Feasibility of Trap and Transport of Adult River Herring to Restore Spawning Populations in A Southeastern U.S. Coastal Watershed

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Abstract: Adult alewife (*Alosa pseudoharengus*) and blueback herring (*A. aestivalis*) (collectively referred to as river herring) have rarely been trapped and transported during the spawning period to restore spawning runs in southern coastal U.S. watersheds, though this is a common practice in New England. We tested the feasibility of this practice in North Carolina to develop a protocol to assist in restocking and conservation efforts. River herring were collected using pound nets in the Scuppernong River at Columbia, North Carolina, from February–April 2007. Fish were removed from pound nets, placed into an oxygenated 833-L holding tank, and transported approximately 30 min to Lake Phelps, a natural Carolina Bay lake on the Albemarle-Pamlico peninsula with an outlet to Albemarle Sound. The density of river herring in the tank was maintained < 1 fish / 3.78 L^{-1}. Survival of river herring associated with capture and transport to the stocking site was 88% each, and was not related to water temperature (range, 9.2–18.7 C). Overall survival after trap, transport, and holding for 24 h in cages was 28.1%, but survival was 68% at water temperatures ≤12 C and 10.6% at water temperatures >12 C. No juvenile river herring were collected in Lake Phelps, thus the success of trap and transport to create a spawning population was unable to be determined. Trap and transport may be most appropriate for alewife because they enter the spawning areas before the water reaches 12 C. The success of river herring trap and transport may ultimately depend on the number of spawning adults relocated to a depleted system and the environmental conditions experienced by early life stages of spawned river herring. Results of this study demonstrated that trap and transport can be conducted successfully in coastal systems of the southeastern United States; however, the issue of the efficacy of this method to restore spawning runs remains unresolved.

Key words: survival, water temperature, population restoration, stocking

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Since the 1970s, anadromous populations of alewife (*Alosa pseudoharengus*) and blueback herring *A. aestivalis* (collectively known as "river herring") have been declining along the Atlantic Coast because of damming and altering flow regimes in rivers, habitat loss, pollution, overfishing, invasive species, and climate change (Rulifson et al. 1994, Limburg and Waldman 2009). The decline also has occurred in North Carolina, where river herring populations are well below historical levels and commercial landings have declined since the 1970s to only a fraction of what the fishery was in the 19th century (Rulifson 1994, Hightower et al. 1996, NCDMF 2007). In 2007, the North Carolina Marine Fisheries Commission voted in favor of a complete moratorium on the river herring fishery, making it illegal to possess them.

A historic river herring spawning run in coastal North Carolina was located in the Scuppernong River and Lake Phelps, a 6,480-ha Carolina Bay lake on the north shore of the Albemarle-Pamlico peninsula (Collier and Odom 1989). The lake drains through a series of outfall canals to the Scuppernong River, which discharges into the Albemarle Sound (Figure 1). The extensive network of canals supports the agricultural demand of the area. Historically, river herring utilized this canal system to enter the lake to spawn (Kornegay and Dineen 1979, Kornegay 1985).

Storm gates located on several outfall canals limit fish access to the lake (Collier and Odom 1989). These gates control the water level of the lake and the surrounding network of canals, and in the past they were opened during the river herring spawning season to allow river herring access to the lake. However, in the 1970s and 1980s drought conditions and use of the lake water to fight forest and peat fires in the area lowered the lake level for a number of years, preventing springtime run off and resultant attractant flows for the river herring spawning migration. Kornegay and Dineen (1979) also noted that extensive clearing and draining of thousands of hectares of timber occurred in natural coastal lakes, which may have lowered the water table and subsequently the lake level. Efforts to restore the river herring run in Lake Phelps were initiated in 1984 with a demonstration Denil-style fish ladder. These ef-

