Relicensing Study 3.3.19

Evaluate the Use of an Ultrasound Array to Facilitate Upstream Movement to Turners Falls Dam by Avoiding Cabot Station Tailrace

Study Report

Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

Prepared for:

FirstLight™
Power Resources

Prepared by:

Kleinschmidt

Gomez and Sullivan
Engineers

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EXECUTIVE SUMMARY

FirstLight Hydro Generating Company (FirstLight) is the current licensee of the Northfield Mountain Pumped Storage Project (Northfield Mountain Project, FERC No. 2485) and the Turners Falls Hydroelectric Project (Turners Falls Project, FERC No. 1889). FirstLight has initiated with the Federal Energy Regulatory Commission (FERC, the Commission) the process of relicensing the Northfield Mountain and Turners Falls Projects using the FERC's Integrated Licensing Process (ILP). The current licenses for the Northfield Mountain and Turners Falls Projects were issued on May 14, 1968 and May 5, 1980, respectively, with both set to expire on April 30, 2018. This report documents the results of Study No. 3.3.19 *Evaluate the Use of an Ultrasound Array to Facilitate Upstream Movement to Turners Falls Dam by Avoiding Cabot Station Tailrace.*

The purpose of this study was to determine if an ultrasound barrier could be used to repel adult American Shad from the Cabot Station tailrace and guide them into the bypass reach. A combination of technologies were used to accomplish the goals of this study, including radio telemetry and Passive Integrated Transponders (PIT), count data from a DIDSON camera deployed in the vicinity of the ultrasound array and the count data from the Cabot Ladder viewing window.

In total, 311 adult American Shad were collected at the Holyoke Dam fish lift. Of the 311 American Shad tagged, 118 were released into the Holyoke exit flume leading to the Holyoke Impoundment. The remaining 193 adult American Shad were tagged by Normandeau (frequencies and codes provided to FirstLight) as part of separate study conducted at Holyoke and released at the Jones Ferry downstream of Holyoke Dam. Releases occurred in multiple batches from May 4th to May 27th, 2016. A series of radio telemetry stations were setup from the Montague Wastewater Facility, located on the Connecticut River just downstream of the Deerfield River confluence, up to Turners Fall Dam (TFD) with stations aggregated into three groups: Downstream Array, In Array and Upstream Array. These aggregations made it possible to relate detection of tagged fish in time with the schedule of the ultrasound array being turned on and off and treatment flows initiated in the bypass reach. Of the 311 tagged fish that were released, 58[1] (18.6%) were detected within the telemetry network and 39 tagged fish (12.5%) were detected somewhere within the ultrasound array aggregate. A competing risk analysis was performed to determine where and why these fish moved after they were detected within the array. From the 39 viable fish detected within the array, 29 of them (~74%) chose to move upstream from there, 9 of them (~23%) chose to move downstream from there and 1 fish (~3%) died within the tailrace.

In order to relate the timing of these movements out of the array to the array status (on or off) and treatment flows, a series of Cox Proportional Regression models were developed. A total of 15 models were developed for all three transitional movements out of the array (upstream, downstream and entering the array from downstream). In all cases, fish were motivated by flow, rather than the status of the array, and these relationships were significant.

The count data from the DIDSON camera revealed that there was no significant difference between median daily fish counts on days that the array was turned on and when it was turned off. Similarly, the count data from the Cabot Ladder viewing window also showed no statistical difference in median daily fish count on days when the array was on or off. The count data from the DIDSON was broken down further on an hourly scale. When the ultrasound system was activated, it was always turned on at 7am. Within the first two hours of the system being activated, there was a significant interaction effect between the system status (on or off) and the treatment flow in the bypass reach. It seems as though there is a temporal effect from the array on the number of fish in the vicinity of Cabot Tailrace for the first two hours of activation.

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[1] Of these 58 tagged fish, 33 were from those fish released into the Holyoke Impoundment and 25 were from those fish released at Jones Ferry below Holyoke Dam.

The use of an ultrasound array to facilitate upstream movement of American Shad to Turners Falls Dam by avoiding Cabot Station Tailrace may be feasible, however more testing may be required to test various modes of the system. There is a temporal effect from the array within the first two hours of activation, which may indicate that fish avoid the array until they become acclimated to the sound. After two hours, there is no statistical difference in the number of fish in the vicinity of the Cabot Ladder entrance when the system is on or off. A more frequent on/off cycle may need to be implemented so fish do not have a long period of time to acclimate to the conditions of the array.

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AIC	Akaike Information Criterion
Alden	Alden Research Laboratory
cfs	cubic feet per second
CRWC	Connecticut River Watershed Council
DIDSON	Dual Frequency Identification SONAR
FERC	Federal Energy Regulatory Commission
FirstLight	FirstLight Hydro Generating Company
glm	generalized linear model
HG&E	Holyoke Gas & Electric
ILP	Integrated Licensing Process
MHz	Megahertz
NHFGD	New Hampshire Fish and Game Department
NAI	Normandeau Associates, Inc.
PAD	Pre-Application Document
PIT	Passive Integrated Transponder
PSP	Proposed Study Plan
QAQC	Quality Assurance and Quality Control
RM	River Miles
RSP	Revised Study Plan
SD1	Scoping Document 1
SD2	Scoping Document 2
SPDL	Study Plan Determination Letter
SQL	MS Access Query
SSI	Scientific Solutions, Inc.
TFD	Turners Falls Dam
TFI	Turners Falls Impoundment
USFWS	United States Fish and Wildlife Services
VY	Vermont Yankee Nuclear Power Plant

1 INTRODUCTION

FirstLight Hydro Generating Company (FirstLight) is the current licensee of the Northfield Mountain Pumped Storage Project (FERC No. 2485) and the Turners Falls Hydroelectric Project (FERC No. 1889). FirstLight has initiated with the Federal Energy Regulatory Commission (FERC, the Commission) the process of relicensing the two Projects using the FERC's Integrated Licensing Process (ILP). The current licenses for Northfield Mountain and Turners Falls Projects were issued on May 14, 1968 and May 5, 1980, respectively, with both set to expire on April 30, 2018.

As part of the ILP, FERC conducted a public scoping process during which various resource issues were identified. On October 31, 2012, FirstLight filed its Pre-Application Document (PAD) and Notice of Intent with the FERC. The PAD included FirstLight's preliminary list of proposed studies. On December 21, 2012, FERC issued Scoping Document 1 (SD1) and preliminarily identified resource issues and concerns. On January 30 and 31, 2013, FERC held scoping meetings for the two Projects. FERC issued Scoping Document 2 (SD2) on April 15, 2013.

FirstLight filed its Proposed Study Plan (PSP) on April 15, 2013 and, per the Commission regulations, held a PSP meeting at the Northfield Visitors Center on May 14, 2013. Thereafter, FirstLight held ten resource-specific study plan meetings to allow for more detailed discussions on each PSP and on studies not being proposed. On June 28, 2013, FirstLight filed with the Commission an Updated PSP to reflect further changes to the PSP based on comments received at the meetings. On or before July 15, 2013, stakeholders filed written comments on the Updated PSP. FirstLight filed a Revised Study Plan (RSP) on August 14, 2013 with FERC addressing stakeholder comments.

On August 27, 2013 Entergy Corp. announced that the Vermont Yankee Nuclear Power Plant (VY), located on the downstream end of the Vernon Impoundment on the Connecticut River and upstream of the two Projects, will be closing no later than December 29, 2014. With the closure of VY, certain environmental baseline conditions will change during the relicensing study period. On September 13, 2013, FERC issued its first Study Plan Determination Letter (SPDL) in which many of the studies were approved or approved with FERC modification. However, due to the impending closure of VY, FERC did not act on 19 proposed or requested studies pertaining to aquatic resources. The SPDL for these 19 studies was deferred until after FERC held a technical meeting with stakeholders on November 25, 2013 regarding any necessary adjustments to the proposed and requested study designs and/or schedules due to the impending VY closure. FERC issued its second SPDL on the remaining 19 studies on February 21, 2014, approving the RSP with certain modifications.

This report contains the results of Study No. 3.3.19 *Evaluate the Use of an Ultrasound Array to Facilitate Upstream Movement to Turners Falls Dam by avoiding the Cabot Tailrace*. In its February 21, 2014 Determination Letter FERC recommended that FirstLight consult with stakeholders and file for Commission approval an amended Study 3.3.19 with its updated study report. On February 18, 2016, FirstLight filed an amended Revised Study Plan for Study 3.3.19 after consulting with stakeholders. On January 13, 2016, FirstLight provided stakeholders with a draft amended RSP and required comments by January 26, 2016. Comments were received from the United States Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), Massachusetts Division of Fish and Wildlife (MADFW), Don Pugh, and Karl Meyer. FERC did not issue another Determination on Study 3.3.19, thus the study was conducted according to the amended RSP.

1.1 Background

Every spring, mature adult American Shad (*Alosa sapidissima)* enter the Connecticut River to search for spawning and rearing habitat necessary for their anadromous life history. Shad migrate inland from marine waters spawning in areas of suitable habitat as they move upstream. During the upstream migration, prior to entering Project waters, shad first encounter the Holyoke Dam in Holyoke, MA. The Holyoke Dam provides upstream passage via a fish lift and allows access to approximately 36 miles of mainstem habitat in the Connecticut River. All fish used in this study were captured at the Holyoke Dam fish lift at the existing fish trapping facility.

The next barrier encountered by upstream migrating fish is the Turners Falls Dam (TFD), located at approximately river mile 122 on the Connecticut River mainstem. Upstream migrating fish may pass the TFD via two potential routes. Downstream of the TFD and near the Cabot Hydroelectric facility, fish may use the Cabot Station Fishway, located at approximately river mile 120, to enter the power canal. The Gatehouse fishway is located at the upstream end of the 2.1-miles long power canal and provides access to Turners Falls Impoundment (TFI). Fish that bypass the Cabot Station fishway may continue to move upstream via the bypassed reach toward the base of the TFD where they can find passage via the Spillway fishway that leads into the Gatehouse fishway.

The purpose of this study was to evaluate the use of an ultrasound array to deflect shad away from the Cabot Station Tailrace and facilitate upstream movement through the bypass reach toward the TFD. A potential alternative to the current configuration of fishways at the Turners Falls Project would be to minimize attraction to the Cabot Station fishway and operate a single fishway facility further upstream, closer to the TFD.

1.1.1 Ultrasound Array

To date, there is no universal behavioral barrier that is effective for all species and life stages of fish. The use of behavioral barriers or deterrents is still considered experimental. Previous work has demonstrated that the alosine species (e.g., American Shad, Blueback Herring, and Alewife) can detect high-frequency sound, such as that produced by an ultrasound array.

American Shad are able to detect high-frequency sound due to their modified inner ear structure that differs from other fishes (Higgs *et. al*., 2004). The inner ear of clupeioforms is surrounded by gas-filled bubbles known as bullae that are connected to the swim bladder via a thin elastic-like thread (Blaxter & Hunter, 1982). As pressure waves intersect a shad, they cause vibrations in the swim bladder and the attached auditory bullae (Denton & Blaxton, 1976). This pressure transfer allows the fish to respond to high-frequency sound that other fish may miss due to the absence of this connected pathway (Higgs *et. al*., 2004).

In the early 1980's, researchers developed a guidance system in the First Level Canal of the Holyoke Canal System for downstream migrating American Shad. Field trials concluded that adult shad avoided the system but were not effectively guided by the ultrasonic array when moving downstream (Kynard & Taylor, 1984). The system was more effective at guiding and even stopping upstream migrants, causing them to vacate the area upstream of the Holyoke Dam trashracks when the sound system was activated (Kynard & Taylor, 1984).

More recently, studies have emerged showing the effectiveness of high-frequency sound fish diversion, particularly at hydroelectric generating facilities. A study at the Annapolis Tidal Generating Station in Nova Scotia, Canada assessed the effectiveness of high-frequency sound to reduce fish passage through the turbines. Researchers concluded the system was not effective for many of the fish species tested, but for members of the genus *Alosa* (specifically, American Shad and Alewife), rates of passage through the turbines decreased by 42% and 48%, respectively, when the system was activated (Gibson & Myers, 2002). In a 2012 study at the Crescent Hydroelectric Project on the Mohawk River, NY, researchers assessed the use of an ultrasonic field to deter out-migrating adult and juvenile Blueback Herring from entering the intake channel to reduce turbine passage impacts. In an attempt to expose fish to an increasing gradient of sound, and to allow more time for avoidance, the sound field was redirected from a perpendicular to a 45-degree, upstream orientation in the main channel of the Mohawk River (Gurshin *et. al*., 2014). Once the ultrasound array was redirected, a 76.5% increase in the proportion of herring migrating downstream via the main channel rather than the intake channel was observed (Gurshin *et. al*., 2014).

The use of high frequency sound as a deterrent for some fish species is becoming more popular but more research is still needed to fully assess its effectiveness in field settings.

1.2 Objectives

In 2016, FirstLight evaluated the use of an ultrasound array to deter adult shad from the Cabot Station tailrace and facilitate upstream movement of American Shad toward the TFD as requested by United States Fish and Wildlife Services (USFWS), New Hampshire Fish and Game Department (NHFGD) and the Connecticut River Watershed Council (CRWC). The goal was to determine if an ultrasound barrier could be used to repel adult shad from the Cabot Station tailrace and guide them into the bypass reach.

The objective of this study was to establish a high-frequency sound (ultrasound) array across the entire Cabot Station tailrace and determine the effect of the ensonified field on upstream migrating shad moving past Cabot Station.

2 STUDY AREA AND SURVEY SITE SELECTION

The study area generally consisted of the Connecticut River extending just upstream from the Jones Ferry landing (approximately 4 River Miles (RM) downstream of Holyoke Dam) to the TFD (Figure 2-1).

The Cabot fishway is a modified “ice harbor” design that consists of 66 pools. Each pool is situated approximately one foot higher than the previous pool. The entrance to the fishway is located adjacent to the Cabot Station tailrace and includes seven gates (numbered 1 through 7 starting at the downstream-most gate) that span the width of the discharge area. The exit of the fishway deposits fish into the power canal. Approximately 2.1 miles upstream at the head of the canal, the Gatehouse fishway permits access to the TFI.

Fish that bypass the Cabot Station fishway may continue to move upstream via the bypassed reach toward to the base of the TFD where they can find passage via the Spillway fishway (modified ice harbor design with 42 pools) into a gallery leading to the Gatehouse fishway, a vertical slot fishway that leads to the TFI.

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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Figure 2-1: Overview of the study area extending from the Turners Falls Impoundment to Holyoke, MA

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3 METHODS

3.1 Study Design and Methods

Beginning in April 2016, FirstLight installed and tested passive and active radio telemetry monitoring equipment within the study area. Fixed monitoring stations were confined to the area between the Montague Wastewater Facility and the Spillway Ladder Entrance just below the TFD (Figures 3.1-1 and 3.1-2). Fixed monitoring locations were sited and designed to answer specific questions as defined in the study objectives. A Dual Frequency Identification SONAR (DIDSON) camera was installed at the entrance to Cabot Fishway to count the number of fish entering the ladder when the ultrasound array was on and/or off.

This study was coordinated with concurrent study efforts of Normandeau Associates, Inc. (NAI) and Holyoke Gas and Electric (HG&E) at Holyoke Dam. Radio tag parameters, frequencies and codes were coordinated such that both study efforts could take advantage of tagged shad to maximize sample sizes.

3.1.1 Ultrasound Array

Alden Research Laboratory (Alden) and Scientific Solutions, Inc. (SSI) configured and installed the ultrasonic deterrent system as a method for repelling adult American Shad away from the Cabot Tailrace and the adjacent fish ladder entrance during the 2016 upstream spawning migration (installation - April 28, 2016). Figure 3.1.1-1 depicts the configuration of the array based on site specific bathymetry and velocities.

A full report detailing the methods of Alden and SSI installation process and testing regarding the ultrasound system is provided in Appendix A.

3.1.2 DIDSON Camera

The DIDSON camera (Sound Metrics Corps. 300m Rear Facing Connector Standard model) was used to evaluate the presence/absence and behavior of untagged shad under the various test scenarios (e.g., ultrasound on/off and bypass flow scenarios of 1500, 2500 and 4400 cfs). The DIDSON was installed at the Cabot Station fishway entrance gate on April 28, 2016. Fishway operation was typical in 2016 with Entrance Gates No. 6 and 7 operational, and Gates 1 through 5 remaining closed throughout the season. The camera was deployed at an elevation of 101.5 feet using a custom bracket that spanned fishway Entrance No. 6. (Figure 3.1.2-1; Figure 3.1.2-2). This elevation allowed for adequate monitoring within the minimum and maximum tailwater elevations at Cabot Station (107-120 feet). Entrance No. 6 was selected for monitoring because prior studies conducted at Cabot Station revealed that it was the most commonly used (57%) entrance by PIT tagged shad during the 2015 Study 3.3.*2 Evaluation of the Upstream and Downstream Passage of Adult American Shad*. The camera was angled 65 degrees toward the entrance such that the field of view concentrated on the crest of the attraction flow discharge at Entrance No. 6 (Figure 3.1.2-1). All shad that entered the fishway through Entrance No. 6 traveled through the monitoring area. The turbulent attraction flow was a noisy environment to monitor, as such an 8-degree concentrator lens was used to confine the sonar beam and minimize noise in the dataset to capture clearer images of shad.

Data were collected using Sound Metrics Corporation DIDSON v. 5.26.06 software, which was programed to record continuously on high frequency with a window length of 5.5 meters to target the upper water column where shad were expected to travel. The files were written to an external hard drive (5 terabytes) in 15-minute intervals. Automated data reduction processes were not effective due to noise in the dataset caused by turbulence and entrained air in the monitoring area. Files were reviewed manually by a trained fisheries technician. Subsampling of the dataset was employed and included review of the first 15 minutes of every hour between sunrise and sunset. Shad were most effectively identified by the acoustic shadow cast as they moved through the DIDSON beam (Figure 3.1.2-3). Files were reviewed in real time to ensure the most accurate fish count. For quality assurance/ quality control (QA/QC) purposes, 10 files were randomly selected to be re-sampled, and fish observations re-counted. If the difference between the fish counts were less than 10% of the original count it was considered a "passing" QA/QC. If the reviewed file failed a QA/QC, each preceding file was reviewed until a "passing" QA/QC was obtained.

3.1.3 Telemetry Network

FirstLight deployed 12 radio telemetry monitoring stations within the study area (Table 3.1.3-1). Radio telemetry monitoring was achieved through the use of Orion receivers manufactured by Sigma Eight, and SRX 800 receivers manufactured by Lotek. Orion and Lotek receivers were deployed to maximize the effectiveness of monitoring stations. The Orion receiver is a broadband receiver capable of monitoring multiple frequencies simultaneously within a 1-megahertz (MHz) band. These receivers are particularly well-suited for monitoring tagged fish in areas where movement through a monitoring zone can occur quickly, such as intakes or bypasses. Lotek receivers are narrowband receivers that have a longer detection range than Orion receivers. However, narrowband receivers can only monitor a single frequency at once and require frequency switching, which can result in less detection reliability in areas where fish move quickly. The telemetry receivers were powered by 12-volt deep cycle batteries, which were maintained via alternating current or solar powered chargers.

Two Passive Integrated Transponder (PIT) monitoring stations were deployed at the entrances of the Cabot and Spillway fishways. The PIT readers were manufactured by Oregon RFID and antennas were custom built onsite. Table 3.1.3-1 summarizes the location of the monitoring stations, the identification numbers and the equipment used.

The radio telemetry monitoring network (Table 3.1.3-1) was designed to monitor tagged shad as they migrated within the study area. Prior to initiating the study, all monitoring locations were tested for calibration to ensure that the desired detection zones were achieved. The results of the calibration efforts are detailed in Appendix B.

3.1.4 Adult Shad Collection and Tagging

Shad used in this study were collected at the upstream fish passage facility at the Holyoke Dam using the existing fish trapping facility. Shad tagging at Holyoke consisted of multiple cohorts that were tagged and immediately released into the Holyoke impoundment via the Holyoke fish lift exit flume.

Additional shad were tagged by the NAI study team and were released downstream of the Holyoke Dam at Jones Ferry. Tags were coordinated between the two studies such that both could take advantage of all the tagged shad in the study area and maximize the sample sizes.

Tagging consisted of esophageal implantation of radio tags and insertion of PIT tags into the peritoneal cavity through a small incision (<1 cm) on the ventral side, anterior to the anal vent (Figure 3.1.4-1). Data were recorded on field data sheets and included sex, total length, condition, and tag identification numbers for each tagged shad. Shad were selected at random, but only those that exhibited vigor and minimal scale loss (<10%, evaluated subjectively in the field) were tagged. Shad were radio tagged with TX-PSC-I-80-M Pisces transmitters manufactured by Sigma Eight. The tags measured 10 mm x 28 mm and operated on two frequencies, 149.740 and 149.780 MHz. They were programed with a two second burst and a mortality function, which defaulted to an eleven second burst upon activation. The expected tag life was approximately 90 days. Activation of mortality was based on relative motionlessness for a period of six hours. PIT tags used in this study were read-only with a 64 bit unique ID (ISO 11784/11785 compatible) and measured 32 mm in length.

3.1.5 Project Operation and Environmental Data

A series of proposed test flows were released in the bypassed reach from the TFD during this study. Tests flows included 1,500 cfs, 2,500 cfs and 4,400 cfs, with releases dependent on river flow conditions. The original study plan included flows to be alternated with the array on for one day then off for one day at

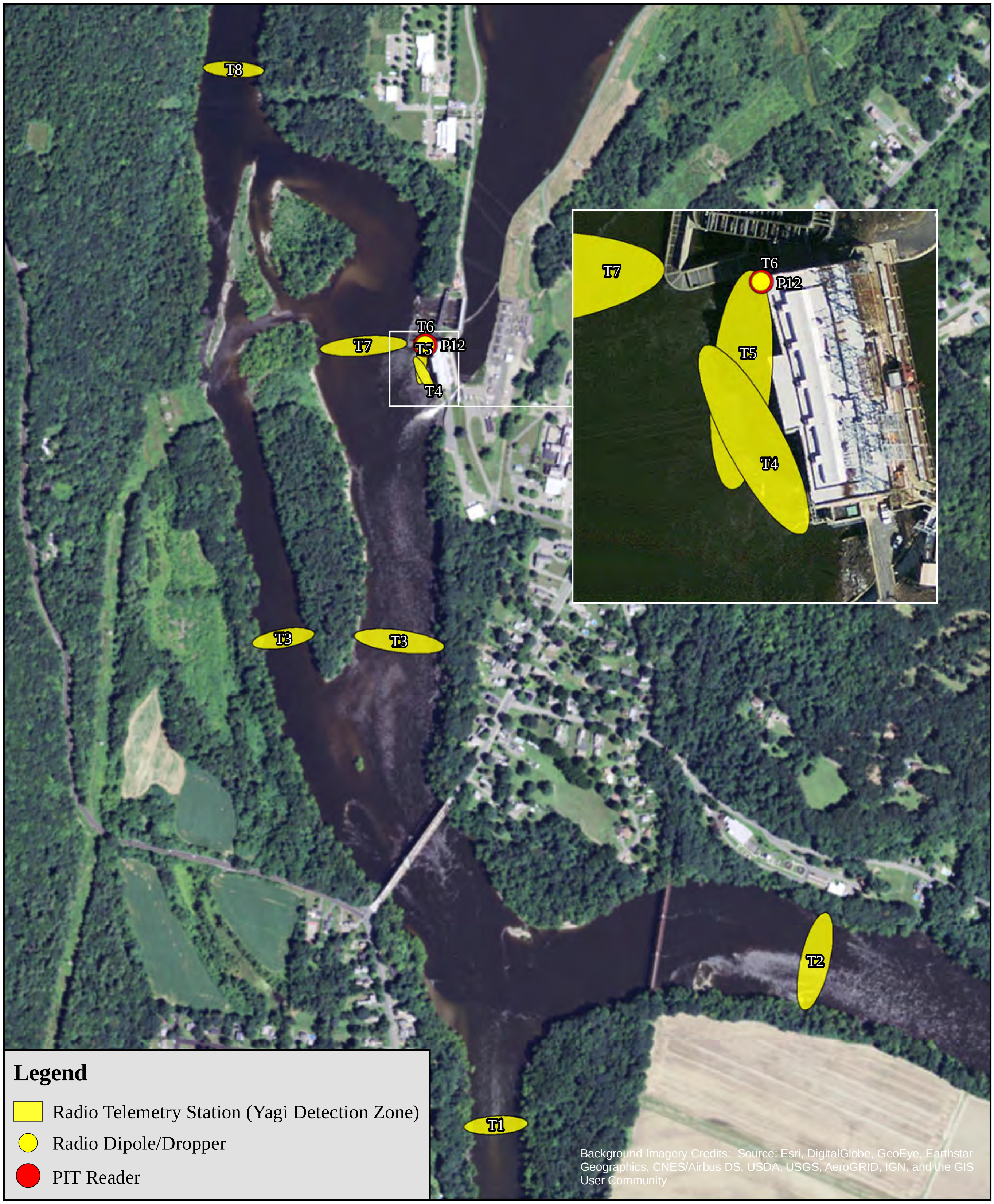
1,500 cfs, followed by one day on and one day off at 2,500 cfs, then one day on and one day off at 4,400 cfs.

As a result of stakeholder comments, the proposed duration of test flows was changed to on for two days and off for one day at 2,500 cfs followed by on for two days and off for one day at 4,400 cfs. This configuration was meant to allow the fish to acclimate to the array to assess any possible effects due to time. The full proposed study flow calendar is provided in Figure 3.1.5-1.

Figure 3.1.5-2 is the actual study flow calendar used in 2016. The ultrasound array was shut down on June 16, 2016 due to preliminary data analysis revealing several fish in the area of the Cabot Station Fish Ladder during “array on” days. Note that days when the ultrasound array was activated, the system was always turned on at 0700.

