Effectiveness of a Fish Passage Facility for Anadromous River Herring Recruitment

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Abstract: Migratory stocks of river herring, alewife *(Alosa pseudoharengus)* and blueback herring *(A. aestivalis)* have declined as a result of overfishing, poor water quality, and loss of spawning and nursery habitat. To provide access to previously blocked spawning and nursery areas, fish passage facilities have been installed at stream blockages. In 1997, a fish ladder was installed on Unicorn Lake, a tributary of the Chester River in Maryland. In 1998 and 1999, we evaluated the effectiveness of the fish ladder for passing adult river herring and surveyed the upstream habitat for juvenile recruitment. In 1998, 18 alewife and 3,800 blueback herring used the fishway. Temporary modifications made to the fishway in 1999 substantially increased passage to 1,270 alewife and 13,400 blueback herring when densities below the dam appeared to be similar between years. Besides using the fishway, an additional 3,375 alewife were manually passed into Unicorn Lake 1999. Although juvenile river herring reportedly reside in upstream areas for several months, only 1 individual was collected during 2 years of the study in Unicorn Lake. The apparent recruitment failure may be attributed to low food availability, poor water quality, early emigration, or predation on early life stages.

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Alewife and blueback herring, collectively termed river herring, are ecologically and commercially important fisheries for coastal Atlantic states (Atl. States Mar. Fish, Comm. 1985). Migratory stocks of river herring have declined dramatically over the past century as a result of overfishing, pollution, and loss of spawning and

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nursery habitat (Atl. States Mar. Fish, Comm. 1985). Restoration efforts for river herring include installing fish passage facilities at stream blockages to provide access to quality historical spawning and nursery habitat that has been blocked, in many cases, for more than 100 years (Railsback et al. 1991, Cada and Sale 1993, Quinn 1994, Chesapeake Bay Program [CBP] 1999).

Although certain fishway designs have proven successful, each fishway must have site-specific modifications and criteria for evaluation to function properly (Railsback et al. 1991). Attraction flow and additional hydrology issues must be addressed to ensure successful fish passage through engineered facilities. Monitoring is essential to ensure that target fish species are able to use the fishway effectively. In some cases, fish passage facilities are deemed successful once any number of target species successfully navigate the facility, and little consideration is given to the effectiveness of passage or spawning success and juvenile recruitment in the new habitat. It is critical that all factors, including effectiveness of passing target species, spawning habitat suitability, spawning habitat use, and subsequent juvenile production are evaluated before determining success of a fish passage facility (Railsback et al. 1991, Cada and Sale 1993, Cada 1998, Haro et al. 1999).

In 1997, a fishway was installed on Unicorn Lake by the Maryland Department of Natural Resources (MDDNR) to pass river herring into upstream habitat blocked by a dam. Our study was designed to evaluate the use of the fishway by migratory river herring and determine subsequent spawning success and juvenile production in the upstream habitat.

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Methods

Unicorn Lake is located on Unicorn Branch, a tributary of the Chester River in Queen Annes County, Maryland. The mill pond, with a dam constructed in 1852, is managed as a largemouth bass *(Micropterus salmoides)* and bluegill *(Lepomis macrochirus)* fishery. The fishway was installed at the dam and opened in March 1997, providing spawning river herring access to 23 km of tributary above the lake. The surface area of the lake is 19.4 ha with a maximum depth of 2.8 m and a 5,800-ha watershed.

The fish ladder at Unicorn Lake is an aluminum Alaskan Steeppass Fishway, located on the southeast end of the 30.5-m wide dam. The steeppass has a slope ratio of 1:4, a vertical rise of 4 m to the top of the dam, and is 0.3 m wide. There is a concrete monitoring trap box approximately 2 m^2 and 1.3 m deep at the upstream end of the ladder. The amount of water passing down the ladder is controlled by stop boards at the upstream opening of the box, and the ladder can be effectively closed when all

