Study Report for the Downstream Juvenile Alosine Passage Assessment

Lawrence Project (FERC No. 2800)

Prepared For
Essex Company, LLC
A subsidiary of Patriot Hydro, LLC

Prepared By
Normandeau Associates, Inc.
25 Nashua Road
Bedford, NH 03110
www.normandeau.com

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1 Introduction

Essex Company, LLC (Essex), a subsidiary of Patriot Hydro, LLC, is the Licensee, owner, and operator of the Lawrence Hydroelectric Project (Project or Lawrence Project), which is Federal Energy Regulatory Commission (FERC or Commission) Project No. 2800. The Project was licensed by the Commission on December 4, 1978 (with an effective date of December 1, 1978), and the license expires on November 30, 2028. The Lawrence Project is located on the Merrimack River in the City of Lawrence in Essex County, Massachusetts.

In accordance with 18 C.F.R. § 5.15, Essex has initiated studies and information gathering activities as provided in the study plan and schedule approved by the Commission. Among the studies undertaken during 2025 was the Downstream Juvenile Alosine Passage Assessment, the scope of which was identified by the Commission in their May 10, 2024, Study Plan Determination (SPD). Prior to the 2025 study period, Essex held a July 29, 2025 consultation meeting onsite at the Lawrence Projects along with representatives from their operational group (PIC Group), Normandeau, Massachusetts Division of Marine Fisheries (MADMF), Massachusetts Division of Fish Wildlife (MADFW), New Hampshire Fish and Game Department (NHFGD), and the National Marine Fisheries Service (NMFS) to review the field methodology for the control, downstream bypass, and spillway components of the study. Consensus was reached on conducting the spillway portion of the juvenile alosine passage assessment by opening the inflatable bladder section abutting the north shoreline. This report describes the Licensee's 2025 implementation of the study plan and schedule, the data collected, and any variances from the study plan and schedule.

2 Project Description

The Lawrence Project works consist of: (1) the 35-foot-high by 900-foot-long gravity Essex Dam of stone masonry construction (also known as the Great Stone Dam), with a five-foot-high pneumatic crest gate system mounted on the spillway crest; (2) a 9.8-mile-long impoundment having a surface area of 655 acres at a normal water elevation of 44.17 feet National Geodetic Vertical Datum of 1929 at the top of the crest gates, and gross storage capacity of approximately 19,900 acre-feet; (3) a powerhouse located at the end of a small forebay adjacent to the south abutment of the Essex Dam containing two 8.4 megawatt generating units and a tailrace channel extending into the Merrimack River channel; (4) fish passage facilities integral with the powerhouse, including a fish lift, downstream fish bypass, an eel lift at the left abutment of the dam, and an eel ladder at the right abutment of the dam; (5) the North Canal, approximately 5,300 feet long by 95 feet wide by 15 feet deep, originating at the north abutment of the dam and paralleling the Merrimack River downstream of the Essex Dam; (6) the South Canal, approximately 2,750 feet long by 35 feet wide by 10 feet deep, originating at the south abutment of the Essex Dam and generally paralleling the Merrimack River downstream of the Essex Dam; (7) a single-circuit, underground/underwater 23.0-kilovolt transmission line to the Massachusetts Electric Company's Lawrence No. 1 substation; and (8) appurtenant facilities.

The Lawrence Project's dam is equipped with an inflatable crest gate system split into three 300-foot sections. The system varies air pressure to adjust gate height to maintain normal headpond elevation at the Project based on river user needs, flow and weather conditions. The installation of the system eliminated the need for impoundment drawdowns required for flashboard replacement, enhanced river debris management with reduced debris build up near the dam, enhanced high flow condition management and reduced false fish attraction away from the fish passage facilities often caused by board leakage and partial board loss.

The downstream bypass facility is located on the shoreside (river right) of the Lawrence powerhouse and consists of a mechanically driven gate which is operated to provide surface spill from the adjacent forebay. The bypass has a surface channel that crosses the powerhouse and then descends through two plunging drops, the second conveying fish directly into the tailrace (Figures 2-1 and 2-2). The downstream bypass is typically operated at a flow of 160 cfs (2% of the hydraulic capacity of the Project units) during the entire fall migration period.

The study area for Downstream Juvenile Alosine Passage Assessment included the Project spillway focusing on the 300-foot inflatable gate section along the north side (river right) and the fish bypass that originates in the forebay and exits into the tailrace.

Figure 2-1 Downstream bypass conditions during the 2025 Downstream Juvenile Alosine Passage Assessment. Upstream plunge (left image) and tailrace plunge (right image) show conditions representing typical discharge (160 cfs).

Figure 2-2. **Relative location of the downstream bypass entrance, test fish release location, exit, and control fish release location associated with the Downstream Juvenile Alosine Passage Assessment at Lawrence.**

3 Goals and Objectives

The goal of this study was to determine if the Project operations negatively affect juvenile alosine survival. Specifically, direct survival of alosines passed downstream through the spillway and fish bypass was estimated using a HI-Z tag-recapture (i.e. balloon tag) evaluation. Specifically this study sought to:

- Estimate the immediate (1-hr) and latent (48-hr) survival and malady-free (MF) estimates with a precision of ±10% with 90% confidence for juvenile alosines passed downstream via the Project spillway and downstream fish bypass.
- Determine the type, severity, and probably cause of observed injuries.

4 Methods

4.1 Project Operations

During the fall downstream migration period (i.e., September 1 through November 15) the downstream bypass is opened and provides 2% of turbine flow. The bypass is most often operated at 2% (or 160 cfs) of the Project's turbine capacity (8,000 cfs) and is not typically altered with any reduced turbine outflow.

Spill occurs at the Project when inflow is in excess of the station capacity of 8,000 cfs. Under conditions where inflow is increasing and turbines are operating at maximum capacity, the crest gate control system will detect the rise in headpond level and respond by incrementally reducing rubber dam inflation to lower a crest gate panel to maintain normal pond level. On detection of decreasing headpond levels, the system will respond by raising the panels to maintain headpond levels and allow the Project outflow to approximate inflow. Inflow during the 2025 downstream migration timeframe (i.e., September 1 through October 15) was estimated as by prorating Merrimack River flows as measured at the Lowell USGS gage and ranged from 543 to 6,956 (Figure 4-1). Based on the flow duration curve for the fall migration period, inflow conditions are expected to exceed station capacity around 20% of the time (Figure 4-2).

Project operations during the Downstream Juvenile Alosine Passage Assessment are presented in Table 4-1. During testing on October 18, 2025, inflow ranged from 1,007-1,017 cfs and Unit 1 was operating continuously, passing between 460-589 cfs. The downstream bypass was operating at 160 cfs. Net head, headpond elevation and tailrace elevation fluctuated only slightly during the October 18 test date.

