Title: Evaluating a technical fishway for river herring passage

Abstract

**Introduction**

Herring in general

Herring NJ

Dams and herring

The hypothesis:

*Given the relative number of herring generally seen in the tailwater compared to the low number observed in the ladder, the hypothesis is that the ladder is not passing herring “effectively.”*

**Methods**

*Study Site*

The study system is the South Branch of the Metedeconk River located in the northern portion of Ocean County, New Jersey, USA (Figure 1). The South Branch Metedeconk has a total drainage area of 7,980 ha and joins with the North Branch of the Metedeconk River to form the second largest freshwater input to the Barnegat Bay-Little Egg Harbor estuary system. Approximately 3.5 river kilometers upstream from the confluence with the North Branch, and 10 river kilometers upstream of the mouth of the river, is Lake Shenandoah. The lake (18 ha in size) was formed in 1968 when a spillway dam was placed across the South Branch Metedeconk and the lake was excavated as part of the construction of a county park facility. Prior to 1968 there was a small spillway dam across the South Branch Metedeconk that likely impeded fish migration at lower flows. The 1968 crescent spillway was built at a height of 3-meters, and was (and remains) the downstream most barrier to fish migration on the waterway. The next barrier to fish migration is the dam at Lake Carasaljo, nearly 2 kilometers upstream.

The first fish ladder was constructed at Lake Shenandoah during the 1968 park construction project. The fishway was a Model A steeppass, and was based on plans from the St. Regis Paper Company fishway on the Machias River in Maine. In 1993 improvements were made to the fishway as part of a larger project at the park; the entrance to the fishway was extended by 1 meter, the turning pool was extended from 1.2 to 1.5 meters, and the exit was reconstructed and slightly extended. Under the current configuration the slope of the fishway is approximately 18.5% (Figure 2 photo of the ladder/drawing?).

*Fish Collection*

River herring were collected during the spring spawning runs of 2013 and 2014 and were injected with RFID tags for the telemetry portion of the study. A modified fyke net (X by X by X rectangular holding pen, 3.175 cm mesh; 2.5cm mesh wings) was deployed approximately 60 meters downstream of the fishway entrance, with the wings blocking the entire width of the river. Fyke net deployments began each year when herring were first observed at the base of the day (generally the second week of April), with the duration of the individual deployments varying depending on weather/flow conditions, but never exceeding more than 4 continuous days. The net was tended at least every 24 hours, with the frequency increasing during peak migration. All fish captured were identified to species and their lengths recorded. River herring were also weighed and then placed into an in-water holding pen for observation. If a fish appeared to be healthy it was removed from the holding pen and scanned for an RFID tag. If no tag was present several scales were removed from the left ventral surface of the fish just posterior to the pelvic fin and an Oregon RFID half duplex passive integrated transponder (PIT) tag (12mm x 2.2mm) was inserted via hypodermic needle into the body cavity. Tagged fish were placed into a separate in-water holding pen for 5-10 minutes for observation; healthy fish were released on the upstream side of the fyke net while less vigorous fish were held for an additional 15 minutes. At the end of that period all live fish were released upstream of the net.

The ages of river herring captured in the fyke net towards the end of 2013 and in 2014 were also determined using scales. Scales (10-15) were removed from an area ventral of the dorsal fin and placed in a coin envelope, with the date, location, species, length, weight, and PIT tag code written on the outside. Scales were brought back to the office and allowed to dry before being placed back into the envelope for storage. Age analysis of river herring scales was conducted at the Barnegat Bay Partnership’s (BBP) laboratory following the protocols developed by the Atlantic States Marine Fisheries Commission 2013 River Herring Ageing Workshop (ASMFC 2014). BBP personnel underwent a one-day training/refresher session conducted by the lead herring ageing team of the New York State Department of Environmental Conservation prior to analyzing any scales collected. When river herring suffered in-net mortality both scales and otoliths were collected and ages were cross-validated for those individuals.

*PIT Array*

To assess fish passage through the fishway we deployed a three-antenna array. The upstream most antenna (A1) was placed in the stop log slot in the fishway exit, while the middle antenna (A2) was placed in the stop log slot in the fishway entrance (Figure 2). The downstream most antenna (A3) spanned the width of the stream, was oriented vertically, and was located approximately 1.5 meters from the entrance to the fishway. The antennas were constructed of PVC tubing with two loops of 10awg THHN wire separated by corrugated plastic inside. A marker tag was attached to each antenna to ensure system reliability. The antennas were connected to an Oregon RFID multi-antenna HDX reader placed inside a waterproof job-site box located on land adjacent to the ladder exit. The system was powered via two 225AH 12V deep cycle marine batteries, also placed inside the job-site box. The batteries were replaced twice a week, during which time the data were downloaded from the receiver via laptop computer.

