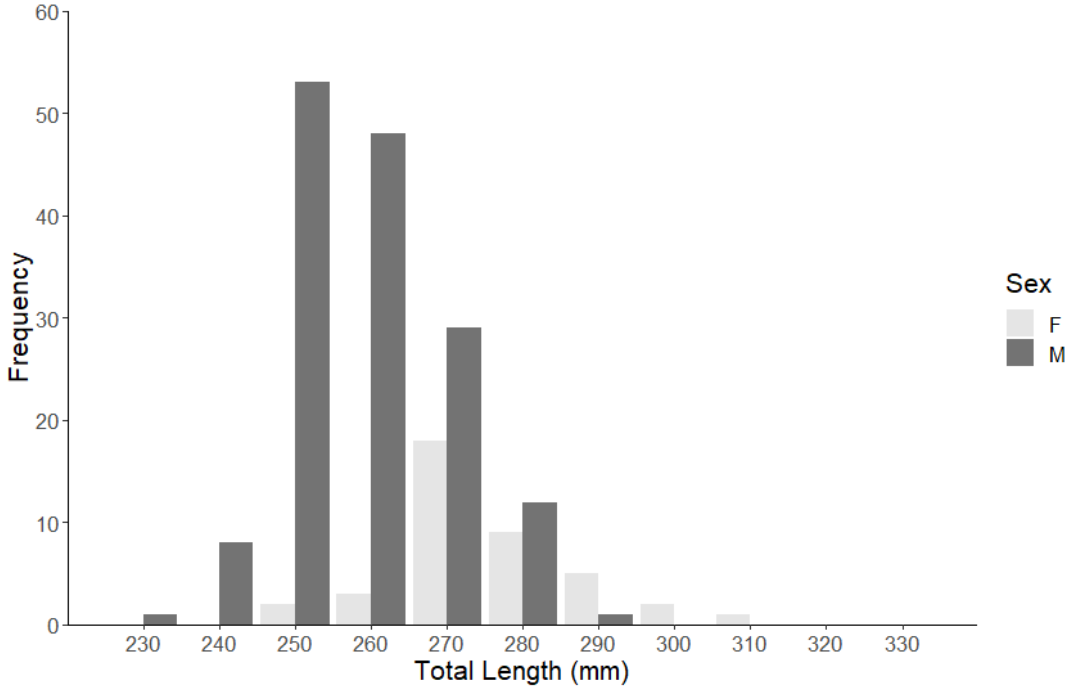

FIGURE 5. Length frequency for male (n = 152) and female (n = 40) Blueback Herring collected in 2019.