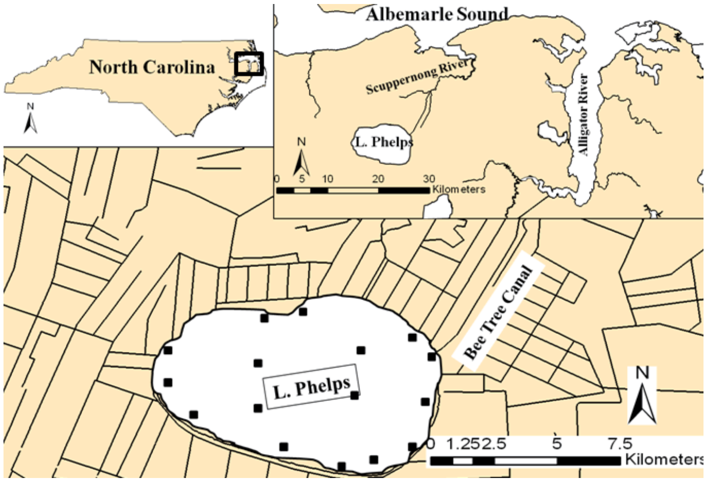

Figure 1. Lake Phelps and Scuppernong River of Albemarle Sound North Carolina. River herring were collected in Scuppernong River and stocked into Lake Phelps. The closed squares represent pushnet sampling locations for Age 0 river herring. Note the extensive surrounding canal system and Bee Tree Canal, the main connector to the Scuppernong River and Albemarle Sound.

forts were mostly unsuccessful because of low water flow through the canal.

River herring spawning runs also have declined in New England, and recent efforts to restore spawning runs to historic locations have used a combination of management strategies, including physically transferring adult river herring to the historic spawning locations (hereafter, trap and transport) (Schmidt et al. 2003, Mather et al. 2012). Trapping and transporting fish is commonly used in stock enhancement and fisheries restoration (Halverson 2008). Fish are captured in areas of adult concentration (e.g., dams), and then transported and stocked in sites with historical spawning runs (Frank et al. 2011). This approach has been widely used throughout New England to restore river herring spawning runs (Havey 1961). Success of these management efforts for river herring was reported in an older study (Havey 1961) but has never been fully evaluated and very little of the original research on the transfer stocking approach is available. No standardized methodology for trapping and transporting river herring is presented in the literature, and this technique has rarely been attempted in the southeastern United States. Early efforts of trap and transport in the Scuppernong-Lake Phelps area were unsuccessful due to high mortality caused by transporting fish more than 120 km from the Neuse River, North Carolina, which took several hours for each trip (Kornegay 1985). Our study assessed the feasibility of using trap and transport techniques as a method to restore river herring runs in a southeastern U.S. watershed. The objectives of this study were: 1) to assess capture and transfer mortality of river herring; 2) to assess the stocking and spawning success of river herring released into Lake Phelps; and 3) to establish a standardized methodology for trap and transport of river herring into historic spawning habitats in the southern portion of their range.

Methods

Experimental Design

From February through April 2007, adult river herring were collected from the Scuppernong River using four 9- × 9-m pound nets with 137-m and 250-m leads. The soaktime for the pound nets varied from two to nine days and it generally took an average of 104 minutes to collect fish from all four pound nets, depending on the amount of fish captured (Table 1). River herring collected from the pound nets were placed in a 833-L circular tank (with a circular flow) mounted on a 5.4-m boat and filled with ambient Scuppernong River water. The water temperature (average of surface and bottom) was recorded at each pound net. To reduce fish stress, the tank was aerated and dissolved oxygen was constantly monitored by a YSI Model 85 water quality meter which was fitted with a 30-m cord to allow us to monitor water quality from the cab of the truck during transport. All river herring were removed from the pound net, placed into the tank on the boat, and transported to the ramp. The fish remained in the onboard tank during transport to Lake Phelps (24 km, approximately 30 min) to reduce handling stress.

Alewife and blueback herring frequently co-occur and are often misidentified by biologists and anglers. They are morphologically and meristically similar and are very difficult to differentiate without handling the fish (MacLellan et al. 1981). Because clupeids, including alewife and blueback herring, are noted for their susceptibility to scale loss and handling stress (Barry and Kynard 1986), transported fish were not identified to species and thus survival estimates were made only for river herring collectively. Upon arrival at Lake Phelps, river herring were slowly acclimated to lake water over a 1.5-h period, consisting of a complete water change in the tank using lake water. Once acclimation was completed, the fish were released into the lake; approximately 10% of the daily catch was sub-sampled and placed into a circular 1-m diameter holding pens. The holding pens were submerged in the lake to assess 24-h mortality. After 24 h, the fish were removed from the pens, euthanized, and transported to the laboratory for further analyses.

