**TRANSCANADA HYDRO NORTHEAST INC.**

# ILP Study 22
# Downstream Migration of Juvenile American Shad at Vernon

## *Final Study Report*

**In support of Federal Energy Regulatory Commission Relicensing of:**

Wilder Hydroelectric Project (FERC Project No. 1892-026)
Bellows Falls Hydroelectric Project (FERC Project No. 1855-045)
Vernon Hydroelectric Project (FERC Project No. 1904-073)

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# EXECUTIVE SUMMARY

The goal of this study was to assess whether Vernon Project operations affect the safe and timely passage of emigrating juvenile American Shad (*Alosa sapidissima*). The objectives of this study were to assess project operation effects on the timing, route selection, migration rates, and survival of juvenile shad migrating past the project; characterize the proportion of juvenile shad using all possible passage routes at Vernon over the period of downstream migration under normal operational conditions; and conduct controlled turbine passage survival tests for juvenile shad to estimate the relative survival specific to turbine unit types. The study was conducted in the fall of 2015.

This final study report incorporates revised route selection telemetry data processing, analysis and results; additional data presentation in response to stakeholder comments on the initial study report filed May 16, 2016 as summarized in TransCanada's August 15, 2016 Response to Comments; and in response to FERC's September 12, 2016 Study Plan Determination.

## *Route Selection*

Utilizing radio telemetry, a total of 310 wild juvenile American Shad were tagged and released approximately 0.5 miles upstream of the Vernon project in three locations over the course of the downstream migration season. Radio-tagged juvenile shad were released in 15 groups from September 25 - October 30, 2015. The study was carried out until November 11, 2015. All releases were conducted between 13:36 and 20:57 hours. Fish ranged in length from 90mm - 120mm. Water temperature over the course of shad passage ranged from 21.4°C down to 9.7°C. Air temperature ranged from 26.1°C down to -5°C.

Of the 310 radio-tagged shad 270 (87.1%) migrated downstream from their release point and were detected arriving at the Vernon forebay. The remaining 40 fish were not detected downstream after release. Approach duration for the 270 arriving shad ranged from approximately 0.1 hours to 70.8 hours (2 days, 22 hours and 8 min) with an overall median duration of 1.9 hours. The majority (68%) of individuals were present within the Vernon forebay within four hours following release. Forebay residency (for 265 of the 270 fish with valid detections) ranged from less than 6 minutes to nearly ten days with an overall median duration of less than 45 minutes. However, forebay residency was longer for fish that did not pass downstream (median = 18.4 hours) than for those that did successfully pass (median = 0.6 hours). Of the 270 shad arriving in the Vernon forebay, 226 (83.7%) were determined to have passed downstream of the dam. The remaining 44 individuals (16.3%) although located in the forebay, did not have confirmed passage. Of the individuals with confirmed passage, a definitive passage route was determined for 75.2% (170 out of the 226). The remaining 24.8% (56 of the 226) were determined to have passed Vernon based on downstream detection information but a definitive passage route could not be determined.

The majority of confirmed passed shad with known passage route (86.5%; 147 of 170) passed through turbine Units 1 through 10. The remaining 13.5% (23 of 170) passed via non-turbine routes (trash/ice sluice, fish pipe, fish tube, fish ladder).

Seventeen shad (10% of 170 with known passage route) used the fish pipe and one used the smaller fish tube.

The majority (85%) of downstream passage events occurred during the late evening hours (approximately 17:00 – 22:00). Downstream passage was also examined as a function of total flow for fish with known passage time. One shad passed during spill, 12.8% (N=29) passed at minimum flow, and approximately half (N=133) passed at flows between approximately 8,000 and 11,000 cfs. Individuals with known passage routes did not necessarily pass downstream via the route with the greatest proportion of total project discharge. Flows at the time of last detection for shad that did not pass ranged from minimum flow to spill flows, and did not show any apparent patterns.

Overall, 70.4% of the 226 radio-tagged juvenile shad passing downstream of Vernon were subsequently detected at the Stebbins Island monitoring station; however, the proportion of fish detected at Stebbins Island should not be interpreted as a direct estimate of survival due to uncertainty with predation and tag retention during downstream passage.

### *Run Timing*

The timing of the emigrating juvenile American Shad was described by continuous collection of acoustic backscatter collected by a calibrated echosounder with an upward-facing, 420-kHz split-beam transducer mounted on the riverbed near the entrance to the downstream fish pipe in the forebay of the Vernon powerhouse from August 15 through November 15, 2015. Echogram patterns of manually classified school echoes indicated small schooling fish first appeared in the Vernon forebay on August 17 and last appeared on October 30 (74 days), however were not consistently present until the beginning of September. The major peak period started with a steady increase in fish density from September 25 to the highest peak in the time series on October 3, which followed a sharp decrease in water temperature (approximately 20°C to 16°C), and then steadily declined to October 8 (a duration of 13 days) before density increased again over several days of fluctuation. Fish density peaked twice again, but moderately, on two isolated late occasions (October 23-24 and 30) before declining to zero by November when water temperatures remained below 10°C. Fish density of school echoes was highest during the afternoon and dusk. Fish schools concentrated in the mid-water column generally between 6 and 10 meters from the transducer (2.5 to 6.5 m depth) during the day and then migrated up toward the surface before and during dusk.

Several independent sampling methods confirmed the presence of juvenile shad, averaging 97-104 mm in total length depending on gear, concurrent with observations of fish school echoes in the Vernon forebay. Data from visual observations, electrofishing, cast netting, and imaging sonar support these echo patterns reflected the timing of out-migrating juvenile shad arriving and departing the forebay of Vernon powerhouse. Juvenile shad were interpreted to have successfully passed the Vernon Project because fish density representative of juvenile shad within the Vernon forebay quickly decreased from observed peak densities, with some peak densities lasting only one or two days, and tracked echoes of juvenile-shad-sized fish primarily moved through the beam in the west-southwesterly direction toward the fish diversion boom and the powerhouse. There was no evidence that juvenile shad accumulated in the forebay over the outmigration season, which would have been indicative of a migratory barrier or migratory delay.

### *Turbine Survival*

Direct relative survival and injury at 1 h for juvenile wild American Shad were estimated in passage through Units 4 and 8 at Vernon Project, Vermont. Juvenile wild in-river shad were used for this study and were collected upstream of the Vernon Project and held in a tank continuously supplied with ambient river water. Water temperature ranged from 14.5 to 15.0°C during the study. Fish tagging, release, and recapture techniques were similar to those used in numerous other turbine survival studies including those previously conducted at the Vernon Project.

A primary objective of the study was to release a sufficient number of juvenile shad to obtain passage survival estimates within a precision (ε) level of ± 10%, 95% of the time (α=0.05). The number of fish released for the analytical sample was 151 and 150 treatment (passed through Units 4 and 8, respectively) and 150 control fish (released downstream).

The total length of treatment fish passed through Unit 4 ranged from 90-131 mm and average 98 mm; total length of treatment fish passed through Unit 8 ranged from 87-121 mm and average 104 mm. The control fish total length ranged from 90-127 mm, average length was 100 mm.

Recapture rates of treatment fish was 87.4% for Unit 4, 94.0% for Unit 8, and 97.3% for control fish. All of the Unit 4 fish were recaptured alive. For Unit 8, 139 fish were recaptured alive and two recaptured dead. All but one of the control fish were recaptured alive. The number of fish assigned dead for Unit 4, Unit 8, and control were 15, 8, and 2; respectively.

The estimated immediate (1 h) survival was 91.7% (confidence interval (CI) 5.5%) for Unit 4 and 95.2% (CI 4.7%) for Unit 8. The estimated 48-hour survival was deemed unreliable due to a high mortality of control fish during the delayed assessment period. This situation is not uncommon in turbine passage studies on juvenile clupeids.

In accordance with the study plan, survival estimates were also calculated with only recaptured fish. The estimated immediate (1-hour) survival was 100.0% (CI 1.3%) for Unit 4 and 99.3% (CI 2.4%) for Unit 8.

All of the 132 (87.4%) Unit 4 and 141 (94.0%) Unit 8 post turbine passage recaptured treatment fish were examined for injuries. A total of 6 (4.5%) of the Unit 4 treatment fish had visible injuries and another three (2.3%) displayed only loss of equilibrium (LOE). The Unit 8 treatment fish were similar with a total of 6 (4.3%) showing visible injuries and two displaying only LOE. Two of the 146 examined control fish had visible injuries and another five fish displayed LOE. Fish displaying visible injuries, more than 20% scale loss per side, or LOE were assigned a malady status.

Malady-free estimate rates were adjusted by any maladies incurred by control fish. The Unit 4 malady-free estimate for recaptured fish was 97.9% (CI 5.7%). The Unit 8 malady-free estimate for recaptured fish was 99.1% (CI 5.5%).

The 1h direct survival estimate for Francis Unit 4 (91.7%) and Kaplan Unit 8 (95.2%) were near the mean direct survival value obtained from similar studies of nine Francis turbines (mean 89.5%) and ten propeller turbines (mean 96.0%). The 1h direct survival (94.7%) for juvenile shad passed through Vernon Francis Unit 10 during a previous study in 1995 was higher than found at all but one of the similar nine Francis turbine studies. The characteristics of the Vernon turbines did affect the direct survival rates. Survival rates increased with an increase in runner diameter and decreased with an increase in rotation rate and number of blades.

Based on the Vernon turbine characteristics, estimated direct juvenile shad survival for the three turbine types tested, and a previous direct survival study on juvenile Atlantic Salmon at Vernon, the juvenile shad should fare best passing through Kaplan Units 5 through 8, followed by Francis Units 9 and 10. The smaller Francis Units 1 through 4 would likely be least friendly.

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# List of Abbreviations

| | |
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| CI | confidence interval |
| CPUE | Catch per unit of effort |
| CRWC | Connecticut River Watershed Council |
| FERC | Federal Energy Regulatory Commission |
| FirstLight | FirstLight Power Resources |
| FWS | U.S. Department of the Interior – Fish and Wildlife Service |
| HA | Hydroacoustics |
| LOE | loss of equilibrium |
| NHDES | New Hampshire Department of Environmental Services |
| NHFGD | New Hampshire Fish and Game Department |
| RSP | Revised Study Plan |
| SE | standard error |
| TL | total length |
| TransCanada | TransCanada Hydro Northeast Inc. |
| TU | Trout Unlimited |
| VANR | Vermont Agency of Natural Resources |
| VDEC | Vermont Department of Environmental Conservation |
| VY | Vermont Yankee Nuclear Power Plant |

# 1.0 INTRODUCTION

This final study report presents the findings of the 2015 assessment of Downstream Migration of Juvenile American Shad at the Vernon Project (ILP Study 22) conducted in support of Federal Energy Regulatory Commission (FERC) relicensing efforts by TransCanada Hydro Northeast Inc. (TransCanada) for the Wilder Hydroelectric Project (FERC Project No. 1892), Bellows Falls Hydroelectric Project (FERC No. 1855) and the Vernon Hydroelectric Project (FERC No. 1904).

This final study report incorporates revised route selection telemetry data processing, analysis and results; additional data presentation in response to stakeholder comments on the initial study report filed May 16, 2016 as summarized in TransCanada's August 15, 2016 Response to Comments; and in response to FERC's September 12, 2016 Study Plan Determination.

Operations of the Vernon Project may have the potential to cause direct effects on juvenile American Shad (*Alosa sapidissima*) outmigration and production. Specifically, operations may influence the downstream passage route selection, forebay residency time, and predation and mortality of juveniles during passage under varying flow conditions. In their study requests, U.S. Department of the Interior-Fish and Wildlife Service (FWS), New Hampshire Department of Environmental Services (NHDES), New Hampshire Fish and Game Department (NHFGD), Vermont Agency of Natural Resources (VANR), Trout Unlimited (TU) and Connecticut River Watershed Council (CRWC) identified these issues and requested a field study to identify project effects on emigrating juvenile shad.

The Revised Study Plan (RSP) was approved without modification (except to delay the study until 2015, and the final report to March 1, 2016) in FERC's February 21, 2014 Study Plan Determination (SPD). However, the RSP was updated (filed with FERC on February 3, 2015) to incorporate proposed study plan modifications based on:

- Stakeholder consultation that occurred on August 26, 2014 in conjunction with the FERC-proposed Vernon Hydroacoustics Study;
- Results of juvenile shad tagging tests conducted in 2014 to evaluate the potential use of hatchery-reared juvenile shad (Normandeau, 2014a; filed with FERC on November 26, 2014);
- Stakeholder comments received on the Initial Study Report (ISR) filed September 15, 2014 and based on the ISR meeting summary held on September 29, 2014; and
- A FERC technical meeting held on November 20, 2014 (also in conjunction with the proposed Study Plan 34 (Vernon Hydroacoustic Study) but related to this study as well).

The Updated RSP was approved by FERC in its May 14, 2015 Order Granting Rehearing and Approving Revised Study 22. That Order also removed the requirement to implement the proposed Vernon Hydroacoustics Study.

## 2.0 STUDY GOALS AND OBJECTIVES

TransCanada conducted this study in the fall of 2015 to assess whether Vernon Project operations affect the safe and timely passage of emigrating juvenile American shad. This study, in conjunction with a previous juvenile American Shad turbine survival study of Unit 10 (Normandeau, 1996) was designed to provide the information needed to evaluate whether turbine passage adversely affects juvenile survival and to evaluate migration timing, forebay residency time, and route selection.

The objectives of this study were to:

- assess Vernon operational effects on the timing, route selection, migration rates, and survival of juvenile shad migrating past the project;
- characterize the proportion of juvenile shad using all possible passage routes at the Vernon Project over the period of downstream migration under normal operational conditions; and
- conduct controlled turbine passage survival tests for juvenile American shad passed through one of the older Francis units (Unit Nos. 1 to 4) and one of the new Kaplan units (Unit Nos. 5 to 8) to estimate the relative survival (±10%, 95% of the time) specific to those unit types while operating at a typical discharge. Also, determine injury rate, type, cause, and severity.

The study area included the Vernon forebay, tailrace, turbines, fish pipe, fish tube, and dam.

## 3.0 METHODS

Due to the configuration and specifications of the Vernon Project and the potential limitations inherent in working with juvenile shad, no single monitoring tool was able to provide the necessary information for this study. Therefore, the use of multiple tools ensured that study objectives were met. As discussed in this section, the methods in this study included the use of radio-telemetry, hydroacoustics, and HI-Z Turb'N tags (HI-Z tags), as requested by the agencies in their original study requests.

### 3.1 Route Selection (Radio-telemetry) Methodology

Route selection and forebay residency time for juvenile shad downstream passage was assessed by radio-tagging and systematically monitoring tagged shad movement and passage through the project. Radio tag size has become smaller in recent years and is now suitable for juvenile shad (Normandeau, 2014a). The Lotek NTQ-1 radio transmitters used in this study have been used with juvenile clupeids in work on the Merrimack River.

Wild juvenile shad were collected at least twice per week via electrofishing in and above the Vernon forebay area (upstream of the log boom), and occurred from mid-September through October. Collection of juvenile shad near the dam, together with hydroacoustic (HA) sampling ensured that the fish were actively migrating. Collection and tagging was intended for releases of two groups of 20-tagged juvenile shad each week during the migration period for a total of up to 320 tagged fish.

Following collections, shad were transported and retained in appropriate holding facilities in a secure location at Vernon. Wild juvenile shad were generally held for short periods (24-48 hours) prior to tagging. Holding facilities consisted of 2 – 4 ft. diameter circular tanks with a volume of approximately 235 gallons. Each tank had a center drain stand-pipe and was supplied with continuously circulating ambient river water discharged through multiple hoses that were oriented to establish a directional flow of approximately 1 ft/s. Water was supplied from the Vernon forebay from two submersible pumps on independent electrical circuits to ensure that water supply would not be disrupted in the event of a single circuit trip. Circulated water was discharged directly back to Vernon forebay. Upon stocking a tank with newly caught fish, salt was added to the tanks to provide a low salinity (approximately 1 psu) to reduce osmoregulatory stress. Once stocked, fish were fed ad libitum with finely ground commercial fish food.

The intent based on the RSP was to select juvenile shad that were at least 100 mm long for tagging. Radio transmitters were Lotek NanoTag NTQ-1 tags. The NTQ-1 tags were 5 mm wide x 3 mm high x 10 mm long in size, weighed ≤0.26 grams in air, and had a calculated life of 10 days, and propagated a signal via a flexible whip antenna. Each tag was seized to a size 16 dry fly hook (total weight ~ 0.4 g in air). Each transmitter contained a unique pulse code to allow for individual fish identification.

Juveniles were selected for tagging by bringing a number of fish to near the surface using a small seine net, then water brailing several fish to a tagging container filled with ambient water and soda water mixture (20:1 ratio) and salt to approximately 5 pounds/square inch. Because of the smaller tag size, individuals were not culled for a specific size, but were visually selected for good condition: minimal scale loss, no evident fungal infection or fin rot, relatively large size (robust, no emaciation). Tagging specimens were held in water and tagged by inserting the hook into the dorsal musculature posterior to the dorsal fin. In most cases, wild fish were captured and tagged within a few days and released back into the river with their migrating cohort. Fifteen groups of 13-20 shad each were externally radio-tagged, transported by boat, and systematically released along a river-wide transect approximately 0.5 miles upstream of Vernon dam over the course of the downstream migration season (2 releases per week). This release scenario allowed for monitoring over a range of environmental and project operating conditions.

Remote telemetry monitoring occurred at the Vernon forebay, log boom and diversion boom, fish pipe, fish tube, turbines, tailrace, and spillway. Radio receivers capable of monitoring multiple radio channels simultaneously at each location were coupled with appropriate antennas or droppers and calibrated to ensure adequate coverage of the individual sites monitored while minimizing overlap between the sites. The monitoring sites were installed at the same sites used in Study 21 – Shad Telemetry Study with the same detection coverage (Figure 3.1-1).

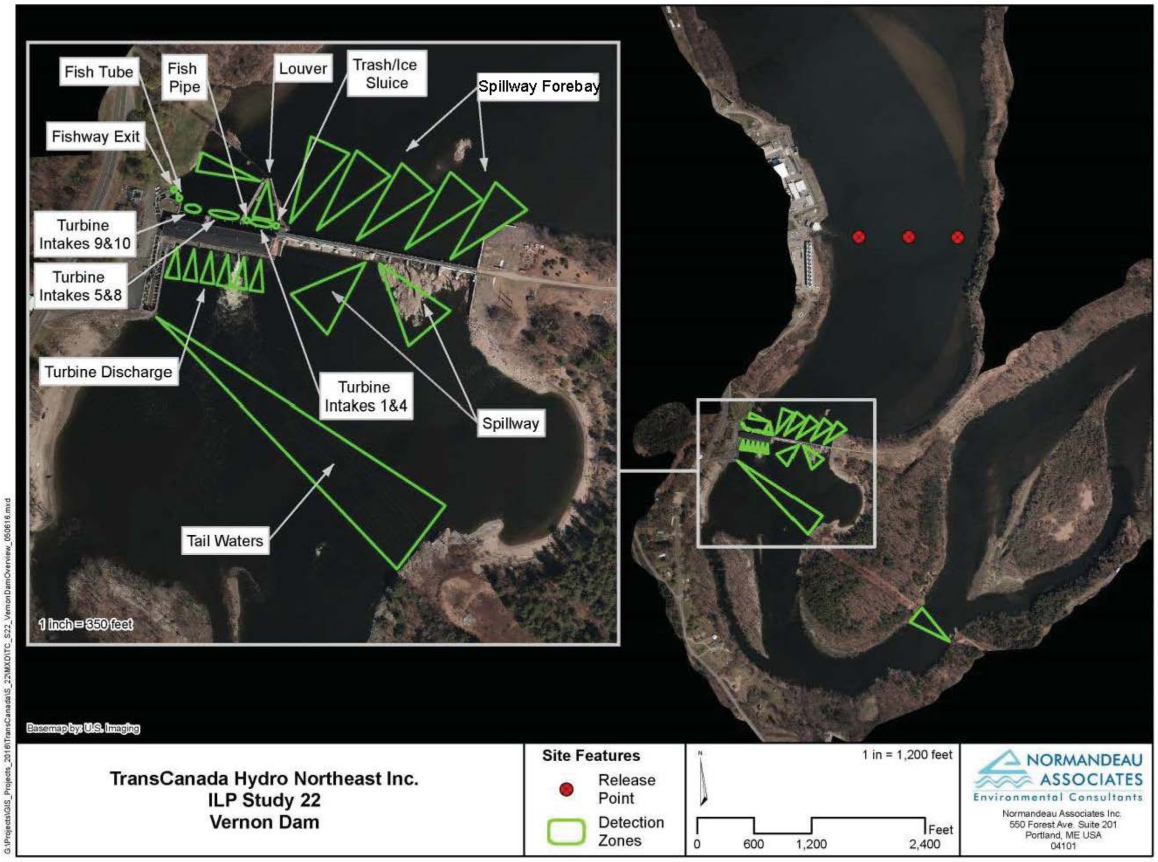



Figure 3.1-1. Detection zones for monitoring stations used to evaluate downstream movement of radio-tagged juvenile shad at Vernon and release points.

Data downloading from the remote telemetry monitoring stations occurred at least three times per week during the course of the study supplemented by manual monitoring by boat to assist in data collection and analysis.

To augment the results reported in Normandeau (2014a) and to provide release-group specific information regarding post-tagging survival and behavior, control specimens were tagged with dummy tags of the same size and weight as the test tags, and control fish were maintained and observed in the holding facilities. During the course of the study, air temperature, water temperature, turbidity, rainfall, river flow, lunar phase, and project operations information were collected.

## 3.2 Run Timing (Hydroacoustics) Methodology

### 3.2.1 Objectives

The timing of the 2015 outmigration run of juvenile American Shad in the vicinity of the entrance to the downstream fish pipe in the forebay of the Vernon powerhouse was described by continuous hydroacoustic sampling (i.e., sonar). The time series of the acoustic index of abundance was used to determine the onset, departure, timing and duration of peak abundance, diel periodicity, and depth distribution of juvenile shad. Temporal trends in the acoustic index of abundance were verified by time series data collected primarily by three independent complementary sampling methods: (1) discrete cast net samples in the forebay, (2) visual observations of fish near the surface in the forebay, and (3) electrofishing samples immediately upstream of the forebay. Relations between abundance and environmental factors were also investigated.

### 3.2.2 Hydroacoustic Sampling Equipment

A calibrated 420-kHz, split-beam echosounder (Model 241 or 244, Hydroacoustic Technology, Inc., Seattle, WA) was used to collect raw acoustic backscatter under four data collection settings (Table 3.2.2-1). The transducer's acoustic frequency of 420 kHz was used because shad may detect (Mann et al., 1997) and avoid ultrasound at commonly used fishery echosounder frequencies (<200 kHz; Dunning et al., 1992; Ploskey et al., 1995), and the higher frequency and range resolution is more suitable for detecting small fish. Acoustic backscatter (i.e., sound reflected from objects) measured from the elapsed time and received voltage response will provide time-stamped data on range, echo signal strength (relative size), and location of single echo detections within the beam. The split-beam functionality allows single echoes to be located within the beam, and their echo strength compensated for sensitivity loss from being off the maximum response axis to provide a target strength measurement. Over successive sound transmissions (pings), single echo detections of a fish form an echo trace that can be tracked in three-dimensions (xyz axes) for describing movement.

Table 3.2.2-1. Summary of echosounder model[a], nominal maximum range, source level, ping rate, and sound speed used during hydroacoustic monitoring of juvenile American Shad in the Vernon forebay, 2015.

| No. | Beginning | End | Model | No. Pings per File | Data Points per Ping | Nominal Maximum Range (m) | Source Level (dB re µPa at 1 m) | Ping Rate (Pings per Second) | Sound Speed (m/s) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 11 Aug 9:19 | 01 Sep 4:54 | 241 | 6000 | 1312 | 20 | 195.6 | 10 | 1497 |
| 2 | 03 Sep 14:13 | 04 Sep 23:24 | 243 | 6000 | 984 | 15 | 202.9 | 10 | 1497 |
| 3 | 08 Sep 12:54 | 02 Oct 18:05 | 243 | 6000 | 984 | 15 | 202.9 | 10 | 1489 |
| 4 | 02 Oct 18:19 | 04 Dec 15:25 | 243 | 4800 | 984 | 15 | 202.9 | 8 | 1447 |

[a] Split-beam echosounder model manufactured by Hydroacoustics Technology, Inc.

The echosounder and split-beam transducer were calibrated before and after data collection using a standard transducer of known sensitivity and source level at the manufacturer prior to deployment (Johannesson and Mitson, 1983; ANSI/ASA 2012). A 76.2-m (250-ft) transducer cable was secured to the dam infrastructure and ran inside to an outdoor shelved cabinet where the echosounder, an Ethernet router and modem, and laptop computer were stored and protected from rainfall

(Figure 3.2.2-1). Two fans and vents were added to keep temperature of the operating electronics from rising, especially during several hot weather days. The half-power beam width of the split-beam transducer measured about 0.4-0.5° wider than the nominal 15° beam width.

Figure 3.2.2-1. Equipment cabinet with laptop computer, communications hardware, uninterrupted power supply, and HTI Model 243 echosounder.

### 3.2.3 Hydroacoustic Sampling Position and Coverage

The presence of juvenile-shad-sized fish over time was acoustically monitored in the vicinity of the entrance to the downstream fish pipe (Figure 3.2.3-1). The fish pipe opening was selected because the fish diversion boom with its 10-foot high louver panels extending to about 16 feet below pond elevation was designed to guide surface-oriented fish such as juvenile shad to pass through the downstream fish pipe. This location is also where Vernon personnel have historically observed great numbers of juvenile shad congregating during the outmigration season.

The transducer mount was lowered to the riverbed and positioned by a diver about 3.9 m (12.8 ft) from the second concrete pillar of fish diversion boom in the forebay upstream of Unit 4 where the water depth was initially 12.4 m (41 ft). Once positioned and leveled the diver secured the mount by placing sand bags under and on top of the mount legs. The transducer cable was tied to chain and run along the transducer mount leg and riverbed to the pillar. The cable was tied to the pillar and louver panels as it was strung up to the surface.

The entrance to the fish pipe is 7.6 feet wide x 4.0 feet high and the sill of the opening sits about 9.5 feet below the average pond elevation during the study (219.5 feet [66.9 m]). The depth layer corresponding to the fish pipe opening was

5.5-9.5 feet (1.7-2.9 m) below the average pond elevation. The bottom-mounted, split-beam transducer was aimed vertically toward the surface to effectively sample more of the water column in this surface layer where juvenile shad naturally prefer (Buckley and Kynard, 1985) and where they will be to pass through the fish pipe. The beam diameter at the fish pipe sill (32 feet [9.7 m] range from transducer) is about 8.5 feet (2.6 m) and spreads to 10.1 feet (3.1 m) at the top of the fish pipe opening at 38 feet (11.5 m) range from the transducer (Figure 3.2.3-2).

In addition to sampling location and coverage, this sampling configuration is capable of producing echo patterns that are easier to interpret for discriminating swimming juvenile shad from other targets. The relative acoustic size (i.e., target strength) is independent of swimming direction when fish are insonified ventrally which makes classification of juvenile shad by the target strength corresponding to their size more reliable than when fish are insonified at multiple swimming directions in horizontally-aimed acoustic beams (e.g., lower target strength swimming to or away from a horizontally aimed transducer).

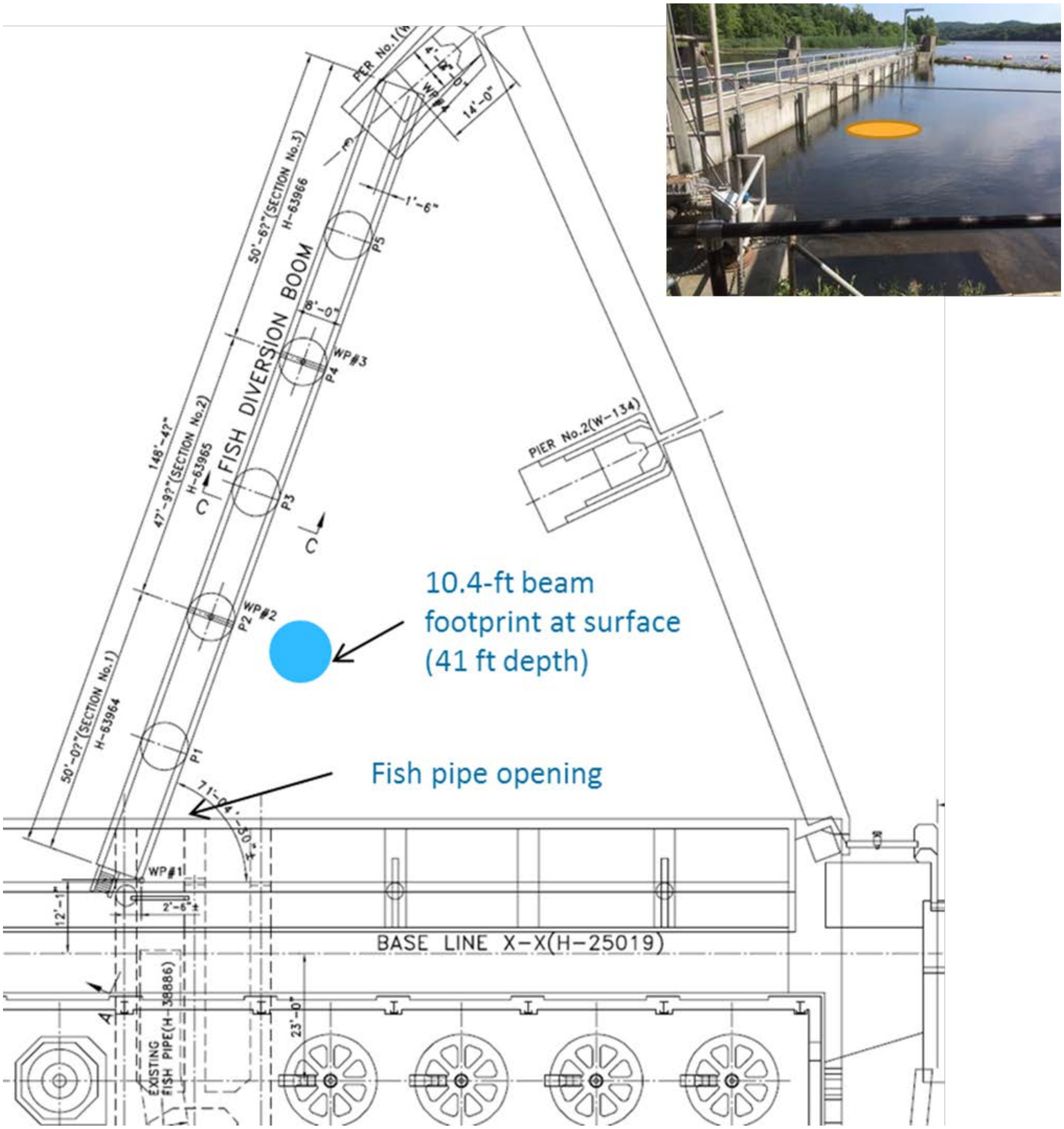



Figure 3.2.3-1. Top plan view of the location and beam footprint (blue circle) of the 15° split-beam transducer used to monitor the presence of juvenile American Shad in the Vernon forebay, 2015.

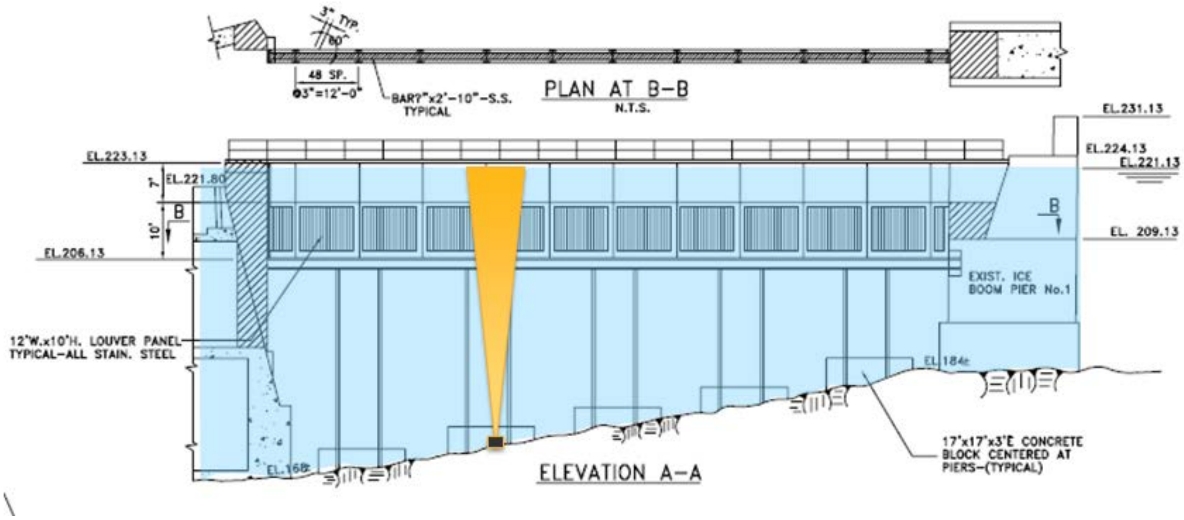



Figure 3.2.3-2. Cross-sectional view of the acoustic beam (orange) from the bottom-mounted split-beam transducer used to monitor the presence of juvenile American Shad in the Vernon forebay, 2015.

### 3.2.4 Temporal Sampling Scheme

The split-beam echosounder system continuously sampled (24 hours/day) from August 15 through November 15, 2015 except when there was equipment or power failure. Several sampling outages did occur due to severe lightning storms, wireless alert communications failure, echosounder failure, and software conflicts that resulted in replacing every component over the course of the study period with exception of the transducer and transducer cable (Appendix A). The hydroacoustic sampling period included approximately 2 weeks before and after the anticipated out-migration period of juvenile shad previously described in the Connecticut River (O'Leary and Kynard, 1986) and in the lower Vernon impoundment (Normandeau, 2013). This timeframe allows for the natural baseline variability in fish echoes before and after the migration period to be assessed and for the migration periodicity to be assessed without truncation at the beginning and end of the run.

The echosounder was set to transmit a 0.2-ms pulse at 10 pings per second for 10 minutes, yielding six 10-minute data files per hour. However, it was later discovered during data collection that the internal echosounder software version implemented by the manufacturer had a software bug that didn't allow all data to be written, which lead to 5-6 files per hour that were slightly longer than 10-minute intervals each with 6000 pings (effectively about 8 pings per second). The ping rate was later set to 8 pings per second for the remainder of the study when it correctly produced six 10-minute files per hour, each with 4800 pings (Table 3.2.4-1).

Table 3.2.4-1. Parameter values for single echo detection and tracking algorithms used in Echoview software to process echogram data collected from hydroacoustic monitoring of juvenile American Shad in the Vernon forebay, 2015.

| Algorithm | Parameter | End |
|---|---|---|
| Single Echo Detection | Target strength threshold (dB) | -65 |
| | Pulse length determination level (dB) | 6 |
| | Minimum/Maximum Normalized Pulse Length | 0.6/1.5 |
| | Maximum beam compensation (dB) | 6 |
| | Major/Minor axis angles maximum standard deviation (degrees) | 0.6 |
| Fish Track Detection | Range alpha/beta (unit less) | 0.2/0.5 |
| | Range exclusion distance (m) | 0.15 |
| | Missed ping expansion (%) | 0 |
| | Minimum number of SEDs in track | 4 |
| | Minimum number of pings in track | 5 |
| | Maximum gap between SEDs (pings) | 3 |

### 3.2.5 Echogram Processing

The relative magnitude of juvenile shad abundance was described by metrics derived from the time series of raw acoustic backscatter collected from August 15 through November 15, 2015. All raw acoustic data files (*.SMP) were imported into Echoview signal processing software (v6.9, Myriax Software Pty. Ltd., Hobart, Australia) using preferred parameterization and settings following standard practices (Parker-Stetter et al., 2009; Rudstam et al., 2009). The volume backscattering coefficient ($s_v$, $m^{-1}$) and its decibel equivalent, volume backscattering strength ($S_v$, dB re $m^{-1}$), from echo integration was assumed to be proportional to fish density (Foote, 1983) and quantified the acoustic energy reflected back from the backscattering cross-sections ($\sigma_{bs}$, $m^2$) of all targets within the sampled volume as defined by MacLennan et al. (2002).