Table 3.1.3-1: Shad monitoring locations and equipment used in the Ultrasound Study

Station Location	Station ID	RM	Receiver Station
Entrance to the Deerfield River	T1	119.5	An Orion receiver with Yagi antenna monitored the full width of the Deerfield upstream of the confluence with the Connecticut River
Montague Wastewater	T2	119.5	A Lotek SRX receiver with Yagi antenna monitored the full width of the river
Downstream Smead Island East Channel	T3-L	120	A Lotek SRX receiver with Yagi antenna monitored the East channel of the river
Downstream Smead Island West Channel	T3-O	120	An Orion receiver with Yagi antenna monitored the West channel of the river
Cabot Tailrace Downstream	T4	120	A Lotek SRX receiver with Yagi antenna monitored the Cabot Tailrace
Cabot Tailrace Upstream	T5	120	An Orion receiver with Yagi antenna monitored the Cabot Tailrace
Cabot Ladder Entrance	T6 and P12	120	An Orion receiver with dipole antenna and two PIT tag readers monitored the entrance
Upstream End of Smead Island	T7	120	A Lotek SRX receiver with Yagi antenna monitored the full width of the river
Bypass Reach	T8	120.5	An Orion receiver with Yagi antenna monitored the full width of the river
Spillway Ladder Entrance	T9 and P13	122	An Orion receiver with dipole antenna and two PIT tag readers monitored the entrance
Spillway Ladder Vicinity	T10	122	A Lotek SRX receiver with Yagi antenna monitored the vicinity in front of Spillway ladder entrance
Gatehouse Exit Dipole	T14		An Orion receiver with dipole antenna measured the exit



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0 380 760 1,520 Feet

Figure 3.1-1: Telemetry Sites Near Cabot Station

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Figure 3.1-2: Telemetry Sites Near Gatehouse

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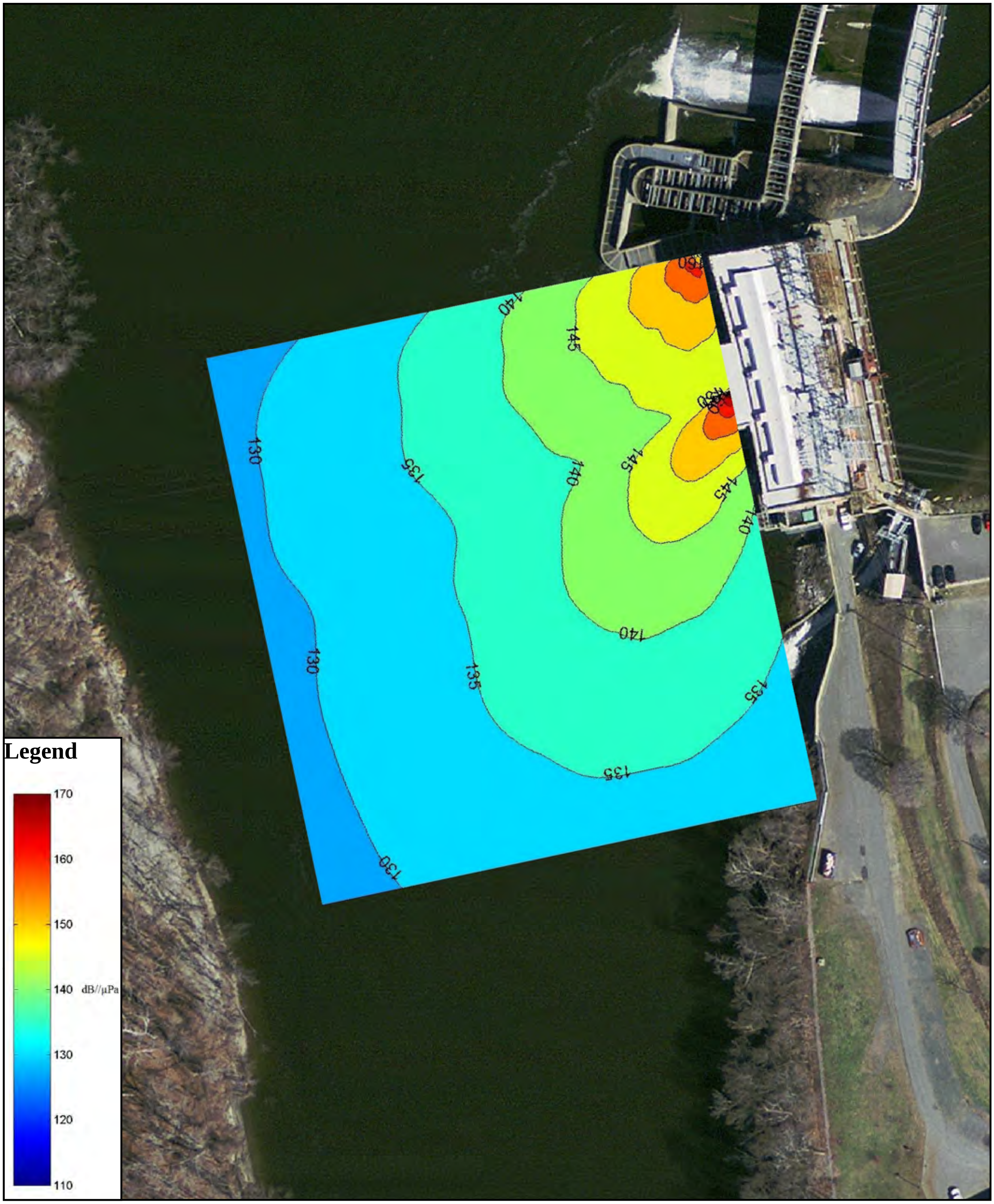

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Figure 3.1.1-1: Configuration of Ultrasound Array

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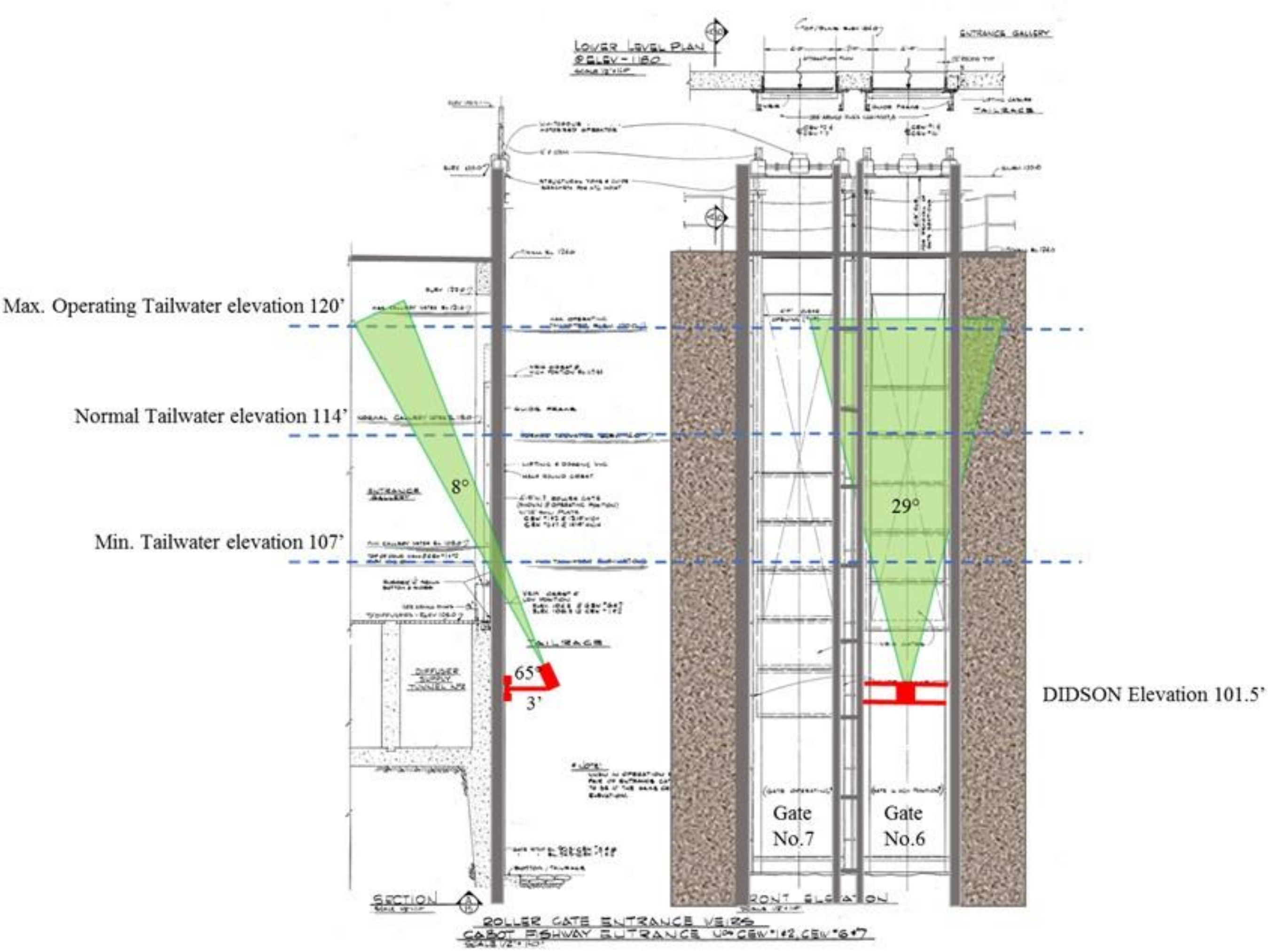


Figure 3.1.2-1: Location of DIDSON camera (red) and its field of view (green) within the area of Cabot Fishway Entrance No. 6

Figure 3.1.2-2: Pre installation of DIDSON camera mounted on custom fabricated bracket

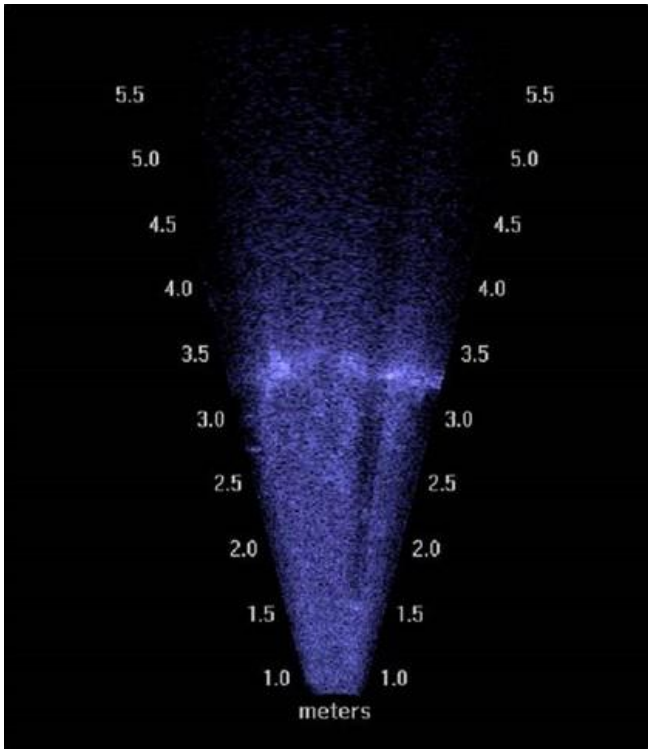
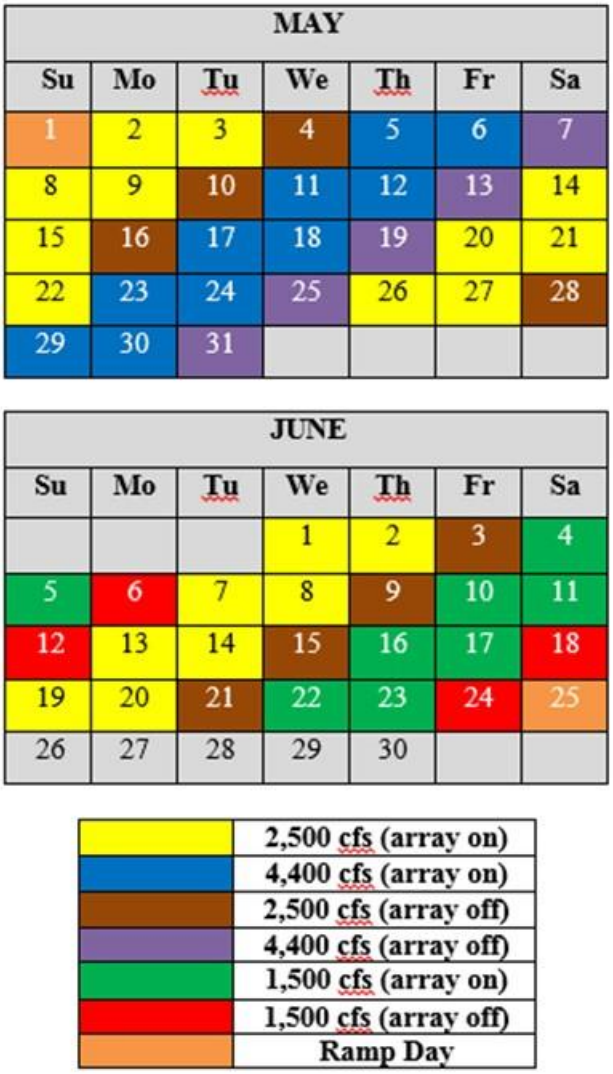


Figure 3.1.2-3: An image of a shad entering the field of view (between 3 and 3.5 m) on the DIDSON camera

Figure 3.1.4-1: Adult Shad PIT tag incision (<1 cm) on the ventral side, anterior of the anal vent



MAY

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🟨 8	🟨 9	🟫 10	🟦 11	🟦 12	🟪 13	🟨 14
🟨 15	🟫 16	🟦 17	🟦 18	🟪 19	🟨 20	🟨 21
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JUNE

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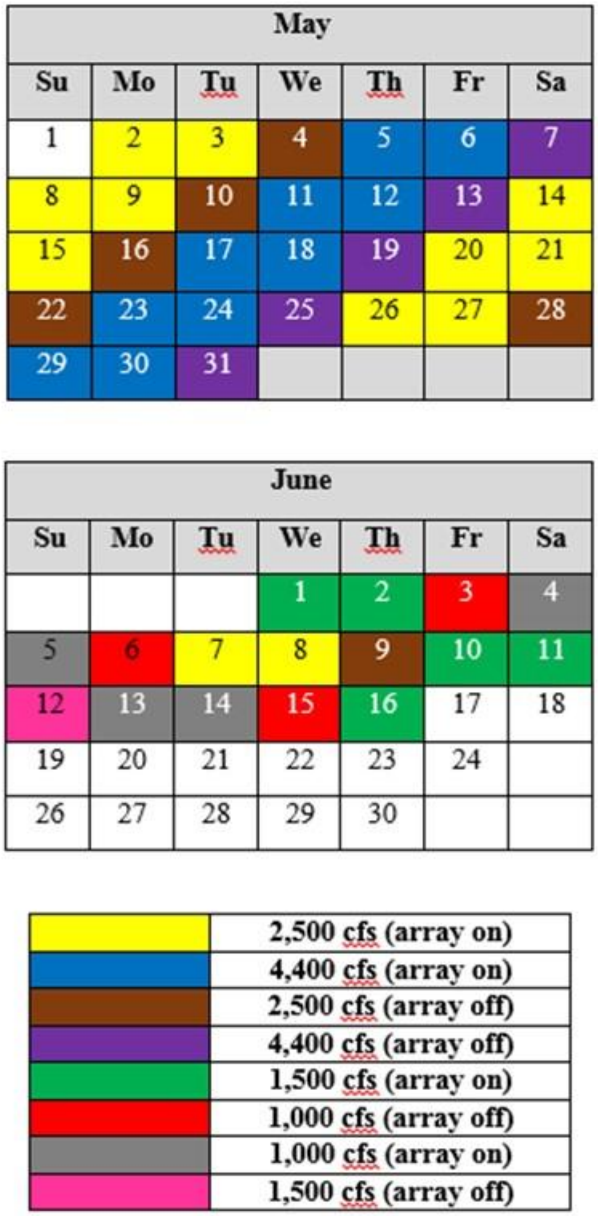
26	27	28	29	30		

🟨	2,500 cfs (array on)
🟦	4,400 cfs (array on)
🟫	2,500 cfs (array off)
🟪	4,400 cfs (array off)
🟩	1,500 cfs (array on)
🟥	1,500 cfs (array off)
🟧	Ramp Day

Figure 3.1.5-1: Proposed 2016 Ultrasound Array Flow Calendar



May

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🟨 8	🟨 9	🟫 10	🟦 11	🟦 12	🟪 13	🟨 14
🟨 15	🟫 16	🟦 17	🟦 18	🟪 19	🟨 20	🟨 21
🟫 22	🟦 23	🟦 24	🟪 25	🟨 26	🟨 27	🟫 28
🟦 29	🟦 30	🟪 31				

June

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⬛ 5	🟥 6	🟨 7	🟨 8	🟫 9	🟩 10	🟩 11
🩷 12	⬛ 13	⬛ 14	🟥 15	🟩 16	17	18
19	20	21	22	23	24	
26	27	28	29	30		

🟨	2,500 cfs (array on)
🟦	4,400 cfs (array on)
🟫	2,500 cfs (array off)
🟪	4,400 cfs (array off)
🟩	1,500 cfs (array on)
🟥	1,000 cfs (array off)
⬛	1,000 cfs (array on)
🩷	1,500 cfs (array off)

Figure 3.1.5-2: Actual 2016 Ultrasound Array Flow Calendar

3.2 Data Analysis

3.2.1 Count Data

Count data from the DIDSON were statistically analyzed with consideration of several factors including flow, treatment (array on/off) and time (hour). A Poisson regression analysis was used to model the count data at the Cabot fishway. A Poisson regression is a generalized linear model form of a standard regression analysis and is used to predict count data as a function of specific parameters or predictors. Count data were broken down hourly (starting at 7:00 am – daily turn on time) and assessed separately.

3.2.2 Telemetry Analysis

The telemetry data analysis relied on the Cox Proportional Hazards and time-to-event analysis as the main statistical procedures to understand the efficiency of the ultrasound array as a behavioral deterrent for American Shad at the Cabot Fishway. This analysis was used to assess delay and explain how the population moves through a telemetered network in time and to determine if the movement rate is a function of the change in system state (i.e., array turned on or off).

3.2.3 False Positive Removal

Radio telemetry receivers record four types of detections based upon their binary nature; true positives, true negatives, false positives and false negatives (Beeman & Perry, 2012). True positives and true negatives are valid data points that indicate the presence or absence of a tagged fish. A false positive is a detection of a fish's presence when it is not there, while a false negative is a non-detection of a fish that is there. False negatives arise from a variety of causes including insufficient detection area, collisions between transmitters, interference from ambient noise or weak signals (Beeman & Perry, 2012)). While the probability of false negatives can be quantified from sample data as the probability of detection, quantifying the rate of false positives (type I error) is more problematic (Beeman & Perry, 2012)). Inclusion of false positives in a dataset can bias study results in two ways: it can favor survivability through a project by including animals that weren't there, or it can increase measures of delay when an animal has already passed. False positives are different from false negatives, which bias statistics in other ways. Inclusion of false negatives may negatively bias statistics because there is no way to know if a fish's absence from a receiver was because it truly wasn't there or if it was just not recaptured. To remove the bias from false positives, they are removed from the dataset prior to analysis as there are no statistical techniques available to remove bias from the estimate. For the purposes of this study, false positive reduction methods relied upon a few metrics, including power floors, reliance on consecutive detections in series, logical errors in site progression and subjective opinion. A probabilistic method for false positive data reduction was sought to reduce the amount of subjectivity in the analysis.

3.2.3.1 Probabilistic Data Reduction – Weight of Evidence

In order to remove and reduce false positives from the dataset, the Bayes Rule was used to provide probabilities of true positives or false positives being correct. Conditional probabilities (probability of a record being true positive), is useful when evaluating false positives and false negatives. By the probability of a hypothesis occurring, the likelihood of data occurring, and how often true or false positives occur a robust dataset can be developed.

3.2.3.2 Naïve Bayes Classifier

An algorithm (Naïve Bayes Classifier) used information from known good detections and known false positives to identify and remove false positives from the dataset. The Naïve Bayes classifier is a database application designed to keep track of which predictor gives evidence to true vs false positive (Richert &

Pedro-Coehlo, 2013). The known true and false positive detections and their associated predictor variables make up a training dataset.

The training dataset consists of known true and false positive detections which were developed by placing study tags at strategic locations throughout the study area for the duration of the study. These tags known as beacon tags give the algorithm information on what a known true positive detection looks like. On the other hand, known false positive detections are generated by the telemetry receivers themselves, and consist of detections coded toward tags that were not present in the list of tags released for the study.

Following the completion of the study, a number of predictor features were calculated for each line of data. Predictor features include a detection history of pulses, the consecutive record hit length, hit ratio, miscode ratio, consecutive detection, detection in series, and power. The pulse detection history is a string of 1's and 0's that looked forwards and backwards in time from the current detection in series, and identifies whether or not a pulse from that particular tag was detected. For example, if a particular tag had a 3 second burst rate, the algorithm will look forwards and backwards in time 3 seconds, query the entire dataset and return 1 if it was detected or 0 if it was not. The algorithm looks forwards and backwards for a user defined set of detection intervals. Consecutive detection length and hit ratio are derived from this detection history. Consecutive detection length simply counts the number of detections in series, while hit ratio is the ratio of the count of heard detections to the length of the detection history string (Table 3.2.3.2-1).

The hit ratio counts the number of correctly assigned detections to the total number of detections within a user defined set of time. The hypothesis behind this predictor stipulates that a detection is more likely to be true when there are less miscoded detections. For consecutive detection to return as true, either the previous or next detection must occur within the next pulse (i.e., 3-second interval).

3.2.4 MS Access Data Management

Quality assurance and quality control (QAQC) procedures were conducted for all telemetry data to check for systematic errors. Type I and II errors were identified, and reasoning included improbable site progression, or the acceptance or rejection of a detection when its supporting data provided overwhelming evidence to suggest that it belonged to another class. For example, this could include accepting a record as true with low power, low hit ratio (< 0.10), high misread ratio, non-consecutive detections and detections not in series.

Following algorithm QAQC, data reduction procedures were carried out with MS Access Query (SQL) methods. If the time stamp of the recapture occurred before the fish was released, then a recapture was deemed false positive. Further, if the calculated hit ratio for a detection was less than 10%, meaning only 1 “heard” detection within a (+/-5) series of detections, the record was deemed as false positive regardless of the posterior probability. Following SQL data reductions, site-specific information was exported and aggregated into a system wide database of recaptured fish. The recapture history of each fish could then be examined through space and time with a three-dimensional visual inspection tool (Figure 3.2.4-1).

These figures identified illegal, improbable, or improper movements between receivers, and allowed the researcher to identify stretches of time in the recaptures database that were indicative of false positive detections. Examples of ‘illegal’ movement include cross chatter, where an individual fish was detected by more than one receiver at the same time due to the large coverage area of the aerial Yagi antennas. The algorithm may identify all of these detections as true positives, making the visual inspection step an invaluable data reduction tool. Once the final false positive detections were identified, data were aggregated into a system wide recaptures database.

With a system wide recaptures database, the next step of the analysis was to identify fish as present at a site. Fish will often mill in front of passage structures or between telemetry receivers. This behavior proves problematic for the assessment of time-to-event because a fish may leave an area only to come back at a later time and finally attempt to pass a structure. In order to perform the time-to-event analysis, the telemetry network was broken down into three regions in relation to the ultrasound array. Receivers within the network were aggregated into (1) Downstream Array (T1, T2, T3-O, T3-L); (2) In Array (T4, T5, T6, T7, P12); and (3) Upstream Array (T8, T10, T9, P13, T14) (Figure 3.1.3-1). These receiver groups were large enough that an algorithm to help attribute a reach to a detection was not needed and as a result this was able to be done manually.