Juvenile river herring were sampled in Lake Phelps from May through September using a push net. During this time, the water control structures that allowed water to flow from the lake through the canals to the Scuppernong River were closed so all fish, including any age-0 river herring, were trapped in the lake. Sampling was conducted during nighttime hours at 16 sampling locations using a bow-mounted push net at a fishing depth of 0.5 m at a lake depth of 1 m. The net was constructed of 1.9-mm nitex mesh and was 3 m

Table 1. Number of river herring captured in Scuppernong River, North Carolina. in 2007 to assess trap and transfer mortality. Capture survival represents fish that survived in the onboard tank prior to transport to Lake Phelps. Transport survival represents the survival in the onboard tank during transport to Lake Phelps. The transport tank biomass was determined by multiplying the average weight (0.134 kg) of the river herring by the number of fish transported in the tank to Lake Phelps. The total time fishing represents the total time required to remove fish from the four pound nets. The maximum time is the maximum time that a fish could have been in the onboard holding tank. This maximum time includes the travel time from the collection site to Lake Phelps and a 90-minute acclimation period to lake conditions. The minimum time a fish was in the tank was ~120 minutes for each day. No fish were transported on 10 April due to only six fish captured in the pound nets and inclement weather.

Date	Water temperature C	Pound net soak time (d)	Total fishing time (min)	Maximum time (min)	Number captured	Capture survival (%)	Number transported	Transport tank biomass (kg)	Transport survival (%)
28 Feb	9.2	3	70	190	304	100	274	36.7	90
5 Mar	10.3	4	150	270	378	100	259	34.7	69
7 Mar	10.0	2	80	200	68	100	67	9.0	99
12 Mar	11.3	4	120	240	128	100	128	17.2	100
14 Mar	11.8	2	100	220	148	100	145	19.4	98
22 Mar	12.0	9	110	230	167	100	167	22.4	100
24 Mar	14.9	2	90	210	98	97	93	12.5	98
28 Mar	16.6	5	130	250	302	97	181	24.3	62
31 Mar	15.3	3	100	220	67	100	67	9.0	100
3 Apr	18.4	3	110	230	277	73	93	12.5	46
5 Apr	18.3	2	100	220	139	83	111	14.9	96
10 Apr	18.7	5	–	–	6	83	–	0.0	
25 Apr	18.2	3	90	210	102	34	23	3.1	100
Total/mean					2,184	88%	1,608	215.5	88%

long with a mouth opening 0.5 m by 1.0 m. The net was mounted in a rectangular (0.5 m × 1.0 m) aluminum frame and deployed from a metal slot mounted on a 5.2-m Carolina skiff powered by a 25-hp outboard motor (Overton and Rulifson 2007). A General Oceanics flowmeter was mounted in the mouth of the push net to estimate the volume of water sampled. Push net sampling began 45 min after sunset, which is the optimum time for the capture of alosine species in a push net (Dixon 1996). At each site, the first sample was taken in one direction, and a replicate sample was collected in the opposite direction. We chose this approach because the distribution of early stages of fish can be affected by wind and current direction thus affecting the catchability of plankton nets (Fortier and Leggett 1983, Fortier and Leggett 1985). Fish were preserved in a 10% buffered formalin solution and returned to the laboratory for examination. All fish and aquatic invertebrates collected in ichthyoplankton samples were identified to the lowest taxonomic level possible and enumerated.

A fish trap was constructed upstream of the water control structure in Bee Tree Canal (Figure 1) to monitor for river herring immigration and emigration. The trap was constructed of 12.7-mm PVC piping and 8-mm plastic coated mesh netting. The trap was divided into two 1-m^3 sections; each section had its own funnel entrance to differentiate those organisms migrating into the lake from those migrating out of the lake. The fish trap was set for 48-h periods and fished every 8 h for the duration of the stocking events. Water quality and environmental conditions were recorded during this period. Fish captured in the traps were placed in a plastic bag with site and time identifiers, and then placed on ice. Once at the laboratory, they were stored in a –20 C freezer until analysis.

Data Analysis

River herring from the net pens and the traps were identified to species, sexed if possible, and measured (FL and TL, mm). Blotted wet weight and gonad weight (g) were recorded. The gonads were removed from each fish and the gonadosomatic index (GSI) was calculated using the formula:

$$GSI = \text{gonad weight/body weight.}$$

Differences in GSI between sexes were assessed for both species using an Analysis of Variance (ANOVA). Data were $\log_{10}$ transformed to normalize the data.