During the 2025 fall downstream migration season only the downstream bypass was tested. In order to properly evaluate the spillway, two days of extended flow release from a bladder section (up to three hours) would be needed to provide spill conditions for a duration of time adequate to tag, release, and recapture test fish. Inflow at the Project was too low to provide water for the spillway testing in a manner that would allow for timely recharge of the impoundment or demonstrate representative environmental conditions (see Figure 4-1).

Table 4-1. Summary of Project operations during the October 18, 2025 HI-Z tag-recapture testing at the Lawrence Project.

Parameter	Minimum	Mean	Maximum
Inflow (cfs)	1,007	1,011	1,017
Bypass Flow (cfs)	160	160	160
Turbine Flow (cfs)	460	598	938
Pond Level (ft)	44.31	44.34	44.36
Tailwater (ft)	12.93	13.14	13.57
Net Head (ft)	30.77	31.20	31.39

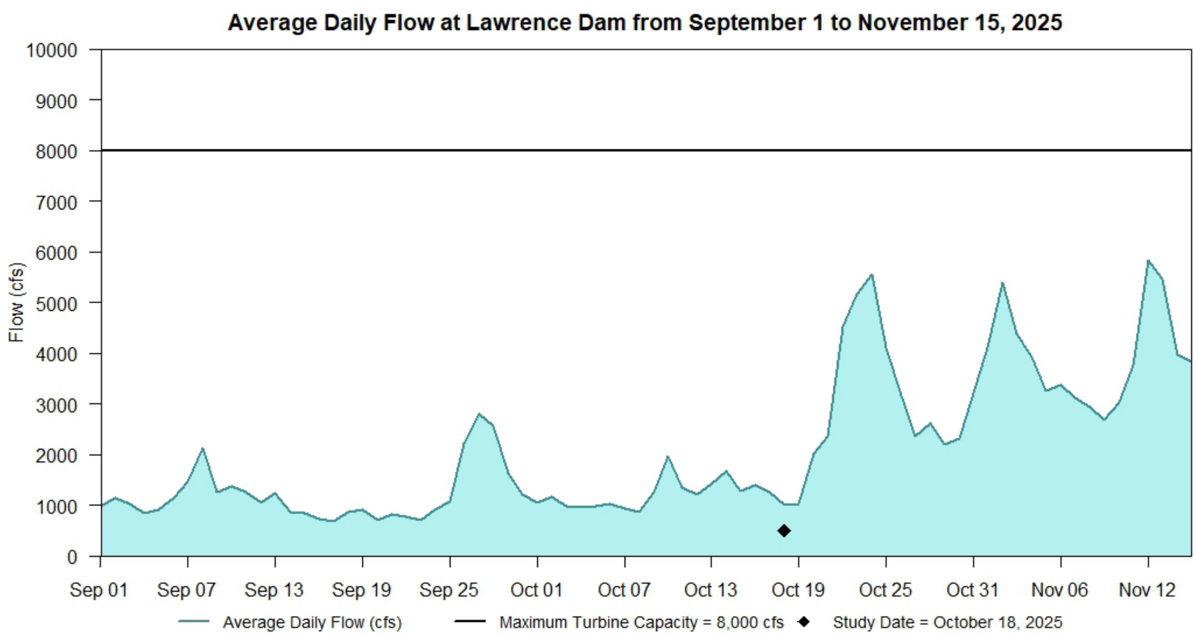

Figure 4-1. Inflow at Lawrence Hydroelectric Project for the September 1 – November 15, 2025 fall downstream migration period.

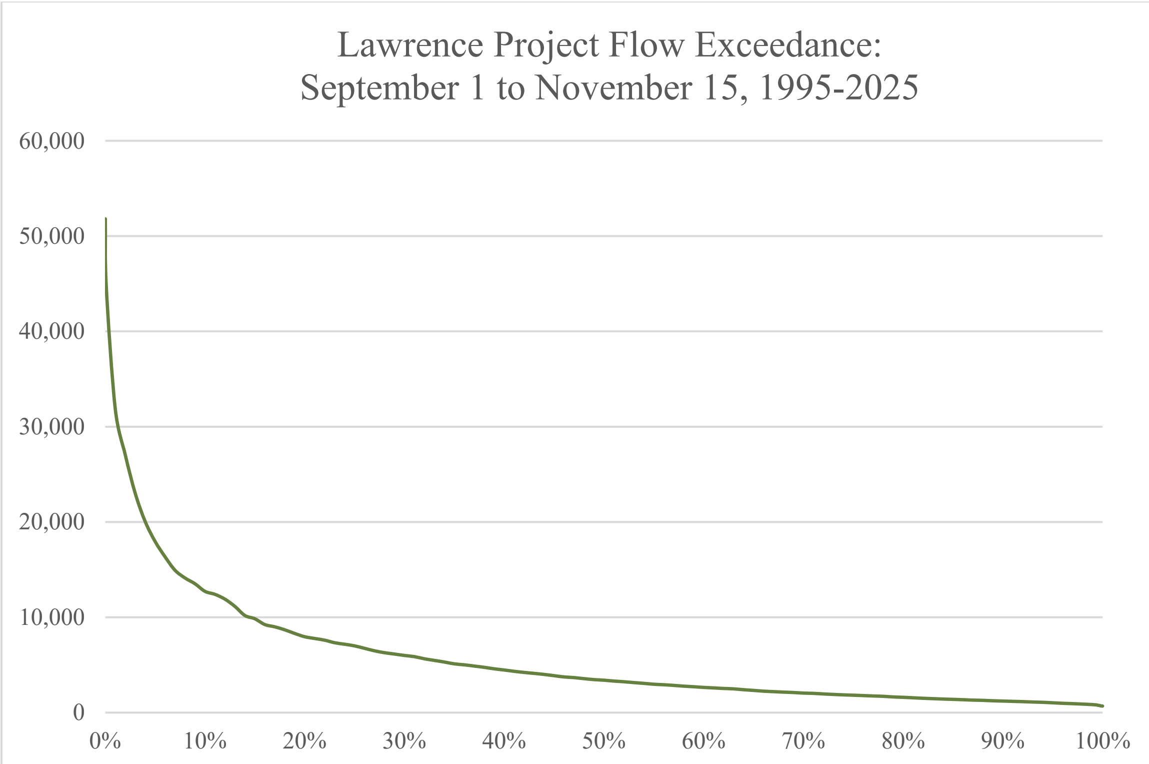

Figure 4-2. Flow duration curve (1995-2025) for the fall downstream migration period at Lawrence Hydroelectric Project (September 1 – November 15).

4.2 Sample Size Determination

One of the primary considerations associated with HI-Z Tag evaluations of direct injury and relative survival of downstream-passed fish is to release an adequate number of individuals such that the resulting survival estimates are within a pre-specified precision (ε) level (Mathur et al. 1996). The required sample sizes are a function of the recapture rate (P), expected passage survival ($\hat{\tau}$) or mortality (1-$\hat{\tau}$), survival of control fish (S), and the desired precision (ε) at a given probability of significance (α). In general, sample size requirements decrease with an increase in control survival and recapture rates. Only precision (ε) and α level can be strictly controlled by the investigator. For the purposes of this study, target releases of 60 treatment fish released for all experimental groups (spillway, bypass, control) were selected to obtain survival estimates with a precision (ε) of ±10% with 90% confidence. This sample size assumed 95% control survival, a recapture rate of ≥99%, and an expected passage survival rate between 85-90% (Table 4-2). During these HI-Z evaluations, the sample sizes can be adjusted in the field to obtain survival estimates that meet the study-specific precision goal.