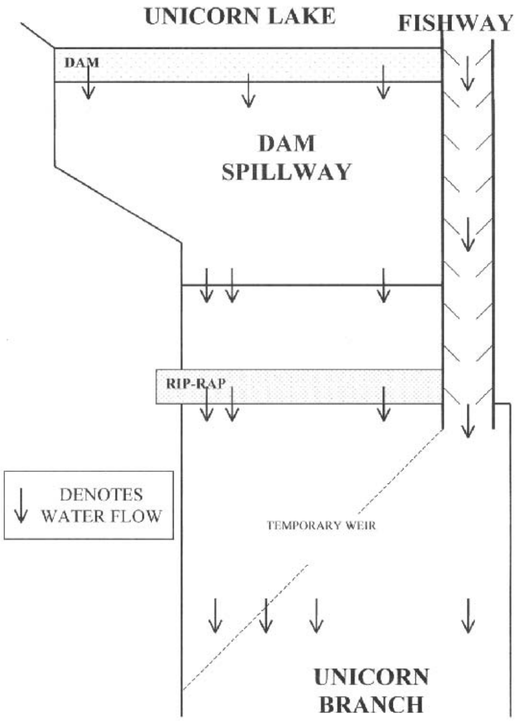

Figure 1. Overhead view of dam tailrace at Unicorn Lake.

stop boards are in place. A screen gate is used in place of the stop-boards when the ladder is open, and the trap box serves as a holding box to monitor fish passing through the ladder. Fish emigrate from the lake by spilling over the dam, and no downstream access is provided.

Below Unicorn Dam (Fig. 1) are 2 levels of concrete spillways, separated by an approximate 0.2-m step. Rip-rap traverses the lower spillway, breaking up the water flow from the dam. The opening of the ladder is adjacent to the rip-rap, and fish that ascend the rip-rap onto the dam spillway cannot access the fishway.

Unicorn Branch below the dam at Unicorn Lake is shallow with water depths ranging to 1.5 m. The stream is composed of riffles and runs with a gravel and sand substrate. Unicorn Branch has a slight tidal influence, with freshwater near the dam, and salinities increasing to 1 mg/liter near the Chester River mainstem depending on tidal stage. Unicorn Branch also supports a substantial freshwater fish population similar to Unicorn Lake. The majority of river herring spawning activity occurs in Unicorn Branch, below the dam at Unicorn Lake.

Employees of MDDNR Unicorn Lake Fish Hatchery monitored fish passage at the fishway in spring 1997. The fishway was opened from approximately 0700 to 1700 hours on weekdays when river herring were observed in Unicorn Branch below the dam. When river herring were observed in the trap box, they were counted, identified, sexed, and manually passed into the lake.

We conducted fish passage evaluations in spring 1998 and 1999 in a similar manner to 1997 methods. We collected a sub-sample of river herring to verify sex and species. Employees of MDDNR opened the fishway on weekdays when river herring were observed below the dam and notified us that herring were passing through the fishway so we could monitor passage. We monitored the fishway on weekends to verify fish passage on all days when fish were present downstream. During periods of peak migration and spawning, the screen gate was removed and fish swam unobstructed into the lake. On these occasions, we conducted 10-minute counts each hour to estimate the number of fish passing on that day (Rideout et al. 1979). We also collected water temperature data and made visual observations of spawning locations in Unicorn Lake and the tributary upstream of the lake.

To increase river herring use of the fishway in 1999, rip-rap was positioned along the dam spillway to divert water and increase attraction flow at the opening of the fishway. A weir constructed with galvanized steel mesh was installed at an angle across Unicorn Branch below the rip-rap directing fish to the opening of the fishway. River herring that ascended the rip-rap onto the spillway were seined and manually passed into the lake. In 1999, we deployed fyke nets in the lake to monitor distance spawning river herring traveled up the lake.

Juvenile river herring recruitment was assessed by surveying for juveniles in 1998 and surveying for eggs, larvae, and juveniles in 1999. To detect egg presence, 19- × 9- × 3-cm clay paving bricks were placed at 20 stations in Unicorn Lake and Unicorn Branch and 2 stations in the upstream tributary. Eggs spawned on the bricks were collected and identified. Ichthyoplankton tows were conducted weekly from 23 April through 31 May and 1 date in June to detect presence of river herring eggs and larvae. Triplicate 2-minute mid-water tows using a 48-cm diameter, 500-micron mesh conical net were towed from a boat in the lake. Larvae from each tow were identified to family.