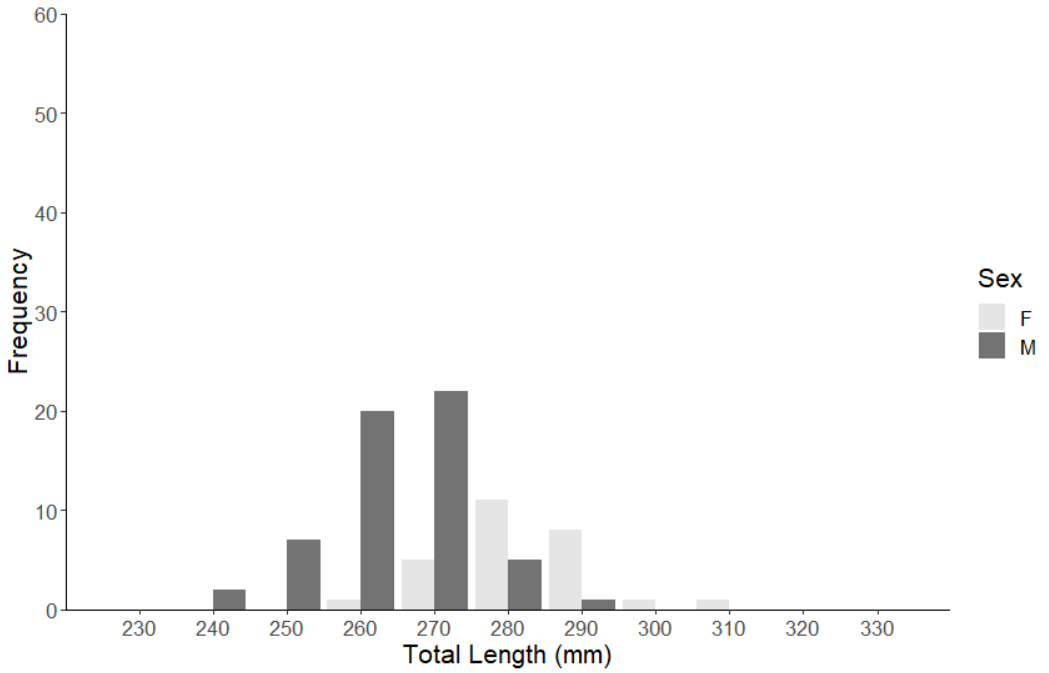

FIGURE 6. 2020 length frequency for male (n = 57) and female (n = 27) Blueback Herring collected in 2020.