Table 4-2. Required sample sizes for HI-Z Tag studies for a range of control survival, recapture rates, and passage survival.

Control Survival (S)	Recapture Rate (P_A)	Passage Survival ($1-\hat{\tau}$)	Sample Size
0.95	0.99	0.95	45
		0.90	54
		0.85	61
	0.95	0.95	67
		0.90	74
		0.85	80
	0.90	0.95	98
		0.90	103
		0.85	107

4.3 Source, Collection, and Holding of Test Fish

Wild juvenile alosines were collected by electrofishing from Pawtuckaway Lake, Lamprey River Watershed on October 10, 2025. Although no effort was made to identify individuals to species, only Alewife are stocked at this location. For the purposes of this evaluation, the collected individuals are assumed to be representative of juvenile American shad, Alewife, and Blueback Herring. Fish were transported to the Project in a 300-gallon insulated tank supplied with aeration and filled with 7.5 ppt brackish saltwater. Onsite, fish were held in a 1,000-gallon flexible vinyl circular tank maintained at approximately 600 gallons. Ambient river water was continuously supplied via two electric pumps powered by separate 110 outlets for redundancy. Fish were held for one week prior to testing and checked daily to ensure adequate holding conditions. No mortality was documented. Fish lengths ranged from 96 mm to 120 mm with an average of 107 mm between both treatment and control fish (Figure 4-2).

Prior to tagging, two airlift post-recapture recovery tanks were prepared, one for the treatment fish and one for the control fish. Tanks were filled with 175 gallons of ambient river water mixed with fine aquarium grade sea salt to achieve a concentration of 7.5 ppt saltwater. The tank was held static without inflow and fitted with an aeration stone within a standpipe to create gentle directional flow for fish orientation. Treatment and control fish were placed in designated recovery tanks after recapture for 24 hours. After that holding period, for the remainder of the 48-hour assessment, ambient river water was supplied to the tanks in a similar flow-through manner as the 1,000-gallon flexible circular tank (Deters et al., 2024) (Figure 4-3).

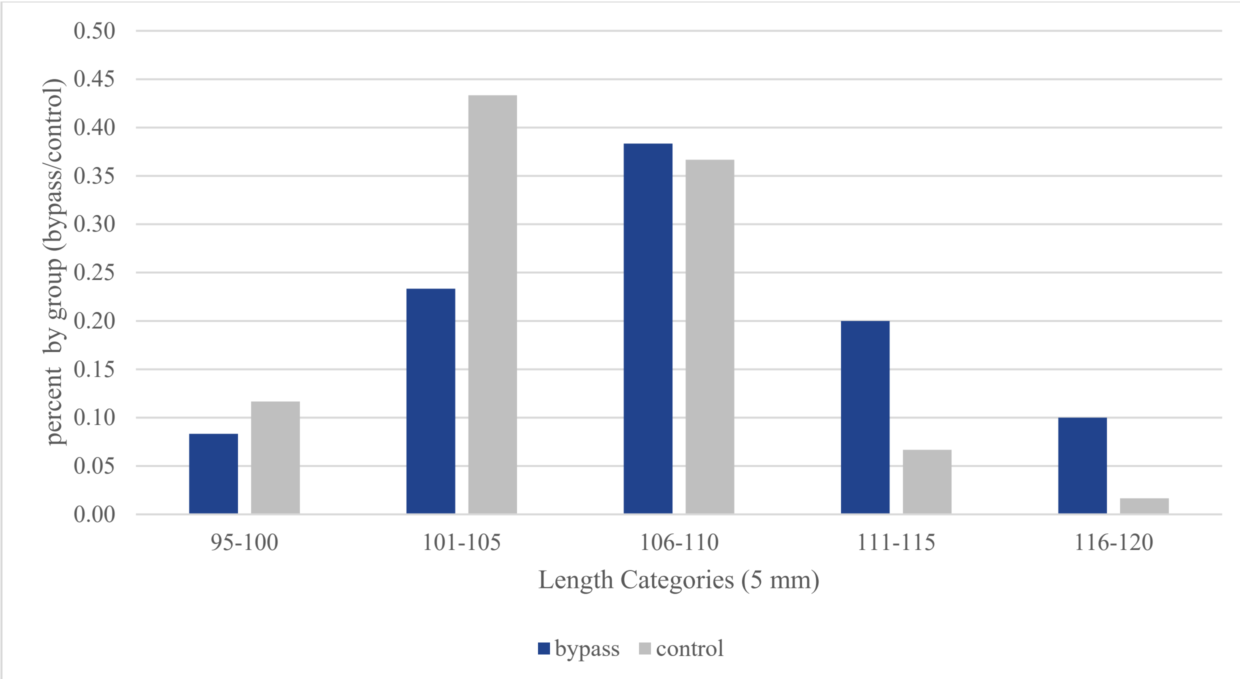

Figure 4-2. Length frequency distribution for juvenile Alewife by test condition (downstream bypass or control) released during the HI-Z mark-recapture study at Lawrence Hydroelectric Project, October 18, 2025

Figure 4-3 Fish pre-test holding facility (center) and post-recapture 48-hour delayed mortality airlift holding tanks.

4.4 Fish Tagging and Release

Fish tagging, release, and recapture techniques were similar to those used in HI-Z studies for juvenile alosines at other hydroelectric stations on the east coast (Heisey *et al*. 1992; RMC 1994; Normandeau Associates 1996, 2016; Normandeau Associates, Inc. and Gomez and Sullivan Engineers, P.C. 2012). Differing from those previous evaluations, anesthetizing juvenile alosines in a solution of MS-222 in 7.5 ppt brackish saltwater was used, a method that has been shown to improve survival during holding (Deters et al. 2024). As described in Section 4.1, a total of 120 juvenile alosines were released as part of the evaluation. Sixty fish were released into bypass while an additional sixty were released into the tailrace as a control group. Each fish was fitted with a neutrally buoyant miniature radio transmitter and one HI-Z Tag.

During testing, batches of ten to fifteen juvenile Alewife were collected from one of the supply holding tanks. Fish were concentrated using a seine net and transferred into a source fish container for tagging using a water-to-water transfer to minimize stress and handling. Fish were then placed into an aerated 5-gallon bucket filled with 7.5 ppt saltwater. A 7.5 ppt saltwater anesthetic bath was prepared as a solution of 120 ppm of MS-222 buffered with an equal concentration of sodium bicarbonate in an 8-liter bucket. Fish were placed individually in an anesthetic bath prior to tagging. Once fish displayed a total loss of equilibrium, fish were examined for any injuries prior to tagging and any observed pre-existing conditions, and the total length of the fish was recorded. A unique fin clip was also made to distinguish treatment and control fish. Fish showing erratic behavior or external injuries and/or fungal infections were rejected and not used.