3.2.5 Time-to-Event Analysis

A multi-state model is used to understand situations where a tagged animal transitions from one state to the next (Crowson, *et al.*, 2016). A standard survival curve (Kaplan-Meier) can be thought of as a simple multi-state model with two states (alive and dead) and one transition between those two states Crowson, *et al.*, 2016). For our purposes, these two states are staging and passing. Competing risks generalize the standard survival analysis of a single endpoint (as described above) into an investigation of multiple first event types (Allignol *et al*., 2011). Competing risks are the simplest multi-state model, where events are envisioned as transitions between states (Allignol *et al*., 2011). For competing risks, there is a common initial state for all models (Allignol *et al*., 2011). For example, with the assessment of time to move either upstream or downstream of the ultrasound array, the common initial state is within the array. When fish move upstream or downstream of the array they enter an absorbing state. The baseline hazard is measured with the Nelson-Aalen cause specific cumulative incidence function. One can think of the hazard as the probability of experiencing an event (movement out of the array) within the next time unit conditional on still being in the initial state (Allignol *et al*., 2011). The Nelson-Aalen ($\hat{A}(t)$ is computed with (Allignol *et al*., 2011):

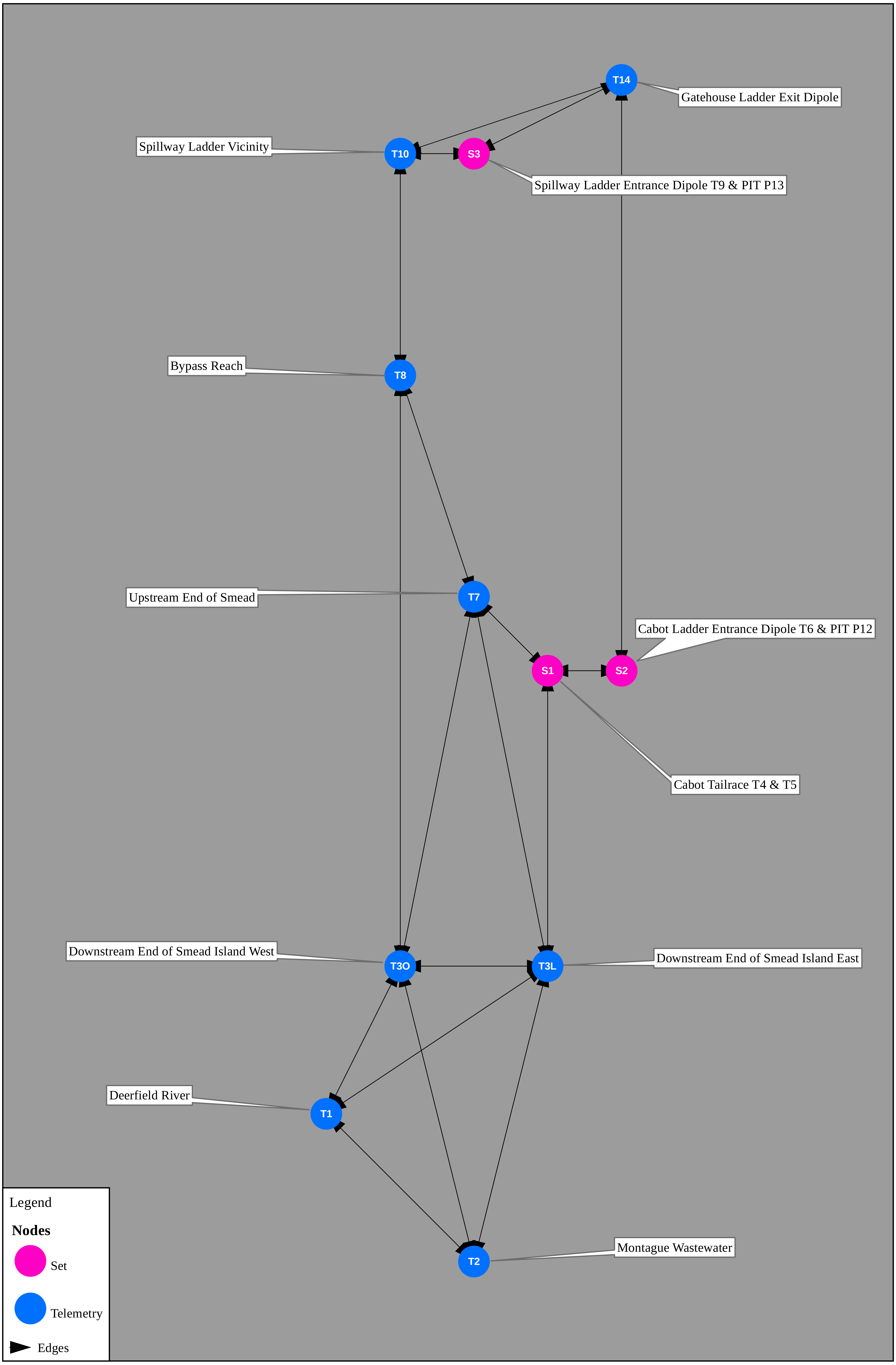
$$\hat{A}(t) = \sum_{k=1}^{K} \frac{number\ of\ individuals\ observed\ to\ transition\ into\ state\ i\ at\ t_k}{number\ of\ individuals\ at\ risk\ just\ prior\ to\ t_k}$$

Where t is a time of interest, K is the number of event times for fish entering state i, and k is an event (duration an animal took to transition from the array into a passing state). This formula is simple, it counts the number of individuals to experience the event of interest (i.e. movement upstream from within the array) at t_k divided by the number of individuals still in the array just prior to t_k. The sum term simply adds the probability across all discrete event times K. Therefore, the end probability is the probability of an animal traversing from the array into an absorbing state i. If we lose track of an animal, it is not censored at its last event time, rather it enters an unknown state. By attributing each tagged animal to a state at all times, we are ensured our final probabilities match empirical expectations. In other words, if 50 out of 100 animals transitioned upstream of the array, and 25 of 100 animals transitioned downstream, and we lost track of 25 animals, the Nelson-Aalen cumulative incidence estimators will result in 50% transitioning upstream of the array, 25% transitioning downstream of the array and 25% within a state-unknown at the final event time. Animals are only censored if they are still being tracked within the array up until the end of study. If we happen to lose track of a fish before the end of the study, they enter an unknown state. After computing the Nelson-Aalen estimators for each route of passage (competing event), and plotting the survival function (Kaplan-Meier) for those fish still remaining in the tailrace, one would generate the probability of being in a state (across all times) while summing to 1.0.

Following the computation of cause-specific Nelson-Aalen estimators, an assessment of delay was carried out with Cox Proportional Hazards regression analysis for each separate event. The Cox models for a competing risk assessment were fit in a procedure analogous to multiple regression modeling, where individual time-dependent covariates were added in an iterative fashion constructing ever more complex models. Model quality was assessed with the omnibus likelihood ratio test statistic, the null hypothesis of which states that the model is not better than chance. If this statistic is rejected at the $\alpha = 0.05$ level, then the model is considered to be better than chance, and we observe the estimated hazard ratio associated with the covariate of interest and its significance. If the covariate is significant at the $\alpha = 0.05$ level, then we conclude that the estimated hazard ratio is significant, and interpret the results. When the hazard ratio is greater than 1, a unit increase in the covariate (i.e., flow) would increase the instantaneous risk (or hazard) of the event occurring and delay is reduced. If for example, the model described attraction towards a ladder with a time varying covariate of flow and the hazard ratio greater than 1.0, then the risk of the event occurring (passage towards the ladder) increases with a unit increase in flow. One would conclude that the population appears to experience less delay as flow is increased. If the hazard ratio is less than 1.0, then the instantaneous risk decreases, and the proportion of fish that have passed into the structure at time (t) decreases, thus delay is incurred. The "best" model minimized Akaike Information Criterion (AIC) scores and/or had a significant omnibus statistic ($p < 0.05$) and informative hazard estimate ($HR \neq 1.0$).

Table 3.2.3.2-1. Example detection histories with their derived consecutive record length and hit ratio predictor feature levels.

Detections in series originating at the present detection (0)							**Consecutive Record Length**	**Hit Ratio**
-3	-2	-1	0	1	2	3		
0	1	0	1	0	1	0	1	3/7
0	0	1	1	1	0	0	3	3/7



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

Relicensing Study 3.3.19

FirstLight Power Resources

N

Figure 3.1.3-1: Telemetry Network

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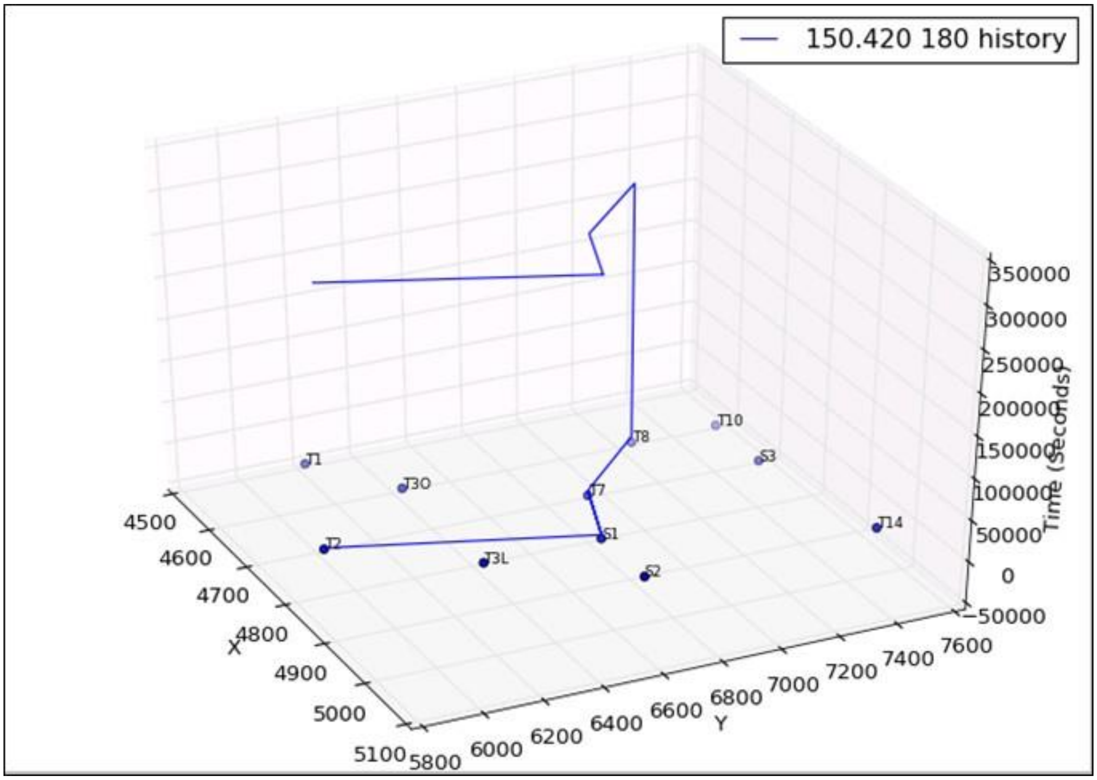

Figure 3.2.4-1: Detection history for shad with frequency 150.420 and code 180 within the study area

Note that this fish was released at Holyoke, was detected at Montague Wastewater (T2) and moved into the Cabot Tailrace (S1 and T7), and moved up to the Bypass Reach (T8) where it stayed for 83 hours. This fish then moved downstream along the same route (through the Cabot Tailrace and back down to Montague Wastewater).

4 RESULTS

4.1 Shad Tagging and Operational Data

FirstLight tagged 118 shad collected at Holyoke Dam and released into the Holyoke impoundment via the Holyoke fish lift exit flume. Tagging and release dates occurred in four batches on May 4, May 10, May 17 and May 24, 2016. The first three batches contained 30 tagged shad each and the last batch contained 28 tagged shad. All shad were tagged with both radio and PIT tags (double tagged).

NAI tagged an additional 193 shad collected at Holyoke Dam and released downstream of the Holyoke Dam at the Jones Ferry landing, Holyoke, MA. The shad were tagged and released in eight batches on May 9, May 11, May 13, May 17, May 18, May 20, May 24 and May 27, 2016. The numbers released are listed in Table 4.1-1.

In total, 311 shad were tagged and released in two locations (upstream and downstream of Holyoke Dam); a summary of all tagging information is located in Table 4.1-1. Males accounted for 49% of the sample size (n=153), whereas females accounted for 51% (n=158). On average, females were larger (total length) than males (Figure 4.1-1). Females ranged in size from 432 mm to 576 mm with an average length of 515 mm. Males ranged in size from 400 mm to 521 mm with an average length of 454 mm.

Figure 4.1-2 depicts the operation (flow) data at Cabot Station, Bypass Flow (as indicated by spill over the TFD) and Station No. 1 throughout the ultrasound study period (May 5 to June 16, 2016). The flow data at Cabot and Station No. 1 were indirectly computed via KWh versus cfs curve for each facility. The flow data spilled at the TFD is based on rating curves. The analysis does not include any measured flow in the Fall River, located just below the TFD, which provides additional flow to the bypass channel.

Table 4.1-1: Summary of American Shad tagged for use in the Ultrasound Study

Date of Collection/Release	Collection Location	Study Team	Release Location	Number of Double Tagged Shad
5/4/2016	Holyoke	KA	Upstream Holyoke	30
5/9/2016	Holyoke	NAI	Downstream Holyoke	24
5/10/2016	Holyoke	KA	Upstream Holyoke	30
5/11/2016	Holyoke	NAI	Downstream Holyoke	24
5/13/2016	Holyoke	NAI	Downstream Holyoke	24
5/17/2016	Holyoke	KA/NAI	Upstream/Downstream Holyoke	30/23
5/18/2016	Holyoke	NAI	Downstream Holyoke	25
5/20/2016	Holyoke	NAI	Downstream Holyoke	24
5/24/2016	Holyoke	KA/NAI	Upstream/Downstream Holyoke	28/25
5/27/2016	Holyoke	NAI	Downstream Holyoke	24
			TOTAL	**311**

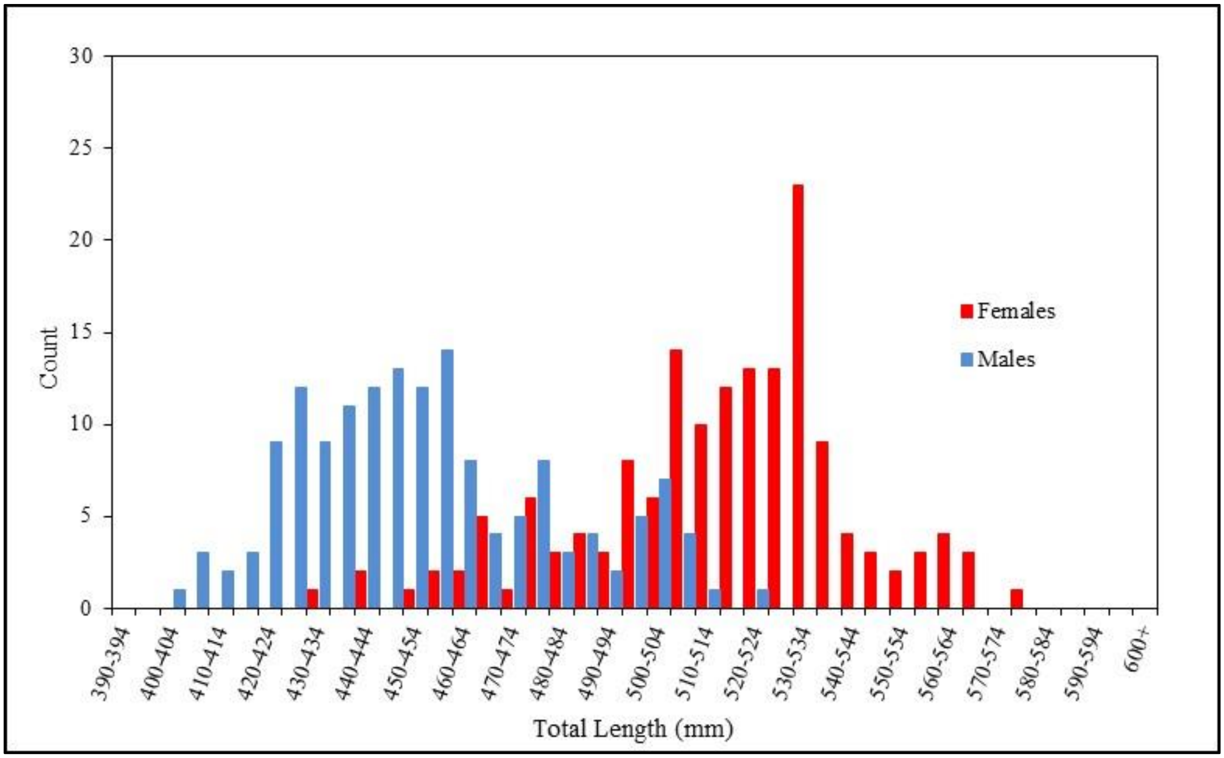

Figure 4.1-1: Length frequency of the 311 shad tagged by FirstLight and NAI

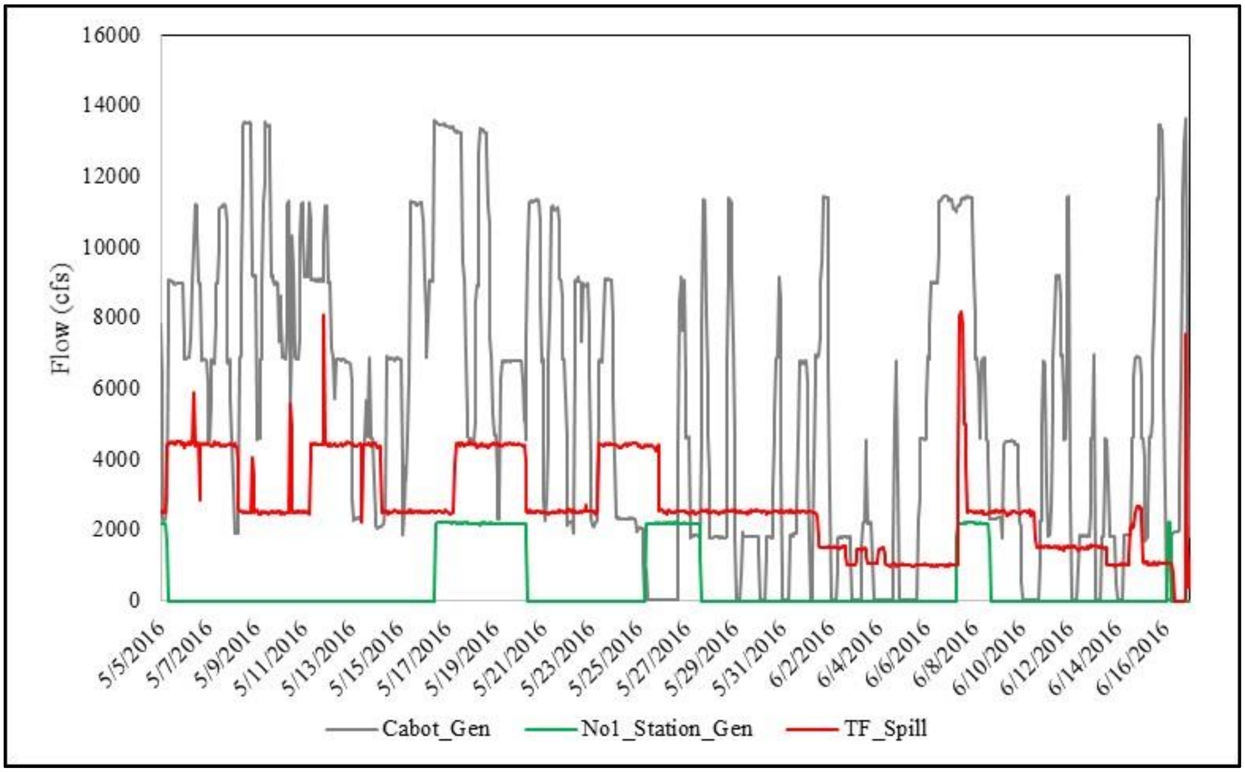

Figure 4.1-2: Operational data from Cabot Station (gray), Station No. 1 (green) and TFD (red) during the ultrasound study period (May 5 to June 16, 2016)

4.2 DIDSON

The DIDSON camera captured data from May 5 to June 16, 2016. The camera did not record data on June 8, 10, 11 and 12, 2016 due to technical difficulties.

The DIDSON camera observed an estimated 22,071 target images of shad in the vicinity of the Cabot fishway entrance from May 5 to June 16, 2016 (Figure 4.2-1). The daily maximum number of observed shad targets (n = 2014) occurred on May 14, 2016 during which the array was on and the test flow through the bypassed reach was approximately 2,500 cfs. Figure 4.2-1 shows three fairly distinct "runs" of shad targets in spring 2016 as recorded by the DIDSON. The three periods can roughly be broken down into the first half of May, the second half of May and after May 26. The overall daily maximum (n = 2,014) occurred in the first "run" on May 14 during an on cycle with 2,500 cfs bypass flow. The daily maximum during the second "run" period (n = 1,712) occurred on May 23 during an on cycle when the bypass flow was 4,400 cfs. The daily maximum during the final "run" period (n = 1,201) occurred on May 28 during an off cycle when the bypass flow was approximately 2,500 cfs (Figure 4.2-1).

Count data (array on/off) was broken down into hourly intervals and plotted against treatment flow in the bypass reach (Figures 4.2-2 through 4.2-5). Within each figure, the "Array On" counts are represented in blue while the "Array Off" counts are represented in red. The fitted lines represent the Poisson regression with the associated standard error in grey. The generalized linear model (glm) summary coefficients with standard error, z-value and associated p-values are displayed in Table 4.2-1 for each hour.

For the hour beginning at 7:00 am (Figure 4.2-2), the interactive effect between flow and treatment (array on/off) is significant ($p < 0.001$) and the relationship is negative (slope = -0.43). Therefore, as flow increases by 1,000 cfs in the Bypass Reach, the number of shad targets in the Cabot Ladder decreases when the ultrasound array is activated for the first hour. When it is not activated, the count of shad targets increase as flow increases. At 8:00 am (Figure 4.2-3), the interactive effect between flow and treatment remains significant (p = 0.001) and the relationship is still negative (slope = -0.21). Therefore, during the hour beginning at 8:00 am, as flow increases by 1,000 cfs in the Bypass Reach, the amount of shad targets in the Cabot Ladder will continue to decrease when the ultrasound array is activated versus when it is not. At 9:00 am-hour (Figure 4.2-4), the interactive effect between flow and treatment is no longer significant (p = 0.13) but the relationship is negative (slope = -0.06). Therefore, at 9:00 am (beginning two hours after system activated), as flow increases by 1,000 cfs in the Bypass Reach, the amount of shad targets in the Cabot Ladder will decrease with the ultrasound array on, however the difference in count is not significant. At 10:00 am (Figure 4.2-At 10:00 am (Figure 4.2-5), the interactive effect between flow and treatment is not significant (p = 0.23), however the relationship remains slightly negative (slope = -0.05). Therefore, for the hour beginning at 10:00 am, as flow increases by 1,000 cfs in the Bypass Reach, the amount of shad targets in the Cabot Ladder will decrease slightly when the ultrasound array is on.

Table 4.2-1: Model summary coefficients for each hour (7 am, 8 am, 9 am, 10 am)

Hour	Coefficients	Estimate	Std. Error	Z value	P value
7:00 am	Intercept	3.36	0.10	35.31	<0.001
	Flow	0.31	0.03	11.28	<0.001
	Treatment On	0.38	0.13	2.89	0.004
	Flow:Treatment On	-0.43	0.04	-10.5	<0.001
8:00 am	Intercept	2.98	0.11	27.33	<0.001
	Flow	0.37	0.03	12.00	<0.001
	Treatment On	0.14	0.14	1.02	0.31
	Flow:Treatment On	-0.21	0.04	-5.01	0.001
9:00 am	Intercept	3.47	0.10	34.51	<0.001
	Flow	0.17	0.03	5.66	<0.001
	Treatment On	-0.23	0.13	-1.70	0.09
	Flow:Treatment On	-0.06	0.04	-1.51	0.13
10:00 am	Intercept	3.49	0.10	33.94	<0.001
	Flow	0.15	0.03	4.80	<0.001
	Treatment On	-0.41	0.14	-2.86	0.004
	Flow:Treatment On	-0.05	0.04	-1.21	0.23