*Environmental Data*

A variety of environmental data, both discrete and continuous, was collected as part of the project. At each fish tagging event temperature, dissolved oxygen, pH, and salinity was measured using a YSI Pro Plus handheld water quality meter. Stream flow (m/s) was also recorded at the fyke net and within the fishway exit using a Swoffer Model 2100 digital current meter at each tagging event. The US Geological Survey (USGS) also maintained a streamflow monitoring station (USGS 01408151) approximately 0.5 km downstream of the fishway that measured daily mean discharge.

A Hobo Tidbit continuous temperature logger was installed near the fishway exit, and recorded temperature at 20-minute intervals throughout the project period. Preliminary review of the data from the logger suggests that it was not fully submerged during certain periods over the course of the two years, likely due to displacement from storm events. To obtain a complete temperature record, temperature values from a USGS meter on the Tom’s River (USGS 01408500), a similar waterbody in an adjacent subwatershed, were compared to the values obtained from the Hobo during April of both years. This time represents a period of high confidence in the quality of the Hobo data. A linear regression between the two yielded an R-squared value of 0.9314 and a p value <0.0001. The equation was then used to predict the temperature values for our site. When comparing the predicted values to the actual values obtained in April, all of the predicted values were within one degree C of the actual values.

*Data methods*

Using the information collected from the telemetry array, we were able to determine the number and percentage of tagged herring who continued their upstream migration to approach the dam and fishway (recorded on A3). From this subset of herring we could then calculate the percentage that were able to successfully locate the fishway entrance (recorded on A2), the percentage that were able to successfully pass through the fishway (recorded on A1), the time spent in the ladder for a successful passage (timestamp A1- timestamp A2), and the time spent in the ladder for an unsuccessful passage (timestamp A2-timetamp A2). The detection range for the antenna at the entrance to the fishway did not extend past the concrete structure under most conditions. As such all presences at A2 were assumed to be attempts to enter the fishway. All presences at A1 were assumed to be successful passage of the fishway given the location of the antenna.

For the data analysis, we ran a survivorship function using the product limit estimate and Kaplan Meier Life tables to estimate proportional rates of passage rather than total rates. We also ran a cox proportional hazards test to determine the importance of several variables in determining passage success. The variables used were: Species, Length, Weight, Fulton’s Condition Index, Flow, Temperature, Release Group, and Total Attempts. Flow was the downstream flow measured at the USGS stream gage just downstream of the site, instead of the ladder flow as the measurements were taken from the top of the ladder and at the fish weir only on tagging days, which wasn’t consistent enough for analysis. Because many of our variables for the Cox’s proportional hazard model were time dependent (number of attempts, flow, temperature) we used a time-event database to set up the model, where every day of the model is considered one event and clustered by ID number. After running the Cox model, it was determined that the significance of Total Attempts may have been exaggerated as an attempt was required to pass. The model was re-run using a modified Attempts factor that did not include a successful pass as an attempt, and only unsuccessful attempts were counted.

Multiple antenna hits on one day were counted as just one attempt as the array setup did not lend itself to parsing out the difference between swim-byes, hanging out near the antenna, and actual attempts to pass the fish ladder.

All data analysis was conducted using the R statistical computing package v3.5.1 (R Core Team 2018). PIT tag data was organized and array detection efficiency (the percentage of fish recorded on an upstream antenna that was not captured on the immediately preceding antenna) computed using the PITR package (Harding et al. 2018)). Means of fish morphometric data were compared via the non-parametric Mann-Whitney test in base R. Survivorship function and cox proportional hazard tests were conducted in XX (reference).

**Results**

*Fish Collection*

We tagged a total of 396 river herring over the course of the two years; 26 alewife and 113 blueback in 2013 and 55 alewife and 202 blueback in 2014 (Table 1). Tagging began April 9 and April 15 in 2013 and 2014, respectively, when alewife were first observed at the dam. Approximately a week after initially observing alewife at the dam bluebacks arrived and quickly became the dominant species captured. Tagging continued until May 7 in 2013 and May 22 in 2014, at which point a majority of the available tags were deployed. We were able to determine the ages of 45 tagged bluebacks in 2013 and 166 bluebacks and 33 alewife in 2014.

Tagged river herring were larger and older in 2013 than 2014, and alewife tended to be larger and older than bluebacks. Mean length across both species in 2013 (232.5 mm) was significantly longer than 2014 (216.2 mm; W = 28385, *p*<0.001), and on average alewife (230.7 mm) were larger than bluebacks (219.7 mm; W=8150, *p<*0.001). The difference in length between species was more pronounced in 2014 (mean of 227.5 mm to 213.2 mm) than 2013 (mean of 237.7 mm to 232.2 mm). The youngest fish tagged were age 3 in both years, while the oldest fish tagged in 2013 and 2014 were ages 6 and 5, respectively. Fish were slightly older in 2013 than 2014 (3.9 years compared to 3.5 years; W=6198.5, *p*<0.001), and alewife were older than bluebacks across both years (3.8 years compared to 3.5 years, W=2622, *p*<0.01).