A range dependent minimum $S_v$ threshold equivalent to a minimum echo strength threshold of -61 dB was applied to the echograms to reduce the contribution of background noise and smaller scatterers to the density estimate of juvenile American Shad (Rudstam et al., 2009). Data within the first 0.75 m from the transducer were excluded from analysis. The maximum range was defined within each echogram prior to further analysis, and varied over the duration of the study due to water level fluctuations or surface noise due to rainfall, and analysis of successive echo detections. Additionally, regions of echograms with backscatter attributable to the louver panel were excluded from analysis (Figure 3.2.5-1). Echograms where fish schools could not be reliably identified due to low signal-to-noise ratio were excluded from analysis.

Another index of juvenile shad abundance was derived from acoustic backscatter classified as juvenile shad schools based on visual examination of 24-hour echograms from each day with viable data. Echoes were classified as juvenile shad following a consistent decision process of manual delineation of echograms regions with echo patterns consistent of small schooling fish. A region of an echogram was defined as a fish school if there were multiple echo traces grouped together that appeared cohesive in movement and duration within the beam (Figure 3.2.5-2). Small groups of fish (i.e., <10 individuals) that were observed coalescing into a distinct school were also classified as schools. A region of high $S_v$ without individual fish traces was classified as a school if it had defined edges, displayed behavior indicative of schooling such as diving or milling, and was clearly not attributable to backscatter from surface noise or powerhouse operations. Regions of high $S_v$ near the surface were only classified as schools when they could be reliably tracked over time as schools that had moved up in the water column. A high contrast color scale was used for more reliable delineation of schools within the relatively noisy region of the echograms between the louver panel edge and the water surface (Figure 3.2.5-2).

Fish density was estimated from echo integration of manually classified fish school echoes and then dividing the mean school $s_v$ by the $\sigma_{bs}$ representative of an individual juvenile shad. Classified school echoes were integrated over the entire water column or by 0.5-m layers, and by day or hour, for investigating different temporal and spatial patterns of juvenile shad abundance. All data points (echogram pixels) not classified as fish schools were treated as zeroes in echo integration (calculation of mean school $s_v$). The $\sigma_{bs}$ used in density calculations was based on the expected $\sigma_{bs}$ (or target strength in decibels, $TS=10\log_{10}[\sigma_{bs}]$) for a fish of size equivalent to the average total length of locally caught juvenile shad during the study. The relation between total length (L) and $\sigma_{bs}$ at a ventral aspect angle and acoustic wavelength (λ) corresponding to 420 kHz used was the equation given by Love (1977):

$$\sigma_{bs} = (1/\pi)(\lambda^2)aL^b$$

where π (pi)=3.142, λ=0.0035 m, a=0.048, and b=1.9. The fish density of classified fish school echoes was then used as a relative index of juvenile shad abundance in examining the time series for onset, departure, and peak abundance of out-migrating juvenile shad, and other spatio-temporal patterns.

Echoes potentially attributable to individual fish within the valid analysis range of each echogram were identified using the Echoview single echo detection (SED) algorithm (Table 3.2.4-1). Single echoes outside of the 15.5° beam width at half power were excluded from analysis. The Echoview track detection algorithm was then used to delineate contiguous traces of multiple SEDs that may represent fish within the analysis region of each echogram. Automated tracking of SEDs used parameters determined by visual evaluation of various values to ensure effective track identification.

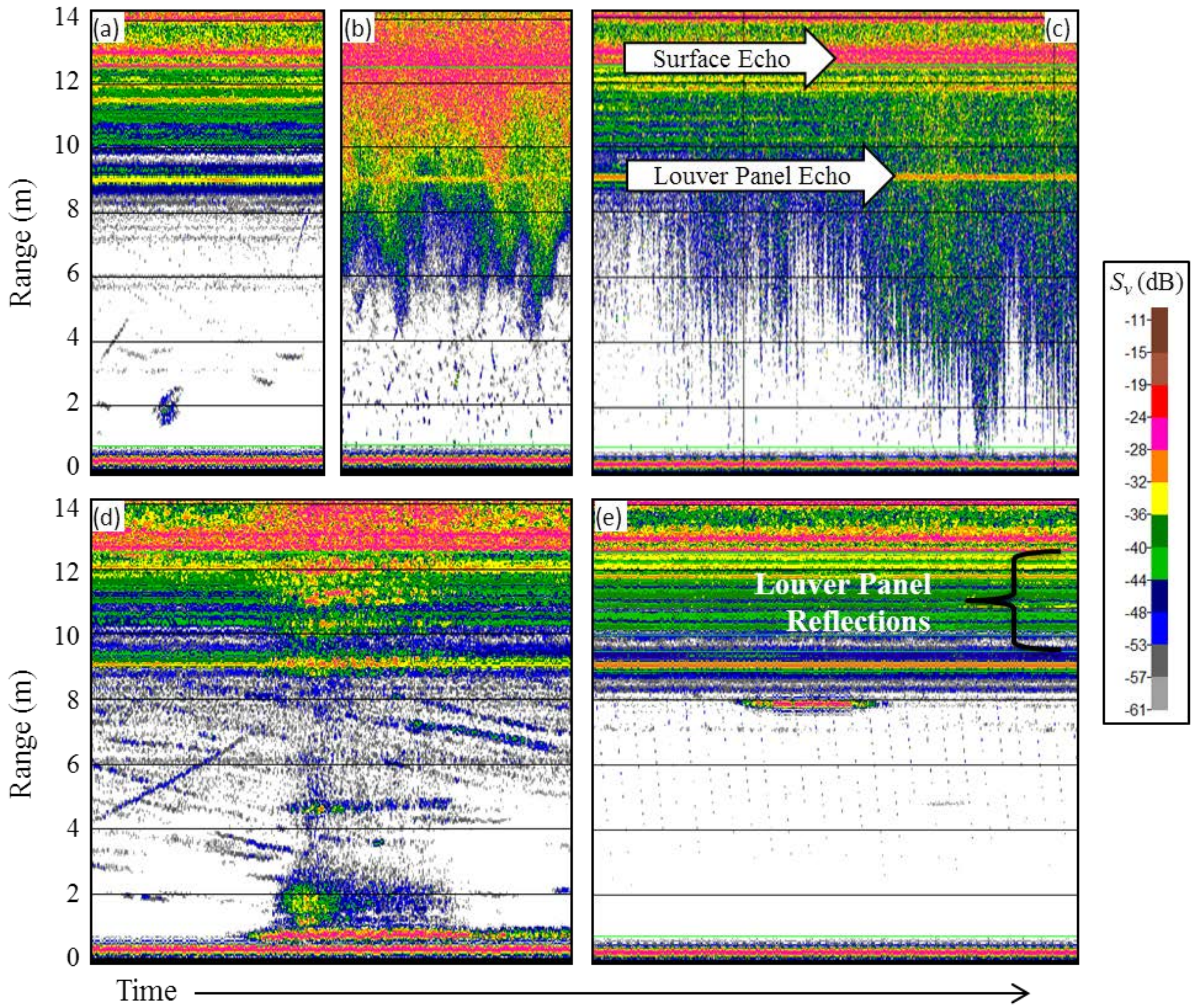



Figure 3.2.5-1. Example echograms of volume backscattering strength ($S_V$) showing (a) small individual fish without rainfall; (b) increase surface noise during rainfall; (c) increase in noise after Unit 4 begins operation; (d) large target moving close to the transducer; and (e) large fish near bottom of louver panel near the entrance to the fish pipe in the Vernon forebay, 2015.

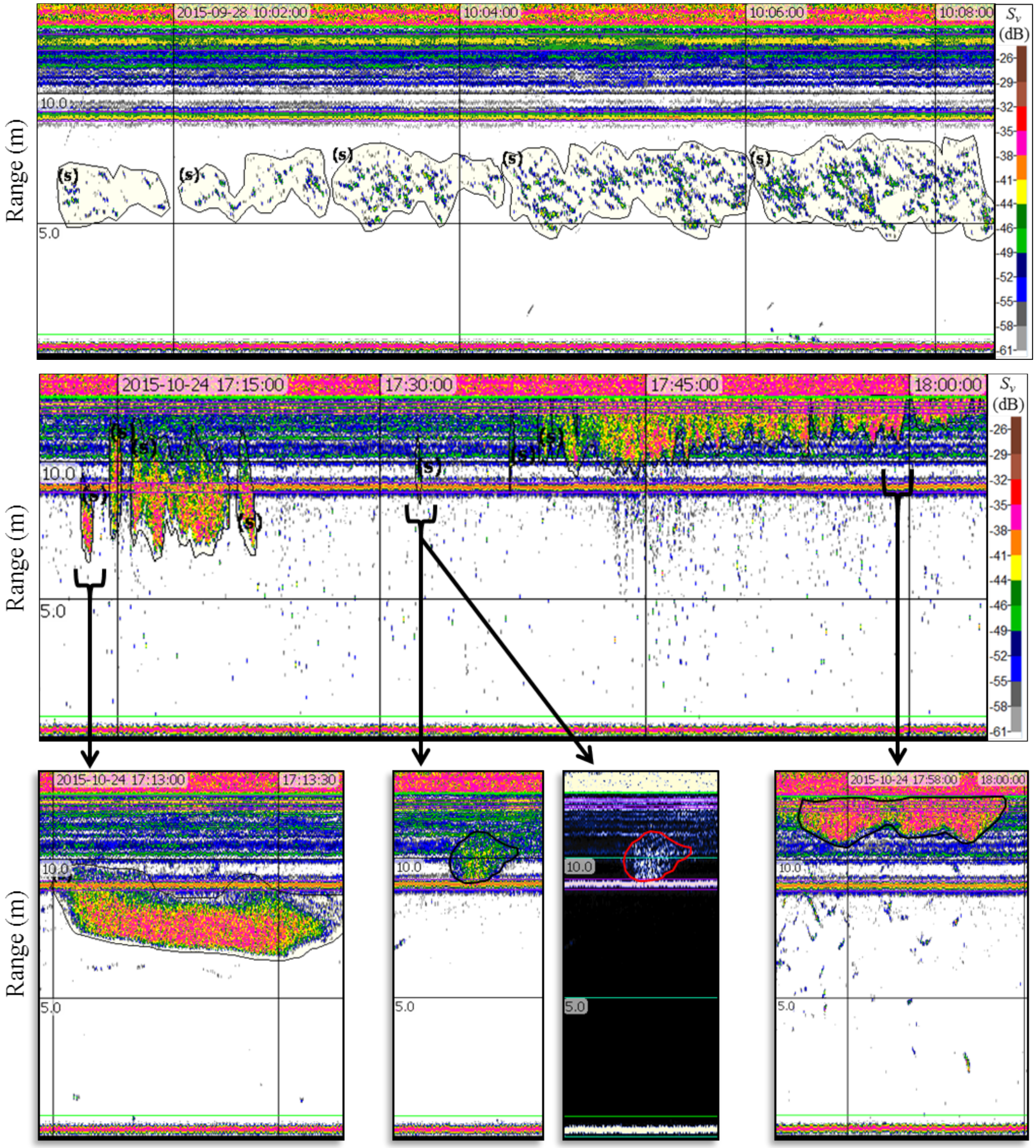



Figure 3.2.5-2. Examples of juvenile American Shad school morphology within echograms from hydroacoustic monitoring near the entrance to the fish pipe in the Vernon forebay, 2015. The top panel shows the aggregation of individual fish into a low density school, and the lower panels show high density schools in various regions of the water column.

### 3.2.6 Verification Sampling

To confirm the presence of juvenile shad, visual surface observations and cast net sampling were concurrently made within 1 hour before or after sunset once per week from August 26 through November 11, 2015 for a total of 12 sampling events. A 3.7-m diameter cast net with 1-cm bar mesh was thrown initially five times off the east side of the fish diversion boom into the forebay and upstream of the transducer. A valid throw was defined as when at least two-thirds of net opened. After the first two weeks with zero catch, cast net sampling effort was increased by 5 additional throws off the west side of the fish diversion boom. Later it was increased to 10 or more throws each side (weather permitting). Each fish caught was identified and measured for total length. Visual observations of near-surface fish activity and shad within a few feet from the surfaces were recorded with cast net data. In addition, thirteen electrofishing sampling events made from September 17 through October 23 for collecting live specimens for radio-telemetry, as described in Section 4.1, also provided another independent relative index of juvenile shad abundance and size distribution. Catch per unit effort was calculated as number of fish per minute for electrofishing and number of fish per 5 casts for cast netting.

### 3.2.7 Environmental Data

The relation between environmental conditions and acoustic indices of shad abundance was investigated for linear trends by regression analysis. River flow (discharge) through Units 1-4 (east side of the fish diversion boom) and all units, precipitation, wind, and water temperature were examined for any possible effects on acoustic backscatter or fish density. Electronic data of hourly flows (in cubic feet per second) for each unit and surface water elevation at Vernon was provided by TransCanada. Hourly precipitation and wind data collected at Keene Dillant-Hopkins Airport located in Swanzey, NH about 15 miles northeast of Vernon were downloaded via online database queries (www.wunderground.com). Water temperature data were obtained from data collected in the Vernon forebay at Station 06-V-01 (RM 142.0) in Study 6 – Water Quality Monitoring Study. Measurements were taken at 15-minute intervals with HOBO® Water Temp Pro v2 (Model U22-001, Onset Computer Corporation) loggers and averaged by hour.

### 3.2.8 Assumptions

This hydroacoustic monitoring plan to describe the temporal migratory pattern of juvenile shad included several important assumptions: (1) the proposed location assumed that a change in historical river bed elevations did not impact deployment or sampling coverage in a meaningful way; (2) transducer deployment met all dam operation and safety requirements; (3) “milling” behavior (multiple re-counting individuals) did not introduce bias in the relative magnitude; (4) juvenile shad arrived and departed (as monitored by hydroacoustics) at the same time as those at other locations at Vernon that were not monitored by hydroacoustics; (5) the acoustic index of relative abundance was proportional to relative abundance of juvenile shad not sampled by hydroacoustics; (6) background noise and acoustic scattering contributions by other targets (e.g., macroinvertebrates, entrained surface bubbles, sediment gas bubbles, other small fish) were assumed to be either negligible, or were either quantified or removed from analysis; and (7) the continuity of the study and the completeness of results was not compromised by natural acts beyond control of the study (e.g., hurricanes, floods, massive floating debris or debris-transducer collision) or by vandalism.

## 3.3 Turbine Survival (HiZ Tag) Methodology

### 3.3.1 Sample Size

One of the main objectives prior to the implementation of this study was the statistical determination of the number of fish to be released to obtain an estimate of turbine passage survival of juvenile American Shad within a precision (ε) level of ± 10%, 95% of the time ($\alpha$=0.05). Appendix B provides the equations used to calculate sample size and precision (ε) for this study. Since the sample size is a function of the recapture rate ($P_A$), expected passage survival ($\tau$) or mortality (1-$\tau$), survival of control fish (S), and the desired precision (ε) at a given probability of significance ($\alpha$), a range of values were used for these parameters to calculate potential sample sizes for various combinations of these parameters. Sample size allocations were initially based on the following range of values: recapture probabilities ($P_A$) of 85 to 98%; control survival: 95 to 100%; and turbine passage survival of 90 to 97%.

Based on several studies on juvenile clupeids (e.g., Heisey et al., 1992; Mathur et al,. 1994, 1996b) utilizing the HI-Z tag-recapture technique, a target release of 150 treatment fish (introduced through the test turbine) accompanied by a release of 75 control fish downstream of the powerhouse was used to obtain a precision (ε) of ± 0.10 on survival estimate at $\alpha$ = 0.05. This sample size assumes ≥95% control survival, a recapture rate of ≥85%, and expected passage survival rates >90% for the study. Because of the embedded flexibility in the HI-Z tag-recapture technique, the sample size requirements can be adjusted downwards or upwards to achieve the desired statistical precision level if the initial assumptions deviate significantly during the course of the study. However, precision and sample size is based on 1-hour survival not on 48-hour survival, so adjustment of sample size can only be done based on 1-hour results. In general, sample size requirements decrease with an increase in control fish survival and recapture rates (Mathur et al., 1996a). Only precision (ε) and $\alpha$ level can be controlled by the investigator. Thus, the effective sample size for survival estimation was 151 and 150 treatment fish passed through Units 4 and 8, respectively and 150 control fish released downstream (Table 3.3.1-1).

Table 3.3.1-1. Daily schedule of released hatchery and wild juvenile American shad passed through Units 4 and 8 at Vernon Station, October 2015.

| Lot No. | Date | Water Temp. (°C) | Unit 4 Wild Fish Used in Analysis | Unit 4 Hatchery Fish[b] | Unit 8 Wild Fish Used in Analysis | Unit 8 Hatchery Fish[b] | Control[a] Wild Fish Used in Analysis | Control Hatchery Fish[b] |
|---|---|---|---|---|---|---|---|---|
| 1 | 10-6 | 15.0 | | 30 | | | | 20 |
| 2 | 10-7 | 15.0 | | | 20 | 20 | 10 | |
| 3 | 10-8 | 14.6 | | | 100 | | 48 | |
| 4 | 10-10 | 14.5 | 60 | | 30 | | 50 | |
| 4a | 10-11 | 15.0 | 91 | | | | 42 | |
| | 10-12 | delayed assessment | | | | | | |
| | 10-13 | delayed assessment | | | | | | |
| | **Total** | | **151** | | **150** | | **150** | |

a. Combined controls released into the tailrace downstream of the station.
b. Hatchery fish not used in analysis.

### 3.3.2 Source of Test Fish

Approximately 500 juvenile shad for this study were transported from the North Attleboro National Fish Hatchery in Massachusetts to Vernon on October 5, 2015. Fish were initially stocked in a 950 gal tank at Vernon which was supplied with ambient river water. Water temperatures ranged from 14.5°C to 15.0°C during the study period coinciding with emigration of juvenile shad in the Connecticut River. Due to high mortality rates of the hatchery fish within a day or two after being placed in the holding tank, a decision was made to use wild in-river fish even though they were much smaller. High mortality of hatchery fish was also observed in the 2014 tagging experiments conducted on wild and hatchery juvenile shad (Normandeau, 2014a). Approximately 600 wild fish were collected by seine and electrofishing techniques in the evening/night hours upstream of Vernon dam. The wild fish were placed in circular tanks continuously supplied with ambient river water. A 50-lb block of salt was initially added to the tanks when fish were stocked and before fish were removed for tagging. The block of salt raised salinity in the tanks to near 5 ppt, which was gradually diluted by the ambient river water. Sufficient fine granular salt was also added to the tagging tub and fish transfers bucket to provide salinity near 5 ppt. The addition of salt to the holding pools reduced osmotic and ionic imbalances in the fish due to handling stress and minimized adverse effects of handling as clupeids are known to be extremely sensitive to handling stress (Heisey et al., 1992; Meinz, 1978).

The treatment fish used at Unit 4 ranged in total length from 90-131 mm, with an average length of 98 mm, and at Unit 8, ranged in total length from 87-121 mm, with an average length of 104 mm. The control fish ranged in length from 90-127 mm, with an average length of 100 mm (Figure 3.3.2-1).

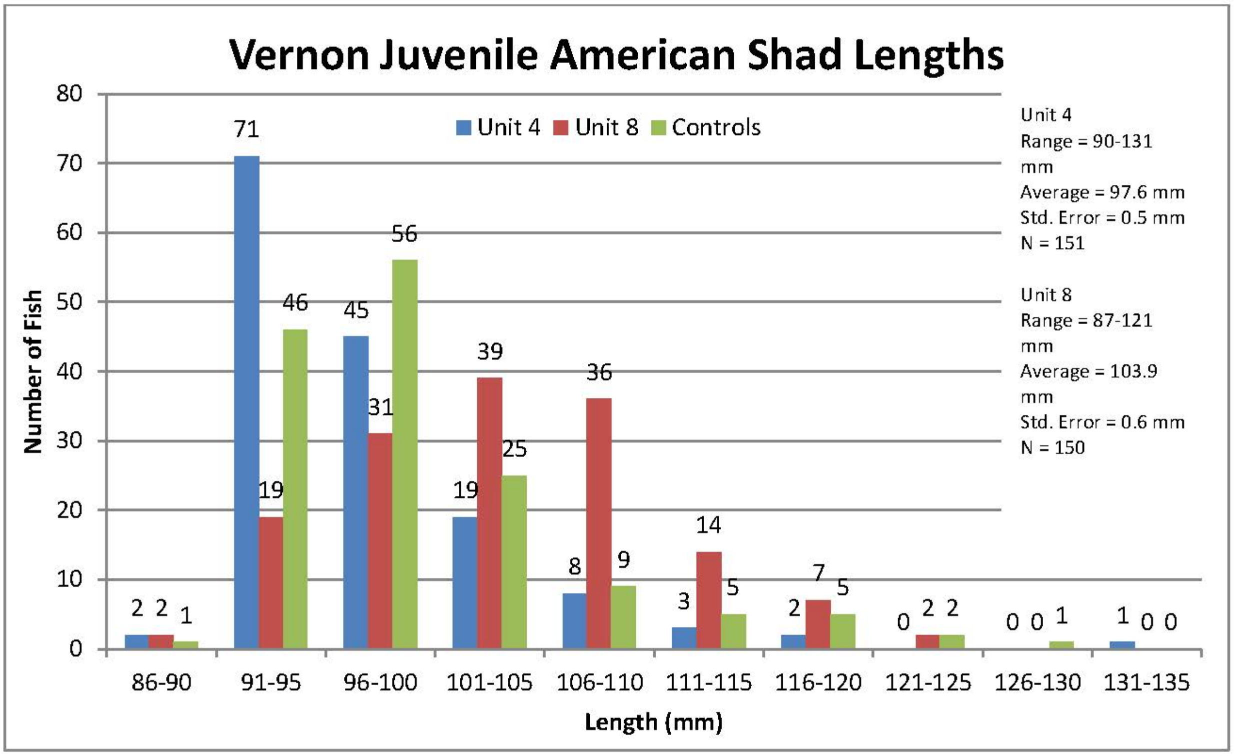



Figure 3.3.2-1: Length frequency (mm) for juvenile wild American Shad released through the Vernon Station, October 2015.

### 3.3.3 Fish Tagging and Release

Fish tagging, release, and recapture techniques were similar to those used in numerous other studies including those conducted at the Vernon Project (Heisey et al., 1992, 2008; RMC, 1994; Normandeau, 1995; 1996). Each fish was corralled in the holding tank with a fine mesh seine net and then removed while in water by a brailer (Figure 3.3.3-1). Each fish was fitted with a miniature radio transmitter and a HI-Z Tag (Figure 3.3.3-2). The radio tags were approximately 6 x 12 mm, weighing 0.5 g in air and propagated radio signals through a 27-cm thin wire antenna. The un-inflated HI-Z Tags were made of bright-colored latex 30 mm long and 10 mm wide and weighing 1.7 g. Tags were attached to the fish by a single stainless steel pin through the dorsal musculature near the insertion of the dorsal fin. The pin was inserted with a modified ear piercing gun and secured by a small plastic disc (Heisey et al., 1992; RMC, 1994). Just prior to release into the induction system, the HI-Z tags were activated by injecting 1-1.5 ml of catalyst (Figure 3.3.3-3).

Figure 3.3.3-1: Juvenile wild American Shad placed in a brailer for transferring to tagging tub at Vernon Station, October 2015.

Figure 3.3.3-2: Attaching a HI-Z balloon tag along with an ATS radio tag to a juvenile wild American Shad at Vernon Station, October 2015.

Figure 3.3.3-3: (Top) Injecting catalyst into the HI-Z tag and (Bottom) releasing a HI-Z tagged juvenile wild American Shad at Vernon Station, October 2015.

Tagged fish were introduced individually into the penstocks of Units 4 and 8 (treatment) by an induction apparatus (Figure 3.3.3-4). The induction apparatus consisted of a holding basin attached to a 4-in discharge hose. A 3-in trash pump supplied river water to ensure that fish were transported quickly within a continuous flow of water to the release point. The release hose was lowered on the downstream side of the intake trash rack with the terminus positioned to release fish approximately 3-5 ft below the intake ceiling (Figures 3.3.3-5 and 3.3.3-6). Procedures for handling, tagging, release and recapture of control fish were similar to those used for treatment fish. The control fish were released directly into the tailrace (Figure 3.3.3-7). Fish showing erratic behavior or external injuries and/or fungal infections were rejected and not used.

Figure 3.3.3-4: Induction system used to release HI-Z tagged juvenile wild American Shad at Vernon Station, October 2015.

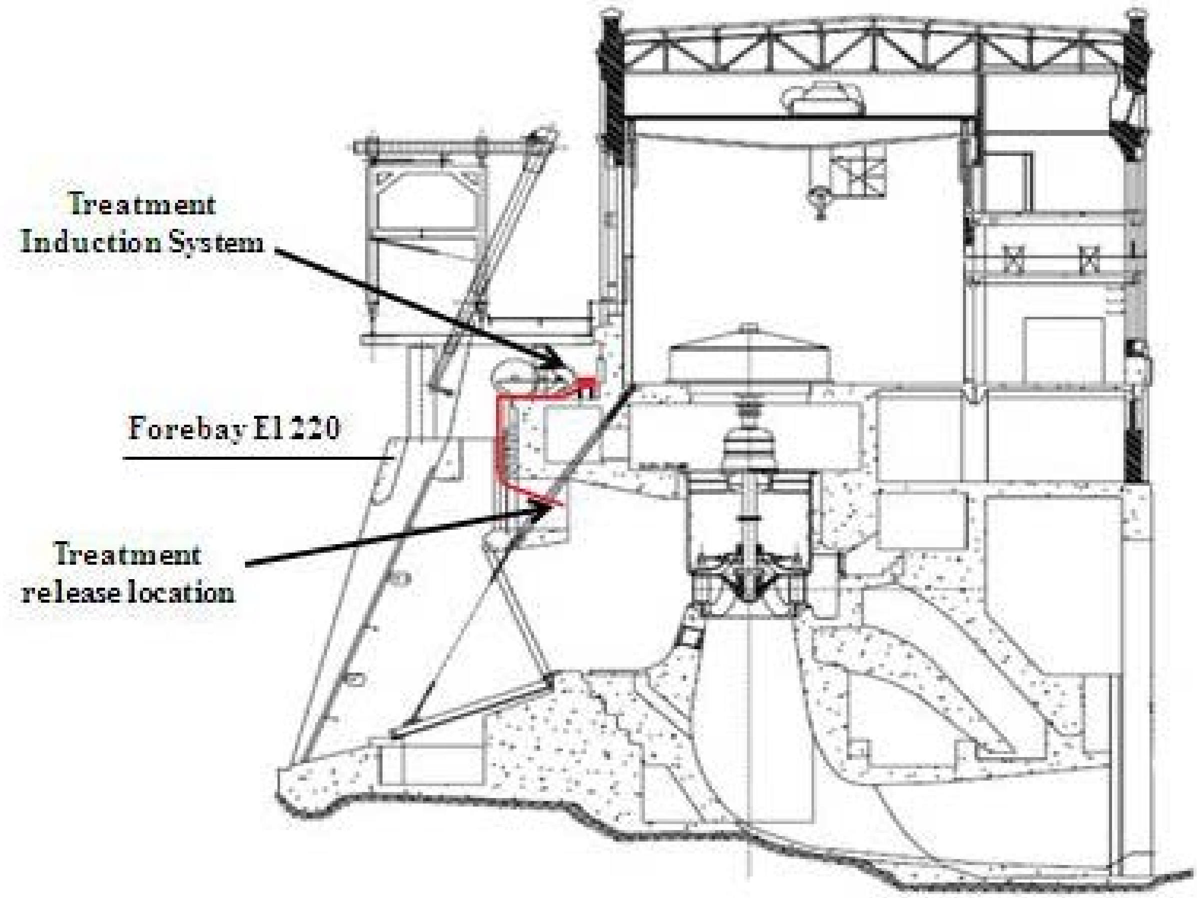



Figure 3.3.3-5: Schematic of Unit 4 showing approximate locations of the treatment induction system and the terminus of the release hose at Vernon Project, October 2015.

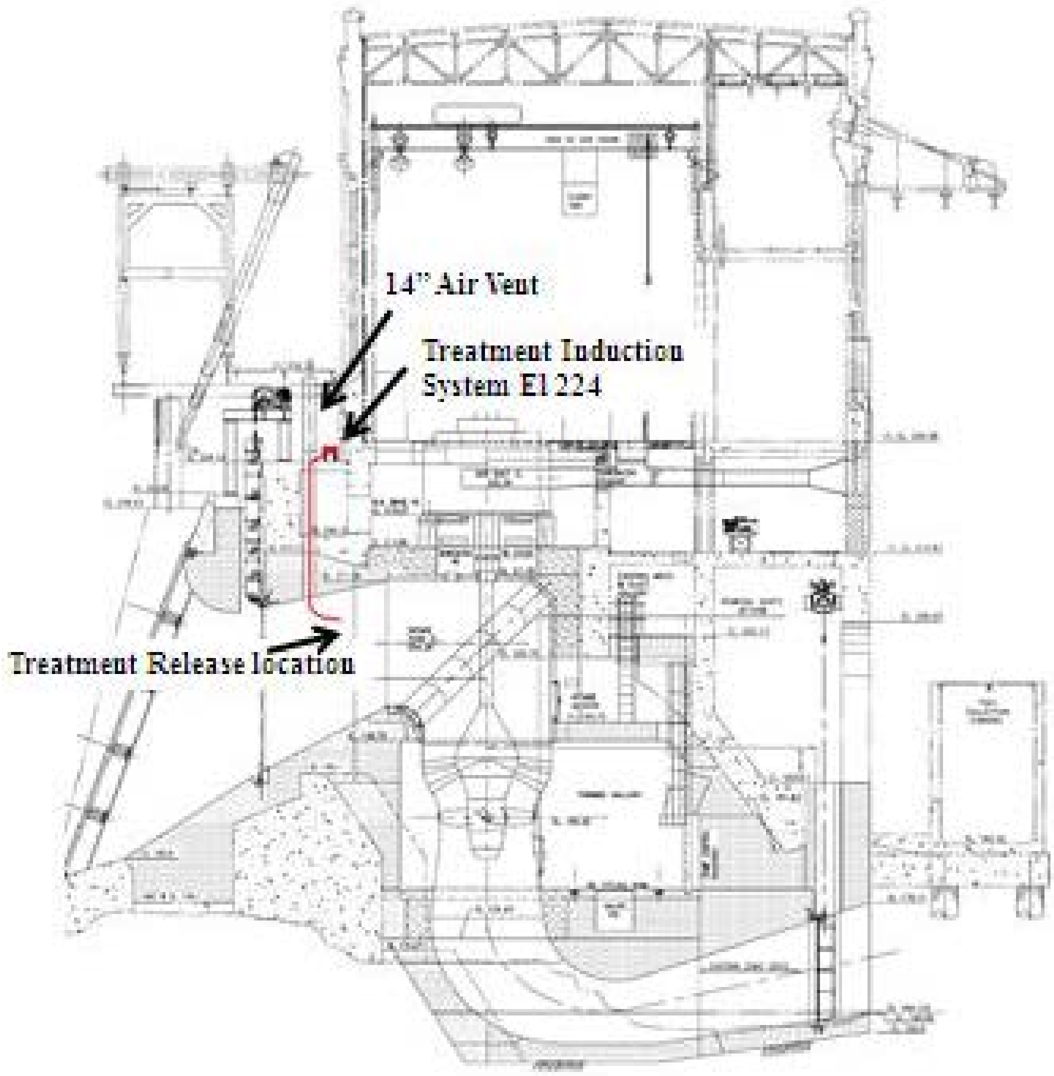



Figure 3.3.3-6: Schematic of Unit 8 showing approximate locations of the treatment induction system and the terminus of the release hose at Vernon Project, October 2015.


Figure 3.3.3-7: Control release site at Vernon Station, October 2015.

### 3.3.4 Recapture Methods

After release (treatment and control), the fish were tracked downstream of the powerhouse by three boat crews and retrieved once buoyed to the surface by the inflated HI-Z tag (Figure 3.3.4-1). Boat crews were notified of the radio tag frequency (48 or 49 MHz) for each fish upon its release. Advanced Telemetry System receivers with a loop antenna were used in tracking both treatment and control fish. Fish that failed to surface shortly after passage were monitored via radio signals for a minimum of 30 minutes.

Boat crews retrieved buoyed fish by a net with a water sanctuary or water brailer to reduce handling and stress. Recaptured fish were placed into a 5-gal pail where tags were removed. To the extent possible, fish were kept in water during recapture and examination. Each fish was immediately examined for maladies including visible injuries, scale loss >20% per side, and/or loss of equilibrium, and were assigned appropriate condition codes (Table 3.3.4-1). Tagging and data recording personnel were notified via a two-way radio system of each fish's recapture time and condition (Appendix C, filed separately in Excel format).


Figure 3.3.4-1: (Top) Recapturing HI-Z tagged juvenile wild American Shad with a brailer and (Bottom) Recaptured HI-Z tagged juvenile wild American Shad after passing through Vernon Station, October 2015.

Table 3.3.4-1. Condition codes assigned to fish and dislodged HI-Z tags for fish passage survival studies.

| **Status Codes** | **Description** |
|---|---|
| * | Turbine/passage-related malady |
| 4 | Damaged gill(s): hemorrhaged, torn or inverted |
| 5 | Major scale loss, >20% |
| 6 | Severed body or nearly severed |
| 7 | Decapitated or nearly decapitated |
| 8 | Damaged eye: hemorrhaged, bulged, ruptured or missing, blown pupil |
| 9 | Damaged operculum: torn, bent, inverted, bruised, abraded |
| A | No visible marks on fish |
| B | Flesh tear at tag site(s) |
| C | Minor scale loss, <20% |
| E | Laceration(s): tear(s) on body or head (not severed) |
| F | Torn isthmus |
| G | Hemorrhaged, bruised head or body |
| H | Loss of Equilibrium (LOE) |
| J | Major |
| K | Failed to enter system |
| L | Fish likely preyed on (telemetry, circumstances relative to recapture) |
| M | Minor |
| P | Predator marks |
| Q | Other information |
| S | Special describe as needed |
| R | Removed from sample |
| T | Trapped in the rocks/recovered from shore |
| V | Fins displaced, or hemorrhaged (ripped, torn, or pulled) from origin |
| W | Abrasion / Scrape |
| **Survival Codes** | |
| 1 | Recovered alive |
| 2 | Recovered dead |
| 3 | Unrecovered – tag & pin only |
| 4 | Unrecovered – no information or brief radio telemetry signal |
| 5 | Unrecovered – trackable radio telemetry signal or other information |
| **Dissection Codes** | |
| 1 | Shear |
| 2 | Mechanical |
| 3 | Pressure |
| 4 | Undetermined |
| 5 | Mechanical/Shear |
| 6 | Mechanical/Pressure |
| 7 | Shear/Pressure |
| B | Swim bladder ruptured or expanded |
| D | Kidneys damaged (hemorrhaged) |
| E | Broken bones obvious |
| F | Hemorrhaged internally |
| J | Major |

| Status Codes | Description |
|---|---|
| L | Organ displacement |
| M | Minor |
| N | Heart damage, rupture, hemorrhaged |
| O | Liver damage, rupture, hemorrhaged |
| R | Necropsied, no obvious injuries |
| S | Necropsied, internal injuries |
| T | Tagging/Release |
| U | Undetermined |
| W | Head removed; i.e., otolith |

Recaptured fish were transported to shore and held in holding pools (600 and 900 gal) to monitor delayed (48-hour) effects of tagging and turbine passage Figure 3.3.4-2). The holding pools were continuously supplied with ambient river water. A 50-lb block of salt was initially placed in each of the pools, and each morning for the next two days to provide salinity near 5 ppt. The continuous flow of ambient river water into the pools gradually diluted the salt concentration. The pools were covered to prevent escapement and minimize external stressors. To further minimize handling stress, exact measurements were taken at the end of the 48-hour assessment period or at the time of mortality. Mortalities in the holding pools were retrieved after 24 hours and 48 hours. Fish that were alive after 48 hours and free of major injuries were released into the river.

