Status of Alewife and Blueback Herring in the Neuse River, 2021

Federal Aid in Sport Fish Restoration
Project F-108

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Raleigh

2022

Keywords: Alewife, Blueback Herring, Neuse River, boat electrofishing, spawning potential ratio

Recommended Citation

VanMiddlesworth, T. D., and B. R. Ricks. 2022. Status of river herring in the Neuse River, 2021. 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 (Alewife *Alosa pseudoharengus* and Blueback Herring *A. aestivalis*) populations in Core and Village creeks, tributaries of the Neuse River, were sampled using boat electrofishing during spring 2021. Alewife were not collected during river herring sampling in the Neuse River in 2021. A total of 179 Blueback Herring were collected. In Core Creek, Blueback Herring weekly CPUE (fish/h) ranged 0.0–63.4 in 2021, and Blueback Herring weekly CPUE (fish/h) ranged 0.0–32.6 in Village Creek during 2021. Mean total length in Core Creek was 262 mm for males and 283 mm for females in 2021. In Village Creek, mean total length was 266 mm for males and 281 mm for females in 2021. Spawning potential ratio for female Blueback Herring has doubled since monitoring began in 2007. However, this increase was not sufficient to indicate population recovery. Future studies will be needed to evaluate if increasing trends in relative abundance, size-structure, and spawning potential ratio are indicative of population recovery. Continuation of annual sampling is imperative to monitor population trends and inform management decisions regarding river herring management in the Neuse River.

Stocks of anadromous river herring (Alewife *Alosa pseudoharengus* and Blueback Herring *A. aestivalis*) remain depleted and near historic lows throughout much of their geographic range (ASMFC 2017a). Harvest moratoria in waters under state jurisdiction were implemented in Connecticut (2002), Rhode Island (2005), Massachusetts (2006), North Carolina (2007), and coastal waters of Virginia flowing into North Carolina (2008). All anadromous river herring fisheries were closed effective January 1, 2012, as mandated by Amendment 2 to the Interstate Fishery Management Plan for Shad and River Herring (ASMFC 2009). However, sustainable fishery management plans that allowed some harvest were approved by the Atlantic States Marine Fisheries Commission (ASMFC) in 2012 for North Carolina, South Carolina, New York, New Hampshire, and Maine. As of 2017, the sustainable fishery management plan that allowed for a small discretionary harvest for North Carolina expired and was not renewed. Commercial and recreational fisheries have been closed in the Neuse River and its tributaries since 2007. Despite concerns for river herring in North Carolina waters, as of June 2019, after a multiyear review of river herring throughout their range, the National Marine Fisheries Service (NMFS) determined that any listing as threatened or endangered under the Endangered Species Act was not warranted (NOAA 2019).

North Carolina, in compliance with ASMFC mandates, is responsible for monitoring anadromous river herring populations. The North Carolina Division of Marine Fisheries (NCDMF) conducts a spring gill net survey in select basins of the Albemarle Sound, while the North Carolina Wildlife Resources Commission (NCWRC) monitors relative abundance of spawning stocks in selected creeks throughout the coastal region during spring months. During 2007–2014, river herring populations in tributaries of the Neuse River were characterized by small fish (few Blueback Herring longer than 280 mm have been observed 2007–2014) at low levels of abundance (CPUE <20 fish/h from 2007 to 2014; NCWRC 2014a, 2014b). In addition, monitoring of river herring in the Neuse River had indicated no consistent upward trend in river herring populations since implementation of the 2007 harvest moratorium until the 2017 sample year when relatively high abundances were observed (NCWRC 2018).

In the Neuse River basin, Core Creek and Village Creek have been sampled annually for river herring since 2007. These tributaries consistently support river herring spawning migrations and were selected to monitor long-term trends in river herring abundance and size structure. Other tributaries have been intermittently surveyed to determine the extent of river herring spawning across the Neuse River basin. The purpose of this survey effort is the continuation of annual river herring monitoring in Core and Village creeks.

Methods

Study site. Field staff surveyed two tributaries of the Neuse River that historically supported river herring spawning migrations known as Core Creek and Village Creek in 2021 (Table 1, Figure 1).

