Relicensing Study 3.3.2

Evaluate Upstream and Downstream Passage of Adult American Shad

Study Report

Northfield Mountain Pumped Storage Project (No. 2485)

and Turners Falls Hydroelectric Project (No. 1889)

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OCTOBER 2016

EXECUTIVE SUMMARY

In support of relicensing efforts for the Northfield Mountain and Turners Falls Projects (Project), American Shad migration and emigration success through the Project area was assessed in 2015. FirstLight conducted a telemetry study employing radio and passive integrated transponder (PIT) technologies to assess behavior, approach routes, passage success, survival, and delay by adult American Shad as they encounter the Project.

FirstLight deployed and tested 29 radio telemetry monitoring stations within the study area. Radio telemetry monitoring was achieved through the use of Orion receivers, manufactured by Sigma Eight, and SRX400 and SRX800 receivers manufactured by Lotek. Thirteen PIT monitoring stations were deployed within the three fishways: Cabot, Spillway and Gatehouse. The half-duplex PIT readers were manufactured by Oregon RFID and antennas were built onsite. In addition, mobile tracking of radio tagged shad was conducted weekly between Holyoke Dam and the Mount Herman School, located on the Turners Falls Impoundment (TFI) upstream of the Northfield Mountain intake. A second day of weekly tracking concentrated on the area between Hatfield, MA and the Cabot Station. Mobile tracking was conducted by boat using a Lotek receiver and a directional 3-element Yagi antenna. A total of 33 mobile tracking surveys were conducted over 9 weeks between May 15, and July 7, 2015.

Shad used in the evaluation were collected at the upstream fish passage facilities at the Holyoke Dam and within the Cabot fish ladder at the Turners Falls Project using the existing fish trapping facilities. Tagging occurred on 12 days from the period beginning on May 6, and ending on June 8, 2015. Approximately half of the shad were tagged with radio and PIT tags (double tagged) (n=397) and half were tagged with PIT only (n=396). In total, FirstLight collected, tagged and released 793 adult shad. The majority (71%, n=561) of the shad were collected at the Holyoke Dam. These fish were released in the Holyoke Impoundment (n=433) or the TFI (n=128). A total of 232 (29%) shad were collected at the Cabot fish ladder trap, of those 100 were released in the Turners Falls Power Canal (Power Canal) and 132 were released in the TFI. Additional shad were tagged by the TransCanada study team. 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 size. TransCanada collected, tagged and released 154 shad over six days between May 10 and May 30, 2015. All 100 of TransCanada's shad collected at the Holyoke Dam were transported to the Pauchaug Brook Boat Launch (in the TFI) for tagging and release. The remaining 54 study fish were collected at the Vernon Dam and released at the Old Ferry Boat Ramp in Brattleboro, VT (Vernon Impoundment).

Cabot Station operated nearly continuously throughout the study period except during a few brief periods. Generation was variable and typically ranged between 10 and 60 MW. All six units operated during the study period. Unit 1, closest to the downstream fish bypass, was prioritized and operated continuously except during periods of no generation. The downstream fish bypass was operated throughout the study period. Generation at Station No. 1 was less variable when compared to that of Cabot Station, generally operating near capacity (~6 MW) or not at all. Station No. 1 did not operate during the beginning or end of the study period from May 6 to May 19, 2015 and from July 6 to July 15, 2015, respectively. The Northfield Mountain Pumped Storage (NMPS) Project operated (pumping and/or generation) almost daily throughout the study period. Maximum generation of 1,015 MW occurred on May 17; however, generation of less than 750 MW was more common. All four units were operational during the study period. Discharge at the Turners Falls Dam occurred throughout the study period except during brief periods between July 10 and 15, 2015. A dynamic flow release schedule was maintained throughout the study and was determined in real time with input from the United States Fish and Wildlife Service (USFWS).

In total, there were 1,034 tagged fish in the Connecticut River during the spring of 2015, which included American Shad, Sea Lamprey and 6 Atlantic Salmon tagged by the United States Geological Survey (USGS). Of those fish, 449 were dual tagged, 451 were PIT tagged only, and 134 were radio tagged only. The resulting data collection effort produced 19,177,280 detections and following data reduction, the final recaptures dataset was 16,784,468 detections. The single most important predictor for the reduction algorithm was detection history and its derived components. It was the pattern of hit to missed detections that drove whether a record was real or false positive.

The assessment of fishway attraction effectiveness, overall passage efficiency, internal fishway efficiency, upstream passage effectiveness and route of passage was conducted using various statistical tests and models, including mark recapture models (*fish ladder entrance and internal efficiency*), Cox regression model for time-to-event analysis (*delay),* multi-state models (*probability of movement between locations*), and hotspot analysis (*maximum upstream extents of migrants*). Fishway attraction effectiveness assessed the ability of a ladder entrance to attract fish. This means fish present in the Cabot Tailrace, spillway and at the Gatehouse Yagi are available to pass into the Cabot, Spillway and Gatehouse ladders respectively. The internal efficiency examined the rates of passage between telemetered reaches within each ladder, and the overall ladder efficiency is simply the product of all internal rates.

Less than half (42%) of the American Shad tagged and released in the Holyoke Impoundment approached the Turners Falls Project. Results demonstrated that the proportion of fish between Holyoke and the Turners Falls Project that turn around and transition downstream increases during high flow (17,100 cfs to the maximum of 38,100 cfs). Time-to-event analysis found that their rate of movement is more affected by day/night than flow, and migrating shad are 2.8 times more likely to arrive at the Turners Falls Project during the day than at night. Once the shad arrive at Montague, they are faced with an array of migratory selections. Fish may choose to migrate into the Deerfield River, to head up the western channel of Smead Island, enter the Cabot tailrace, or pass directly up the bypass reach (eastern channel of Smead Island). Flow influences their choices, and the fish appear to minimize energy expenditure by finding areas of refuge during high flow. From Montague, the proportion of shad moving into Cabot Tailrace is always greater than the other routes, however the proportion decreases with increasing discharge from Cabot Station and the bypass reach. As Cabot and bypass reach flow increases, the proportion of fish transitioning towards the west channel of Smead Island increases, either as an alternate route of passage or area of flow refuge.

Attraction to the Cabot ladder is a complex process with multiple avenues of passage and attraction to the Cabot ladder increases as Cabot discharges increase. However, as bypass flow increases, the overall attraction to the bypass reach is lower. As bypass flow increases further, movement from the Cabot Tailrace into the bypass reach decreases. The overall Cabot ladder efficiency from arrival in the Cabot Tailrace to passage at the upper most ladder receiver (P12) was 10.2%. Further, the data suggested that fish abandon attempts after 40 hours with the last successful passage attempt after 30 hours. If a fish does not navigate the Cabot ladder, they may continue their migration upstream through the bypass reach.

Rawson Island, located in the bypass reach, represents a migratory hurdle that all fish must pass on their route through the reach towards Spillway ladder. It appears that fish mill between the eastern and western channels of Rawson Island, with relatively little upstream success from the eastern channel where the Rock Dam appears to be a significant barrier to upstream migration. Further, fish do not spend much time within the western channel. After fish migrate past Rawson Island, they are able to approach and use the Spillway ladder.

Fifty percent of the tagged American Shad that reach the Spillway ladder take roughly 96 hours to ascend the bypass reach from Montague. The median travel time to the project from Holyoke was 232 hours. Once fish arrive in the upper bypass (receivers T19 and T20), it appears that they have trouble being attracted to the Spillway ladder entrance during high flow at the Bascule gates as evident with the low transition probabilities towards the ladder as flow increases (65% at 2,569 cfs to 41% at 6,226 cfs). The internal efficiency was 35% and the overall Spillway ladder efficiency was 33%, which included the entrance.

Once upstream migrating shad enter the canal from the Cabot ladder, their upstream migration is complicated. Time-to-event analysis quantified the amount of migratory delay from when fish enter the canal until they reach the Gatehouse Yagi antenna. Under the 25th percentile flow (3,519 cfs) 50% of the population will reach T22 in under 3.4 hours, however at the 75th percentile flow (12,242 cfs), 50% of the population will reach T22 in 365 hours. Multi-state modeling uncovered milling within the lower canal near the Cabot Forebay and downstream bypass area and fish may take as long as 48 hours to leave the area. Fish attracted to the Station No. 1 forebay take upwards of 15 hours to leave. Once fish arrive at the canal immediately downstream of the Gatehouse, or pass via the Spillway ladder, they need to pass the Gatehouse ladder.

The Gatehouse ladder was the best performing ladder of the three fish ladders. The overall Gatehouse ladder efficiency was 76.9% with 50% of the successful attempts occurring after only 1.5 hours. Once fish pass through the Gatehouse ladder, they enter the TFI and many pass relatively unimpeded up to Vernon Dam.

The migrating shad within the TFI (fish that migrated successfully through Gatehouse ladder or were released into the TFI) faced little migratory disruption due to the NMPS Project operations. A total of 145 dual tagged adult shad were released into TFI. Thirteen of those were fish released at Holyoke that migrated through Gatehouse ladder and 132 were dual tagged shad that were released directly into TFI. Of those 145 fish, 100 were recaptured at the upper most receiver in the TFI at Shearer Farms. The attraction of fish from downstream of the NMPS Project intake towards the intake decreases as nightly pumping operations increase; however, this may be due to the reluctance of fish to migrate at night.

For emigrating fish, movement downstream decreases slightly with increasing NMPS generation operations; however, attraction towards the intake also decreases with increasing generation. No adult shad were entrained at NMPS Project. Once emigrating fish arrive at Turners Falls Dam, they are faced with two primary migratory routes. Emigrating American Shad prefer to migrate downstream through the canal (76%), with the remainder passing via bascule gate.

Overall, once in the canal, 50% of the population will find downstream passage after 23 hours. Fish are likely to move downstream in the canal as flows increase. However, milling occurs within the Cabot Forebay as fish attempt to find downstream passage. It does appear that fish have more success locating the downstream bypass as canal flows increase. In total, 86 fish utilized the canal in their emigration. Of those fish, 39 transitioned from the downstream bypass to the Cabot Tailrace. Three fish transitioned from the Upper Canal (T18, T21) to the Cabot Tailrace without being detected at any additional telemetry stations in the Cabot Forebay. One fish transitioned from the Lower Canal to the Cabot Tailrace without being detected at any additional telemetry stations in the Cabot Forebay. These four fish have unconfirmed passage routes through the canal. An additional 24 fish transitioned from the Cabot Forebay to the Cabot Tailrace and based on those transitions, the estimated rate of entrainment at Cabot Station was 28%. Of the 86 fish that entered the canal, 39 were confirmed to have passed via the downstream bypass (45%). Overall, 78% of the fish that entered the canal were able to find downstream passage.

In summary, less than half the American Shad lifted upstream of Holyoke Dam approach the Turners Falls Project; some of these may have returned downstream after the tagging process, lost their tag, or spawned below the Project and returned downstream. Once at the Project, fish are faced with a route selection and appear to choose pathways that minimize energy expenditure with fish finding refuge behind Smead Island during high river flow. High flow over the Bascule Gates is an issue at the entrance to Spillway ladder, and fish appear to not be able to find the entrance during high flow. Once in the canal, fish mill in front of Cabot Forebay and higher flows in the upper canal appear to impede migration. Passage through Gatehouse ladder is relatively successful and fish pass unimpeded. Once in the TFI, upstream and downstream migration is affected little by operations at the NMPS Project. Further, fish that do get attracted to the NMPS Project intake are able to leave relatively quickly. During their downstream migration, fish overwhelmingly choose to migrate through the canal.

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ASMFC	Atlantic States Marine Fisheries Commission
°C	degrees Celsius
°F	degrees Fahrenheit
cfs	cubic feet per second
CJS	Cormack-Jolly-Seber
CRASC	Connecticut River Atlantic Salmon Commission
CRWC	Connecticut River Watershed Council
FERC	Federal Energy Regulatory Commission
FirstLight	FirstLight Hydro Generating Company
ILP	Integrated Licensing Process
MDFW	Massachusetts Division of Fisheries and Wildlife
MSM	multi-state Markov
NHDES	New Hampshire Department of Environmental Services
NHFGD	New Hampshire Fish and Game Department
NMFS	National Marine Fisheries Service
NMPS	Northfield Mountain Pumped Storage Project
NOAA	National Oceanic and Atmospheric Administration
PAD	Pre-Application Document
PIT	Passive Integrated Transponder
PSP	Proposed Study Plan
QAQC	Quality Assurance and Quality Control
RM	River mile
RSP	Revised Study Plan
SCADA	Supervisory Control and Data Acquisition
SD1	Scoping Document 1
SD2	Scoping Document 2
SPDL	Study Plan Determination Letter
TFD	Turners Falls Dam
TFI	Turners Falls Impoundment
TU	Trout Unlimited
USFWS	United States Fish and Wildlife Service
VTDEC	Vermont Department of Environmental Conservation
VTFWD	Vermont Fish and Wildlife Department
VY	Vermont Yankee Nuclear Power Plant

1 INTRODUCTION

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 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.

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 for this study with certain modifications. In FERC's February 21, 2014 Study Plan Determination for Aquatic Studies it approved Study No. 3.3.2 *Evaluate Upstream and Downstream Passage of Adult American Shad* with the following modifications:

- FirstLight should modify its study plan to repeat each of the five test flows three times. In addition, to avoid any effect this study may have on Shortnose Sturgeon spawning activity, egg incubation, and larval rearing within the Turners Falls bypassed reach, FirstLight should ramp the flows between each test flow and between each repeated set of flows for a duration of at least 24 hours.

- FirstLight should increase the proposed sample size of tagged adult shad by an additional 100 shad (50 radio- and PIT-tagged and 50 PIT-tagged only).

- FirstLight should install two requested radio telemetry receivers and six additional receivers at the indicated locations along the power canal.

- FirstLight should install a PIT antenna in the second turning pool of the Spillway fishway.

- FirstLight should implement radio tagging tracking at the Northfield Mountain Project Upper Reservoir.

- FirstLight should record and document mortality data collected through the study area from all fixed telemetry stations and during mobile tracking efforts throughout the entire study area.

- FirstLight should increase the frequency of mobile telemetry monitoring to twice per week in the riverine reach from Turners Falls Dam (TFD) at river mile (RM) 122 downstream through the Hatfield S-Turn to RM 93.

- FirstLight should use the annual digital counting of all fish species at the three fish ladder viewing windows (Spillway, Cabot Station and Gatehouse ladders), required by Article 38 of the current license, and the proposed PIT-tag monitoring to evaluate the effectiveness and efficiency of the three fish ladders.

An evaluation of upstream and downstream passage of adult American Shad was requested by the FERC, United States Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), Massachusetts Division of Fisheries and Wildlife (MDFW), New Hampshire Department of Environmental Services (NHDES), New Hampshire Fish and Game Department (NHFG), Vermont Department of Environmental Conservation (VTDEC), Connecticut River Watershed Council (CRWC), Trout Unlimited (TU) and the Town of Gill. FirstLight developed a study plan to guide the evaluation. The study methods employed the use of both radio and Passive Integrated Transponder (PIT) telemetry technologies and were developed in consultation with state and federal resource agencies and stakeholders.

On November 17, 2014, FirstLight held a stakeholder meeting to discuss study plans that included radio telemetry components. During the meeting several of the stakeholders indicated that they would like to relocate four (4) of the radio telemetry receivers from the Cabot Canal to elsewhere. There was a consensus among the group that there were redundant receivers in the Cabot Canal and relocating these receivers would provide improved detection at the Cabot and Spillway ladder entrances and in the vicinity of the confluence of the Turners Falls Dam bypass reach and the Cabot Station tailrace area. In a letter to FERC dated December 8, 2014, FirstLight requested concurrence with the proposed alteration to the study design. In FERC's January 22, 2015 Determination on Requests for Study Modifications and New Studies, it approved the proposed changes to the study plan.

On March 24, 2015, FirstLight held a meeting with stakeholders to further discuss Study No. 3.3.2. The purpose of the meeting was to finalize the flow releases and logistics for the field work. It was agreed that a small group of stakeholders from USFWS, MADFW and NMFS would be available to discuss study flow releases during the study.

On April 22, 2015, FirstLight held a meeting with stakeholders to further discuss Study No. 3.3.2, among other studies. The primary issue discussed was the gatehouse entrance antennae, which originally malfunctioned, but became operational on April 24, 2015.

On March 8, 2016, FirstLight held a "workshop" meeting with stakeholders to explain how it would analyze the data.

The following report details the specific objectives of the evaluation, the methods used, the results and conclusions of the study effort.

1.1 Project Background

Each spring, shad enter the Connecticut River drainage in search of spawning and rearing habitat necessary for their anadromous life history. They migrate inland from marine waters spawning in suitable habitat as they move upstream. American Shad are iteroparous, meaning they spawn more than once in their life time.

During their upstream migration and prior to entering Project waters, shad encounter the Holyoke Dam in Holyoke, MA. The Holyoke Dam provides upstream passage via a fish lift and opens approximately 36 miles of mainstem habitat in the Connecticut River. The Turners Falls Dam (TFD) is the next dam located at approximately river mile 122 in the Connecticut River mainstem. Access to habitat upstream of the TFD began in 1980 when upstream passage was provided via three fishways opening access to an additional 20 miles of habitat, extending to the base of the Vernon Dam in Vernon, VT. An upstream fishway at Vernon Dam was completed and commenced operation in 1981.

The Connecticut River Atlantic Salmon Commission (CRASC) and the Atlantic States Marine Fisheries Commission (ASMFC) have developed management plans designed to enhance shad stocks. Specific management goals within the Connecticut River drainage include:

- Achieve and sustain an adult population of 1.5 to 2 million individuals entering the mouth of the Connecticut River annually.
- Achieve annual passage of 40 to 60% of the spawning run (based on a 5-year running average) at each successive upstream barrier on the Connecticut River mainstem.
- Maximize outmigrant survival for juvenile and spent adult shad.

The ASMFC identifies the following objectives as outlined in their Interstate Fishery Management Plan for Shad and River Herring (American Shad Management) (2010):

- American Shad must be able to locate and enter the passage facility with little effort and without stress.
- Where appropriate, improve upstream fish passage effectiveness through operational or structural modifications at impediments to migration.
- Fish that have ascended the passage facility should be guided/routed to an appropriate area so that they can continue upstream migration, and avoid being swept back downstream below the obstruction.
- To enhance survival at dams during emigration, evaluate survival of post spawning and juvenile fish passed via each route (e.g., turbines, spillage, bypass facilities, or a combination of the three) at any given facility, and implement measures to pass fish via the route with the best survival rate.

Successful spawning, juvenile production and effective passage and access to spawning and rearing habitat are necessary to help achieve shad management restoration goals for the Connecticut River.