Figure 3.3.4-2: Delayed assessment tanks used to hold juvenile wild American Shad at Vernon Station, October 2015.

### 3.3.5 Classification of Recaptured Fish

As in previous turbine passage investigations (Heisey et al., 1992; Mathur et al., 1994, 1996a, 1996b), the immediate post passage status of each recaptured fish and recovery of inflated tags dislodged from fish were designated as alive, dead, or unknown. The following criteria were established to make these designations: (1) alive—recaptured alive and remaining so for 1 hour; (2) alive—fish did not surface but radio signals indicated movement patterns; (3) dead—recaptured dead or dead within 1 hour of release; (4) dead—only inflated dislodged tag(s) were recovered, or telemetric tracking or the manner in which inflated tags surfaced was not indicative of a live fish; and (5) unknown—no fish or dislodged tag was recaptured, or radio signals were received only briefly, and the subsequent status could not be ascertained. Fish that moved into areas where they could not be recaptured (i.e., at rip rap along the shore, in submerged crevices, or in areas of high turbulence) were excluded from the statistical analysis. Mortalities of recaptured fish occurring after 1-hour were assigned 48-hour post passage status effects, although the fish were observed at approximately 12-hour intervals during the interim. Per the RSP, fish and tags falling into criteria 4 and 5 above were to be censored from the data set.

### 3.3.6 Assessment of Fish Injuries

All recaptured fish were examined for types and extent of external injuries. Dead fish were also necropsied for internal injuries when there were no apparent external injuries. Additionally, all specimens alive at 48 hours were closely examined for injury. The initial examination allowed detection of some injuries, such as bleeding and minor bruising that may not be evident after 48 hours due to natural healing processes. Injuries were categorized by type, extent, and area of body. Fish without visible injuries that were not actively swimming or were swimming erratically at recapture were classified as having “loss of equilibrium” (LOE). This condition has been noted in most past HI-Z tag direct survival/injury studies and often disappears within 10 to 15 minutes after recapture if the fish is not injured. Visible injuries and LOE were categorized as minor or major (Table 3.3.6-1). The criteria for this determination were based primarily on field observations.

Fish without visible injuries and/or loss of equilibrium were designated “malady-free”. The malady-free metric is established to provide a standard way to depict a specific passage route’s effects on the condition of entrained fish (Normandeau et al., 2006). The malady-free metric is based solely on fish physically recaptured and examined. Additionally, the malady-free metric in concert with site-specific hydraulic and physical data may provide insight into which passage conditions and locations present safer fish passage.

Table 3.3.6-1. Guidelines for major and minor injury classifications for fish passage survival studies using the HI-Z Tags.

| |
|---|
| A fish with only Loss of Equilibrium (LOE) is classified as major if the fish dies within 1 hour. If it survives or dies beyond 1 hour it is classified as minor. |
| A fish with no visible external or internal maladies is classified as a passage related major injury if the fish dies within 1 hour. If it dies beyond 1 hour it is classified as a non-passage related minor injury. |
| Any minor injury that leads to death within 1 hour is classified as a major injury. If it lives or dies after 1 hour it remains a minor injury. |
| Hemorrhaged eye: minor if less than 50%. Major if 50% or more |
| Deformed pupil(s) are a: major injury. |
| Bulged eye: major unless one eye is only slightly bulged. Minor if slight. |
| Bruises are size-dependent. Major if 10% or more of fish body per side. Otherwise minor. |
| Inverted or bleeding gills or gill arches is major |
| Operculum tear at dorsal insertion is: major if it is 5 % of the fish or greater. Otherwise minor. |
| Operculum folded under or torn off is a major injury |
| Scale loss: major if 20% or more of fish per side. Otherwise minor |
| Scraping (damage to epidermis): major if 10% or more per side of fish. Otherwise minor. |
| Cuts and lacerations are generally classified as major injuries. Small flaps of skin or skinned up snouts are: minor. |
| Internal hemorrhage or rupture of kidney, heart or other internal organs that results in death at 1 to 48 hours is a major injury. |
| Multiple injuries: use the worst injury |

### 3.3.7 Estimation of Survival and Malady-Free

In order to obtain the survival estimate comparable to other HI-Z tag direct survival studies and also to follow the Updated RSP, survival estimates were calculated for all juvenile shad (including classification 4 and 5 see Section 3.3.5) and also with only recaptured fish. The release and recapture data were analyzed by a likelihood ratio test to determine whether recapture probabilities were similar for dead ($P_D$) and alive ($P_A$) fish (Mathur et al., 1996a, 1996b). The statistic tested the null hypothesis of the simplified model (Ho: $P_A$=$P_D$) versus the alternative generalized model (Ha: $P_A \neq P_D$). The simplified model has three parameters (P, S, τ) with three minimum sufficient statistics ($a_c$, $a_T$, $d_T$) while the alternative generalized model (recapture probabilities of alive and dead fish are unequal) has four parameters ($P_A$, $P_D$, S, τ) and four minimum sufficient statistics ($a_c$, $a_T$, $d_c$, $d_T$). If homogeneity ($P > 0.05$) was revealed by the chi-square test, turbine passage survival can be estimated by the simplified model with increased precision. Appendix B provides the definition of terms, derivation of likelihood estimates, and assumptions of the likelihood model. The maximum likelihood estimators associated with the model are:

$$\hat{\tau} = \frac{a_T R_C}{R_T a_C}$$

$$\hat{S} = \frac{R_T d_C a_C - R_C d_T a_C}{R_C d_C a_T - R_C d_T a_C}$$

$$\hat{P}_A = \frac{d_C a_T - d_T a_C}{R_T d_C - R_C d_T}$$

$$\hat{P}_D = \frac{d_C a_T - d_T a_C}{R_C a_T - R_T a_C}$$

The variance (Var) and standard error (SE) of the estimated passage mortality ($1-\hat{\tau}$) or survival ($\hat{\tau}$) are:

$$Var(1-\hat{\tau}) = Var(\hat{\tau}) = \frac{\tau}{SP_A}\left[\frac{(1-S\tau P_{A)}}{R_T} + \frac{(1-SP_A)\tau}{R_C}\right]$$

$$SE(1-\hat{\tau}) = SE(\hat{\tau}) = \sqrt{Var(1-\hat{\tau})} \ .$$

Separate survival probabilities (1- and 48- hour), malady-free estimates, and their associated standard errors were estimated using the likelihood model given in Appendix D. The formulas are:

Survival (τ), 1 and 48 hours

Where:

$$\hat{\tau}_i = \frac{a_{Ti} R_c}{R_{Ti} a_c},$$

$R_{Ti}$ = Number of fish released for the treatment condition

$a_{Ti}$ = Number of fish alive for the treatment condition;

$R_c$ = Number of control fish released;

$a_c$ = Number of control fish alive.

Malady-Free (MF) Fish

Where:

$$MF_i = \frac{c_{Ti} R_c}{R_{Ti} c_c},$$

$C_{Ti}$ = Total number of fish without maladies for treatment;

$R_{Ti}$ = Number of fish recovered that were examined for maladies for treatment;

$C_c$ = Number of control fish recovered without maladies;

$R_c$ = Number of control fish recovered that were examined for maladies.

Since the likelihood ratio tests showed equality of $P_A$ and $P_D$ ($P>0.05$), survival and malady-free estimates were made using the reduced model. Appendix D presents outputs of these analyses along with estimates of standard errors.

Because of high control and treatment fish mortality (≥20%) during the delayed assessment period only the 1h survival estimate were deemed reliable. Similar high juvenile American Shad mortality rates have occurred during the delayed assessment period in other HI-Z tag studies conducted at projects on the Susquehanna and Connecticut rivers.

### 3.3.8 Assignment of Probable Sources of Injury

Limited controlled experiments (Neitzel et al., 2000; Pacific Northwest National Laboratory et al., 2001) to replicate and correlate each injury type/characteristic to a specific causative mechanism provides some indication of the cause of observed injuries in the field. Some injury symptoms can be manifested by two different sources that may lessen the probability of accurate delineation of a cause and effect relationship (Eicher Associates, 1987). Only probable causal mechanisms of injury were assigned for the present investigation. Injuries likely to be associated with direct contact of turbine runner blades or structural components are classified as mechanical and include: bruise, laceration, and severance of the fish body (Dadswell et al., 1986; Eicher Associates, 1987). Passage through gaps between the runner blades and the hub, or at the distal end of the blades may result in a pinched body. Injuries likely to be attributed to shear forces are decapitation, torn or flared opercula, and hemorrhaged eyes (Neitzel et al., 2000).

# 4.0 RESULTS AND DISCUSSION

## 4.1 Route Selection

### 4.1.1 Control Fish Tagging Experiment

As stated in Section 3.1, to augment the results reported in Normandeau (2014a) and to provide release-group specific information regarding post-tagging survival and behavior, control specimens were tagged with dummy tags of the same size and weight as the test tags, and control fish were maintained and observed in the holding facilities. Four control fish tagging trials were conducted throughout the study period on September 28 and October 6, 12, and 19. Mortality observed in these trials ranged from 14-30% and was likely biased based on the fact that trial shad had to be held and maintained with additional wild-caught shad being used for the HI-Z survival study once it was determined that hatchery fish provided by the FWS were not suitable for testing due to high mortality rates.

### 4.1.2 In-river Releases

A total of 310 juvenile shad were equipped with radio tags and released upstream of Vernon dam on 15 occasions during a six-week period between September 25 and October 30, 2015 (Table 4.1.2-1). Fish were tagged and released in groups of 13 to 20 individuals and released in three general areas (east, west and mid-river) along a perpendicular transect across the river which originated near the Vermont Yankee (VY) Intake (Figure 3.1-1). Of the 310 released, 270 (87.1%) approached Vernon. Of the total number released, 12.9% (40 of the 310) were determined to not have approached the project based on a lack of detections within the stationary receiver array. When examined among the 15 release groups, the percentage of juvenile shad failing to approach Vernon was greatest during the earlier releases. Of those 40 individuals, 52% were associated with releases 1 through 5; 31% were associated with releases 6 through 10; and 17% were associated with releases 11 through 15. Four individuals failing to approach Vernon were located during manual tracking efforts upstream of the project and the rest went undetected following release. The final fate of those individuals is unknown. It is possible their tags became dislodged, they died and settled on the bottom, or they were -preyed upon. Regardless, as these individuals failed to approach Vernon they were excluded from all subsequent analyses.

Table 4.1.2-1. Summary of radio-tagged juvenile American Shad releases, fall 2015.

| Release Date | Release Group | Release Time | No. of Fish Released | | | River Temp (°C) | Vernon Discharge (cfs) |
|---|---|---|---|---|---|---|---|
| | | | Mid-river | NH side of river | VT side of river | | |
| 25-Sep-15 | 1 | 19:02-19:46 | 7 | 7 | 6 | 21.5 | 2,137 |
| 28-Sep-15 | 2 | 20:46-20:57 | | 10 | 10 | 20.4 | 2,007 |
| 03-Oct-15 | 3 | 18:37-20:05 | 7 | 7 | 6 | 15.5 | 13,526 |
| 05-Oct-15 | 4 | 19:23-19:59 | 6 | 7 | 7 | 14.7 | 9,360 |

| Release Date | Release Group | Release Time | No. of Fish Released | | | River Temp (°C) | Vernon Discharge (cfs) |
|---|---|---|---|---|---|---|---|
| | | | Mid-river | NH side of river | VT side of river | | |
| 07-Oct-15 | 5 | 19:25 | 7 | 7 | 6 | 15.1 | 9,173 |
| 09-Oct-15 | 6 | 20:02 | | 13 | | 15.2 | 11,226 |
| 12-Oct-15 | 7 | 19:00 | 27 | | | 14.6 | 8,064 |
| 14-Oct-15 | 8 | 19:50 | | | 20 | 14.6 | 10,206 |
| 16-Oct-15 | 9 | 18:55 | | 20 | | 13.9 | 8,374 |
| 19-Oct-15 | 10 | 18:18 | | | 20 | 13.5 | 6,737 |
| 21-Oct-15 | 11 | 18:37 | 20 | | | 11.8 | 9,170 |
| 23-Oct-15 | 12 | 18:13 | | 20 | | 11.2 | 8,528 |
| 26-Oct-15 | 13 | 18:00 | | | 20 | 10.4 | 10,051 |
| 28-Oct-15 | 14 | 13:36 | 27 | | | 10.0 | 2,353 |
| 30-Oct-15 | 15 | 16:09 | | 23 | | 9.7 | 14,150 |
| **Total** | | | **101** | **114** | **95** | | |

### 4.1.3 Movement and Behavior

Where data were available, approach duration, forebay residency time, tailrace residency time, downstream transit time, and total time in the study area was calculated for each individual. Approach times were calculated as the duration of time from release into the river until initial detection at one or more of the forebay monitoring stations. Forebay residency times were calculated as the duration of time from the initial detection at one of the forebay monitoring stations until the final detection at either a confirmed passage route receiver (for individuals passing Vernon in a known manner) or a forebay monitoring station (for individuals approaching Vernon but failing to successfully pass or individuals passing Vernon via an unknown manner). Tailrace residency times were calculated as the duration of time from the initial to final detections among receivers monitoring the unit discharges, spillway or general tailrace area. Downstream transit times were calculated as the duration of time from the final detection among the tailrace receivers until initial detection at the remote receiver located downstream near Stebbins Island.

#### Approach Duration

Valid detection information was available to determine the approach duration for each of the 270 shad that entered the forebay area. When all of these individuals are considered, approach duration ranged from approximately 0.1 hours to 70.8 hours (2 days, 22 hours and 8 min) with an overall median duration of 1.9 hours (Table 4.1.3-1). The majority (68%) of individuals were present within the Vernon forebay within four hours following release (Figure 4.1.3-1).

Table 4.1.3-1. Minimum, maximum, mean, and median approach duration (hrs) for release groups 1 through 15 of radio-tagged juvenile American Shad at Vernon, fall 2015.

| Release Group | Approach Duration (hours) | | | | | River Temp (°C) | Vernon Discharge (cfs) |
|---|---|---|---|---|---|---|---|
| | Min | Max | Mean | Median | N | | |
| 1 | 1.2 | 70.8 | 14.1 | 8.2 | 17 | 21.5 | 2,137 |
| 2 | 0.5 | 44.8 | 9.0 | 4.9 | 9 | 20.4 | 2,007 |
| 3 | 0.4 | 2.7 | 1.3 | 1.4 | 20 | 15.5 | 13,526 |
| 4 | 0.6 | 2.8 | 1.1 | 1.0 | 18 | 14.7 | 9,360 |
| 5 | 0.1 | 22.6 | 3.4 | 0.5 | 17 | 15.1 | 9,173 |
| 6 | 0.3 | 1.7 | 1.2 | 1.3 | 12 | 15.2 | 11,226 |
| 7 | 0.6 | 43.2 | 9.1 | 3.7 | 24 | 14.6 | 8,064 |
| 8 | 0.7 | 67.6 | 8.9 | 1.7 | 14 | 14.6 | 10,206 |
| 9 | 1.4 | 63.7 | 16.2 | 3.0 | 18 | 13.9 | 8,374 |
| 10 | 0.6 | 36.3 | 5.8 | 1.3 | 17 | 13.5 | 6,737 |
| 11 | 0.2 | 2.1 | 1.2 | 1.1 | 19 | 11.8 | 9,170 |
| 12 | 0.5 | 61.7 | 8.7 | 3.5 | 18 | 11.2 | 8,528 |
| 13 | 1.0 | 28.0 | 8.6 | 3.9 | 20 | 10.4 | 10,051 |
| 14 | 1.7 | 14.4 | 5.3 | 4.6 | 25 | 10.0 | 2,353 |
| 15 | 0.4 | 1.9 | 1.2 | 1.3 | 22 | 9.7 | 14,150 |
| **All** | **0.1** | **70.8** | **6.2** | **1.9** | **270** | | |

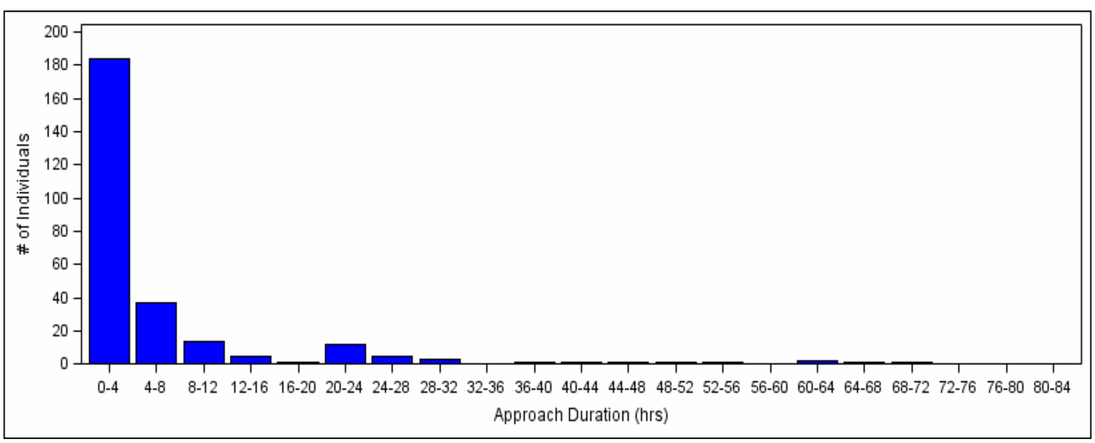



Figure 4.1.3-1. Frequency distribution of approach duration (in hours) for radio-tagged juvenile American Shad approaching Vernon from the upstream release site, fall 2015.

### Forebay Residency

Valid detection information was available to determine the forebay residency duration for 265 of the 270 radio-tagged juvenile shad known to have entered the forebay area. For those fish, forebay residency time ranged from less than 0.1 hours to 237.7 hours (9 days, 21 hours, 42 min) with an overall median duration of 0.7 hours (44 min) (Table 4.1.3-2, Appendix I-1 and I-3, filed separately in Excel format). When examined by release group, the highest median forebay residency time occurred during release 1 (39.5 hours; 1 day, 15 hours, 30 min) which was conducted on October 3rd. The extended residency time indicates that fish spent a greater amount of time milling around immediately upstream of the project than was observed for subsequent releases conducted later in the season. Of the eighteen individuals from release group 1 that approached Vernon, 38% (7 of the 18) were determined to have not successfully passed the project.

When individuals from all 15 release groups are considered, the forebay residency time was significantly longer for individuals that did not pass relative to those that moved downstream of Vernon (Mann-Whitney test; $z$ =6.5048 $p$ = <0.0001). The frequency distribution of forebay residency times for all individuals passing and not passing Vernon are presented in Figure 4.1.3-2.

Table 4.1.3-2. Minimum, maximum, mean, and median forebay residency times (hrs) for release groups 1 through 15 of radio-tagged juvenile American Shad at Vernon, fall 2015.

| Release Group | Forebay Residency (hours) | | | | |
|---|---|---|---|---|---|
| | **Min** | **Max** | **Mean** | **Median** | **N** |
| 1 | 0.2 | 125.1 | 38.7 | 39.5 | 17 |
| 2 | 0.1 | 129.5 | 29.6 | 3.1 | 9 |
| 3 | <0.1 | 4.8 | 0.4 | 0.2 | 20 |
| 4 | <0.1 | 150.5 | 12.0 | 0.5 | 18 |
| 5 | 0.1 | 237.7 | 27.3 | 1.8 | 17 |
| 6 | <0.1 | 1.0 | 0.4 | 0.4 | 12 |
| 7 | <0.1 | 149.2 | 14.4 | 0.5 | 22 |
| 8 | 0.1 | 152.3 | 32.5 | 13.9 | 14 |
| 9 | <0.1 | 23.1 | 9.5 | 3.8 | 18 |
| 10 | <0.1 | 149.0 | 15.2 | 0.9 | 17 |
| 11 | <0.1 | 1.2 | 0.4 | 0.4 | 18 |
| 12 | <0.1 | 154.1 | 14.7 | 1.5 | 18 |
| 13 | <0.1 | 21.5 | 4.1 | 0.7 | 20 |
| 14 | <0.1 | 7.7 | 0.9 | 0.4 | 23 |
| 15 | 0.1 | 15.9 | 1.4 | 0.6 | 22 |
| **All** | **<0.1** | **237.7** | **12.2** | **0.7** | **265** |

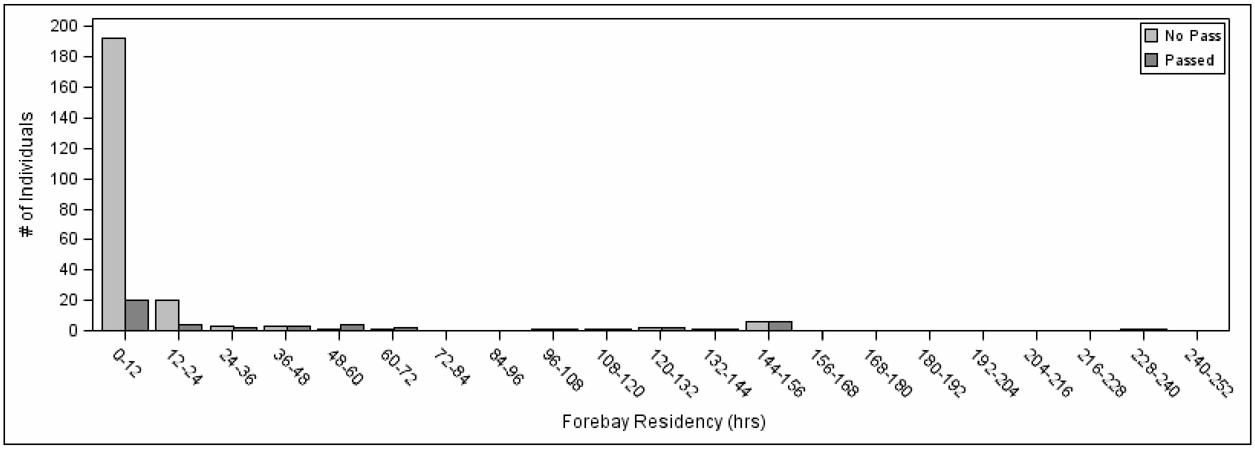



Figure 4.1.3-2. Frequency distribution of forebay residency times (in hours) for radio-tagged juvenile American Shad passing and not passing Vernon, fall 2015.

The minimum, maximum, mean, and median forebay residency times (in hours) by passage route and for non-passing shad are presented in Table 4.1.3-3. Results of a Kruskal Wallis test ($\chi^2$ = 50.2588; *df* = 9; *p* = <0.0001) indicated a significant difference in the mean forebay residency time among passage routes. To examine that effect, a series of individual Mann-Whitney tests were used to conduct pairwise comparisons between routes with a reasonable sample size (i.e., fish pipe, units 1-4, units 5-8, units 9-10, and no pass). Among those comparisons, the only significant differences occurred between the four primary passage routes (fish pipe, units 1-4, units 5-8, and units 9-10) and individuals not passing.[1]

Approximately 87% of shad that passed Vernon did so in 12 hours or less (median residency for all passed shad = 0.6 hours, mean = 4.2 hours). By passage route, the only group of passed fish with a median forebay residency greater than one hour was the group of two individuals that passed via the fish ladder (median = 15.4 hr) (Table 4.1.3-3).

[1] Fish pipe vs. No Pass (Mann-Whitney test; *z* =-3.6113 *p* = 0.0003)
Units 1-4 vs. No Pass (Mann-Whitney test; *z* =-4.8221 *p* = <0.0001)
Units 5-8 vs. No Pass (Mann-Whitney test; *z* =6.0160 *p* = <0.0001)
Units 9-10 vs. No Pass (Mann-Whitney test; *z* =-4.7422 *p* = <0.0001)

Table 4.1.3-3. Minimum, maximum, mean and median forebay residency times (hrs) by downstream passage route for radio-tagged juvenile American Shad at Vernon, fall 2015.

| Passage Route | Forebay Residency (hours) | | | | |
|---|---|---|---|---|---|
| | Min | Max | Mean | Median | N |
| No Passage | 0.1 | 237.7 | 51.9 | 18.4 | 44 |
| Spill | 0.1 | 0.1 | 0.1 | 0.1 | 1 |
| Fish Pipe | <0.1 | 39.5 | 4.4 | 0.6 | 17 |
| Fish Tube | 0.8 | 0.8 | 0.8 | 0.8 | 1 |
| Fish Ladder | 7.9 | 23.0 | 15.4 | 15.4 | 2 |
| Units 1-4 | <0.1 | 2.2 | 0.6 | 0.4 | 22 |
| Units 5-8 | <0.1 | 66.7 | 4.9 | 0.4 | 88 |
| Units 9-10 | <0.1 | 21.6 | 2.6 | 0.9 | 35 |
| Unknown | <0.1 | 41.5 | 5.7 | 0.9 | 53 |
| Trash/ice sluice | 0.7 | 1.0 | 0.9 | 0.9 | 2 |
| **All** | **<0.1** | **237.7** | **12.2** | **0.7** | **265** |
| **All Passed** | **<0.1** | **67.8** | **4.3** | **0.6** | **221** |

### Proportion of Detections in Forebay Detection Areas

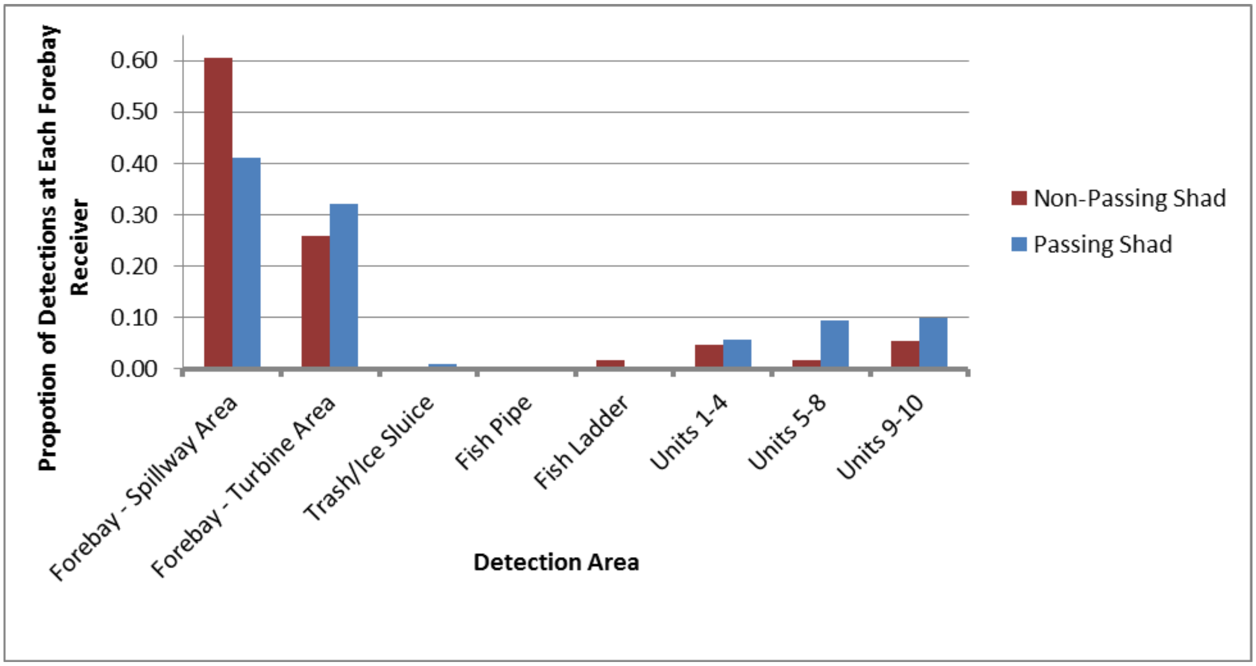
The mean proportion of all detections (including multiple detections per individual fish) during forebay residency in each forebay detection area was compared for the group of 44 non-passing shad and the group of 226 shad that did pass (Table 4.1.3-4, Figure 4.1.3-3). It should be noted that the contribution to total detection by any one monitoring station within the Vernon forebay or at a specific downstream passage route is a function of the intended detection range for each receiver.

Proportion of detections was used rather than duration of time because the calculation of cumulative residence duration at a particular locations relies on the ability to identify the breaks in the detection time series for a particular individual to indicate when that fish is or is not present in the detection field for a particular receiver. Since signal transmissions during a period of residence within the detection zone of a single receiver can go unrecorded for a variety of reasons (e.g., receiver scan time, signal collision, background interference, etc.), it is not appropriate to set a threshold time interval between detections equal to the transmission rate of the tags. To determine the appropriate threshold interval for a particular monitoring station, the intervals between all successive detections for each individual at that location should be calculated. In theory, sequential detections within a particular zone should be some multiple of the burst rate for the transmitters being used with longer intervals decreasing in frequency of occurrence. A threshold interval for determining continued presence can be identified as the 95th percentile of the observed set of interval durations. The threshold value is then used to delineate when each period of residence is started and completed for a tagged individual. The departure of a tagged fish from a particular receiver's detection area is determined when the time interval between successive detections exceeded the threshold interval for that zone.

As expected, the majority of forebay detections for all individuals were dominated by the aerial antennas covering the areas upstream of the spillway gates and unit intakes (average = 75% of detections per individual) prior to passage. The remaining detections were specific to nearfield areas at the various downstream passage routes (i.e., units, fish pipe, etc.) when individuals were more likely to be committed to that passage route. The majority of detections for non-passing shad occurred in the large spillway area of the forebay (60.6%) compared to 41% of detections for shad that passed. The percentage of detections in the forebay turbine area was 25.8% for non-passing shad compared to 32.2% for passing shad. Non-passing fish were detected in the vicinity of potential passage routes (trash/ice sluice, fish pipe, fish ladder, turbine units); however, not surprisingly these fish had a lower proportion of their forebay detections (13.6%) near the potential passage routes than did fish that passed (26.8%).

Table 4.1.3-4. Percent of all forebay detections of passing and non-passing juvenile shad, by detection area, Vernon 2015.

| **Detection Area** | **All Forebay Detections (%)** | |
|---|---|---|
| | **Non-Passing Shad** | **Passing Shad** |
| **Forebay Receivers** | | |
| Spillway Area | 60.6 | 41.0 |
| Turbine Area | 25.8 | 32.2 |
| **Total Forebay** | **86.4** | **73.2** |
| **Near Field / Passage Route Receivers** | | |
| Trash/Ice Sluice | 0.2 | 1.0 |
| Fish Pipe | 0.0 | 0.4 |
| Fish Ladder | 1.5 | 0.5 |
| Units 1-4 | 4.8 | 5.6 |
| Units 5-8 | 1.8 | 9.4 |
| Units 9-10 | 5.3 | 10.0 |
| **Total Near Field** | **13.6** | **26.8** |




Note: Values < 0.01 do not show on the figure.

Figure 4.1.3-3. Proportion of forebay detections of juvenile shad, Vernon 2015.

**Tailrace Residency Time**

Tailrace residency time was calculated as the duration of time from initial detection to final detection at tailrace receivers located on the downstream side of the spillway, at the turbine discharges, or in the tailrace itself (Figure 3.1-1).

Although the retention rate for externally attached radio-transmitters on juvenile shad during downstream passage through the various available passage routes at Vernon is unknown, tailrace residency following passage was calculated for all individuals where detections at tailrace receivers were available. Following downstream passage, valid detection information was available to determine the tailrace residency duration for 221 of the 226 individuals known to have passed the project. Tailrace residency time for these fish ranged from less than 0.1 hours to 272.2 hours (11 days, 6 hours, 12 min) with an overall median duration of 0.5 hours.

Table 4.1.3-5 presents tailrace residency by release group and Table 4.1.3-6 presents the same data by passage route. Release group 5 had the longest median tailrace residency (14.5 hours) followed by release group 9 (7.1 hours). The two shad that passed by the trash/ice sluice and the two that passed by the fish ladder had much longer tailrace residency (median = 88.4 hours, and 70.3 hours, respectively) than shad that passed by other routes.

Table 4.1.3-5. Minimum, maximum, mean, and median tailrace residency times (hrs) for release groups 1 through 15 of radio-tagged juvenile American Shad that passed Vernon, fall 2015.

| Release Group | Tailrace Residency (hours) | | | | No. |
|---|---|---|---|---|---|
| | Min | Max | Mean | Median | |
| 1 | 0.2 | 38.3 | 6.9 | 0.5 | 8 |
| 2 | 0.2 | 8.9 | 4.7 | 4.8 | 3 |
| 3 | 0.1 | 142.9 | 28.2 | 0.4 | 20 |
| 4 | 0.1 | 272.2 | 42.4 | 1.3 | 15 |
| 5 | <0.1 | 119.9 | 40.8 | 14.5 | 11 |
| 6 | 0.1 | 145.6 | 41.5 | 0.5 | 11 |
| 7 | 0.1 | 94.7 | 13.7 | 0.2 | 18 |
| 8 | 0.1 | 127.0 | 24.4 | 1.0 | 11 |
| 9 | 0.2 | 132.4 | 38.7 | 7.1 | 15 |
| 10 | <0.1 | 148.9 | 25.5 | 0.3 | 15 |
| 11 | 0.1 | 165.0 | 34.0 | 0.8 | 18 |
| 12 | 0.2 | 164.5 | 42.7 | 1.5 | 15 |
| 13 | 0.1 | 122.5 | 9.8 | 0.2 | 19 |
| 14 | 0.1 | 189.6 | 37.5 | 0.4 | 23 |
| 15 | <0.1 | 158.5 | 11.1 | 0.3 | 19 |
| **All** | **<0.1** | **272.2** | **27.9** | **0.5** | **221** |

Table 4.1.3-6. Minimum, maximum, mean, and median tailrace residency times (hrs) by passage route for radio-tagged juvenile American Shad that passed Vernon, fall 2015.

| Passage Route | Tailrace Residency (hours) | | | | No. |
|---|---|---|---|---|---|
| | Min | Max | Mean | Median | |
| Fish Ladder | 20.6 | 119.9 | 70.3 | 70.3 | 2 |
| Fish Pipe | 0.1 | 93.5 | 11.8 | 1.0 | 17 |
| Fish Tube | 0.2 | 0.2 | 0.2 | 0.2 | 1 |
| Spill | 0.2 | 0.2 | 0.2 | 0.2 | 1 |
| Trash/Ice Sluice | 69.1 | 107.7 | 88.4 | 88.4 | 2 |
| Units 1-4 | 0.0 | 272.2 | 47.8 | 4.9 | 22 |
| Units 5-8 | 0.0 | 165.0 | 25.7 | 0.4 | 86 |
| Units 9-10 | 0.1 | 189.6 | 30.6 | 0.5 | 34 |
| Unknown | <0.1 | 164.5 | 24.0 | 0.5 | 56 |
| **All** | **<0.1** | **272.2** | **27.9** | **0.5** | **221** |

Because tailrace residency time may have been impacted by tag loss or predation, tailrace residency time was assessed for the subset (N=157) of radio-tagged juvenile shad determined to have moved from the Vernon tailrace downstream to the monitoring station located at Stebbins Island (a distance of approximately 0.8 river miles, see Figure 3.1-1). Table 4.1.3-7 presents tailrace residency duration (in hours) by release group and Table 4.1.3-8 presents the same data by downstream passage route for the subset of radio-tagged juvenile shad that passed downstream of Vernon and were subsequently detected at the Stebbins Island stationary receiver.