Following sedation, measurement, and fin clipping, fish were tagged with a 0.5-gram radio transmitter weighing paired with a deflated HI-Z Tag. The tagging process included one HI-Z Tag attached via stainless steel pin inserted through the musculature beneath the dorsal fin allowing for fish to surface and ensure rapid recapture after release (Figure 4-4). Fish were then placed in fresh water to recover prior to release as either a control or treatment individual.

Prior to release, the HI-Z tag was activated by injecting a small amount of water that initiated tag activation for quick recapture. Treatment and control fish were both released through a fish injection system consisting of an elevated holding basin fitted with a 4-in discharge hose. River water was continuously supplied with a 3-in trash pump to ensure swift transport of fish to the designated release point. The release hose was lowered into the fish bypass and fixed in place approximately 5 meters downstream of the forebay entrance (Figure 4-4). Procedures for the control fish handling, tagging, and release were similar to treatment fish with only the release location, into the tailrace, varying. For both locations, fish were released near the water surface. Release locations are shown in Figure 4-5. Test fish released into the bypass ranged in size (total length, mm) from 100-120 mm with a mean of 109 mm. Control group fish ranged from 96-119 mm with a mean of 105 mm (Figure 4-2).

Figure 4-4. Juvenile Alewife with a single HI-Z tag attached by pin through the musculature below the dorsal fin.

Figure 4-5. Fish injection system with 4-inch diameter hose connected (left image) and deployed at the fish bypass downstream of the forebay (right image)

4.5 Recapture

Prior to release, boat crews were provided with the radio frequency (48 MHz) and radio-tag ID for each fish to be released. After release (treatment or control) recapture crews situated in the tailrace were notified via two-way radio as each fish was released into the bypass. To eliminate crew bias, boat crews were not assigned to recapture specific groups of fish (treatment or control). Fish were tracked by boat within the tailrace and downstream of the fish bypass system and retrieved once buoyed to the surface by an inflated HI-Z Tag using an Advanced Telemetry System R2000 receiver coupled with a loop antenna (Figure 4-6). Active radio transmitters that fail to surface were tracked for the remainder of the day to determine if fish moved downstream after release. Buoyed fish were retrieved using a long-handled net equipped with a water basin. This aided crews in maintaining water to water transfer techniques to safely place fish into an onboard recovery bucket. To minimize stress, no more than 5 fish were placed in one bucket. Each recovery bucket was also equipped with a bubbler. Buckets were filled with approximately 2.5 gallons of ambient river water mixed with a salt concentration of 7.5 ppt.

Fish associated with active transmitters that failed to surface were tracked throughout the day to determine whether those transmitters are suspected of being dislodged from the fish, continuing to display downstream movement patterns typical of emigrating alosines, or show rapid movement within the tailrace into and out of turbulent areas (typical of predation).

After recapture, the HI-Z Tag was removed, and each fish was immediately examined for maladies consisting of visible injuries and/or loss of equilibrium (LOE or disorientation). Tagging and data recording personnel were then notified via a two-way radio system of each fish’s recapture time, and disposition.

Recaptured fish were then transported and placed into their designated airlift tank to assess potential delayed effects of passage through the downstream bypass. The airlift system remained static (i.e. not flow through with ambient river water) with aerator powered directional flow for 24-hours to maintain the 7.5 ppt salinity. After 24-hours ambient river water was supplied to the tank and remained a flow through system until 48-hour delayed assessments were complete.

Figure 4-6. Recapture boats in the tailrace of Lawrence Hydroelectric Project.

4.6 Classification of Recaptured Fish

As in previous HI-Z Tag evaluations, the immediate post-passage statuses of individual recaptured fish were designated as either alive, dead, predation, or unknown. The following criteria were used to make these designations: (1) alive: the fish was recaptured alive and remained so for one hour; (2) alive: the fish did not surface, but radio signals indicated movement patterns typical of adult fish; (3) dead: recaptured dead, or died within one hour of release; (4) dead: only inflated dislodged tag(s) were recovered, and the manner in which inflated tags surfaced was not indicative of a live fish or based on radio telemetry signals indicative of a dead fish; and (5) unknown: no fish or dislodged tags were recaptured, or radio signals were received only briefly, and the subsequent status could not be ascertained. Data recording personnel recorded a live or dead code for each fish and a designated status code was assigned to describe the disposition of each fish based on the criteria presented in Table 4-3. Appendix A provides the codes assigned to each individual fished released during the study.

Mortality of recaptured fish after 1 h post-passage were considered 48-h mortality. The condition of fish was evaluated at intervals of approximately 12 hours. Dead fish were examined for descaling and injury and were necropsied to determine the probable cause of mortality.

Table 4-3. Designated status codes assigned to recaptured HI-Z tagged fish.

Status Code	Description
1	fish recaptured without passage-related maladies
2	fish recaptured with passage-related maladies
3	fish recaptured with loss of equilibrium only (LOE). If the fish recovered within 15 minutes, then the Status was changed to 1
4	fish recaptured with a tear at the tag site (HI-Z Tag dislodged)
5	fish not recaptured; stationary radio signal
6	fish not recaptured; mobile radio signal
7	fish not recaptured and a single, detached HI-Z Tag is recaptured
8	fish not recaptured and multiple detached HI-Z Tags are recaptured
9	fish not recaptured and likely preyed upon based on telemetry or other info
10	replaced; unrecoverable conditions
11	replaced; trapped
12	replaced; failed to enter system
13	other information
14	no information

4.7 Assessment of Injuries

Recaptured fish were transferred to onsite 8-ft-diameter circular holding tanks equipped with a redundant water supply via electric, submersible pumps. Fish were held for 48-h to monitor delayed mortality using holding methods described in Section 4.5. A final thorough injury examination occurred at the end of the 48-h holding period to detect injuries that may not have been apparent or were overlooked during the initial evaluation at recapture. Photographs of dead and injured fish were taken after the 48-h holding period.

All recaptured fish were examined for the type and extent of external injuries. Any dead and injured fish were necropsied and examined for internal injuries if the cause of death was not obvious (severance, decapitation, major bruising, damaged gills, etc.). However, all fish were recaptured alive and remained so for the 48-hour assessment. Injuries were categorized by type, extent, and area of body, and they were documented with digital photographs (Appendix B). Fish without visible injuries that were not actively swimming or were swimming erratically at recapture were classified as having LOE. This condition has been noted in previous HI-Z Tag direct survival/injury studies and often disappears within 15 to 30 minutes of recapture if the fish is not injured. Each fish was assigned one or more malady codes based on the initial examination of external injuries and on any internal injuries documented during the necropsy, if they were applicable (Table 4-4).