1.2 Objectives

In 2015, FirstLight conducted a telemetry based study to investigate the behavior, approach routes, passage success, survival, and delay of American Shad as they encounter the Turners Falls Project and Northfield Mountain Pumped Storage Project (NMPS) during both upstream and downstream migration. The study was designed to evaluate the effects of the Turners Falls and NMPS Projects on adult shad migration with the following specific objectives:

- Describe the effectiveness of the Cabot fish ladder;
- Evaluate attraction, entrance efficiency and internal efficiency of the Gatehouse ladder;
- Identify migration delays resulting from operation of the Turners Falls Project;

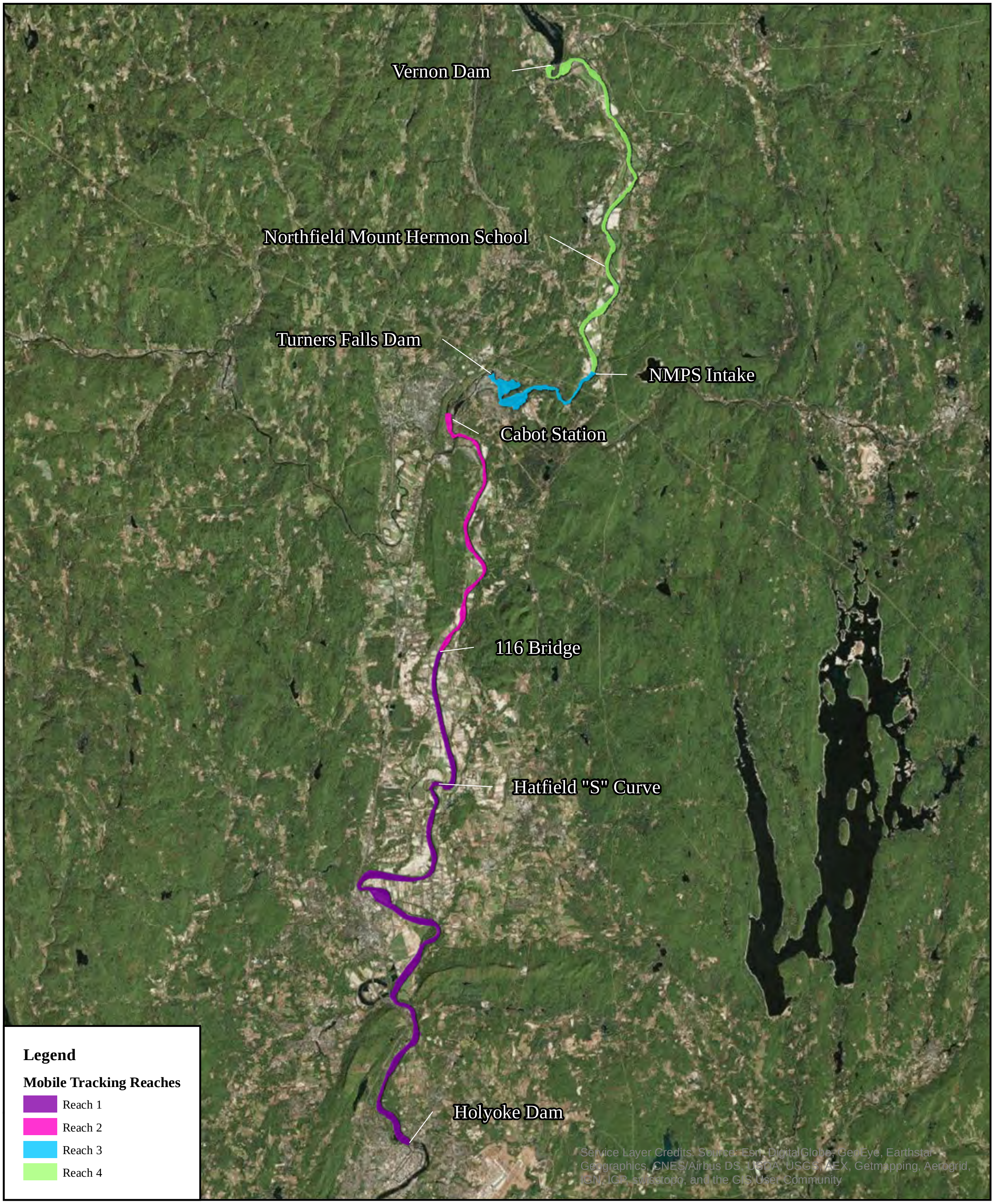
- Determine route selection and behavior of upstream migrating shad at the Turners Falls Project under various spill flow levels;
- Evaluate attraction, entrance efficiency and internal efficiency of the Spillway ladder for shad reaching the dam spillway, under a range of spill conditions;
- Evaluate migration through the Turners Falls Impoundment (TFI);
- Identify impacts of Northfield Mountain, Cabot Station and Station No. 1 operations on upstream and downstream adult shad migration, including delays, entrainment, behavioral changes and migration direction shifts.
- Estimate downstream passage route selection, timing/delay, and survival at Turners Falls Dam; and
- Estimate passage rates and routes taken by shad migrating downstream through the canal, and evaluate Cabot Station fish bypass effectiveness.

2 STUDY AREA

The study area generally consisted of the Connecticut River extending upstream from the Holyoke Dam to the Vernon Dam located in the towns of Holyoke, MA and Vernon, VT, respectively (Figure 2-1). For the purposes of this study, the study area was divided into multiple reaches for the analysis and presentation of results to inform on specific questions as described in the objectives. Collectively the study area is referred to as the telemetry network, which was segmented into a series of subnetworks, each containing various fixed monitoring stations that were used to evaluate specific elements of shad migration.

For the purposes of analysis and presentation of results of the mobile tracking effort, the study area was divided into the following reaches with the exception of the bypass reach:

- **Reach 1** extended from the Holyoke Dam (RM 85) to the Route 116 bridge (RM 111) in Sunderland, MA;
- **Reach 2** extended from Route 116 bridge (RM 111) in Sunderland, MA to the Cabot Station (RM 120);
- **Reach 3** extended from the TFD (RM 122) to the NMPS intake (RM 127); and
- **Reach 4** extended from the NMPS intake (RM 127) to the Vernon Dam (RM 142).



Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)
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Figure 2-1: Overview of the study area extending from the Holyoke Dam to the Vernon Dam.

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3 METHODS

The methods used in this evaluation were developed in consultation with state and federal resource agencies and stakeholders. A collaborative approach was employed and included additional study scoping meetings as described above, as well as data analysis workshops with stakeholders to present the proposed data analysis methods, address comments, and gain agency concurrence.

3.1 Review Existing Information

Data have already been collected at the Turners Falls Project from multiple years of passage assessments conducted for FirstLight by the United States Geological Survey (USGS) S.O. Conte Anadromous Fish Research Center (Conte Lab) researchers. Data were also collected in 2011 and 2012 during a USFWS telemetry study conducted over the full range of their Connecticut River migration season from the mouth of the river to above Vernon Dam. Review of the data has led to a collaborative effort between Conte Lab and FirstLight to develop more rapid telemetry data reduction techniques. These techniques were used to analyze the telemetry data collected during this study. In addition, the history of the passage of anadromous fish (primarily American Shad and Atlantic Salmon) at the Turners Falls Project since 1980 was compiled and submitted May 29, 2016 in the Final Application for New License, Exhibit –E (*Pages E 162 to E 168*). Regulatory events, fish passage, passage evaluation, and changes in infrastructure and operations were summarized and discussed.

3.2 Study Design and Methods

Beginning in March 2015, FirstLight installed and tested passive and active radio telemetry monitoring equipment within the study area. Mobile tracking was conducted throughout the entire study area, with the exception of the Power Canal and bypass reach, whereas fixed monitoring stations were confined to the area between the Route 116 Bridge in Sunderland, MA and the Shearer Farms area located midway in the TFI. Fixed monitoring stations were located and designed to answer specific questions as defined in the study objectives. Mobile tracking was conducted to inform on migration and mortality events between fixed stations.

This study was coordinated with concurrent study efforts occurring at TransCanada Projects located upstream of the Turners Falls and NMPS Projects on the Connecticut River. Radio tag parameters, frequencies and codes were coordinated such that both study efforts could take advantage of tagged shad to maximize sample size.

Concurrently with the telemetry study, FirstLight monitored upstream passage of adult shad at the three fishways, as it and its predecessors have typically done for decades. Monitoring consisted of video surveillance. In 2015, the fishways were operated under normal operational parameters at TFD including a 1-ft differential at the entrances to the fish ladders.

3.2.1 Telemetry Network

FirstLight deployed and tested 29 radio telemetry monitoring stations within the study area (Table 3.2.1-1). Radio telemetry monitoring was achieved through the use of Orion receivers, manufactured by Sigma Eight, and SRX400 and SRX800 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-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 at intakes and 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 can move through quickly. As such, Lotek receivers were used in areas requiring longer range, such as in the TFI where fish are unlikely to move through the monitoring area without detection due to frequency switching. Lotek receivers were programmed to switch frequencies at a 2.2 second interval with a total scan time of 11 seconds for the five frequencies used in the study. The telemetry receivers were powered by 12 volt deep cycle batteries, which were maintained via AC or solar powered chargers.

Fourteen PIT monitoring stations were deployed within the three fishways: Cabot, Spillway and Gatehouse. The half-duplex PIT readers were manufactured by Oregon RFID and antennas were built onsite. Table 3.2.1-1 summarizes the location of the monitoring stations, their identification number and the equipment used.

The radio telemetry monitoring network was designed to: a) monitor tagged shad as they migrated upstream and downstream within the study area; b) document the route of passage through the Turners Falls Project; c) document occurrences of entrainment at Cabot Station and Station No. 1; and d) document presence in the NMPS Project intake area and upper reservoir. The monitoring zones achieved by the telemetry technologies are presented in Figures 3.2.1-1 through 3.2.1-9. Prior to initiating the study, all monitoring locations were tested for calibration to ensure that the desired zones were achieved. The results of the calibration effort are detailed in Appendix A.

The telemetry network model is illustrated in Figure 3.2.1-10. For the purposes of analysis, the telemetry network model was divided into 15 subnetworks to answer specific questions as detailed in the objectives. Table 3.2.1-2 describes the intent of the sub-model, its spatial extent and associated monitoring stations, and the analytical approached employed.

3.2.2 Adult Shad Collection and Tagging

Shad used in the evaluation were collected at the upstream fish passage facilities at the Holyoke Dam and within the Cabot fish ladder at the Turners Falls Project using the existing fish trapping facilities. Shad tagging at Holyoke consisted of multiple cohorts that were tagged and released in the Holyoke fish lift exit flume as well as cohorts that were transported, tagged and released in the TFI, approximately 1,200 ft. upstream of the TFD. Shad tagging at the Cabot fishway consisted of multiple cohorts that were tagged and released in the Power Canal, immediately upstream of the fishway exit, and within the TFI, approximately 1,200 ft. upstream of the TFD.

Additional shad were tagged by the TransCanada study team. 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 size. TransCanada collected shad at the Holyoke Dam fish lift and at the Vernon Dam fishway and release occurred at the Pauchaug Brook Boat Launch in Northfield, MA (TFI Impoundment) and Old Ferry Boat Ramp in Brattleboro, VT (Vernon Impoundment) (TransCanada 2016).

Shad were tagged immediately prior to release. For those shad that were trucked to the release locations, tagging was conducted at the release site. Test shad were transported via a customized shad hauling truck leased from the USFWS (Figure 3.2.2-1). The transport truck contained a 500 gallon circular holding tank. A current was maintained in the tank via two gas powered recirculating pumps such that the shad could orient within the current. Salt was added to the tank to reduce osmoregulatory stress. Water quality was monitored and oxygen concentration was maintained at a high level (≥ 100% saturation) via an oxygen diffusor. No more than 60 shad were hauled at one time to minimize transport and overcrowding stress.

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 3.2.2-2). Data were recorded on a dedicated field book and included: water quality, gender, 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 five frequencies: 149.720, 149.780, 149.800, 150.440 and 150.540 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 6 hours. The period of relative motionlessness was initially set for a period of 24 hours for the first release cohort. However, this period was reduced to 6 hours for all subsequent releases based on discussions with and recommendation by Conte Lab personnel. The concern was that a 24-hour period may be too long to expect motionlessness in a riverine study. PIT tags used in the study were read-only with a 64 bit unique ID (ISO 11784/11785 compatible) and measured 32 mm in length.

3.2.3 Project Operation and Environmental Data

A series of proposed test flows were released in the Turners Falls bypass reach during this study as agreed during agency consultation. The purpose of the flow releases was to investigate how bypass flows may affect shad migration into and through the bypass reach. Flows ranging between 2,500 and 6,300 cfs were evaluated. Flows were proposed to be tested for 3-day periods in May and June. However, the stakeholders agreed it may not be possible to provide the planned flows as there is no way to predict river flow. A smaller group of stakeholders from USFWS, MADFW and NMFS was available to discuss study flow releases during the study. During the study period, there were many days where FirstLight and the stakeholders discussed the best flow scenarios.

During May, flow scenarios ranged from 2,500 to 6,300 cfs as these flows have been identified for successful spawning for ESA-listed Shortnose Sturgeon (Kieffer & Kynard, 2012). Following the Shortnose Sturgeon spawning period[1], lower flow releases of 1,000 and 1,500 cfs were tested in June and the first half of July.

Relevant operations and environmental data were collected including river flow, generation (MW), water temperature and dissolved oxygen. These parameters were monitored continuously at fifteen-minute intervals throughout the study period. Water quality was monitored within the Turners Falls bypass reach immediately upstream of the Station No. 1 tailrace using a HOBO U26 Dissolved Oxygen Logger equipped with a dissolved oxygen and temperature sensor. In addition, water quality was periodically monitored using a YSI 556 water quality meter at various locations throughout the study area; data were recorded in a dedicated field notebook and include sample location, date, dissolved oxygen (mg/L), pH, conductivity (µS/cm), and water temperature (°C). Operations data were systematically collected and archived by FirstLight using a Supervisory Control and Data Acquisition system (SCADA).

3.2.4 Sample Size

A total of 551 shad were detected during the study, Each separate analysis included assumptions and a specific sub-network of the study area. Therefore, the final sample size (N) for each test is listed in the results.

3.2.5 Mobile Tracking and Evaluation of Mortality

Mobile tracking of radio tagged shad was conducted weekly between Holyoke and the Mount Herman School. A second day of weekly tracking concentrated on the area between the '*Hatfield S curve*' and the Cabot Station. Mobile tracking was conducted by boat using a Lotek receiver and a directional 3-element Yagi antenna (Figure 3.2.5-1). GPS coordinates of the locations of detected shad were recorded.

[1] Shortnose sturgeon spawning season generally occurs late April through May.

Table 3.2.1-1. Shad monitoring locations and equipment used in the adult shad study.

Station Location	Station ID	RM	Receiver Station
Red Cliffe Canoe Club	T1	86.5	A Lotek SRX receiver with Yagi antenna monitored the full width of the River.
Sunderland Route 116 Bridge	T2	111	A Lotek SRX receiver with a double 3 element Yagi antenna monitored the full width of the River.
Montague Wastewater	T3	119.5	A Lotek SRX receiver with a double 3 element Yagi antenna monitored the full width of the River.
Deerfield River Confluence	T33	119.5	An Orion receiver with Yagi antenna monitored the full width of the Deerfield River upstream of its confluence with the Connecticut River.
Cabot Station Tailrace (near field)	T5	120	An Orion with two Yagi antenna monitored attraction to the Cabot Station tailwater.
Cabot Station Tailrace (far field)	T6	120	A Lotek SRX with Yagi antenna monitored the full river width.
Cabot Fishway	T7, P111, P112, and P12	120	An Orion receiver with dipole antenna and two PIT tag readers monitor the entrance (T7, P111 and P112) and one PIT reader monitored the exit (P12).
Lower Cabot Fishway	T29	120	An Orion receivers with dropper antenna was deployed in the lower fishway at the first slot upstream of the first turning pool.
Cabot Station Forebay	T8	120	An Orion with two Yagi antennas monitor the full width of the canal immediately upstream of the Cabot Station
Cabot Station Downstream Bypass	T9 and P13	120	An Orion with dipole antenna (T9) and PIT receiver (P13) monitored the entrance to the Cabot downstream bypass.
Smead Island complex	T11	120	An Orion receiver and Yagi antenna were used to monitor the west channel of Smead Island complex.
Rawson Island	T12E and T12W	120.5	The east and West channel were monitored using an Orion receiver employing antenna switching between two Yagi antennas.
Mid Canal	T13	120.5	An Orion receiver and Yagi antenna monitored the full width of the canal immediately upstream of canal pool.
Lower Canal	T14	120.5	A Lotek with double Yagi antennas monitored full width of the canal in the vicinity of the Conte Lab intake.
Conte Tailrace	T15	120.5	An Orion with a Yagi antenna was used to monitor the full width of the bypass reach in the vicinity of the Conte discharge.
Downstream of Station No. 1	T18	121	An Orion receiver and Yagi antenna were used to monitor the full width of the canal just downstream of the Station No. 1 power canal.

Station Location	Station ID	RM	Receiver Station
Station 1 Tailrace	T16	121	A Lotek SRX with double Yagi 3 element antennas monitored the tailrace area. The detection zone extended across the wetted bypass reach area.
Station 1 Forebay	T17	121	An Orion with Yagi antenna monitored the full width of the intake canal.
Turners Falls Spillway Fishway	T30, P21, P22, P23SL, P23TP, P24, P25 and P34Z	122	An Orion receiver was used to monitor the fishway entrance with a dipole antenna (T30) and seven PIT tag readers monitor the ladder; 1) Entrance (P21 and P22) 2) Between the ladder entrance and first turn pool (P23SL) 3) At the first turn pool exit (P23TP) 4) At the second turning pool exit (P24) 5) Downstream of the counting window (P25) 6) Exit (P34Z)
Below Turners Falls Dam (River Right)	T19	122	An Orion receivers with Yagi antenna monitored the area below the dam on the north side of the river.
Below Turners Falls Dam (River Left)	T20	122	An Orion receivers with Yagi antenna monitored the area below the dam on the south side of the river.
Upper Canal	T21	122	An Orion with a Yagi antenna monitored the full width of the canal located approximately 1200 ft downstream of the Gatehouse in the upper canal.
Gatehouse Ladder	T22, P34, P31, P32, and P33	122	An Orion receiver with dipole and Yagi antenna monitored the Gatehouse entrance and canal immediately downstream of the Gatehouse (T22). Four PIT receivers monitored the Gatehouse Ladder; 1) Entrance (P34) 2) First vertical slot (P31) 3) Last vertical slot (P32) 4) Upstream of the viewing window (P33)
Turners Falls Impoundment	T23	122	A Lotek with double 3-element Yagi antennas monitored the full width of the impoundment.
NMPS Gill Bank	T24	126.5	A Lotek with double 3-element Yagi antennas monitored the full width of the impoundment.
NMPS Intake	T25	127	An Orion with a Yagi antenna monitored the intake area.
Upper Reservoir	T31	127	An Orion with double 3-element Yagi and dropper antennas monitored the intake area.
Shearer Farms (River Left)	T26	127.5	A Lotek with a double 3-element Yagi antenna was used to monitor approximately half of the river width.
Shearer Farms (River Right)	T27	127.5	A Lotek with a double 3-element Yagi antenna was used to monitor approximately half of the river width.

Table 3.2.1-2. The telemetry subnetwork Model employed during the analysis of the adult shad study.