Table 4.1.3-7. Minimum, maximum, mean, and median tailrace residency times (hrs) by release group for radio-tagged juvenile American Shad that passed Vernon and were detected at Stebbins Island, fall 2015.

| Release Group | Tailrace Residency (hours) | | | | No. |
|---|---|---|---|---|---|
| | Min | Max | Mean | Median | |
| 1 | 0.2 | 14.7 | 16.9 | 0.5 | 7 |
| 2 | 0.2 | 0.2 | 0.2 | 0.2 | 1 |
| 3 | 0.1 | 0.8 | 0.3 | 0.2 | 14 |
| 4 | 0.1 | 93.5 | 12.7 | 0.3 | 8 |
| 5 | 0.2 | 119.0 | 59.6 | 59.6 | 2 |
| 6 | 0.1 | 123.8 | 15.7 | 0.2 | 8 |
| 7 | 0.1 | 12.0 | 1.8 | 0.2 | 13 |
| 8 | 0.1 | 24.0 | 4.0 | 0.5 | 9 |
| 9 | 0.2 | 34.2 | 5.2 | 0.5 | 9 |
| 10 | 0.0 | 30.5 | 3.3 | 0.2 | 10 |
| 11 | 0.1 | 8.6 | 1.6 | 0.2 | 11 |
| 12 | 0.2 | 2.4 | 0.8 | 0.5 | 9 |
| 13 | 0.1 | 122.5 | 9.8 | 0.2 | 19 |
| 14 | <0.1 | 13.0 | 1.0 | 0.2 | 18 |
| 15 | <0.1 | 25.9 | 2.8 | 0.1 | 19 |
| **All** | **<0.1** | **123.8** | **5.0** | **0.2** | **157** |

Table 4.1.3-8. Minimum, maximum, mean, and median tailrace residency times (hrs) by downstream passage route for radio-tagged juvenile American Shad that passed Vernon and were detected at Stebbins Island, fall 2015.

| Passage Route | Tailrace Residency (hours) | | | | No. |
|---|---|---|---|---|---|
| | Min | Max | Mean | Median | |
| Fish Pipe | 0.1 | 93.5 | 10.1 | 0.5 | 14 |
| Fish Tube | 0.2 | 0.2 | 0.2 | 0.2 | 1 |
| Spill | 0.2 | 0.2 | 0.2 | 0.2 | 1 |
| Units 1-4 | 0.1 | 25.9 | 4.3 | 0.5 | 13 |
| Units 5-8 | <0.1 | 57.3 | 2.3 | 0.2 | 66 |
| Units 9-10 | 0.1 | 122.5 | 6.1 | 0.3 | 23 |
| Unknown | <0.1 | 123.8 | 7.7 | 0.2 | 39 |
| **All** | **<0.1** | **123.8** | **5.0** | **0.2** | **157** |

Results of a Kruskal Wallis test ($\chi^2$ = 7.0705; *df* = 6; *p* = 0.3144) indicated no significant difference in the mean tailrace residency time among downstream passage routes. Results of a Kruskal Wallis test ($\chi 2$ = 29.83; df = 14; p = 0.008) indicated there were significant difference in the mean tailrace residency time among release groups. Release group 3 with mean tailrace residency of 0.1 hours was significantly less than release groups 7 (0.4 hr), 9 (1.0 hr), 12 (0.6 hr), and 13 (0.9 hr) based on pairwise comparisons of the ranked data (Tukey-Kramer adjusted P < 0.05). Release group 9 with the second highest mean tailrace residency (1.0 hr) was significantly higher than release groups 1 and 3 with the lowest residency times, whereas the release group 5 with a mean 3.1-hour residency was not significantly different from any other release group although group 5 had only two shad with wide variability in tailrace residency times.

The mean tailrace residency duration was also compared between shad detected downstream at Stebbins Island and those that were not detected there. Tailrace residency was significantly longer for individuals not detected at Stebbins Island suggesting the impact of stationary transmitters (Wilcoxon Test; *z* = 9.1993; *p* = <0.0001). Stationary tags can be attributed to 1) mortality due to passage; 2) mortality due to predation; or 3) tag loss during or just after passage. As tag retention is unknown for individuals passing downstream via turbulent routes, it is not possible to distinguish causes of stationary tags. Additionally, the mean tailrace residency duration was compared between the full set of radio-tagged juvenile shad that passed Vernon and the subset of those detected at Stebbins Island. Tailrace residency for all passed shad was significantly longer than for those that were detected at Stebbins Island (Wilcoxon Test; *z* = -3.8594; *p* = 0.0001).

### Downstream Transit Time

Downstream transit time was calculated as the duration of time from the last detection in the tailrace to the first detection at the receiver located just upstream of Stebbins Island. Table 4.1.3-9 presents the minimum, maximum, mean, and median transit durations for each of the fifteen release group, and Table 4.1.3-10 presents the same data by passage route. Figure 4.1.3-3 presents the frequency distribution of transit duration for all individuals detected from the tailrace to Stebbins Island. Transit time ranged from less than 0.1 hour to 19.5 hours with an overall median duration of 0.2 hours. The majority (96%) of fish reaching Stebbins Island from the tailrace arrived in less than 2 hours (Figure 4.1.3-4).

Table 4.1.3-9. Minimum, maximum, mean, and median downstream transit times (hrs) for release groups 1 through 15 of radio-tagged juvenile American Shad at Vernon, fall 2015.

| Release Group | Downstream Transit (hours) | | | | No. |
|---|---|---|---|---|---|
| | Min | Max | Mean | Median | |
| 1 | <0.1 | 0.2 | 0.1 | 0.1 | 7 |
| 2 | 0.1 | 0.1 | 0.1 | 0.1 | 1 |
| 3 | <0.1 | 0.4 | 0.1 | 0.1 | 14 |
| 4 | 0.1 | 4.5 | 0.7 | 0.2 | 8 |
| 5 | 0.2 | 5.9 | 3.1 | 3.1 | 2 |
| 6 | 0.1 | 19.5 | 2.6 | 0.2 | 8 |
| 7 | 0.1 | 1.1 | 0.4 | 0.2 | 13 |
| 8 | 0.1 | 1.4 | 0.4 | 0.2 | 9 |
| 9 | 0.3 | 5.4 | 1.0 | 0.5 | 9 |
| 10 | 0.1 | 1.5 | 0.4 | 0.2 | 10 |
| 11 | 0.1 | 1.7 | 0.4 | 0.2 | 11 |
| 12 | 0.1 | 2.1 | 0.6 | 0.3 | 9 |
| 13 | <0.1 | 11.4 | 0.9 | 0.2 | 19 |
| 14 | <0.1 | 0.7 | 0.2 | 0.2 | 18 |
| 15 | 0.1 | 4.4 | 0.4 | 0.2 | 19 |
| **All** | **< 0.1** | **19.5** | **0.6** | **0.2** | **157** |

Table 4.1.3-10. Minimum, maximum, mean, and median downstream transit times (hrs) by passage route for radio-tagged juvenile American Shad at Vernon, fall 2015.

| Passage Route | Downstream Transit (hours) | | | | No. |
|---|---|---|---|---|---|
| | Min | Max | Mean | Median | |
| Fish Pipe | 0.1 | 4.5 | 0.7 | 0.2 | 14 |
| Fish Tube | 0.4 | 0.4 | 0.4 | 0.4 | 1 |
| Spill | 0.1 | 0.1 | 0.1 | 0.1 | 1 |
| Units 1-4 | 0.0 | 4.4 | 0.6 | 0.2 | 13 |
| Units 5-8 | 0.1 | 1.5 | 0.3 | 0.2 | 66 |
| Units 9-10 | <0.1 | 11.4 | 0.9 | 0.2 | 23 |
| Unknown | 0.0 | 19.5 | 1.1 | 0.2 | 39 |
| **All** | **< 0.1** | **19.5** | **0.6** | **0.2** | **157** |

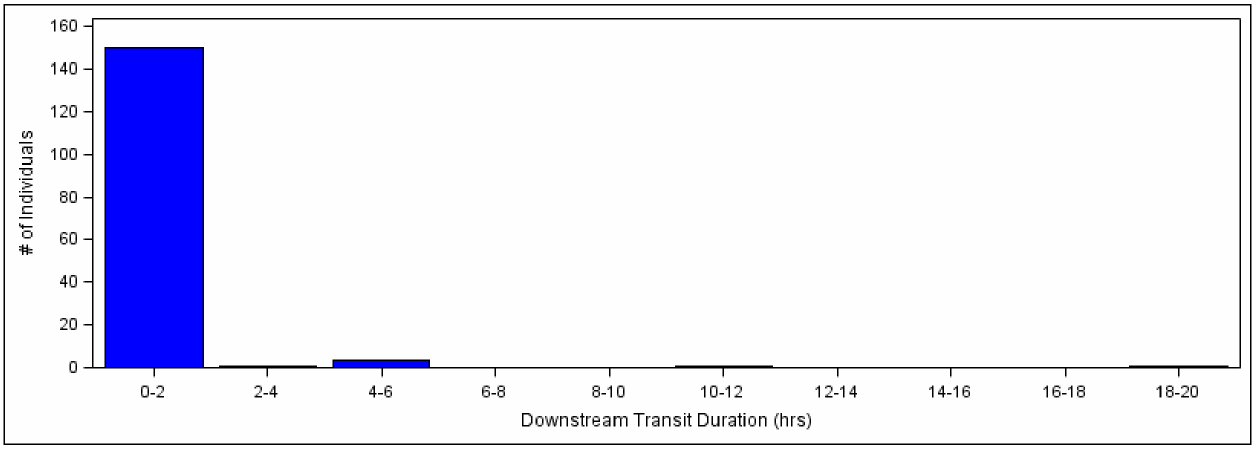



Figure 4.1.3-4. Frequency distribution of downstream transit times (in hours) for radio-tagged juvenile American Shad between the Vernon tailrace and Stebbins Island, fall 2015.

### 4.1.4 Route Selection

A total of 270 (87.1% of the 310 released upstream) radio-tagged juvenile American Shad were detected within the Vernon forebay area following release (Table 4.1.4-1). Of that total, 226 individuals (83.7%) were determined to have passed downstream of the dam. The remaining 44 individuals (16.3% of those detected in the forebay), although located in the forebay, did not have confirmed passage. Of the individuals with confirmed passage, a definitive passage route was determined for 75.2% (170 out of the 226). The remaining 24.8% (56 of the 226) were determined to have passed Vernon based on downstream detection information but a definitive passage route could not be determined. Maps of movement and passage for example passed fish are provided in Figures 4.1.4-1 and 4.1.4-2.

Table 4.1.4-1. Summary of juvenile American Shad emigration at Vernon, fall 2015.

| Status | No. | % of Number Released |
|---|---|---|
| Total Released | 310 | 100.0 |
| Total Detected in Forebay | 270 | 87.1 |
| Total Failing to Exit Forebay | 44 | 14.2 |
| Total Passing Vernon | 226 | 72.9 |
| Total Passing Vernon via known passage route | 170 | 54.8 |
| Total Passing Vernon via unknown route | 56 | 18.1 |
| Total Detected at Stebbins Island | 159 | 51.3 |

The majority of confirmed passed shad (86.5%; 147 of 170) passed through turbine Units 1 through 10 and the remaining 13.5% (23 of 170) passed via non-turbine routes (trash/ice sluice, fish pipe, fish tube, fish ladder). The frequency of downstream passage routes used ranged from 39.8% at turbine Units 5-8 to 0.4% through the fish tube and open spill gates (Table 4.1.4-2).

Table 4.1.4-2. Summary of passage routes taken by juvenile American Shad though Vernon, fall 2015.

| Passage Route | No. | % of Total | % of those with Known Passage Route |
|---|---|---|---|
| Units 5-8 | 90 | 39.8 | 52.9 |
| Units 9-10 | 35 | 15.5 | 20.6 |
| Units 1-4 | 22 | 9.7 | 12.9 |
| Fish Pipe | 17 | 7.5 | 10.0 |
| Fish Ladder | 2 | 0.9 | 1.2 |
| Trash/Ice Sluice | 2 | 0.9 | 1.2 |
| Fish Tube | 1 | 0.4 | 0.6 |
| Spill | 1 | 0.4 | 0.6 |
| Unknown | 56 | 24.8 | n/a |
| **Total** | **226** | **100.0** | **100.0** |

Downstream passage route could not be determined for all individuals known to have passed Vernon based on initial detections in the forebay followed by detections in the downstream tailrace area and/or at the Stebbins Island receiver. The detection probability of route-specific receiver/antennas installed at entrances to the fish pipe, fish tube, fish ladder, trash/ice sluice, Units 1-4, Units 5-8, and Units 9-10 had an estimated combined detection probability of 75.2%.[2] Of the 226 individuals known to have passed Vernon, 56 (24.8%) did so by an unknown route. Passage times for those 56 individuals were identified as the first recorded detection among receivers monitoring the unit discharge area, spillway area or general tailrace. The identified passage times for those individuals were merged with hourly operations records for Vernon to generate a list of potential routes available based on the presence of flow (Table 4.1.4-3). In all instances, multiple routes of exit from the forebay were available (based on flow) at the time of downstream passage for each of the 56 individuals classified as unknown.

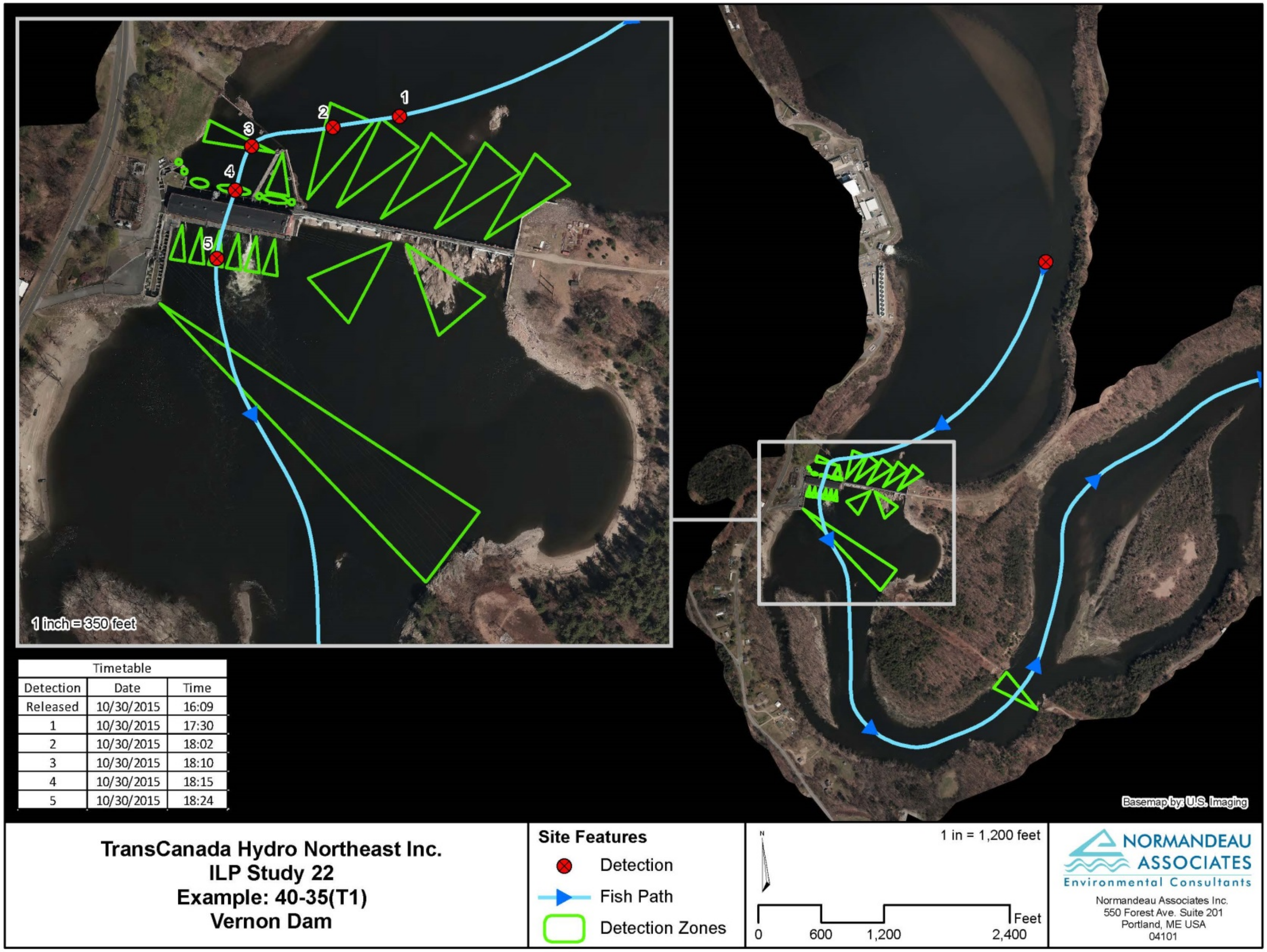
When the proportion of flow among potential passage routes is examined, the majority of project discharge was through Units 5-8 during 80% of the downstream passage events classified as unknown and through Units 9-10 during the remaining 20% of the downstream passage events classified as unknown. Those two routes were also the most frequently used by shad with determined passage routes (Table 4.1.4-2). However, the spatial distribution of downstream passage by juvenile shad is not fully driven by flow proportions (life history characteristics may also influence route selection), so those 56 individuals remained classified as having an unknown passage route for the purposes of this study.

[2] As estimated through the use of a Cormack-Jolly Seber model performed using Program MARK (White and Burnham, 1999).

Table 4.1.4-3. Proportional distribution of total project discharge at the time of downstream passage for individuals with a passage route designation of "unknown".

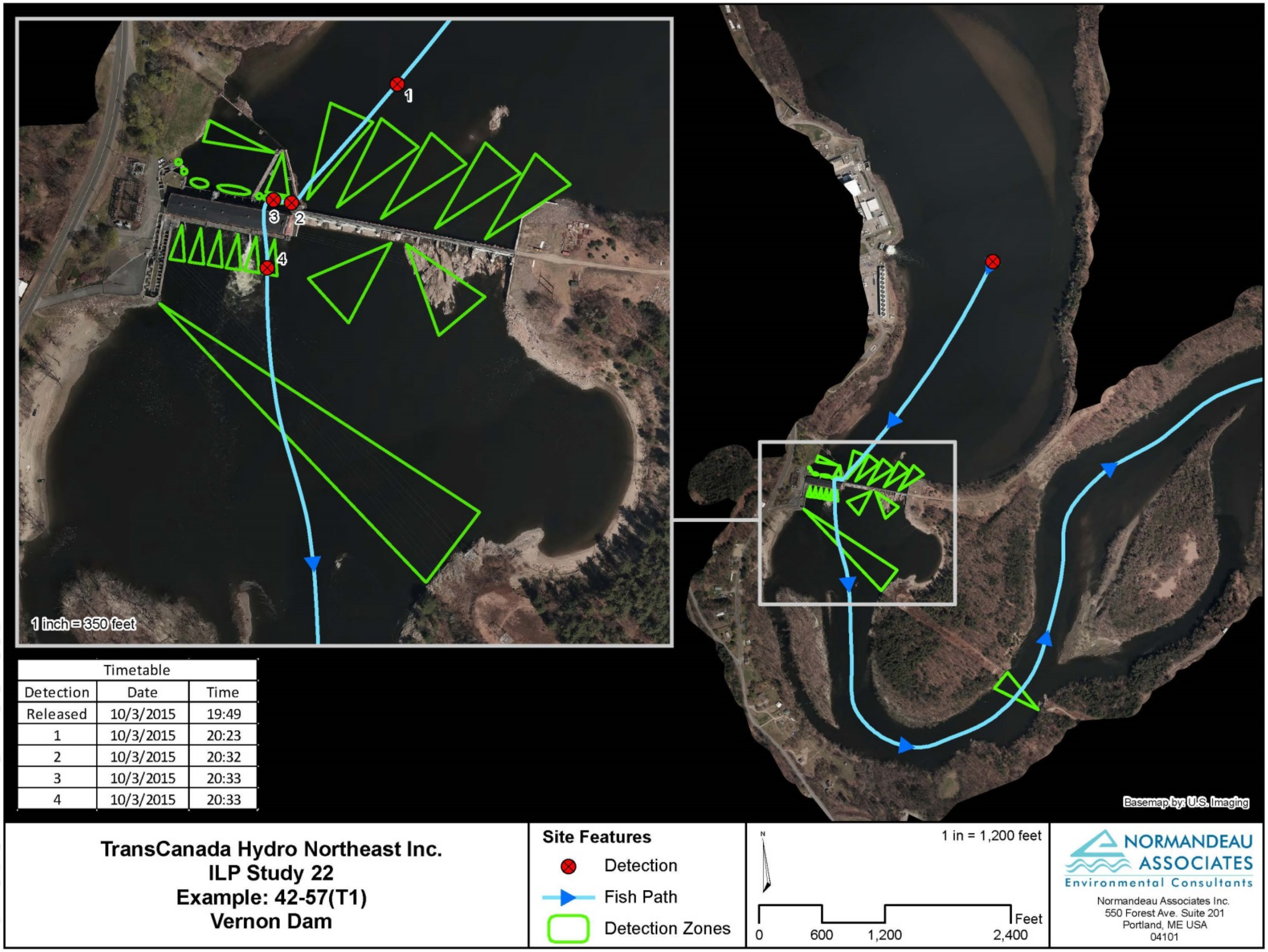
| Release Group | Channel | Code | Passage Date-Time | Total Project Discharge (cfs) | Proportion of Total Project Discharge | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Units 1-4 | Units 5-8 | Units 9-10 | Trash/ Ice Sluice | Spill Gates | Attraction Flow | Fish Pipe | Fish Tube | Fish Ladder |
| 1 | 42 | 113 | 27SEP15:03:24:40 | 1,917 | 0.00 | 0.00 | 0.76 | 0.00 | 0.00 | 0.00 | 0.18 | 0.02 | 0.03 |
| 1 | 42 | 127 | 27SEP15:03:04:03 | 1,917 | 0.00 | 0.00 | 0.76 | 0.00 | 0.00 | 0.00 | 0.18 | 0.02 | 0.03 |
| 1 | 40 | 129 | 27SEP15:19:27:39 | 6,466 | 0.00 | 0.68 | 0.22 | 0.00 | 0.00 | 0.03 | 0.05 | 0.01 | 0.01 |
| 1 | 42 | 130 | 27SEP15:20:52:56 | 6,518 | 0.00 | 0.71 | 0.22 | 0.00 | 0.00 | 0.00 | 0.05 | 0.01 | 0.01 |
| 3 | 44 | 30 | 03OCT15:21:46:31 | 13,628 | 0.22 | 0.51 | 0.23 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 |
| 3 | 40 | 54 | 04OCT15:02:30:58 | 9,319 | 0.00 | 0.78 | 0.17 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 0.01 |
| 3 | 44 | 36 | 04OCT15:18:30:35 | 8,322 | 0.00 | 0.73 | 0.19 | 0.00 | 0.00 | 0.02 | 0.04 | 0.00 | 0.01 |
| 4 | 40 | 69 | 05OCT15:20:26:53 | 9,170 | 0.09 | 0.70 | 0.17 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 0.01 |
| 4 | 42 | 51 | 05OCT15:20:46:22 | 9,170 | 0.09 | 0.70 | 0.17 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 0.01 |
| 4 | 42 | 49 | 05OCT15:20:54:25 | 9,170 | 0.09 | 0.70 | 0.17 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 0.01 |
| 4 | 44 | 44 | 05OCT15:21:12:06 | 9,156 | 0.08 | 0.70 | 0.16 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 0.01 |
| 4 | 42 | 121 | 05OCT15:21:31:41 | 9,156 | 0.08 | 0.70 | 0.16 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 0.01 |
| 4 | 40 | 72 | 06OCT15:07:55:37 | 1,944 | 0.00 | 0.00 | 0.77 | 0.00 | 0.00 | 0.00 | 0.18 | 0.02 | 0.03 |
| 5 | 40 | 59 | 08OCT15:04:18:14 | 1,815 | 0.00 | 0.00 | 0.75 | 0.00 | 0.00 | 0.00 | 0.19 | 0.02 | 0.04 |
| 6 | 40 | 63 | 09OCT15:21:19:41 | 11,222 | 0.22 | 0.60 | 0.14 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.01 |
| 7 | 40 | 44 | 12OCT15:21:58:49 | 10,140 | 0.11 | 0.69 | 0.16 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.01 |
| 7 | 42 | 76 | 12OCT15:21:56:11 | 10,140 | 0.11 | 0.69 | 0.16 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.01 |
| 7 | 44 | 117 | 12OCT15:21:47:02 | 10,140 | 0.11 | 0.69 | 0.16 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.01 |
| 7 | 44 | 53 | 12OCT15:22:05:43 | 10,238 | 0.10 | 0.69 | 0.16 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.01 |
| 7 | 44 | 118 | 13OCT15:00:57:41 | 1,827 | 0.00 | 0.00 | 0.75 | 0.00 | 0.00 | 0.00 | 0.19 | 0.02 | 0.04 |
| 7 | 42 | 80 | 13OCT15:05:38:50 | 1,703 | 0.00 | 0.00 | 0.73 | 0.00 | 0.00 | 0.00 | 0.21 | 0.02 | 0.04 |
| 7 | 42 | 77 | 13OCT15:06:02:18 | 1,686 | 0.00 | 0.00 | 0.73 | 0.00 | 0.00 | 0.00 | 0.21 | 0.02 | 0.04 |
| 7 | 44 | 110 | 13OCT15:09:36:43 | 6,506 | 0.00 | 0.68 | 0.22 | 0.00 | 0.00 | 0.03 | 0.05 | 0.01 | 0.01 |
| 7 | 44 | 113 | 13OCT15:18:56:09 | 10,111 | 0.17 | 0.61 | 0.15 | 0.00 | 0.00 | 0.02 | 0.03 | 0.00 | 0.01 |
| 7 | 40 | 42 | 13OCT15:19:57:58 | 10,239 | 0.17 | 0.61 | 0.15 | 0.00 | 0.00 | 0.02 | 0.03 | 0.00 | 0.01 |
| 7 | 44 | 56 | 13OCT15:19:58:25 | 10,239 | 0.17 | 0.61 | 0.15 | 0.00 | 0.00 | 0.02 | 0.03 | 0.00 | 0.01 |
| 7 | 40 | 45 | 14OCT15:16:43:37 | 4,392 | 0.23 | 0.30 | 0.32 | 0.00 | 0.00 | 0.05 | 0.08 | 0.01 | 0.01 |
| 8 | 44 | 119 | 14OCT15:20:38:04 | 10,053 | 0.16 | 0.63 | 0.16 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.01 |
| 8 | 44 | 116 | 15OCT15:04:09:13 | 1,887 | 0.00 | 0.00 | 0.76 | 0.00 | 0.00 | 0.00 | 0.19 | 0.02 | 0.03 |
| 9 | 40 | 81 | 17OCT15:16:36:49 | 6,675 | 0.00 | 0.70 | 0.20 | 0.00 | 0.00 | 0.03 | 0.05 | 0.01 | 0.01 |
| 9 | 42 | 31 | 17OCT15:17:33:40 | 6,711 | 0.00 | 0.70 | 0.20 | 0.00 | 0.00 | 0.03 | 0.05 | 0.01 | 0.01 |
| 9 | 40 | 89 | 17OCT15:18:43:23 | 6,737 | 0.00 | 0.70 | 0.20 | 0.00 | 0.00 | 0.03 | 0.05 | 0.01 | 0.01 |
| 9 | 40 | 87 | 17OCT15:20:18:28 | 6,618 | 0.00 | 0.73 | 0.20 | 0.00 | 0.00 | 0.00 | 0.05 | 0.01 | 0.01 |
| 9 | 44 | 71 | 19OCT15:17:57:28 | 8,402 | 0.00 | 0.75 | 0.17 | 0.00 | 0.00 | 0.02 | 0.04 | 0.00 | 0.01 |

| Release Group | Channel | Code | Passage Date-Time | Total Project Discharge (cfs) | Proportion of Total Project Discharge | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Units 1-4 | Units 5-8 | Units 9-10 | Trash/ Ice Sluice | Spill Gates | Attraction Flow | Fish Pipe | Fish Tube | Fish Ladder |
| 10 | 40 | 96 | 19OCT15:19:54:09 | 8,552 | 0.00 | 0.75 | 0.17 | 0.00 | 0.00 | 0.02 | 0.04 | 0.00 | 0.01 |
| 10 | 42 | 85 | 19OCT15:19:44:06 | 8,552 | 0.00 | 0.75 | 0.17 | 0.00 | 0.00 | 0.02 | 0.04 | 0.00 | 0.01 |
| 10 | 40 | 121 | 19OCT15:20:39:43 | 8,363 | 0.00 | 0.77 | 0.18 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 0.01 |
| 10 | 44 | 129 | 19OCT15:20:37:23 | 8,363 | 0.00 | 0.77 | 0.18 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 0.01 |
| 10 | 40 | 123 | 20OCT15:18:47:51 | 8,688 | 0.00 | 0.75 | 0.17 | 0.00 | 0.00 | 0.02 | 0.04 | 0.00 | 0.01 |
| 10 | 40 | 110 | 20OCT15:20:46:17 | 8,732 | 0.00 | 0.77 | 0.17 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 0.01 |
| 10 | 44 | 80 | 20OCT15:21:15:16 | 8,860 | 0.00 | 0.78 | 0.17 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 0.01 |
| 11 | 42 | 70 | 21OCT15:19:52:46 | 10,939 | 0.22 | 0.59 | 0.13 | 0.00 | 0.00 | 0.02 | 0.03 | 0.00 | 0.01 |
| 11 | 44 | 125 | 21OCT15:19:51:45 | 10,939 | 0.22 | 0.59 | 0.13 | 0.00 | 0.00 | 0.02 | 0.03 | 0.00 | 0.01 |
| 11 | 40 | 79 | 21OCT15:20:10:56 | 10,965 | 0.23 | 0.60 | 0.13 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.01 |
| 11 | 40 | 84 | 21OCT15:20:33:20 | 10,965 | 0.23 | 0.60 | 0.13 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.01 |
| 11 | 40 | 76 | 21OCT15:21:10:56 | 11,077 | 0.22 | 0.61 | 0.13 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.01 |
| 11 | 44 | 122 | 21OCT15:21:29:07 | 11,077 | 0.22 | 0.61 | 0.13 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.01 |
| 12 | 40 | 114 | 23OCT15:21:30:55 | 8,415 | 0.00 | 0.77 | 0.18 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 0.01 |
| 12 | 40 | 119 | 24OCT15:18:28:17 | 8,464 | 0.24 | 0.54 | 0.15 | 0.00 | 0.00 | 0.02 | 0.04 | 0.00 | 0.01 |
| 12 | 42 | 108 | 24OCT15:18:33:31 | 8,464 | 0.24 | 0.54 | 0.15 | 0.00 | 0.00 | 0.02 | 0.04 | 0.00 | 0.01 |
| 12 | 42 | 96 | 25OCT15:08:40:02 | 1,987 | 0.00 | 0.03 | 0.64 | 0.00 | 0.00 | 0.10 | 0.18 | 0.02 | 0.03 |
| 14 | 44 | 89 | 28OCT15:17:27:45 | 1,644 | 0.00 | 0.17 | 0.43 | 0.00 | 0.00 | 0.12 | 0.21 | 0.02 | 0.04 |
| 14 | 40 | 103 | 28OCT15:18:32:05 | 9,740 | 0.19 | 0.60 | 0.14 | 0.00 | 0.00 | 0.02 | 0.04 | 0.00 | 0.01 |
| 14 | 40 | 95 | 28OCT15:19:36:04 | 10,952 | 0.19 | 0.62 | 0.14 | 0.00 | 0.00 | 0.02 | 0.03 | 0.00 | 0.01 |
| 14 | 40 | 27 | 28OCT15:21:07:13 | 10,795 | 0.19 | 0.63 | 0.14 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.01 |
| 14 | 42 | 106 | 28OCT15:22:30:58 | 10,792 | 0.18 | 0.64 | 0.14 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.01 |




| Timetable | | |
|---|---|---|
| Detection | Date | Time |
| Released | 10/30/2015 | 16:09 |
| 1 | 10/30/2015 | 17:30 |
| 2 | 10/30/2015 | 18:02 |
| 3 | 10/30/2015 | 18:10 |
| 4 | 10/30/2015 | 18:15 |
| 5 | 10/30/2015 | 18:24 |

Figure 4.1.4-1. Example of passage route for juvenile shad through Units 5-8.




| Timetable | | |
|---|---|---|
| Detection | Date | Time |
| Released | 10/3/2015 | 19:49 |
| 1 | 10/3/2015 | 20:23 |
| 2 | 10/3/2015 | 20:32 |
| 3 | 10/3/2015 | 20:33 |
| 4 | 10/3/2015 | 20:33 |

Figure 4.1.4-2. Example of passage route for juvenile shad through Units 1-4.

When all radio-tagged juvenile shad passing Vernon were considered, the majority (85%) of downstream passage events occurred during the late evening hours (approximately 17:00 – 22:00; Figure 4.1.4-3). This observation is consistent with previous studies (O'Leary and Kynard, 1986).

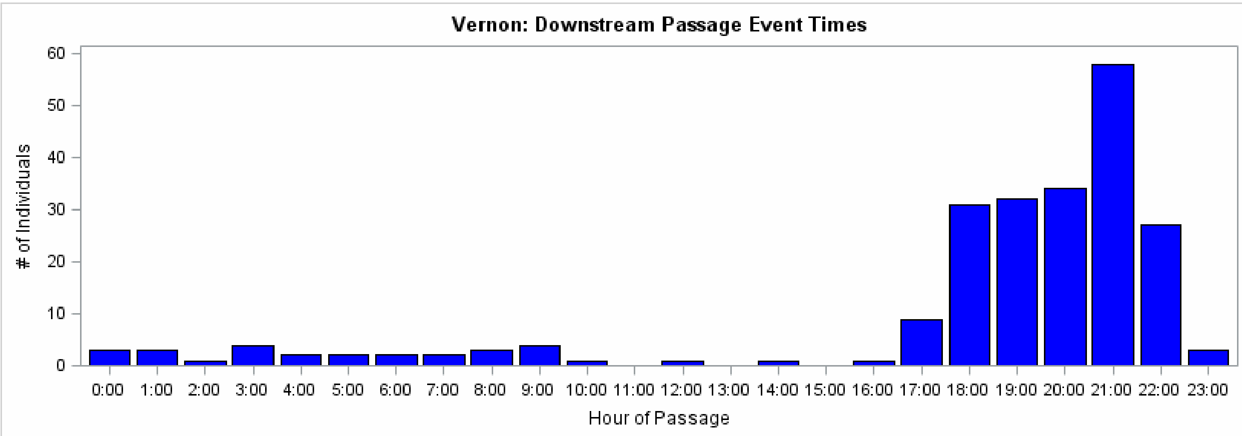



Figure 4.1.4-3. Passage of juvenile American Shad by time of day at Vernon, fall 2015.

Downstream passage was also examined as a function of total flow for individuals with known passage time (N=163). Whereas one shad passed Vernon during spill (i.e., river flow greater than maximum station generating capacity of 17,100 cfs), 12.8% (N=29) passed at approximate minimum flow, and approximately half (N=133) passed at flows between approximately 8,000 and 11,000 cfs (Figure 4.1.4-4).

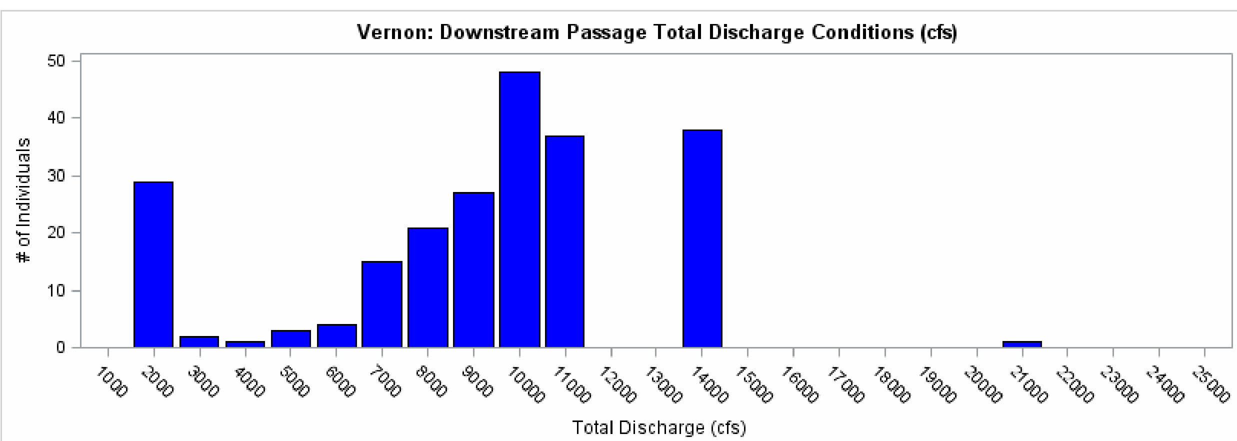



Figure 4.1.4-4. Passage of juvenile American Shad by discharge at Vernon, fall 2015.