Field collection. Core Creek and Village Creek were sampled using a boat-mounted electrofishing unit (Smith-Root 7.5 GPP) using 1,000 volts, 4–6 amps, and 120-Hz pulsed DC with one dip netter to collect adult Alewife and Blueback Herring. Two transects (approximately 900 s electrofishing time) were sampled in each creek weekly March 2–April 15, 2021. River herring were netted, enumerated by species, measured for total length to the nearest

millimeter (TL; mm), and weighed to the nearest gram (g). Sex was determined for each captured river herring by applying directional pressure to the abdomen toward the vent and observing the presence of milt (male) or eggs (female). A subsample of 10 Blueback Herring per 10-mm size-class were sacrificed for sagittal otolith extraction and age determination. Additionally, electrofishing effort (seconds), water temperature (°C), oxygen saturation (%), dissolved oxygen (mg/L), conductivity (µS/cm), and salinity ($^0/_{00}$) were measured after each electrofishing transect using a Pro2300 YSI meter (Table 2). Daily discharge (ft^3/s) data were also obtained from USGS gage 02091814 on the Neuse River near Fort Barnwell, NC (Table 1). A Trimble Yuma field computer was used to record data during sampling events. Data were downloaded and stored in BIODE Fish.

Otolith ageing. Once field collection was complete, each Blueback Herring otolith was cleaned by removing organics, dried, and placed under a dissecting microscope for a whole view read. Two readers aged each otolith individually, and discrepancies between the two readers were resolved with a third read in concert. River herring otoliths were used for this survey because otoliths are more accurate than compared to ages determined by using Blueback Herring scales (Kornegay 1978). Additionally, river herring otoliths have more uniform size, less false annuli, and less variability in annuli position than river herring scales.

Data analyses. Relative abundance of Blueback Herring was indexed as catch per unit effort (CPUE; fish/h). Length-frequency distributions (10-mm size-classes) of Blueback Herring by sex were used to evaluate size structure. Annual spawning potential ratio (SPR) was estimated from all Neuse River female Blueback Herring data during 2007–2021 using Program R (Hordyk 2015, 2019; R Core Team 2021). Our SPR analysis required raw Neuse River female Blueback Herring TL data from 2007–2021 and raw Neuse River female Blueback Herring otolith age data from 2018, 2019, and 2021 (Buckley and Ricks 2019). All unaged Neuse River female Blueback Herring were assigned an age using an age-length-key in Program R. Additionally, SPR required Blueback Herring von Bertalanffy growth function (VBGF) parameters, natural mortality, and length at maturity (Hordyk 2019). Blueback Herring VBGF parameters and natural mortality were used from the latest ASMFC coastwide stock assessment (ASMFC 2017b), while length at maturity was used from Amendment 1 of the North Carolina Fishery Management Plan for River Herring (NCDMF 2007).

Results

During the 2021 river herring survey in the Neuse River, water temperature ranged 10.4°C to 20.7°C with a mean of 14.3°C, which was within the optimal spawning temperature range for river herring. A total of 179 Blueback Herring were collected from routine monitoring sites in Core (n=93) and Village (n=86) creeks (Table 3). Alewife were not collected during river herring sampling in the Neuse River in 2021.

In Core Creek, 47 male and 46 female Blueback Herring were collected, with weekly CPUE ranging 0.0–63.4 fish/h (Table 4). In Village Creek, 44 male and 42 female Blueback Herring were collected, while weekly CPUE ranged 0.0–42.8 fish/h (Table 5). Total CPUE (20.8 fish/h) in Core Creek during 2021 was similar to the mean total CPUE (21.7 fish/h) from 2007–2021 (Table 6). As for Village Creek, the 2021 total CPUE was 18.9 fish/h and was slightly less than 50% of

the time series mean (39.9 fish/h; Table 7). Both Core Creek and Village Creek had 1:1 male to female ratios (M:F) in 2021 (Tables 6, 7).