To determine if juvenile river herring were produced in Unicorn Lake and Unicorn Branch, we electrofished in the lake twice per month from 25 June to 27 October 1998 and in the lake and the branch from 7 July to 28 September 1999. Juvenile river herring were measured (fork length-FL), weighed, and identified to species. On each sampling date, we collected data on temperature, pH, dissolved oxygen, and conductivity. On several occasions in 1999, dense mats of filamentous algae in Unicorn Lake prevented sampling efforts.

Zooplankton density information was collected on 27 April, 24 May, and 12 July 1999 in both the lake and the stream below the lake to determine the available forage base for river herring. Oblique tows were conducted with a 12.7-cm diameter, 125-micron mesh zooplankton net in open water areas of the lake and stream. Zooplankton were identified as cladocerans, copepods, or other, and the average number of organisms per liter was calculated.

Results

A total of 524 blueback herring used the Unicorn Lake fishway between 27 March and 30 May 1997. Employees of MDDNR did not observe any fish other than river herring using the fishway (S. Compton, MDDNR, pers. commun.).

In 1998, 18 alewife passed through the fishway on 9 April and 11 April. Water temperature was 12 and 16 C, respectively. An estimated 3,800 blueback herring passed between 16 and 26 April, with 2 distinct pulses of spawning adults noted using the fishway on 5 days. The ratio of blueback herring males to females on 26 April 1998 was 1.2:1. During the run, water temperature ranged from 14 to 18 C. American eel *(Anguilla rostrata)* elvers were the only other fish observed in the fishway in 1998.

In 1999, alewives were present in Unicorn Branch from 24 March until 1 May. An estimated 1,270 alewife passed into Unicorn Lake through the fishway on 20 days. An additional 3,375 alewife were seined off the dam spillway and carried into the lake. Water temperature ranged from 10 to 17 C during the run. Males predominated each day of passage with an overall ratio of 1.68:1.

The blueback herring run in 1999 began on 28 April and lasted until 8 May for a total of 11 days with 3 distinct pulses. Fish passage into the lake was only noted on 5 of those days and was estimated at 13,400 fish. Only 50 blueback herring were passed by seine from the dam spillway, with the remainder ascending the fishway. Males dominated during the blueback herring run with an overall ratio of 5.03:1. Water temperature ranged from 17 to 21 C during the run.

We did not observe any species besides river herring using the fishway in 1999. We observed bluegill in the trap box when the screen had been removed, but we could not determine if the bluegill had ascended the fishway or had entered the trap box from the lake.

We observed adult river herring spawning within several meters of the dam along the shoreline of Unicorn Lake in 1998, but no fish were observed further into the lake or in the tributary above the lake. Many fish immediately washed downstream over the dam after exiting the fishway. In 1999, river herring were observed spawning along the banks of the lake near the dam and in the tributary above the lake. Fyke nets set in 1999 captured fish further upstream than were observed in 1998.

No egg or larva collection was conducted in Unicorn Lake or Unicorn Branch in 1998. Electrofishing in the summer and fall in Unicorn Lake recovered only 1 juvenile alewife (81 mm FL) on 31 July 1998. Electrofishing for juveniles was not conducted in Unicorn Branch in 1998.

River herring were observed spawning along the shoreline of Unicorn Lake in 1999. Eggs were collected from 16 of the 20 paving bricks in the lake and Unicorn Branch and from aquatic vegetation along the shoreline. No eggs were collected on the bricks in the tributary above the lake. Post yolk sac river herring were collected in Unicorn Lake on 3 of the 6 days surveyed. Densities ranged from 0–233 larvae per 100 m^3 of water. Of the samples collected, river herring consisted of 49% of the sample in April and 10% of the sample in May. Centrarchids made up 31% of the sample

Table 1. Water quality measurements for sampling days in Unicorn Lake and Unicorn Branch in 1999.