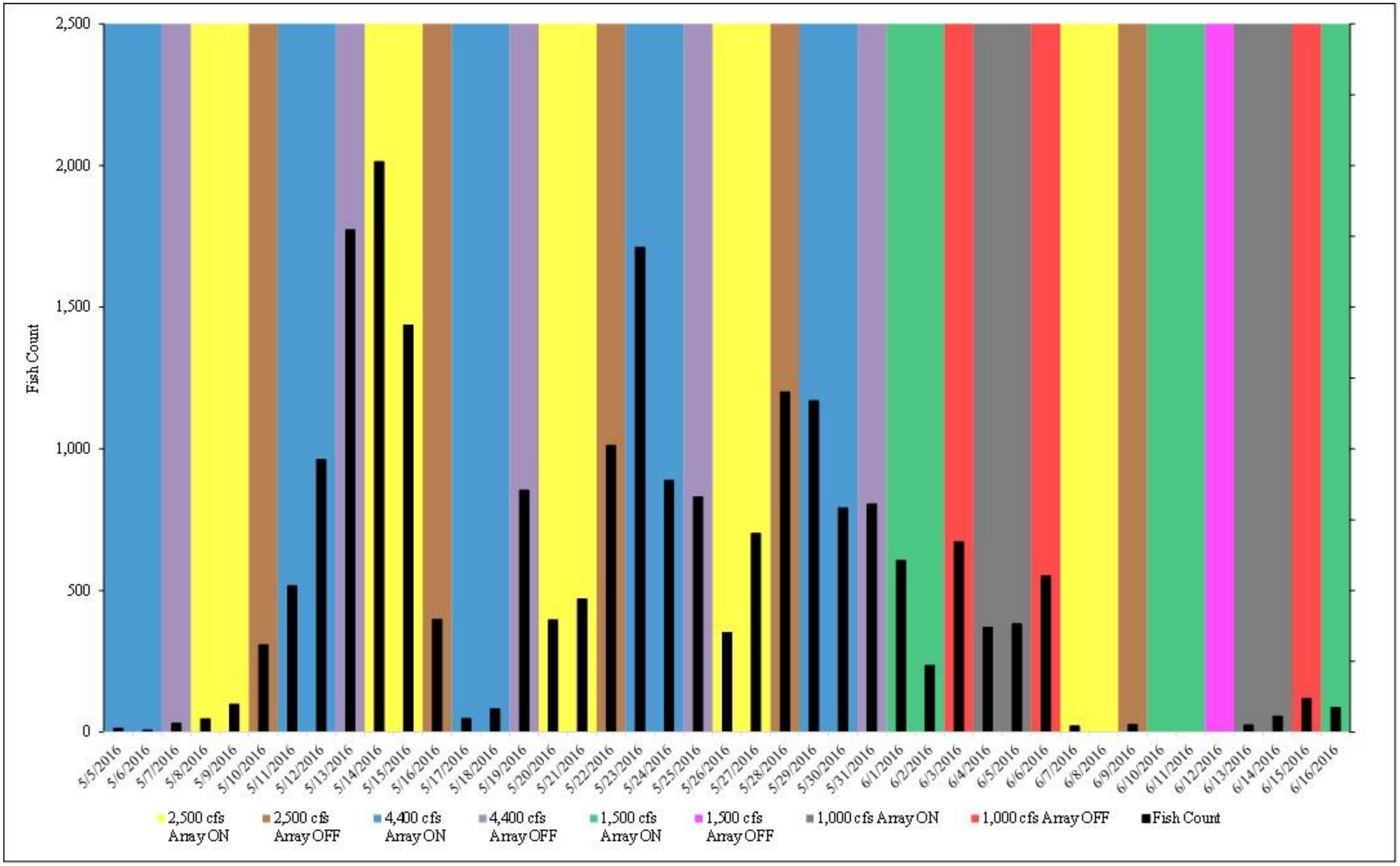

Figure 4.2-1: Raw fish counts from the DIDSON camera data

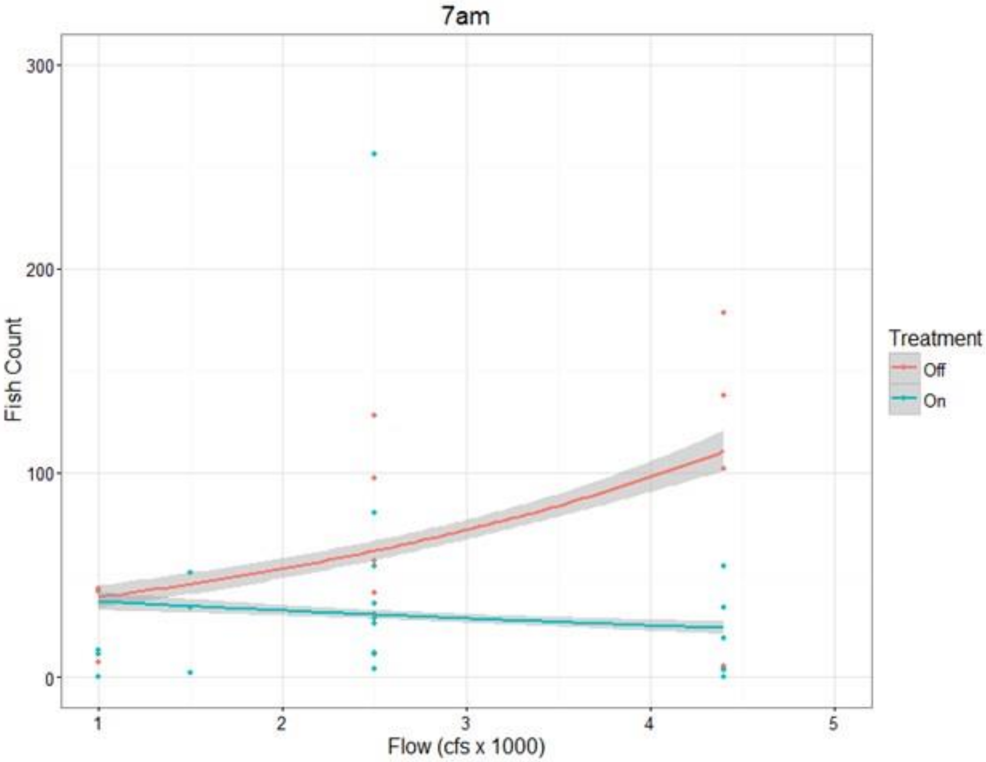

Figure 4.2-2: Ultrasound Counts from 7:00 am including all days of the study period (May 5 to June 16, 2016)

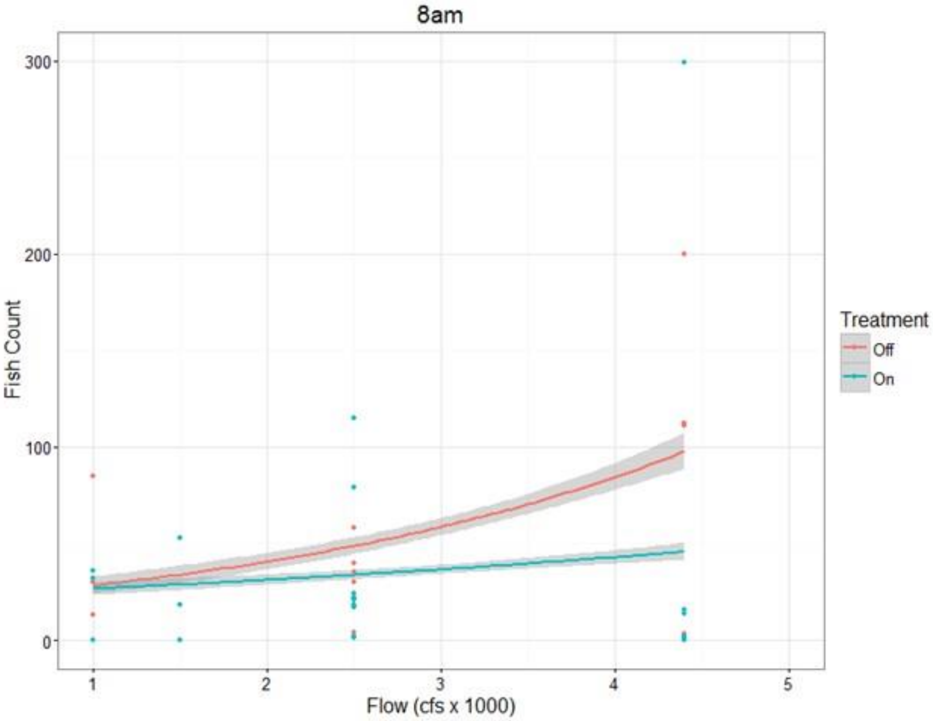

Figure 4.2-3: Ultrasound Counts from 8:00 am including all days of the study period (May 5 to June 16, 2016)

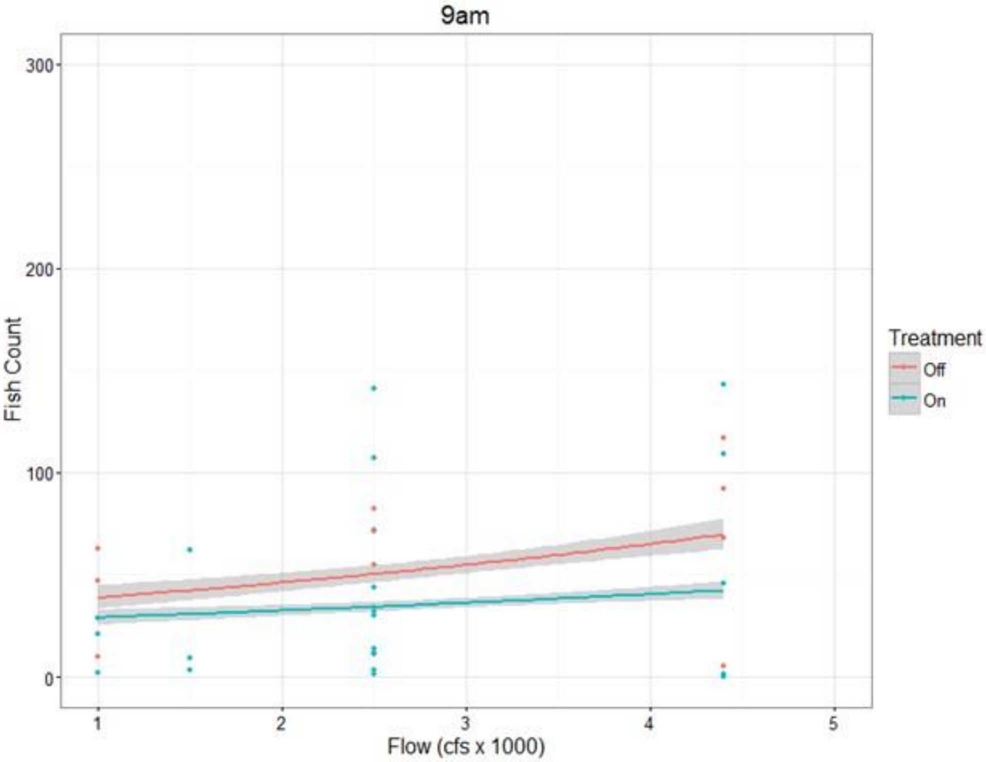

Figure 4.2-4: Ultrasound Counts from 9:00 am including all days of the study period (May 5 to June 16, 2016)

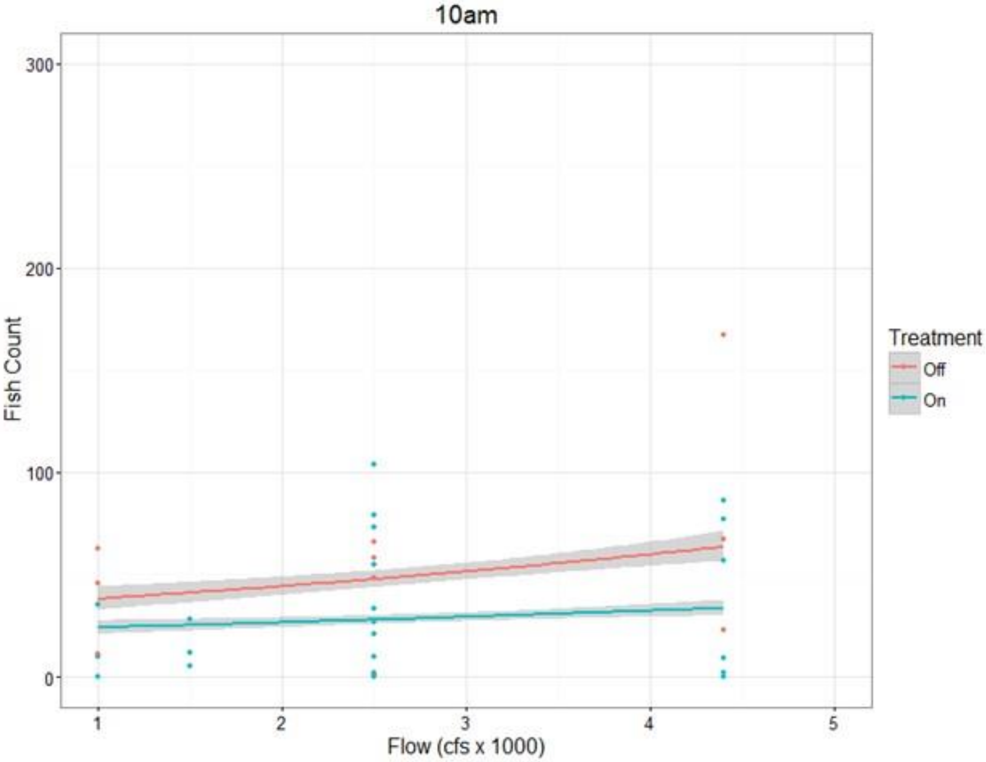

Figure 4.2-5: Ultrasound Counts from 10:00 am including all days of the study period (May 5 to June 16, 2016)

4.3 Cabot Shad Counts

FirstLight records the number of shad passing through the Cabot Fish Ladder annually via manual counting at the viewing window located near the ladder exit. The total number of shad reported to pass into the power canal through the Cabot ladder from May 5 to June 16, 2016 was 33,275 individuals.

As compared to Figure 4.2-1, Figure 4.3-1 also shows three fairly distinct “runs” of shad passing the Cabot Fish ladder. The three periods can roughly be broken down into the first half of May, the second half of May and after May 26. The overall daily maximum (n = 2,823) occurred in the first “run” on May 15 during an on cycle when the Bypass flow was 2,500 cfs. The daily maximum during the second “run” (n = 1,420) occurred on May 21 during an on cycle when the Bypass flow was 2,500 cfs. The daily maximum during the final “run” (n = 2,515) occurred on May 29 during an on cycle when the Bypass flow was 4,400 cfs. While these dates don’t match exactly with the daily maximums identified by the DIDSON data, they all occurred during periods when the ultrasound array was activated. The fact that these daily maximum counts all occurred during 2,200 or 4,400 cfs treatment flow in the bypass reach may be evidence that the system is not effective during higher flow scenarios.

Figure 4.3-2 plots the median daily counts of American Shad at the Cabot Fish Ladder (+/- Std Error) based on data recorded from the viewing window and the DIDSON camera during on and off cycles of the ultrasound array (May 5 to June 16, 2016). When the ultrasound array was activated, the median daily count from the DIDSON camera data was 235 fish. When the ultrasound was deactivated, the median daily count from the DIDSON camera data was 474.5. A Mann-Whitney U test was used to test the null hypothesis that there is no difference in the medians of the two samples, with 95% confidence levels and confidence intervals that assume normal distribution. There was no significant difference between the median counts from the DIDSON data when the ultrasound is on or off (p = 0.26).

When the ultrasound was activated, the median daily count from the Cabot Ladder viewing window data was 551 individuals. When the ultrasound was deactivated, the median daily count from the Cabot Ladder viewing window data was 716 shad (Figure 4.3-2). According to the Mann-Whitney U test, there was no significant difference between the median counts from the Cabot Ladder viewing window when the ultrasound was on or off (p = 0.86).

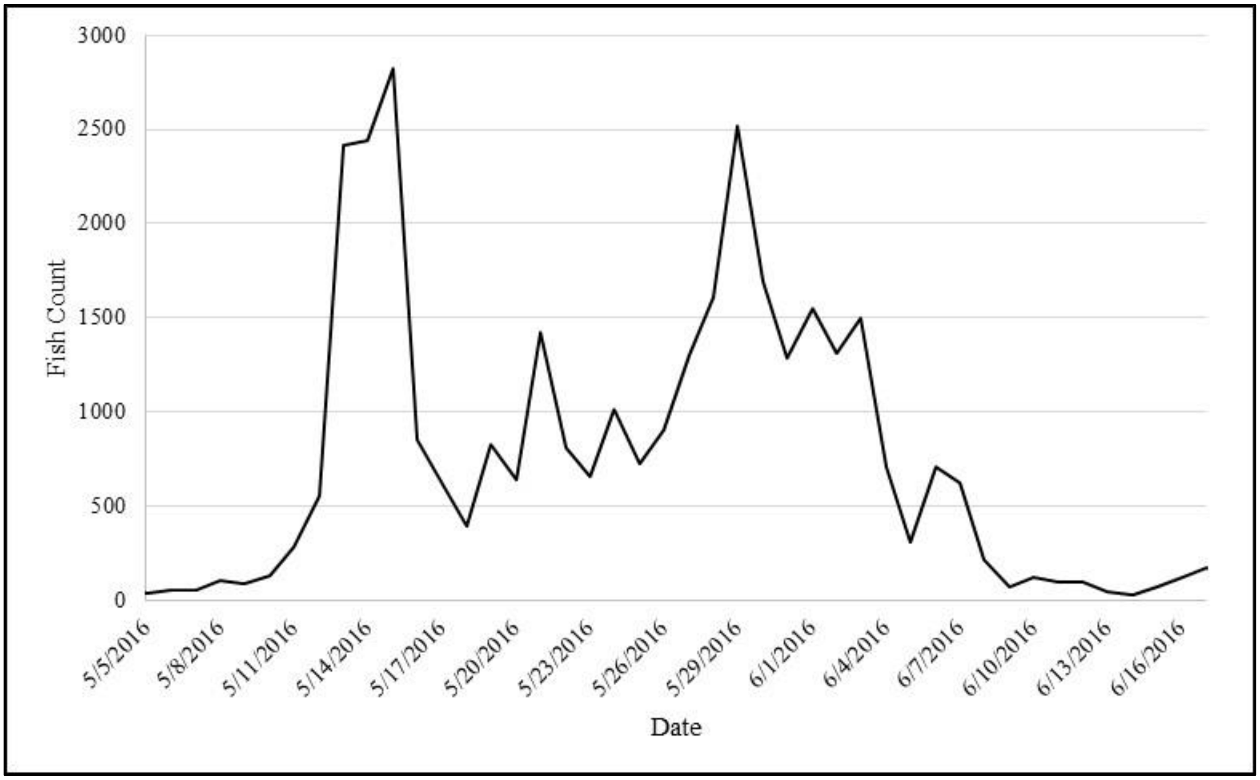

Figure 4.3-1: Cabot Ladder Shad Counts from May 5 to June 16, 2016 based on viewing window data

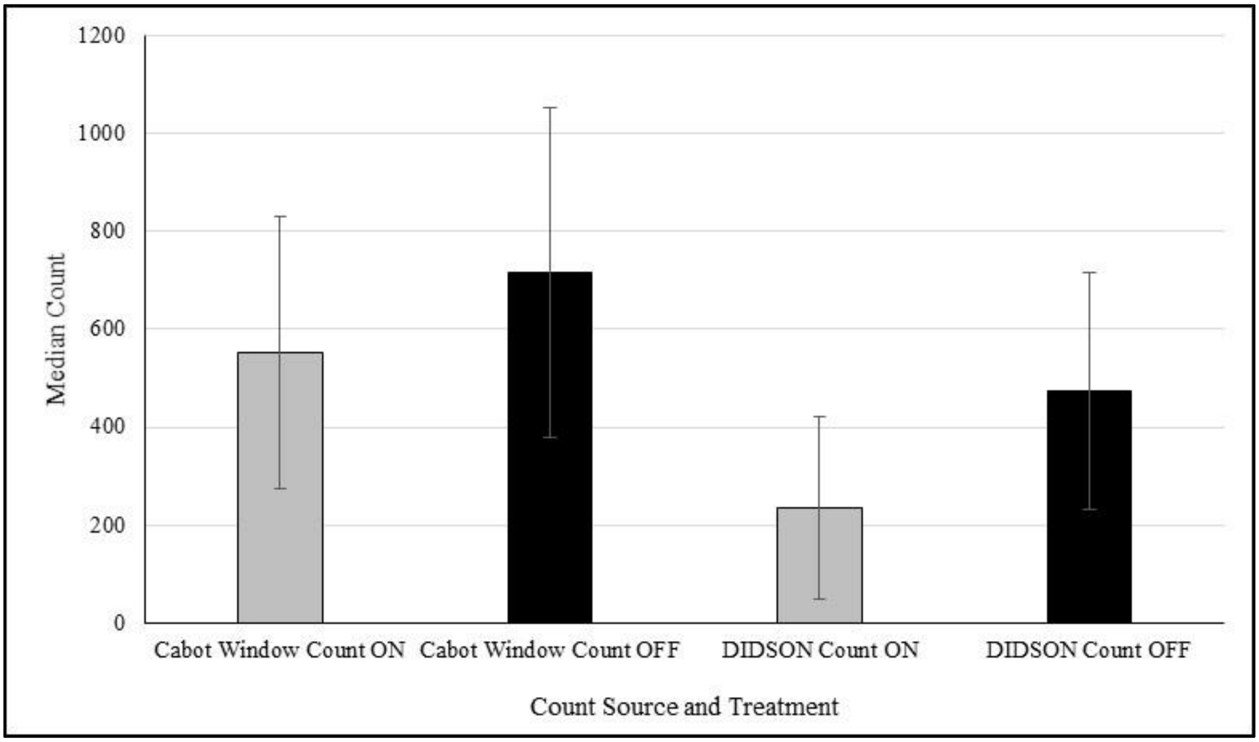

Figure 4.3-2: Median Daily Shad Counts (+/- Std Err) at Cabot Fish Ladder (May 5 to June 16, 2016) from Cabot viewing window and DIDSON camera under Array on/off conditions

4.4 Telemetry Analysis

A complete table of all American Shad tagged and released upstream of Holyoke Dam (n = 118) is located in Appendix C (Table C-1). The fate of each fish is described including fish identification, release date, release location, detection history, date and time of last detection within the telemetry network, fallback time and any additional comments. Also included in Appendix C is Table C-2 describing any fish released downstream of Holyoke Dam (Jones Ferry) that made it to the study telemetry network including all descriptive parameters described above. The most downstream radio telemetry station is the Montague Wastewater Facility (T2), any fish that was detected at T2 is considered to have made it to the network.

4.4.1 Fish Detected in Network

The fish released upstream of Holyoke Dam that were detected in the telemetry network (n = 33), represent approximately 28% of that release cohort. The fish released downstream of Holyoke Dam at Jones Ferry that were detected in the telemetry network (n = 25) represent approximately 13% of that release cohort. In total, 58 fish out of 311 reached the telemetry network (18.6% of all releases). Of the 58 fish that ultimately reached the telemetry network, 12 fish were only detected on the PIT receivers and never detected at the radio telemetry receivers.

4.4.2 Fish not Detected in Network

Of the 118 fish released upstream of the Holyoke Dam, 85 fish (72%) were not detected within the telemetry network. Out of those 85 fish, 54 were recaptured by a monitoring station at Holyoke Dam and 31 were never detected post-release. The time it took those 54 fish from release to recapture at Holyoke Dam ranged from 12 to 809 hours, with a mean fallback time of 366.4 hours (based on detections from NAI database at Holyoke Dam).

4.4.3 Competing Risk: Assessment of Movement from Ultrasound Array

4.4.3.1 Possible State Transitions

Once fish entered the ensonified field within the Cabot Tailrace (In Array), they either moved upstream (Upstream Array) or downstream (Downstream Array). Subsequent detections at the following receivers mean that the fish moved downstream of the array: T1, T2, T3-O, T3-L. Subsequent detections at the following receivers mean that the fish moved upstream of the array: T8, T10, T9, P13, T14. The event time (transition into one of these absorbing states) was taken to be the time of first recapture after transition. Some fish were identified as 'dead' after identifying a mortality pulse with an Orion receiver. The first recapture in the 'dead' state was taken to be the time of death. There were 12 fish that were detected solely at P12 (In Array). However, these fish were never detected at any radio telemetry stations; hence, their transition to any other state could not be computed.

4.4.3.2 Transition Counts by Release Cohort

The majority of fish, once detected in the array chose to transition upstream and into the bypass reach (Table 4.4.3.2-1). Of the 39 viable fish detected in the array from both release cohorts, 29 chose to move upstream (29/39 = 74%). In contrast, only 9 fish from both release cohorts (23%) chose to move downstream after leaving the array.

4.4.3.3 Event Times

Once fish entered the ultrasound array, they quickly transitioned upstream, with the minimum event time occurring 2.74 days after release (Table 4.4.3.3-1). Fish continue to transition upstream from the array throughout the entire study period, with the last upstream event occurring 32.08 days after release. The median event time of a fish transitioning upstream of the array was 9.49 days after release, whereas the median event time of a fish transitioning downstream of the array was 15.14 days after release.

4.4.3.4 Competing Risks –Baseline Hazard and Probability in States

The Kaplan-Meier survival plot (Figure 4.4.3.4-1) shows the last fish to transition out of the ultrasound array did so in approximately 32 days after release. The flat line in the first 2 to 3 days since release indicate the time it takes fish to migrate from Holyoke, transition into the array, and to finally transition outside of the ultrasound array. As depicted in the Nelson-Aalen cumulative incidence plot, the probability that a tagged fish will be in a state at the end of the study (Figure 4.4.3.4-2) matched empirical expectations.