Project operations at the time of last forebay detection were evaluated for the 44 shad that did not pass Vernon. Half of non-passing shad (N=22) were last detected at times of approximate minimum flow; 25% (N=11) were last detected at flows from minimum flow to 7,000 cfs; 20.5% (N=9) were last detected at flows between 7,000 and 14,000 cfs; and two shad (4.5%) were last detected when the project was spilling at flows greater than 20,000 cfs.

A summary of proportional route discharge conditions at the time of downstream passage for shad with known downstream passage routes is provided in Table 4.1.4-4. Individuals did not necessarily pass downstream via the route with the greatest proportion of total project discharge at that time. Passage via the downstream route with the greatest proportion of flow at the time of passage occurred only 53.5% of the time. Two shad passed via the trash-ice sluice when TransCanada flow monitors did not register any flow through the trash/ice sluice during the time of passage, although there was likely to be leakage flow. Therefore, actual flows and proportional flows through the trash/ice sluice could not be calculated and those shad are not included in Table 4.1.4-4. A full listing of discharges from all sources for radio-tagged juvenile shad passing Vernon is provided along with a listing of arrival and passage information in Appendix I-2 (filed separately in Excel format).

Table 4.1.4-4. Summary of juvenile shad passage through known routes and proportion of flow at Vernon, fall 2015.

| Passage Route | No. | Discharge from Passage Route at Time of Passage | | | | | | Discharge from all other Sources (non-passage routes) at Time of Passage | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | cfs | | | % of Total Discharge | | | cfs | | | % of Total Discharge | | |
| | | Min | Max | Mean | Min | Max | Mean | Min | Max | Mean | Min | Max | Mean |
| Units 5-8 | 90 | 282 | 7010 | 5996 | 17.2 | 76.9 | 60.1 | 1361 | 7412 | 3852 | 23.1 | 82.8 | 39.9 |
| Units 9-10 | 35 | 1030 | 3138 | 1756 | 13.0 | 77.6 | 29.4 | 455 | 11425 | 6897 | 22.4 | 87.0 | 70.6 |
| Units 1-4 | 22 | 382 | 4058 | 2527 | 7.0 | 28.6 | 21.2 | 4308 | 10668 | 8909 | 71.4 | 93.0 | 78.8 |
| Fish Pipe | 17 | 350 | 350 | 350 | 2.5 | 21.3 | 7.0 | 1293 | 13517 | 7943 | 78.6 | 97.5 | 93.0 |
| Fish Ladder | 2 | 65 | 65 | 65 | 1.2 | 2.7 | 1.9 | 2322 | 5565 | 3944 | 97.3 | 98.8 | 98.1 |
| Fish Tube | 1 | 40 | 40 | 40 | 0.6 | 0.6 | 0.6 | 6697 | 6697 | 6697 | 99.4 | 99.4 | 99.4 |
| Spill | 1 | 6089 | 6089 | 6089 | 28.8 | 28.8 | 28.8 | 15067 | 15067 | 15067 | 71.2 | 71.2 | 71.2 |

### 4.1.5 Downstream Detection after Passage

The route selection component of Study 22 was not intended to evaluate downstream passage survival. The study objectives for this component of the study were to evaluate route selection, travel time, and residency only. Downstream passage survival for juvenile American shad at Vernon was evaluated using an appropriate methodology (HiZ evaluation; Section 3.3). As there are no available estimates of background mortality on outmigrating juvenile American Shad in the project area, the impact of predation on the downstream detection of radio-tagged juveniles cannot be quantified. In addition, the retention rate of externally attached Lotek NTQ-1 transmitters for juvenile shad passing via any turbulent passage route (e.g., turbines, fish pipe, spill, etc.) is unknown. The pilot study evaluating tag retention (Normandeau, 2014a) was conducted in a tank environment and was intended to be representative of retention of transmitters by juvenile shad moving through the forebay area and in the period of time immediately prior to downstream passage. Interpretation of downstream detection information for externally tagged juvenile American Shad as “project survival” is likely negatively biased by lowered tag retention associated with turbulent downstream passage.

Considering the factors above, the downstream progress for radio-tagged juvenile shad following passage at Vernon is shown by release group in Table 4.1.5-1 and by passage route in Table 4.1.5-2. Overall, 70.4% of the 226 radio-tagged juvenile shad passing downstream of Vernon were subsequently detected at the Stebbins Island monitoring station. When examined by release group, the percentage detected at Stebbins Island was lowest for groups 2, 4 and 5. Group 2 was limited by sample size (only 3 fish passing Vernon).

Table 4.1.5-1. Number and percentage of radio-tagged juvenile shad that passed downstream of Vernon and were detected at Stebbins Island (by release group), fall 2015.

| Release Group | No. Passing Vernon | No. Detected at Stebbins | % Detected at Stebbins |
|---|---|---|---|
| 1 | 8 | 7 | 87.5 |
| 2 | 3 | 1 | 33.3 |
| 3 | 20 | 14 | 70.0 |
| 4 | 15 | 8 | 53.3 |
| 5 | 12 | 2 | 16.7 |
| 6 | 11 | 8 | 72.7 |
| 7 | 19 | 14 | 73.7 |
| 8 | 11 | 9 | 81.8 |
| 9 | 15 | 9 | 60.0 |
| 10 | 15 | 10 | 66.7 |
| 11 | 18 | 11 | 61.1 |
| 12 | 15 | 9 | 60.0 |
| 13 | 19 | 19 | 100.0 |
| 14 | 25 | 19 | 76.0 |
| 15 | 20 | 19 | 95.0 |
| **Total** | **226** | **159** | **70.4** |

Table 4.1.5-2. Number and percentage of radio-tagged juvenile shad that passed downstream of Vernon and were detected at Stebbins Island (by downstream passage route), fall 2015.

| Passage Route | No. Passing Vernon | No. Detected at Stebbins | % Detected at Stebbins Island |
|---|---|---|---|
| Units 5-8 | 90 | 68 | 75.6 |
| Units 9-10 | 35 | 23 | 65.7 |
| Units 1-4 | 22 | 13 | 59.1 |
| Fish Pipe | 17 | 14 | 82.4 |
| Fish Ladder | 2 | 0 | 0.0 |
| Trash/Ice Sluice | 2 | 0 | 0.0 |
| Fish Tube | 1 | 1 | 100.0 |
| Spill | 1 | 1 | 100.0 |
| Unknown | 56 | 39 | 69.6 |
| **Total** | **226** | **159** | **70.4** |

When individuals that had passed via the turbine units are considered, the proportion detected at Stebbins Island (65%) is lower than the 1-hour direct survival estimates for juvenile American Shad of 91.7% for Francis Unit 4 and 95.2% for Kaplan Unit 8 (Section 4.3.2). As discussed below in Section 4.3.2, 48-hour direct turbine survival estimates could not be made reliably. Again, it should be noted that the proportion of fish detected at Stebbins Island should not be interpreted as a direct estimate of survival due to uncertainty with predation and tag retention during downstream passage.

### 4.1.6 Environmental Conditions

Analysis of shad passage by other environmental conditions (water temperature, lunar phase, air temperature, etc.) as outlined in the RSP could not adequately be assessed with the radio telemetry portion of this study as the median travel and residency times were short and releases were controlled, therefore there was little if any change in environmental variables that occurred during those time windows. However, water temperatures throughout the study period ranged from 21.4°C down to 9.7°C which is consistent with the emigration temperatures observed previously for shad on the Connecticut River (O'Leary and Kynard, 1986). Environmental conditions are discussed in Section 4.2.4 as part of the run timing analysis.

## 4.2 Run Timing

### 4.2.1 Volume Backscattering Strength (SV)

Echograms showed echoes corresponding to physical features that were consistent over time at certain ranges such as the side of the louver panels or surface, and those that dynamically changed over time such as increased background noise from reverberation during rainfall or high wind events or from debris scattering following rainfall events (Figure 3.2.5-1). Echoes from these physical features often made identification of fish echoes and quantifying their backscattering strength difficult. Otherwise, recognizable mid-water column echo patterns in echograms were attributable to the presence of juvenile American Shad (Figure 3.2.5-2).

Peaks in hourly mean $S_V$ reflected the presence of numerous juvenile shad in the middle to upper water column periodically from mid-September through mid-October (Figure 4.2.1-1). Other peaks in hourly mean $S_V$ reflected full-water column scattering from particulates being drawn by river flow into Units 1 - 4 following rainfall events when one or more of those turbines were operating, or from entrained bubbles originating from the surface coincidental to operating turbines at those units. These non-shad peaks in $S_V$ led to peaks in daily mean $S_V$ time series coincidental mainly to peaks in river flow, wind, and precipitation (Figure 4.2.1-2). This was most evident in the time series for the bottom layer 1-1.5 m away from the transducer when environmental noise increased $S_V$ down to the river bottom. When all depth layers were included in daily mean $S_V$, the residual noise from near surface layers was the principal driver for the relative magnitude. When the mid-water column layer (4-8 m range) where school echoes were observed was used in the daily mean $S_V$, the principal peaks, especially when converted to fish density based on the expected target strength of the average juvenile shad, remained driven by environmental conditions.

A time series in daily mean $S_V$ of the mid-water column (4-8 m range) was derived specifically for the dawn, day, dusk, and night periods to highlight peaks in shad abundance, if juvenile shad preferred to move into the forebay in a given diel period. In addition, echograms where elevated environmental noise extended to the bottom four depth layers (0.5-2.5 m range) were excluded from the daily diel $S_V$ time series. Between mid-September and mid-October, the daily mean $S_V$ during night and dawn was below the 24-hour mean $S_V$ and was above the 24-hour mean $S_V$ during the day (Figure 4.2.1-3). Within the second half of September when flow, wind speed, and precipitation was low and when juvenile shad were caught by cast nets (Figure 5.2-3), the few peaks in daily mean $S_V$ during the day that were observed likely reflect periods of higher shad densities in the forebay. The higher $S_V$ observed during the day and dusk, especially during October, was attributable to more persistent higher densities of juvenile shad in the mid-water column layers (Figure 4.2.1-4).

During October through November, environmental conditions made the daily time series of $S_V$ highly variable and less predictable for a suitable index of shad abundance. Thus, the daily mean $S_V$ from all scatterers above threshold at any depth layer(s) was not always suitable as a relative index of shad density as a result of frequent periods of high background noise from increased river flow, precipitation, and wind.

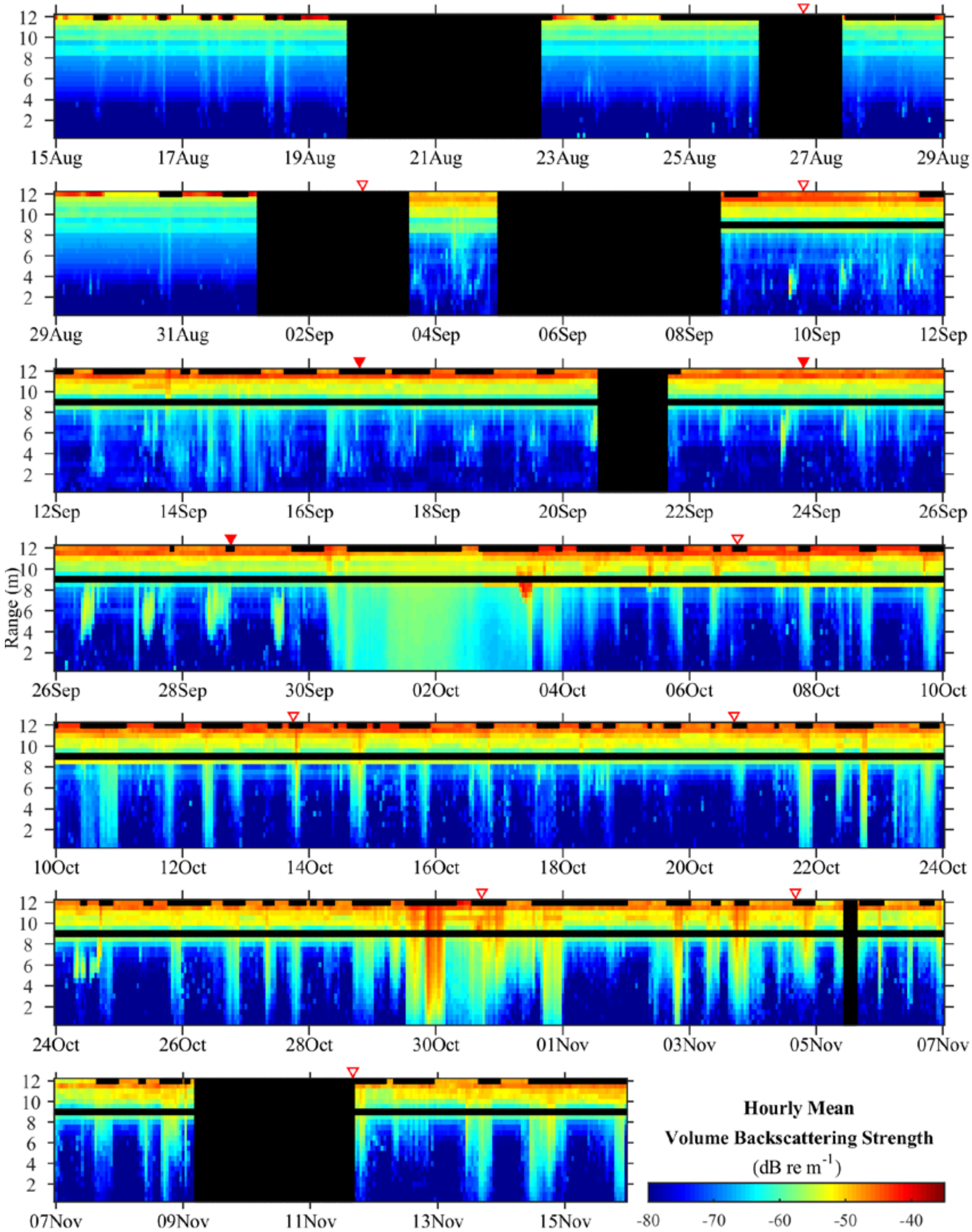



Figure 4.2.1-1. Echogram of hourly mean volume backscattering strength for 0.5-m range (depth) layers, Vernon 2015. Inverted red filled and open triangles indicate shad present and absent in cast net catches, respectively.

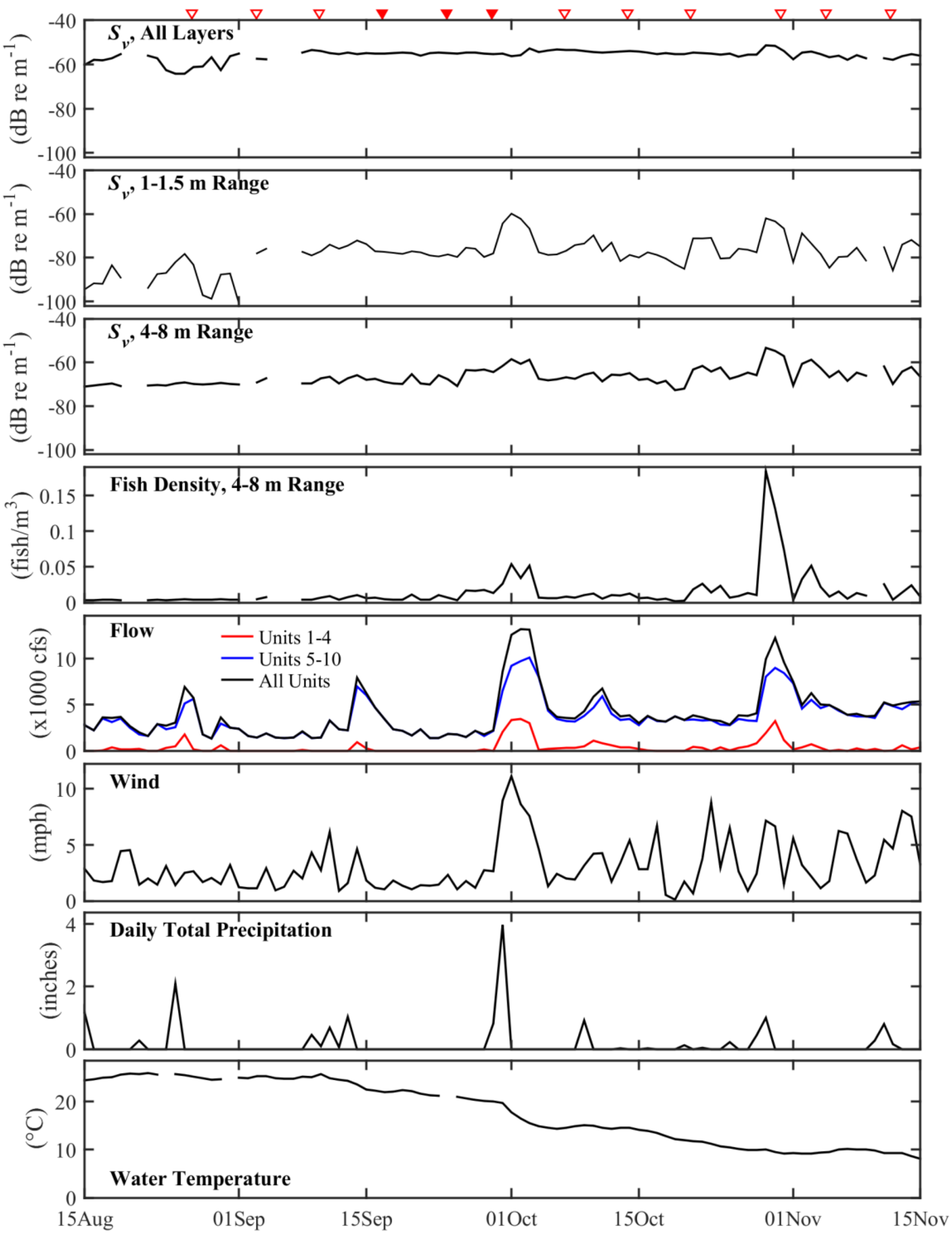



Figure 4.2.1-2. Daily mean volume backscattering strength ($S_V$) for all 0.5-m range (depth) layers, a near bottom layer (1-1.5 m range), and mid-water column layers (4-8 m range); mid-water column $S_V$ converted to daily mean fish density; daily mean river flow through the power house, daily mean wind speed, daily total precipitation, and daily mean water temperature at Vernon, 2015. Inverted red filled and open triangles indicate shad present and absent in cast net catches, respectively.

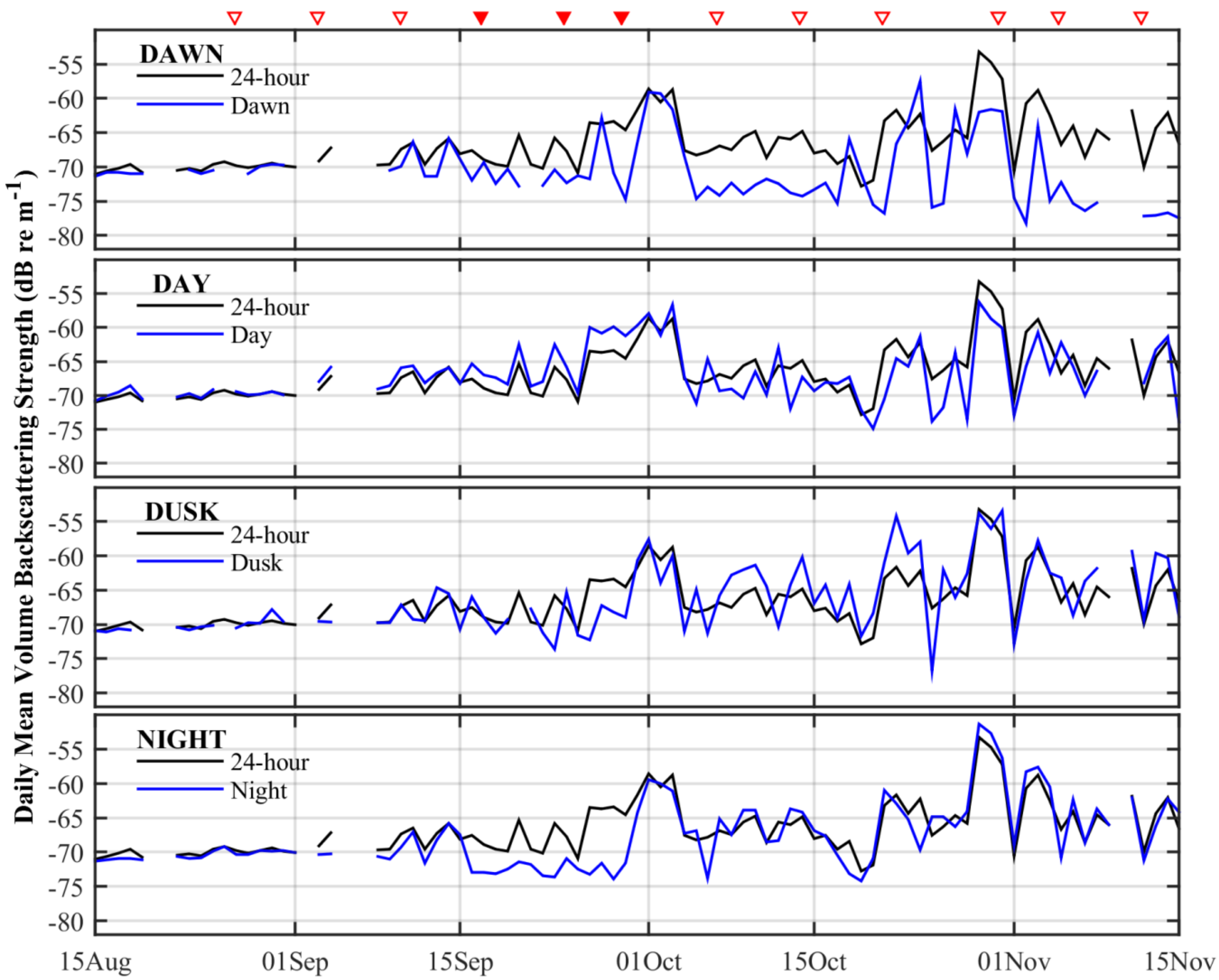
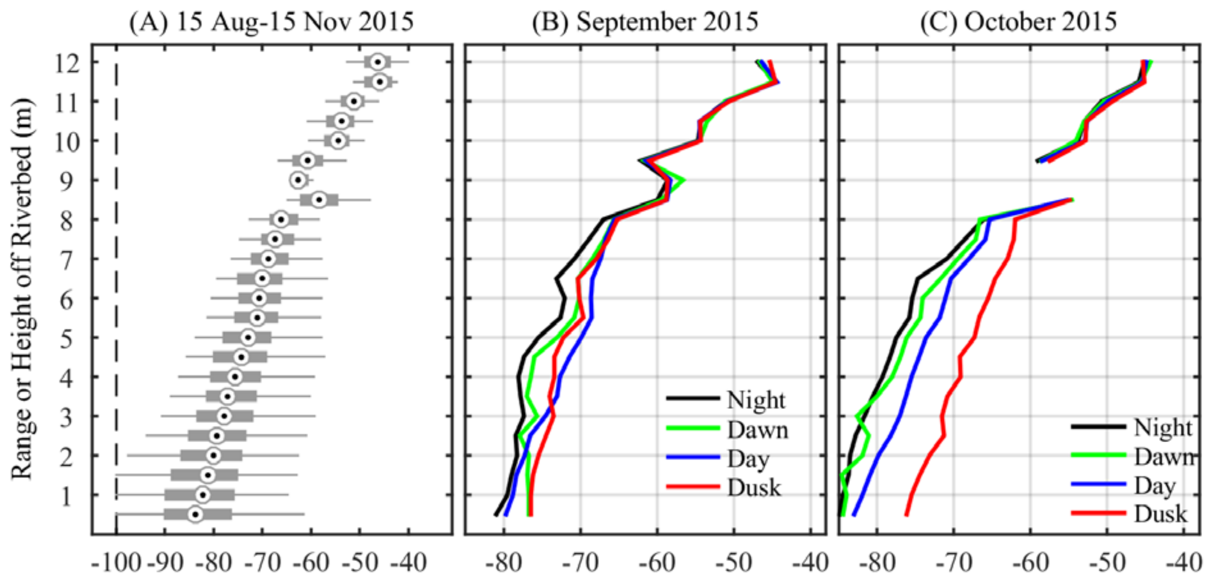



Figure 4.2.1-3. Daily mean volume backscattering strength ($S_V$) for mid-water column layers (4-8 m range) during each 24-hour period, dawn, day, dusk and night periods, Vernon, 2015. Inverted red filled and open triangles indicate shad present and absent in cast net catches, respectively.




Note: Box plot extent is the 25th and 75th percentiles, whiskers at ±1.5 times the interquartile range, and the symbol is the median. Data filtered for noisy echograms.

Figure 4.2.1-4. Box plot of hourly mean volume backscattering strength ($S_V$) by 0.5-m range layers from (A) August 15 - November 15, 2015, and (B) September 16-30, 2015 at Vernon when shad were present and background noise was low; (C) Median of hourly mean $S_V$ versus range during night, dawn, day, and dusk.

### 4.2.2 Acoustic Classification of Fish Schools (School-SV)

Numerous school echoes were observed in the echograms including those that had elevated background noise or debris scattering associated with weather events or power generation through Units 1-4 (Figure 4.2.2-1). School echoes were observed in 65 of the 83 days examined (76%), excluding data for 10 days that were missing or too noisy. The daily mean school $S_v$ was low at the beginning of the study and increased during September and October when it fluctuated with a few peaks before decreasing to zero by November 1. When the temporal trend in daily mean school $S_v$ was converted to fish density using a constant target strength representative of the mean total length in the electrofishing catch, fish densities increased during late September, peaked on October 3, decreased on subsequent days, and then peaked moderately twice on two isolated days (October 24 and 30) before declining to zero by November (Figure 4.2.2-2). Acoustically derived fish density was initially zero on August 15, and increased slightly with the presence of a few school echoes by the start of September. Fish school echoes first appeared on August 17. Fish echoes were steadily observed every day beginning September 3 and increasing in fish density as September progressed to the highest density on October 3. After a decline in fish density on the following days, fish density decreased to less than 1 fish per 1000 $m^3$ and remained low until fish density peaked over 1 fish per 1000

$m^3$ on October 23-24 and again on October 30. By November 1 and for the remainder of the study, no school echoes were observed.

Fish congregated to form schools near the entrance to the fish pipe in the forebay at different times of the day during the emigration season. The median value of hourly mean $S_v$ and fish density estimates of classified school echoes was significantly higher during day and dusk periods than at night and dawn periods (Figure 4.2.2-3). Fish schools peaked between 13:00 and 18:00 and very few schools were observed during night hours.

The vertical distribution of school echoes varied throughout the study period, but followed some trends. In September, school echoes were concentrated more in the mid-water column layers between 4 and 8 m range from the transducer and 2 to 6 m below the sill depth of the fish pipe opening (Figure 4.2.2-4 A). In October, school echoes were more consistently observed higher in the water column, generally within the depth layer of the fish pipe opening or within 3 m of the sill depth. While fish density was highest during the day period, schools concentrated in the mid-water column generally between 6 and 10 m range while the central tendencies of the schools migrated up toward the surface before and during dusk (Figure 4.2.2-4 B, C). Based on mean horizontal direction of echo traces representative of small fish equivalent to juvenile shad, fish in the forebay exhibited strong west-southwesterly movement through the beam toward the louver panels and Units 5-10, presumably following flow (Figure 4.2.2-5). If the observed movement of tracked echoes is representative of swimming direction of juvenile shad, then milling behavior or non-directional movement was less likely to have introduced positive bias in the relative index of density from multiple counting of the same fish.

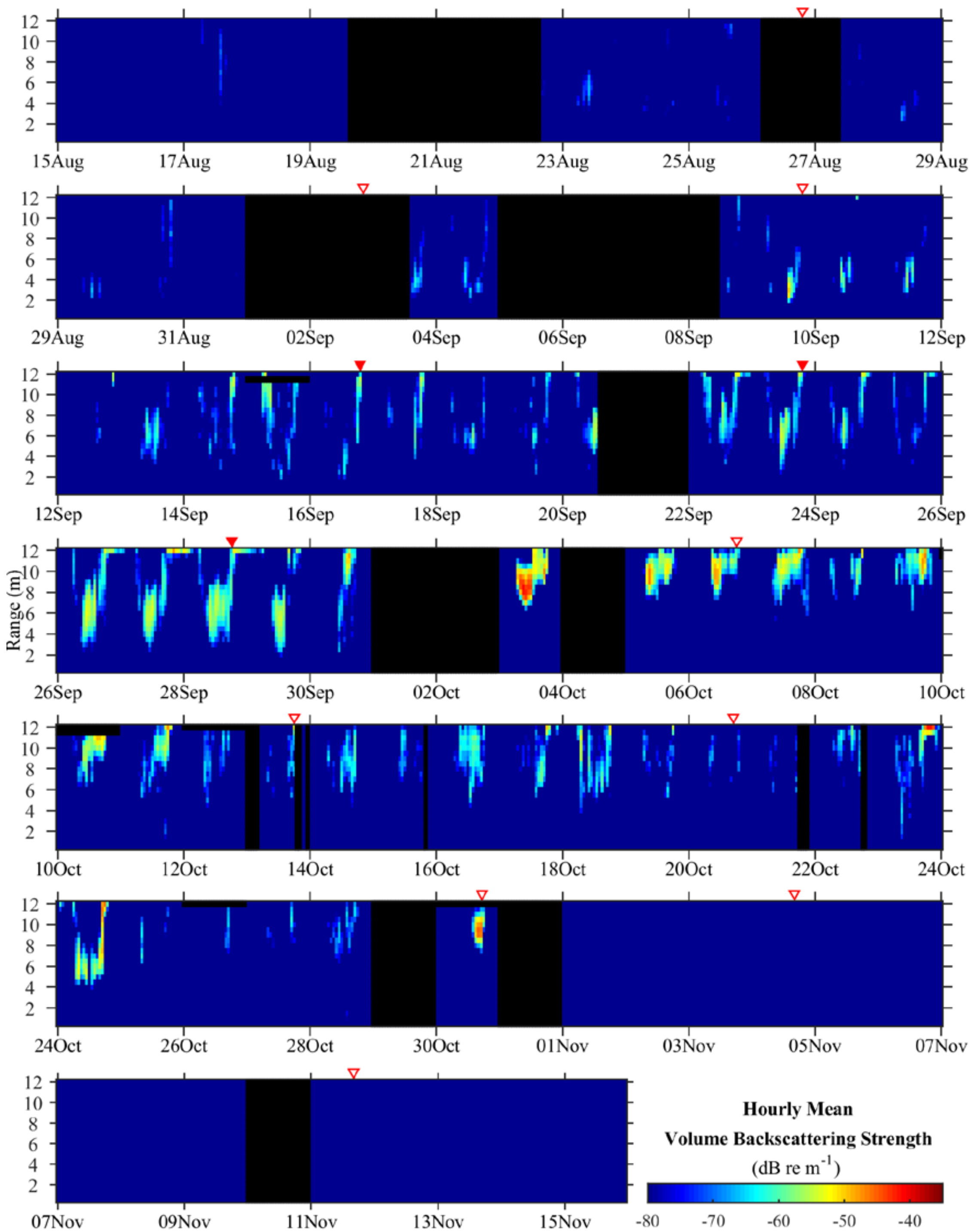



Figure 4.2.2-1. Echogram of hourly mean volume backscattering strength of manually classified fish school echoes in 0.5-m range (depth) layers at Vernon, 2015. Inverted red filled and open triangles indicate shad present and absent in cast net catches, respectively.