Date	Time (hours)	Location	Dissolved oxygen (mg/L)	Conductivity (μS)	pH	Water temp. (°C)
8 Jul	1830	Unicorn Lake	12.0	0.149	8.7	32.1
21 Jul		Unicorn Branch	5.1	0.168	7.6	27.9
3 Aug	1945	Unicorn Lake		0.165	9.2	29.7
3 Aug	1600	Unicorn Branch		1.55	8.6	29.2
16 Aug	2000	Unicorn Lake	12.6	0.162	9.6	29.2
16 Aug	1730	Unicorn Branch	13.8	3.86	7.8	29.2
9 Sep	1800	Unicorn Branch	10.1	1.70	6.8	27.5
13 Sep	1800	Unicorn Lake	11.8	0.157	8.2	25.4
28 Sep	1600	Unicorn Branch	8.4	0.172	7.2	20.8
28 Sep	1900	Unicorn Lake	6.1	0.162	6.6	21.1

in April and 88% in May. No river herring larvae were collected in ichthyoplankton tows after 13 May 1999.

Zooplankton densities were higher in the lake than in Unicorn Branch below the lake on all sampling occasions. Densities in the lake ranged from 0.43 to 6.0 zooplankton/liter.

No juvenile river herring were collected while electrofishing in Unicorn Lake or in the tributary above the lake from July through September 1999. However, electrofishing collected 23 alewife and 121 blueback herring juveniles in Unicorn Branch below the dam during the same time period.

Water temperature and dissolved oxygen were similar between Unicorn Lake and Unicorn Branch on all sampling days, but pH was consistently higher in Unicorn Lake (Table 1).

Discussion

The number of river herring passing through the Unicorn Lake fishway increased each year during the study. More fish passed in 1998 than in 1997 because the ladder was opened on weekends which was when nearly all fish passed in 1998. By making temporary modifications to the fishway site in 1999, we were able to increase the alewife passage 70 fold and triple the number of blueback herring using the fishway. The number of river herring passed at Unicorn Lake in 1999 was one of the highest numbers passed in a fishway in the state of Maryland (Fary and Golden 1998; J. Fary, MDDNR, unpubl. data).

Although large numbers of river herring were passed into Unicorn Lake, they were a small proportion of the number of fish observed below the dam. During 1998 and 1999, large numbers of both alewife and blueback herring were observed staging and spawning below the dam in Unicorn Branch, but few of the fish ascended the fishway. Other fishways in the Chesapeake Bay drainage and the northeast United

States also report small proportions of staging fish ascending fishways (Havey 1961, Fary and Golden 1998, Jones 1999).

Poor passage rates at Unicorn Lake may be the result of available spawning habitat below the dam. Reduced passage efficiency may also be attributed to lack of attraction flow at the entrance of the fishway (Williams 1998). At low densities, river herring congregated where water velocities were highest below the dam and never located the ladder entrance. At high densities, river herring were dispersed across the entire length of the dam resulting in more fish finding the ladder entrance. Therefore alewife, which were consistently present in lower densities than blueback herring, were not as successful at finding the entrance to the fishway and had lower passage rates than blueback herring. We also observed that alewife ascended onto the spillway rather than use the fishway, resulting in more alewife seined from the dam spillway than blueback herring. Other studies also indicate that alewife do not use Alaskan Steeppass fishways as successfully as blueback herring in Mid-Atlantic systems (Fary and Golden 1998, Jones 1999).

Temporary site modifications at Unicorn Lake in 1999, which increased the number of spawning fish above Unicorn Dam, were not long-term solutions to problems associated with the fishway. The re-positioning of the rip-rap appeared to attract more river herring to the fishway entrance. Likewise, the temporary weir appeared to direct fish to the ladder entrance, and was most effective when river herring were present in high numbers. On a routine basis we also netted fish from the spillway and passed them manually into the lake. Combined, these methods may explain the substantial increase of fish passage from 1998 to 1999, but more permanent measures to increase attraction flow and keep fish off the dam spillway must be implemented to consistently pass high numbers of fish.

A successful fishway should pass fish into suitable habitat so as to ultimately increase juvenile production. Because juvenile river herring are reported to stay in impoundments through late summer to early fall (Burbidge 1974, Kissil 1974, Stokesbury and Dadswell 1989, Yako 1998, Jones 1999), we expected that juvenile herring would be present in Unicorn Lake during the summer sampling periods. However, only 1 juvenile alewife and no juvenile blueback herring were observed in the lake in 1998. The apparent lack of recruitment in 1998 may have been attributable to a high rainfall event that occurred after the 26 April spawn. The majority of blueback herring spawning activity occurred on this date with most fish spawning near the dam in Unicorn Lake. Although initially adhesive, eggs become pelagic after several hours and may have washed over the dam during high flow. Although few alewife spawned in the lake, spawning occurred prior to the rain event and juveniles may have been large enough to resist water current and remain in the lake.