Table 4.4.3.2-1: Transition counts once fish are detected in the Ultrasound Array from both release cohorts

Reach	Upstream Holyoke Release Cohort	Downstream Holyoke Release Cohort	All Cohorts
In Array	24	15	39
Downstream	5	4	9
Upstream	18	11	29
Mortality	1	1	2

Table 4.4.3.3-1: Event times once fish were detected in array

	Time (days)				
Event	**Min**	**25%**	**Median**	**75%**	**Max**
Downstream	5.55	11.31	15.14	24.16	27.94
Upstream	2.74	6.09	9.49	12.87	32.08
Mortality	9.13	10.49	11.85	13.21	14.56

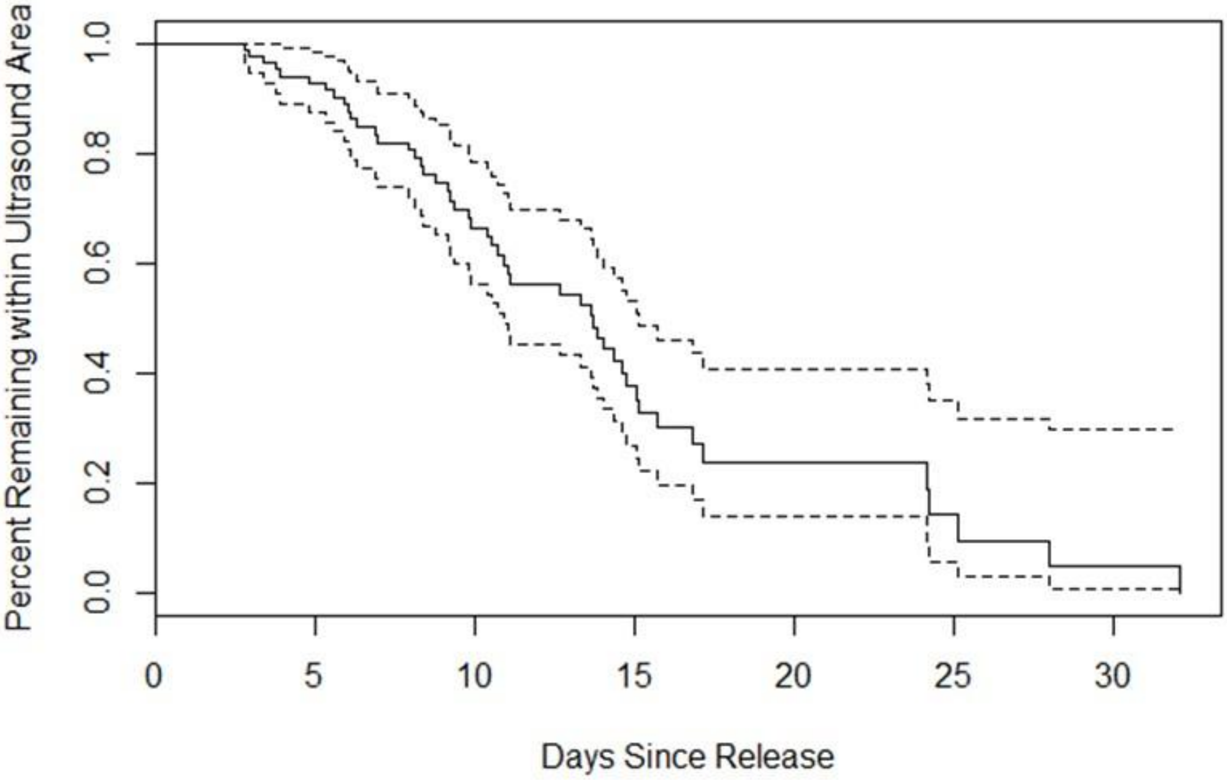

Figure 4.4.3.4-1: Kaplan-Meier plot of percent of fish remaining within the Ultrasound array after release date (days)

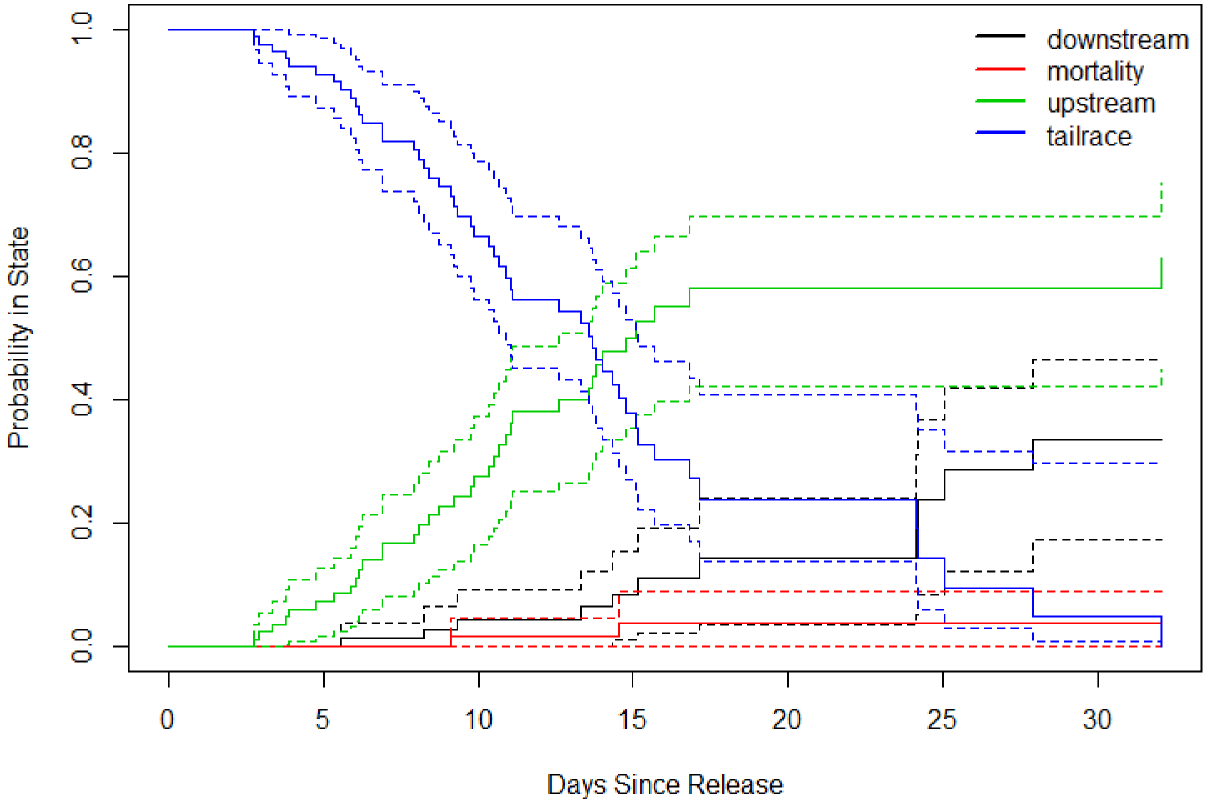

Figure 4.4.3.4-2: Cumulative Incident Probabilities plot of where fish transitioned after being detected in the array (days since release)

4.4.4.1 Movement Upstream from Ultrasound Array

The first event of interest was movement upstream of the array once fish entered the ensonified field. A series of Cox Proportional Hazard regression models were fit and summarized in Table 4.4.4.1-1. The statistic of interest is the hazard ratio, which is the ratio of the hazard rates corresponding to the conditions described by two levels of an explanatory variable (i.e., the array is on or the array is off). Hazards are the instantaneous probability that a tagged fish will experience the event of interest (i.e., upstream movement from the Ultrasound Array) in the next period of time. For example, the first event of interest is movement upstream from the ultrasound array, and the dependent covariate in Model 1 is the Array being on or off. The hazard ratio is the immediate probability of fish transitioning upstream of the ensonified field depending on whether the array is on or off. If the hazard ratio is >1.0, this means the probability of fish transitioning upstream of the array is higher depending on whether the array is turned on or off. In this case, the ultrasound array has no effect on time to upstream movement ($p = 0.58$, $HR = 0.83$).

The best model upstream movement model was Model 3, which had lowest overall AIC of 465.41 and incorporated Bypass Flow. The model was highly significant ($LR < 0.001$). The model indicates that Bypass Flow has a large effect on time to upstream movement. A hazard ratio of 1.46 (1.30, 1.62) indicates that fish are 1.46 times more likely to move upstream as flow in the Bypass Reach increases by 1,000 cfs. Model 1, which incorporated the ultrasound operations, was the worst model in regard to influence on upstream movement out of the array. It appears as though the array has no effect on the probability of movement. It appears fish are motivated by flow (most specifically Bypass flow) when moving upstream and out of the Cabot Tailrace (ensonified area), while the ultrasound array has no effect on the probability that a fish will leave the tailrace and transition into the bypass reach.

4.4.4.2 Movement Downstream from Ultrasound Array

The second event of interest was movement downstream of the array once fish entered the ensonified field. A series of Cox Proportional Hazard regression models were fit and summarized in Table 4.4.4.2-1. Similar to the model outputs describing upstream transitions, movement downstream from the array does not depend on the ultrasound array being on or off, rather it depends on flow. In this case, Model 2 was the best model which incorporated Cabot Station generation (AIC = 143.05). The model is significant ($p = 0.02$) and the hazard ratio is 1.17 (1.03, 1.34) suggesting that as Cabot flow (generation) increases, the probability that a fish will move downstream increases, thus reducing time to downstream movement.

4.4.4.3 Movement within the array from downstream

The last event of interest was movement into the ultrasound array from downstream. A series of Cox Proportional Hazard regression models were fit and summarized in Table 4.4.4.3-1. Once again, the worst model is Model 1 (AIC = 21.84), which incorporates the ultrasound array being turned on or off. The status of the array has no effect ($p = 0.92$) on fish moving into the ensonified area from downstream. No models in this analysis were significant.

Table 4.4.4.1-1: Cox Proportional Hazard Regression models for upstream movement out of the ultrasound array

Model Number	Covariates	AIC	LR Test	Hazard Ratio	SE	P	(+/-)
1	Array on/off	494.95	0.58	0.83	0.35	0.58	(0.42,1.62)
2	Cabot Generation	477.88	0.07	1.07	0.04	0.06	(0.99,1.17)
3	Bypass Flow	465.41	< 0.001	1.46	0.06	< 0.001	(1.30,1.62)
4	Montage Gage Flow	479.92	< 0.001	1.12	0.02	< 0.001	(1.06,1.18)
5	Cabot and Bypass Flow	465.66	< 0.001	1.03	0.005	< 0.001	(1.02,1.04)

Table 4.4.4.2-1: Cox Proportional Hazard Regression model outputs for downstream movement out of the ultrasound array

Model Number	Covariates	AIC	LR Test	Hazard Ratio	SE	P	(+/-)
1	Array on/off	148.18	0.53	0.68	0.61	0.53	(0.21,2.24)
2	Cabot Generation	143.05	0.02	1.17	0.07	0.02	(1.03,1.34)
3	Bypass Flow	148.55	0.87	0.96	0.24	0.87	(0.60,1.53)
4	Montage Gage Flow	145.99	0.11	1.09	0.05	0.09	(0.99,1.21)
5	Cabot and Bypass Flow	147.96	0.52	1.01	0.01	0.47	(0.98,1.04)

Table 4.4.4.3-1: Cox Proportional Hazard Regression model outputs for movement into the ultrasound array from downstream

Model Number	Covariates	AIC	LR Test	Hazard Ratio	SE	P	(+/-)
1	Array on/off	21.84	0.92	1.14	1.24	0.92	(0.10, 12.96)
2	Cabot Generation	20.38	0.27	0.88	0.12	0.27	(0.69, 1.11)
3	Bypass Flow	21.35	0.48	0.73	0.47	0.51	(0.29, 1.84)
4	Montage Gage Flow	18.89	0.08	0.83	0.12	0.13	(0.65, 1.06)
5	Cabot and Bypass Flow	20.11	0.22	0.96	0.04	0.31	(0.90, 1.04)

5 DISCUSSION

In an effort to determine whether an ultrasound array could be used to repel adult shad from the Cabot Station tailrace and guide them into the bypass reach, 311 shad were tagged and released in two locations. The first cohort included 118 shad released in four batches between May 4 and May 24, 2016 just upstream of the Holyoke Dam fish lift. The second cohort included an additional 193 shad released in eight batches between May 9 and May 27, 2016 downstream of Holyoke Dam at Jones Ferry. A series of radio telemetry monitoring stations were setup between the Montague Wastewater Facility and up to the TFD (Figure 3.1.3-1), with stations aggregated into three groups: Downstream Array, In Array and Upstream Array. These groups allowed for analysis of movement through and within areas influenced by the ultrasound field with regard to timing as related to the ultrasound/test flow conditions (Figure 3.1.5-1). To further analyze non-telemetered fish movement in time, a DIDSON camera was setup in the vicinity of the Cabot Station Fish Ladder Entrance. In addition, count data from the Cabot Fish Ladder viewing window were used to determine fish movement through and within the ensonified area.

In total, 58 fish (18.65%) were detected within the telemetry network and 39 fish (12.5%) were detected somewhere within the ultrasound array aggregate. A competing risk analysis was performed to determine where and why these fish moved after they were detected within the array. From the 39 viable fish detected within the array, 29 of them (~74%) chose to move upstream after leaving the array, 9 of them (~23%) chose to move downstream after leaving the array and 1 fish (~3%) died within the tailrace.

To further relate the timing of those transitional events (upstream or downstream movement from the array) to one or more predictors (array status or flow), Cox Proportional Hazard regression models were developed. The analysis of fish moving upstream from within the array concluded that the status of array had no influence on when fish decided to move upstream out of the array ($p = 0.58$). In fact, that model (Model 1 – Table 4.4.4.1-1) was the worst model (i.e., highest AIC score) out of all five upstream models included in the analysis. The fish moving upstream out of the array were most influenced by Bypass flow (Model 3 – Table 4.4.4.1-1) regardless of whether the array was on or off. Similarly, fish that moved downstream out of the ultrasound field were not influenced by the array being on or off (Model 1 – Table 4.4.4.2-1). Rather, the fish moving downstream out of the array were most influenced by Cabot Generation (Model 2 – Table 4.4.4.2-1). A third CPH analysis was performed on fish entering the ultrasound array from downstream. As expected, the array being on or off had no impact on when fish entered the Cabot Tailrace and was the worst model out of the five (Model 1 – Table 4.4.4.3-1). Fish moving into the array from downstream were most influenced by flow as measured at the Montague gage (Model 4 – Table 4.4.4.3-1).

To conclude, the tagged fish moving into the array from downstream seemed to be impacted by total flow at the Montague gage, which represents cumulative flow from the bypass reach, Cabot Station discharge, and the Deerfield River. Those fish that entered the array and moved upstream from there did so because of the bypass flow, and this relationship was highly significant ($p < 0.001$). In other words, bypass flow has an effect on timing of upstream movement from the Cabot Tailrace and the probability of movement is linearly proportional to flow. Fish that entered the array and moved downstream from there did so because of Cabot Station generation, and this relationship was also significant ($p = 0.02$). As Cabot Station generation increases, time to downstream movement decreases.

Count data from the DIDSON camera were used to further analyze the presence of shad within the ultrasound array in time. Reviewing the raw count data in conjunction with the ultrasound and test flow schedule, it appears there is no effect from the ultrasound array on the amount of fish at the Cabot Ladder Entrance (Figure 4.2-1). The median daily count from the DIDSON camera data when the ultrasound array was on was 235 fish and when the ultrasound array was off was about 475 fish. While this seems as though it is a large difference, plotting the standard error (Figure 4.3-2) shows that there is a large amount of overlap between the two counts and when tested with a Mann-Whitney U test, the difference is not statistically significant (p = 0.26). In addition to the DIDSON data, the count data from the Cabot Ladder viewing window were analyzed in the same fashion and revealed similar results. Daily count data show that when the ultrasound array was on, the median daily count was 551 fish as compared to a median count of 716 fish per day when the ultrasound was off. Once again, when these numbers are plotted with their associated standard error (Figure 4.3-2), there is quite a bit of overlap and the difference between the two is not statistically significant (p = 0.86). Therefore, there is no statistical difference in the amount of fish in the vicinity of the Cabot Ladder Entrance when the ultrasound array is on or off.

The DIDSON camera count data was broken down further on an hourly scale to see if there was any possible effect on fish entering the vicinity of the Cabot Fish Ladder from the moment the system was turned on at 7 am. Count data were plotted against treatment flow in the Bypass Reach and fit with a Poisson regression to reveal any significant differences between the array on and the array off counts with respect to Bypass Flow. At 7 am, there is a significant interaction effect (p<0.001) between Bypass flow and treatment (Array on or off). This suggests that from the moment the ultrasound array is turned on at 7 am, there are less fish around the entrance to the Cabot Fish Ladder compared to when the system remains off, and the number of fish will decrease with increasing Bypass Flow (Figure 4.2-2) when the system is on. This significant interaction effect remains true at 8 am (p = 0.001, slope = -0.21), suggesting that as Bypass Flow increases by 1,000 cfs, the number of shad at the Cabot Ladder entrance will decrease when the ultrasound array is on. This relationship is no longer significant during the 9 am and 10 am hours.

These data reveal that there may be an initial effect of the ultrasound array on the number of shad around the Cabot Ladder entrance only for a brief period of time (1 to 2 hours after being turned on). After the first two hours of the system running, fish appear to have no problem swimming through or within the area influenced by the array and there is no significant differences in count data as seen from the DIDSON camera and the Cabot Fish Ladder viewing window data. The fact that there is a significant difference in the number of shad at the Cabot Ladder entrance within the first two hours of the ultrasound being activated may mean that a more frequent activation schedule needs to be followed to keep the fish away from the Cabot fishway. If the system is being turned on, then off and back on again more frequently, it may deter fish from acclimating to the array being activated for long periods of time. The combination of analyses, including telemetered fish, DIDSON camera counts and the Cabot Fish Ladder viewing window counts, reveals that the ultrasound array has potential to be an effective deterrent for fish approaching the Cabot Station Tailrace, but additional testing at shorter intervals is required. Fish seem to be motivated by flow, in the Bypass Reach when moving upstream out of the tailrace, and by Cabot discharge (or generation) when moving downstream from the tailrace.

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APPENDIX A – ALDEN RESEARCH LABORATORY AND SCIENTIFIC SOLUTIONS REPORT

APPENDIX A – ALDEN AND SCIENTIFIC SOLUTION REPORT

Alden Research Laboratory, Inc. (Alden) and Scientific Solutions, Inc. (SSI) were contracted to configure and install an ultrasonic sound deterrent system at Cabot Station as part of a proof-of-concept study designed to repel upstream migrating adult American shad away from the tailrace and the fish ladder entrance located on the north end of the powerhouse. The goal was for repelled fish to continue upstream through the bypass reach to the spillway fish ladder located at the base of the Turners Falls Dam. In addition to configuring and installing the sound system, Alden and SSI also conducted measurements of the sound deterrent field in the Cabot Station tailrace and, prior to installation, SSI conducted modeling of the sound field to optimize the placement of transducers.

Ultrasonic Sound System Hardware Configuration and Signal Generation

The ultrasonic sound system deployed at Cabot Station included a power amplifier, underwater sound projectors (transducers), and a PC-based signal generator. A custom user interface for the operation of the system was developed with National Instruments Labview software. The primary hardware components of the sound system were:

1. Instruments, Inc. Model L6 Power Amplifier
2. National Instruments Model PCI-6713 Analog Output Device
3. International Transducer Corporation Model ITC-3406 Transducers

A schematic of the hardware components is provided on Figure 1. A 150 kHz low pass filter was installed between the PCI-6713 output and the L6 Amplifier input to remove high frequency signal content associated with the digital-to-analog conversion process. A Tektronix TDS-220 digital oscilloscope was used to monitor the voltage and current signals delivered to the transducers by the power amplifier. Attenuated voltage and current monitor signals were available through the L6 amplifier.

The attributes of the test signal/stimulus were defined and implemented by using the signal generation features of National Instruments Labview. A signal waveform was generated by a signal generation virtual instrument (VI) and stored as a Labview waveform file on the local PC hard disk drive. The signal used for the study was a random noise signal band-limited to 122-128 kHz. The pulse duration was set to 0.5 seconds. These signal characteristics are similar to those used for other applications of ultrasonic sound as a means to repel species of the sub-family Alosinae (Gibson and Myers 2002; Gurshin et al. 2015) at hydropower projects. The pulse envelope of the signal was shaped by adding a 10 millisecond "ramp up" and a 10 millisecond "ramp down" at the leading and trailing edges of the pulse. The pulse shaping was done to avoid excitation of the resonant response of the transducer, which can introduce signal harmonics and other unwanted frequency content to the projected signal. A waveform player VI was written to support the testing protocols for the study. The waveform player VI allows the user to specify a waveform, adjust the amplitude of the waveform by specifying a scale factor, specify the repetition rate of the waveform, and specify the total runtime of the test period.

The transducer source level is determined primarily by the following factors:

1. The capability of the transducer
2. The impedance matching and load capacity of the power amplifier
3. The crest factor of the signal

The limitations of the transducers with respect to source level, according to guidance provided by the manufacturer, for a submergence depth of 6 ft and a 50% duty cycle is an applied voltage of 260 Vrms (48.3 dB//Vrms). The L6 power amplifier is limited by its own internal voltage and current limits. Using the proper impedance matching and the voltage and current limits of the L6 power amplifier with five transducers connected in parallel, the operating condition for the ultrasonic deterrent system was selected to maximize the applied voltage level (and correspondingly, the transducer source level) without reaching any of the internal limits of the amplifier. The transducers were being driven at 35.8 dB//Vrms for the five transducer installation. Based on the nominal transmit voltage response (TVR) of the transducers of 140.8 dB//µPa/V @ 1yd (derived from the manufacturers calibration curves) at 125 kHz, transducer source level achieved at the maximum drive level for the sound system with the selected band-limited random noise signal was estimated to be 177.6 dB //µPa at 3 ft.

Sound System Bench Testing and Transducer Drive Levels

Prior to installation at Cabot Station, the sound deterrent system hardware was deployed in Alden's large fish testing flume to bench test the hardware configuration and verify functionality of the system end-to-end. The transducers were connected one at a time to the power amplifier, a signal was applied to the transducers, and the transducer outputs were monitored by a hydrophone located about 12.5 ft away.

With five transducers attached (to match the transducer configuration for the Cabot Station installation), the amplitude of the drive signal (122-128 kHz random noise signal developed for the study) was varied systematically until a peak level was achieved. The peak voltage level had a scale factor of 7 dB while on the 150 V output transformer tap of the power amplifier. The drive signal applied to the input of the L6 Power Amplifier, as captured by a portable data acquisition (DAQ) system is shown in Figure 2. The output voltage of the L6 Power Amplifier (voltage applied to the Transducers) is shown in Figure 3. The L6 power amplifier load current is shown in Figure 4. The root-mean-squared (rms) levels over the 0.5 second pulse duration computed from the measured voltage and current waveforms are 61.75 Vrms (or 35.81 dB//Vrms) and 3.40 Arms (or 10.63 dB//Arms).

Sound Field Modeling

Predictive sound field modeling was used to determine the number of transducers and locations that would optimize the deterrent signal output in the Cabot Station tailrace. The sound system configuration was constrained by the available hardware, which included up to six transducers and a Model L6 Power Amplifier. Predictive modeling, using proprietary Matlab scripts, was used to evaluate multiple configuration arrangements of the transducers with the objective of filling the tailrace area with the most regular sound pressure level possible with the goal of establishing a barrier/perimeter around the area with a sound pressure level threshold of about 145 dB or higher. Additionally, it was considered important to limit the penetration of the sound field into the primary river channel to avoid blocking shad from moving upstream into the bypass reach and towards the spillway fish ladder.

A three dimensional model was developed in which the boundaries of the test area were idealized to constitute a rectangular volume with constant depth, but with varying water levels of low, normal, and maximum. The intersection of the powerhouse wall with the fishway wall at the base elevation of 90.5 ft was established as the origin of the coordinate system for the modeled domain. Each transducer was located in three dimensional space by an x, y, z coordinate and a unit direction vector of n = [i, j, k] that orients the major response axis of the transducer. The ITC transducers are directive (about 30 degree beam width) and resonant at about 120 kHz. The idealized beam pattern of the transducer projector is shown in Figure 5. In each configuration evaluated, the transducers were generally arranged in clusters of two or three transducers each with the aim of the transducer offset by 30 degrees. In this manner, the respective beam patterns of adjacent transducers would overlap each other at the -3 dB (half power) points of the beam patterns and three transducers oriented in this fashion could be used to fill a 90 degree sector with a reasonably uniform sound pressure field. A three dimensional grid mesh of computational points was defined and the sound field was calculated for each cell in the grid mesh.

A pressure release (zero pressure) boundary condition at the water surface and a pressure doubling boundary condition at the river bed were defined. The aggregate sound pressure field of the entire group of transducers was determined as the incoherent sum of the pressure fields predicted for each of the individual transducers. The modeling technique utilized assumes a homogeneous propagation environment with uniform sound velocity and does not include the scattering or dispersion effects of in-homogeneities in the propagation medium. The predictive model is an "ideal" or "best case" solution to the sound field and does not account for site specific conditions of the medium that may affect the propagation of sound, such as entrained air.

Several transducer configurations were evaluated. Practical constraints for mounting transducers and cabling the transducers back to a common power amplifier were considered during the iterative process of refining the installation plan. Modeling showed that the sound pressure contours could be made relatively insensitive to variations in water depth if the transducers were allowed to rise and fall with the water elevation. This resulted in a cluster of three transducers, offset horizontally by 30 degrees each, to fill a 90 degree sector bounded by the powerhouse wall and the fishway wall, and with each transducer angled downward by 15 degrees in the vertical plane. A second cluster containing two transducers was located near the mid-span of the powerhouse in order to extend the region of higher sound pressure level along the full length of the tailrace to provide more uniformity to the sound pressure field throughout the tailrace. Practical considerations precluded the installation of "floating" transducers at the location of the second cluster. Consequently, these transducers were mounted in a fixed position at an elevation of 102 ft with a vertical offset of 15 degrees upwards. The two transducers were aimed horizontally to fill a 60 degree sector (defined by the -3dB points on the transducer beam pattern) with rotations in the horizontal plane of 75 and 45 degrees (clockwise rotation with 0 degrees being parallel to the powerhouse wall looking in the downstream direction).

Figure 6 shows the predicted sound pressure field at mid-water column at "normal" water elevation (118 ft) where the x and y dimensions are in feet and the sound pressure level is in dB//µPa. Figure 7 provides the same result super-imposed on a satellite view of the Cabot Station powerhouse and tailrace.

Hydrophone Survey Methodology

Hydrophone surveys were conducted on April 20 and May 4 in the tailrace of Cabot Station to measure the sound pressure field produced by the ultrasonic deterrent system. Sound pressure levels were recorded using a hydrophone suspended over the side of a boat. A battery powered portable data acquisition system (DAQ) was used to record a digital record of the hydrophone signals. For the majority of the hydrophone measurements, the signals were acquired at a sampling rate of 330 kHz. In order to ensure that at least one complete signal pulse was present within each hydrophone data record, the acquisition time was set to 1600 milliseconds during the first survey and to 2600 milliseconds for the second survey.

Data Reduction Techniques

The hydrophone records acquired during the survey periods were analyzed using proprietary Matlab scripts. The raw hydrophone time series was first squared, after which a sliding analysis window with a time length of 0.5 seconds (to match the duration of the transmitted signal) was used to calculate the root-mean-squared (RMS) signal level of all of the data points within the analysis window. Local peaks in the computed RMS level vs. time were used to locate the leading edge of each transmitted pulse in the data record. The RMS signal peaks were converted from RMS volts to RMS sound pressure level (dB//µPa) by correcting for the EPAC amplifier gain and the gain in the pass band of the band pass filter, and then applying the sensitivity (dB//V/ µPa) of the Reson TC4013 hydrophone.

Hydrophone Survey Measurements

The hydraulic conditions in the survey area in and around the Cabot Station tailrace produced a difficult environment in which to conduct the hydrophone surveys. During the April survey, the measurement platform (jon boat) was drifting with the current (turbine discharge) during the measurement process. A recording GPS was used to track the position of the boat. The operating condition of the survey began with six units operating and the fish ladder and attraction flow on. Subsequent measurements were taken with only the three southernmost units operating and the fish ladder and attraction flow remaining on.