Results

From February through April, we collected 2,184 river herring from the Scuppernong River. Blueback herring ranged from 215–286 mm TL and alewife ranged from 229–305 mm TL (Figure 2). Of the fish captured in the pound net, 1,436 were released into Lake Phelps. The capture survival, which represents fish that survived in the onboard tank prior to transport to Lake Phelps, ranged from 100% to 33.5% (Table 1) but capture survival was greater than 97% at temperatures less than 16.6 C. The survival of fish transported to Lake Phelps ranged from 46%–100% (Table 1). Mean capture and transport survival was 88%, respectively.

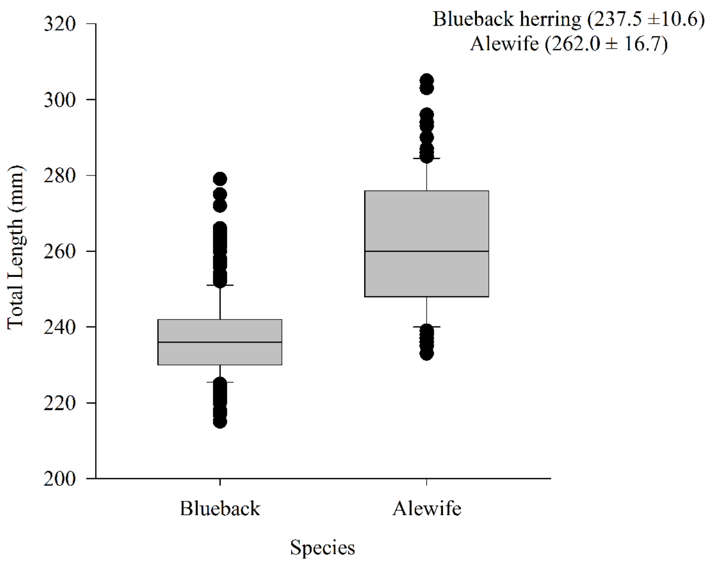

Figure 2. Boxplot showing the median (horizontal line within box), 25th percentile (lower edge of box), 75th percentile (upper edge of box), 10th percentile (lower t-bar) and 90th percentile (upper t-bar) of total length (mm) (GSI) for alewife and blueback herring in Scuppernong River during the 2007 (25 February – 7 April, 2007) spawning run.

Table 2. Number of river herring released into Lake Phelps, North Carolina, in 2007 and the number of river herring held in holding pens for the 24-h survival trial. The 24-h survival is survival (percent) after being held in the holding pens. No fish were transported on 10 April due to only six fish captured in the pound nets and inclement weather.

Date	Water temperature C	Number released	Number in holding pen	Escapement (from holding pen)	24-h % survival	Initial/final holding pen biomass (kg)
28 Feb	9.2	247	27	22	100	3.6/0.7
5 Mar	10.3	234	25	1	16.7	3.4/0.5
7 Mar	10.0	61	6	0	100	0.8/0.8
12 Mar	11.3	116	12	2	60	1.6/0.8
14 Mar	11.8	131	14	0	28.6	1.9/0.5
22 Mar	12.0	151	16	0	18.8	2.1/0.4
24 Mar	14.9	84	9	0	22.2	1.2/0.3
28 Mar	16.6	163	18	18	–	2.4/–
31 Mar	15.3	61	6	2	25	0.8/0.1
3 Apr	18.4	74	19	2	17.6	2.5/0.4
5 Apr	18.3	101	10	4	0	1.3/–
10 Apr	18.7	–	–	–	–	–
25 Apr	18.2	13	10	0	0	1.3/–
Total		1,436	172	51	28.1	

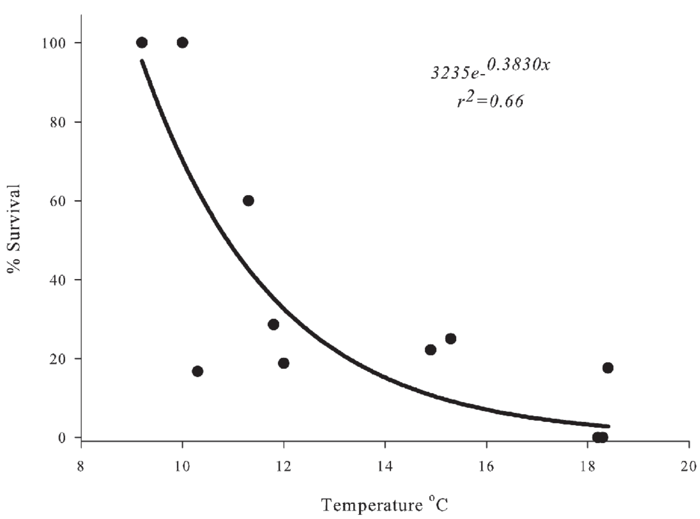

Figure 3. Relationship of river herring survival 24 h after trap and transport to the ambient river water temperature in Lake Phelps at the time of collection in spring 2007.