A malady classification was established to include fish with injuries, scale loss >20%, and/or LOE. Fish without maladies were designated “malady-free” (MF). The MF metric is established to provide a standard way to depict a specific passage route’s effect on the condition of entrained fish. The MF metric is based solely on fish physically recaptured and examined (Normandeau and

Skalski 2005). Maladies, which include visible injuries and LOE, were categorized as minor or major. The criteria for this determination were based primarily on field staff's previous field experience (Table 4-5).

Injuries likely to be associated with direct contact with structural components were classified as mechanical and include bruising, lacerations, and severance of the fish body. Contacting concrete structures within the passage route may also result in swaths of scale loss. Also, with submerged rocks or concrete structures at the discharge areas of spill can also be an attribute to these injuries. Injuries likely to be attributed to shear forces are decapitation (with the isthmus attached to the body and a slanted wound), torn or flared opercula, and inverted or broken gill arches. The probable pressure-related effects are manifested as bloody eyes, ruptured/bulging eyes, air bladder rupture, hemorrhaged internal organs, and embolism; however, shear forces can also inflict hemorrhaged/ruptured eyes, and most eye injuries resulting from turbine and spillway passage have been attributed to shear forces (Pflugrath et al. 2021).

Probable causes of injury (e.g., mechanical, shear, or pressure-related) were ascribed to each injured fish depending on the observed injury characteristics. In the case of some injuries, probable causes cannot be attributed directly to one source. However, in other instances the unique characteristics of the observed injuries could be used to delineate specific causes of injury.

Table 4-4 Designated malady codes assigned to recaptured fish

Injury Code	Description
A	no visible injuries and fish and did not display LOE
B	damaged gill(s): hemorrhaged, torn, or inverted
C	damaged operculum: torn, bent, removed
D	major scale loss (>50%)
E	minor scale loss (>20%, but <50%)
F	damaged eye(s): hemorrhaged, bulged, ruptured, or removed
G	severed or nearly severed body
H	decapitated or nearly decapitated
I	laceration(s): tear(s) on body or head (not severed)
J	torn isthmus
K	hemorrhaged or bruised head or body
L	fin damage: displaced, hemorrhaged, ripped/torn, or removed
M	abrasion/scrape
N	LOE and remaining so for >15 minutes
O	tear at the tag site (HI-Z Tag dislodged)
P	predation injuries/marks
Q	substantial bleeding at tag site(s)
1	swim bladder ruptured
2	damaged kidneys
3	broken bones obvious
4	internal hemorrhaging

Injury Code	Description
5	organ displacement
6	heart damage (ruptured, hemorrhaged)
7	liver damage (ruptured, hemorrhaged)
8	necropsied; no internal injuries observed
9	spine damage (broken vertebrae, hemorrhaged)

Table 4-5 Guidelines for major and minor injury classifications for fish passage survival studies using the HI-Z Tag Method

Injury/Condition	Classification	
	Major	Minor
Loss of equilibrium (LOE) only	Fish dies within 1 h	Fish survives beyond 1 h
No visible external or internal injuries	Fish dies within 1 h	Fish survives beyond 1 h
Any minor injury	Fish dies within 1 h	Fish survives beyond 1 h
Hemorrhaged eye(s)	>50% hemorrhaged	<50% hemorrhaged
Deformed pupil(s)	Always considered major	N/A
Bulged eyes	1 or both eyes entirely bulged	Only one eye slightly bulged
Bruises	>10% of body per side	<10% of body per side
Operculum tear	>5% of operculum	<5% of operculum
Operculum folded under or torn off	Always considered major	N/A
Bleeding from gills	Fish dies within 48 h	Injury is healed and fish survives 48 h
>20% scale loss	Always considered major	N/A
Scrape (damage to epidermis)	>10% per side	<10% per side
Cut/laceration	Generally, any cut/ laceration	Small flap of skin cut/torn
Internal hemorrhage or ruptured organ	Fish dies within 48 h	Fish survives beyond 48 h
Broken backbone	Always considered major	N/A
Multiple injuries	Dependent upon worst injury	

4.8 Survival and Malady-Free Estimation

Survival and malady-free (MF) estimates were calculated for the bypass. The MF metric provides a standardized way to depict a specific passage route's effect on the condition of passing fish and was based solely on fish recaptured and examined. The MF metric did not include fish that were assumed to be either dead or alive based on telemetric information or the recovery of inflated HI-Z Tags only.

Passage survival or MF rates were estimated relative to the respective control rates using the likelihood model given in Mathur et al. 1996.

The estimators associated with the likelihood model are:

For estimating survival ($\hat{\tau}$):

$$\hat{\tau} = \frac{a_T R_c}{R_T a_c}$$

where:

R_T = number of fish released for the treatment condition;

a_T = number of fish alive for the treatment condition;

R_c = number of control fish released; and

a_c = number of control fish alive.

For malady-free (MF):

$$MF = \frac{m_T E_c}{E_T m_c}$$

where:

E_T = number of treatment fish examined for maladies;

m_T = number of treatment fish without maladies;

E_c = number of control fish examined for maladies; and

m_c = number of control fish without maladies.

MF rates were based on the proportion of recaptured fish without passage-related visible injuries, LOE, and/or scale loss (>20%) or fish with injuries that are not attributable to passage.

5 Results

HI-Z tag-recapture testing was conducted on October 18, 2025. Insufficient inflow during the fall downstream migration season precluded the ability to refill the impoundment in a timely manner following the duration of spill releases required for spillway testing. As a result, testing was limited to the assessment of the downstream bypass (and associated control fish to adjust for handling effects). A total of 60 juvenile test fish were successfully tagged and released at the upstream entrance of the downstream bypass facility[1] and 60 juveniles were tagged and released directly into the tailrace as controls (Figure 2-1).

5.1 Recapture Data

The recapture rates for juvenile Alewife released for the fish bypass treatment was 90% (54 out of 60 released fish). Of the six-treatment fish not recaptured in the bypass assessment, five were assigned a 'dead status' based on consistent stationary radio-tag detections while one was unknown after not being detected post release. Physical recapture rate of the control fish was 100% (60 out of 60 released fish) (Table 5-1). The time at large (time elapsed between release and recapture) for treatment fish ranged from 3 to 20 minutes. The recapture time for control fish ranged from three to 13 minutes with both groups averaging around 7 minutes (Figure 5-1).

Table 5-1 Release and recapture data for the downstream bypass treatment and control fish released as part of the 2025 Downstream Juvenile Passage Assessment at Lawrence

Parameter	Bypass	Control
No. Released	60	60
No. Recaptured alive	54	60
No. Recaptured dead	0	0
No. Assigned alive	0	0
No. Assigned dead	5	0
No. Unknown	1	0
Physical Recapture Rate	**90.0**	**100.0**

[1] During the July 29, 2025 site visit, it was discussed that testing for the downstream bypass would rely on releases occurring toward the downstream portion of the powerhouse where fish would immediately be subjected to the first plunging flow. During testing on October 18 an assessment of the bypass at full flow indicated fish placed at the upstream end would provide a more comprehensive assessment of the full experience of passage through the downstream bypass and allow fish to approach the first plunge in a manner similar to wild fish.