In Core Creek, male Blueback Herring ranged 228–286 mm while female Blueback Herring ranged 267–304 mm (Table 3). As for Village Creek, male Blueback Herring ranged 231–284 mm while female Blueback Herring ranged 255–306 mm (Table 3). In Core Creek, Blueback Herring mean total length for males was 262 mm and 283 mm for females (Table 6). In Village Creek, Blueback Herring mean total length for males was 266 mm and 281 mm for females (Table 7). Male Blueback Herring in Core Creek exhibited a bimodal length-frequency distribution, while the female distribution was unimodal in 2021 (Figure 2). The male and female length-frequency distributions in Village Creek were unimodal in 2021 (Figure 3). The majority of male Blueback Herring in Core Creek (80.9%; Figure 2) and Village Creek (90.9%; Figure 3) ranged 240–270 mm. The majority of female Blueback Herring ranged 260–290 mm in Core Creek (95.7%; Figure 2) and Village Creek (85.7%; Figure 3) in 2021.

Blueback Herring otolith samples (n=102) ranged from age 3 to age 6. Readers agreed on 89 out of 102 (87.25%) otolith samples. The majority of male (51.9%) and female (44.0%) Blueback Herring were age 4 (Figure 4).

Spawning potential ratio (SPR) was 0.28 (28%) in 2021 and ranged 0.14–0.29 during the monitoring period (Figure 5).

Discussion

Our analysis suggests that Blueback Herring in the Neuse River basin have experienced population gains since the moratorium began in 2007. Upward trends in Blueback Herring abundance metrics, size-structure, and SPR were detected in 2021. Relative abundance of Blueback Herring collected in 2021 was similar to the mean relative abundance since monitoring began in 2007, and although annually variable, relative abundance has been increasing throughout the time series. The ratio of male to female Blueback Herring in 2021 was desirable for a healthy Blueback Herring population. Blueback Herring mean total length for males and females from 2021 were the highest observed in Core and Village creeks since monitoring began in 2007, suggesting that age-structure might be expanding due to reduced mortality. An SPR of 35%–40% is considered sustainable for most species (Hordyk et al. 2015), and while annual Blueback Herring SPR was below sustainable values in all years, annual SPR has doubled since monitoring began in 2007.

Alewife were not collected during river herring sampling in the Neuse River from 2007–2013, 2016, 2019, or 2021, yet Alewife were collected in Core Creek in 2014 (n=1) and 2017 (n=2), in Village Creek in 2015 (n=1) and 2018 (n=1), and Contentnea Creek in 2020 (n=1). Although Alewife are rare in Village and Core creeks, spawning aggregations of Alewife have been observed in Slocum Creek (Buckley and Ricks 2019). To better document Alewife abundance in the Neuse River basin, weekly sampling in Slocum Creek should be considered, and additional exploratory sites should be investigated within other tributaries in the lower Neuse River where Alewife may occur regularly during the spawning season.

Future studies are needed to evaluate if increasing trends in abundance, size-structure, and spawning potential ratio are indicative of population recovery. The increasing trends may be the start of recovery for the river herring population in the Neuse River and its tributaries, but

continuation of annual monitoring in Core and Village creeks and sampling additional exploratory sites are needed to determine if these upward trends continue. Success criteria for population recovery do not currently exist, but the time series data from annual monitoring can be used to develop sustainability metrics that could eventually allow the moratorium to be lifted.

Management Recommendations

1. Maintain the current harvest moratorium on Alewife and Blueback Herring.
2. Continue annual river herring surveys in Core Creek and Village Creek.
3. Sample additional tributaries in the Neuse River to expand occurrence data as time allows.
4. Evaluate spawning stock biomass and percent of repeat spawning individuals by age.
5. Develop success criteria and sustainability metrics specific to the Neuse River that could indicate population recovery and allow for harvest.
6. Identify funding options to add temperature monitoring to the Neuse River USGS gage 02091814 at Fort Barnwell, NC.

Acknowledgments

We appreciate suggestions and comments from Kevin Dockendorf and Jeremy McCargo to previous drafts to improve this report.

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TABLE 1. Sample site information for the 2021 river herring survey in the Neuse River.

Site name	Latitude	Longitude
Core Creek Upstream	35.285860	-77.287370
Core Creek Left Side	35.294480	-77.287820
Village Creek Upstream	35.307700	-77.301780
Village Creek Downstream	35.303610	-77.297820

TABLE 2. Water quality measurements collected at electrofishing sample sites from the 2021 river herring survey in the Neuse River.