A second hydrophone survey was conducted in May in an attempt to improve the quality of the hydrophone data and to confirm by in-situ measurement that the transducers were indeed operating at the expected source levels. The objectives of the second survey were to acquire measurements at the lowest generating flow rates possible. However, the initial condition for sound field measurements during the May survey was with all six units operating and the fish ladder attraction flow was turned off. Instead of letting the workboat drift with the hydrophone, it was held stationary by tethering off to both the powerhouse wall and the fish ladder wall using two marked tethers. By securing the boat to land, the location of the hydrophone and the distance to the transducers were known with far greater accuracy than during the previous survey. However, with six units operating and the fish ladder attraction flow off, there was a large eddy circulating in a clockwise direction in front of the fish ladder, with water moving along the fish ladder wall towards the fish ladder entrance. Due to the unsteady current, there was some motion to the work boat despite being tethered. During the series of measurements, the boat moved in a range of 2-5 feet in any direction. A series of measurements were also performed with the boat wedged in the corner of the tailrace just outside the fish ladder entrance. For these measurements, the position of the hydrophone is known with more certainty.

The May hydrophone survey was hampered by weather and the inability to have a low turbine discharge on the day scheduled for measurements. The low generation discharge was due to operational considerations at the plant, including a control system fault at the upstream gatehouse where flow into the power canal is controlled. Increasingly threatening weather conditions and uncertainty regarding the ability to achieve a change in flow conditions caused the survey to be suspended with sound measurements recorded at only a single flow condition. The highest SPL measured (data provided in Figure 8) was at a range of 4 to 6 ft from the projector at a depth of 9 ft. The measured sound pressure level at this location was 172 dB//µParms. Applying a range correction of 4.5 dB (average correction for range uncertainty of 4 to 6 ft) would imply a projector source level of ~176.5 dB// µParms at 3 ft. This agrees closely with the predicted source level of 177.6 dB //µPa at 3 ft based on the transducer transmit voltage response and the known applied voltage to the transducer.

Measurements made at a range of at about 35 ft from the transducers indicated sound pressure levels between 140 and 145 dB //µParms were being achieved at this distance. Based on the predictive modeling and the application of spherical spreading laws, the expected sound pressure level at this range from the transducers would be about 155 dB //µParms. The most plausible explanation for the difference between the model predictions and the field measurements is that the sound pressure level was being attenuated more than expected due to air entrainment in the tailrace.

The attributes of the tailrace area that presented the biggest problems for the hydrophone survey during the April survey period are summarized here:

High, fluctuating flow velocity: A sound pressure wave propagating from a transducer array in an unbounded medium can be expected to attenuate with range at a rate of 20*log10(range). Therefore, the amplitude of the received signal at any location within the sound pressure field will be range dependent. In the case of a directive transducer, the amplitude will also be bearing dependent, depending on the orientation of the measurement location to the major response axis of the directive transducer (although the Cabot Station installation was designed to provide overlap of the beam patterns in the horizontal plane, there is still directivity in the vertical plane). In a high flow velocity environment, as a drifting hydrophone moves quickly through the measurement domain, the sound pressure incident on the hydrophone is also rapidly changing. This provides a challenge to setting the system gains to provide sufficient resolution of the signal (not enough gain) while avoiding signal clipping (too much gain). A fast moving measurement platform also provides correspondingly higher uncertainty of the location of the hydrophone for any given measurement. The irregular velocity field in the tailrace resulted in erratic and unpredictable motions of the measurement platform (jon boat). In many situations the engine had to be used to maneuver the boat to maintain safety. The hydrophone and hydrophone depression weight were not typically in the same current (direction or strength) as the boat on the surface and, as a result, the hydrophone would not hang straight down over the side and relative velocity and turbulence would cause vibratory motion of the hydrophone cable and suspension system.

Steep slope at boundary of tailrace to very shallow water: When the hydrophone was deployed near the fish ladder entrance to begin a measurement traverse, the flow was at a velocity that resulted in the jon boat being displaced from the tailrace area into the shallow water further out in the river in the time it took to trigger and complete an acquisition. With hydrophone depth set to survey the mid-water column in the tailrace (or even at shallower depths), the hydrophone would very quickly become grounded as it was dragged over the upslope of the riverbed at the edges of the tailrace. The flow velocities were too high for acquiring quality data for measurement traverses that started with the boat in the fish ladder discharge. Slightly better results were achieved when drifting outside of the main flow of the fish ladder discharge and attraction flow, where the flow direction had a greater downstream direction component.

Geo-location uncertainty: The accuracy of the recording GPS was insufficient to provide useful information for the location of the measurement hydrophone relative to the source transducer mounting location. A contributing factor is the shadowing effect of the powerhouse itself, with the jon boat in close to the powerhouse much of the sky is obstructed, reducing the accuracy of the GPS.

Despite the measurement difficulties and the high uncertainty with locating measurement points within the survey area, the sound pressure levels measured during the first survey indicated that the amplitude of the sound field was significantly lower than that predicted by the sound field model. The highest sound pressure levels measured for the full flow condition (six turbines generating) was 129 dB//µParms with most measurements being significantly lower (~85 – 110 dB//µParms). The measured sound pressure level with only three units generating were generally higher and more uniform with greater density of higher level records in the region closer to the fish ladder entrance. The highest measured sound pressure level in this operating condition was 154 dB//µParms with a large number of measurement points with sound pressure levels greater than 120 dB//µParms. The data also showed a trend towards increasing sound pressure level with depth. The region in front of the three operating units (southernmost) showed very low signal levels, similar to that seen when all six units had been operating.

Conclusions of Hydrophone Survey

Based on the available data from the two hydrophone surveys and direct observations of the nature of the flow conditions in the Cabot Station tailrace when sound measurements were recorded, the following conclusions were made regarding the transmitted sound field:

1. The transducer source level was about 177 dB// µParms at 3 ft.
2. The sound field was heavily attenuated due to air entrainment throughout the tailrace, with the source of air coming from both the turbine discharge and the fish ladder attraction flow.
3. Higher transducer source levels may have been achievable with the same transducer design with additional power amplification capacity (up to a limit of about 189 dB// µParms at 3 ft). With a higher source level, the measured sound field would also scale up accordingly (dB for dB sound

pressure increase as source level is increased). However, the sound pressure would still attenuate at a higher rate than expected due to the high level of air entrainment.

4. Higher sound pressure levels could be achieved throughout the tailrace if air entrainment were reduced significantly.

5. The impracticality of reducing air entrainment (shutting off attraction flow and/or eliminating air entrainment from the turbine discharge) suggests that a region of sufficiently high SPL throughout the tailrace could only be achieved by adding additional rows of transducers out towards the centerline of the river outside of the high air entrainment region and with sufficient power amplification to achieve the maximum source level possible, as constrained by the transducer drive limitations.

Literature Cited

Gibson, A. J. F., and R. A. Myers. 2002. Effectiveness of a High-Frequency-Sound Fish Diversion System at the Annapolis Tidal Hydroelectric Generating Station, Nova Scotia. North American Journal of Fisheries Management 22:770-784.

Gurshin, C. W., M. P. Balge, M. M. Taylor, and B. E. Lenz. 2015. Importance of Ultrasonic Field Direction for Guiding Juvenile Blueback Herring Past Hydroelectric Turbines. North American Journal of Fisheries Management 34: 1242-1258.

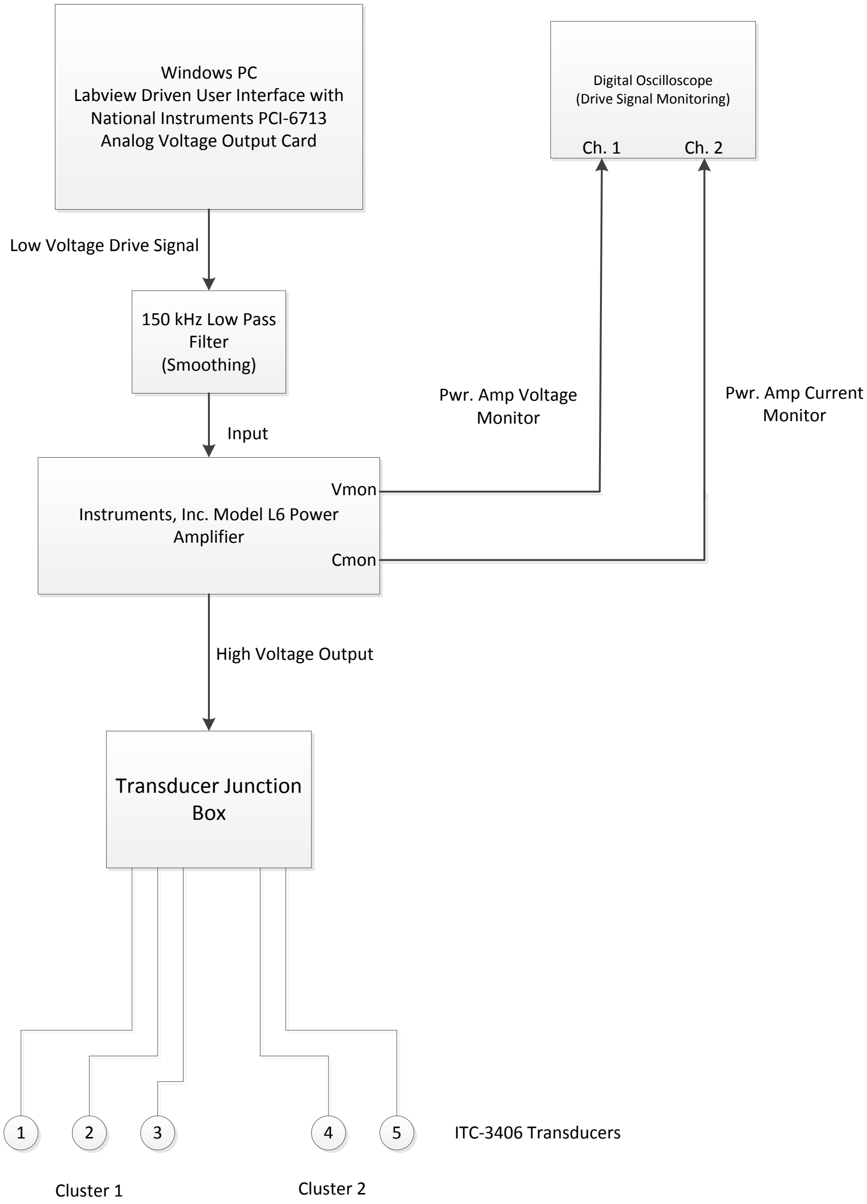

Figure 1 – High Frequency Sound System Schematic

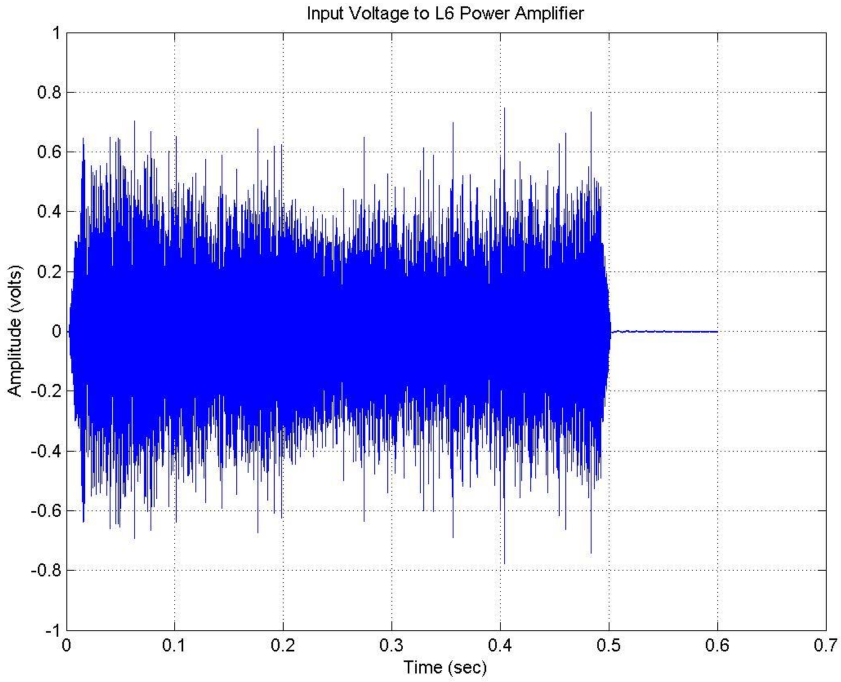

Figure 2 – Voltage Waveform Applied to Power Amplifier Input

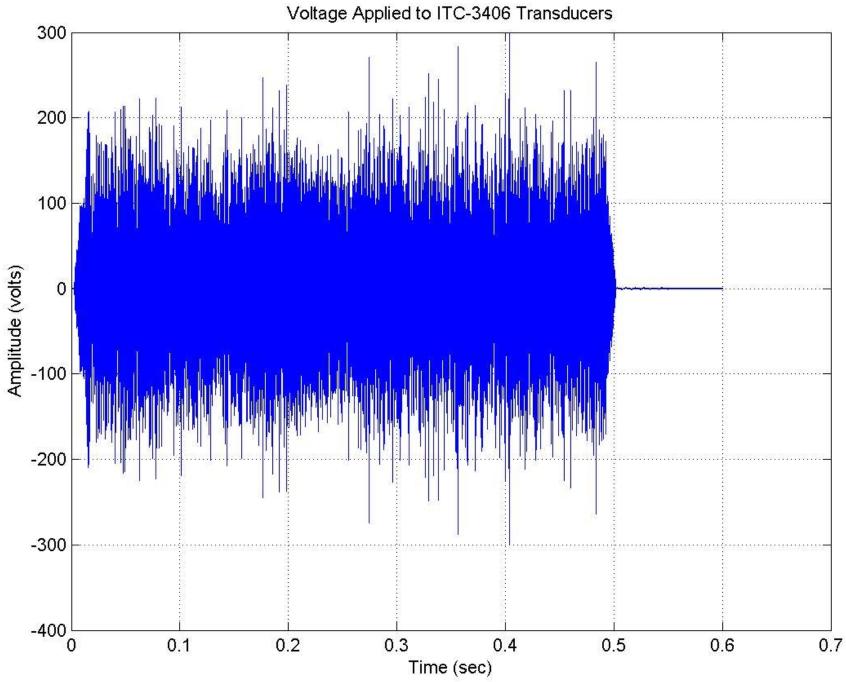

Figure 3 – Voltage Waveform Applied to ITC-3406 Transducers

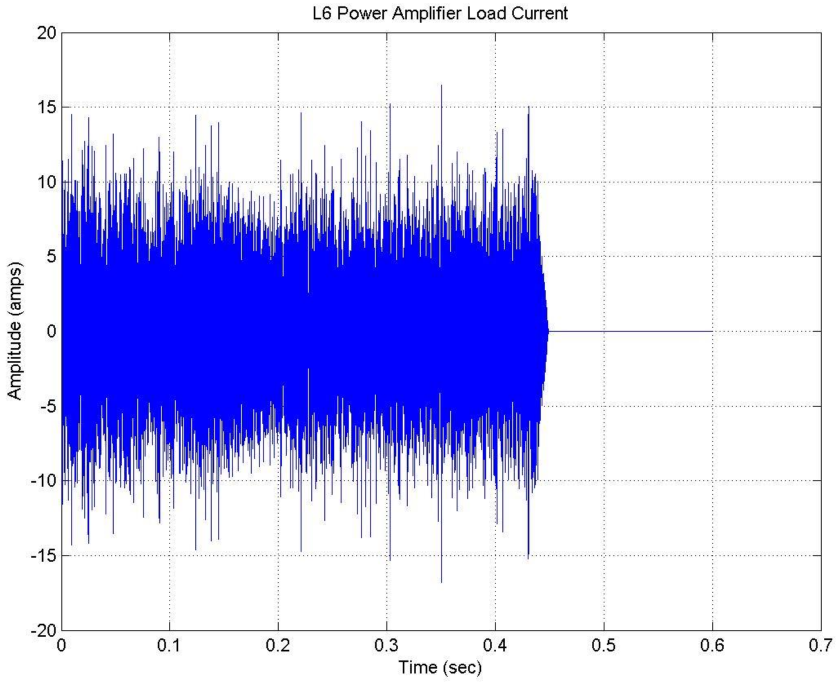

Figure 4 – L6 Power Amplifier Load Current

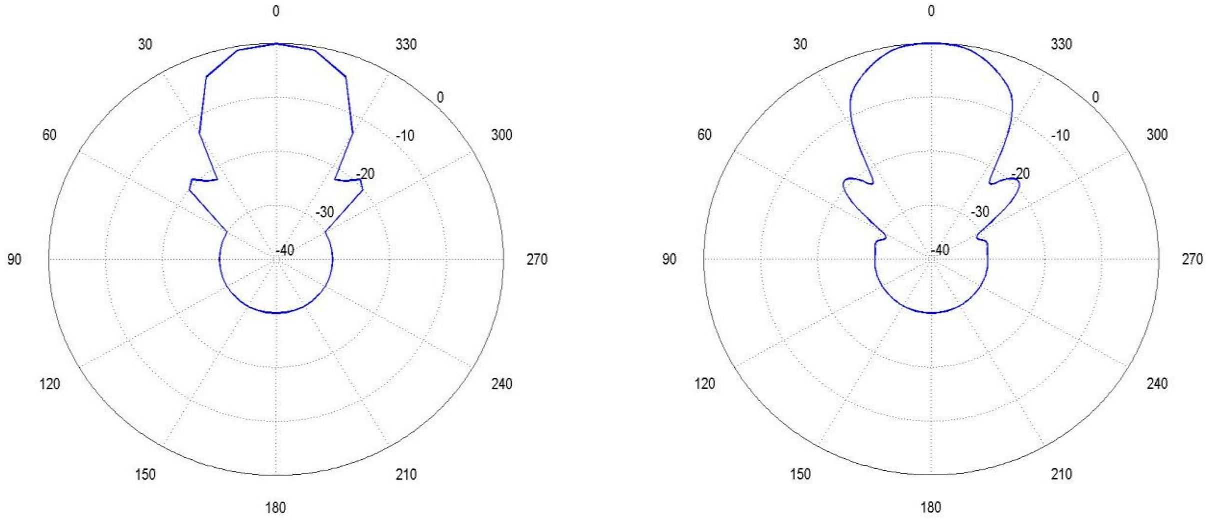

Figure 5 – Directivity Pattern of ITC-3406 Transducer. Left side is input beam pattern; right side is interpolated beam pattern.

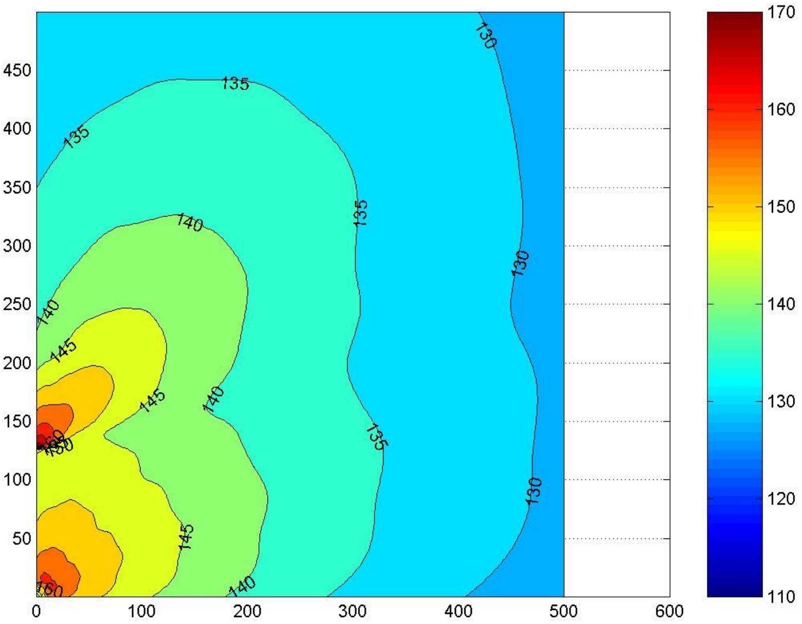

Figure 6 – Predicted sound pressure level contours on a horizontal plane at mid-water column at "normal" water elevation (118 ft) for a 5 transducer arrangement. The predictive modeled used a source level of 178 dB//µPa at 3 ft and a configuration with three transducers clustered at the fish ladder entrance and two clustered near the mid-span of the powerhouse wall.

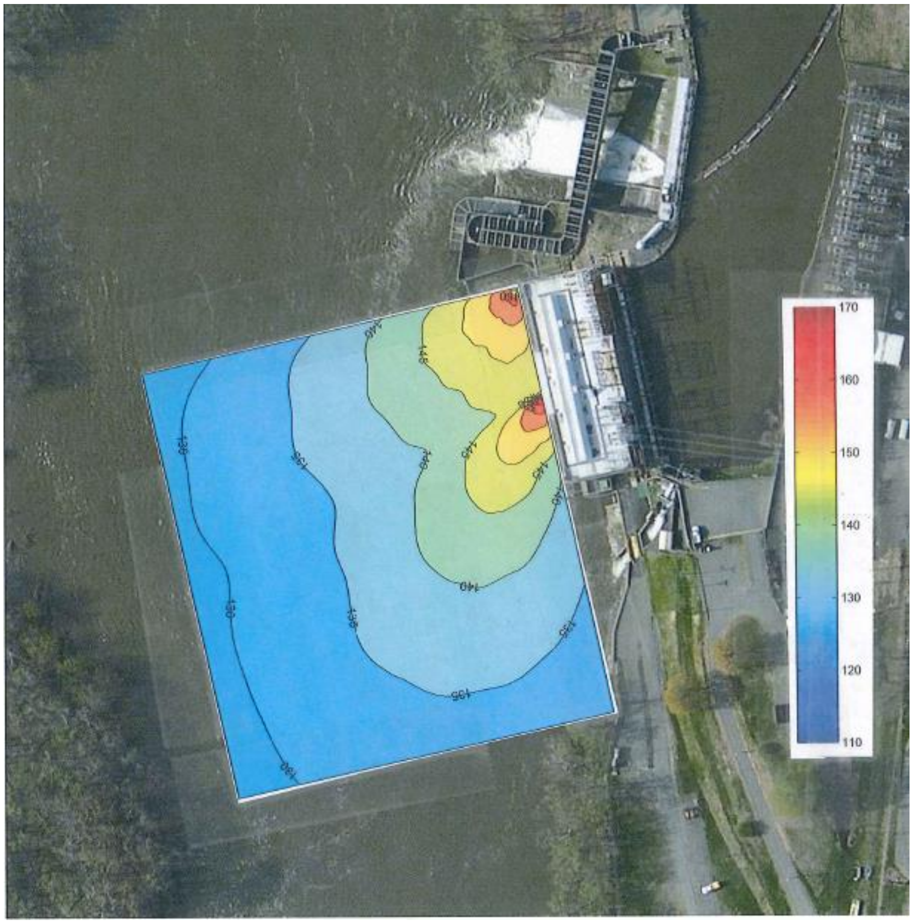

Figure 7 – Predicted Sound Pressure Level Contours super-imposed on a plan view of the Cabot Station tailrace.

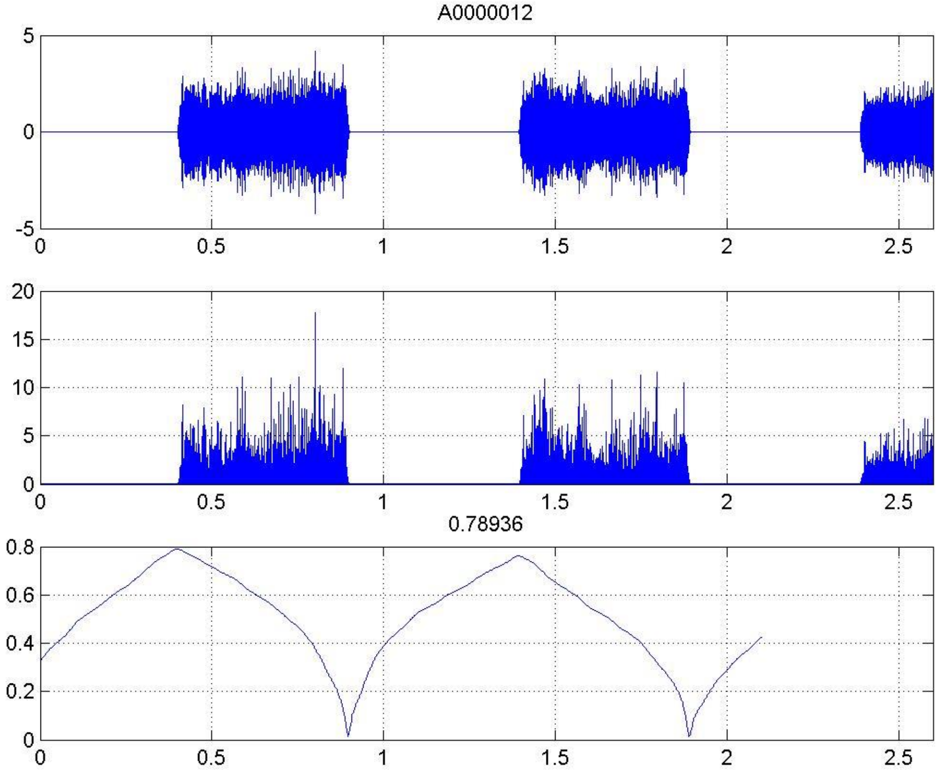

Figure 8 – Hydrophone measurement at 4 to 6 ft range from source projector at depth of 9 ft (recorded on May 4).