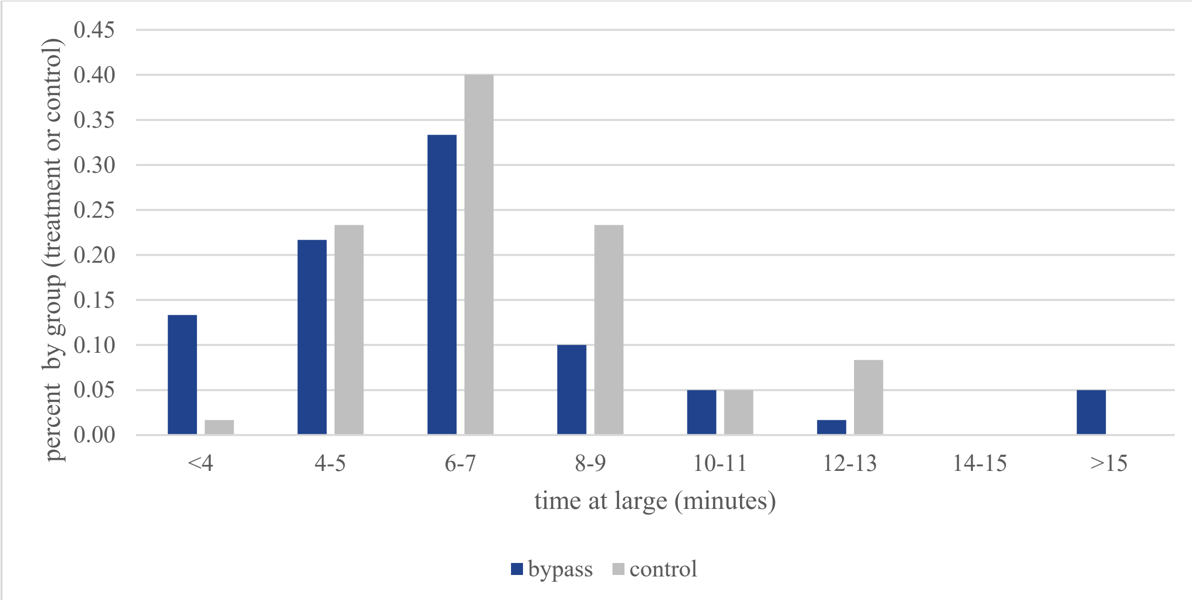

Figure 5-1 Frequency distribution of the time at large (for test and control fish) observed for juvenile alewife following release at Lawrence.

5.2 Survival and Malady-free Results

All fish recaptured (i.e., 54 treatment and 60 control) were alive and remained alive for the duration of the 48-hour delayed assessment period. Of the six fish that were not recaptured, one was assigned an unknown status based on radio signals never being detected by boat-based recapture crews from time of release to the end of day. For five other fish released were located as stationary radio tag detections with only a single detached HI-Z tag was recaptured. These five test fish were conservatively assumed dead in the analysis based on criteria defined in Mathur et al. 1996. (i.e., a fish that is recaptured dead or assigned a dead or unknown status constitute dT in the likelihood functions). The 1- and 48-hour survival estimates were equal (no fish died during the delayed assessment) and were 90.0 ±6.4% with 90% confidence (Table 5-2).

Six of 54 treatmentfish were documented having passage related injuries. Additionally, three control fish were recaptured with maladies which were minor. This resulted in a Malady-free estimate of 93.6%. (Table 5-2). Fish injuries occurred on the head, body, mouth and eyes which are indicative of mechanical and shear injuries. All injuries were classified as minor (Table 5-3).

Table 5-2 Survival and malady-free estimates for juvenile alosines (Alewife) produced following completion of the HI-Z tag-recapture study at Lawrence during October 2025

Parameter	Bypass	Control
Released	60	60
Recaptured alive	54	60
Recaptured dead	0	0
Assigned alive	0	0
Assigned dead	5	0
Unknown	1	0
1-h survival (%)	**90.0**	**100.0**
SE (%)	3.9	N/A
90% Margin of Error	6.4	N/A
No. held for 48 hours	54	60
No. dead at 48 hours	0	0
48-h survival (%)	**90.0**	**100.0**
SE (%)	3.9	N/A
90% Margin of Error	6.4	N/A
No. examined for maladies	54	60
No. with maladies	6	3
Malady-free estimate (%)	**93.6**	**N/A**
SE (%)	3.3	N/A

Table 5-3 Detailed passage-related injury information for juvenile alosines (Alewife) released at Lawrence via the downstream bypass facility or directly into the tailrace as handling controls

Scenario	Fish ID	Fish Length	Vital Status	Hour	Injury Description	Probable Cause	Status
Bypass	10	109	Alive	1-hr	Hemorrhaging in left eye	Shear	Minor
Bypass	16	114	Alive	1-hr	Minor hemorrhaging on dorsal fin	Mechanical	Minor
Bypass	19	109	Alive	1-hr	Minor hemorrhaging on left side of body	Mechanical	Minor
Bypass	23	102	Alive	1-hr	Slight bleeding left operculum, minor scale loss left side	Mechanical	Minor
Bypass	33	120	Alive	1-hr	Hemorrhaging in left eye	Shear	Minor
Bypass	59	115	Alive	1-hr	Bleeding lower left jaw	Mechanical	Minor
Control	92	107	Alive	1-hr	Bleeding lower jaw	Mechanical	Minor
Control	108	106	Alive	1-hr	Bleeding from lower right jaw	Mechanical	Minor
Control	120	104	Alive	1-hr	Hemorrhaging in left eye	Shear	Minor

6 Discussion

This study was intended to estimate the immediate (1-hr) and latent (48-hr) survival and malady-free rates with a precision of ±10% with 90% confidence for juvenile alosines passed downstream via the Project spillway and through the downstream fish bypass. Determination of the type, severity, and probable cause of observed injuries were assessed for all recaptured fish. Low Merrimack River flows during the entirety of the fall downstream migration period (i.e., September 1 to November 15) prevented testing of the spillway. Despite low inflow, downstream passage survival and injury rates for juvenile alosines passing downstream via the Project downstream bypass facility was completed during 2025.

A total of 60 HI-Z tagged fish were released at the upstream end of the downstream bypass facility on October 18, 2025, and flows through that facility were at 2% of station capacity (160 cfs) during testing. Of the 60 fish released, 54 were recaptured and survived the initial 1-hour immediate survival period and the 48-hour latent survival period. All 60 control fish were recaptured alive and remained alive through the 48-hour latent survival period. Six treatment were documented as having minor passage related injuries attributable to either shear or mechanical causes. HI-Z tag-recapture testing completed during fall of 2025 demonstrated latent (i.e., 48-hour) survival and malady-free rates for juvenile alosines of 90% (±6.2% with 90% confidence) and 93.6%, respectively.