Parameter	Mean	SE	Minimum	Maximum
Water Temperature (°C)	14.3	0.6	10.4	20.7
Dissolved Oxygen (mg/L)	8.8	0.4	4.5	12.0
Conductivity (µS/cm)	73.9	3.7	56.1	138.0
Salinity ($^0/_{00}$)	0.03	0.01	0.0	0.1

TABLE 3. Total number collected, percent collected, minimum total length (mm), maximum total length (mm), and mean total length (mm) of Blueback Herring collected in Core and Village creeks during the 2021 river herring survey in the Neuse River.

Species	Number collected	Percent collected (%)	Minimum total length (mm)	Maximum total length (mm)	Mean total length (mm)
Core Creek	93	52.0	228	304	273
Village Creek	86	48.0	231	306	273
Total	179	100			

TABLE 4. Summary statistics of Blueback Herring weekly electrofishing sampling in Core Creek during the 2021 river herring survey in the Neuse River. Note: All discharge data provided below were recorded on the USGS Fort Barnwell, NC, Neuse River gage number 02091814 located near the Maple Cypress boating access area.

Sample date	Number collected	CPUE (fish/h)	Number males	Number females	Mean water temp (°C)	Discharge (CFS)
3/2/2021	9	16.2	5	4	12.5	16,000
3/9/2021	16	27.9	8	8	10.7	11,700
3/15/2021	36	63.4	18	18	14.5	9,620
3/22/2021	19	31.9	10	9	12.0	13,100
3/29/2021	10	18.0	6	4	18.1	6,960
4/5/2021	3	5.3	0	3	14.5	8,560
4/15/2021	0	0.0	0	0	20.7	4,490
Total	93		47	46		

TABLE 5. Summary statistics of Blueback Herring weekly electrofishing sampling in Village Creek during the 2021 river herring survey in the Neuse River. Note: All discharge data provided below were recorded on the USGS Fort Barnwell, NC, Neuse River gage number 02091814 located near the Maple Cypress boating access area.

Sample date	Number collected	CPUE (fish/h)	Number males	Number females	Mean water temp (°C)	Discharge (CFS)
3/3/2021	14	25.2	11	3	11.9	14,500
3/9/2021	21	38.4	13	8	10.4	11,700
3/15/2021	28	42.8	4	24	14.3	9,620
3/22/2021	11	18.3	8	3	11.7	13,100
3/29/2021	7	13.4	4	3	17.7	6,960
4/5/2021	5	8.5	4	1	14.9	8,560
4/15/2021	0	0.0	0	0	20.7	4,490
Total	86		44	42		

TABLE 6. Annual summary statistics of Blueback Herring electrofishing sampling in Core Creek during the 2007–2021 river herring survey in the Neuse River. Due to disruptions necessitated by the Covid-19 pandemic, river herring sampling in the Neuse River was reduced in 2020, and therefore, interpretation of results from 2020 should be cautioned when compared to other sampling years.

Year	Effort (h)	Catch Males	Catch Females	M:F Ratio	Total CPUE	Peak CPUE	Mean Weekly CPUE	Mean Weekly CPUE (SE)	Male Mean TL (mm)	Female Mean TL (mm)	Max TL (mm)
2007	6.0	8	5	1.6:1	2.2	7.0	2.6	1.4	240	263	286
2008	5.9	63	42	1.5:1	17.8	70.5	15.0	7.7	247	264	301
2009	8.1	8	20	0.4:1	3.5	12.7	3.4	1.7	246	262	286
2010	9.9	47	26	1.8:1	7.4	28.2	7.5	3.2	236	261	294
2011	3.8	14	9	1.6:1	6.1	13.8	4.4	3.3	249	259	275
2012	3.5	25	12	2.1:1	10.6	25.0	9.7	5.6	238	255	270
2013	3.6	36	29	1.2:1	18.1	25.0	15.9	5.1	242	259	294
2014	3.5	10	16	0.6:1	7.4	18.0	7.4	2.7	253	267	284
2015	3.9	32	53	0.6:1	21.8	29.4	17.9	5.4	254	271	296
2016	2.0	15	3	5.0:1	8.9	63.6	9.0	7.7	246	283	295
2017	4.2	173	60	2.9:1	55.9	293.1	56.3	24.2	247	259	294
2018	3.9	55	25	2.2:1	20.3	52.6	17.6	7.2	248	265	282
2019	3.8	48	63	0.8:1	29.6	53.9	28.9	7.4	253	268	315
2020	2.0	121	73	1.7:1	95.1	214.5	95.8	40.2	260	278	309
2021	4.5	47	46	1.0:1	20.8	63.4	20.3	7.5	262	283	304
Time Series Mean	4.6	47	32	1.7:1	21.7	64.7			248	266	292