Subnetwork Model	Analysis Objective	Monitoring Station ID	Analytical Method
1. Downstream of Turners Falls Dam	To understand bi-directional movement and residence time within the downstream portion of the project from the Holyoke Dam upstream to Montague Wastewater.	T1, T2 and T3	• Multi State Markov (movement)
2. Montague Spoke	To understand route selection as shad migrate upstream from the Montague area to the Cabot tailwater area and how discharge effects route selection and time-to-event.	T2, T3, T5, T6, T11, T15, and T33.	• Multi State Markov (movement), and • Cox Proportional Hazards Regression (time-to-event/delay)
3. Cabot Ladder Attraction	To understand attraction and delay to the Cabot Ladder under varying bypass flows with competing routes to the lower bypass reach and downstream locations.	T3, T5, T6, T7, T11, T15, T33, P111 and P112	• Multi State Markov (movement), and • Cox Proportional Hazards Regression (time-to-event/delay)
4. Cabot Ladder Internal Efficiency	To understand the internal efficiency of the ladder and ladder entrance.	T5, T6, T7, T29, P12, P111 and P112	• Cormack-Jolly-Seber
5. Cabot Ladder Passage and Delay	To understand overall ladder passage efficiency and delay.	T5, T6, T7, T29, P12, P111 and P112	• Cox Proportional Hazards Regression (time-to-event/delay)
6. Rawson Island and Station No. 1 Delay	To understand passage around and delay at Rawson Island and Station No. 1 under varying bypass flows.	T12E, T12W, T15, T16, T19 and T20	• Multi State Markov (movement), and • Cox Proportional Hazards Regression (time-to-event/delay)

Subnetwork Model	Analysis Objective	Monitoring Station ID	Analytical Method
7. Spillway Ladder Attraction	To understand attraction to the spillway ladder and delay under varying bypass flows.	T19, T20, T30, P21, P22, P23SL, P23TP, P24, P25 and P34Z	• Multi State Markov (movement), and • Cox Proportional Hazards Regression (time-to-event/delay)
8. Spillway Ladder Internal Efficiency	To understand the internal efficiency of the ladder.	T19, T20, T30, P21, P22, P23SL, P23TP, P24, P25 and P34Z	• Cormack-Jolly-Seber
9. Spillway Ladder Passage and Delay	To understand overall ladder passage efficiency and delay.	T19, T20, T30, P21, P22, P23SL, P23TP, P24, P25 and P34Z	• Multi State Markov (movement), and • Cox Proportional Hazards Regression (time-to-event/delay)
10. Cabot Forebay and Downstream bypass	To understand migration delay in the Cabot forebay area and the risk of entrainment.	T8, T9, T13, T14, T18, T21,	• Multi State Markov (movement, • Cox Proportional Hazards Regression (time-to-event/delay)
11. Power Canal	To understand migration routes and delay within the canal and the risk of entrainment at Station No. 1.	T13, T14, T16, T17, T18, T22	• Multi State Markov (movement), and • Cox Proportional Hazards Regression (time-to-event/delay)

Subnetwork Model	Analysis Objective	Monitoring Station ID	Analytical Method
12. Gatehouse Internal Efficiency	To understand the internal efficiency of the ladder.	T22, T23, P31, P32, P33	• Cormack-Jolly-Seber
13. Gatehouse Ladder Passage and Delay	To understand overall ladder passage efficiency and delay.	T19, T20, T22, T23, P21, P22, P23SL, P23TP, P24, P25 T30, P31, P32, P33 and P34Z	• Multi State Markov (movement), • Cox Proportional Hazards Regression (time-to-event/delay)
14. TF Impoundment	To understand migration and delay in the TFI and investigate the risk of entrainment at the NMPS intake.	T23, T24, T25, T26, T27 and T31	• Multi State Markov (movement), and • Cox Proportional Hazards Regression (time-to-event/delay)
15. TF Dam Spoke	To understand route selection during emigration.	T19, T20, T22, T23, P31, P32, P33, P34 and P34Z	• Multi State Markov (movement)

FirstLight Power Resources

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

Evaluate Upstream and Downstream
Passage of Adult American Shad
Relicensing Study 3.3.2

N

0 0.1 0.2 0.4 Miles

Figure 3.2.1-1: Approximate monitoring zone for Station T1

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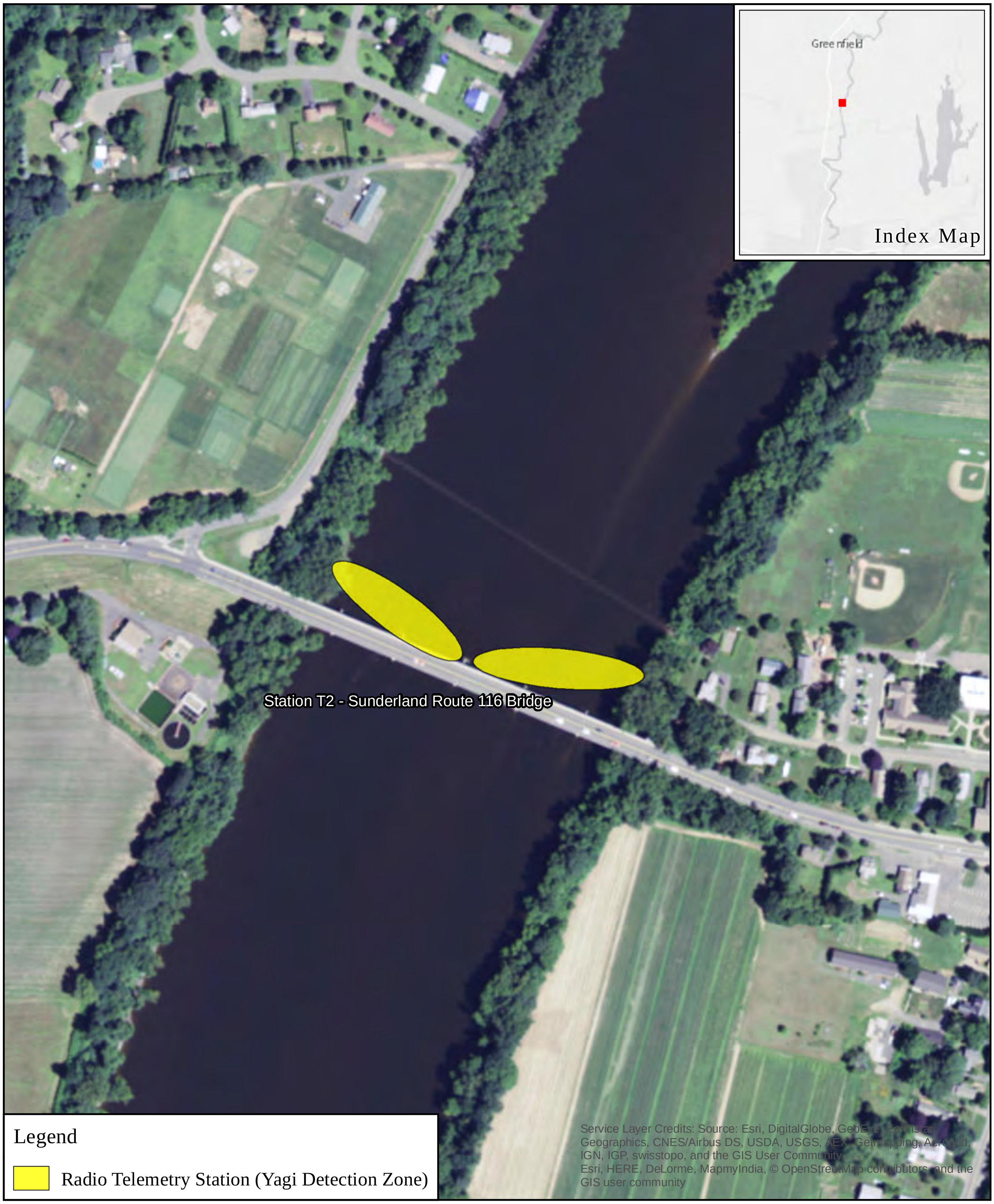

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Northfield Mountain Pumped Storage Project (No. 2485)
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Evaluate Upstream and Downstream
Passage of Adult American Shad
Relicensing Study 3.3.2

Figure 3.2.1-2: Approximate monitoring zone for Station T2

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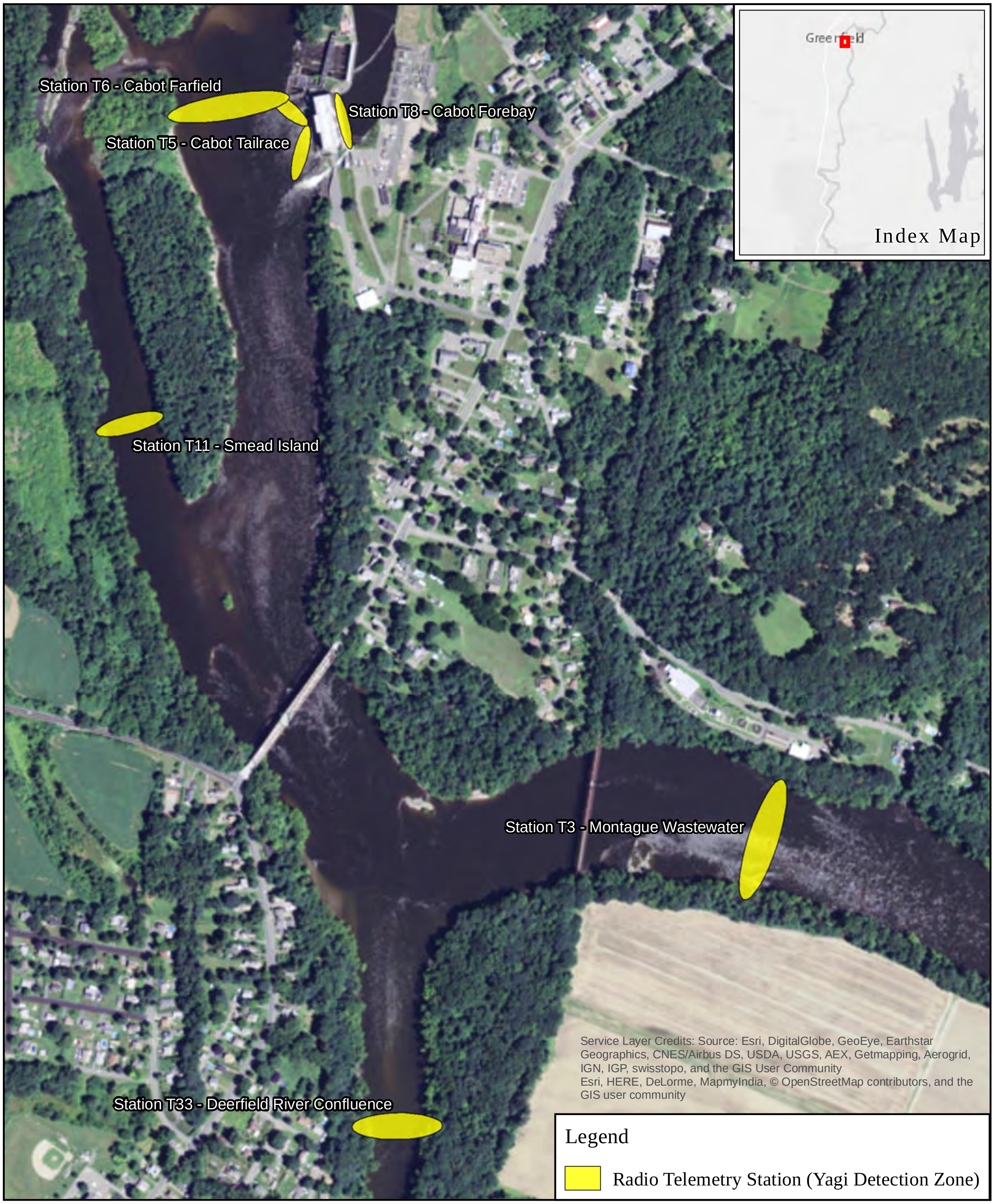

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Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

Evaluate Upstream and Downstream Passage of Adult American Shad
Relicensing Study 3.3.2

Figure 3.2.1-3: Approximate monitoring zones for fixed telemetry stations near Cabot Station

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

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Relicensing Study 3.3.2

Figure 3.2.1-4: Cabot PIT and Dipole/Dropper Locations

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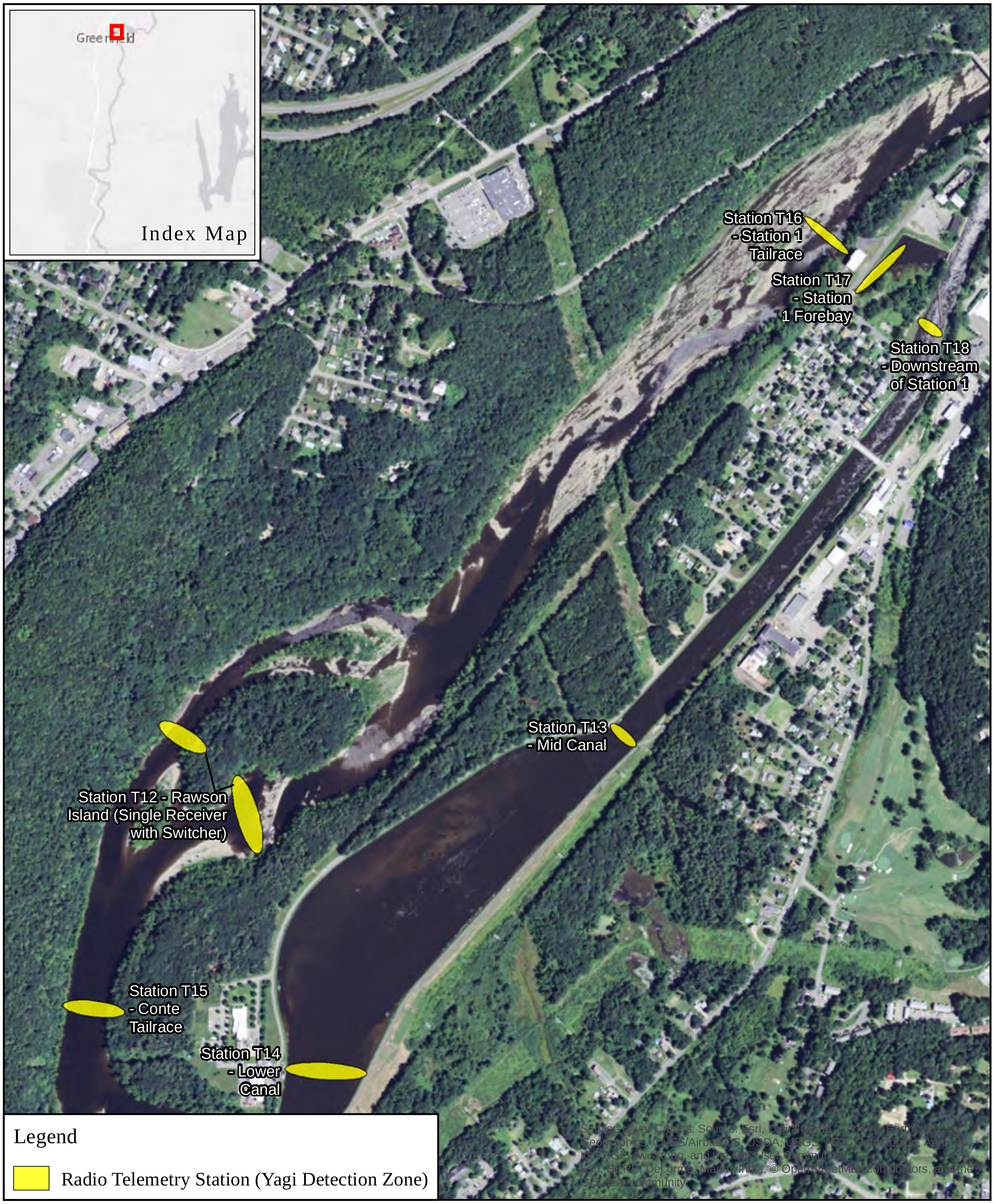

Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)

Evaluate Upstream and Downstream
Passage of Adult American Shad
Relicensing Study 3.3.2

N

0 0.075 0.15 0.3
Miles

Figure 3.2.1-5: Approximate monitoring zones for fixed telemetry stations in the Bypass Reach and Canal

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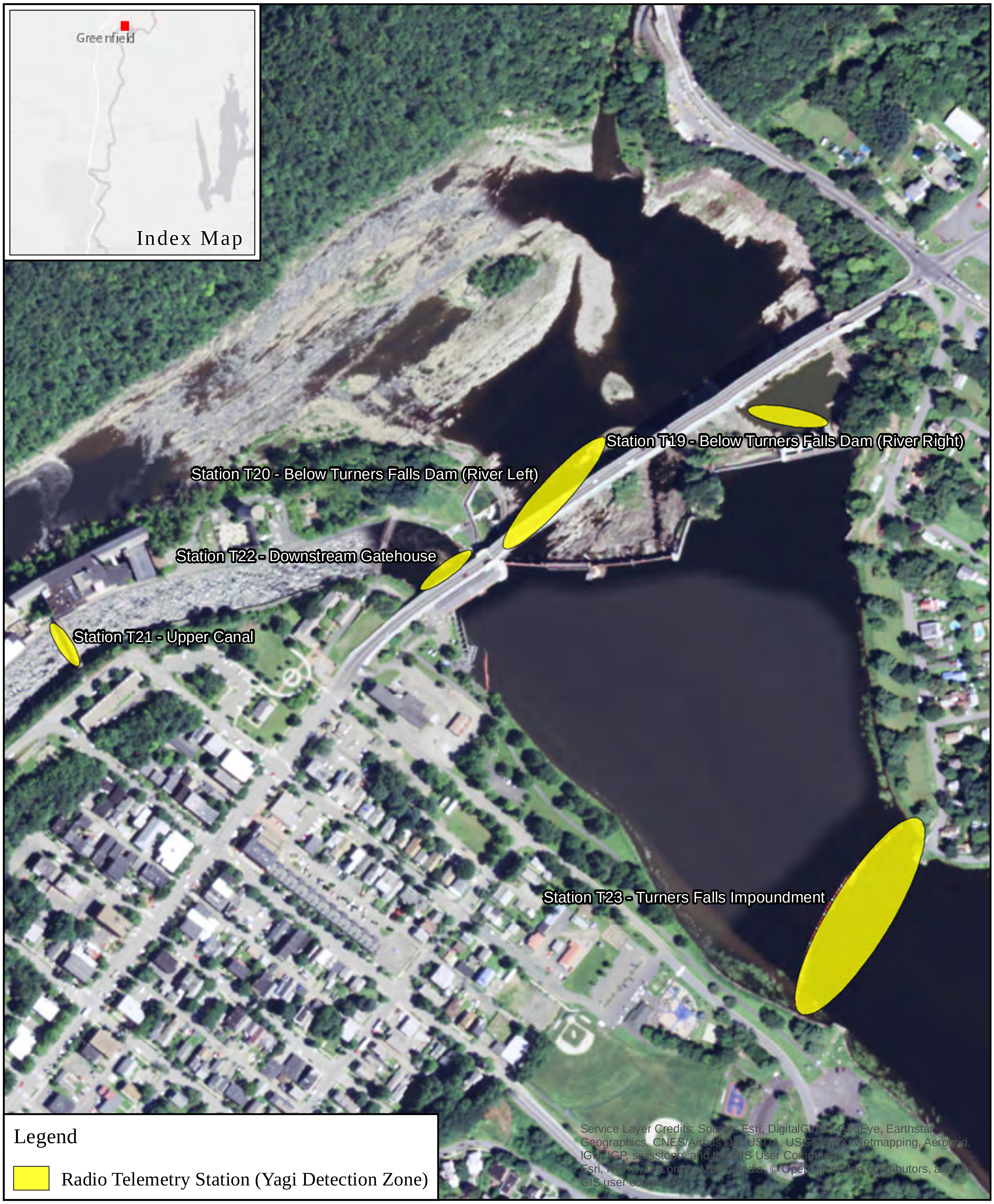

FirstLight Power Resources

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

Evaluate Upstream and Downstream
Passage of Adult American Shad
Relicensing Study 3.3.2

N

0 0.0375 0.075 0.15 Miles

Figure 3.2.1-6: Approximate monitoring zones for fixed telemetry stations near Turners Falls Dam