*PIT Array*

The antenna array was active throughout the majority of the spawning season in both years, and detection efficiency varied by antenna. In 2013 antennas 1 and 2 began recording on April 15, with antenna 3 coming online on April 22. All three antennas remained on until June 19, with the exception of a 24-hour period on May 21-22 and a 36-hour period on June 2-4. In 2014 antennas 1 and 2 began recording April 11 and continued recording data until the system was decommissioned on July 1. Antenna 3 came online April 24, but was damaged and permanently disabled on the evening of May 2 by debris from a severe storm. Weekly detection efficiency for antenna 2 was 100% in 2013 and ranged from 90% to 100% (mean = 98%) in 2014, when calculable. The weekly detection efficiency for antenna 3 in 2013 averaged 63%, while in 2014 it was 66% during the brief period it was in operation.

*Environmental data*

I need some sort of opening statement. Mean daily river discharge in the spring (April-May) tended to be higher in 2014 than 2013, but summer (June) discharges were higher in 2013 (Figure 3). Mean daily river discharge values typically ranged between 40cfs and 100cfs, though higher discharges associated with storm events were recorded, particularly on June 11 2013 and May 1-2 2014, when values were 2.5 and 4 times greater than normal, respectively. Discrete sampling of water velocities within the exit to the fishway and at the fyke location during fish sampling events revealed relatively steady flows within the fishway across both years (0.63-1.19 m/s, mean of 0.94 m/s), while there was substantially more variability at the fyke location (0.11-0.79 m/s, mean of 0.53).

Mean daily water temperatures generally increased throughout the study period in both years, though dramatic changes driven by meteorological events are present (Figure 5). Water temperatures in the beginning of April were approximately 10C, increasing to near 25C by the beginning of July in each year. There was no significant difference in mean temperature between the two years (pairwise t-test, *p*=0.4). River herring were first observed in the study area as temperatures approached 12C.

*Fishway Efficiency*

From the pool of 139 fish tagged in 2013, 33 were detected within the antenna array. Thirty-two individuals were detected at the downstream most antenna, with the first detection on April 22 and the last on June 6. Individual fish were detected as few as one time up to multiple detections over the course of 32 days. Fourteen fish were detected at the entrance to the fishway, including one individual that was not recorded at the downstream antenna. Almost half of these fish were detected over the course of less than one minute each, with the remainder detected multiple times over timespans from 5 hours to 11 days. Only 2 fish (one alewife, one blueback) successfully transited the fishway, doing so in one minute and forty seconds and eight minutes, respectively.

Utilizing the 2013 antenna array data with no corrections for detection efficiency, approximately 24% (33 detected within the array/139 total tagged) of the tagged fish continued their upstream migration, and 41% (14/34) of the herring that approached the dam in 2013 were able to locate the entrance to the fishway. Of those fish that located the fishway entrance 14% (2/15) were able to successfully transit. Utilizing a detection efficiency of 63% for the downstream antenna throughout 2013 suggests that 51 tagged fish (37%) continued their migration, leading to an attraction rate of 29% (15/51).

In 2014 70 different fish (55 blueback, 15 alewife) were detected within the antenna array, four of which (3 blueback, 1 alewife) had been tagged the previous year. During the eight days in which the downstream antenna was functioning six alewife and three blueback were detected. Six of those fish (four alewife, two blueback) plus an additional 60 fish (9 alewife, 51 blueback) were detected at the entrance to the fishway. Slightly more than one third (n=25) of these fish were detected over the course of less than one minute each, though seven were subsequently recorded at the exit to the fishway. The remainder were detected multiple times over timespans of 2 minutes to 21 days. A total of 19 fish successfully exited the fishway (15 blueback, 4 alewife), including 2 blueback that were tagged in 2013. Time spent transiting the fishway ranged from slightly less than two minutes up to nineteen minutes. Additionally, one alewife was recorded traversing the ladder headed upstream on May 24 and then again heading downstream 11 days later on June 5.

Because the downstream antenna was only operational for a brief period of time in 2014 the percentage of fish that continued their migration after tagging, and the attraction efficiency of the fishway, cannot be reliably calculated. However, the percentage of herring that were able to successfully transit the fishway in 2014 (28%) was double that of 2013. Utilizing the mean detection efficiency of 98% for the fishway entrance antenna suggests that 67 fish would have attempted passage, leaving the passage success rate essentially unchanged.

*Fancy Math*

How long do we say a fish is no longer detected at A3 before it has abandoned the approach zone? Given it is only 63% efficient we likely miss many detections.

**Discussion**

Comparison to other ladder findings

Herrings – Archer, new report – but those mostly alewives, ours bluebacks?

How did fish that passed compare to those that didn’t – lengths. I.e. because of the issues with the ladder was there a sweet spot to passing – too large couldn’t get in, too small weren’t strong enough?

Did the fish tagged in 2013 that came back in 2014 pass the ladder either time?

Other species

Fallback\*\*\*\*\*\*\*\*

Using Fancy Math

Problems with ladder

Attraction flow – USFWS report

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**Literature Cited**

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