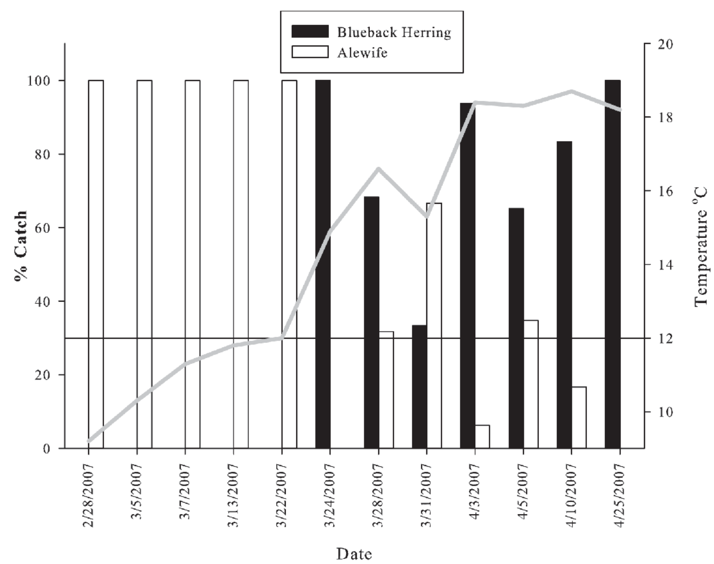

Figure 4. Percent catch of alewife and blueback determined from the mortalites from trap and transport in Scuppernong River, North Carolina (25 February – 7 April, 2007).

Transport survival showed no real clear patterns with respect to temperature (Table 1). We experienced some fish escapement and bird predation in the 24-h holding pen in pens. Once this was accounted for, overall survival in the 24-h holding pens decreased throughout the study and mean survival for the whole study was 28.1% (Table 2). However, survival was affected by water temperature; mean survival was 69% at temperatures ≤12 C and 10.6% at temperatures >10 C (Figure 3). On one occasion (5 March) the 24-h survival was low (16.7%) even though the water temperature was 10.3 C.

Although the species composition of transported river herring was not determined, examination of the subsampled fish placed into the net pens revealed that alewife arrived almost one month earlier than blueback herring (Figure 4). Blueback herring did not arrive until the water temperatures reached 14 C; which correlated with lower survival rates throughout the study (Figure 4).