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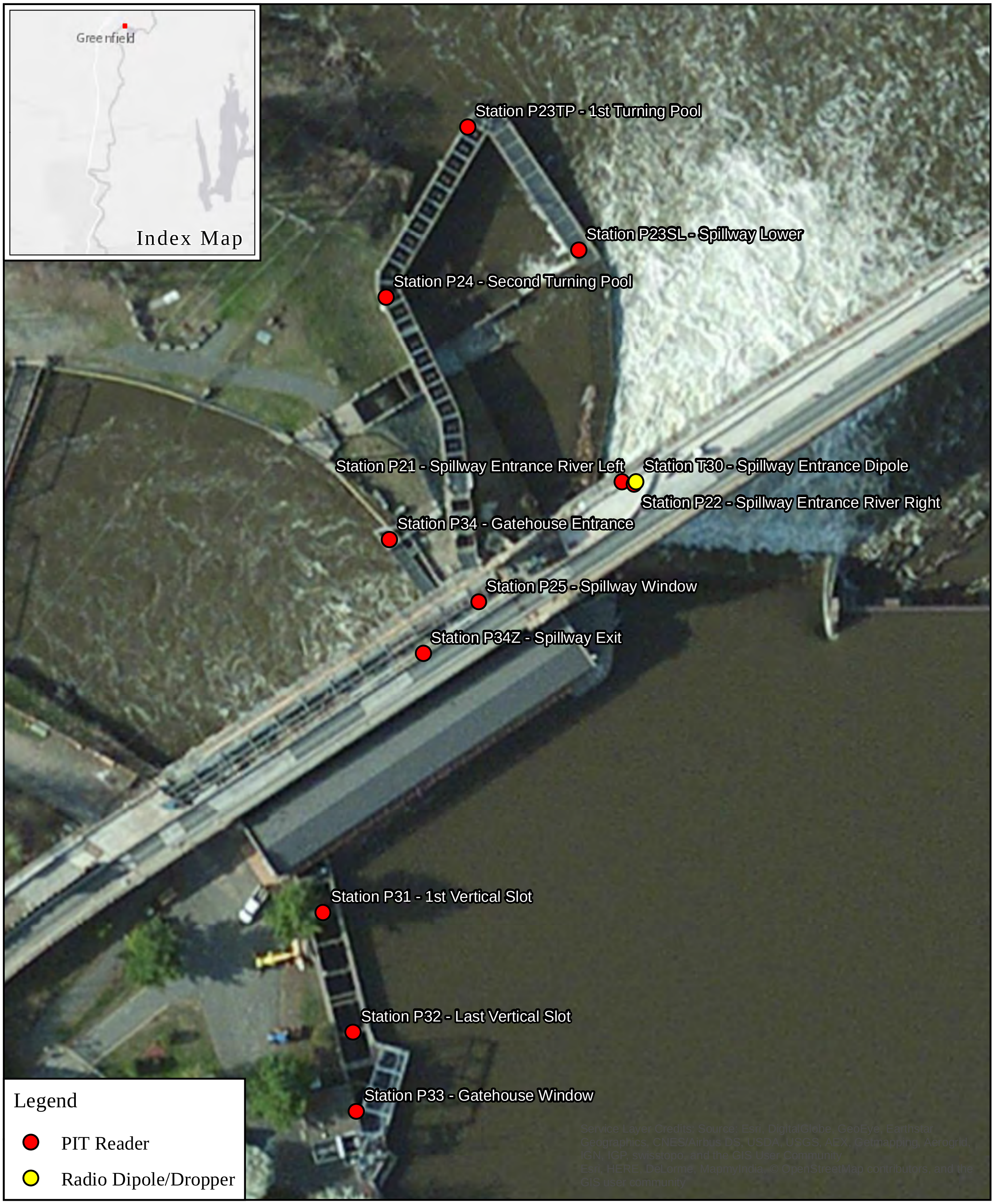

FirstLight Power Resources

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

N

Evaluate Upstream and Downstream
Passage of Adult American Shad
Relicensing Study 3.3.2

0 0.005 0.01 0.02 Miles

Figure 3.2.1-7: PIT & Dipole/ Dropper Locations at Gatehouse

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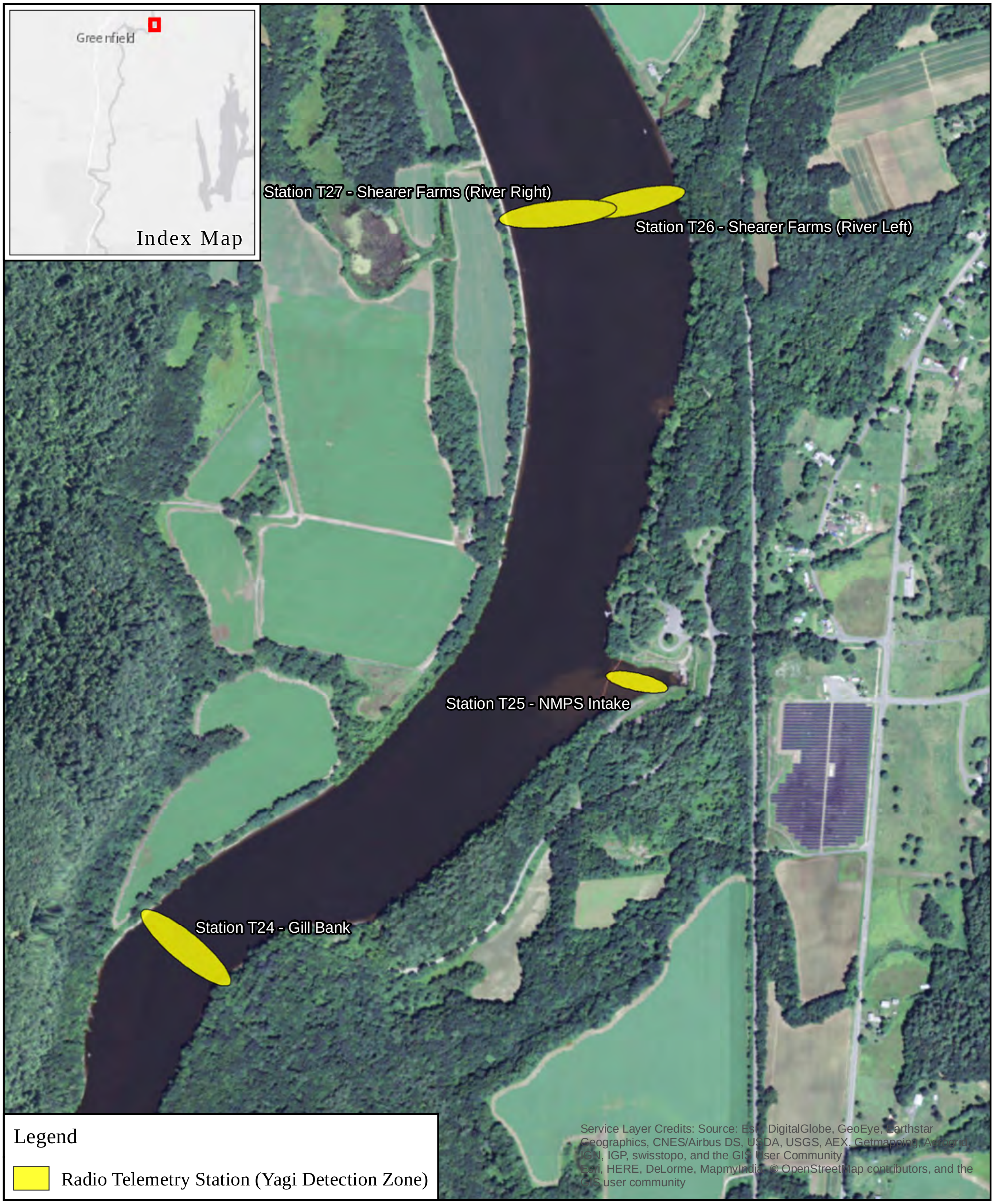

Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

Evaluate Upstream and Downstream Passage of Adult American Shad

Relicensing Study 3.3.2

Figure 3.2.1-8: Approximate monitoring zones for fixed telemetry stations near NMPS Intake

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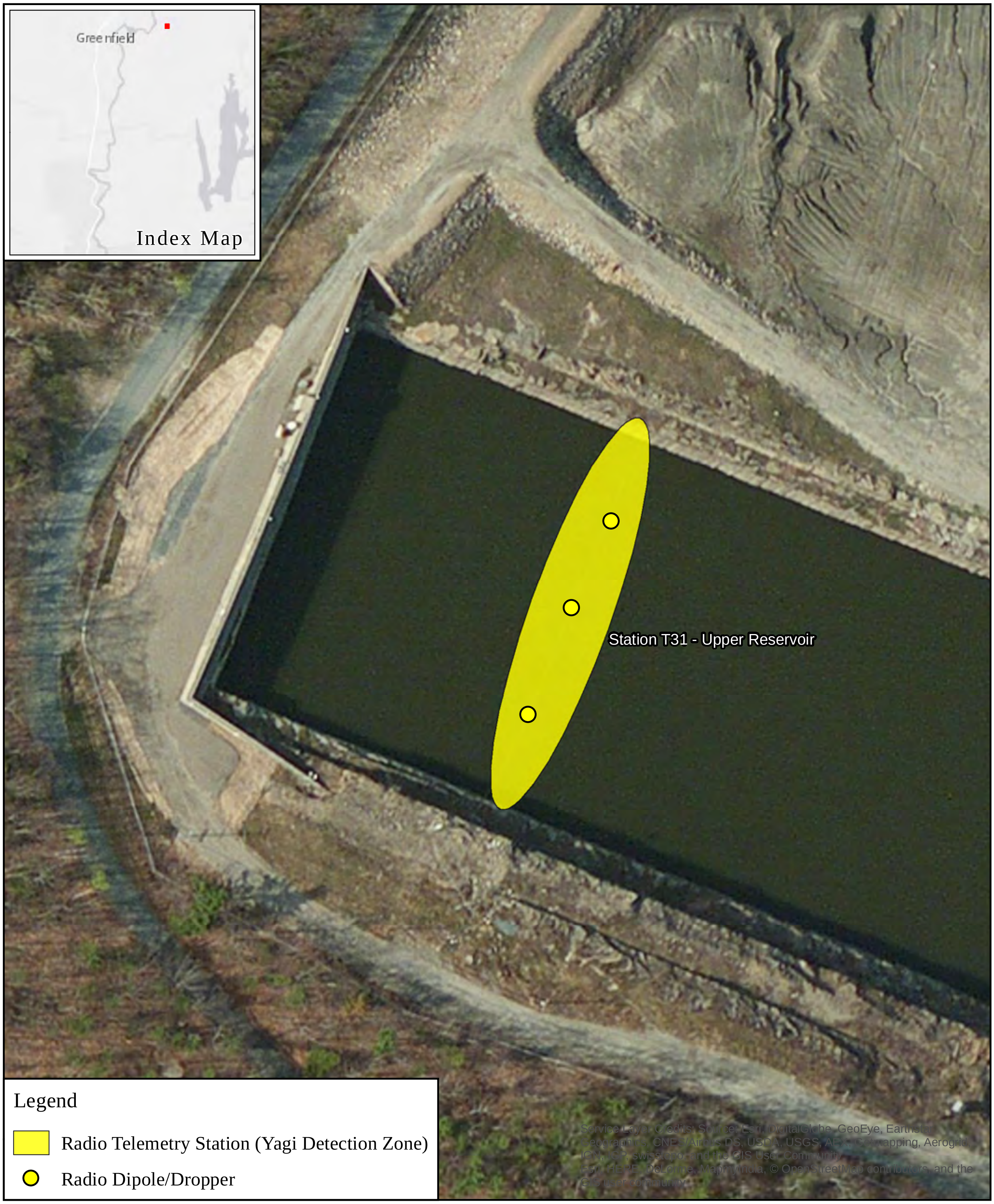

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Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

Evaluate Upstream and Downstream Passage of Adult American Shad Relicensing Study 3.3.2

Figure 3.2.1-9: Approximate monitoring zone for Station T31

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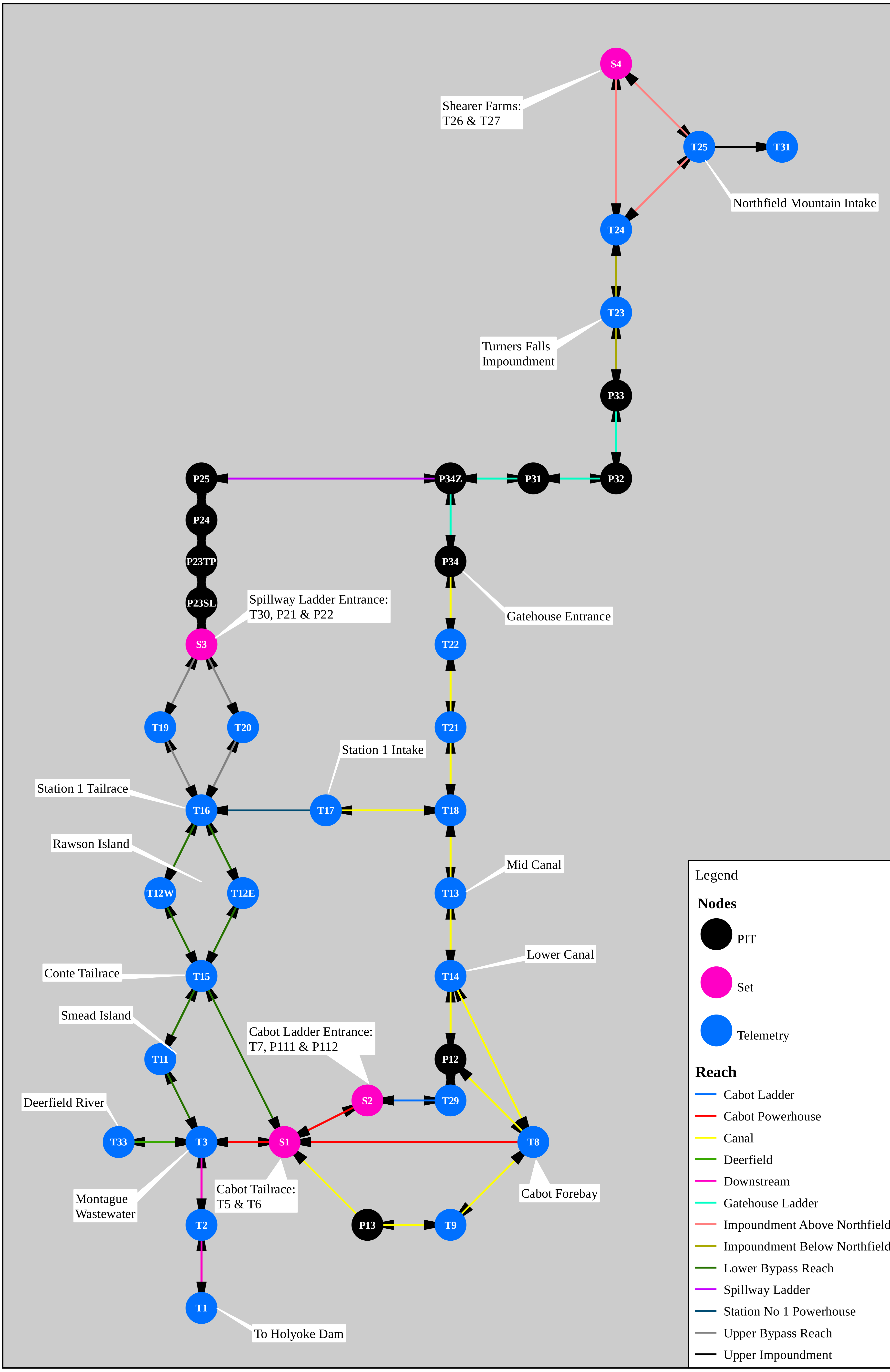

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Turners Falls Hydroelectric Project No. 1889

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Figure 3.2.1-10: Overall Telemetry Network

FirstLight Power Resources

N

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Figure 3.2.2-1. The USFWS haul truck used to transport the shad used in this study.

Figure 3.2.2-2. Shad tagging using radio tags (left) and PIT tags (right) during the adult shad study.

Figure 3.2.5-1. The mobile tracking system used during the adult shad study.

3.3 Data Analysis

The data analysis relied upon four main statistical procedures to understand adult American Shad migration through the project. Hot spot analyses identified spatial clusters in mobile tracking data; multi-state Markov (MSM) models identified routes of passage and enumerated the expected number of visits (forays) to receivers of interest; Cox Proportional Hazards and time-to-event analysis was used to assess delay; and the classic Cormack-Jolly-Seber (CJS) open population mark recapture model assessed the internal efficiencies of the Project's ladders. In essence, the MSM model asks, given a fish's current location, where will it end up next? The Cox regression model explains how a population moves through a telemetered reach in time, and also attempts to determine if the movement rate is a function of the change in system state. The hot spot analysis looks at the spatial distribution of points on a map and identifies clusters, which could point to a significant use of an area over time by the population of tracked fish. Finally, the CJS model incorporates the presence/absence of a fish within a telemetered reach and returns back an unbiased estimate of survival, or in the case of fish ladders, successful passage. Each statistical procedure has its own set of data requirements, assumptions, and limitations, which are explained in detail. However, before a discussion on data analysis, it is necessary to describe the steps required to remove false positive detections from the dataset.

Due to the limitations of Lotek receiver's ability to detect a mortality signal while scanning multiple frequencies (see Section 4.4), mortality was not included as a state in mark recapture, time-to-event or MSM models. However, mobile tracking identified the locations of fish mortalities, which were assessed with a hot spot analysis.

In general, the entrance efficiency of passage structures was assessed by accounting for the fish attempting a structure divided by the fish available to pass said structure. The fish available to pass are defined as those within the general location of the entrance to a passage structure (e.g. Cabot tailrace > Cabot ladder). The internal efficiency of passage structures assessed the efficiency from the entrance to the exit, while the overall efficiency accounted for the entrance and internal efficiency. While passage rates provide an understanding of the overall performance of a structure, it does not account for delay incurred by tagged animals. Therefore, we have also incorporated estimates of delay into each efficiency measure.

3.3.1 False Positive Removal

Radio telemetry receivers' record four types of detections based upon their binary nature; true positives, true negatives, false positives and false negative (Beeman & Perry, 2012). True positives and true negatives are valid data points which 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: they can favor survivability through a project by including animals that weren't there, or they 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. The CJS model accounts for a receivers recapture rate and removes this bias from rates of survival (successful passage) while the MSM model and time-to-event only include data from known detection histories. To remove the bias from false positives we must remove them 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, some of them arbitrary, including power floors, reliance on consecutive detections in series, logical errors in site progression and subjective opinion. We rely upon data and quantitative insight to reduce the amount of subjectivity in the analysis. Therefore, a probabilistic method for false positive data reduction was sought.

3.3.1.1 Probabilistic Data Reduction – Weight of Evidence

Bayes Rule is a rigorous method for interpreting evidence in the context of previous experience or knowledge (Stone, 2013). Bayes rule cannot guarantee the correct answer, but rather provides the probability that each alternative answer (either true or false positive) is correct. Bayes theorem updates conditional probabilities (probability of a record being true positive given some data), and is particularly useful when evaluating diagnostic tests (false positives and false negatives).

Specifically, Bayes rule calculates the posterior probability, or the probability of our hypothesis occurring given some information about its present state, and is written with $P(\theta_i|x_j)$. Where θ_i is our hypothesis (true or false positive) and x_j is observed data. Formally, Bayes rule is:

$$P(\theta_i|x_j) = \frac{P(x_j|\theta_i)P(\theta_i)}{P(x_j)}$$

Equation 1

Where $(x_j|\theta_i)$ is referred to as the likelihood of the j^{th}data occurring given the hypothesis (θ_i), $P(\theta_i)$ is the prior probability of the i^{th}hypothesis (θ), and $P(x_j)$ is the marginal likelihood or evidence. In most applications, including this one, the marginal likelihood is ignored as it has no effect on the relative magnitudes of the posterior probability (Stone, 2013). Therefore, there is no need to waste computational effort by calculating the joint probability. We can state that the posterior probability is approximately equal to the prior probability times the likelihood or:

$$posterior \propto prior * likelihood$$

Equation 2

The prior probability is estimated by looking at how often each class (true or false positive) occurs in the training dataset, while the likelihood is estimated from the histogram of the values of each predictor (observed data) in the training dataset given each hypothesis (true or false positive) (Marsland, 2009). A kernel density function was fit for continuous predictors while qualitative predictors replied upon a multinomial probability distribution.

In most circumstances, the data (x), is usually a vector of feature values or predictor variables with n levels (x_n). As the dimensionality of x increases (number of predictor variables increase), the amount of data within each bin of the histogram of related variables shrinks, and it becomes difficult to estimate the posterior probability without more training data (Marsland, 2009). For example, long strings of continuous detections in series may only occur when the power of a detection is fairly high. Therefore, a simplifying assumption was sought and found in the Naïve Bayes Classifier.

3.3.1.2 Naïve Bayes Classifier

The Naïve Bayes Classifier assumes that the elements (j) of the feature vector x (predictor variables) are conditionally independent of each other given the classification (Marsland, 2009). Therefore, the probability of getting a particular string of feature values of predictor variables is equal to the product of multiplying together all of the individual probabilities (Marsland, 2009). The likelihood is given with:

Equation 3

$$P(x_1, \dots, x_n|\theta_i) = \prod_{j=1}^{n} P(x_j|\theta_i)$$

Where n is equal to the number of features or predictor variables in x and θ_i is the hypothesis (either true or false positive). The classifier rule for Naïve Bayes is to select the detection class θ_i for which the following computation is maximized:

$$argmax\left\{ P(\theta_i|x_n) \propto P(\theta_i) * \prod_{j=1}^{n} P(x_j|\theta_i) \right\}$$

Equation 4

The detection class θ_j with the maximum posterior probability classifies every line of data belonging to a study tag into one of two classes; true or false positive. This is known as the maximum a posteriori or MAP hypothesis (Marsland, 2009).