TABLE 7. Annual summary statistics of Blueback Herring electrofishing sampling in Village Creek during the 2007–2021 river herring survey in the Neuse River. Due to disruptions necessitated by the Covid-19 pandemic, river herring sampling in the Neuse River was reduced in 2020, and therefore, interpretation of results from 2020 should be cautioned when compared to other sampling years.

Year	Effort (h)	Catch Males	Catch Females	M:F Ratio	Total CPUE	Peak CPUE	Mean Weekly CPUE	Mean Weekly CPUE (SE)	Male Mean TL (mm)	Female Mean TL (mm)	Max TL (mm)
2007	4.1	43	17	2.5:1	14.6	81.3	12.2	9.2	239	259	293
2008	4.4	89	34	2.6:1	28.0	146.0	26.0	12.3	250	264	291
2009	5.7	7	20	0.4:1	4.7	20.0	3.9	2.4	246	265	289
2010	8.2	68	27	2.5:1	11.6	52.2	10.7	5.0	239	257	290
2011	3.3	94	26	3.6:1	36.4	60.0	26.8	12.2	246	258	282
2012	3.4	95	33	2.9:1	37.6	91.9	37.2	16.8	247	268	292
2013	3.4	154	62	2.5:1	63.5	102.1	58.2	16.1	246	267	299
2014	3.6	16	18	0.9:1	9.4	22.0	9.5	1.3	256	261	288
2015	4.0	33	34	1.0:1	16.8	51.2	15.3	5.7	249	257	294
2016	2.0	48	3	16.0:1	25.4	137.4	25.0	24.3	252	270	281
2017	4.1	391	39	10.0:1	104.2	557.0	104.7	46.9	253	268	305
2018	4.0	224	78	2.9:1	75.3	172.8	72.5	18.2	255	267	294
2019	3.7	97	73	1.3:1	46.6	112.4	46.3	11.9	251	269	314
2020	2.1	152	65	2.3:1	105.9	174.2	105.4	29.1	262	278	307
2021	4.6	44	42	1.0:1	18.9	42.8	18.3	5.7	266	281	306
Time Series Mean	4.0	104	38	3.7:1	39.9	121.6			250	266	295