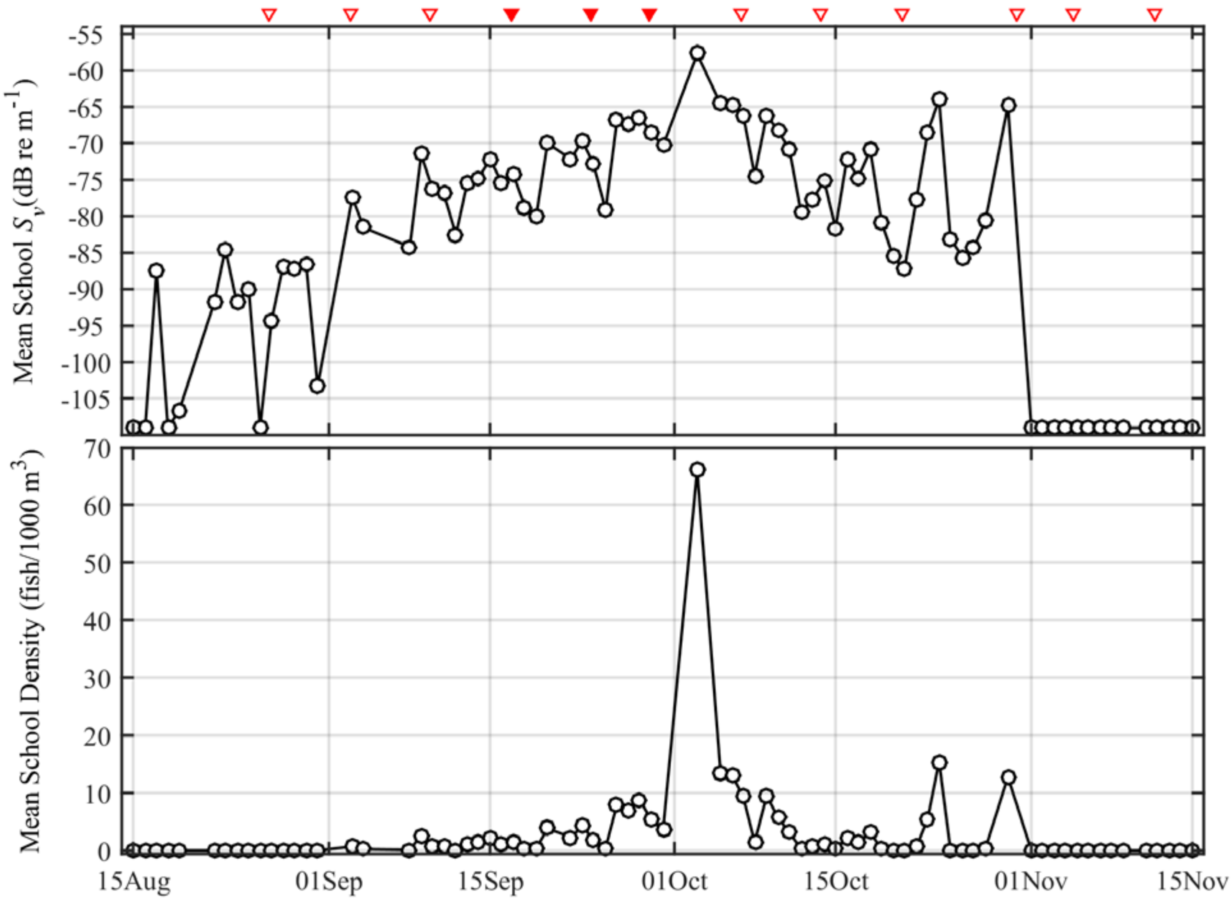
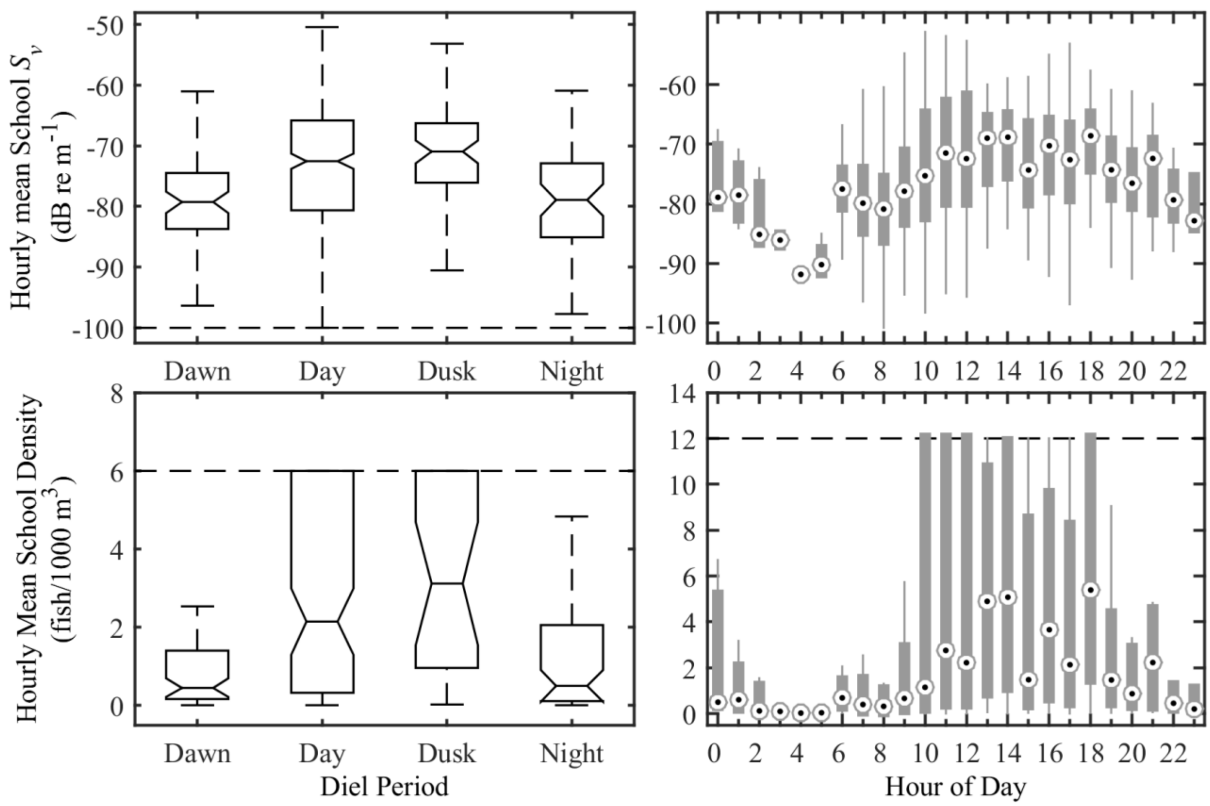
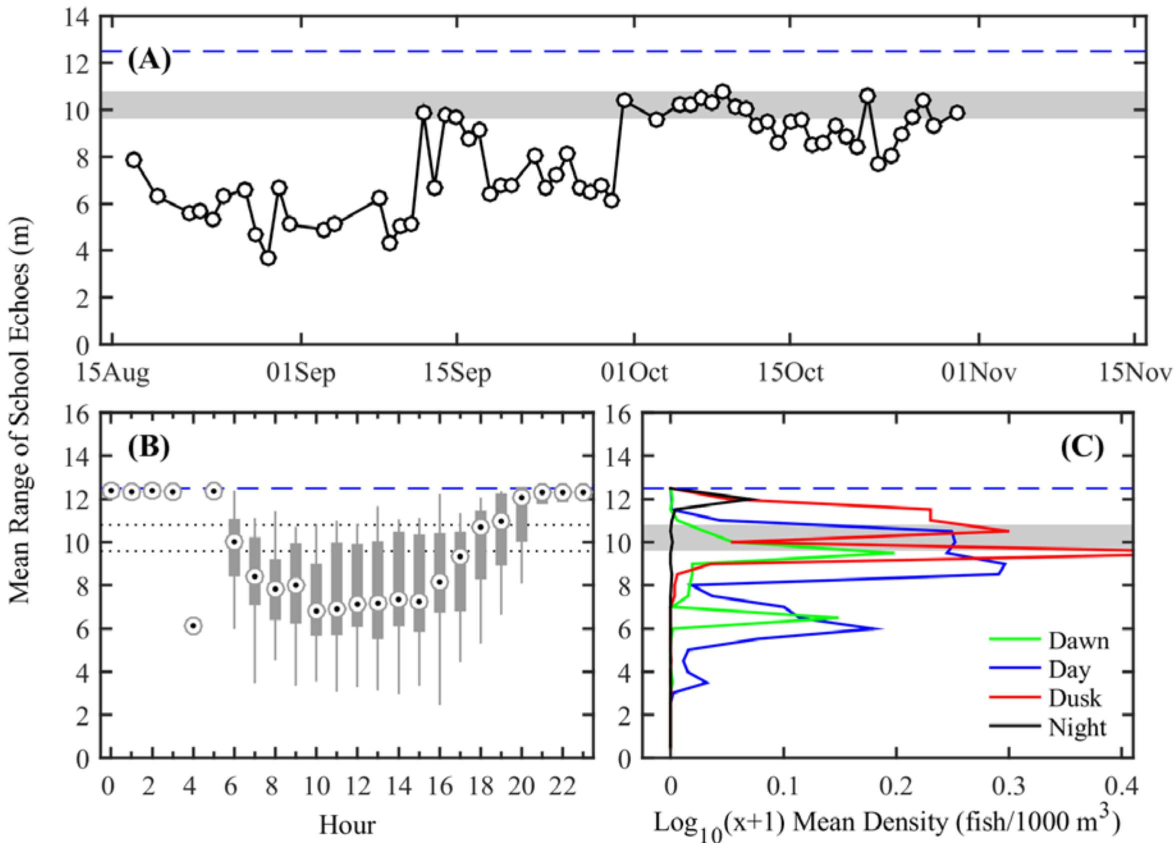



Figure 4.2.2-2. Daily mean volume backscattering strength ($S_V$) and fish density of manually classified fish school echoes at Vernon among selected days from August 15 - November 15, 2015. Inverted red filled and open triangles indicate shad present and absent in cast net catches, respectively.



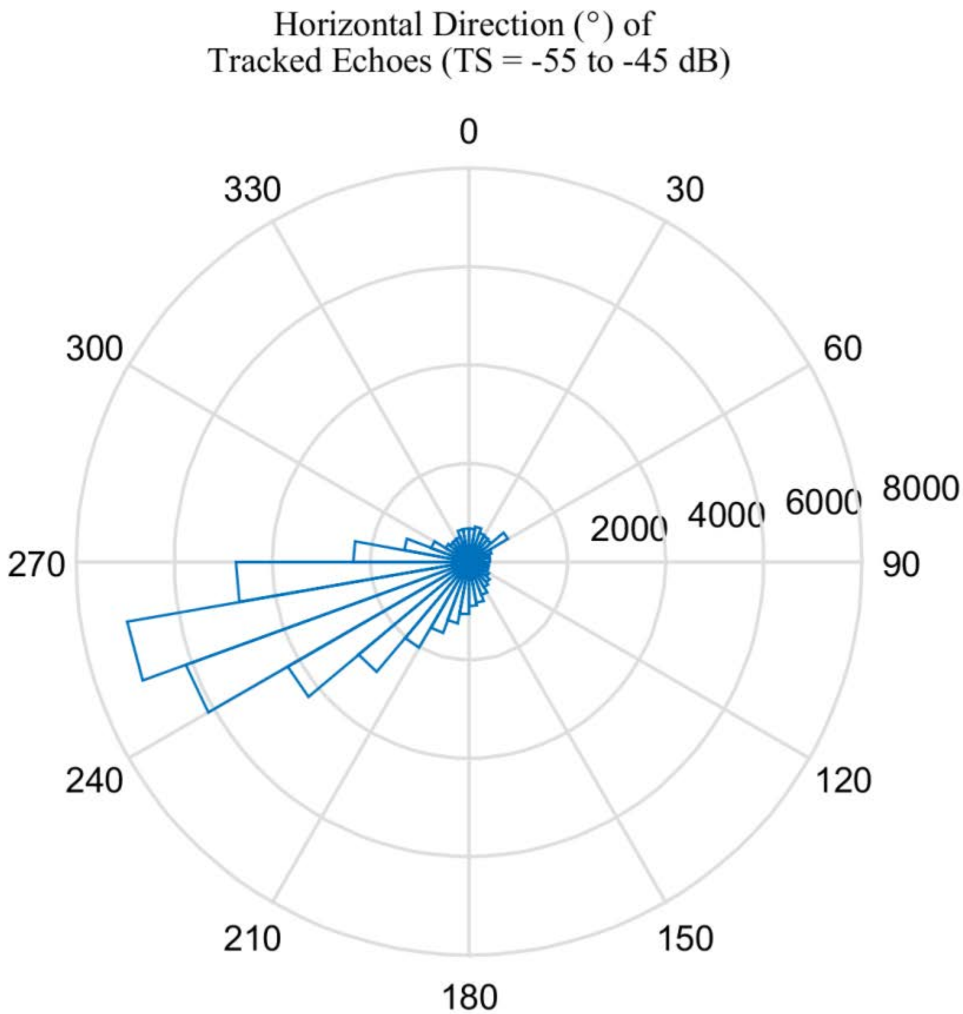

Note: Box plot extent is the 25th and 75th percentiles, whiskers at ±1.5 times the interquartile range, and the symbol or notched line is the median. Non-overlapping notches indicate medians are significantly different at the 95% confidence level (McGill et al. 1978).

Figure 4.2.2-3. Diel patterns in hourly mean volume backscattering strength ($S_V$) and fish density of manually classified fish school echoes at Vernon from September 1 - October 31, 2015 when shad were present at moderate to high densities.




Note: Box plot extent is the 25th and 75th percentiles, whiskers at ±1.5 times the interquartile range, and the symbol is the median. Data >10 m range was not included.

Figure 4.2.2-4. Vertical distribution of manually classified fish school echoes at Vernon on selected days from August 15 through November 15, 2015; (A) daily mean range of school echoes; (B) Box plot of hourly mean range of school echoes; (C) log-transformed mean fish density in 0.5-m range bins during dawn, day, dusk and night periods. Dashed blue line represents a nominal range of water surface; region filled in grey or outlined by dotted line represents the layer equivalent to fish pipe opening.




Note: Filtered to exclude rising bubble echo traces and echo traces less than 7 single echo detections. 0° = true North. Angular bin width of rose plot = 15°

Figure 4.2.2-5. Horizontal (azimuth) distribution of tracked echo traces within the expected size range of juvenile American Shad at Vernon during September and October 2015, when juvenile American Shad and school echoes were mostly present.

### 4.2.3 Verified Acoustic Observations of Juvenile American Shad

Several independent sampling methods confirmed the presence of juvenile American Shad coincident with acoustic observations in the Vernon forebay. Cast nets caught juvenile shad (n=5) in the forebay on September 16, 23, and 28 that averaged 104 mm TL and ranged from 97 to 117 mm TL (Table 4.2.3-1). Fish of similar shape and size as juvenile shad were observed near the surface during cast net sampling from August 26 through October 13. While some days when juvenile shad could be seen, increased cast net effort sometimes did not result in catch.

Boat electrofishing CPUE in the vicinity upstream of the Vernon forebay confirmed the presence of juvenile shad in September and higher abundance during early October (Figure 4.2.3-1). The larger electrofishing catch provided a more representative sample of the size and predicted target strength distribution of individual juvenile shad (Figure 4.2.3-2). During a single opportunity on October 8, several schools of juvenile shad were simultaneously sampled by the upward-looking split-beam transducer and pole-mounted imaging sonar (Figure 4.2.3-3). Data collected from the imaging sonar corroborated the classification method of the echo patterns observed in the echograms from the split-beam transducer as small schooling fish (i.e., juvenile shad). Data from visual observations, electrofishing, cast netting, and imaging sonar support the observed echo patterns to reflect the timing of out-migrating juvenile shad arriving and departing the Vernon forebay.

Table 4.2.3-1. Summary of concurrent visual surface observations and sampling by a 3.7-m diameter cast net with 1-cm bar mesh to compliment hydroacoustic monitoring with presence/absence (P/A) and catch per unit effort (CPUE) of juvenile shad west (W) and east (E) of the fish diversion boom (louver), Vernon, 2015.

| Sample Date | Time | | Number of Casts | | | Shad Catch | | | CPUE (shad / 5-casts) | | | P / A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Start | End | W | E | Total | W | E | Total | W | E | Total | |
| 26 Aug | 19:37 | 20:04 | -- | 5 | 5 | 0 | 0 | 0 | -- | 0.0 | 0.0 | P |
| 02 Sep | 19:52 | 20:22 | -- | 5 | 5 | 0 | 0 | 0 | -- | 0.0 | 0.0 | P |
| 09 Sep[a] | 19:38 | 19:49 | 3 | 4 | 7 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 | P |
| 16 Sep | 19:16 | 19:43 | 5 | 5 | 10 | 3 | 0 | 3 | 3.0 | 0.0 | 1.5 | P |
| 23 Sep[b] | n/a | n/a | 5 | 5 | 10 | 0 | 1 | 1 | 0.0 | 1.0 | 0.5 | P |
| 28 Sep[c] | n/a | n/a | 10 | 10 | 20 | 1 | 0 | 1 | 0.5 | 0.0 | 0.2 | P |
| 06 Oct[d] | n/a | n/a | 13 | 13 | 26 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 | P |
| 13 Oct | n/a | n/a | 8 | 8 | 16 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 | P |
| 20 Oct | n/a | n/a | 10 | 10 | 0 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 | A |
| 30 Oct | 16:50 | 17:45 | 12 | 12 | 24 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 | A |
| 04 Nov | 16:10 | 17:40 | 15 | 10 | 25 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 | A |
| 11 Nov | 16:25 | 16:51 | 5 | 5 | 10 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 | A |

Note: n/a indicates times were not recorded.
a. Sampling discontinued due to thunderstorm activity
b. American Shad total lengths (TL) were 99, 102, 117 mm; one 432-mm Walleye caught
c. 97 mm TL
d. 105 mm TL

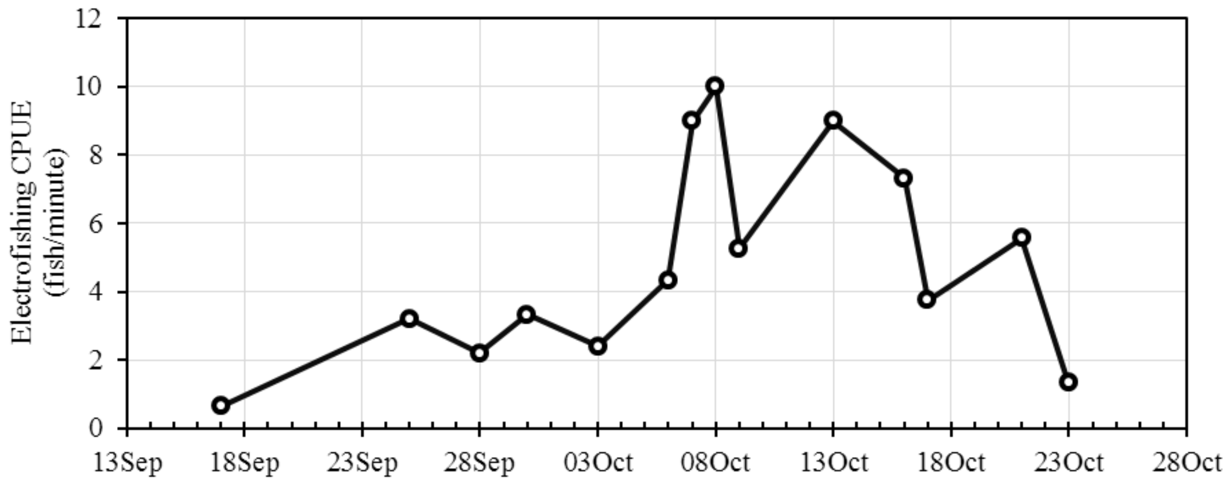



Figure 4.2.3-1. Catch per unit effort (CPUE) of juvenile shad by boat electrofishing in the immediate upstream vicinity of Vernon dam from September 17 through October 30, 2015.

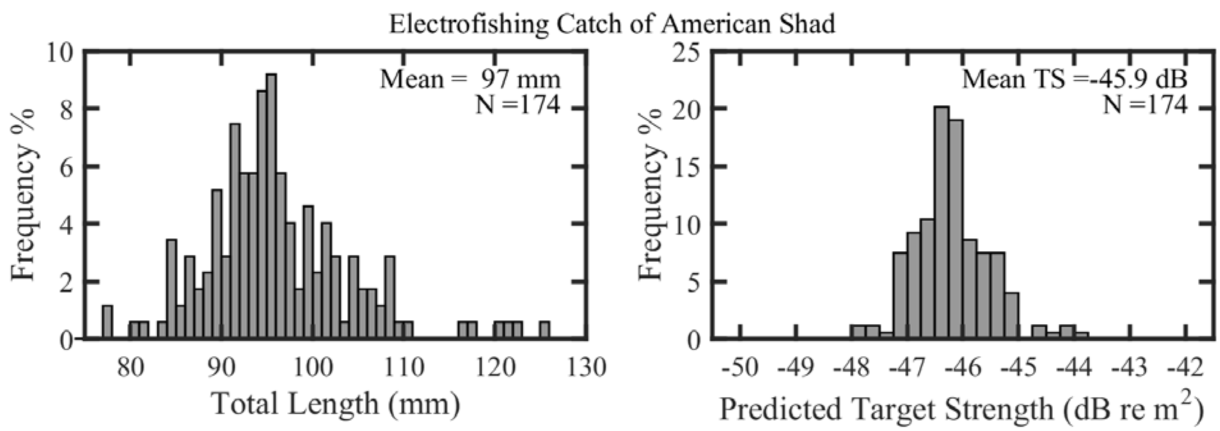



Figure 4.2.3-2. Total length distribution (left) and target strength (right) predicted by Love (1977) from total length of juvenile shad caught by electrofishing in the immediate upstream vicinity of Vernon dam from September 17 through October 30, 2015.

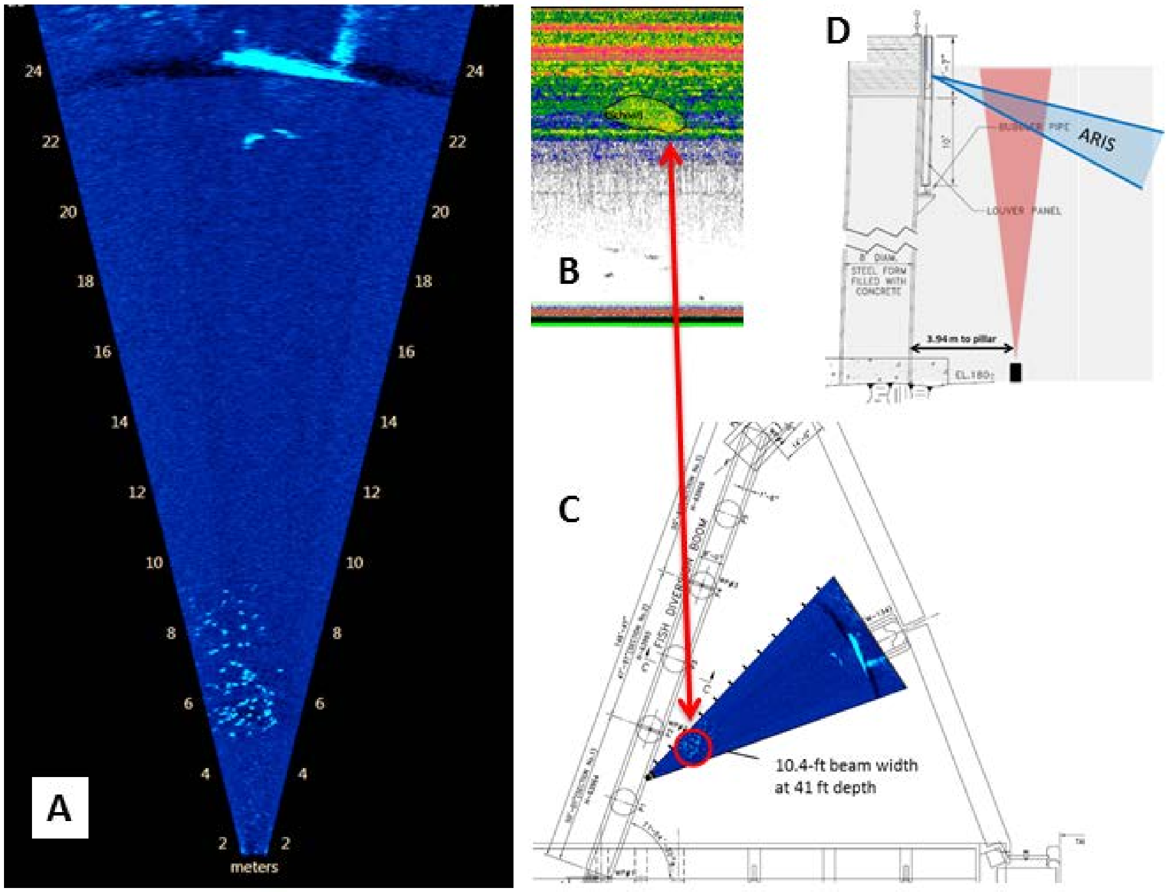



Figure 4.2.3-3. (A) Image of fish school echoes from a single ping by an ARIS 1800 kHz multibeam sonar in the Vernon forebay, October 8, 2015; (B) same fish school echo in the echogram from the 420-kHz split-beam transducer concurrently sampled by the ARIS sonar; (C) plan view of the ARIS field of view in blue and beam footprint of the split-beam transducer (red circle); (D) vertical extent of the two sonars (red=split-beam and blue=ARIS).

### 4.2.4 Environmental Factors

Surface reverberation and higher background noise coincidental to precipitation events and periods of higher flow and wind made detection and discrimination of juvenile shad difficult (Figure 4.2.2-2). Increases in river flow through turbine Units 1-4 (east of the fish diversion boom) and all Units combined increased the $S_v$ in surface, mid-water and bottom layers and accounted for up to 39% of the variation in $S_v$ (Figure 4.2.4-1). A significant, but weak, positive correlation between $S_v$ and wind was also found. Decreases in water temperature significantly increased $S_v$ and explained up to 44% of variation in near-surface $S_{v.}$

Variation in $S_v$ and fish density of classified school echoes was similarly shown to be related to unit flow, water temperature, and change from the previous daily water temperature (Figure 4.2.4-2). Significant weak positive correlation with unit flow explained less variation in abundance of fish school echoes. While there was a significant relation between precipitation and fish density, an outlying single data point of high precipitation may have influenced this relation since the relation between precipitation and $S_v$ (analogous to a log-transformed abundance index) was not significant. A daily rate of change in water temperature was significantly correlated with an increase in fish density of classified school echoes. Most daily changes in water temperature were less than 1°C, but there was a period of days with water temperature decreasing about 4°C over three days. This substantial drop in water temperature, which followed after about 4 inches of rainfall on September 30, coincided with the highest density of classified fish echoes during the study (Figure 4.2.4-3).

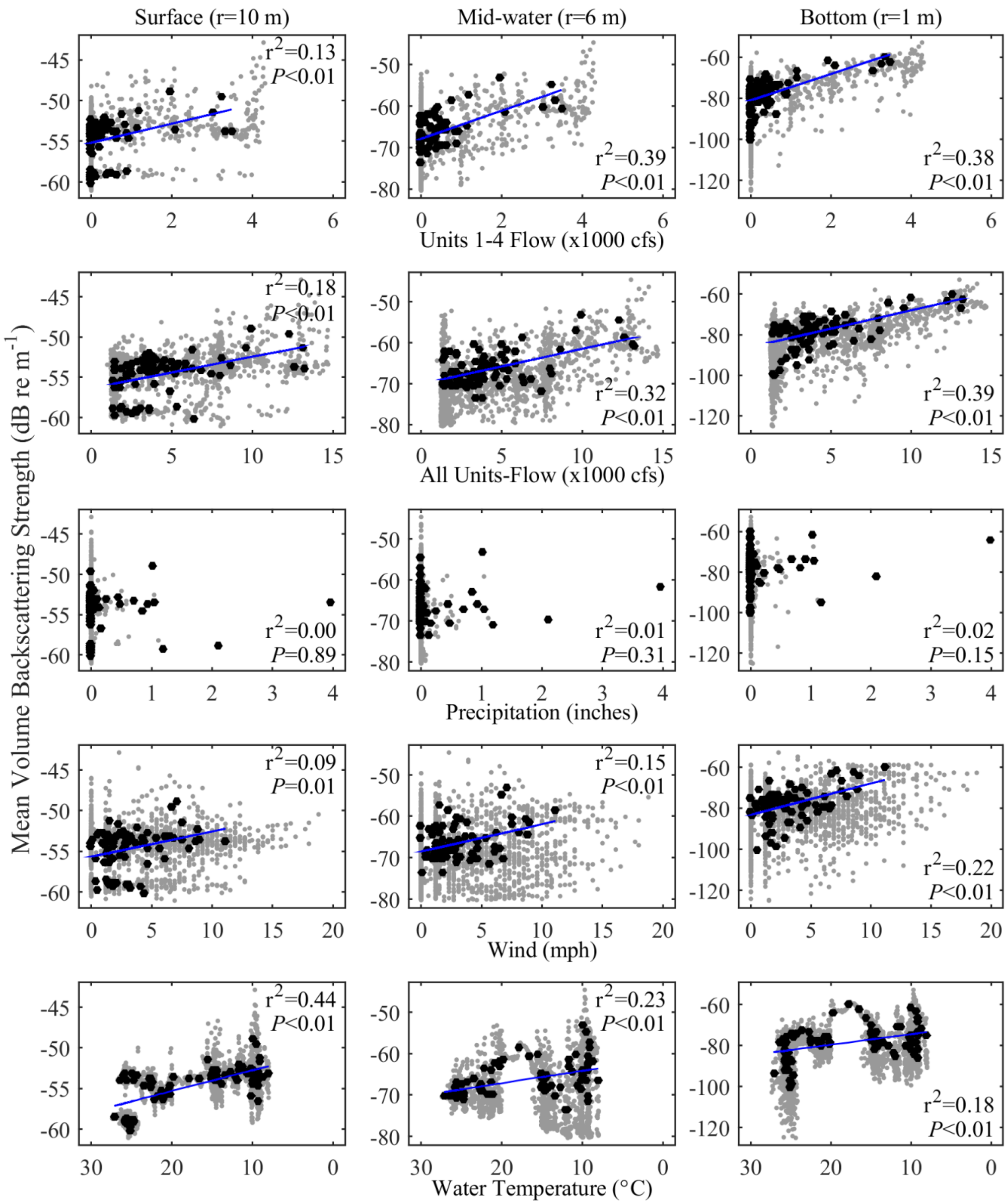



Figure 4.2.4-1. Scatter plots of hourly (grey dots) and daily (black dots) mean volume backscattering strength ($S_V$) for the near surface layer (10-10.5 m in range), mid-water column layer (6-6.5 m in range), and bottom layer (1-1.5 m in range) as a function of river flow through Units 1-4 and Units 1-10; total precipitation; wind, and water temperature from continuous monitoring at Vernon, 2015. A linear trend (blue line) is shown for statistically significant regression models ($P$<0.05).

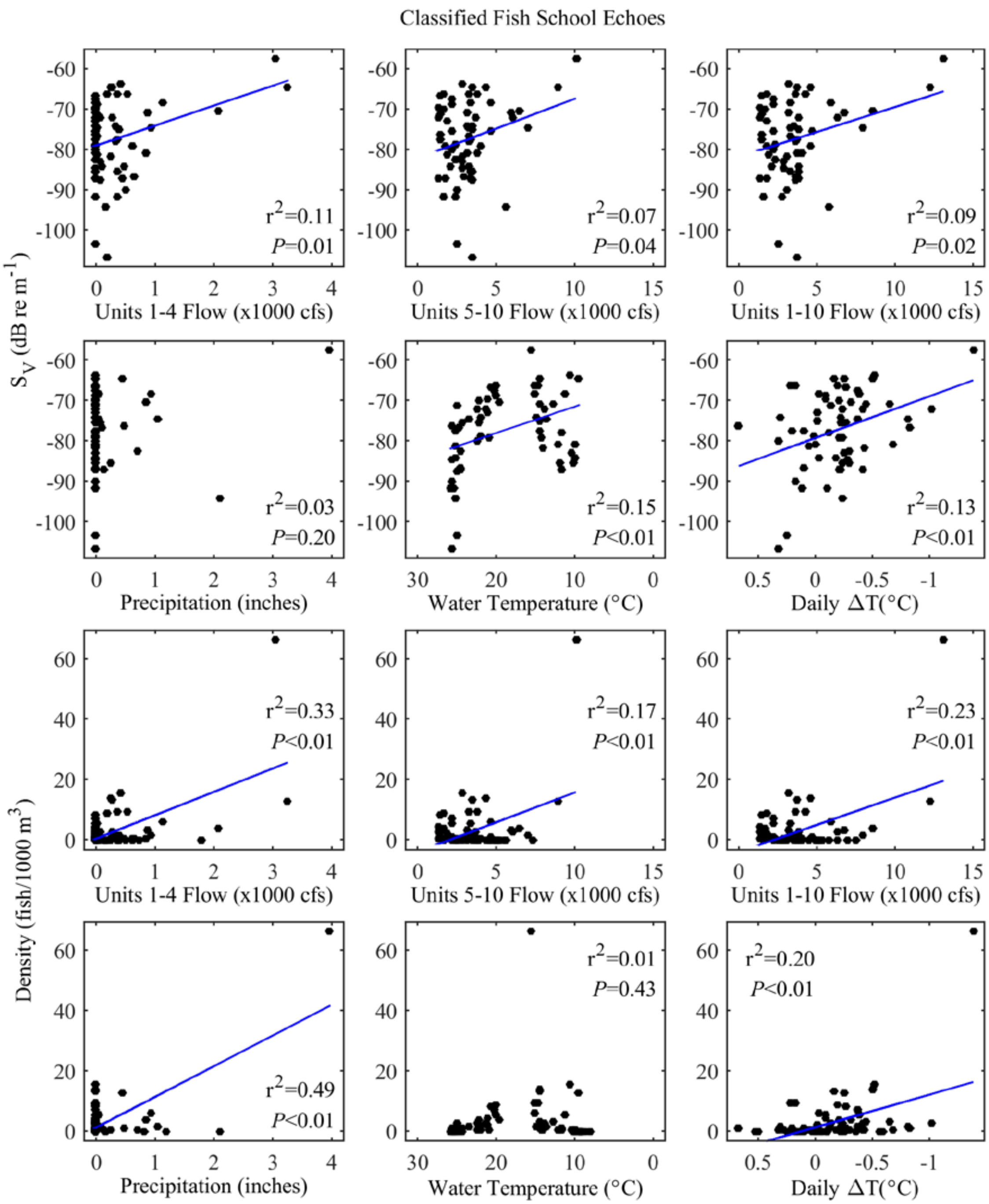



Figure 4.2.4-2. Scatter plots of daily (black dots) mean volume backscattering strength ($S_V$) and fish density of classified fish school echoes as a function of river flow through Units 1-4, Units 5-10 and Units 1-10; total precipitation; and water temperature from continuous monitoring at Vernon, 2015. A linear trend (blue line) is shown for statistically significant regression models ($P<0.05$).

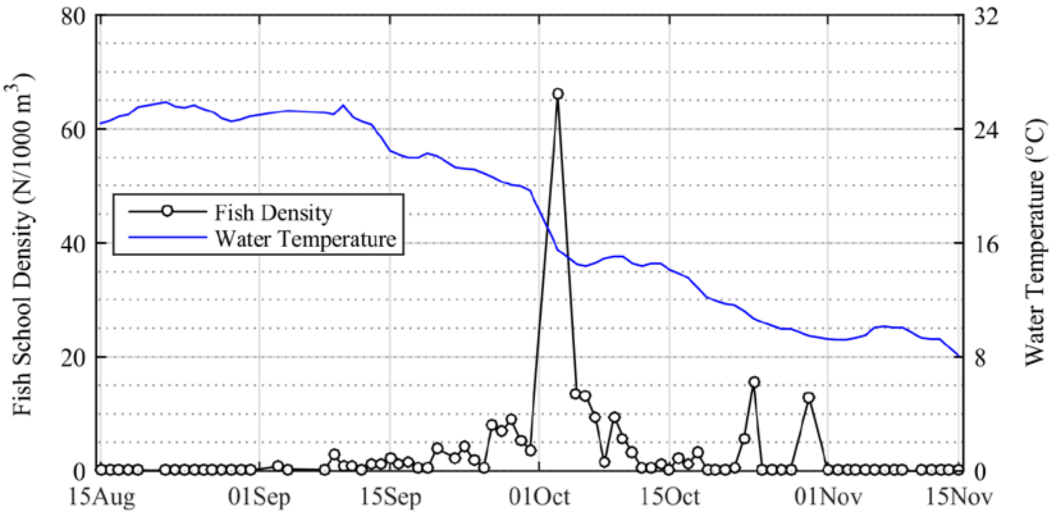



Figure 4.2.4-3. Time series of daily mean fish density of classified school echoes (black line) and daily mean water temperature (blue line) near the entrance to the fish pipe in the forebay of the Vernon powerhouse from August 15 through November 15, 2015.

## 4.3 Turbine Survival

### 4.3.1 Recapture Rates and Times

The HI-Z tag recapture technique performed satisfactorily with generally high recapture rates (physical retrieval of live and dead fish). Recapture rates for the treatment fish were 87.4% for Unit 4 and 94.0% for Unit 8, and for control fish 97.3% (Table 4.3.1-1). The number of fish assigned dead for Unit 4, Unit 8, and controls were 15, 8, and 2, respectively. Of the recaptured fish, all from Unit 4 fish were alive; all but two from Unit 8 were alive, and all but one of the control fish were alive. Dislodged inflated HI-Z tags (without fish) were recaptured on 15 (9.9%) of Unit 4 treatment fish and 7 (4.7%) of Unit 8 treatment fish. There was one (0.7%) dislodged tag for the control fish. The status of four Unit 4 (2.6%) treatment fish and one (0.7%) Unit 8 treatment fish could not be determined. Status of two (1.3%) of the control fish could not be determined. Fish with dislodged tags were either assigned a dead status (Table 4.3.1-1) or not included in the analysis (see section 4.3.5).

Table 4.3.1-1. Tag-recapture data and estimated 1-hour and 48-hour survival for wild juvenile American Shad passed through Units 4 and 8 at Vernon, October 2015.

| | Treatment | | | | | | Control[a] | |
|---|---|---|---|---|---|---|---|---|
| | Unit 4 | | Unit 8 | | Vernon Station | | | |
| **No. Released** | **151** | **%** | **150** | **%** | **301** | **%** | **150** | **%** |
| **Recapture Rate** | 132 | 87.4 | 141 | 94.0 | 273 | 90.7 | 146 | 97.3 |
| **No. Alive** | 132 | 87.4 | 139 | 92.7 | 271 | 90.0 | 145 | 96.7 |
| **No. Recaptured Dead** | 0 | 0.0 | 2 | 1.3 | 2 | 0.7 | 1 | 0.7 |
| **No. Assigned Dead** | 15 | 9.9 | 8 | 5.3 | 23 | 7.6 | 2 | 1.3 |
| Tags Only | 15 | 9.9 | 7 | 4.7 | 22 | 7.3 | 1 | 0.7 |
| Stationary Signal | 0 | 0 | 1 | 0.7 | 1 | 0.3 | 1 | 0.7 |
| **No. Unknown** | 4 | 2.6 | 1 | 0.7 | 5 | 1.7 | 2 | 1.3 |
| **Survival 1 hour** | 91.7% | | 95.2% | | 93.5% | | | |
| **Confidence Interval (CI)** | 5.5% | | 4.7% | | 3.9% | | | |
| **No. Held** | 132 | | 139 | | 271 | | 145 | |
| **Died in Holding** | 24 | | 42 | | 66 | | 44 | |
| **Alive 48 hours** | 108 | | 97 | | 205 | | 101 | |
| **Survival at 48 hours[b]** | N/A | | N/A | | N/A | | | |
| **Confidence Interval (CI)** | N/A | | N/A | | N/A | | | |

a. Controls released into tailrace downstream of the station.

b. 48-hour survival estimate is deemed unreliable due to high number of control mortality (30.3%) during delayed assessment period.