In 1999, subsequent sampling recovered both river herring eggs and larvae but no juveniles. Late spring and summer of 1999 were drought conditions in Maryland and Delaware, water levels dropped below the top of the dam in Unicorn Lake by early June. The only way for juveniles to emigrate from Unicorn Lake was to pass over the dam spillway before this time. Although larval river herring could have left Unicorn Lake shortly after hatching, it was unlikely because of low flows and the distance many fish were spawned from Unicorn Dam likely impeded migration for most fish before water stopped flowing over the dam. Therefore, juveniles were trapped in Unicorn Lake until water level increased in September. Because we did not collect any juvenile river herring we assumed there was no recruitment in 1999. This apparent lack of recruitment could have been attributed to poor water quality, predation of early life stages, lack of food or a combination of these factors.

Unsuitable water quality, including high pH and water temperatures, may also have been a factor in the lack of juvenile recruitment in Unicorn Lake. The pH in Unicorn Lake attained a maximum of 9.6 in August 1999, and during the spring, pH values were near the suggested upper tolerance for early life stages of river herring, possibly causing significant mortality in young river herring (Klauda et al. 1991, Kosa 1997). Likewise, a maximum water temperature of 32 C was recorded in early July and average summer water temperatures exceeded 29 C in Unicorn Lake in 1999, which were at or near the upper tolerance level for early life stages of river herring (Klauda et al. 1991). However, 10 juvenile alewife were collected in a hatchery pond adjacent to Unicorn Lake in June 1999. The pond was filled with water from Unicorn Lake, presumably containing eggs or larvae, during the alewife spawning run. The pond also experienced pH and water temperatures similar to the lake but was successful in rearing alewife (S. Compton, MDDNR, pers. commun.).

Predation on eggs and larvae may have impacted river herring recruitment in Unicorn Lake. Although it was not quantified, we observed juvenile sunfish *(Lepomis)* feeding on river herring eggs in the lake. Unicorn Lake also has a large population of golden shiners, which are noted to consume eggs and larvae of shad and river herring and have had significant impacts on production in other systems (Edsall 1964, Loesch 1987, Johnson and Dropkin 1992, Rottiers and Johnson 1993).

Zooplankton, the primary food source for juvenile river herring, were sampled during late spring and early summer in Unicorn Lake and numbers were found to be well below the number considered suitable (≥100 zooplankton/liter) for river herring production (Pardue 1983). It may be possible that the juveniles had an insufficient food source in the lake to survive through the fall migration period. Burbidge (1974) suggested low zooplankton densities (<3.25 zooplankton/liter) have been responsible for absence of river herring early life stages in some areas. The presence of alewives in fish rearing ponds, where artificial feed was dispensed, further suggests that food availability may have been too low in the lake to sustain herring production.

Despite the apparent lack of recruitment in Unicorn Lake, juveniles were abundant in Unicorn Branch during the study in 1999. Numbers of river herring collected generally decreased throughout the study when adjusted for effort and few juveniles were present by mid-September in Unicorn Branch and in the mainstem of the Chester River. Hurricane Floyd increased water flow in the Chester River system in early September 1999, at which point most herring had apparently migrated out of the system.

In conclusion, slight modifications made to the fish ladder at Unicorn Lake greatly increased passage success for river herring. Despite passing substantial numbers of river herring into the previously blocked lake and tributary, juvenile production was not successful, possibly due to a combination of biotic and abiotic factors. Although fish passage facilities can potentially open miles of upstream habitat for spawning anadromous fish, successful use of the fishway and production of juveniles in the impoundment above the fishway are not guaranteed. Evaluation of fish passage facility use, available habitat, and recruitment of target species should be tools used to determine fish passage success rather than basing success on miles of tributary presumably re-opened by a passage facility.

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