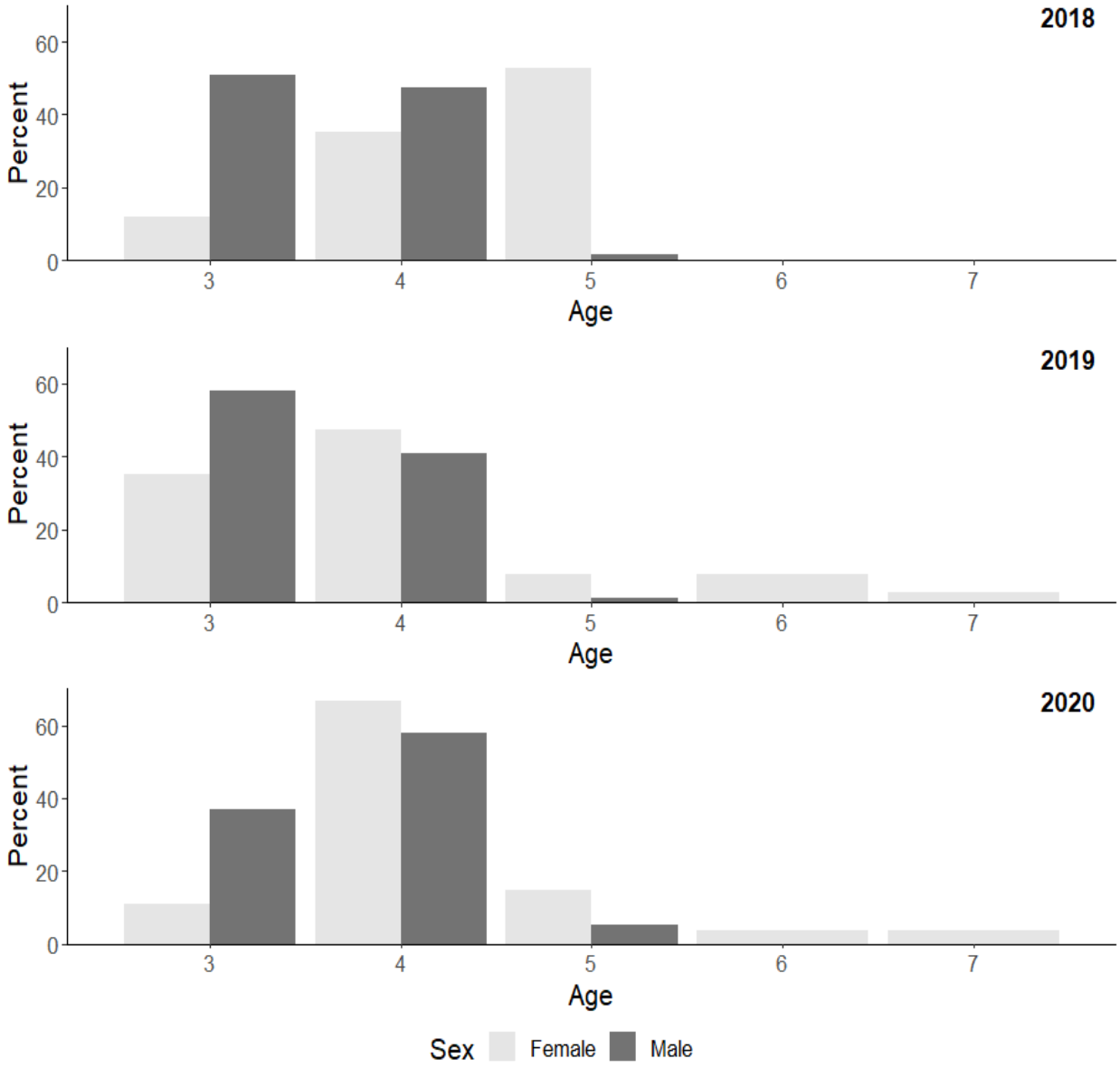

FIGURE 7. Age distribution of male and female Blueback Herring, 2018–2020.

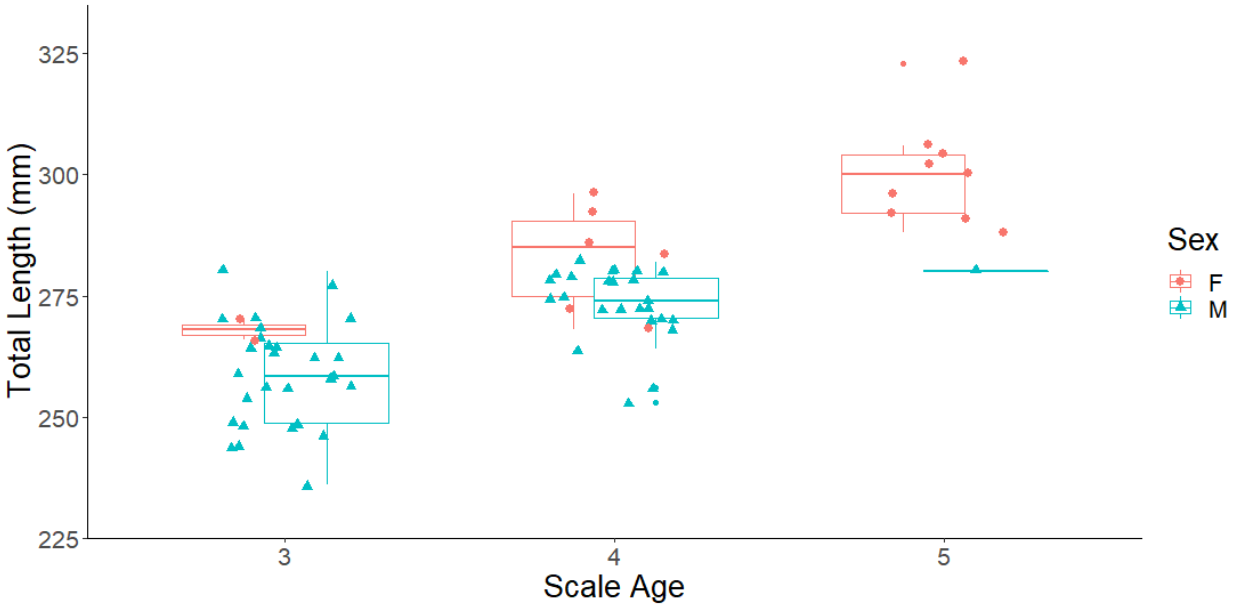

FIGURE 8. Box plot of length-at-age for male and female Blueback Herring collected in 2018.