The average recapture times (the time interval between fish release and subsequent recapture) for the treatment fish passed through Units 4 and 8 were 5.3 and 6.3 minutes, respectively. The average recapture time for control fish was 4.8 minutes. The longest time before recapture was 61 minutes for a Unit 8 treatment fish (Figure 4.3.1-1).

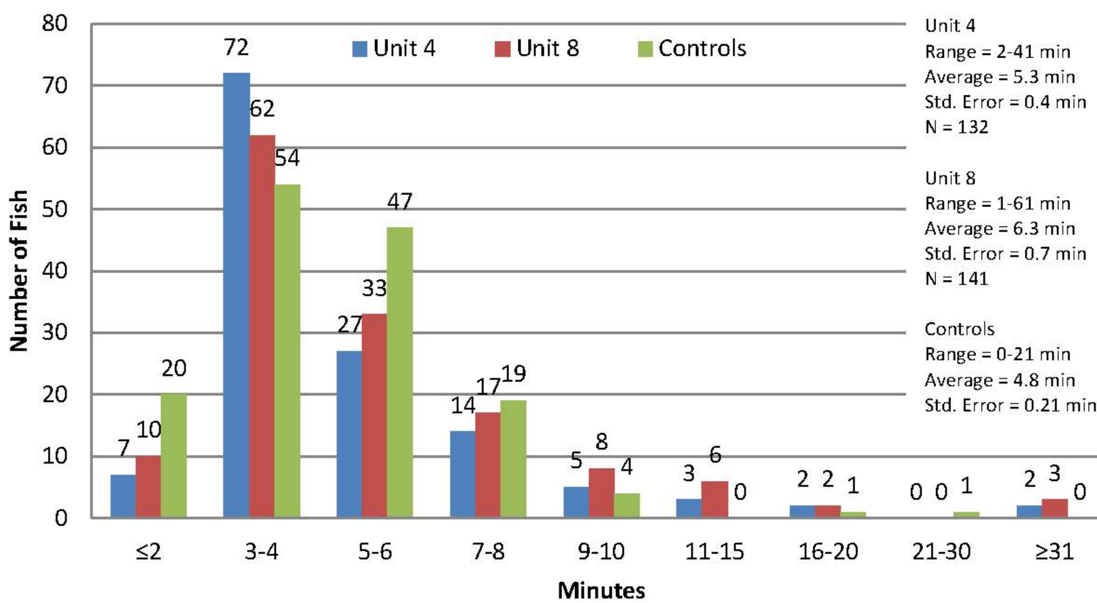



Figure 4.3.1-1. Recapture times (minutes) for juvenile wild American Shad released through Vernon, October 2015.

#### 4.3.2 Survival Estimates

Because the likelihood ratio statistic detected equality in recovery probabilities of alive (PA) and dead (PD) fish (PA = PD), survival estimates derived from the reduced model were used (Table 4.3.1-1 and Appendix D). The estimated immediate (1-hour) survival was 91.7% (confidence interval or CI 5.5%) for Unit 4 and 95.2% (CI 4.7%) for Unit 8. The overall estimated immediate (1-hour) survival was 93.5% (CI 3.9%). The desired precision (≤ ± 10%, 95% of the time) on the survival estimates was met.

In accordance with the RSP, survival estimates were also calculated with only recaptured fish. The estimated immediate (1-hour) survival was 100.0% (CI 1.3%) for Unit 4 and 99.3% (CI 2.4%) for Unit 8 (Table 4.3.2-1). The overall estimated immediate (1-hour) survival was 99.9% (CI 1.8%).

Table 4.3.2-1. Tag-recapture data and estimated 1-hour and 48-hour survival for only recaptured juvenile wild American Shad after passing through Units 4 and 8 at Vernon, October 2015.

| | Treatment | | | | | | Control[a] | |
|---|---|---|---|---|---|---|---|---|
| | Unit 4 | | Unit 8 | | Vernon Station | | | |
| **No. Released** | **151** | **%** | **150** | **%** | **301** | **%** | **150** | **%** |
| **No. Recaptured** | 132 | 87.4 | 141 | 95.0 | 273 | 90.7 | 146 | 97.4 |
| **No. Alive** | 132 | 87.4 | 139 | 92.7 | 271 | 90.0 | 145 | 96.7 |
| **No. Dead** | 0 | 0.0 | 2 | 1.3 | 2 | 0.7 | 1 | 0.7 |
| **Survival 1 hour** | 100.0% | | 99.3% | | 99.9% | | | |
| **Confidence Interval (CI)** | 1.3% | | 2.4% | | 1.8% | | | |
| **No. Held** | 132 | | 139 | | 271 | | 145 | |
| **Died in Holding** | 24 | | 43 | | 66 | | 44 | |
| **Alive 48 hours** | 108 | | 97 | | 205 | | 101 | |
| **Survival at 48 hours[b]** | N/A | | N/A | | N/A | | | |
| **Confidence Interval (CI)** | N/A | | N/A | | N/A | | | |

a. Controls released into tailrace downstream of the station.
b. 48-hour survival estimate is deemed unreliable due to high number of control mortality (30.3%) during delayed assessment period.

The estimated 48-hour survival was deemed unreliable due to the high number of control mortalities during the delayed assessment period of 44 out of 145 fish held (Table 4.3.1-1 and Appendix E, filed separately in Excel format). This situation is not uncommon, particularly in turbine passage studies on juvenile clupeids (Mathur et al., 1996b). Three studies (Heisey et al., 1992; Mathur et al., 1994; Ruggles et al., 1990) discuss the effects of high control mortality on the reliability of estimated turbine passage mortality. Based on studies on juvenile clupieds it was recommended that in order to obtain reliable estimates of turbine passage mortality, control mortality in a turbine passage experiment be minimized (preferably <20%) and recapture rates maximized (preferably >90%). These criteria were followed in this study to produce reliable estimates. In the present case, the 1-hour estimate appeared more reliable than the 48-hour estimate and in agreement with results from similar studies on juvenile clupieds. The negative exponential relationship between estimated turbine passage mortality and control mortality is illustrated in Figure 4.3.2-1 below. It shows that as control mortality increases, estimates of turbine passage mortality increase thus producing increasing levels of uncertainty. As a result, it becomes increasingly difficult to separate the effects of turbine passage from those due to handling, tagging, and recapture.

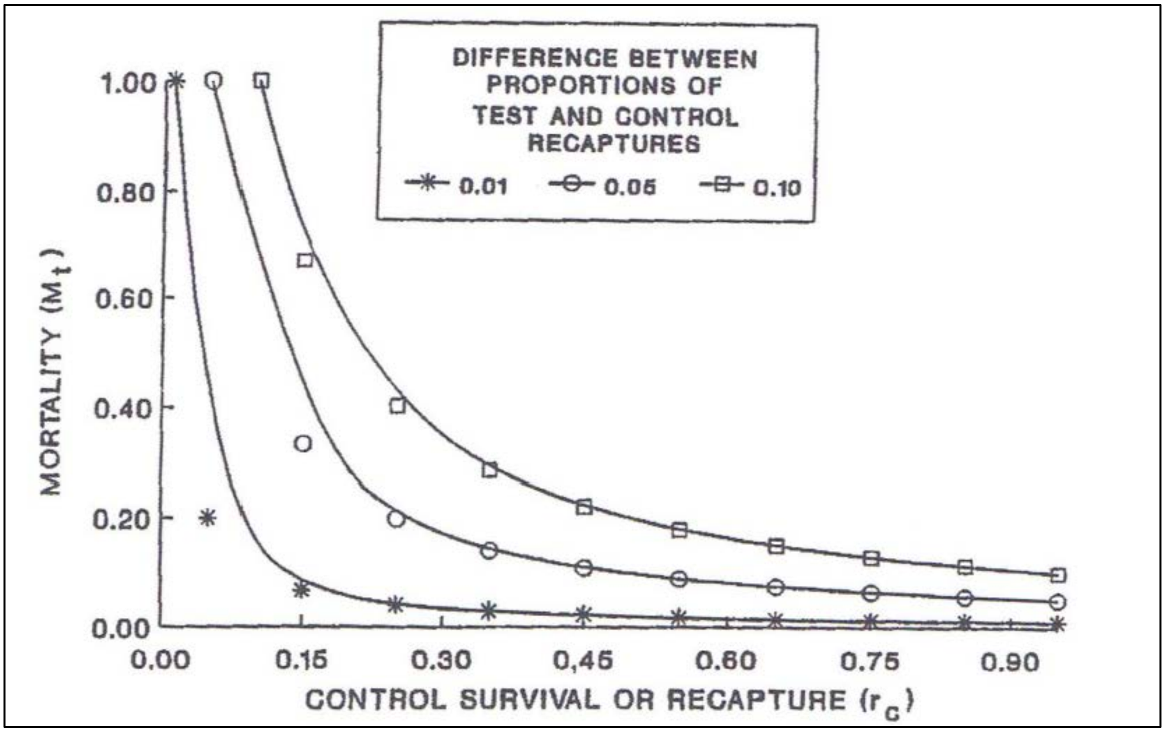



Figure 4.3.2-1. Effects of control fish recapture rates on estimated turbine-related mortality (Mather et al., 1994).

### 4.3.3 Post-Passage Injury Rate, Types, and Probable Source

All of the 132 (87.4%) Unit 4 and 141 (94.0%) Unit 8 post turbine passage recaptured treatment fish were examined for injuries. Of the 132 Unit 4 fish, 126 fish (95.5%) had no visible injuries and 135 of the 141 (95.7%) Unit 8 fish had no visible injuries. Six (4.5%) of the Unit 4 treatment fish had visible injuries and another three (2.3%) displayed only loss of equilibrium (LOE). The Unit 8 treatment fish were similar with six fish (4.3%) having visible injuries and two displaying only LOE (Table 4.3.3-1 and Appendix F, filed separately in Excel format). Some fish displayed more than one type of injury.

The primary injury type observed on Unit 4 fish was hemorrhaging on the body, which occurred on three fish (2.3%). Other injury types included hemorrhaged eye(s) (0.8%), hemorrhaged/bruised head (0.8%), and lacerations on the body (0.8%). The primary injury type observed on Unit 8 fish was operculum/gill damage, which occurred on three fish (2.1%). Other injury types included hemorrhaged/bruised head (1.4%), hemorrhaged eye(s) (0.7%), and lacerations on the body (0.7%). All but four of the 150 control fish released were examined (97.3%) and two (1.4%) had visible injuries. The two control fish had hemorrhaging around the head and snout, which was attributed to the sensitivity of American Shad when handling or holding (Figure 4.3.3-1). At least three of the treatment fish displayed similar type hemorrhaging around the head and snout, which was most likely due to handling and holding in pools. Five control fish

(3.4%) had LOE at recapture (Appendix F and Appendix G, filed separately in Excel format).


Figure 4.3.3-1: Control juvenile wild American Shad exhibiting hemorrhaging on the head after being released and recaptured at Vernon, October 2015.

Mechanical forces alone or in combination with shear, were attributed to most observed injuries (5 of 9 or 56%) on the Unit 4 passed fish displaying injuries (Table 4.3.3-2). One Unit 4 fish exhibited injuries attributed to shear and four were undetermined. The mechanical injuries were likely caused by blade strike or contact with other structures within the flow path. A majority of the maladies (8 of 9 or 89%) inflicted during Unit 4 passage were classified as minor. Mechanical forces alone, or in combination with shear, were attributed to most observed injuries (4 of 8 or 50%) on the Unit 8 passed fish displaying injuries (Table 4.3.3-2). Two Unit 8 fish exhibited injuries attributed to shear and two were undetermined. The mechanical injuries were likely caused by blade strike or contact with other structures within the flow path. A majority of the maladies (5 of 8 or 63%) inflicted during Unit 8 passage were classified as major. All dead fish (Unit 4, Unit 8, and controls) were necropsied and no internal injuries were observed.

Malady-free estimates (i.e., fish free of passage-related maladies) are presented in Table 4.3.3-3. Malady-free estimate rates were adjusted by any maladies incurred by control fish. The Unit 4 malady-free estimate for recaptured fish was 97.9% (CI 5.7%). The Unit 8 malady-free estimate for recaptured fish was 99.1% (CI 5.5%). The overall Vernon station malady-free estimate for recaptured fish was 98.5% (CI 4.7%). The desired precision (≤ ± 10%, 95% of the time) on the malady-free estimates was met.

Table 4.3.3-1. Summary of visible injury types and injury rates observed on recaptured wild juvenile American Shad passed through Units 4 and 8 at Vernon Station, October 2015.

| No. Released | No. Examined | | Passage Related Visibly Injured | | Injury Type[a] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | LOE[b] only | | Operculum / Gill Damage | | Hemorrhaged eye(s) | | Hemorrhaged / Bruised head | | Laceration on body | | Hemorrhaged / Bruised body | |
| | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % |
| **Unit 4** | | | | | | | | | | | | | | | | |
| 151 | 132 | 87.4 | 6 | 4.5 | 3 | 2.3 | 0 | 0.0 | 1 | 0.8 | 1 | 0.8 | 1 | 0.8 | 3 | 2.3 |
| **Unit 8** | | | | | | | | | | | | | | | | |
| 150 | 141 | 94.0 | 6 | 4.3 | 2 | 1.4 | 3 | 2.1 | 1 | 0.7 | 2 | 1.4 | 1 | 0.7 | 0 | 0.0 |
| **Vernon Station (Units 4 and 8 Combined)** | | | | | | | | | | | | | | | | |
| 301 | 273 | 90.7 | 12 | 4.4 | 5 | 1.8 | 3 | 1.1 | 2 | 0.7 | 3 | 1.1 | 2 | 0.7 | 3 | 1.1 |
| **Controls[c]** | | | | | | | | | | | | | | | | |
| 150 | 146 | 97.3 | 2 | 1.4 | 5 | 3.4 | 0 | 0.0 | 0 | 0.0 | 2 | 1.4 | 0 | 0.0 | 0 | 0.0 |

a. Some fish had multiple injury types.
b. Loss of equilibrium (LOE).
c. Controls released into tailrace downstream of the station.

Table 4.3.3-2. Probable sources and severity of maladies observed on recaptured wild juvenile shad at Vernon Station, October 2015.

| No. of Fish Examined | Total With Maladies[a] | | Mechanical | | Mechanical / Shear | | Shear | | Undetermined | | Severity | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Minor | | Major | |
| | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % |
| **Unit 4** | | | | | | | | | | | | | | |
| 132 | 9 | 6.8 | 4 | 3.0 | 0 | 0.0 | 1 | 0.8 | 4 | 3.0 | 8 | 6.1 | 1 | 0.8 |
| **Unit 8** | | | | | | | | | | | | | | |
| 141 | 8 | 5.7 | 3 | 2.1 | 1 | 0.7 | 2 | 1.4 | 2 | 1.4 | 3 | 2.1 | 5 | 3.5 |
| **Vernon Station (Units 4 and 8 Combined)** | | | | | | | | | | | | | | |
| 273 | 17 | 6.2 | 7 | 2.6 | 1 | 0.4 | 3 | 1.1 | 6 | 2.2 | 11 | 4.0 | 6 | 2.2 |
| **Controls[b]** | | | | | | | | | | | | | | |
| 146 | 7 | 4.8 | 2 | 1.4 | 0 | 0.0 | 0 | 0.0 | 5 | 3.4 | 6 | 4.1 | 1 | 0.7 |

a. Maladies include both visible injuries and LOE attributed to turbine passage.
b. Controls released into tailrace downstream of the station.

Table 4.3.3-3. Summary of malady data and malady-free estimates for recaptured wild juvenile shad passed at Vernon Station, October 2015.

| | Unit 4 | | Unit 8 | | Vernon Station | | Control | |
|---|---|---|---|---|---|---|---|---|
| **Number released** | 151 | % | 150 | % | 301 | % | 150 | % |
| **Number examined for maladies** | 132 | 87.4 | 141 | 94.0 | 273 | 90.7 | 146 | 97.3 |
| **Number with passage related maladies** | 9 | 6.8 | 8 | 5.7 | 17 | 6.2 | 7 | 4.8 |
| Visible injuries | 6 | 4.5 | 6 | 4.3 | 12 | 4.4 | 2 | 1.4 |
| Loss of equilibrium only | 3 | 2.3 | 2 | 1.4 | 5 | 1.8 | 5 | 3.4 |
| **Number without passage related maladies** | 123 | 93.2 | 133 | 94.3 | 256 | 93.8 | 139 | 95.2 |
| **Without passage related maladies that died** | 21 | 15.9 | 39 | 27.7 | 50 | 18.3 | 44 | 30.1 |
| **Malady-free rate** | 97.9% | | 99.1% | | 98.5% | | | |
| **Confidence Interval** | 5.7% | | 5.5% | | 4.7% | | | |
| **Malady rate** | 2.1% | | 0.9% | | 1.5% | | | |
| **Confidence Interval** | 5.7% | | 5.5% | | 4.7% | | | |

# 5.0 STUDY CONCLUSIONS

## 5.1 Residency and Route Selection

Of the 270 radio-tagged juvenile shad arriving in the Vernon forebay, 226 (83.7%) were determined to have passed downstream of the project. Residency time in the Vernon forebay was short (median 0.6 hours, or 36 minutes) for passed fish, but longer for fish that did not pass (median 18.4 hours). The dominate route of passage was via the turbines (65% of all passed fish) with Units 5-8 being the primary turbine route (39.8%) of all passed fish, followed by Units 9-10 (15.5%), and Units 1-4 (9.7%). Seventeen shad (7.5% of 170 with known passage route) used the fish pipe and one used the smaller fish tube, the preferred downstream passage routes. Most passage occurred during the late evening, and approximately half of passed shad (N=133) passed at flows between approximately 8,000 and 11,000 cfs. Individuals with known passage routes did not necessarily pass downstream via the route with the greatest proportion of total project discharge. Overall, 70.4% of the 226 radio-tagged juvenile shad passing downstream of Vernon were subsequently detected at the Stebbins Island monitoring station; however, interpretation of the proportion of fish detected at Stebbins Island should not be interpreted as a direct estimate of survival due to uncertainty with predation and tag retention during downstream passage. Given these results, the Vernon project and its operations do not appear to limit the ability of juvenile shad to quickly locate downstream routes through the Vernon project.

## 5.2 Run Timing

The results from this hydroacoustic study were interpreted as representative of the outmigration of juvenile American Shad at Vernon given the weight of evidence presented and that the assumptions were satisfactorily met. The sampling volume was not impacted by fluctuating water surface elevations (range = 43 cm [1.4 ft] and standard deviation = 9 cm [0.3 ft]). The transducer was safely deployed and securely mounted to the riverbed for the duration of the study. Acoustic contributions from high flow, high wind, and precipitation were minimized by manual acoustic classification of fish school echoes. Periods of high fish density of school echoes observed by a single transducer were not able to be discriminated from periods when different groups of fish sequentially move through the beam or periods when the same group of fish persistently move in and out of the beam (i.e., “milling”), where the latter could artificially inflate the relative index of abundance. However, the trend over time within a day and long term were believed to be unbiased given the strong southwesterly movement of tracked fish echoes. The predominant direction of fish echoes was with the predominant flow toward Units 5-10 (west of the fish diversion boom) and along the louver panels. While the boat electrofishing effort to capture live specimens for radio-telemetry was not standardized spatially within the lower Vernon impoundment upstream of Vernon dam, the general trend of increasing CPUE through September, peaking in early October, and declining late October supports the assumptions that timing and relative magnitude of emigrating juvenile shad sampled within the forebay was similar to other locations at Vernon that were not sampled. Continuous monitoring was interrupted but the time series was sufficiently complete (89% complete) to describe the seasonal outmigration of juvenile shad.

Continuous hydroacoustic sampling was able to successfully describe temporal trends and depth distribution of juvenile shad near the entrance to the downstream fish pipe in the Vernon forebay during the 2015 fall outmigration season. Echo patterns indicated small (7-10 cm) schooling fish first appeared in the Vernon forebay on August 17 and last appeared on October 30 (74 days); however, they were not consistently present until the beginning of September. Fish density from manually classified school echoes increased through September to the highest density on October 3, decreased on subsequent days, and then peaked moderately on two isolated late occasions (October 23-24 and 30) before declining to zero by November. The major peak started with a steady increase in fish density from September 25 to the highest peak in the time series on October 3 and then steadily declined to October 8 (a duration of 13 days) before density increased again over several days of fluctuation. The second highest daily mean fish density of the time series occurred on October 24 during a 2-day peak on October 23-24. A single-day peak with the fifth highest daily mean fish density occurred on October 30. These temporal trends are consistent with a single major outmigration run followed by two pulses of late migrants.

Timing of the outmigration observed in this study (mid-August through October) was in reasonable agreement with observations made by others in other locations in the Connecticut River in the past. O'Leary and Kynard (1986) reported the migration season to last 41 days (September 10 – October 21) in 1981 and 52 days (September 19 - November 9) in 1982 at Holyoke Dam, 55 river miles downstream from Vernon. O'Leary and Kynard (1986) similarly observed the highest abundance (>80% of the catch) over a short period of 14 to 22 days. Early September had the highest CPUE of juvenile shad caught by biweekly beach seine sampling in the lower Vernon impoundment during 2012, 2013 and 2014 (Normandeau, 2013; 2014b; 2015), but shad were also present through most of October in most years. As observed in other studies (Leggett and Whitney, 1972; O'Leary and Kynard, 1986; O'Donnell and Letcher, 2008), fish school echoes were most abundant following a sharp decrease in water temperature (approximately 20°C to 16°C) and were absent once water temperatures remained below 10°C. Results indicate some correlation between density in the forebay and river flow, in addition to peak densities triggered by decreasing water temperature.

The observed diel and depth distribution of fish school echoes was consistent with the behavior of juvenile shad. Fish density of school echoes was highest during the afternoon and dusk, which were periods when juvenile shad are known to move at other locations in the Connecticut River (O'Leary and Kynard, 1986). Schools concentrated in the mid-water column generally in the 6 - 10 m range during the day and then migrated up toward the surface before and during dusk. Buckley and Kynard (1985) observed a preference for near surface depths in juvenile shad. There was a central tendency of school echoes found closer to the surface and within the depth layer of the fish pipe opening later in the season during October.

Several independent sampling methods confirmed the presence of juvenile shad concurrent with observations of fish school echoes in the Vernon forebay. The expected target strength for the mean total length of juvenile shad caught by cast nets (104 mm) and electrofishing (97 mm) correspond within a few dB of the observed target strength estimates from tracked echoes. Data from visual observations, electrofishing, cast netting, and imaging sonar support these echo patterns reflected the timing of out-migrating juvenile shad arriving and departing the Vernon forebay. Juvenile shad were interpreted to have successfully passed Vernon because fish density representative of juvenile shad within the forebay quickly decreased from observed peak densities, with some peak densities lasting only one or two days, and tracked echoes of juvenile-shad-sized fish primarily moved through the beam in the west-southwesterly direction toward the fish diversion boom and the powerhouse. There was no evidence that juvenile shad accumulated in the forebay over the outmigration season, which would have been indicative of a migratory barrier or migratory delay.

## 5.3 Turbine Survival

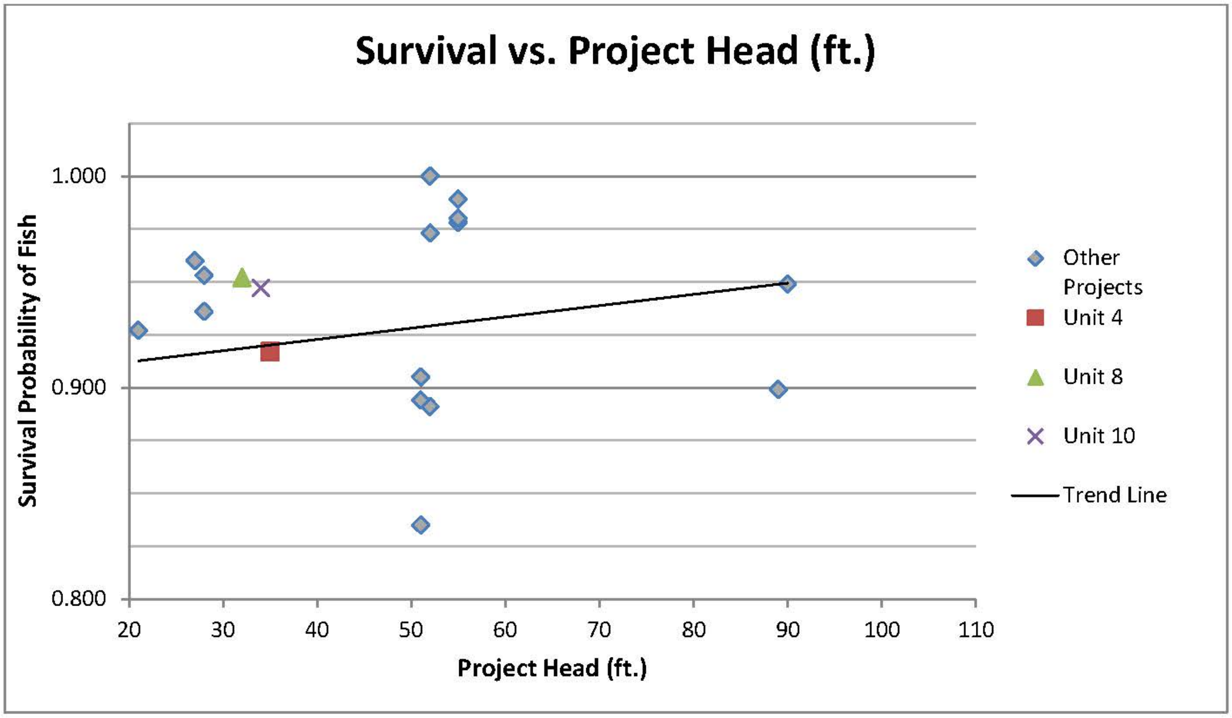
The 1h direct survival estimates for juvenile American Shad of 91.7% for Francis Unit 4 and 95.2% for Kaplan Unit 8 are near the median and mean direct survival estimates attained at nineteen similar direct survival studies conducted on juvenile clupeids. The 1h direct survival at nine different Francis turbines (including Vernon Units 4 and 10) ranged from 77.1 to 95.3% (Appendix H, filed separately in Excel format) with mean and median values of 89.5 and 90.5%, respectively. The corresponding survival estimates at ten propeller type turbines (including Vernon Unit 8) ranged from 89.1 to 100%, with a mean of 96.0%, and median of 96.7%. The 1h direct survival estimate for juvenile shad (mean length 92 mm) passed through Francis Unit 10 in 1995 (Normandeau, 1995) was 94.7%, which was next to the highest estimate (95.3%) for the Francis units.

The relatively high survival (94.7%) for juvenile shad passing through Francis Unit 10 is supported by similar survival results for juvenile Atlantic Salmon (*Salmo salar)* passed through Francis Unit 10 in 1996 (Normandeau, 1996). Although the Atlantic Salmon were larger (mean length 145 mm) and generally hardier than juvenile shad, the salmon direct 1h survival through Francis Unit 10 was 95.9%. The lower survival (91.7%) for juvenile shad passed through the smaller Francis Unit 4 is also supported by a lower 1h direct survival rate of 85.1% for juvenile Atlantic Salmon also passed through Unit 4 in 1996.

All recaptured fish were monitored for 48 hours. Since the delayed mortality remained high for both treatment and control fish computing a reliable-48 hour survival estimate was not possible. A primary effect of high delayed control mortalities to is to either produce estimates with wide confidence intervals or give nonsensical estimates (e.g., 48-hour survival being higher than 1-hour survival). However, examination of the injury rates, types, and severity gives an indication of the long term effects of turbine passage. Only 4.4% of the recaptured turbine-passed juvenile shad at Vernon were injured. If it is assumed that these injuries would result in eventual death then the 48-hour survival for juvenile shad passing Vernon Units 4 and 8 could be as high as 95.6%.

The characteristics of the turbines do have an effect on the direct survival estimates of juvenile clupeids. Figures 5.3-1 and 5.3-2 show the relationship between direct 1h survival and operational head, turbine rotation rate per minute (rpm), number of blades, and turbine diameter. The trend lines indicate that survival rates increase with an increase in runner diameter and operational head and survival rates decrease with an increase in number of blades. The trend line did show a slight increase in survival with increased rpm, however numerous direct survival studies on juvenile salmonids indicate that increased rpm results in higher mortality (Figure 5.3-3). The survival rates for the Francis turbines (Units 4 and 10) and the Kaplan turbine (Unit 8) tested at Vernon followed the trends observed for the relationship between survival and runner diameter and number of blades. The smallest diameter (62.5 in) Unit 4 had the lowest survival (91.7%) while survival rates were 94.7 and 95.2% for the larger Francis (156 in) and Kaplan (122 in) units. The effect of the number of blades on survival was most evident when comparing the results for the 5-bladed Unit 8 to those for the 13-bladed Unit 4. The relative high survival (94.7%) for the 15-bladed Unit 10 was primarily due to its larger diameter and slower runner speed (74 rpm). Unit 4 runner speed is 133 rpm, nearly twice that of Unit 10. Operational head was not a factor because all three Vernon units had similar operating head.

Based on turbine characteristics, estimated direct juvenile American Shad survival for the three turbine types tested, and a previous direct survival study on juvenile Atlantic Salmon at Vernon, the juvenile shad should fare best passing through Kaplan Units 5 through 8, followed by Francis Units 9 and 10. The smaller Francis Units 1 through 4 would likely be least fish friendly.



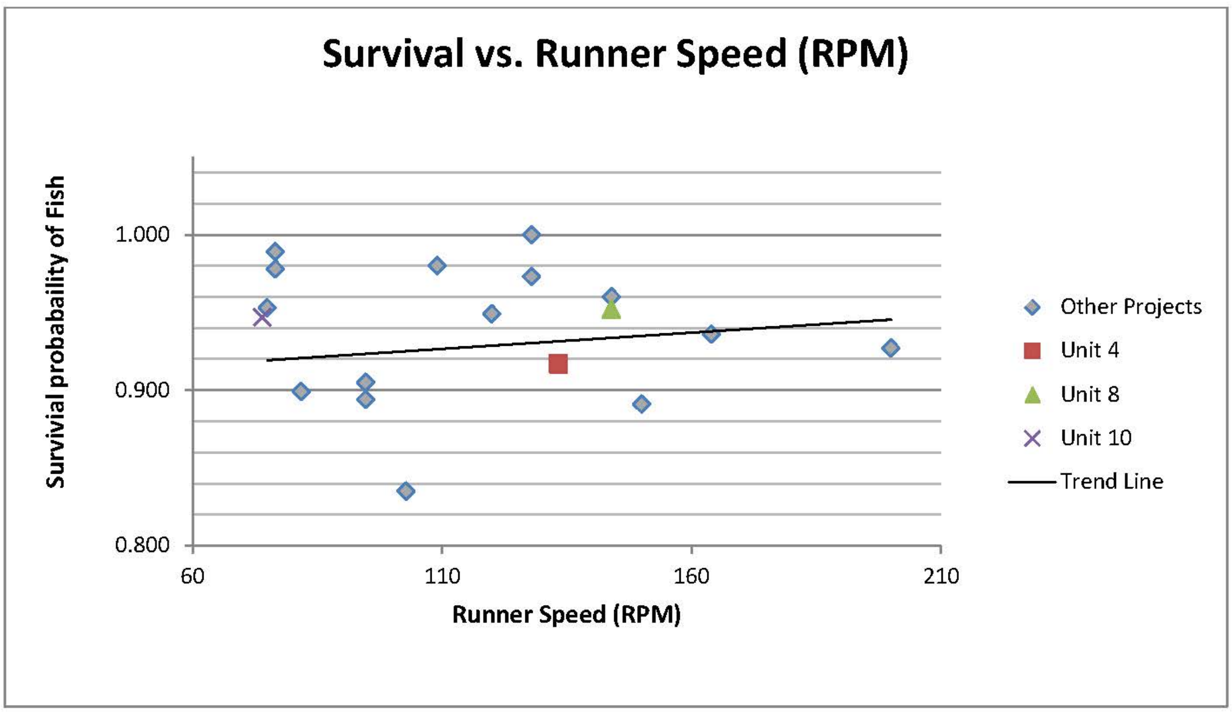
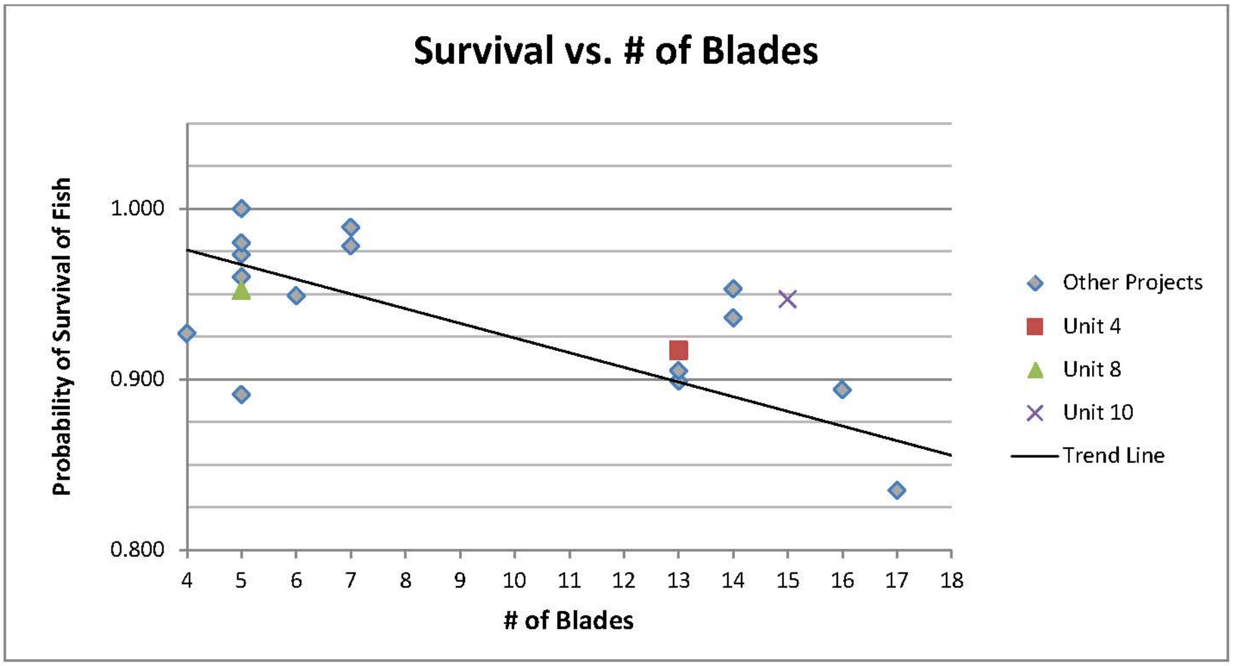




Figure 5.3-1: Plots of immediate (1-hour) survival estimates versus station parameters (project head, runner speed) for Unit 4 and Unit 8 (present study) and Unit 10 (1995) at Vernon and other projects.