The constructed Naïve Bayes classifier was nothing more than a database application designed to keep track of which feature gives evidence to which class (Richert & Pedro-Coehlo, 2013). However, there were circumstances where a particular feature variable level did not occur for a given detection class in the feature dataset (e.g. false positive detection with very high power and many consecutive hits in series), meaning that the likelihood for that feature given a detection class is zero. When multiplied together, the posterior probability was zero and uninformative. Therefore, the Naïve Bayes classifier used add-one smoothing, which simply adds 1 to all histogram counts (Richert & Pedro-Coehlo, 2013). The underlying assumption here is that even if the feature value was not seen in the training dataset for a particular detection class, the resultant likelihood probability would be close to zero allowing for an informative posterior.

The training dataset consists of known true and false positive detections. By sacrificing study tags and placing them at strategic locations throughout the study area for the duration of the study, 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 towards 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 received 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 3.3.1.2-1).

Note from Table 3.3.1.2-1 that both detection history events are considerably different, but they have the same hit ratios. However, the derived consecutive record length features are not the same. 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. Consecutive detections, and detections in series are binary in nature and quite similar, but the consecutive detection feature was stricter. For consecutive detection to return as true, either the previous or next detection must occur within the next pulse. Detections in series allows the previous or next detection to occur at intervals greater than the first pulse, however recaptures need to be in series. For example, if the pulse rate is 3 seconds and the next consecutive detection was missed, series hit would return true if the next recorded transmission occurred on the 6th or 9th second. In other words, the pulse rate must be a factor of the difference in time between the present detection and next detection for a series hit to return true. The last predictor, power, is hypothesized to be higher for true detections than false positives.

3.3.2 MS Access Data Management

Quality assurance and quality control (QAQC) procedures were conducted for each receiver, and consisted of randomly selecting 50 American Shad and checking 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, than a recapture was deemed false positive. Further, if the calculated hit ratio for any 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 reduction, site specific information was exported and aggregated into a system wide recaptures database. The recapture history of each specimen could then be examined through space and time with a 3D visual inspection tool (Figure 3.3.2-1). Figure 3.3.2-1 shows the history for the fish with the frequency and code (149.800 – 30), a 500 mm female shad released at Holyoke on May 6, 2015. This fish migrated through the first two reaches of the study area and passed relatively quickly through the Cabot ladder and into the power canal where it exhibited substantial back and forth movement (milling) in the canal. The fish eventually passed through the Gatehouse ladder and into the TFI where it appears to have spent nearly a month (30 days = 700 hours). The fish then outmigrated through the canal where it faced relatively little delay and passed through the powerhouse. These figures identified illegal, improbable, or improper movements between reaches, and allowed the researcher to identify stretches of time in the recaptures database that were false positive detections. Examples of "illegal" movement include cross chatter, where an animal would be in the bypass reach, but large aerial Yagi antennas in the canal would pick up the fish. Because the detections coming into the canal Yagi appeared to be good detections, the algorithm identified them as true positive. Therefore, the visual inspection step proved 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. To understand this milling behavior, the lag between detections for each fish within each river reach was calculated. These lag times were then binned into 30 second categories, and the frequency of detections occurring within each bin was enumerated. The plot of lag bin vs count provides the researcher with a picture of fish behavior in front of each receiver. Long lags between consecutive detections identify when a fish has left the reach only to come back, while short lags mean the fish is present and able to pass the structure (Personal Communication with Ted Castro-Santos). Research has shown that these lag frequency plots can identify up to three behaviors of interest to the researcher (Personal Communication with Ted Castro-Santos), therefore a brute force algorithm was created that fit a series of three piecewise linear equations to each lag frequency plot that minimized regression error. The algorithm chose the series of equations with minimal error, which provided the bounds between lag bins and thus categorized behavior. The boundary between the second and third piecewise equation was taken to be the break in behavior, i.e. when a fish has abandoned a reach only to come back and try it again. This break in behavior signifies when a fish is present at a receiver, in other words it is a new attempt. Following the brute force algorithm, Kleinschmidt inspected the results and provided QAQC. There were scenarios where there was no evidence to suggest that a fish left a telemetered reach (especially a ladder), but the algorithm calculated a new visit to the location because of the duration between recaptures. Therefore, we scrutinized every ladder event and manually adjusted event enumeration when required.

3.3.3 Analysis of Mortality and Maximum Upstream Extent

The maximum upstream extent (maximum latitude) by fish and the first observed mortality detections determined where fish turned around and where fish died, respectively. An SQL query identified the maximum latitude obtained by Holyoke-released fish recaptured during mobile tracking. As a QAQC procedure, fish were removed from this analysis if they were recaptured at a stationary receiver upstream of the maximum latitude as recorded during mobile tracking. The mortality hot spot analysis used the location of the first mortality. The Getis-Order Gi* Hot Spot Analysis employing the Optimized Hot Spot tool within ArcGIS determined if any locations within the study area had clusters of these types of detections.

Mortality was also assessed with simple catch-curve mortality methods for downstream migrating fish at the Turners Falls Project. Fish migrating downstream through hydroelectric projects are subjected to a complex suite of physical and biological stressors that may contribute to delayed mortality after passing through project features (Budy *et al.*, 2002). In order to gain an understanding of passage-related mortality associated with the downstream movement of shad through the Turners Falls Project features, linear regression, adapted from catch-curve mortality estimates described in Miranda and Bettoli (2007), were used to calculate the daily mortality rates of mobile-tracked fish that passed through project features. Similarly, linear regression was used to calculate mortality rates per river mile, in order to examine the relationship between mortality of mobile-tracked fish after passing a specific project feature and distance traveled downstream from the particular project feature in question. Finally, linear regression was used to calculate daily mortality rates of mobile-tracked fish that we released at Holyoke but did not pass through Turners Falls Project features to serve as a reference for natural mortality of emigrating shad in the system. It was not possible to account for mortality of fish that migrated out of the project area; therefore, these fish that were detected alive at least once were considered alive for the entire duration of the study in all calculations of daily mortality.

3.3.4 Analysis of Mark Recapture Data with MARK

Mark recapture survival analysis is typically used to assess passage through fish ladders (Perry, *et al.*, 2012). Use of the term "survival" is standard for mark recapture analysis, which is predominantly used to assess the actual survival of marked animals over time. In this study, survival simply means successful passage, it should not convey mortality. Given that the temporal and spatial horizon is very short for those stretches studied with mark recapture techniques (on the order of hours to less than 1000 ft), mortality was not tested using a mark recapture framework, and no animals found to have died within the stretches of river assessed with mark recapture techniques. However, mark recapture theory terminology was maintained for this assessment; therefore, survival refers to the successful passage of a fish from one receiver to the next. It does not refer to the probability that a fish will die along the way. To estimate survival parameters in the field under natural or anthropogenic conditions, individually marked animals are followed through time (Lebreton *et al.*, 1992). However, it is rarely possible to follow all individuals of an initial sample over time (Lebreton *et al.*, 1992) as is evident by varying recapture rates at each telemetry receiver location. Open population mark recapture models allow for change (emigration and mortality) during the course of a study (Armstrup, McDonald & Manly, 2005). The CJS model is based solely on recaptures of marked animals and provides estimates of survival and capture probabilities only (Armstrup, McDonald & Manly, 2005). The CJS model has the following assumptions:

- Every marked animal present in the population at time (t) has the same probability of recapture (p_t),
- Every marked animal in the population immediately after time (t) has the same probability of surviving to time $(t + 1)$,
- Marks are not lost or missed,

- All samples are instantaneous, relative to the interval between occasion (t) and $(t+1)$, and
- Each release is made immediately after the sample (Cooch & White, 2006).

A fish that has not been observed for some time may have survived and escaped recapture by chance or for biological reasons, its recapture might occur if the study were to continue (Lebreton *et al*., 1992). With this binary state of nature in mind, the presence and absence of animals at each location along a telemetry network is encoded with a string of 1s or 0s denoting presence and absence, respectively. To properly assess survival with variability in recapture, more parameters are required.

Under the assumption of independence of fates and identity of individuals, the observed detection history strings are an observation of a multinomial probability distribution (Lebreton *et al*., 1992). The method of maximum likelihood estimation was used to estimate the parameters in the model (Lebreton *et al*., 1992). The statistical likelihood is the product of the probability of observing a particular detection history given release over those capture histories actually observed (Lebreton *et al*., 1992). More than one animal may have the same recapture history; therefore, the number observed in each recapture history appears as an exponent in its corresponding probability likelihood statement (Lebreton *et al*., 1992). MARK uses the profile likelihood estimation of variance to construct the a = 0.05 confidence intervals (Cooch & White 2006). Consequently, the shape of the log-likelihood function estimated by the maximum likelihood procedure provides information on the precision of the estimators (Lebreton *et al*., 1992). Profile likelihood intervals have better coverage with small samples and because the distribution of estimators are often very non-normal and the parameter space has boundaries [0, 1] (Lebreton *et al*., 1992).

In accordance with Lebreton et al. (1992) and Cooch & White (2006), the following model creation and selection procedure was followed for analysis of survival through the Projects:

1. Build a global model compatible with the biology of the species studied and with the design of the study,
2. Assess model fit using appropriate goodness of fit (GOF) measures,
3. Select a more parsimonious model using Akaikes Information Criteria (AIC) to limit number of formal tests,
4. Test for the most important biological questions by comparing this model with neighboring ones using likelihood ratio tests, and
5. Obtain maximum likelihood estimates of model parameters with estimates of precision.

The first step is to build a saturated model, which is loosely defined as the model where the number of parameters equals the number of data points or data structures (Cooch & White, 2006). The saturated model estimated a survival (ϕ) between each facility location and recapture (p) probability at each facility relocation location (Figure 3.3.3-1). It is not possible to differentiate between the final survival (ϕ_5) and recapture station (p_4) because it is not known if an animal died or was simply not recaptured at the final telemetry station. Following the creation of the saturated model, goodness of fit testing was performed.

Next, Goodness of Fit (GOF) procedures tested the assumptions underlying the models we are trying to fit to the data. GOF is a necessary first step to ensure that the most general model adequately fits the data (Cooch & White, 2006). To accommodate for lack of fit, we needed a measure of how much extra binomial noise (variation) is in the data, this is known as the variance inflation factor or $\hat{c}$ (Cooch & White, 2006). The internal MARK program RELEASE assessed goodness of fit for CJS model and consists of two important tests, Test 2 and 3. Test 2 deals with those animals known to be alive between time t and $t+1$ and tests the assumption that all marked animals should be equally detectable at location $t+1$ independent of whether or not they were captured at occasion t. Test 3 tests the assumption that all marked animals alive at t have the same probability of surviving to $t+1$. If the resultant χ^2tests are significant, the assumptions are violated. Further, if the overall GOF test proves significant, it is necessary to assume the assumptions are violated. If the assumptions were violated, the Median-$\hat{c}$ procedure within MARK estimated the variance inflation factor and the models were adjusted accordingly. After adjustment or non-significant GOF, a series of reduced models were created: reduced survival and individual recapture $(\phi.p(t))$, individual survival and reduced recapture$(\phi(t)p.)$), reduced time and reduced recapture $(\phi.p.)$.

Following model creation, model selection starts with comparing AIC values and then computing Likelihood Ratio Tests. Model selection is important as parsimony is desired. Therefore, models relating sample data and population parameters should contain enough parameters to account for all of the significant variation (Lebreton *et al.*, 1992). An important tradeoff exists between the number of parameters in the model and sampling variance (Lebreton *et al.*, 1992). The goal in model selection is to identify a biologically meaningful model that explains the variability in the data but excludes unnecessary parameters. The AIC is a measure of the relative quality of statistical models for a given set of data and provides a means for model selection. The lower the AIC, the more parsimonious the model (best fit with fewest parameters). However, the AIC value should not be the deciding factor, especially when hypothesis testing is available with other techniques. The likelihood ratio test compares a restricted model nested within the full model. If the likelihood ratio test is significant, there is evidence to suggest for variance in survival between stations. Once the final model was chosen, MARK provides estimates of critical survival (ϕ) and recapture (p) ratios.

3.3.5 Multi State Markov (MSM) Modeling

The multi state Markov (MSM) modeling method quantifies movement between states (locations) in continuous time. The resultant movement probabilities are actually the joint probability of a fish surviving, transitioning and being detected at the next receiver. Thus, estimates may be biased (underestimate movement) if the detection probabilities at a receiver or reach are critically low. The precision in the estimate will also suffer under low probabilities of detection, and the (a = 0.05) confidence interval is expected to be large. To alleviate low detection probability, telemetered reaches were aggregated together whenever possible because it was highly unlikely for a fish to transfer through multiple receivers without being detected. For example, Cabot ladder consisted of receivers T7, P111, P112, T29 and P12. Presence at any one site would mean the fish was present in the entire ladder. The receivers used for each reach analysis and their associated states are listed in the results section. The MSM model has a number of assumptions and data requirements.

Data for MSM consisted of observations (recaptures) that were assumed to occur at exact times because the telemetry equipment allowed for continuous, uninterrupted observation. The Markov assumption for the model states that the future evolution only depends on the current state (Jackson, 2011). The “msm” R package allows individual-specific or time dependent covariates to be fitted to transition intensities, thus we were able to quantify the probability that a marked animal survives, transitions and is detected between locations under different operational scenarios. Time dependent covariates are assumed to be piecewise constant between recaptures. The MSM procedure requires data in the counting process style, with a variable describing the first recapture for a fish and a variable describing the time between subsequent detections and the first detection. Therefore, only fish with known detection histories contribute to the estimate. Further, MSM requires more than 1 observation and transition per fish. Therefore, if a fish was only recaptured once and/or only at one telemetry station for an hour or less, it had to be removed from analysis. Once formatted, data was imported into R for use with the *msm* package.

A useful way to summarize multi-state data is a frequency table of pairs of consecutive states, called the state table. The state table counts all individuals, and the number of times an individual had an observation in one state (from) followed by an observation in another state (to). The count of individuals from and to the same site represent the number of times marked animals were recaptured within an hour. Large from-to counts at a particular site means that animals spent considerable time at a site before transitioning. Transitions are assumed to be instantaneous, and are never recounted. This table is useful to describe the total number of forays into specific reaches, however it should be noted that it is representative of the entire population and not individual fish, and may represent more than 1 foray per fish. To fit an MSM model to this state table, we let R calculate the initial transition probability matrix using the *crudeinits* function. These initial probabilities are then fed to the *msm* function, and a likelihood optimizer based upon the Newton-Raphson method quantified state transition intensities. There were instances when the quasi-Newton method failed to converge. In these cases an optimizer based on simulated annealing was applied. A series of models were fit to each location incorporating diurnal cues and operations data (flow) in a method analogous to multiple regression. The best model was determined using a likelihood ratio procedure where nested models (smaller > larger) were tested against each other. The null hypothesis for the likelihood ratio procedure specified no difference between nested models. If the result was significant, we rejected the null hypothesis and concluded that the more complex model explained a significantly larger amount of variance than the simpler model, thus the more complex model was better. Once we were satisfied we had an appropriate model to describe movement, we used the *pnext* and *envisits* functions to describe the probability of where an animal will survive, transition and be detected next given its current location and the expected number of visits (forays) to a station respectively. If there is extensive milling between two locations, the transition probability table will reflect this, and we may find that marked animals are more likely to return to their original location rather than passing through a given structure. Therefore, this probability of transition will be different from the overall rates calculated with a traditional approach that simply calculates the number of successful attempts divided by the number of animals able to pass. Thus the multi-state approach takes into account milling and the total number of forays an animal will make at a structure. Of interest to the study team were the state table, *pnext* table, and *envisits* table (when number of forays was required).

3.3.6 Cox Proportional Hazards Regression Modeling

Following analysis of movement, the assessment of time-to-event (delay) was carried out with Cox Proportional Hazards regression analysis within the survival analysis framework. Survival estimates are an essential compliment to multivariate regression models for time-to-event data, both for prediction and covariate effects (Thomas & Reyes, 2014). Recaptures data for each sub-model were formatted into the "counting process" style and imported into R for use with the "survival" package. Competing models were fit in a procedure analogous to multiple regression modeling, where individual 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 doesn't explain more variance than it does. In other words, the null hypothesis 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 (hazard) of the event occurring. If for example, the model described attraction towards a ladder with a time varying covariate of flow and the hazard ratio > 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 < 1.0 than the instantaneous risk decreases, and the proportion of fish to have passed into the structure at time (t) decreases, thus delay is incurred. The "best" model minimized AIC scores and/or had a significant omnibus statistic ($p < 0.05$) and informative hazard estimate ($HR \neq 1.0$).

Table 3.3.1.2-1. 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

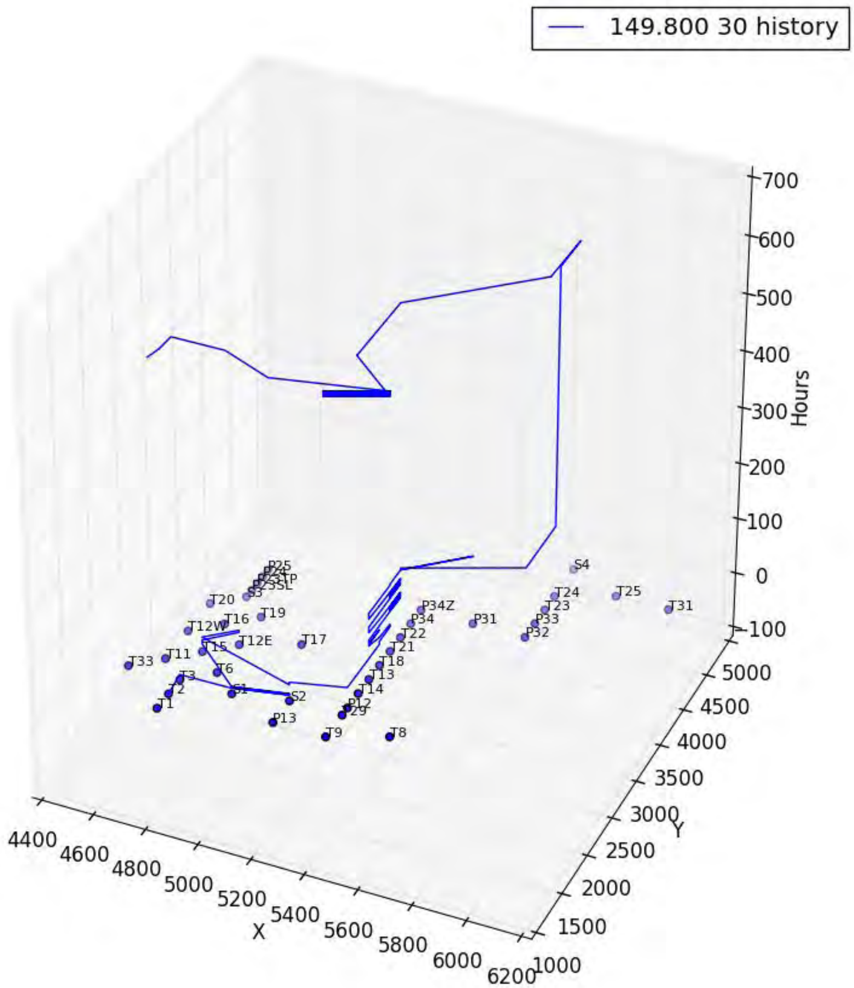

Figure 3.3.2-1. Detection history for shad KA-SHD-0025 with frequency 149.800 and code 30 within the project area.