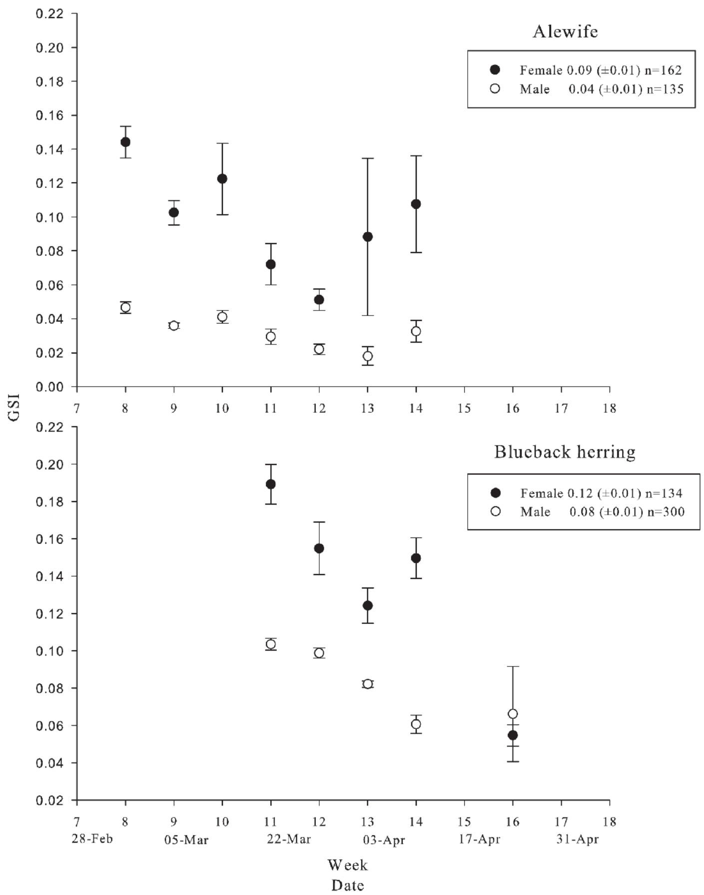

Figure 5. Mean (± standard error) Gonadal Somatic Index (GSI) of male and female alewife and blueback herring in Scuppernong River during the 2007 (25 February – 7 April, 2007) spawning run. n represents the sample size.

The GSI declined for both alewife and blueback herring during the sampling period (Figure 5). Alewife GSI was lower than blueback herring GSI for both females ($F = 10.5$; $df = 1{,}294$; $P = 0.001$) and males ($F = 79.5$; $df = 1{,}434$; $P < 0.001$). Mean GSI for female alewife was highest (0.14) at the start of the study (week 8; 28 February) and declined 64% by week 12. By weeks 13 and 14, GSI of female alewives increased and became more variable (Figure 5). Male GSI for blueback herring declined from 0.10 at arrival during week 11 to 0.07 after three weeks. The GSI increased by the end of the spawning run (week 16); similar to patterns observed in male and female alewife (Figure 5).

No juvenile river herring were captured by push nets in Lake Phelps during 2007. The push net samples consisted mostly of juvenile banded killifish (*Fundulus diaphanous*), bluegill (*Lepomis macrochirus*), golden shiner (*Notemigonus crysoleucas*), and pumpkinseed (*L. megalotis*).

Discussion

The intent of this study was to determine the feasibility of transfer stocking as a means of restoring the river herring populations in North Carolina and to develop a standardized protocol for trap and transport adult transfer stocking in the southern portion of the range. In New England this practice is widely used for American shad *A. sapidissima*, where a 3.78-L of water per fish hauling density standard is used to reduce stress during the transfer process. Fishery resource personnel in New England suggested that the comparatively smaller-sized river herring should reduce mortality of transported fish to a minimum. Results of our study demonstrated the truth of this impression; overall capture and transfer survival was 88% when this hauling density was maintained. The sub-lethal effects of river herring collected in pound nets are unknown. Soaktimes for the pound nets ranged from 2 to 9 days, yet survival rates of river herring during trap and transport remained high. These soaktimes were necessary to collect enough fish for feasible transport to Lake Phelps. Other methods to capture river herring were considered, including electrofishing, but the catch rates for pound nets were the highest of all the gears assessed for this project.

The results from our work suggest there is an overall temperature effect on successful trap and transport of river herring. With respect to capture and transport survival, there were no real observed temperature patterns on survival. However, in the 24-h holding cage experiments, water temperatures greater than 12 C reduced river herring survival in the 24-h treatment. We could not account for the additional stress of confinement while in the 24-h holding cages. The overall survival is likely higher than our 24-h holding cage estimates. The temperature effect on successful trap and transfer has been observed for other species including salmonids (Cowx 1994) and striped bass (Davis and Parker 1990).

This project established a standard protocol and should be readily adapted for future use on a larger scale for coastal watersheds. The basic transfer protocol recommended is listed here:

1. Record ambient water quality parameters at capture location.
2. Fill an insulated round tank with water at capture location.
3. Monitor dissolved oxygen and percent saturation, and aerate tank water with bottled oxygen to maintain 8 mg L^{-1} and 100% saturation.
4. Maintain a circular flow to reduce stress and scale loss.
5. Once tank water oxygen and flow is stabilized, place river herring in tank and the density inside of the tank should be <1 fish / 3.78 L^{-1}.
6. Transport fish to stocking location.

7. Take ambient water quality at stocking location.

8. Acclimation-Replace tank water with ambient water; this process should be slower (~1.5 hour) at higher water temperatures, especially above 12 C.

9. When tank water has equilibrated to ambient water, proceed with stocking the adult fish at the stocking location.

10. Fish should be collected early during the spawning season before the water temperature reaches the optimal spawning temperatures (21 to 25 C; Klauda et al. 1991) to reduce transfer stress and to stock fish before they reach their peak GSI.