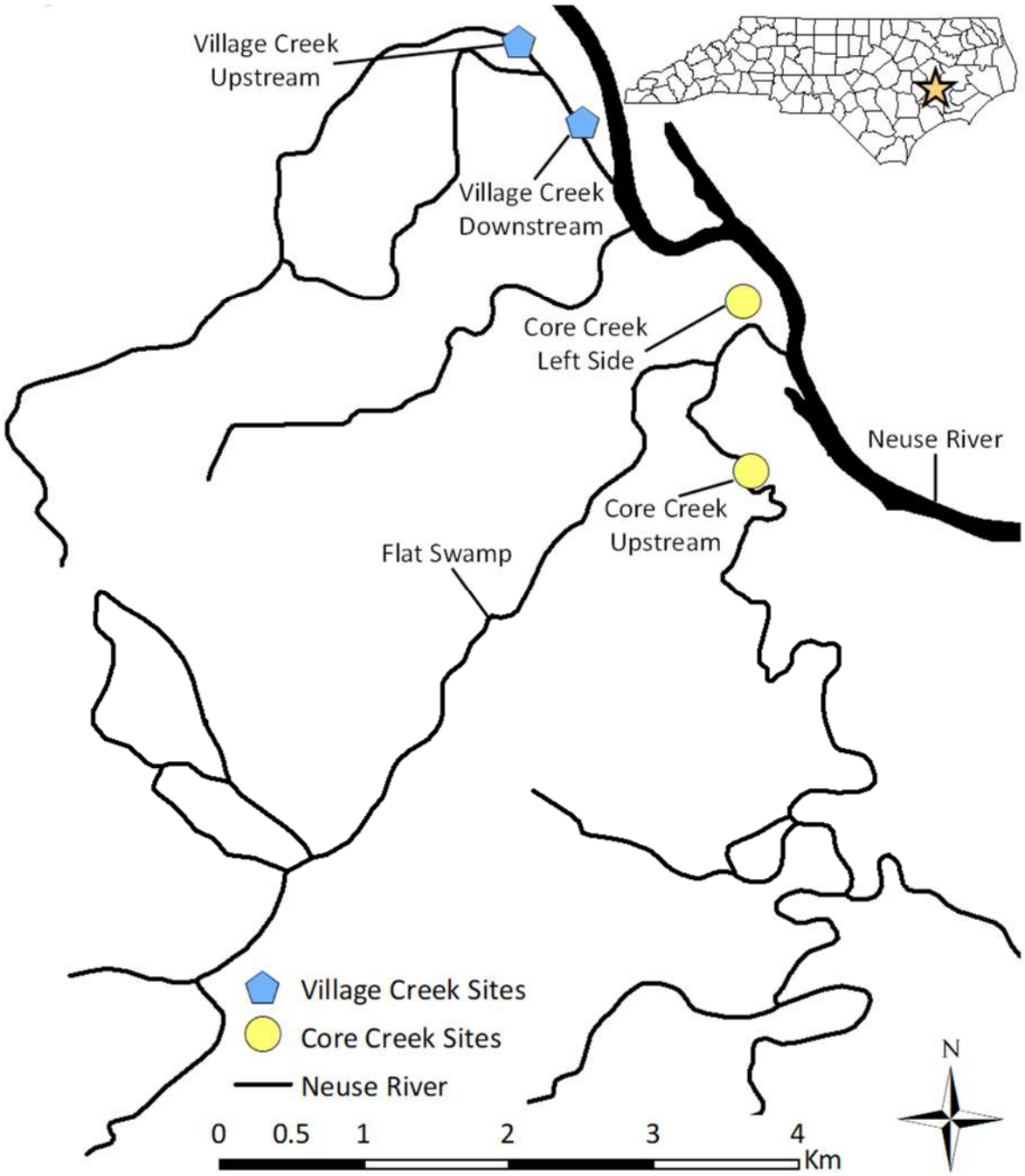

FIGURE 1. Map of Core and Village Creek sites sampled annually with boat electrofishing during the 2007–2021 river herring survey in the Neuse River basin.

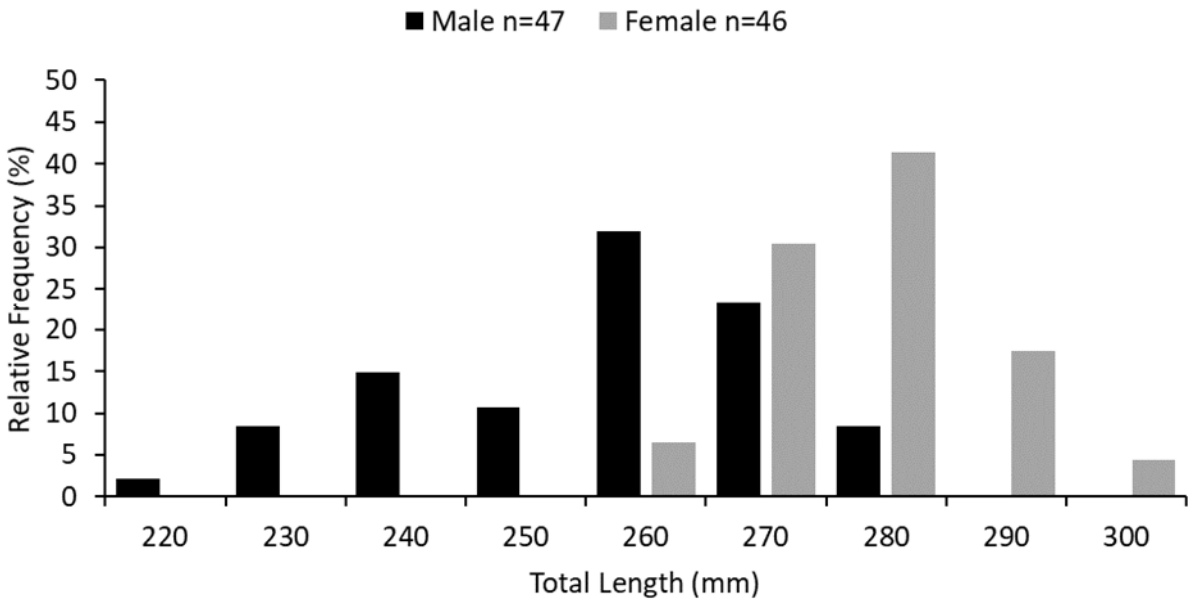

FIGURE 2. Length frequency distribution of male and female Blueback Herring collected from Core Creek during the 2021 river herring survey in the Neuse River.