7 Variances to the Study Plan

The Downstream Juvenile Alosine Passage Assessment was conducted as set forth in FERC's May 10, 2024, SPD with the following exception:

- As noted in Section 4.1, inflows at Lawrence were insufficient to support a HI-Z tag-recapture assessment of juvenile alosine passage downstream via the Project spillway. In order to conduct the spillway tests, two days of extended releases from a bladder section (up to three hours) needed to provide spill conditions for a duration of time adequate to tag, release, and recapture test fish. Inflow to the Project was too low to provide water for the spillway testing in a manner that would allow for timely recharge of the impoundment.

8 Literature Cited

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Appendix A: Individual Fish Disposition Data

Date	Scenario	Fish ID	Length	Release Time	Recaptured?	Recapture Time	1-h Survival
10/18/2025	Treatment	1	105	9:10	Yes	9:21	1
10/18/2025	Treatment	2	113	9:15	Yes	9:33	1
10/18/2025	Treatment	3	110	9:20	Yes	9:23	1
10/18/2025	Treatment	4	102	9:34	Yes	9:44	1
10/18/2025	Treatment	5	112	9:34	Yes	9:43	1
10/18/2025	Treatment	6	110	9:34	Yes	9:43	1
10/18/2025	Treatment	7	104	9:35	No	N/A	4
10/18/2025	Treatment	8	107	9:35	Yes	9:40	1
10/18/2025	Treatment	9	105	9:48	Yes	9:53	1
10/18/2025	Treatment	10	109	9:48	Yes	9:51	1
10/18/2025	Treatment	11	113	9:48	Yes	9:52	1
10/18/2025	Treatment	12	113	9:50	Yes	9:57	1
10/18/2025	Treatment	13	105	10:09	Yes	10:12	1
10/18/2025	Treatment	14	103	10:09	Yes	10:12	1
10/18/2025	Treatment	15	110	10:09	Yes	10:16	1
10/18/2025	Treatment	16	114	10:09	Yes	10:15	1
10/18/2025	Treatment	17	110	10:10	Yes	10:14	1
10/18/2025	Treatment	18	109	10:29	No	N/A	4
10/18/2025	Treatment	19	109	10:27	Yes	10:30	1
10/18/2025	Treatment	20	108	10:29	Yes	10:42	1
10/18/2025	Treatment	21	116	10:30	Yes	10:37	1
10/18/2025	Treatment	22	110	10:28	Yes	10:34	1

Date	Scenario	Fish ID	Length	Release Time	Recaptured?	Recapture Time	1-h Survival
10/18/2025	Treatment	23	102	10:28	Yes	10:37	1
10/18/2025	Treatment	24	114	10:29	Yes	10:35	1
10/18/2025	Treatment	25	107	10:30	Yes	10:36	1
10/18/2025	Treatment	26	105	11:02	Yes	11:06	1
10/18/2025	Treatment	27	107	10:59	Yes	11:10	1
10/18/2025	Treatment	28	104	11:00	Yes	11:04	1
10/18/2025	Treatment	29	112	11:01	Yes	11:08	1
10/18/2025	Treatment	30	107	11:01	Yes	11:21	1
10/18/2025	Treatment	31	110	11:02	No	N/A	13
10/18/2025	Treatment	32	114	10:59	Yes	11:05	1
10/18/2025	Treatment	33	120	11:01	Yes	11:07	1
10/18/2025	Treatment	35	110	11:00	Yes	11:05	1
10/18/2025	Treatment	36	100	11:26	No	N/A	4
10/18/2025	Treatment	37	100	11:24	Yes	11:28	1
10/18/2025	Treatment	38	104	11:27	Yes	11:33	1
10/18/2025	Treatment	39	117	11:24	Yes	11:31	1
10/18/2025	Treatment	40	104	11:28	Yes	11:35	1
10/18/2025	Treatment	41	110	11:25	Yes	11:32	1
10/18/2025	Treatment	42	110	11:26	Yes	11:31	1
10/18/2025	Treatment	43	120	11:25	Yes	11:31	1
10/18/2025	Treatment	44	100	11:28	Yes	11:32	1
10/18/2025	Treatment	45	110	11:27	No	N/A	4
10/18/2025	Treatment	46	110	11:48	Yes	11:56	1

Date	Scenario	Fish ID	Length	Release Time	Recaptured?	Recapture Time	1-h Survival
10/18/2025	Treatment	47	109	11:48	Yes	11:56	1
10/18/2025	Treatment	48	106	11:47	Yes	11:50	1
10/18/2025	Treatment	49	105	11:49	Yes	11:56	1
10/18/2025	Treatment	50	111	11:49	Yes	11:52	1
10/18/2025	Treatment	51	100	11:50	Yes	11:55	1
10/18/2025	Treatment	52	113	11:47	Yes	11:50	1
10/18/2025	Treatment	53	113	11:47	Yes	11:55	1
10/18/2025	Treatment	54	105	11:50	Yes	11:55	1
10/18/2025	Treatment	55	120	11:50	Yes	11:57	1
10/18/2025	Treatment	56	108	12:03	Yes	12:09	1
10/18/2025	Treatment	57	100	12:03	No	N/A	4
10/18/2025	Treatment	58	105	12:03	Yes	12:10	1
10/18/2025	Treatment	59	115	12:02	Yes	12:07	1
10/18/2025	Treatment	60	110	12:04	Yes	12:11	1
10/18/2025	Treatment	61	119	12:04	Yes	12:23	1
10/18/2025	Control	62	104	13:01	Yes	13:06	1
10/18/2025	Control	63	106	13:03	Yes	13:09	1
10/18/2025	Control	64	105	13:03	Yes	13:10	1
10/18/2025	Control	65	100	13:01	Yes	13:09	1
10/18/2025	Control	66	105	13:03	Yes	13:09	1
10/18/2025	Control	67	105	13:17	Yes	13:23	1
10/18/2025	Control	68	101	13:18	Yes	13:24	1
10/18/2025	Control	69	104	13:17	Yes	13:21	1