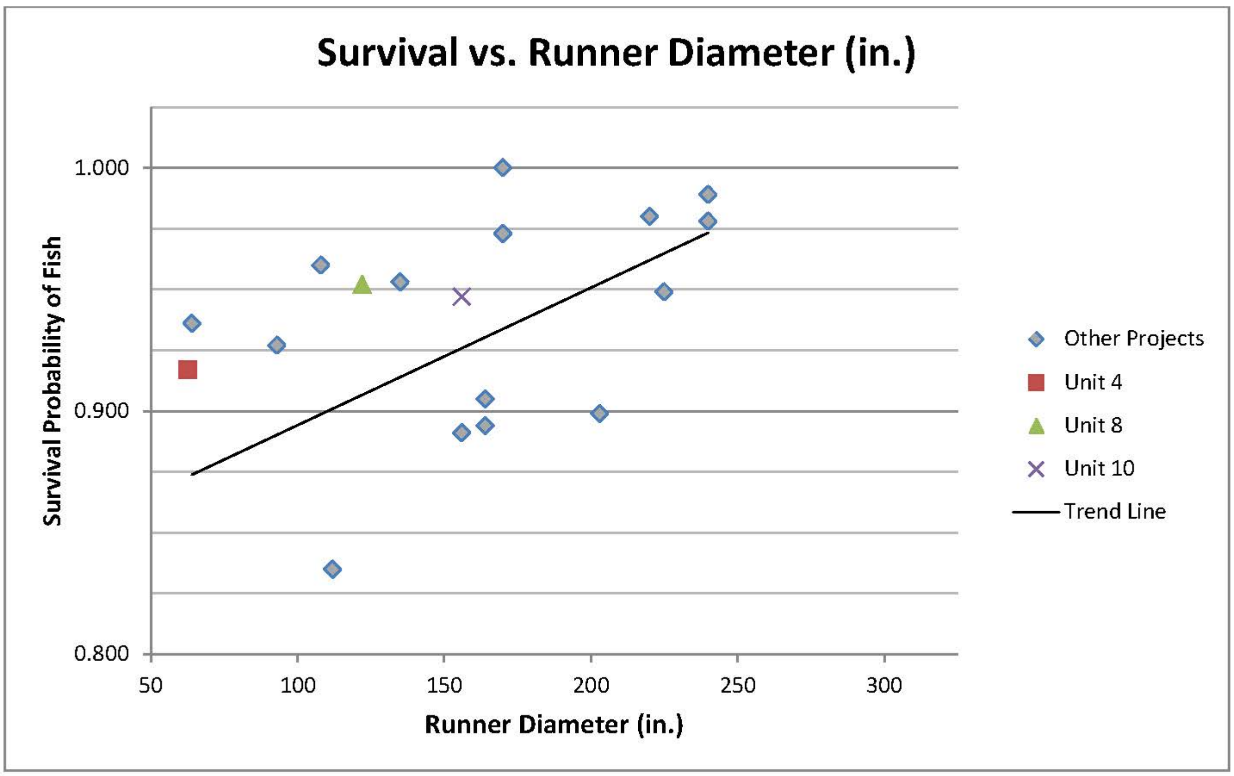




Figure 5.3-2: Plots of immediate (1-hour) survival estimates versus station parameters (number of blades/buckets, and runner diameter) for Unit 4 and Unit 8 (present study) and Unit 10 (1995) at Vernon and other projects.

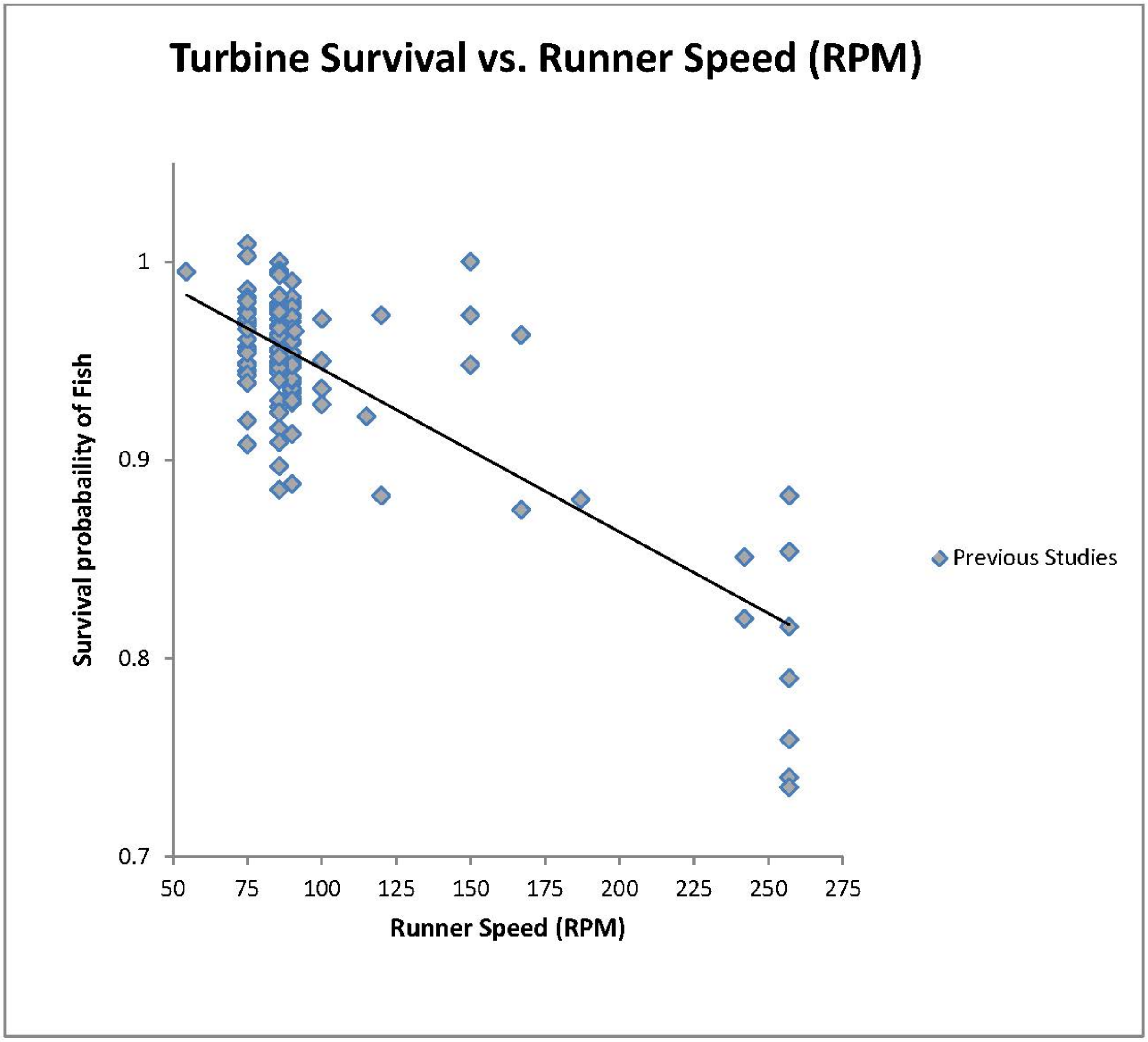



Figure 5.3-3: Comparison of juvenile salmonid turbine passage survival from HI-Z tag studies conducted at 19 different hydroelectric projects.

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# APPENDIX A

## Hydroacoustic System Sampling Outages

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## Hydroacoustic System Sampling Outages

| Period | Duration | Problem | Corrective Action |
|---|---|---|---|
| 16Sep 11:06 — 16Sep 11:47 | 41 min | Remotely detected lost network connectivity | Reboot system & reconfigured IP address |
| 19Aug 14:15 — 22Aug 16:35 | 3.1 days | Remotely detected lost network connectivity; echosounder failed to reboot | Brought system back to office for troubleshooting & returned to field after system rebooted (heat/humidity issue or intermittent hardware issue) |
| 26Aug 03:01 — 27Aug 10:34 | 1.3 days | Lost network connectivity | Automatically rebooted back online; replaced USB modems with Sierra network modem |
| 01Sep 4:54 — 03Sep 14:03 | 2.4 days | Remotely detected lost network connectivity; echosounder failed to reboot | HTI FedEx overnight delivery of echo sounder replacement (but FedEx delayed 1 day) HTI rep assisted in the field |
| 04Sep 23:24 — 08 Sep 12:54 | 3.6 days | Computer insufficient resources error; potential memory leak | Replaced laptop computer; Removed Pulseway system monitoring software to eliminate potential conflicts; HTI rep assisted in the field |
| 20Sep 13:52— 21Sep 16:03 | 26 hours | Sounder waiting for commands; suspected conflict with duplicate DEP software sessions | Remotely rebooted echo sounder and returned to online |
| 24Sep 15:34-16:59 | 85 min | Same issue | Remotely rebooted echo sounder and returned to online; removed DEP desktop shortcut to prevent accidental 2nd sessions to open; limit number of users to log-in remotely |
| 16Sep 11:06 — 16Sep 11:47 | 41 min | Remotely detected lost network connectivity | Reboot system & reconfigured IP address |
| 19Aug 14:15 — 22Aug 16:35 | 3.1 days | Remotely detected lost network connectivity; echosounder failed to reboot | Brought system back to office for troubleshooting & returned to field after system rebooted (heat/humidity issue or intermittent hardware issue) |

# APPENDIX B

## Turbine Survival Sample Size Equations and Definitions

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**DERIVATION OF PRECISION, SAMPLE SIZE, AND MAXIMUM LIKELIHOOD PARAMETERS**

The statistical description below is excerpted from Normandeau Associates *et. al*. (2000). For the sake of brevity, references within the text have been removed. However, interested readers can look up these citations in the report prepared by Normandeau Associates *et. al*. (2000).

The estimation for the likelihood model parameters and sample size requirements discussed in the text are given herein. Additionally, the results of statistical analyses for evaluating homogeneity in recapture and survival probabilities, and in testing hypotheses of equality in parameter estimates under the simplified ($H_O$:$P_A$=$P_D$) versus the most generalized model ($H_A$:$P_A \neq P_D$) are given.

The following terms are defined for the equations and likelihood functions which follow:

| | | |
|---|---|---|
| $R_C$ | = | Number of control fish released |
| $R_T$ | = | Number of treatment fish released |
| R | = | $R_C$=$R_T$ |
| n | = | Number of replicate estimates $\hat{\tau}_i$ (*i*=1,…,n) |
| $a_C$ | = | Number of control fish recaptured alive |
| $d_C$ | = | Number of control fish recaptured dead |
| $a_T$ | = | Number of treatment fish recaptured alive |
| $d_T$ | = | Number of treatment fish recaptured dead |
| S | = | Probability fish survive from the release point of the controls to recapture |
| $P_A$ | = | Probability an alive fish is recaptured |
| $P_D$ | = | Probability a dead fish is recaptured |
| τ | = | Probability a treatment fish survives to the point of the control releases (*i.e.*, passage survival) |
| 1-τ | = | Passage-related mortality. |

The precision of the estimate was defined as:

$$P(-\varepsilon < \hat{\tau} - \tau < \varepsilon) = 1 - \alpha$$

or equivalently

$$P(-\varepsilon <| \hat{\tau} - \tau |< \varepsilon) = 1 - \alpha$$

where the absolute errors in estimation, *i.e.*, $|\hat{\tau} - \tau|$, is <ε (1-α) 100% of the time, $\hat{\tau}$ is the estimated passage survival, and ε is the half-width of a (1-α) 100% confidence interval for $\hat{\tau}$ or 1-$\hat{\tau}$. A precision of ±10%, 95% of the time is expressed as P($|\hat{\tau} - \tau|$<0.10)=0.95.

Using the above precision definition and assuming normality of $\hat{\tau} - \tau$, the required total sample size (R) is as follows:

$$P\left( \frac{-\varepsilon}{\sqrt{Var(\hat{\tau})}} < Z < \frac{\varepsilon}{\sqrt{Var(\hat{\tau})}} \right) = 1 - \alpha$$

$$P\left(Z < \frac{-\varepsilon}{\sqrt{Var(\hat{\tau})}}\right) = \alpha / 2$$

$$\Phi\left(\frac{-\varepsilon}{\sqrt{Var(\hat{\tau})}}\right) = \alpha / 2$$

$$\frac{-\varepsilon}{\sqrt{Var(\hat{\tau})}} = Z_{\alpha/2}$$

$$Var(\hat{\tau}) = \frac{\varepsilon^2}{Z^2_{1-\frac{\alpha}{2}}}$$

$$\frac{\tau}{SP_A}\left[\frac{(1-S\tau P_A)}{R_T} + \frac{(1-SP_A)\tau}{R_C}\right] = \frac{\varepsilon^2}{Z^2_{1-\frac{\alpha}{2}}} \ .$$

where Z is a standard normal deviate satisfying the relationship $P(Z>Z_{1-\alpha/2})=\alpha/2$, and $\Phi$ is the cumulative distribution function for a standard normal deviate.

If data can be pooled across trials and letting $R_C=R_T=R$, the sample size for each release is

$$R = \frac{\tau}{SP_A}\left[1+\tau-2S\tau P_A\right]\frac{Z^2_{1-\alpha/2}}{\varepsilon^2} \ .$$

By rearranging, this equation can be solved to predetermine the anticipated precision given the available number of fish for a study. In most previous investigations (Normandeau Associates *et. al*. 2000) this equation has been used to calculate sample sizes because of homogeneity between trials; in the present investigation sample size was predetermined using this equation.

If data cannot be pooled across trials the precision is based on

$$\sum_{i=1}^{n}(1-\hat{\tau}_i)/n = 1-\sum_{i=1}^{n}\hat{\tau}_i/n = 1-\bar{\hat{\tau}} \ .$$

Precision is defined as

$$P(|\bar{\hat{\tau}}-\bar{\tau}| < \varepsilon) = 1-\alpha$$

$$P(-\varepsilon < \bar{\hat{\tau}}-\bar{\tau} | < \varepsilon) = 1-\alpha$$

$$P\left(\frac{-\varepsilon}{\sqrt{Var(\bar{\hat{\tau}})}} < t_{n-1} < \frac{\varepsilon}{\sqrt{Var(\bar{\hat{\tau}})}}\right) = 1-\alpha$$

$$P\left(t_{n-1} < \frac{-\varepsilon}{\sqrt{Var(\bar{\hat{\tau}})}}\right) = \alpha / 2$$

$$\Phi\left(\frac{-\varepsilon}{Var(\bar{\hat{\tau}})}\right) = \alpha / 2$$

$$\frac{-\varepsilon}{\sqrt{Var(\bar{\hat{\tau}})}} = t_{\alpha/2,n-1}$$

$$Var(\bar{\hat{\tau}}) = \frac{\varepsilon^2}{t^2_{1-\alpha/2,n-1}}$$

$$\frac{\sigma_\tau^2 + \frac{\tau}{SP_A}\left[\frac{(1-S\tau P_A)}{R_T} + \frac{(1-SP_A)\tau}{R_C}\right]}{n} = \frac{\varepsilon^2}{t^2_{1-\alpha/2,n-1}}$$

where $\sigma_\tau^2$=natural variation in passage-related mortality.

Now letting $R_T=R_C$

$$\frac{\sigma_\tau^2 + \frac{\tau}{SP_A}\left[\frac{(1-S\tau P_A)}{R} + \frac{(1-SP_A)\tau}{R}\right]}{n} = \frac{\varepsilon^2}{t^2_{1-\alpha/2,n-1}}$$

which must be iteratively solved for n given R. Or R given n where

$$R = \frac{\frac{\tau}{SP_A}\left[(1-S\tau P_A) + (1-SP_A)\tau\right]}{\left[\frac{n\varepsilon^2}{t^2_{1-\alpha/2,n-1}} - \sigma_\tau^2\right]}$$

$$R = \frac{\frac{\tau(1+\tau)}{SP_A}}{\left[\frac{n\varepsilon^2}{t^2_{1-\alpha/2,n-1}} - \sigma_\tau^2\right]}$$

$$R = \frac{\tau(1+\tau)}{SP_A}\left[\frac{t^2_{1-\alpha/2,n-1}}{n\varepsilon^2 - \sigma_\tau^2 t^2_{1-\alpha/2,n-1}}\right].$$

The joint likelihood for the passage-related mortality is:

$$L\,(S,\ \tau,\ P_A,\ P_D \mid R_C,\ R_T,\ a_C,\ a_T,\ d_C,\ d_T)=$$

$$\binom{R_C}{a_c d_C}(SP_A)^{a_C}((1-S)P_D)^{d_C}(1-SP_A-(1-S)P_D)^{R_C-a_C-d_C}$$

$$\times\binom{R_T}{a_T d_T}(S\tau P_A)^{a_T}((1-S\tau)P_D)^{d_T}(1-S\tau P_A-(1-S\tau)P_D)^{R_T-a_T-d_T}\ .$$

The likelihood model is based on the following assumptions: (1) fate of each fish is independent, (2) the control and treatment fish come from the same population of inference and share that same survival probability, (3) all alive fish have the same probability, $P_A$, of recapture, (4) all dead fish have the same probability, $P_D$, of recapture, and (5) passage survival ($\tau$) and survival (S) to the recapture point are conditionally independent. The likelihood model has four parameters ($P_A$, $P_D$, S, $\tau$) and four minimum sufficient statistics ($a_C$, $d_C$, $a_T$, $d_T$).

Because any two treatment releases were made concurrently with a single shared control group we used the likelihood model which took into account dependencies within the study design (Normandeau Associates *et al.* 1995). For any two treatment groups (denoted $T_1$ and $T_2$), the likelihood model is as follows:

$$L(S,\tau_1,\tau_2,P_A,P_D \mid R_C,R_{T_1},R_{T_2},a_C,d_c,a_{T_1},d_{T_1},a_{T_2},d_{T_2})=$$

$$\binom{R_C}{a_c d_C}(SP_A)^{a_C}((1-S)P_D)^{d_C}(1-SP_A-(1-S)P_D)^{R_C-a_C-d_C}$$

$$\times\binom{R_{T_1}}{a_{T_1} d_{T_1}}(S\tau_1 P_A)^{a_{T_1}}((1-S\tau_1)P_D)^{d_{T_1}}(1-S\tau_1 P_A-(1-S\tau_1)P_D)^{R_{T_1}-a_{T_1}-d_{T_1}}$$

$$\times\binom{R_{T_2}}{a_{T_2} d_{T_2}}(S\tau_2 P_A)^{a_{T_2}}((1-S\tau_2)P_D)^{d_{T_2}}(1-S\tau_2 P_A-(1-S\tau_2)P_D)^{R_{T_2}-a_{T_2}-d_{T_2}}\ .$$

This likelihood model has the same assumptions as stated in Normandeau Associates *et. al*. (2000) but has five estimable parameters (S, $\tau_1$, $\tau_2$, $P_A$, and $P_D$). The survival rate for treatment $T_1$ is estimated by $\tau_1$ and for treatment $T_2$, by $\tau_2$. A likelihood ratio test with 1 degree of freedom was used to test for equality in survival rates between treatments $\tau_1$ and $\tau_2$ based on the hypothesis $H_O$: $\tau_1 = \tau_2$ versus $H_a$: $\tau_1 \neq \tau_2$.

Likelihood models are based on the following assumptions: (a) the fate of each fish is independent; (b) the control and treatment fish come from the same population of inference and share the same natural survival probability, S; (c) all alive fish have the same probability, $P_A$, of recapture; (d) all dead fish have the same probability, $P_D$, of recapture; and (e) passage survival ($\tau$) and natural survival (S) to the recapture point are conditionally independent.

The estimators associated with the likelihood model are:

$$\hat{\tau}=\frac{a_T R_C}{R_T a_C}$$

$$\hat{S}=\frac{R_T d_C a_C - R_C d_T a_C}{R_C d_C a_T - R_C d_T a_C}$$

$$\hat{P}_A = \frac{d_C a_T - d_T a_C}{R_T d_C - R_C d_T}$$

$$\hat{P}_D = \frac{d_C a_T - d_T a_C}{R_C a_T - R_T a_C} \; .$$

The variance (Var) and standard error (SE) of the estimated passage mortality ($1 - \hat{\tau}$) or survival ($\hat{\tau}$) are:

$$Var(1-\hat{\tau}) = Var(\hat{\tau}) = \frac{\tau}{SP_A}\left[\frac{(1-S\tau P_{A)}}{R_T} + \frac{(1-SP_A)\tau}{R_C}\right]$$

$$SE(1-\hat{\tau}) = SE(\hat{\tau}) = \sqrt{Var(1-\hat{\tau})} \; .$$

**DERIVATION OF VARIANCE FOR WEIGHTED AVERAGE SURVIVAL ESTIMATE**

The variance of a weighted average is estimated by the formula

$$\hat{\bar{\theta}}_W = \frac{\sum_{i=1}^{n} W_i \hat{\theta}_i}{\sum_{i=1}^{n} W_i}$$

with

$$\mathrm{Var}\left(\hat{\bar{\theta}}_W\right) = \frac{\sum_{i=1}^{n} W_i \left(\hat{\theta}_i - \hat{\bar{\theta}}_W\right)^2}{(n-1)\sum_{i=1}^{n} W_i}$$

where $\hat{\bar{\theta}}_W$ = the weighted average,

$\hat{\theta}_i$ = the parameter estimate for the *i*th replicate,

$W_i$ = weight.

# APPENDIX C – filed separately in Excel format

## Short Term Turbine Survival Data

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# APPENDIX D

## Turbine Survival Statistical Analysis

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One hour survival estimates for all juvenile wild American Shad passed through Units 4 and 8, Vernon Station, October 2015.
Controls released into tailrace downstream of the station. Control fish: 150 released, 145 alive, and 3 assigned dead;
**Unit 4:** 151 released, 132 alive, and 15 assigned dead;
**Unit 8:** 150 released, 139 alive, and 10 assigned dead.
==================================================
RESULTS FOR FULL MODEL (UNEQUAL LIVE/DEAD RECOVERY)

| | estim. | std.err. | |
|---|---|---|---|
| S1 = | 0.9764 | (0.0146) | Control group survival |
| Pa = | 0.9922 | (0.0099) | Live recovery probability |
| Pd = | 0.8822 | (0.1197) | Dead recovery probability |
| S2 = | 0.8830 | (0.0301) | Unit 4 survival |
| S3 = | 0.9298 | (0.0215) | Unit 8 survival |

*Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.
Log-likelihood: -135.5737

Tau = 0.9043 (0.0312) Unit 4/Control ratio
Tau = 0.9522 (0.0253) Unit 8/Control ratio

Z statistic for the equality of equal turbine survivals: 1.1938
Compare with quantiles of the normal distribution:

| | 1-tailed | 2-tailed |
|---|---|---|
| For significance level 0.10: | 1.2816 | 1.6449 |
| For significance level 0.05: | 1.6449 | 1.9600 |
| For significance level 0.01: | 2.3263 | 2.5758 |

Confidence intervals:

| | Unit 4 | Unit 8 |
|---|---|---|
| 90 percent: | (0.8530, 0.9556) | (0.9106, 0.9938) |
| 95 percent: | (0.8432, 0.9654) | (0.9027, 1.0018) |
| 99 percent: | (0.8240, 0.9846) | (0.8871, 1.0173) |

==================================================
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

| | estim. | std.err. | |
|---|---|---|---|
| S1 = | 0.9797 | (0.0116) | Control group survival |
| Pa = Pd | 0.9845 | (0.0058) | Recovery probability |
| S2 = | 0.8980 | (0.0250) | Unit 4 survival |
| S3 = | 0.9329 | (0.0205) | Unit 8 survival |

*Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.

Log-likelihood: -135.8827

Tau = 0.9165 (0.0277) Unit 4/Control ratio
Tau = 0.9522 (0.0238) Unit 8/Control ratio

Z statistic for the equality of equal turbine survivals: 0.9770

Compare with quantiles of the normal distribution:

| | 1-tailed | 2-tailed |
|---|---|---|
| For significance level 0.10: | 1.2816 | 1.6449 |
| For significance level 0.05: | 1.6449 | 1.9600 |
| For significance level 0.01: | 2.3263 | 2.5758 |

Confidence intervals:

| | Unit 4 | Unit 8 |
|---|---|---|
| 90 percent: | (0.8710, 0.9621) | (0.9131, 0.9913) |
| 95 percent: | (0.8623, 0.9708) | (0.9056, 0.9988) |
| 99 percent: | (0.8452, 0.9878) | (0.8910, 1.0134) |

=====================================================

Likelihood ratio statistic for equality of recovery probabilities: 0.6180
Compare with quantiles of the chi-squared distribution with 1 d.f.:

For significance level 0.10: 2.706
For significance level 0.05: 3.841
For significance level 0.01: 6.635

=====================================================

One hour survival estimate for <u>all juvenile wild American Shad</u> passed through the Vernon Station, October 2015.
Controls released into tailrace downstream of the station. Control fish: 150 released, 145 alive, and 3 assigned dead;
**Vernon Project Combined:** 301 released, 271 alive, and 25 assigned dead.

```
=======================================================
RESULTS FOR FULL MODEL (UNEQUAL LIVE/DEAD RECOVERY)
          estim. std.err.
S =      0.9787 (0.0129)    Control group survival
Pa =     0.9877 (0.0126)    Live recovery probability
Pd =     0.9389 (0.1591)    Dead recovery probability
Tau =    0.9314 (0.0228)    Vernon Station survival
1-Tau =  0.0686 (0.0228)    Vernon Station mortality

Log-likelihood: -136.433674

Profile likelihood intervals:
        Vernon Station survival    Vernon Station mortality
90 percent: (0.8942, 0.9686)          (0.0314, 0.1058)
95 percent: (0.8869, 0.9760)          (0.0240, 0.1131)
99 percent: (0.8725, 0.9916)          (0.0084, 0.1275)
=======================================================
=======================================================
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

          estim. std.err.
S =      0.9797 (0.0116)    Control group survival
Pa = Pd  0.9845 (0.0058)    Recovery probability
Tau =    0.9345 (0.0199)    Vernon Station survival
1-Tau =  0.0655 (0.0199)    Vernon Station mortality

Log-likelihood: -136.469783

Profile likelihood intervals:
        Vernon Station survival    Vernon Station mortality
90 percent: (0.9013, 0.9688)          (0.0312, 0.0987)
95 percent: (0.8946, 0.9762)          (0.0238, 0.1054)
99 percent: (0.8813, 0.9919)          (0.0081, 0.1187)

=======================================================
Likelihood ratio statistic for equality of recovery probabilities:  0.072217
Compare with quantiles of the chi-squared distribution with 1 d.f.:
 For significance level 0.10:  2.706
 For significance level 0.05:  3.841
 For significance level 0.01:  6.635
=======================================================
```

One hour survival estimate for <u>only recaptured</u> juvenile wild American Shad passed through Units 4 and 8 at the Vernon Station, October 2015.
Controls released into tailrace downstream of the station. Control fish: 146 released, 145 alive, and 1 dead;
**Unit 4:** 132 released, 132 alive, and 0 dead;
**Unit 8:** 141 released, 139 alive, and 2 dead.
==================================================
RESULTS FOR FULL MODEL (UNEQUAL LIVE/DEAD RECOVERY)

| | estim. std.err. | |
|---|---|---|
| S1 = | 0.9932 (0.0068) | Control group survival |
| Pa = | 1.0 N/A | Live recovery probability* |
| Pd = | 1.0 N/A | Dead recovery probability* |
| S2 = | 1.0 N/A | Unit 4 survival* |
| S3 = | 0.9858 (0.0100) | Unit 8 survival |

*Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.
Log-likelihood: -16.4771

Tau = 1.0069 (0.0069) Unit 4/Control ratio
Tau = 0.9926 (0.0121) Unit 8/Control ratio

Z statistic for the equality of equal turbine survivals: 1.0228

Compare with quantiles of the normal distribution:

| | 1-tailed | 2-tailed |
|---|---|---|
| For significance level 0.10: | 1.2816 | 1.6449 |
| For significance level 0.05: | 1.6449 | 1.9600 |
| For significance level 0.01: | 2.3263 | 2.5758 |

Confidence intervals:

| | Unit 4 | Unit 8 |
|---|---|---|
| 90 percent: | (0.9955, 1.0183) | (0.9727, 1.0126) |
| 95 percent: | (0.9933, 1.0205) | (0.9688, 1.0164) |
| 99 percent: | (0.9891, 1.0247) | (0.9614, 1.0238) |

==================================================
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

| | estim. std.err. | |
|---|---|---|
| S1 = | 0.9932 (0.0068) | Control group survival |
| Pa = Pd | 1.0 N/A | Recovery probability* |
| S2 = | 1.0 N/A | Unit 4 survival* |
| S3 = | 0.9858 (0.0100) | Unit 8 survival |

*Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.
Log-likelihood: -16.4771

Tau = 1.0069 (0.0069) Unit 4/Control ratio
Tau = 0.9926 (0.0121) Unit 8/Control ratio

Z statistic for the equality of equal turbine survivals: 1.0228

Compare with quantiles of the normal distribution:

| | 1-tailed | 2-tailed |
|---|---|---|
| For significance level 0.10: | 1.2816 | 1.6449 |
| For significance level 0.05: | 1.6449 | 1.9600 |
| For significance level 0.01: | 2.3263 | 2.5758 |

Confidence intervals:

| | Unit 4 | Unit 8 |
|---|---|---|
| 90 percent: | (0.9955, 1.0183) | (0.9727, 1.0126) |
| 95 percent: | (0.9933, 1.0205) | (0.9688, 1.0164) |
| 99 percent: | (0.9891, 1.0247) | (0.9614, 1.0238) |

======================================================

Likelihood ratio statistic for equality of recovery probabilities: 0.0000
Compare with quantiles of the chi-squared distribution with 1 d.f.:

For significance level 0.10: 2.706
For significance level 0.05: 3.841
For significance level 0.01: 6.635

======================================================

One hour survival estimate for only recaptured juvenile wild American Shad after passing through the Vernon Station, October 2015.
Controls released into tailrace downstream of the station. Control fish: 146 released, 145 alive, and 1 dead;
**Vernon Station Combined:** 273 released, 271 alive, and 2 dead.

```
=======================================================
RESULTS FOR FULL MODEL (UNEQUAL LIVE/DEAD RECOVERY)
          estim. std.err.
S =      0.9932 (0.0068)     Control group survival
Pa =     1.0     N/A         Live recovery probability*
Pd =     1.0     N/A         Dead recovery probability*
Tau =    0.9995 (0.0086)     Vernon Station survival
1-Tau =  0.0005 (0.0086)     Vernon Station mortality

*Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.
Log-likelihood: -17.805479

Profile likelihood intervals:
          Vernon Station survival     Vernon Station mortality
90 percent: (0.9852, 1.0000)          (0.0000, 0.0148)
95 percent: (0.9819, 1.0000)          (0.0000, 0.0181)
99 percent: (0.9748, 1.0000)          (0.0000, 0.0252)
=======================================================

=======================================================
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

          estim. std.err.
S =      0.9932 (0.0068)     Control group survival
Pa = Pd  1.0     N/A         Recovery probability*
Tau =    0.9995 (0.0086)     Vernon Station survival
1-Tau =  0.0005 (0.0086)     Vernon Station mortality

*Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.
Log-likelihood: -17.805479

Profile likelihood intervals:
          Vernon Station survival     Vernon Station mortality
90 percent: (0.9852, 1.0000)          (0.0000, 0.0148)
95 percent: (0.9819, 1.0000)          (0.0000, 0.0181)
99 percent: (0.9748, 1.0000)          (0.0000, 0.0252)

=======================================================
Likelihood ratio statistic for equality of recovery probabilities: 0.000000
Compare with quantiles of the chi-squared distribution with 1 d.f.:
  For significance level 0.10:  2.706
  For significance level 0.05:  3.841
  For significance level 0.01:  6.635

=======================================================
```

Malady-free rates for recaptured juvenile wild American Shad passed through Units 4 and 8 at Vernon Station, October 2015. Controls released into tailrace downstream of the station.
Controls: 146 examined, 139 alive no maladies, and 7 with maladies;

**Unit 4**: 132 examined, 123 alive with no maladies, and 9 with maladies;
**Unit 8**: 141 examined, 133 alive with no maladies, and 8 with maladies.

```
======================================================
RESULTS FOR FULL MODEL (UNEQUAL LIVE/DEAD RECOVERY)
          estim. std.err.
S1 =    0.9521 (  +NAN)   Control group survival
Pa =    1.0     N/A       Live recovery probability*
Pd =    1.0     N/A       Dead recovery probability*
S2 =    0.9318 (0.0219)   Unit 4 Malady-free
S3 =    0.9433 (0.0195)   Unit 8 Malady-free

*Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.
Log-likelihood: -91.6727

Tau =   0.9787 (  +NAN)   Unit 4 Malady-free/Control ratio
Tau =   0.9908 (  +NAN)   Unit 8 Malady-free/Control ratio

Z statistic for the equality of equal turbine survivals:    +NAN
Compare with quantiles of the normal distribution:
                                  1-tailed   2-tailed
  For significance level 0.10:   1.2816     1.6449
  For significance level 0.05:   1.6449     1.9600
  For significance level 0.01:   2.3263     2.5758

Confidence intervals:
              Unit 4 Malady-free      Unit 8 Malady-free
90 percent: (  +NAN,   +NAN)      (  +NAN,   +NAN)
95 percent: (  +NAN,   +NAN)      (  +NAN,   +NAN)
99 percent: (  +NAN,   +NAN)      (  +NAN,   +NAN)
======================================================
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)
          estim. std.err.
S1 =    0.9521 (0.0177)   Control group survival
Pa = Pd  1.0     N/A      Recovery probability*
S2 =    0.9318 (0.0219)   Unit 4 Malady-free
S3 =    0.9433 (0.0195)   Unit 8 Malady-free

*Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.
Log-likelihood: -91.6727

Tau =   0.9787 (0.0294)   Unit 4 Malady-free/Control ratio
Tau =   0.9908 (0.0275)   Unit 8 Malady-free/Control ratio

Z statistic for the equality of equal turbine survivals:  0.2988
```

Compare with quantiles of the normal distribution:

| | 1-tailed | 2-tailed |
|---|---|---|
| For significance level 0.10: | 1.2816 | 1.6449 |
| For significance level 0.05: | 1.6449 | 1.9600 |
| For significance level 0.01: | 2.3263 | 2.5758 |

Confidence intervals:

| | Unit 4 Malady-free | Unit 8 Malady-free |
|---|---|---|
| 90 percent: | (0.9305, 1.0270) | (0.9455, 1.0360) |
| 95 percent: | (0.9212, 1.0363) | (0.9368, 1.0447) |
| 99 percent: | (0.9032, 1.0543) | (0.9199, 1.0616) |

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Likelihood ratio statistic for equality of recovery probabilities: -0.0001
Compare with quantiles of the chi-squared distribution with 1 d.f.:

For significance level 0.10: 2.706
For significance level 0.05: 3.841
For significance level 0.01: 6.635

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Malady-free rates for recaptured juvenile wild American Shad passed the Vernon Station, October 2015.
Controls released into tailrace downstream of the station.
Controls: 146 examined, 139 alive no maladies, and 7 with maladies;

**Vernon Station Combined:** 273 examined, 256 alive with no maladies, and 17 with maladies.
=======================================================
RESULTS FOR FULL MODEL (UNEQUAL LIVE/DEAD RECOVERY)
estim. std.err.
S = 0.9521 (0.0177) Control group survival
Pa = 1.0 N/A Live recovery probability*
Pd = 1.0 N/A Dead recovery probability*
Tau = 0.9850 (0.0239) Vernon Station malady-free
1-Tau = 0.0150 (0.0239) Vernon Station malady

*Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.
Log-likelihood: -91.749066

Profile likelihood intervals:

| | Vernon Station malady-free | Vernon Station malady |
|---|---|---|
| 90 percent: | (0.9474, 1.0000) | (0.0000, 0.0526) |
| 95 percent: | (0.9403, 1.0000) | (0.0000, 0.0597) |
| 99 percent: | (0.9262, 1.0000) | (0.0000, 0.0738) |

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=======================================================
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)
estim. std.err.
S = 0.9521 (0.0177) Control group survival
Pa = Pd 1.0 N/A Recovery probability*
Tau = 0.9850 (0.0239) Vernon Station Malady-free
1-Tau = 0.0150 (0.0239) Vernon Station malady

*Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.
Log-likelihood: -91.749066

Profile likelihood intervals:

| | Vernon Station malady-free | Vernon Station malady |
|---|---|---|
| 90 percent: | (0.9474, 1.0000) | (0.0000, 0.0526) |
| 95 percent: | (0.9403, 1.0000) | (0.0000, 0.0597) |
| 99 percent: | (0.9262, 1.0000) | (0.0000, 0.0738) |

=======================================================
Likelihood ratio statistic for equality of recovery probabilities: 0.000000
Compare with quantiles of the chi-squared distribution with 1 d.f.:
For significance level 0.10: 2.706
For significance level 0.05: 3.841
For significance level 0.01: 6.635
=======================================================

# APPENDIX E – filed separately in Excel format

## Daily Turbine Survival Recapture Data

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# APPENDIX F – filed separately in Excel format

## Daily Turbine Survival Injury Data

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# APPENDIX G – filed separately in Excel format

## Turbine Survival Incidence of Maladies

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# APPENDIX H – filed separately in Excel format

## Turbine Survival Physical and Hydraulic Characteristics for American Shad and River Herring Studies

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# APPENDIX I-1, I-2, I-3 filed separately in Excel format

## Revised Downstream Passage Radio Telemetry Data