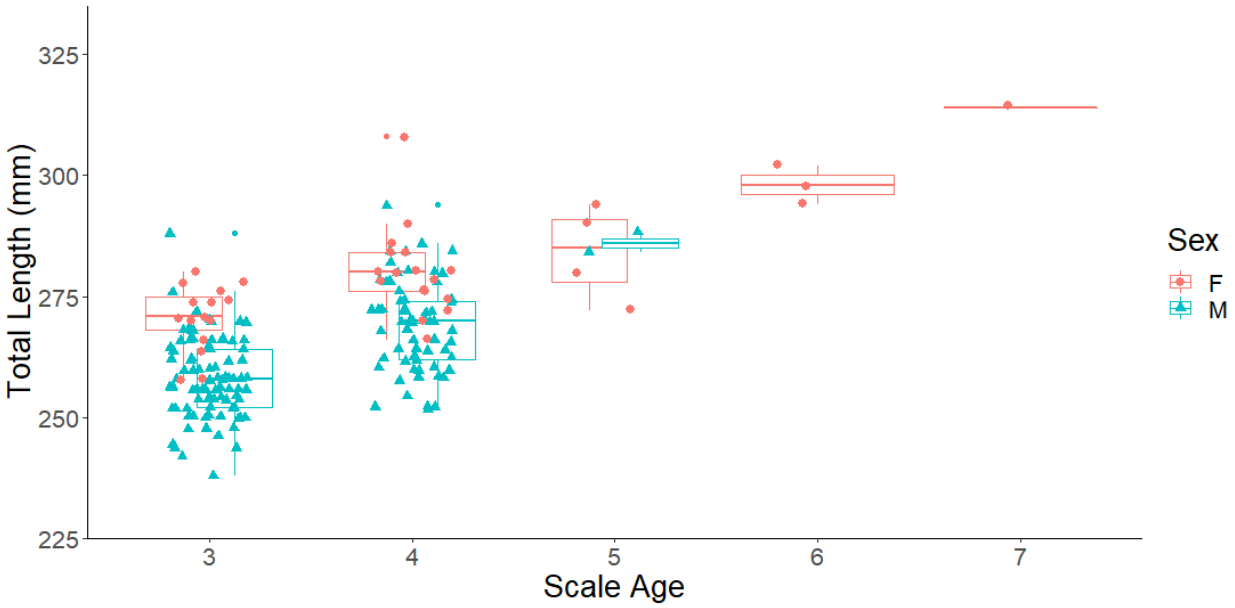

FIGURE 9. Box plot of length-at-age for male and female Blueback Herring collected in 2019.

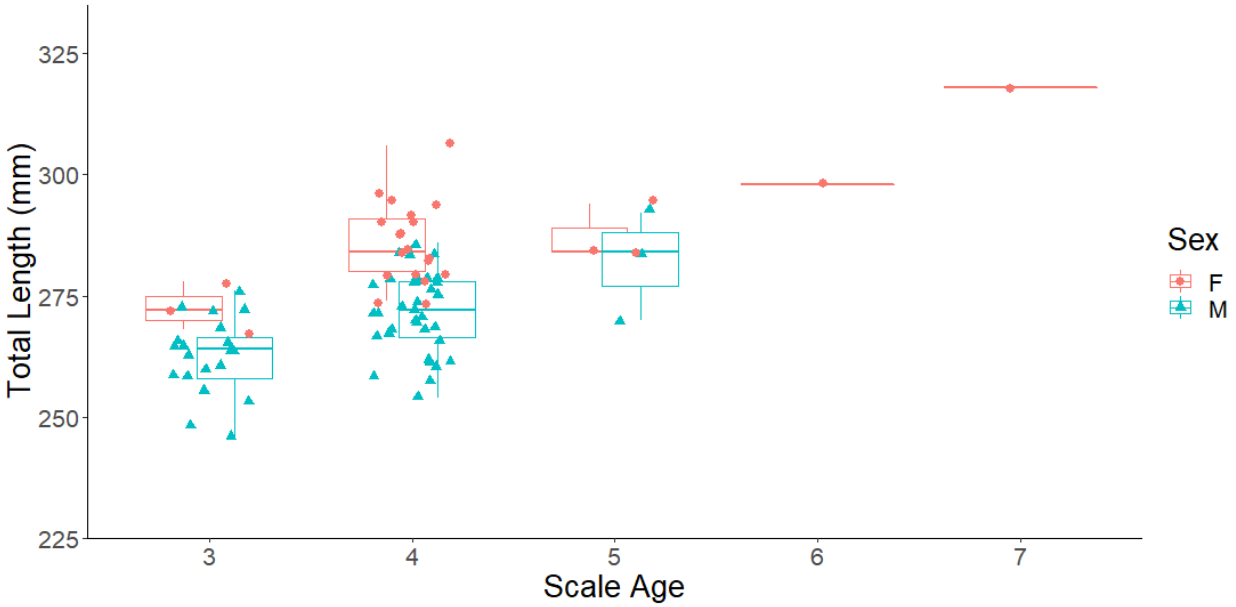

FIGURE 10. Box plot of length-at-age for male and female Blueback Herring collected in 2020.