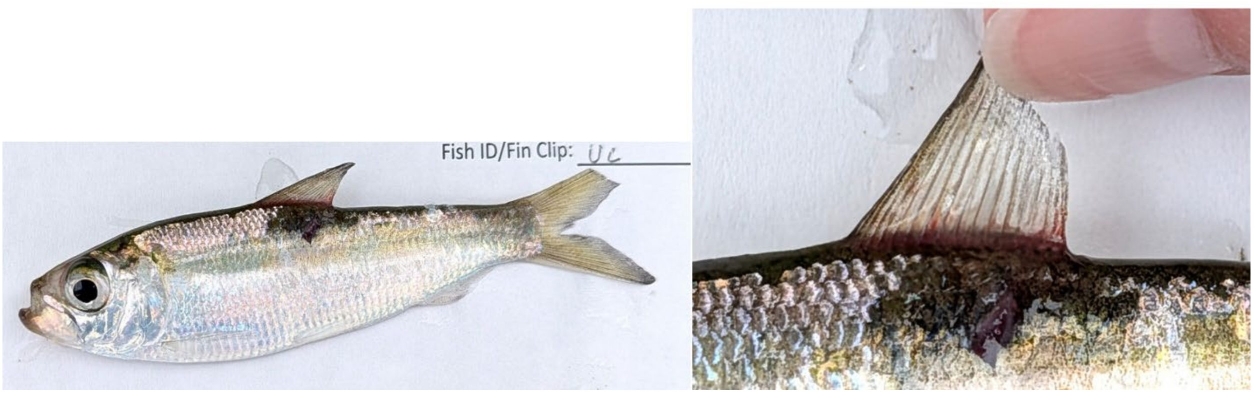
Date	Scenario	Fish ID	Length	Release Time	Recaptured?	Recapture Time	1-h Survival
10/18/2025	Control	70	106	13:17	Yes	13:20	1
10/18/2025	Control	71	98	13:16	Yes	13:29	1
10/18/2025	Control	72	109	13:33	Yes	13:43	1
10/18/2025	Control	73	101	13:32	Yes	13:40	1
10/18/2025	Control	74	109	13:34	Yes	13:42	1
10/18/2025	Control	75	110	13:33	Yes	13:41	1
10/18/2025	Control	76	111	13:34	Yes	13:42	1
10/18/2025	Control	77	108	13:38	Yes	13:47	1
10/18/2025	Control	78	112	13:37	Yes	13:44	1
10/18/2025	Control	79	107	13:38	Yes	13:44	1
10/18/2025	Control	80	106	13:36	Yes	13:43	1
10/18/2025	Control	81	106	13:37	Yes	13:49	1
10/18/2025	Control	82	105	13:55	Yes	14:04	1
10/18/2025	Control	83	96	13:55	Yes	14:03	1
10/18/2025	Control	84	105	13:53	Yes	13:59	1
10/18/2025	Control	85	115	13:53	Yes	13:59	1
10/18/2025	Control	86	102	13:54	Yes	14:01	1
10/18/2025	Control	87	109	14:09	Yes	14:15	1
10/18/2025	Control	88	100	14:08	Yes	14:16	1
10/18/2025	Control	89	105	14:08	Yes	14:14	1
10/18/2025	Control	90	107	14:08	Yes	14:12	1
10/18/2025	Control	91	98	14:07	Yes	14:17	1
10/18/2025	Control	92	107	14:21	Yes	14:25	1

Date	Scenario	Fish ID	Length	Release Time	Recaptured?	Recapture Time	1-h Survival
10/18/2025	Control	93	119	14:21	Yes	14:28	1
10/18/2025	Control	94	110	14:20	Yes	14:27	1
10/18/2025	Control	95	101	14:20	Yes	14:25	1
10/18/2025	Control	96	103	14:20	Yes	14:26	1
10/18/2025	Control	97	105	14:43	Yes	14:50	1
10/18/2025	Control	98	105	14:43	Yes	14:48	1
10/18/2025	Control	99	114	14:42	Yes	14:46	1
10/18/2025	Control	100	101	14:42	Yes	14:46	1
10/18/2025	Control	101	104	14:44	Yes	14:52	1
10/18/2025	Control	102	105	14:56	Yes	15:05	1
10/18/2025	Control	103	102	14:55	Yes	15:04	1
10/18/2025	Control	104	110	14:56	Yes	15:09	1
10/18/2025	Control	105	109	14:57	Yes	15:09	1
10/18/2025	Control	106	104	14:57	Yes	15:10	1
10/18/2025	Control	107	101	14:59	Yes	15:05	1
10/18/2025	Control	108	106	14:59	Yes	15:06	1
10/18/2025	Control	109	109	15:01	Yes	15:06	1
10/18/2025	Control	110	98	15:00	Yes	15:05	1
10/18/2025	Control	111	105	15:01	Yes	15:08	1
10/18/2025	Control	112	105	15:14	Yes	15:25	1
10/18/2025	Control	113	107	15:15	Yes	15:20	1
10/18/2025	Control	114	106	15:14	Yes	15:20	1
10/18/2025	Control	115	110	15:15	Yes	15:21	1

Date	Scenario	Fish ID	Length	Release Time	Recaptured?	Recapture Time	1-h Survival
10/18/2025	Control	116	100	15:16	Yes	15:23	1
10/18/2025	Control	117	107	15:23	Yes	15:29	1
10/18/2025	Control	118	106	15:22	Yes	15:27	1
10/18/2025	Control	119	105	15:21	Yes	15:26	1
10/18/2025	Control	120	104	15:21	Yes	15:26	1
10/18/2025	Control	121	102	15:22	Yes	15:30	1

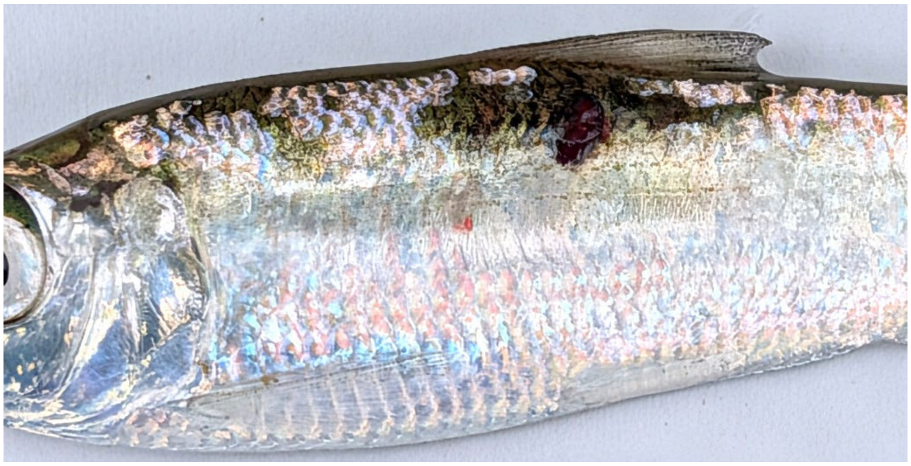
Appendix B: Fish Injury Photos

Treatment, Fish ID 10, Hemorrhage to the right eye.



Treatment, Fish Id 16, Hemorrhage to the dorsal fin.

Treatment, Fish ID 19, Hemorrhage on left side body.



Treatment, Fish ID 23, Slight bruising on left operculum. Minor scale loss on left side of the body.

Treatment, Fish ID 33, Hemorrhaging in left eye.

Treatment, Fish ID 59, Bleeding from the left lower jaw.

Control, Fish ID 92, Bleeding from the lower jaw.

Control, Fish ID 108, Bleeding from the lower right jaw.

Control, Fish ID 120, Minor hemorrhaging on the left eye.