The plastic tank used in our study was not insulated, which may have contributed to increased mortality later in the spawning season. We recommend using an insulated tank to minimize thermal stress during transport. Also, we recommend positioning the intake for the circular flow pump at the top of the tank. In our study, the intake was located on the bottom of the tank causing river herring to school near the bottom of the tank resulting in fish impingement on the intake screen. Moving the intake to the top of the tank should alleviate this problem and still provide an uninterrupted circular flow.

The patterns that we observed in GSI for blueback herring and alewife were similar to patterns observed in other systems (Norden 1967, McBride et al. 2010). However, the increase in the GSI at the end of the spawning season was not expected. The slight increase that we observed in GSI probably indicates a short secondary spawning run by alewives. This is evident by the larger variability in the mean GSI values during weeks 13 and 14 where the new spawners (higher GSI) were being collected with the fish that had already spawned. Additionally, because the GSI declined over time for both alewife and blueback herring, trap and transport should be concentrated in the first weeks of the spawning run when water temperatures are lower to maximize spawning success of transported fish.

Multiple fisheries management policies and tools are needed to restore the river herring stock. With harvest moratoriums in place in North Carolina and other coastal states, proactive approaches are needed to aid in this recovery. Our study demonstrated that trap and transfer of river herring past barriers to historic spawning areas is possible. The pound net was an effective gear to collect fish. In order to assess successful trap and transport beyond the release stage, independent fishery data would be needed to establish monitor strength of spawning runs and spawning habitat utilization.

Our attempt to establish a spawning run in Lake Phelps for restoration was unsuccessful. Over 1,400 river herring were released into Lake Phelps and these fish varied in their reproductive output potential (GSI). There are several possible reasons why our attempts were unsuccessful. First, because no estimates exist of the historic spawning run size during the years of documented spawning success, it is possible that we did not transfer enough adult river herring to reestablish a river herring run. Secondly, survival during early life stages may ultimately be dependent on the spawning location of the stocked adults and the quality of the habitats used by young developing fish (Overton et al. 2012). The uncertainty of the number of fish required to successfully restore a spawning run needs to be resolved. Thirdly, the absence of juvenile river herring in push net samples strongly suggests that spawning by transferred fish was not successful or that recruitment of eggs and larvae to the juvenile stage failed. Also, no juvenile river herring were observed during routine electrofishing sampling during summer 2007 (Kevin Dockendorf, North Carolina Wildlife Resource Commission, personal communication). We did, however, collect juvenile sunfishes (*Lepomis* spp.) that will prey on river herring eggs and larvae (Eyler et al. 2002). Additionally, golden shiners (*Notemigonus crysoleucas*) are common in Lake Phelps and can limit production of shad and river herring (Edsall 1964, Johnson and Dropkin 1992).

The temperature effect may ultimately limit the success of trap and transport, especially because of the differences in spawning migration patterns between alewives and blueback herring. Alewives enter the spawning areas before blueback herring (Dadswell et al. 1987). In our study, they entered the spawning area when the water temperatures were cool (<12 C), followed by blueback herring almost four weeks later at concomitantly higher water temperatures. Thus, blueback herring may be subjected to higher stress levels and lower survival after trap and transport due to higher water temperatures. Further study of differences in stress responses and survival of both species over a range of temperatures would help resolve this issue. Possibly less stressful capture methods, such as electrofishing, may be necessary to successfully trap and transport blueback herring in river systems in the southern portion of their range.

Trapping and transporting anadromous fish can stress the animals such that their seasonal reproductive output and survival, as well as their behavior, is affected (Schreck et al. 2001, Olney et al. 2006). The highest survival rate of river herring during trap and transport was observed in the sample with the highest GSI and the lowest water temperatures, suggesting that the fish during that period were minimally stressed during trap and transport. However, fish transported later in the season had lower GSI, suggesting that spawning already occurred. Spawning stress certainly lowered reproductive output of stocked fish and also could have caused higher mortality, especially at higher water temperatures.

It may be many years until the North Carolina river herring moratorium has an observable effect on population sizes. Results of this study demonstrated that trap and transport can be conducted successfully in coastal systems of the southeastern United States; however, the efficacy of this method to restore spawning runs remains unresolved. Continued use and evaluation of the trap and transport should be considered as a viable method, as this could be one possible mechanism to enhance and restore river herring spawning runs in southern watersheds.

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