Note that this fish was released at Holyoke, successfully passed Cabot ladder, was delayed within the power canal, successfully passed gatehouse ladder, spent nearly 700 hours within the TFI impoundment, migrated back through the power canal and passed via the Cabot Powerhouse. The X and Y locations presented on the figure are arbitrary. They are simply the locations of the network nodes in arbitrary space. Note, the node locations are the same on this figure as in Figure 3.2.1-10.

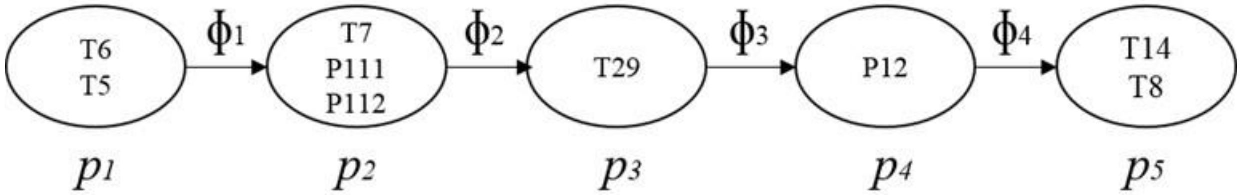

Figure 3.3.3-1. Graphical schematic of the MARK model to assess fish passage effectiveness at the Cabot Fishway showing estimable parameters. Survival probabilities (ϕ_i) are assessed between stations while recapture rates (p_i) are measured at a station.

4 RESULTS

4.1 Receiver Reliability and Missing Fish

This study consisted of a complex network of fixed telemetry stations to monitor and track American Shad through the study area extending from Holyoke Dam in Holyoke, MA to the Vernon Dam in Vernon, VT. A combination of 29 radio telemetry stations and 13 PIT monitoring stations were used to answer specific questions and objectives regarding the movement of 793 tagged shad by FirstLight. While most of the receivers worked well throughout the 61 day study period, there were a few stations that did not perform efficiently. One of the most problematic stations was P34Z, the PIT monitoring station located at the Gatehouse ladder entrance. During calibration and testing this PIT antenna was unable to pick up any consistent read range of detections from the test tag. Field staff made several attempts to tune and re-tune the PIT reader with no success. The reader was then swapped out twice with new equipment, recalibrated and re-tuned each time, however no equipment seemed to work consistently in this location. Throughout the 61 days, the PIT reader was deemed 'malfunctioning' for 14 days from May 8 to May 21, 2015 and did not receive any contacts or detections for 36 days to follow.

The entrance to Spillway ladder contained three monitoring stations (two PIT and one dipole antenna). These stations performed poorly throughout most of the study, the two PIT readers (P21 and P22) only received contacts or detections on 9 out of the 61 days of the study period. The remaining 52 days these stations were either deemed 'malfunctioning,' or simply did not receive any detections when running. The dipole antenna (T30) was not operational from 05/06/2015 to 05/11/2015 and from 05/28/2015 to 06/08/2015. These malfunctions could have potential repercussions when assessing the efficiency of the entrance and the time to ascent for Spillway ladder and Gatehouse ladder. Mark recapture theory allows us to correct for biases at the entrance, but time-to-event analysis will exhibit negative bias when estimating delay because only those fish with complete recapture histories are used. These problems could have been from multiple sources, including and not limited to: power loss, antenna failure due to debris strike, spill inundation from BG 1, data corruption, high noise disruption, and/or hardware/software issues, and are not uncommon to radio telemetry based studies. Field staff were aware of these malfunctions in real time and did make daily/weekly efforts to resolve these issues with limited success. The last problem station was one of the two telemetry stations in the Cabot Tailrace (T5). This receiver was inadvertently programmed to scan only one frequency (149.800) between 05/06/2015 to 05/26/2015. Therefore, no data for fish on the other four frequencies was collected during that timeframe. The remaining days of the study the station was operational and scanning properly on all frequencies. While this antenna was down for a number of weeks, it does not impact the analysis of data, because T5 and T6 were always grouped together into one analysis state, aka the Cabot Tailrace. Collectively, these station errors and malfunctions can explain some of the poor efficiency in recapture data around Spillway and Gatehouse ladder entrances. A full calendar of equipment effectiveness can be found at the end of Appendix A. In summary, receiver effectiveness could affect estimates of time-to-event more than estimates of effectiveness. The mark recapture (CJS) procedure accounts for receiver detection rates and produces an unbiased estimate of survival, however estimates of delay are negatively affected because the clock starts while an animal is currently within the ladder and not as it enters. However, given the short distance between the malfunctioning entrance antennas and the next upstream antenna within the Spillway and Gatehouse ladders, this bias should be minimal.

There was a total of 433 dual and PIT tagged fish released at Holyoke, 182 of those fish (42%) made it to the project area and were detected by fixed telemetry stations. Most likely many of the fish that did not make it to the project area spawned in the river below the project area and returned downstream. During mobile tracking, 244 fish were detected either in the lower river, or in the Project area. Therefore, 189 fish were never accounted for using a combination of fixed and mobile tracking telemetry techniques. Of the 100 fish that were released into the Cabot power canal, 82 fish (82%) were detected via fixed telemetry stations. Of the 260 fish released in the Turners Falls Impoundment, 172 fish (66%) were detected via fixed telemetry stations.

4.2 Shad Tagging, Release and Reach Recapture

Tagging occurred over 12 days from the period beginning on May 6, and ending on June 8, 2015. Approximately half of the shad were tagged with radio and PIT tags (double tagged) (n=397) and half tagged with PIT only (n=396). In total, FirstLight collected, tagged and released 793 adult shad as summarized in Table 4.2-1 and Figure 4.2-1. The majority (71%, n=561) of the shad were collected at the Holyoke Dam. Of those 499 (89%) were released in the Holyoke Impoundment. The remaining 62 (11%) shad were transported to the TFI. A total of 232 (29%) shad were collected at the Cabot fish ladder trap, of those 100 were released in the Power Canal and 132 were released in the TFI.

TransCanada collected, tagged and released 154 Shad over six days in May, 2015 beginning on the 10th and ending on the 30th. Table 4.2-2 summarizes the TransCanada tagging and release effort. All 100 of TransCanada's shad collected at the Holyoke Dam were transported to the Pauchaug Brook Boat Launch for tagging and release. The remaining 54 study fish were collected at the Vernon Dam and released at the Old Ferry Boat Ramp in Brattleboro, VT.

Of the 793 shad collected by FirstLight just over half (54%, n=428) were males. Females accounted for 46% of the sample size (n=365). On average, females were larger (total length) than males (Figure 4.2-1). Females ranged in length from 413mm to 587mm with an average size of 516mm. Males ranged in length from 374mm to 568mm with an average length of 471mm.

The raw number of dual-tagged stationary telemetry recaptures by reach and release are found in Tables 4.2-3 to 4.2-5 and Figures 4.2-3 through 4.2-5. Generally, the number of recaptures by reach declined the further away fish were from their release location. However, what is not depicted on these figures are bi-directional movement. Fish may abandon a reach only to try a new one, or may make multiple forays in competing reaches. Table 4.2-3 and Figure 4.2-3 contain Holyoke released fish. Of the 215 dual tagged fish released, 140 were recaptured in the lower river (T1, T2, and T3) and 9 were recaptured in the Turners Falls Impoundment below the NMPS intake (T23 and T24). Holyoke fish were recaptured in all reaches with the exception of the upper impoundment at Northfield Mountain where there were no recaptures and thus no entrainment for any release. Of the 50 fish released at Cabot Station within the Power Canal (Table 4.2-4 and Figure 4.2-4), 7 were recaptured within the Turners Falls Impoundment below the NMPS intake, while 37 were recaptured within the lower river (T1, T2 and T3) and at least 46 attempted the downstream bypass (T9 and P13). Cabot released fish were recaptured in most reaches with the exceptions of the upper bypass (T19 and T20), Spillway ladder and the upper impoundment at NMPS. Of the 132 dual tagged fish released into the impoundment (Table 4.2-5 and Figure 4.2-5), 84 were recaptured upstream of the NMPS Intake (T26 and T27) with a significant number (65) recaptured within the lower river (T1, T2 and T3). As with the Cabot fish, a large number (48) attempted the downstream bypass (T9 and P13).

Table 4.2-1. FirstLight shad collection, tagging and release summary.

Date of Collection/Release	Collection Location	Release Location	Number of Double Tagged Shad	Number of PIT only Shad	Total Tagged and Released
5/6/15	Holyoke	Holyoke	72	1	73
5/7/15	Holyoke	Holyoke	0	72	72
5/12/15	Holyoke	Holyoke	48	1	49
5/13/15	Holyoke	Holyoke	0	47	47
	Cabot	Canal	25	25	50
5/15/15	Holyoke	TFI	33	29	62
5/16/15	Cabot	TFI	33	33	66
5/18/15	Cabot	Canal	0	25	25
5/19/15	Holyoke	Holyoke	48	48	96
	Cabot	Canal	25	0	25
5/22/15	Holyoke	TFI	33	33	66
5/23/15	Cabot	TFI	33	33	66
5/26/15	Holyoke	Holyoke	24	24	48
6/8/15	Holyoke	Holyoke	23	25	48
Totals			**397**	**396**	**793**

Table 4.2-2. Shad collection, tagging and release by TransCanada.

Date of Collection/ Release	Collection Location	Release Location	Number of Double Tagged Shad	Number of Radio Only Tagged Shad	Number of PIT only Shad	Total Tagged and Released
5/10/15	Holyoke	Pauchaug Brook Boat Launch	20	0	20	40
5/14/15	Holyoke	Pauchaug Brook Boat Launch	20	0	20	40
5/17/15	Vernon	Old Ferry Boat Ramp Brattleboro, VT	0	20	0	20
5/24/15	Vernon	Old Ferry Boat Ramp Brattleboro, VT	0	23	0	23
5/28/15	Holyoke	Pauchaug Brook Boat Launch	12	0	8	20
5/30/15	Vernon	Old Ferry Boat Ramp Brattleboro, VT	0	11	0	11
Totals			**52**	**54**	**48**	**154**

Table 4.2-3. Raw data stationary telemetry dual-tagged recaptures by reach – Holyoke Release

Reach	Receivers	Recaptures (out of 215)
Lower River	T1, T2, T3	140
Deerfield	T33	11
Cabot Tailrace	T5, T6	90
Lower Bypass	T11, T15, T12E, T12W	59
Station 1 Tailrace	T16	2
Upper Bypass	T19, T20	23
Cabot Ladder	T7, P111, P112, T29, P12	27
Spillway Ladder	T30, P21, P22, P23SL, P23TP, P24, P25	8
Downstream Bypass	T9, P13	5
Cabot Forebay	T8	7
Canal	T13, T14, T18, T21	8
Station 1 Forebay	T17	1
Gatehouse Entrance Yagi	T22	8
Gatehouse Ladder	P34Z, P34, P31, P32, P33	9
DS NFM Intake	T23, T24	9
NFM Intake	T25	2
US NFM Intake	T26, T27	9

Table 4.2-4. Raw data stationary telemetry dual-tagged recaptures by reach – Cabot Release

Reach	Receivers	Recaptures (Out of 50)
Lower River	T1, T2, T3	37
Deerfield	T33	3
Cabot Tailrace	T5, T6	33
Lower Bypass	T11, T15, T12E, T12W	2
Station 1 Tailrace	T16	1
Upper Bypass	T19, T20	0
Cabot Ladder	T7, P111, P112, T29, P12	2
Spillway Ladder	T30, P21, P22, P23SL, P23TP, P24, P25	0
Downstream Bypass	T9, P13	46
Cabot Forebay	T8	50
Canal	T13, T14, T18, T21	49
Station 1 Forebay	T17	5
Gatehouse Entrance Yagi	T22	18
Gatehouse Ladder	P34Z, P34, P31, P32, P33	9
DS NFM Intake	T23, T24	7
NFM Intake	T25	3
US NFM Intake	T26, T27	7

Table 4.2-5. Raw data stationary telemetry dual-tagged recaptures by reach – TFI Release

Reach	Receivers	Recaptures (out of 132)
Lower River	T1, T2, T3	65
Deerfield	T33	2
Cabot Tailrace	T5, T6	68
Lower Bypass	T11, T15, T12E, T12W	29
Station 1 Tailrace	T16	0
Upper Bypass	T19, T20	20
Cabot Ladder	T7, P111, P112, T29, P12	2
Spillway Ladder	T30, P21, P22, P23SL, P23TP, P24, P25	0
Downstream Bypass	T9, P13	48
Cabot Forebay	T8	55
Canal	T13, T14, T18, T21	60
Station 1 Forebay	T17	2
Gatehouse Entrance Yagi	T22	54
Gatehouse Ladder	P34Z, P34, P31, P32, P33	1
DS NFM Intake	T23, T24	126
NFM Intake	T25	27
US NFM Intake	T26, T27	84

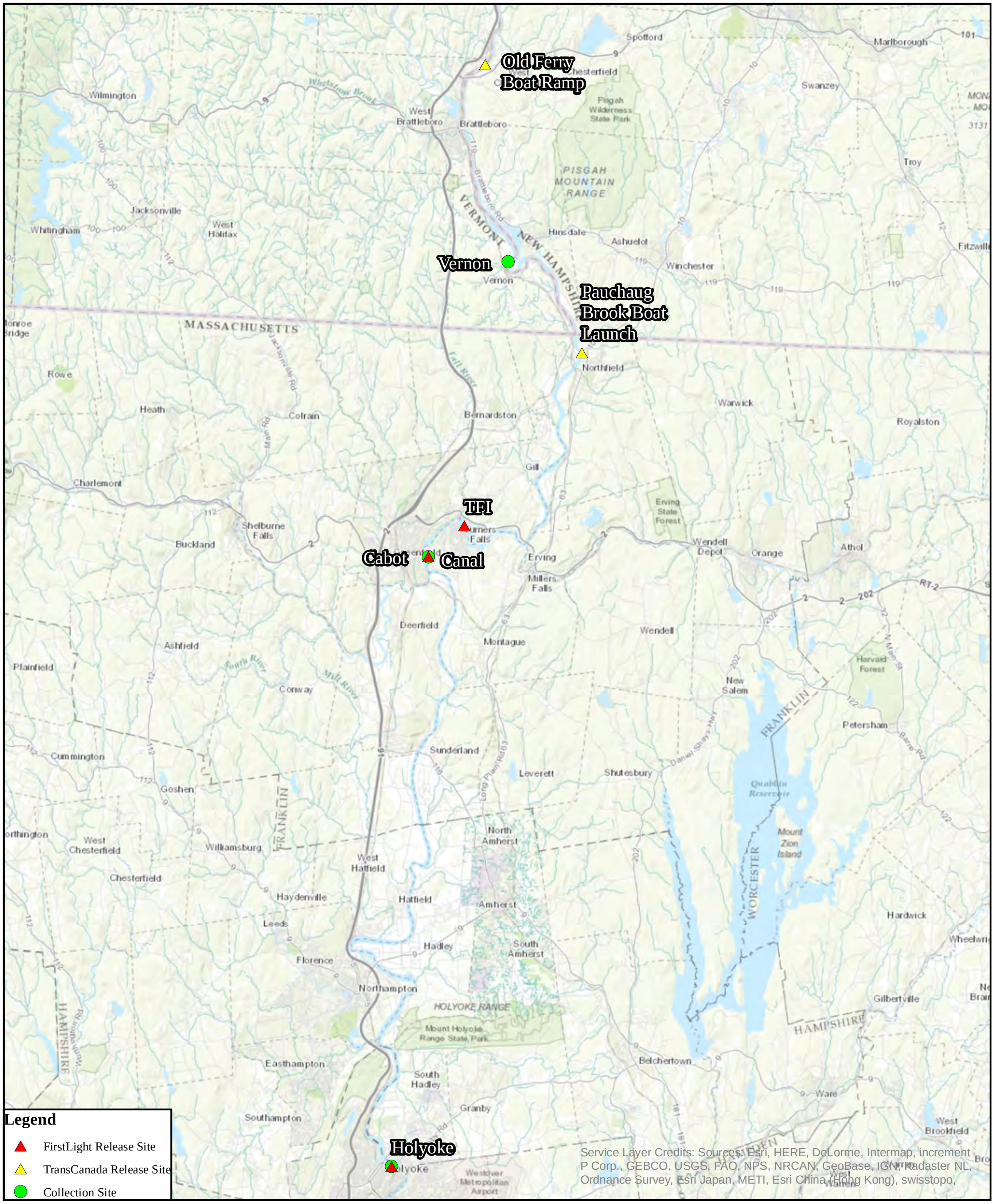

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Figure 4.2-1: Shad collection and release sites.

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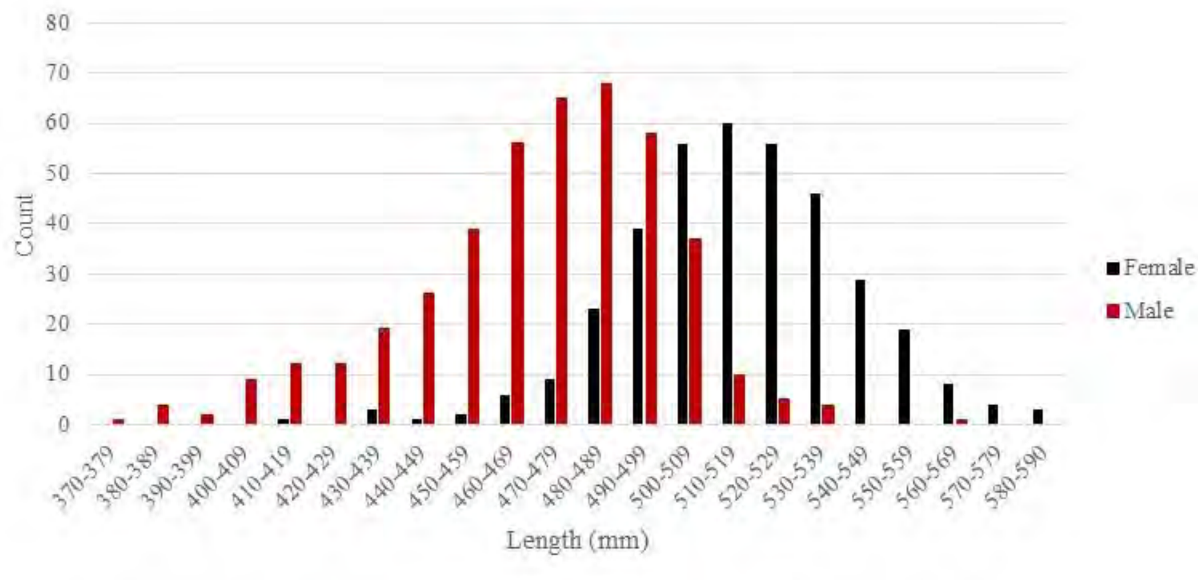