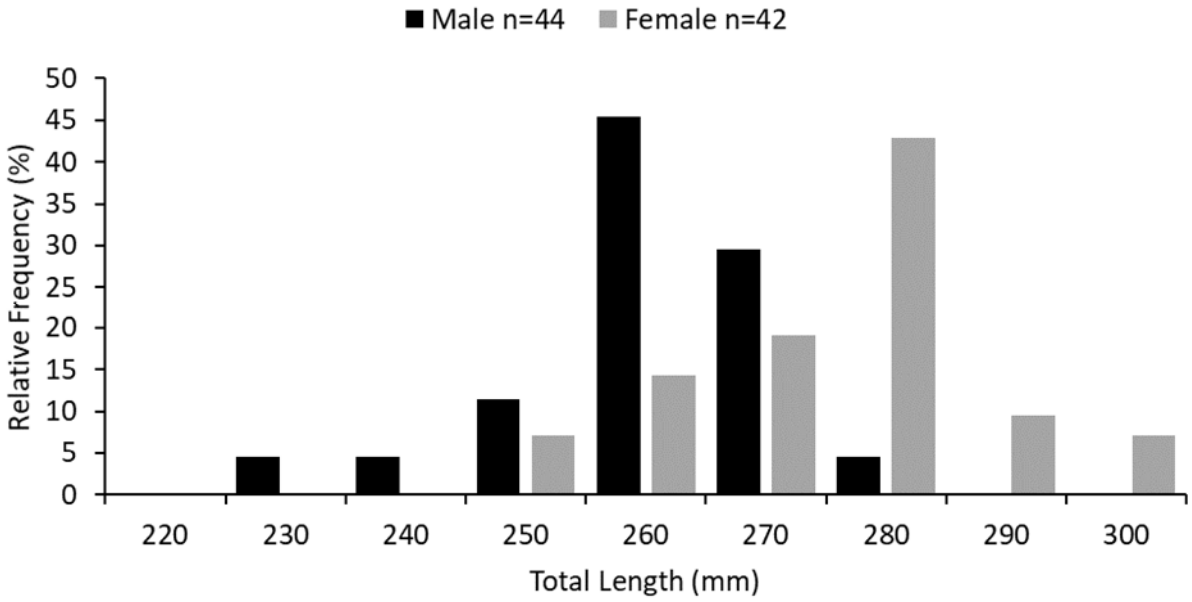

FIGURE 3. Length frequency distribution of male and female Blueback Herring collected from Village Creek during the 2021 river herring survey in the Neuse River.