APPENDIX B – TELEMETRY STATION CALIBRATION RESULTS

APPENDIX B: Telemetry Network Calibration and Equipment Effectiveness

PIT Station Calibration

Each PIT antenna was tested by attaching an Oregon RFID auto Tuner to the antenna and plugging an RTS Tuning Indicator/Sender into the reader. Using the corresponding inductance (Range = 24 to 102 µH) of the antenna wires, a proper jumper setting listed in the jumper chart provided by Oregon RFID was used within each tuner box. The ATC auto tuner was then adjusted to fine tune the reader until a green OK LED remained on for multiple seconds indicating the reader is in tune and the tuning indicator can be removed. If the reader is ever turned off, the tuning settings are automatically saved in the flash memory. Once the tuning indicator was unplugged, a test tag was used to test the upstream and downstream read range of each antenna. Every PIT reader and antenna went through this procedure and the manual was followed precisely to get the best performance out of each location. Many of the antennas were located in areas of high noise making it difficult to obtain an adequate tune or calibration. The tag used for testing was not used when tagging any adult shad. A summary of each antenna and the corresponding read ranges and any comments is provided in Table 1.

Table 1: Summary of each PIT antenna location and the read range obtained during testing

Station	Location	Read Range (ft)	Comments
P12	Cabot Ladder Entrance	1 to 2	Tested Strong
P13	Spillway Ladder Entrance	1 to 2	Tested Strong – some non-detectable areas in the middle of antenna

Radio Telemetry Calibration:

Each telemetry station was tested with a Radio Tag prior to any Shad being release to ensure adequate power readings, range and proper calibration of equipment. Field staff turned on and coded one tag to be used as a '*test tag*' during the calibration period and did not use the same frequency and/or code during the study. A radio tag was attached to fishing line and tested at a water depth of approximately 4 to 5 ft to mimic the swimming depth of adult American Shad. One member of the field crew remained on land monitoring the receiver output signals and two field staff used a boat to test the targeted detection zone at each telemetry station. Communication via handheld two-way-radios allowed transfer of power signals at different locations that were recorded for calibration purposes.

A list of the receivers used for this study is provided in Table 3.1.3-1 of the main report. Orion receivers output an average power number for each contact, which is recorded in decibel levels (db). These numbers are negative, with less negative numbers being higher in signal strength. Lotek receivers output an average power number for each contact, which is also recorded in decibel levels (db). These numbers are positive, with high numbers signifying a stronger signal.

All station figures listed below show the position of the 'test tag' and the average power levels associated within the detection zones recorded during testing (noted in white). Several test detections were recorded at each location.

<u>Station</u>: Entrance to the Deerfield River

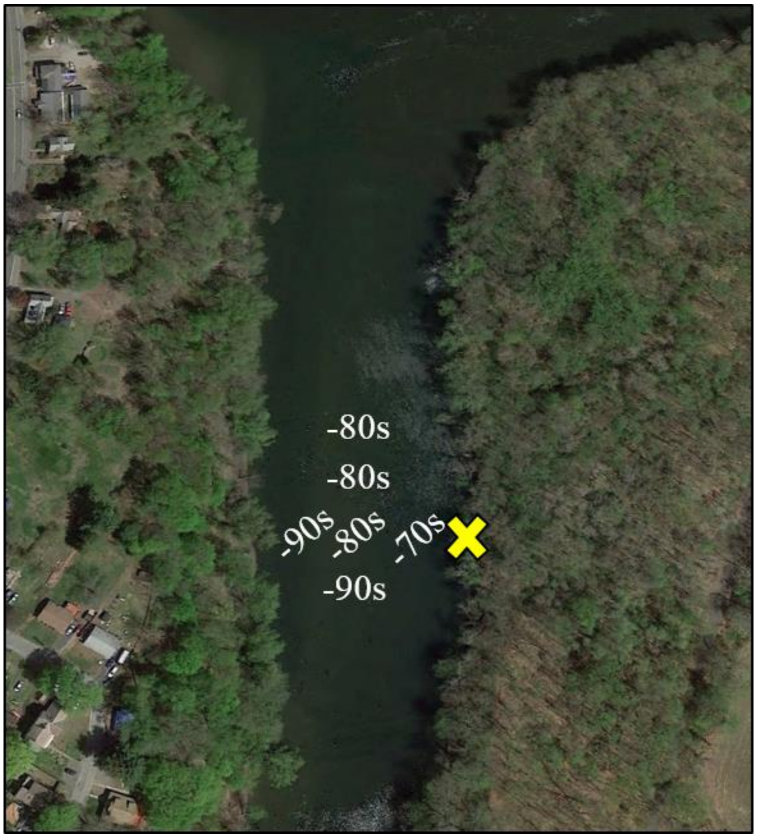

Figure 1: The large X marks the approximate location of the Yagi antenna and the Orion receiver used to detected fish moving across the width of the Deerfield River at River Mile 119.5. The radio test tag produced power levels ranging from -70s to -90s bd with highest powers located near the bank and attenuating slightly toward the far bank of the river.

Station: Montague Wastewater

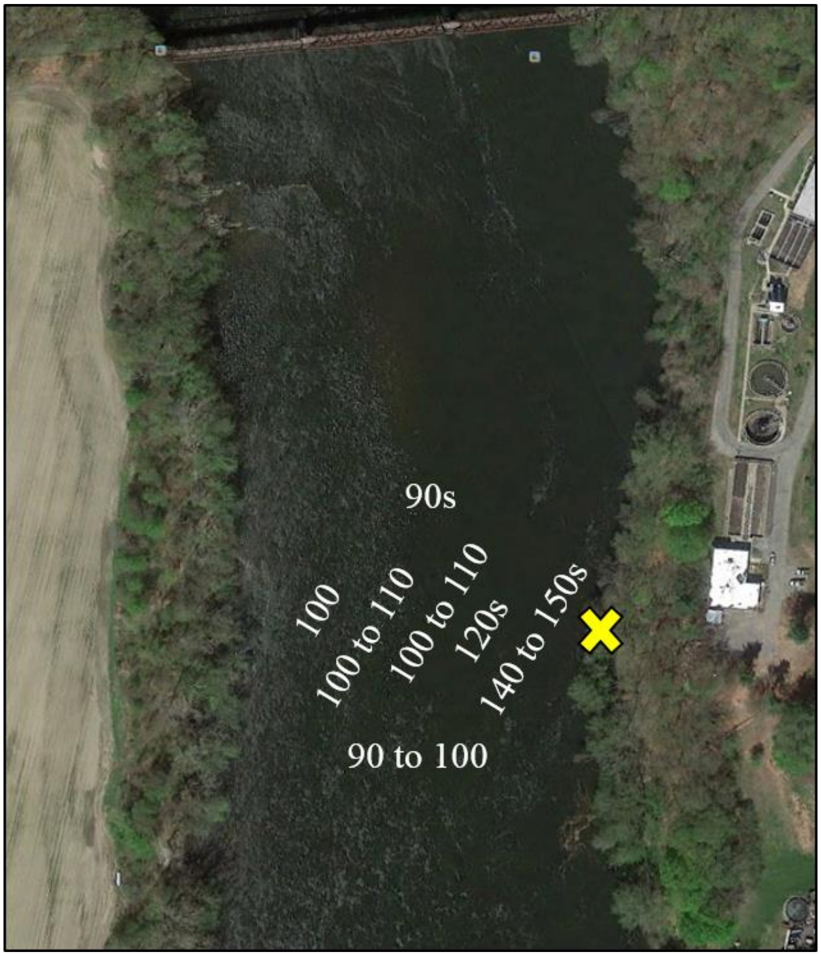

Figure 2: The large yellow X marks the approximate placement of the yagi antenna and the Lotek receiver used to detect fish moving across the width of the river at River Mile 119.5. The radio test tag produced power levels ranging from 90s to 150 db with highest powers located near the bank of the river closest to the yagi antenna and attenuating slightly toward the far bank.

Station: Downstream Smead Island East Channel

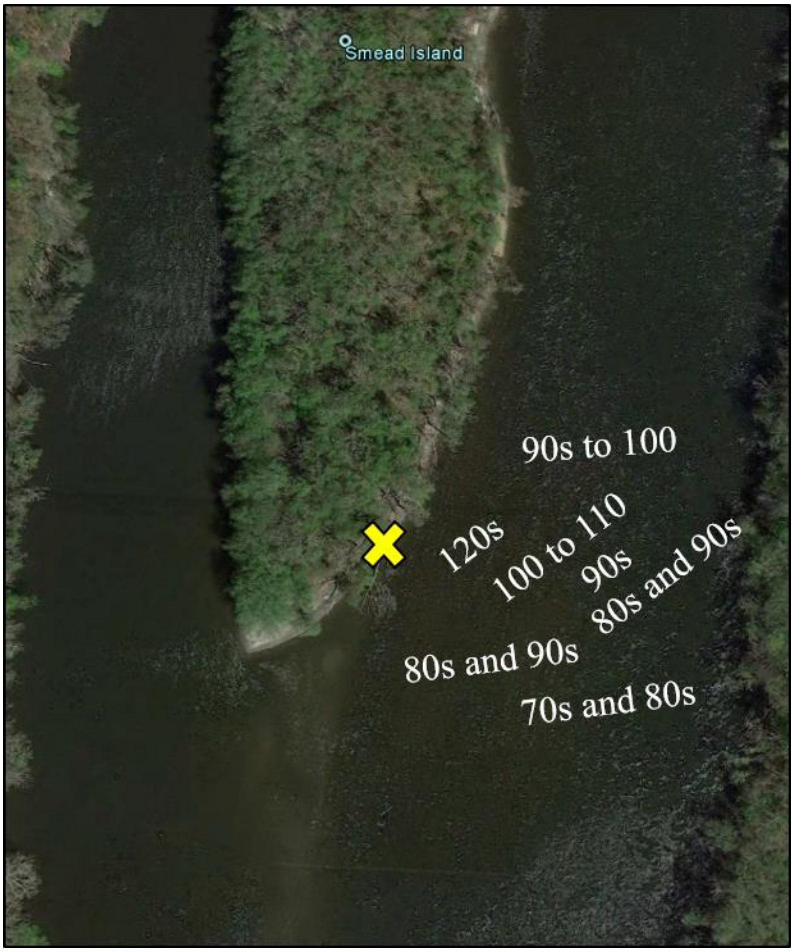

Figure 3: The large yellow X marks the approximate placement of the yagi antenna and the Lotek receiver used to detect fish moving across the width of the river at River Mile 120. The radio test tag produced power levels ranging from 70s to 120 db with highest powers located near the bank of the river on the East channel of Smead Island closest to the yagi antenna and attenuating slightly toward the far bank.

<u>Station</u>: Downstream Smead Island West Channel

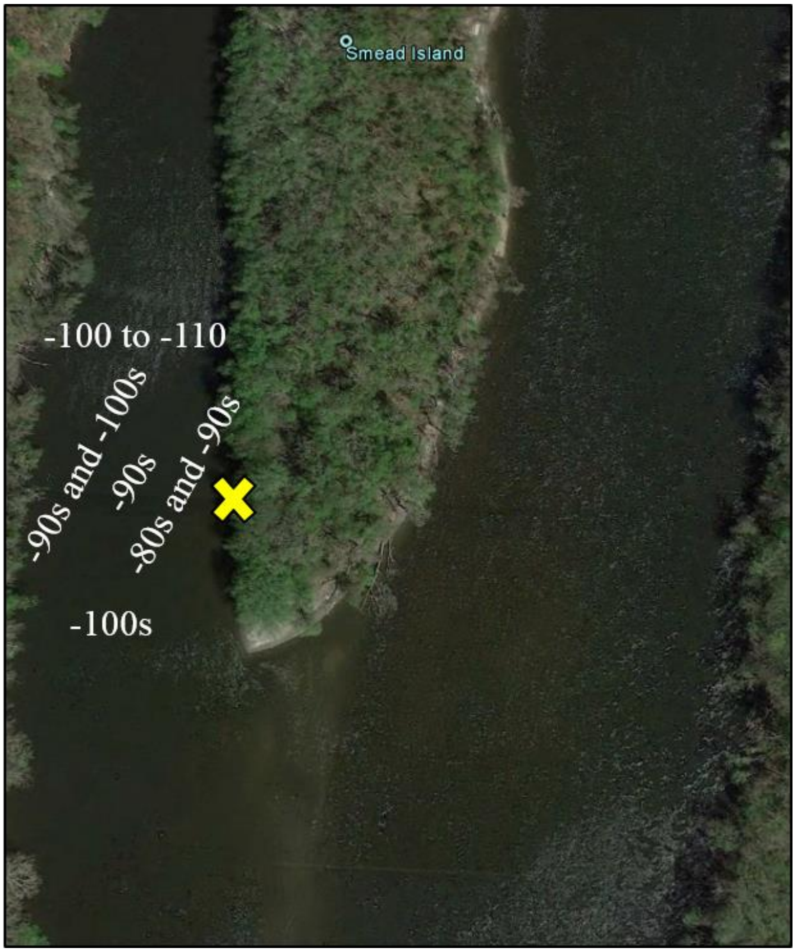

Figure 4: The large yellow X marks the approximate placement of the yagi antenna and the Orion receiver used to detect fish moving across the width of the river at River Mile 120. The radio test tag produced power levels ranging from -80s to -110 db with highest powers located near the bank of the river on the West channel of Smead Island closest to the yagi antenna and attenuating slightly toward the far bank.

Station: Cabot Tailrace Downstream

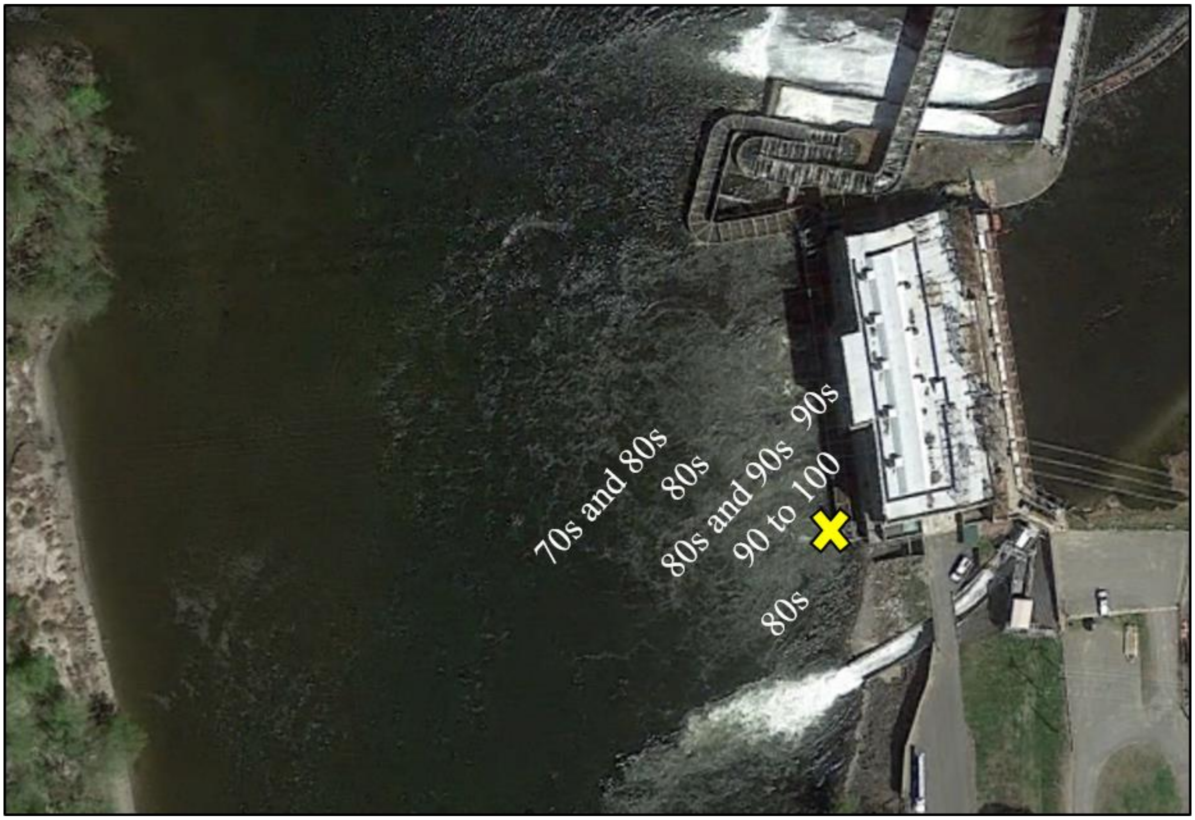

Figure 5: The large yellow X marks the approximate placement of the yagi antenna and the Lotek receiver used to detect fish moving into the Cabot Tailrace at River Mile 120. The radio test tag produced power levels ranging from 70s to 100 db with highest powers located near Cabot Station on the downstream end of the tailrace closest to the yagi antenna and attenuating slightly toward the far bank.

<u>Station</u>: Cabot Tailrace Upstream

Figure 6: The large yellow X marks the approximate placement of the yagi antenna and the Orion receiver used to detect fish moving in the Cabot Tailrace at River Mile 120. The radio test tag produced power levels ranging from -60s to -90s db with highest powers located near Cabot Station Fish ladder closest to the yagi antenna and attenuating slightly farther out.

Station: Cabot Ladder Entrance Dipole

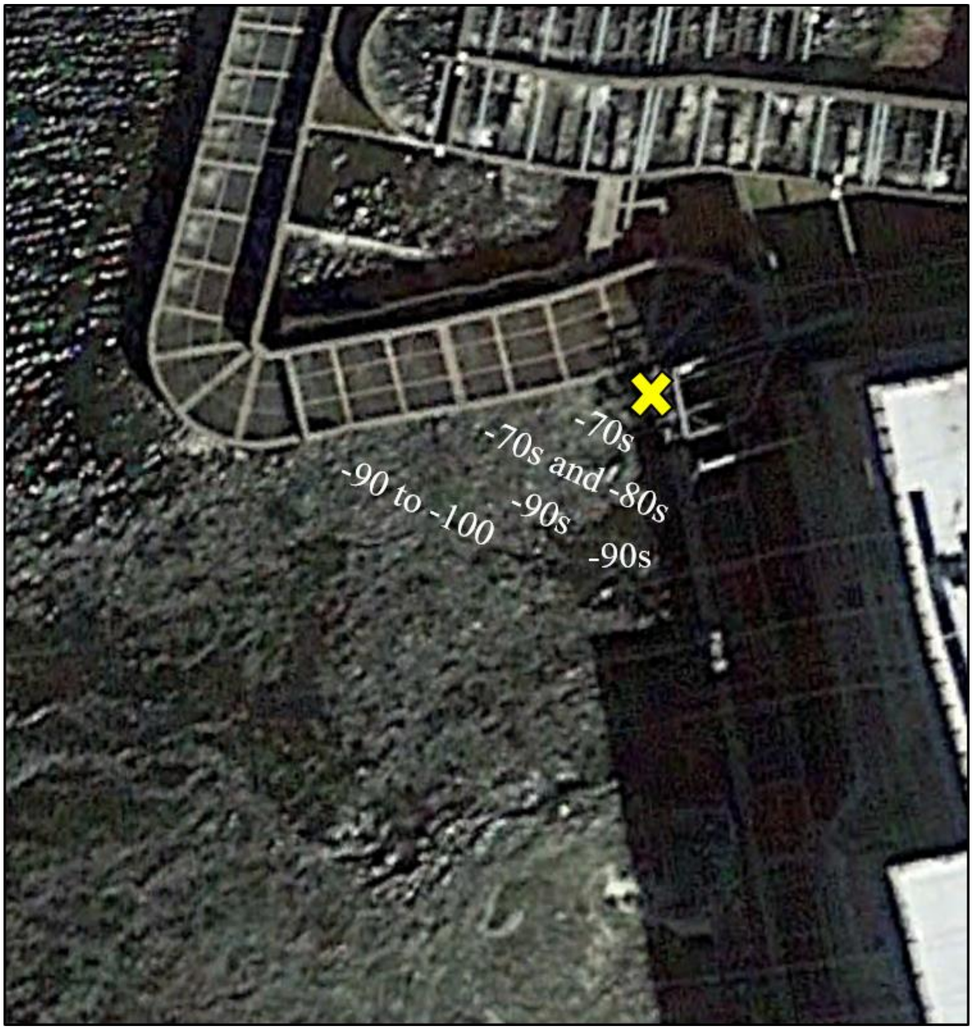

Figure 7: The large yellow X marks the approximate placement of the dipole antenna and the Orion receiver used to detect fish moving to the Cabot Ladder entrance at River Mile 120. The radio test tag produced power levels ranging from -70s to -100 db with highest powers located near Cabot Fish ladder entrance and attenuating slightly farther out.

Station: Upstream end of Smead Island

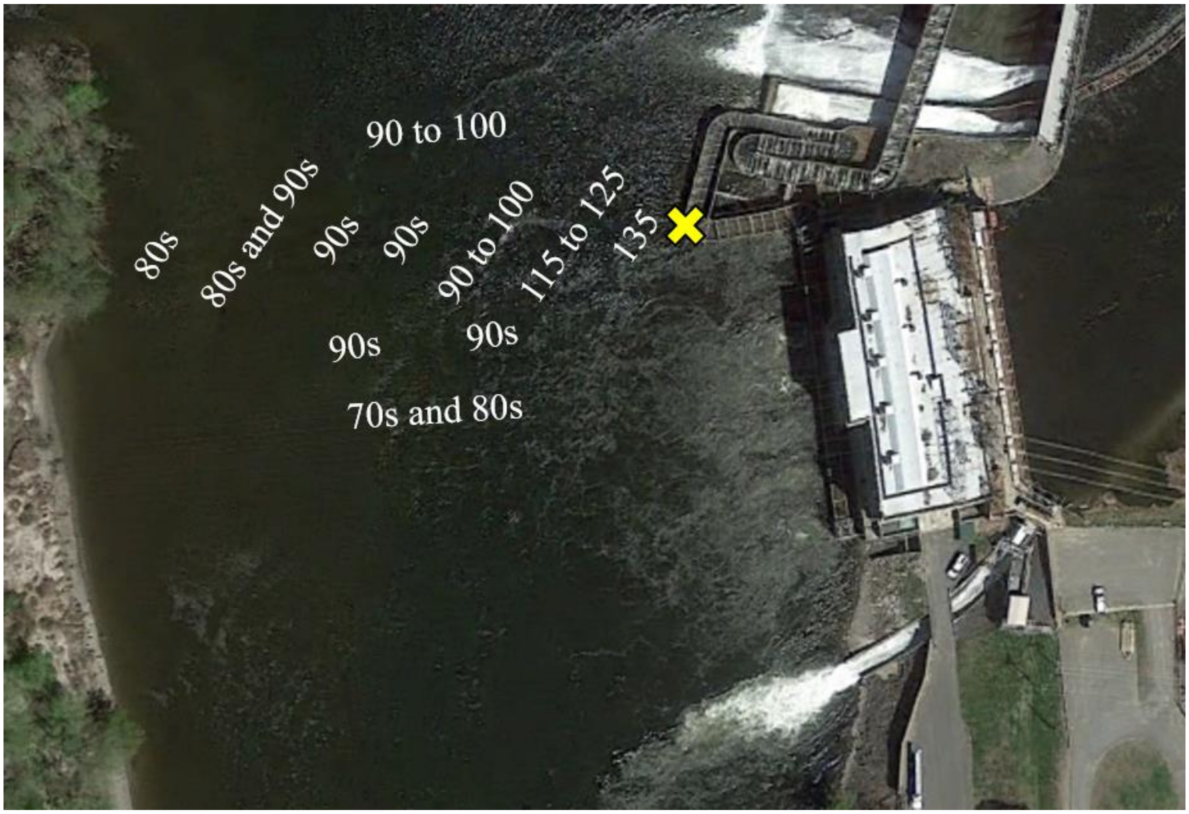

Figure 8: The large yellow X marks the approximate placement of the Yagi antenna and the Lotek receiver used to detect fish moving passed the upstream end of Smead Island at River Mile 120. The radio test tag produced power levels ranging from 80s to 135 db with highest powers located near the yagi antenna and attenuating toward the opposite bank of the river.

Station: Bypass Reach

Figure 9: The large yellow X marks the approximate placement of the Yagi antenna and the Orion receiver used to detect fish moving upstream through to the Bypass Reach at River Mile 120. The radio test tag produced power levels ranging from -60s to -105 db with highest powers located near the yagi antenna and attenuating toward the opposite bank of the river.

<u>Station</u>: Spillway Ladder Entrance Dipole

Figure 10: The large yellow X marks the approximate placement of the dipole antenna and the Orion receiver (under bridge) used to detect fish moving to the Spillway Ladder entrance at River Mile 120. The radio test tag produced power levels ranging from -60s to -100 db with highest powers located near Spillway Fish ladder entrance and attenuating farther out.

<u>Station</u>: Spillway Ladder Vicinity

Figure 11: The large yellow X marks the approximate placement of the Yagi antenna and the Lotek receiver (under bridge) used to detect fish moving in the vicinity of the Spillway Ladder at River Mile 122. The radio test tag produced power levels ranging from 60s to 110 db with highest powers located near Spillway Fish ladder entrance and attenuating farther out.