Figure 4.2-2. The length frequency of the 793 shad tagged by FirstLight

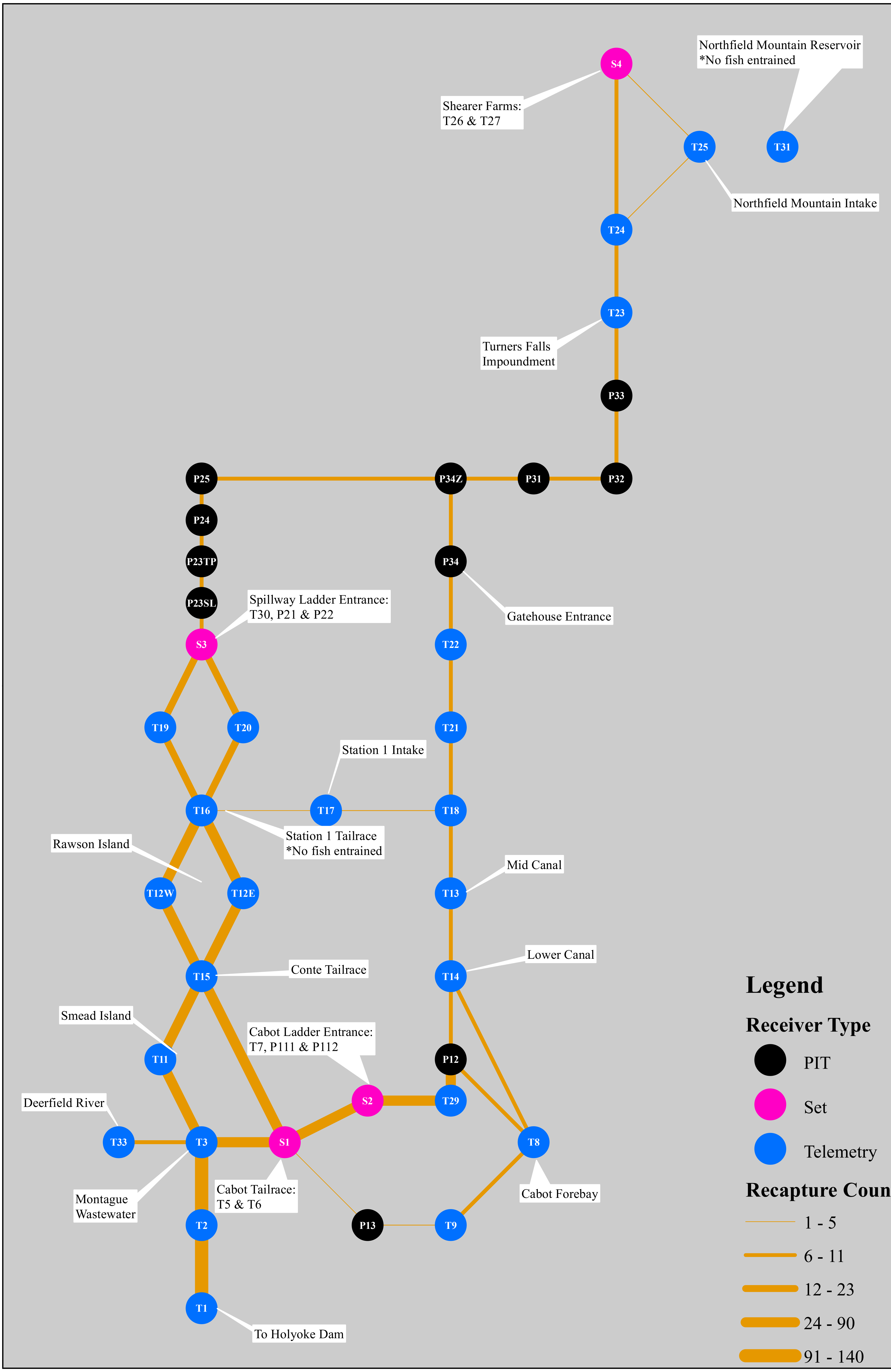

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Figure 4.2-3: Holyoke Release Recapture Count

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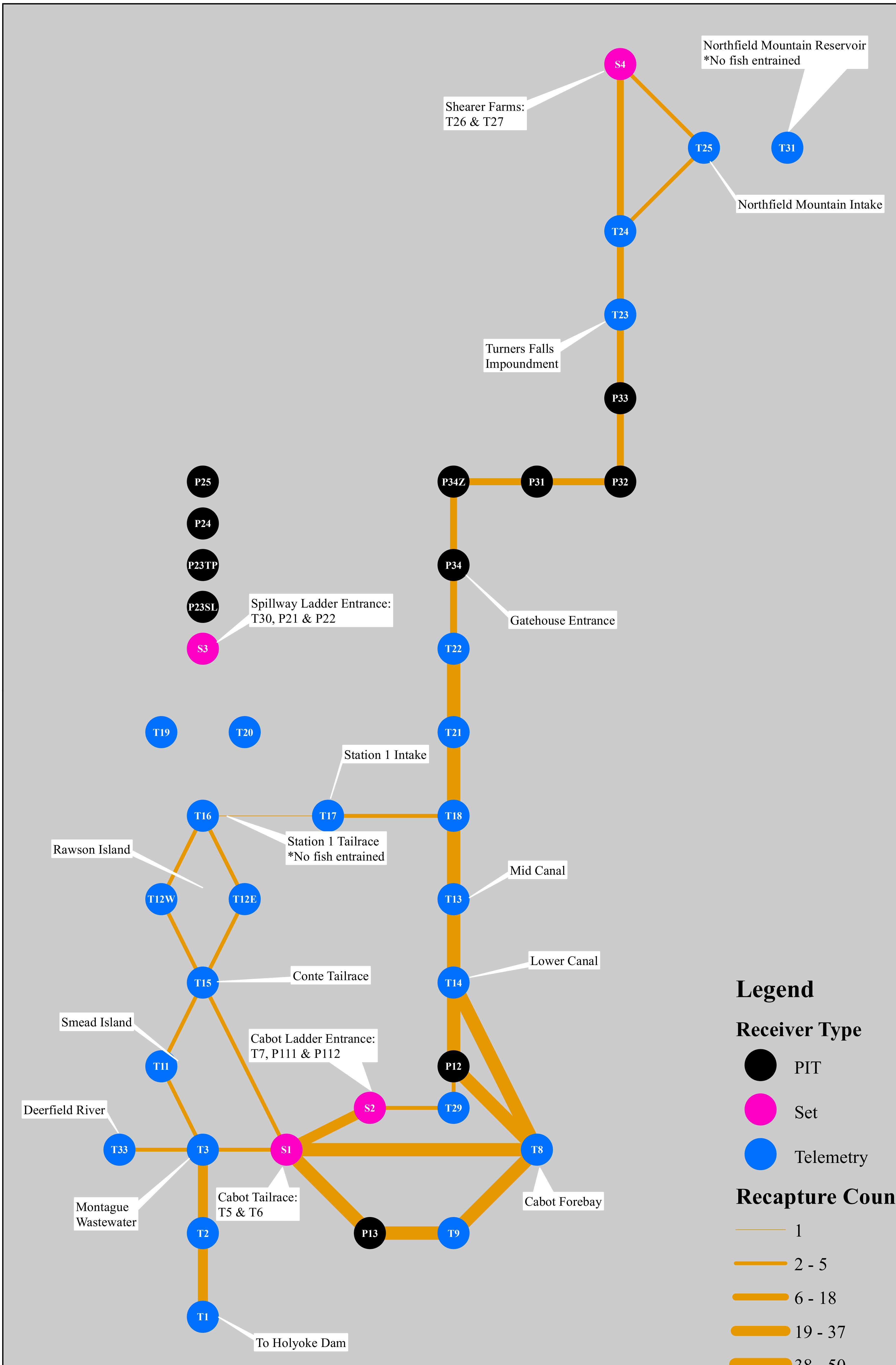

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Figure 4.2-4: Canal Release Recapture Count

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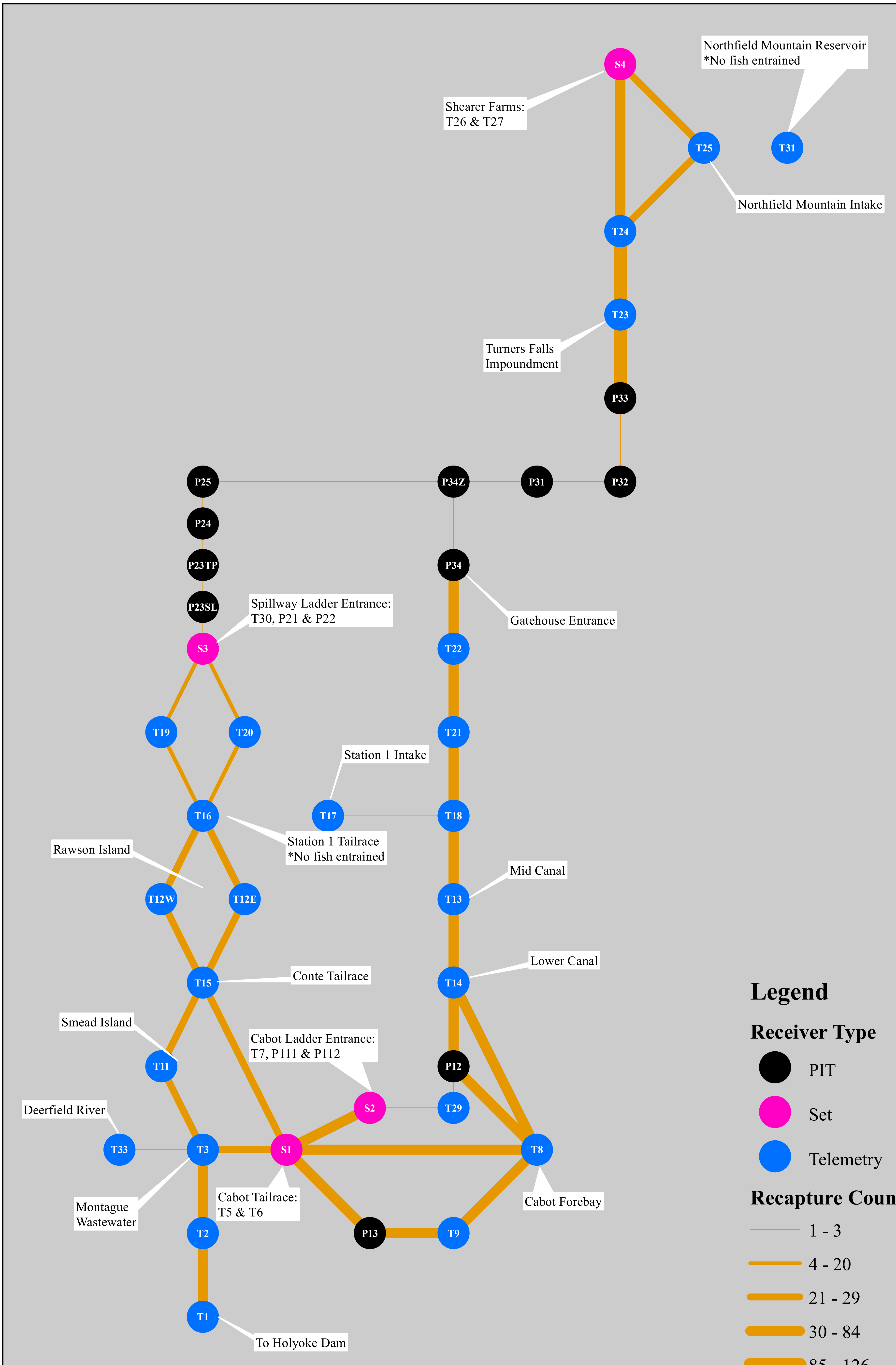

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Figure 4.2-5: TFI Release Recapture Count

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4.3 Project Operation, Discharge and Environmental Data

Cabot Station operated nearly continuously throughout the study period except during brief periods from May 18 to May 21, May 27 to May 31, and on July 11th and 12th (Figure 4.3-1). Generation was variable and typically ranged between 10 and 60 MW. All six units operated during the study period. Unit 1, closest to the downstream fish bypass, was prioritized and operated continuously except during periods of no generation. The downstream fish bypass was operated throughout the study period.

Generation at Station No. 1 was less variable when compared to that of Cabot Station, generally operating near capacity (~6 MW) or not at all (Figure 4.3-2). The exceptions included two brief periods between May 22 and May 24, 2015 and between May 27 and June 1, 2015 in which Station No. 1 operated at approximately 3 MW. Station No. 1 did not operate during the beginning or end of the study period from May 6 to May 19, 2015 and from July 6 to July 15, 2015, respectively.

The NMPS Project pumps water during periods of low electrical demand, typically at night from midnight to 6am, and discharges to generate electricity during periods of peak demand typically during day time hours. This operational approach results in daily alternating period of pumping and discharge as shown in the generation graphs (Figures 4.3-3 through 4.3-5). The NMPS Project operated (pumping and/or generation) daily throughout the study period. Generation occurred daily except on May 24, June 1 and July 11, 2015. Maximum generation of 1,015 MW occurred on May 17; however, generation of less than 750 MW was more common. All four units operated during the study period.

Discharge at the TFD occurred throughout the study period except during brief periods between July 10 and 15, 2015 (Figure 4.3-6). Discharge was conveyed to the bypass reach through Bascule Gates (BG) 1 and 4. The taintor gates and BG 2 and 3 did not operate during the study period except for a brief period (several hours) on May 6, 2015 when BG 2 discharged. Discharge to the bypass reach was managed to evaluate shad migration under various flow scenarios for alternating periods of three days as shown in Figure 4.3-7. Discharge exceeded the schedule when inflow exceeded Project capacity (18,000 cfs) (Figure 4.3-8). Such exceedances were most prominent and prolonged in late June and early July.

Flow in the Connecticut River ranged from a low of 3,180 cfs on May 30, 2015 to a maximum of 39,300 cfs on June 24, 2015 as measured at the USGS 01170500 Connecticut River at Montague City, MA (Figure 4.3-9). The Connecticut River flow during the study period was somewhat atypical with generally lower flows in May and higher flows in June and July when compared to the Median Daily Statistic calculated over the past 112 years as shown in Figure 4.3-9. This trend was likely a result of precipitation in the study area and watershed (Figure 4.3-10). The month of May was dry, whereas the months for June and July were wet. A total of 1.04 inches of rain fell in the month of May 2015 while the monthly average is 3.2 inches, a deficit of 2.16 inches (Weather Underground, 2016). June was particularly wet with a total rainfall of 7.54 inches, over twice the average rainfall for the month (3.56 inches) (Weather Underground, 2016). In July the study area received 3.3 inches of rainfall, exceeding the monthly average of 2.86 by nearly a half inch.

Dissolved oxygen and water temperature were monitored continuously at a 15 minute interval in the bypass reach (Figure 4.3-11). Temperature ranged from a low of 12.2°C on May 6, 2015 to a high of 25.2°C on July 15, 2015. Water temperature generally increased throughout the study period but declines were observed and likely associated with high flow events. Dissolved oxygen generally declined throughout the study period and ranged from a low of 6.54 mg/L on June 24, 2015 to a high of 16.31 on June 22, 2015. The high daily variability of dissolved oxygen levels in late June and July are not well understood but may be due to spill events at TF Dam (discussed further in 3.2.1 Water Quality Monitoring Study report). Figure 4.3-12 illustrates water temperature and dissolved oxygen trends related to discharge at the dam and Station No. 1 operations.

Additional water quality parameters were measured periodically at various locations throughout the study area using a YSI 556 water quality meter (Table 4.3-1). Dissolved oxygen ranged from 8.26 mg/L on June 24 at the *Hatfield S Curve* to a maximum of 12.02 mg/L in the Power Canal on May 13, 2015. pH in the study area ranged from a low of 6.07 measured in the Power Canal on May 13, to a maximum of 7.88 measured at the confluence of the Fall River in the bypass reach on June 17, 2015. Conductivity ranged from a low of 69 µS/cm in the Sawmill River confluence on June 23 to a maximum of 210 µS/cm at the Fall River confluence on June 24, 2015. Water temperature ranged from a low of 14.09°C at the Holyoke dam on May 7 to a maximum of 23.75°C at the Millers River confluence on June 24, 2015.

Table 4.3-1. Water quality at sites collected throughout study area during the adult shad study.

Date	Location	DO (mg/L)	DO % sat	pH	Conductivity (µS/cm)	Water Temp (°C)
5/7/2015	Holyoke Dam	-	-	6.8	76	14.09
5/12/2015	Holyoke Dam	10.34	-	6.62	85	18.38
5/13/2015	Holyoke Dam	10.82	-	6.43	93	16.98
5/13/2015	Cabot Station (Canal)	12.02	-	6.07	93	16.44
5/15/2015	Turners Falls Impoundment	-	-	6.2	114	16.22
5/15/2015	Turners Falls Impoundment	10.9	118	6.09	78	15.45
5/16/2015	Cabot Station (Canal)	10.09	-	6.55	76	14.91
5/19/2015	Cabot Station (Canal)	11.6	-	6.13	95	16.13
5/21/2015	Sunderland	10.28	104.1	6.9	91	15.95
5/22/2015	Turners Falls Impoundment	9.73	-	6.98	82	16.9
5/23/2015	Turners Falls Impoundment	10.33	106	6.78	80	16.51
5/26/2015	Cabot Station (Canal)	10.06	104.9	6.55	83	17.65
5/28/2015	Sunderland	8.5	95.3	7.05	103	20.74
5/28/2015	Turners Falls Impoundment	9.15	100.6	6.65	97	19.74
6/11/2015	Stebbins Island	10.47	-	7.51	110	18.98
6/11/2015	Rock Dam	10.47	-	6.3	82	18.62
6/11/2015	Deerfield River Confluence	9.66	112.2	6.96	86	22.44
6/12/2015	Millers River Confluence	9.23	101.4	7.08	158	19.83
6/12/2015	Ashuelot River Confluence	8.86	99.2	6.72	138	20.72
6/16/2015	Hatfield "S" Curve	10	107.5	7.41	85	19.1
6/17/2015	Ashuelot River Confluence	9.62	108	7.52	107	20.76
6/17/2015	Fall River Confluence	11.04	116.2	7.88	187	17.59
6/17/2015	Fall River Confluence	10.75	112.6	7.76	201	17.79
6/17/2015	Millers River Confluence	8.95	10.3.3	7.44	135	22.51
6/18/2015	Hatfield "S" Curve	8.98	97.8	7.57	74	19.5
6/19/2015	Stebbins Island	8.63	91.6	7.54	72	18.45
6/19/2015	Ashuelot River Confluence	9.17	104.3	7.54	122	21.69
6/19/2015	Millers River Confluence	8.63	101.2	7.53	141	23.19
6/19/2015	Stebbins Island	9.07	96.3	7.52	73	18.52
6/23/2015	Sawmill River	8.62	90.2	7.24	69	17.43
6/23/2015	CT River (near Sawmill River)	9.14	100.9	7.36	114	20.38
6/23/2015	Hatfield "S" Curve	8.26	91.1	7.32	101	20.4
6/24/2015	Fall River Confluence	10.65	113.2	7.57	210	17.9
6/24/2015	Millers River Confluence	8.82	104.4	7.48	133	23.75
6/24/2015	Ashuelot River Confluence	8.76	98.3	7.52	152	21.15
6/24/2015	Stebbins Island	9.98	108.2	7.42	101	19.2
6/24/2015	Stebbins Island	9.75	106.1	7.34	85	19.22
6/29/2015	Hatfield "S" Curve	9.51	100.4	7.37	81	18

Date	Location	DO (mg/L)	DO % sat	pH	Conductivity (µS/cm)	Water Temp (°C)
6/30/2015	Hatfield "S" Curve	10.23	109.1	7.21	75	18.3
6/30/2015	Fall River Confluence	10.4	-	7.34	122	15.6
6/30/2015	Ashuelot River Confluence	10.65	114.2	-	104	18.44
6/30/2015	Millers River Confluence	10.22	114	7.19	120	20.67
6/30/2015	Stebbins Island	11.32	118.5	-	105	17.57
6/30/2015	Stebbins Island	11.5	120	-	104	17.43
7/2/2015	Ashuelot River Confluence	8.87	96.6	7.44	71	19.42
7/2/2015	Fall River Confluence	11.57	113.9	7.49	109	14.64
7/2/2015	Millers River Confluence	9.28	101.3	7.48	109	19.23
7/2/2015	Stebbins Island	9.11	95.3	7.44	82	17.4
7/2/2015	Stebbins Island	9.32	97.9	7.41	70	17.39
7/6/2015	Ashuelot River Confluence	8.86	102.3	7.59	79	22.26
7/6/2015	Millers River Confluence	9.28	105.5	7.31	120	21.25
7/7/2015	Hatfield "S" Curve	9.39	105	7.48	105	20.18
7/10/2015	Stebbins Island	9.5	107.8	7.38	113	21.64
7/10/2015	Fall River Confluence	10.71	116.6	7.71	126	19.54
7/10/2015	Stebbins Island	9.9	105.4	7.51	114	21.83

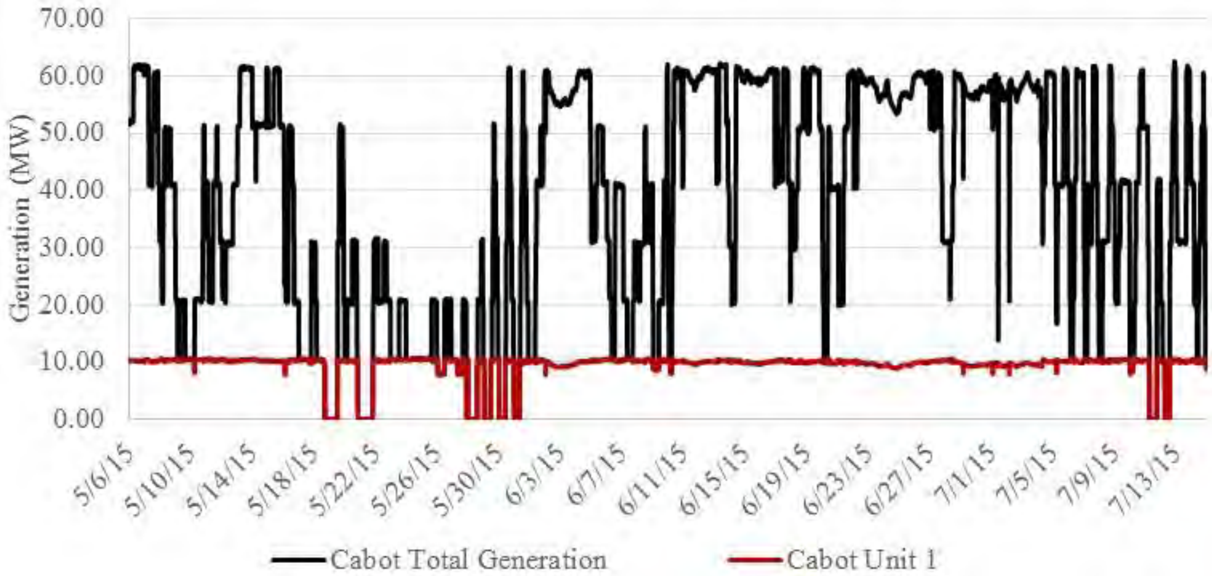


Figure 4.3-1. Cabot Station operation during the adult shad study.