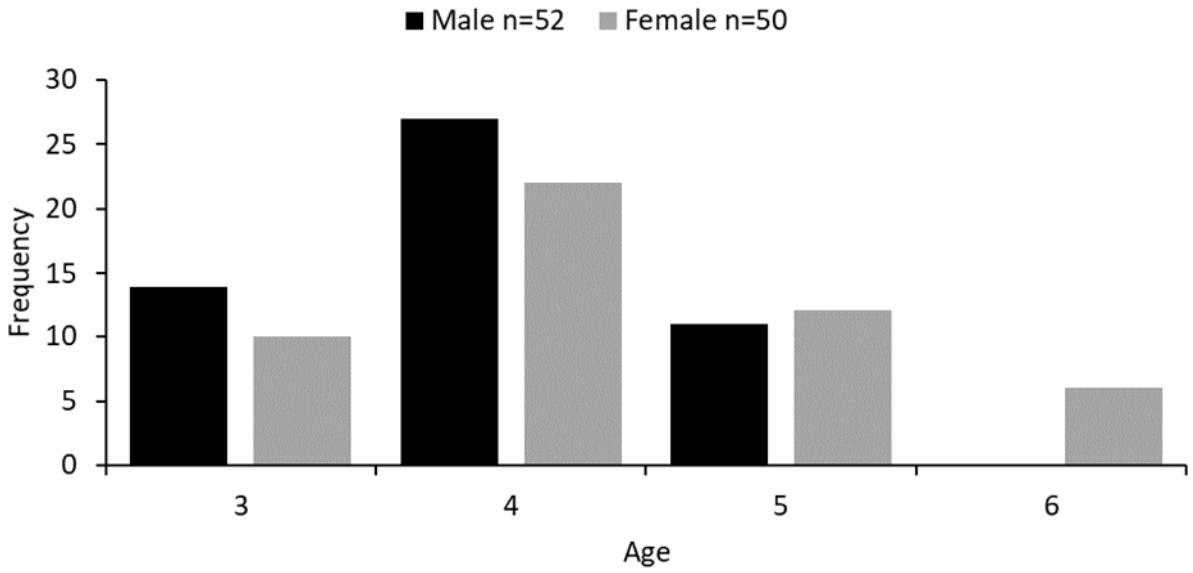

FIGURE 4. Age frequency distribution of male and female Blueback Herring collected during the 2021 river herring survey in the Neuse River.

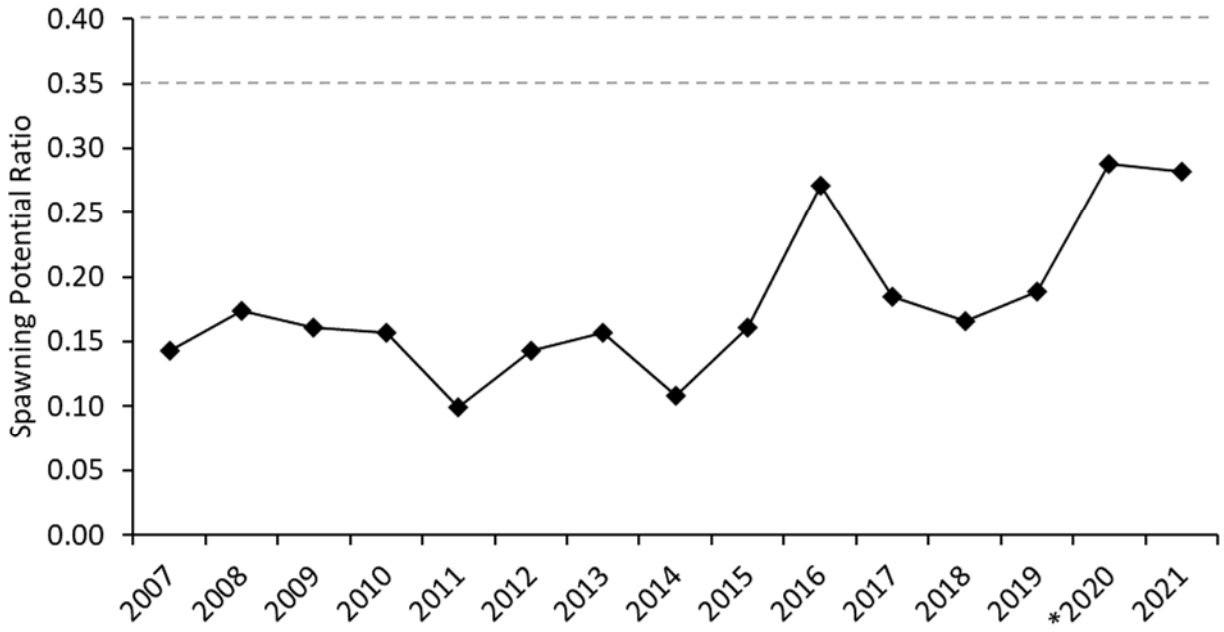

FIGURE 5. Annual spawning potential ratio of female Blueback Herring collected from the 2007-2021 river herring survey in the Neuse River. Due to disruptions necessitated by the Covid-19 pandemic, river herring sampling in the Neuse River was reduced in 2020 and therefore, interpretation of results from 2020 should be cautioned when compared to other sampling years. Dashed line represents sustainable range of 35%–40% (Hordyk et al. 2015).