<u>Station</u>: Gatehouse Exit Dipole

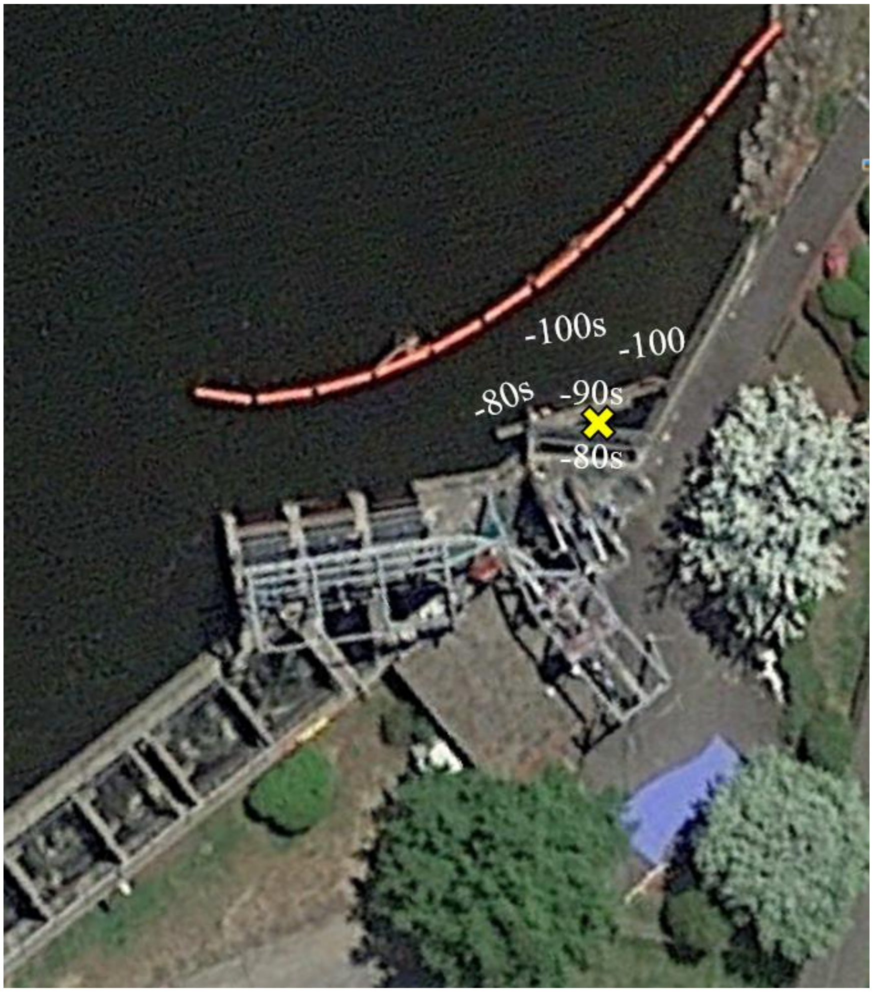

Figure 12: The large yellow X marks the approximate placement of the Yagi antenna and the Lotek receiver (under bridge) used to detect fish moving in the vicinity of the Spillway Ladder at River Mile 122. The radio test tag produced power levels ranging from 60s to 110 db with highest powers located near Spillway Fish ladder entrance and attenuating farther out.

APPENDIX C – TABULAR INFORMATION FOR TELEMETERED FISH

APPENDIX C: Tabular information based off of telemetry results on all fish released upstream of Holyoke Dam (Table C-1) and the fish released at Jones Ferry (Table C-2) that were detected in the study telemetry network.

Table C-1: The fate of all fish released above Holyoke Dam (n = 118)

Count	Fish ID	Release Date	Release Location	Detection History	DateTime of last Detection*	Time to Fallback (h)	Comments
1	149.740 20	5/04/2016	Holyoke	Fish detected at Montague, Smead, moved into Cabot Tailrace, up to the Bypass Reach, back and forth from Cabot Tailrace and Cabot Ladder. Downstream to Smead, Deerfield and Montague	Montague - 5/14/2016 10:37:39 PM		NAI confirmed at Holyoke 5/29/2016 04:02
2	149.740 21	5/04/2016	Holyoke	Fallback Fish	-	460	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/23/2016 5:27PM
3	149.740 22	5/04/2016	Holyoke	Fallback Fish	-	804	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/7/2016 1:55AM
4	149.740 23	5/04/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
5	149.740 24	5/04/2016	Holyoke	Fish detected at Montague, Smead, moved into Cabot Tailrace, up to the Bypass Reach, back and forth from Cabot Tailrace and Montague several times	Montague - 5/28/2016 10:25:38 PM		NAI confirmed at Holyoke 5/30/2016 10:26PM
6	149.740 25	5/04/2016	Holyoke	Fish detected at Montague, Smead, moved into Cabot Tailrace, up to the Bypass Reach, down to Cabot Tailrace to Montague	Montague - 6/10/2016 5:31:42 AM		NAI confirmed at Holyoke 6/11/2016 1:53AM
7	149.740 26	5/04/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
8	149.740 27	5/04/2016	Holyoke	Fallback Fish	-	590	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/29/2016 3:03AM
9	149.740 28	5/04/2016	Holyoke	Fallback Fish	-	682	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/1/2016 11:52PM
10	149.740 29	5/04/2016	Holyoke	Fallback Fish	-	128	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/9/2016 9:54PM
11	149.740 30	5/04/2016	Holyoke	Fish Detected at Cabot Ladder	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. **DETECTED AT PIT STATION P12**
12	149.740 31	5/04/2016	Holyoke	Fallback Fish	-	663	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/1/2016 4:01AM
13	149.740 32	5/04/2016	Holyoke	Fallback Fish	-	502	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/25/2016 11:29AM
14	149.740 33	5/04/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
15	149.740 34	5/04/2016	Holyoke	Fallback Fish	-	809	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/7/2016 6:35AM
16	149.740 50	5/10/2016	Holyoke	Fallback Fish	-	212	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/19/2016 11:16AM
17	149.740 51	5/10/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
18	149.740 52	5/10/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
19	149.740 53	5/10/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
20	149.740 54	5/10/2016	Holyoke	Fish detected at Montague, Smead, moved into Cabot Tailrace, back to Smead and Montague	Montague - 5/16/2016 5:20:25 PM		NAI confirmed at Holyoke 5/21/2016 5:05AM
21	149.740 55	5/10/2016	Holyoke	Fallback Fish	-	113	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/15/2016 8:56AM
22	149.740 56	5/10/2016	Holyoke	Fallback Fish	-	134	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/16/2016 5:16AM
23	149.740 57	5/10/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
24	149.740 58	5/10/2016	Holyoke	Fallback Fish	-	256	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/21/2017 7:15AM
25	149.740 59	5/10/2016	Holyoke	Fish detected at Montague	Montague - 6/6/2016 2:23:16 PM		-
26	149.740 60	5/10/2016	Holyoke	Fallback Fish	-	227	NAI confirmed at Holyoke 5/20/2016 2:32AM
27	149.740 61	5/10/2016	Holyoke	Fish detected at Montague, Smead, moved into Cabot Tailrace, up to the Bypass Reach, back and forth from Cabot Tailrace and Cabot Ladder. Downstream to Smead, Deerfield and Montague	Montague - 5/27/2016 10:01:39 PM		NAI confirmed at Holyoke 6/3/2016 7:31PM
28	149.740 62	5/10/2016	Holyoke	Fallback Fish	-	156	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/17/2016 3:20AM
29	149.740 63	5/10/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
30	149.740 64	5/10/2016	Holyoke	Fallback Fish	-	291	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/22/2016 6:31PM
31	149.740 80	5/17/2016	Holyoke	Fallback Fish	-	160	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/24/2016 2:19AM

Count	Fish ID	Release Date	Release Location	Detection History	DateTime of last Detection*	Time to Fallback (h)	Comments
32	149.740 81	5/17/2016	Holyoke	Fallback Fish	-	453	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/5/2016 7:46AM
33	149.740 82	5/17/2016	Holyoke	Fish detected at Montague, moved into the Cabot Tailrace, back down to Montague	Montague - 6/6/2016 11:11:16 PM		NAI confirmed at Holyoke 6/7/2016 3:58PM
34	149.740 83	5/17/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
35	149.740 84	5/17/2016	Holyoke	Fish Detected at Cabot Ladder	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. **DETECTED AT PIT STATION P12**
36	149.740 85	5/17/2016	Holyoke	Fallback Fish	-	152	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/23/2016 6:46PM
37	149.740 87	5/17/2016	Holyoke	Fallback Fish	-	378	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/2/2016 4:34AM
38	149.740 88	5/17/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
39	149.740 89	5/17/2016	Holyoke	Fallback Fish	-	484	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/6/2016 2:11PM
40	149.740 90	5/17/2016	Holyoke	Fish detected at Montague, Smead, moved into Cabot Tailrace, up to the Bypass Reach, to Spillway vicinity, back to Bypass Reach, Cabot Tailrace and Montague	Montague - 6/7/2016 3:12:05 AM		NAI confirmed at Holyoke Intake Rack 6/11/2016 5:34AM
41	149.740 91	5/17/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
42	149.740 92	5/17/2016	Holyoke	Fallback Fish		596	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/11/2016 6:41AM
43	149.740 93	5/17/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
44	149.740 94	5/17/2016	Holyoke	Fallback Fish	-	707	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/15/2016 9:03PM
45	149.740 98	5/17/2016	Holyoke	Fallback Fish	-		No Detections
46	149.740 110	5/24/2016	Holyoke	Fallback Fish	-	328	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/7/2016 4:03AM
47	149.740 111	5/24/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
48	149.740 112	5/24/2016	Holyoke	Fish detected at Montague, Smead, moved into the Cabot Tailrace, up to the Bypass Reach, back to Cabot Tailrace and Montague	Montague - 6/21/2016 9:31:31 AM		-
49	149.740 113	5/24/2016	Holyoke	Fallback Fish	-	323	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/6/2017 11:45PM
50	149.740 114	5/24/2016	Holyoke	Fish detected at Montague, moved into the Cabot Tailrace and back down to Montague	Montague - 6/6/2016 7:28:59 PM		NAI confirmed at Holyoke 6/17/2016 8:09PM
51	149.740 115	5/24/2016	Holyoke	Fish detected at Montague, moved into the Deerfield River and back down to Montague	Montague - 6/22/2016 6:56:26 AM		NAI confirmed at Holyoke 6/24/2016 11:59PM
52	149.740 116	5/24/2016	Holyoke	Fallback Fish	-	603	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/18/2016 3:30PM
53	149.740 117	5/24/2016	Holyoke	Fish detected at Montague, Smead, moved into the Cabot Tailrace, back down to Montague	Montague - 6/21/2016 10:35:23 AM		-
54	149.740 118	5/24/2016	Holyoke	Fallback Fish	-	201	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/1/2016 9:06PM
55	149.740 119	5/24/2016	Holyoke	Fish detected at Montague, Smead, moved into Cabot Tailrace, up to the Bypass Reach, to Spillway Ladder, back to Bypass Reach, Cabot Tailrace and Montague	Montague - 5/30/2016 10:05:46 PM		NAI confirmed at Holyoke 6/6/2016 7:54PM
56	149.740 120	5/24/2016	Holyoke	Fish detected at Montague, Smead, moved into Cabot Tailrace, up to the Bypass Reach, back to Cabot Tailrace, Smead and Montague	Montague - 6/7/2016 11:15:22 AM		-
57	149.740 121	5/24/2016	Holyoke	Fallback Fish	-	80	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/27/2016 8:28PM
58	149.740 122	5/24/2016	Holyoke	Fallback Fish	-	545	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/16/2016 5:39AM
59	149.740 123	5/24/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
60	149.780 35	5/04/2016	Holyoke	Fish detected at Montague, Deerfield, Smead, moved into Cabot Tailrace, up to the Bypass Reach, to Spillway Ladder vicinity, back to Bypass Reach, Cabot Tailrace, Smead and Montague	Montague - 5/29/2016 5:44:35 AM		-
61	149.780 36	5/04/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
62	149.780 37	5/04/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
63	149.780 38	5/04/2016	Holyoke	Fish detected at Montague	Montague - 5/14/2016 5:24:15 AM		NAI confirmed at Holyoke 5/30/2016 2:28PM
64	149.780 39	5/04/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
65	149.780 40	5/04/2016	Holyoke	Fish detected at Montague, moved into Cabot Tailrace, up to the Bypass Reach, back to Cabot Tailrace and Montague	Montague - 5/17/2016 11:18:31 AM		NAI confirmed at Holyoke 5/27/2016 10:22PM
66	149.780 41	5/04/2016	Holyoke	Fallback Fish	-	582	NAI confirmed at Holyoke 5/28/2016 7:54PM
67	149.780 42	5/04/2016	Holyoke	Fallback Fish	-	564	NAI confirmed at Holyoke 5/28/2016 1:01AM
68	149.780 43	5/04/2016	Holyoke	Fallback Fish	-		-

Count	Fish ID	Release Date	Release Location	Detection History	DateTime of last Detection*	Time to Fallback (h)	Comments
69	149.780 44	5/04/2016	Holyoke	Fish detected at Montague, Smead, moved into Cabot Tailrace, up to Bypass Reach, back to Cabot Tailrace, Smead, Montague, Deerfield and back to Montague	Montague - 5/23/2016 1:14:59 AM		NAI confirmed at Holyoke 6/1/2016 1:47AM
70	149.780 45	5/04/2016	Holyoke	Fallback Fish	-		-
71	149.780 46	5/04/2016	Holyoke	Fish detected at Montague, Smead, moved into the Cabot Tailrace, up to the Bypass Reach, back to Cabot Tailrace, Smead and Montague	Montague - 5/16/2016 7:16:26 PM		-
72	149.780 47	5/04/2016	Holyoke	Fish Detected at Cabot Ladder	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. **DETECTED AT PIT STATION P12**
73	149.780 48	5/04/2016	Holyoke	Fish detected at Montague, Smead, moved into the Cabot Tailrace, up to Bypass Reach, back to Cabot Tailrace, Smead and Montague	Montague - 5/23/2016 7:58:40 AM		NAI confirmed at Holyoke 5/30/2016 12:39AM
74	149.780 49	5/04/2016	Holyoke	Fallback Fish	-	286	NAI confirmed at Holyoke 5/16/2016 11:38AM
75	149.780 65	5/10/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
76	149.780 66	5/10/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
77	149.780 67	5/10/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
78	149.780 68	5/10/2016	Holyoke	Fallback Fish	-	49	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/12/2017 4:36:00 PM
79	149.780 69	5/10/2016	Holyoke	Fallback Fish	-	400	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/27/2017 7:48:00 AM
80	149.780 70	5/10/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
81	149.780 71	5/10/2016	Holyoke	Fallback Fish	-	70	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/13/2017 1:38:00 PM
82	149.780 72	5/10/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
83	149.780 73	5/10/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
84	149.780 74	5/10/2016	Holyoke	Fallback Fish	-	621	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/5/2017 12:58:00 PM
85	149.780 75	5/10/2016	Holyoke	Fallback Fish	-	12	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/11/2017 3:34:00 AM
86	149.780 76	5/10/2016	Holyoke	Fallback Fish	-	416	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/27/2017 11:20:00 PM
87	149.780 77	5/10/2016	Holyoke	Fallback Fish	-	379	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/26/2017 10:01:00 AM
88	149.780 78	5/10/2016	Holyoke	Fallback Fish	-	547	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/2/2017 10:53:00 AM
89	149.780 79	5/10/2016	Holyoke	Fallback Fish	-	124	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/15/2017 7:23:00 PM
90	149.780 95	5/17/2016	Holyoke	Fish Detected at Cabot Ladder	-		**DETECTED AT PIT STATION P12**
91	149.780 96	5/17/2016	Holyoke	Fallback Fish	-	255	NAI confirmed at Holyoke 5/28/2017 1:27AM
92	149.780 97	5/17/2016	Holyoke	Fish detected at Montague, moved into Cabot Tailrace, up to the Bypass Reach, to Spillway Ladder and up to Gatehouse Ladder exit	Gatehouse Ladder Exit - 5/29/2016 8:33:48PM		-
93	149.780 98	5/17/2016	Holyoke	Fallback Fish	-	238	NAI confirmed at Holyoke 5/27/2017 8:17AM
94	149.780 99	5/17/2016	Holyoke	Fallback Fish	-		No Detections
95	149.780 100	5/17/2016	Holyoke	Fallback Fish	-	56	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/19/2017 6:39:00 PM
96	149.780 101	5/17/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
97	149.780 102	5/17/2016	Holyoke	Fallback Fish	-	181	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/24/2017 11:32:00 PM
98	149.780 103	5/17/2016	Holyoke	Fallback Fish	-	512	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/7/2017 6:18:00 PM
99	149.780 104	5/17/2016	Holyoke	Fallback Fish	-	493	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/6/2017 11:20:00 PM
100	149.780 105	5/17/2016	Holyoke	Fallback Fish	-	269	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/28/2017 3:47:00 PM
101	149.780 106	5/17/2016	Holyoke	Fish detected at Montague, moved to the Deerfield and back to Montague	Montague - 5/20/2016 1:52:57 AM		NAI confirmed at Holyoke 5/29/2017 5:44:00 PM
102	149.780 107	5/17/2016	Holyoke	Fallback Fish	-	402	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/3/2017 4:08:00 AM
103	149.780 108	5/17/2016	Holyoke	Fish Detected at Cabot Ladder			**DETECTED AT PIT STATION P12**
104	149.780 109	5/17/2016	Holyoke	Fallback Fish	-	18	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 5/18/2017 4:34:00 AM
105	149.780 124	5/24/2016	Holyoke	Fish detected at Montague, Smead, moved into the Cabot Tailrace, back to Smead, Deerfield and Montague	Montague - 6/1/2016 7:01:54 PM		-

Count	Fish ID	Release Date	Release Location	Detection History	DateTime of last Detection*	Time to Fallback (h)	Comments
106	149.780 125	5/24/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
107	149.780 126	5/24/2016	Holyoke	Fallback Fish	-		No Detections
108	149.780 127	5/24/2016	Holyoke	Fish detected at Montague, Smead, moved into the Cabot Tailrace, back to Montague	Montague - 6/2/2016 7:46:29 PM		NAI confirmed at Holyoke 6/6/2017 9:11:00 PM
109	149.780 128	5/24/2016	Holyoke	Fallback Fish	-	370	No Detections NAI confirmed at Holyoke 6/8/2017 10:10:00 PM
110	149.780 129	5/24/2016	Holyoke	Fish detected at Montague, Smead, moved into the Cabot Tailrace, up to the Bypass Reach, back to the Cabot Tailrace and Montague	Montague - 6/3/2016 12:29:03 AM		-
111	149.780 130	5/24/2016	Holyoke	Fallback Fish	-	529	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/15/2017 1:27:00 PM
112	149.780 131	5/24/2016	Holyoke	Fallback Fish	-	605	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/18/2017 5:21:00 PM
113	149.780 132	5/24/2016	Holyoke	Fallback Fish	-	429	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/11/2017 9:35:00 AM
114	149.780 133	5/24/2016	Holyoke	Fallback Fish	-		Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive.
115	149.780 134	5/24/2016	Holyoke	Fish detected at Montague, moved into the Cabot Tailrace, up to the Bypass Reach, Spillway Ladder vicinity, back to the Bypass Reach, Cabot Tailrace and Montague	Montague - 6/18/2016 2:27:03 AM		NAI confirmed at Holyoke 6/21/2017 5:04:00 AM
116	149.780 135	5/24/2016	Holyoke	Fish detected at Montague, Smead, moved into the Cabot Tailrace, up to the Bypass Reach, Spillway Ladder and Gatehouse Ladder Exit	Gatehouse Ladder Exit - 6/2/2016 3:59:03 PM		-
117	149.780 136	5/24/2016	Holyoke	Fish detected at Montague, Smead, moved into the Cabot Tailrace, up Cabot ladder and to Gatehouse Ladder Exit	Gatehouse Ladder Exit 5/30/2016 6:39:14 PM		-
118	149.780 137	5/24/2016	Holyoke	Fallback Fish	-	343	Large inconsistent random lags with no detection patterns, a lot of noise. All hits false positive. NAI confirmed at Holyoke 6/7/2017 7:48:00 PM

*Last detection within KA study Telemetry network (Figure 3.1.3-1)

Table C-2: 25 shad tagged and released by NAI that made it to the KA telemetry network (Figure 3.1.3-1)

Count	Fish ID	Release Date	Release Location	Detection History	DateTime of last Detection*	Comments
1	150.420 102	5/6/2016	Jones Ferry	Fish detected at Montague, Smead, back to Montague, Deerfield, and Montague	Montague - 6/3/2016 12:31:58 AM	-
2	150.420 105	5/6/2016	Jones Ferry	Fish detected at Montague, moved into the Cabot Tailrace, back and forth between Cabot Tailrace, back to Smead, Montague, Cabot Tailrace, and Montague	Montague - 6/3/2016 6:24:40 PM	-
3	150.420 111	5/6/2016	Jones Ferry	Fish detected at Cabot Ladder	Cabot Ladder - 5/25/2016 6:32:30 AM	**DETECTED AT PIT STATION P12**
4	150.420 114	5/11/2016	Jones Ferry	Fish detected at Montague, Smead, moved into the Cabot Tailrace, back to Smead and Montague	Montague - 5/28/2016 6/4/2016 6:23:14 PM	-
5	150.420 115	5/11/2016	Jones Ferry	Fish detected at Montague, Cabot Tailrace, moved into the Cabot Tailrace, up to the Bypass Reach, back down to Cabot Tailrace and Montague	Montague - 5/28/2016 8:32:18 PM	-
6	150.420 124	5/11/2016	Jones Ferry	Fish detected at Cabot Ladder	Cabot Ladder - 5/31/2016 6:57:35 AM	**DETECTED AT PIT STATION P12**
7	150.420 138	5/17/2016	Jones Ferry	Fish detected at Montague, Smead, moved into the Cabot Tailrace, up to the Bypass Reach, Spillway Ladder Vicinity, back to the Bypass Reach, Cabot Tailrace, Smead, and Montague	Montague - 6/3/2016 2:15:25 PM	-
8	150.420 143	5/18/2016	Jones Ferry	Fish Detected at Cabot Ladder	Cabot Ladder - 5/29/2016 2:16:39 PM	**DETECTED AT PIT STATION P12**
9	150.420 146	5/18/2016	Jones Ferry	Fish detected at Montague, moved into the Cabot Tailrace, up to the Bypass Reach, and back to Cabot Tailrace	Cabot Tailrace - 6/22/2016 1:17:28 AM	Fish died in Cabot Tailrace. Time of last detection is time of death.
10	150.420 152	5/18/2016	Jones Ferry	Fish detected at Montague, Smead, moved into the Cabot Tailrace, up to the Bypass Reach, back to Cabot Tailrace and Gatehouse Ladder Exit	Gatehouse Ladder Exit - 5/29/2016 2:50:15 PM	Fish looks to have reached TFI via the Canal. No evidence of emigration back down out of the project
11	150.420 163	5/20/2016	Jones Ferry	Fish detected at Montague, Smead, moved into the Cabot Tailrace, and up to the Bypass Reach	Bypass Reach - 5/28/2016 11:49:50 AM	No evidence of emigration back down out of the project
12	150.420 175	5/24/2016	Jones Ferry	Fish detected at Cabot Ladder	Cabot Ladder - 6/3/2016 9:16:15 AM	**DETECTED AT PIT STATION P12**
13	150.420 177	5/24/2016	Jones Ferry	Fish detected at Montague, moved into the Cabot Tailrace, up to the Bypass Reach, Spillway Ladder Vicinity, back down to the Bypass Reach, Cabot Tailrace, and Montague	Montague - 6/9/2016 5:05:41 AM	-
14	150.420 180	5/27/2016	Jones Ferry	Fish detected at Montague, moved into the Cabot Tailrace, up to the Bypass Reach, back to Cabot Tailrace, and Montague	Montague - 6/10/2016 11:13:16 PM	-
15	150.420 188	5/27/2016	Jones Ferry	Fish detected at Montague, moved into the Cabot Tailrace, up to the Bypass Reach, Spillway Ladder Vicinity, back to the Bypass Reach, and Cabot Tailrace	Cabot Tailrace -6/7/2016 6:22:17 PM	-
16	150.420 193	5/13/2016	Jones Ferry	Fish detected at Montague, Smead, moved into the Cabot Tailrace, up to the Bypass Reach, Spillway Ladder Vicinity, Spillway Ladder, back to Bypass Reach, Cabot Tailrace, and Montague	Montague - 6/5/2016 8:11:09 PM	-
17	150.420 195	5/13/2016	Jones Ferry	Fish detected at Montague, Smead, moved into the Cabot Tailrace, back to the Cabot Tailrace, Smead, and Montague	Montague - 5/30/2016 9:24:32 AM	-
18	150.460 115	5/20/2016	Jones Ferry	Fish detected at Cabot Ladder	Cabot Ladder - 6/4/2016 3:37:09 PM	**DETECTED AT PIT STATION P12**
19	150.460 116	5/20/2016	Jones Ferry	Fish detected at Montague	Montague - 5/29/2016 11:53:56 AM	
20	150.460 117	5/20/2016	Jones Ferry	Fish detected at Cabot Ladder		**DETECTED AT PIT STATION P12**
21	150.460 123	5/20/2016	Jones Ferry	Fish detected at Montague, Smead, moved into the Cabot Tailrace, and back to Montague	Montague - 6/6/2016 4:32:03 PM	-
22	150.460 174	5/13/2016	Jones Ferry	Fish detected at Montague, Smead, moved into the Cabot Tailrace, up to the Bypass Reach, back to Cabot Tailrace, Smead, and Montague	Montague - 6/8/2016 4:40:52 AM	-
23	150.460 178	5/13/2016	Jones Ferry	Fish detected at Montague, Smead, moved into the Cabot Tailrace, up to the Bypass Reach, Spillway Ladder Vicinity, Spillway Ladder, and Gatehouse Ladder Exit	Gatehouse Ladder Exit - 5/30/2016 5:39:23 PM	Fish reached TFI via Spillway Ladder. No evidence of emigration back down out of the project
24	150.460 188	5/17/2016	Jones Ferry	Fish detected at Montague	Montague - 6/4/2016 10:22:06 AM	-
25	150.460 189	5/17/2016	Jones Ferry	Fish detected at Cabot Ladder	Cabot Ladder - 5/31/2016 9:31:38 PM	**DETECTED AT PIT STATION P12**

* Last detection within KA study Telemetry network (Figure 3.1.3-1)