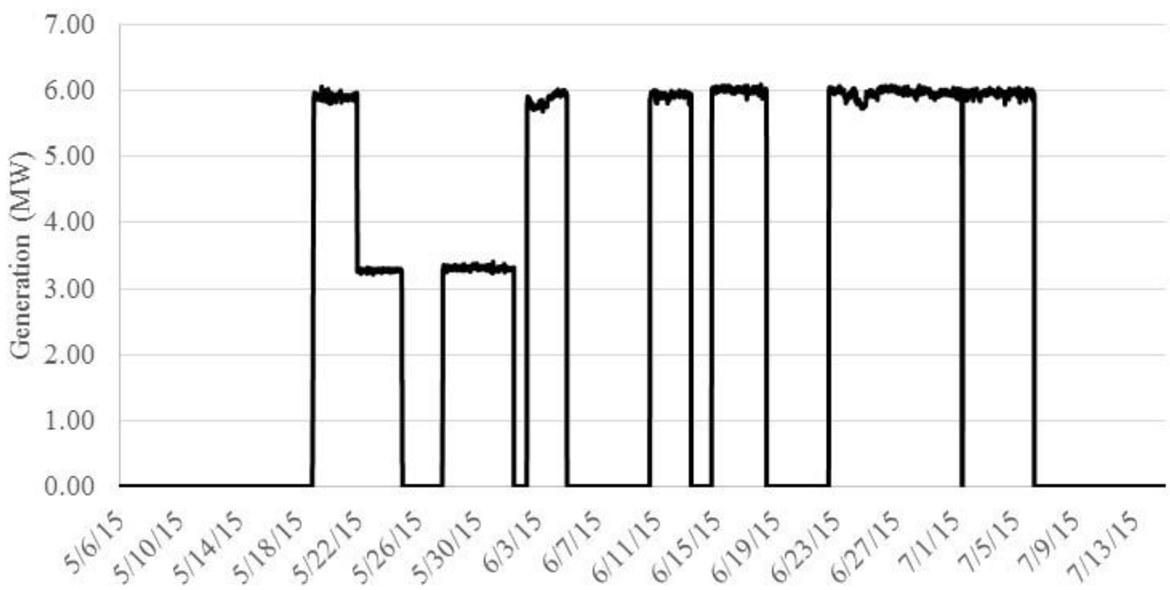


Figure 4.3-2. Station No.1 operation during the adult shad study.

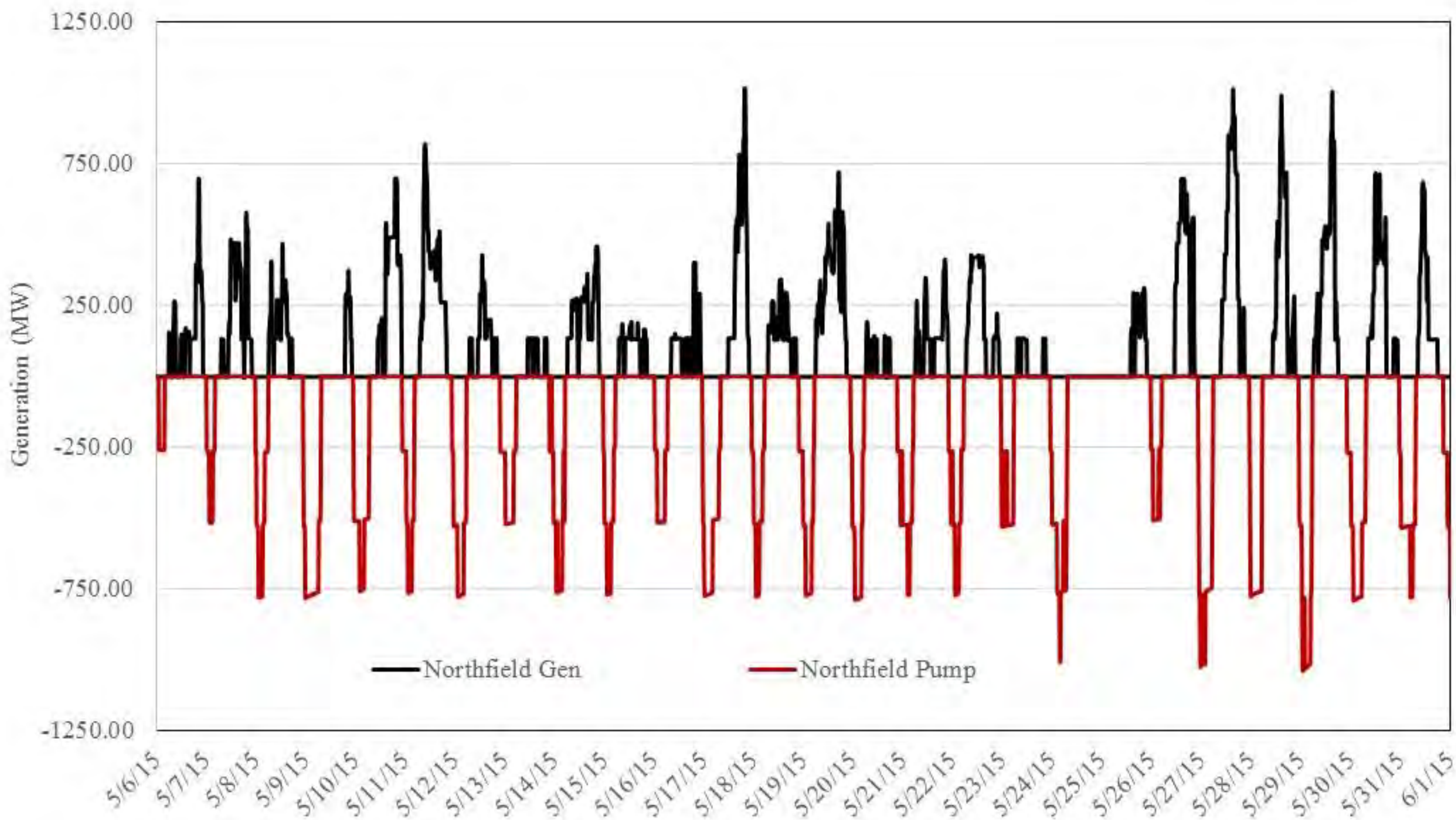


Figure 4.3-3. NMPS operation in May 2015 during the adult shad study.

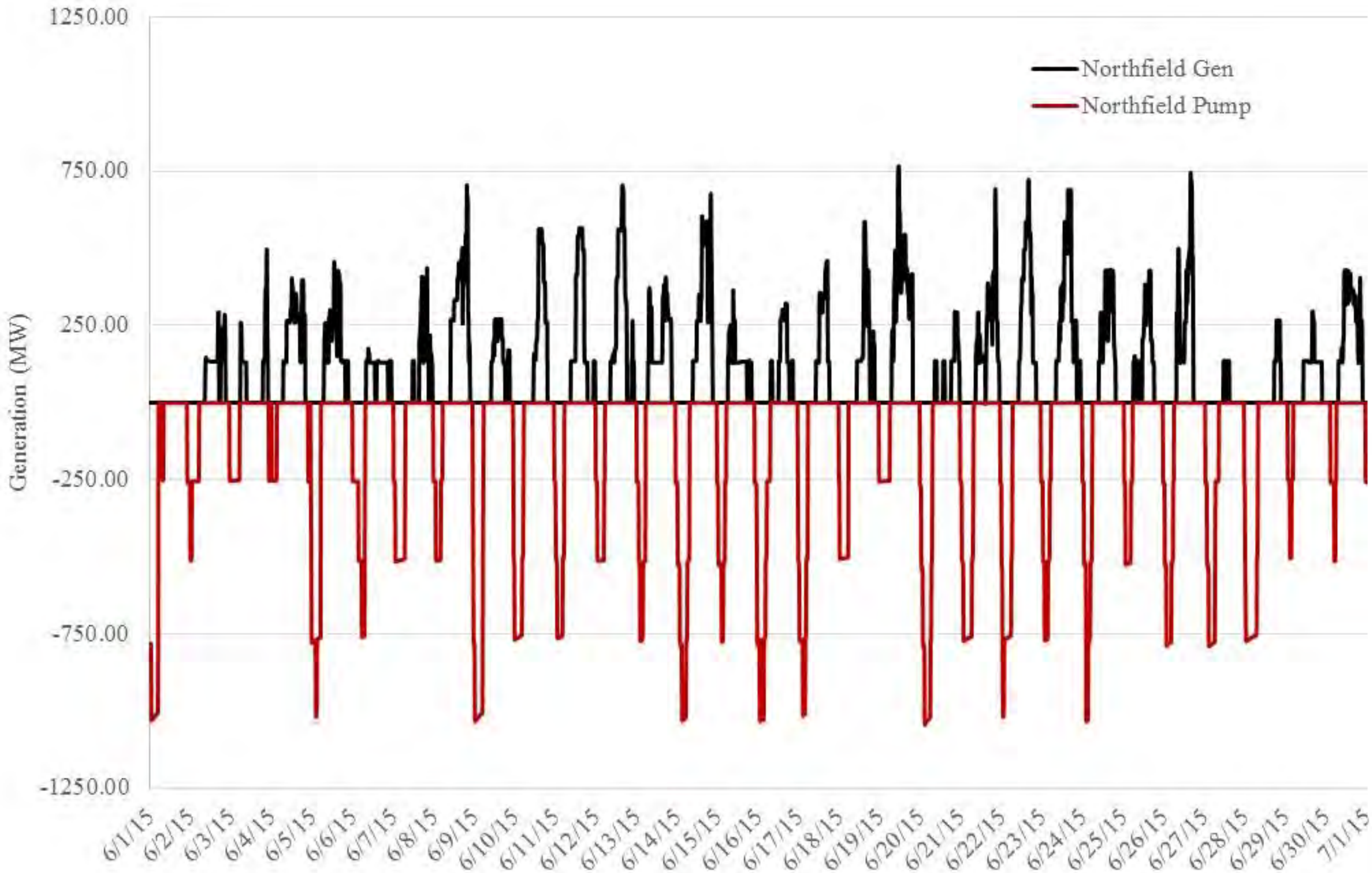


Figure 4.3-4. NMPS operation in June 2015 during the adult shad study.

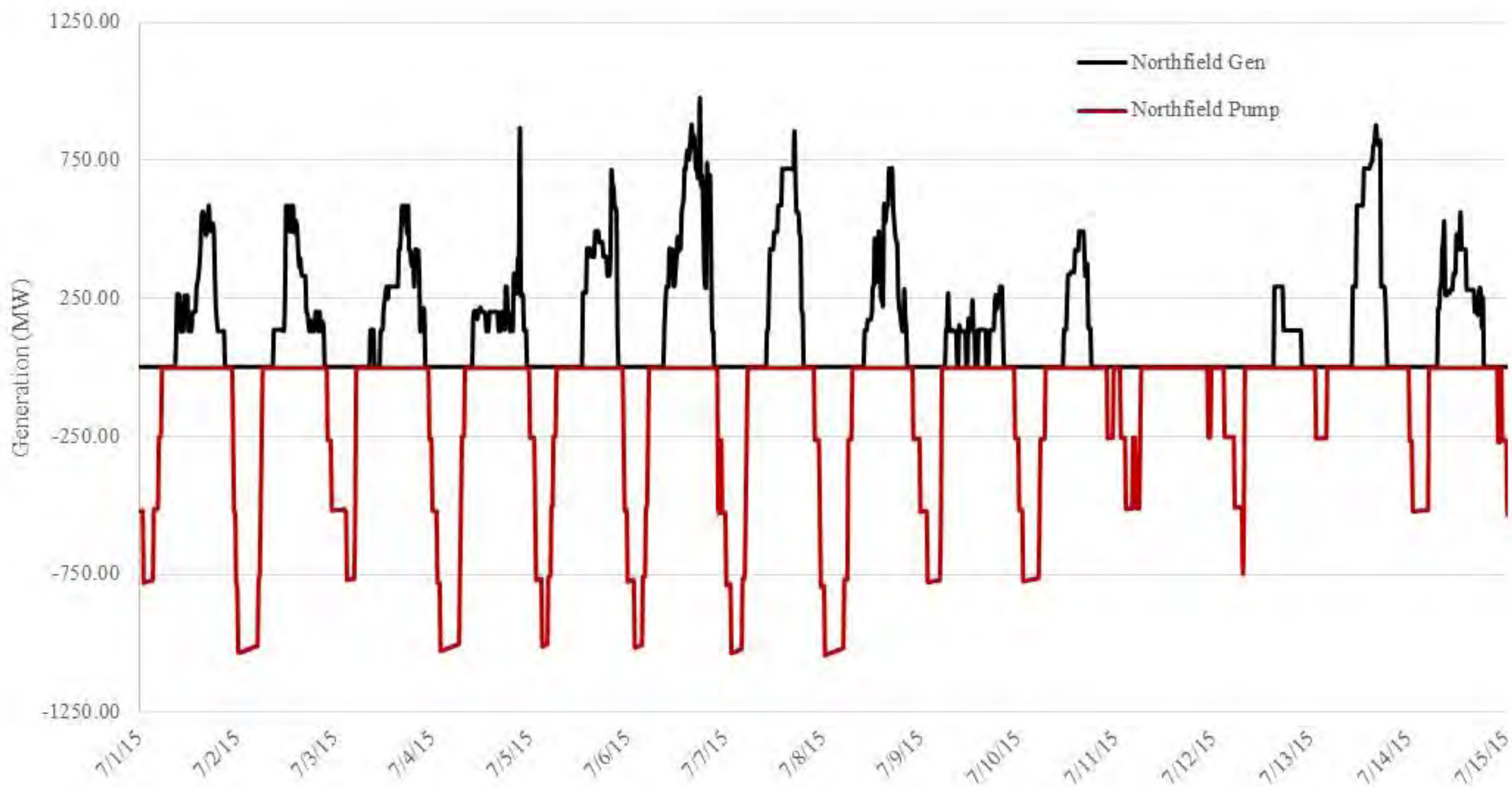


Figure 4.3-5. NMPS operation in July 2015 during the adult shad study.

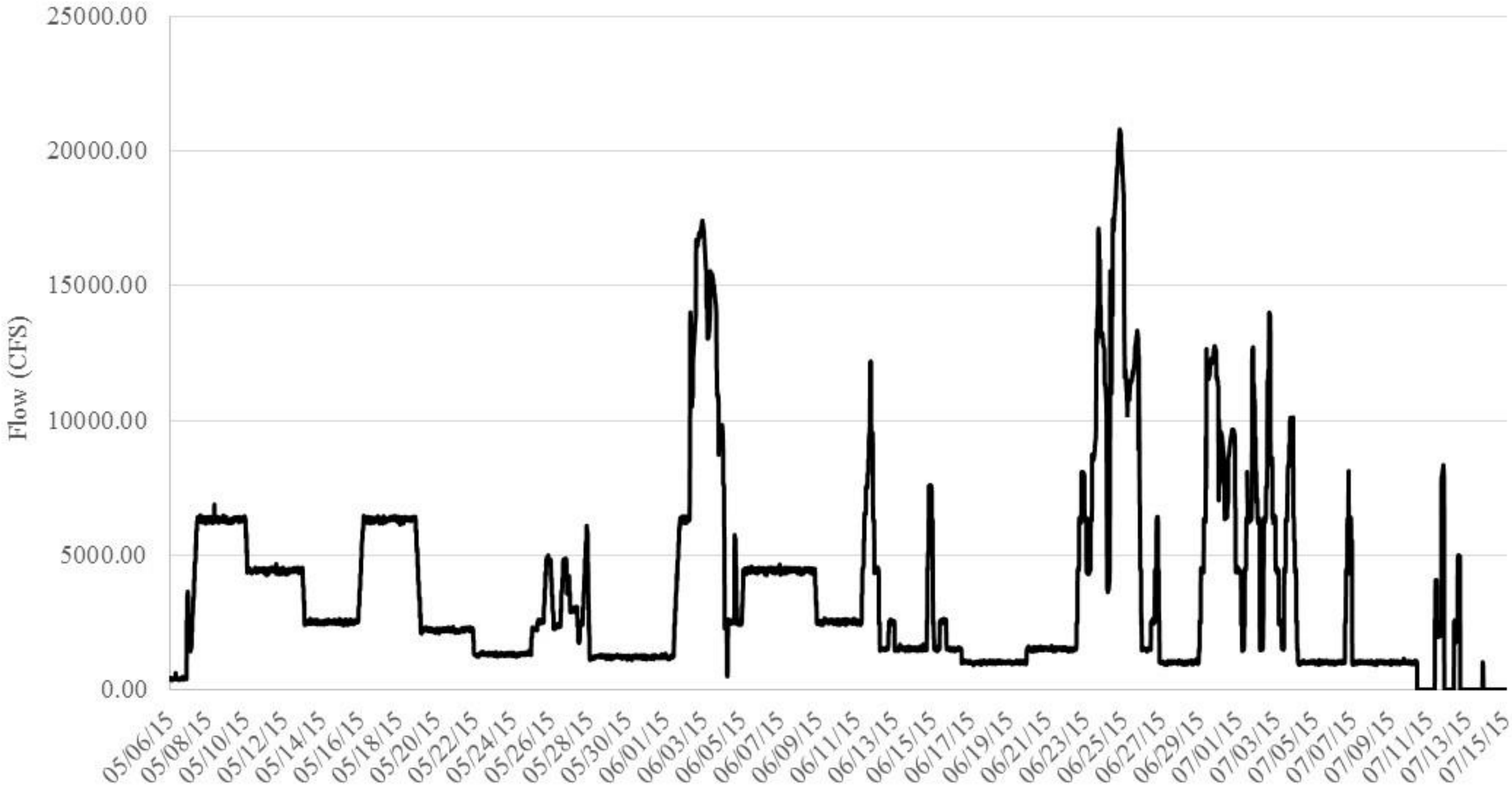


Figure 4.3-6. Discharge at the Turners Falls Dam during the adult shad study.

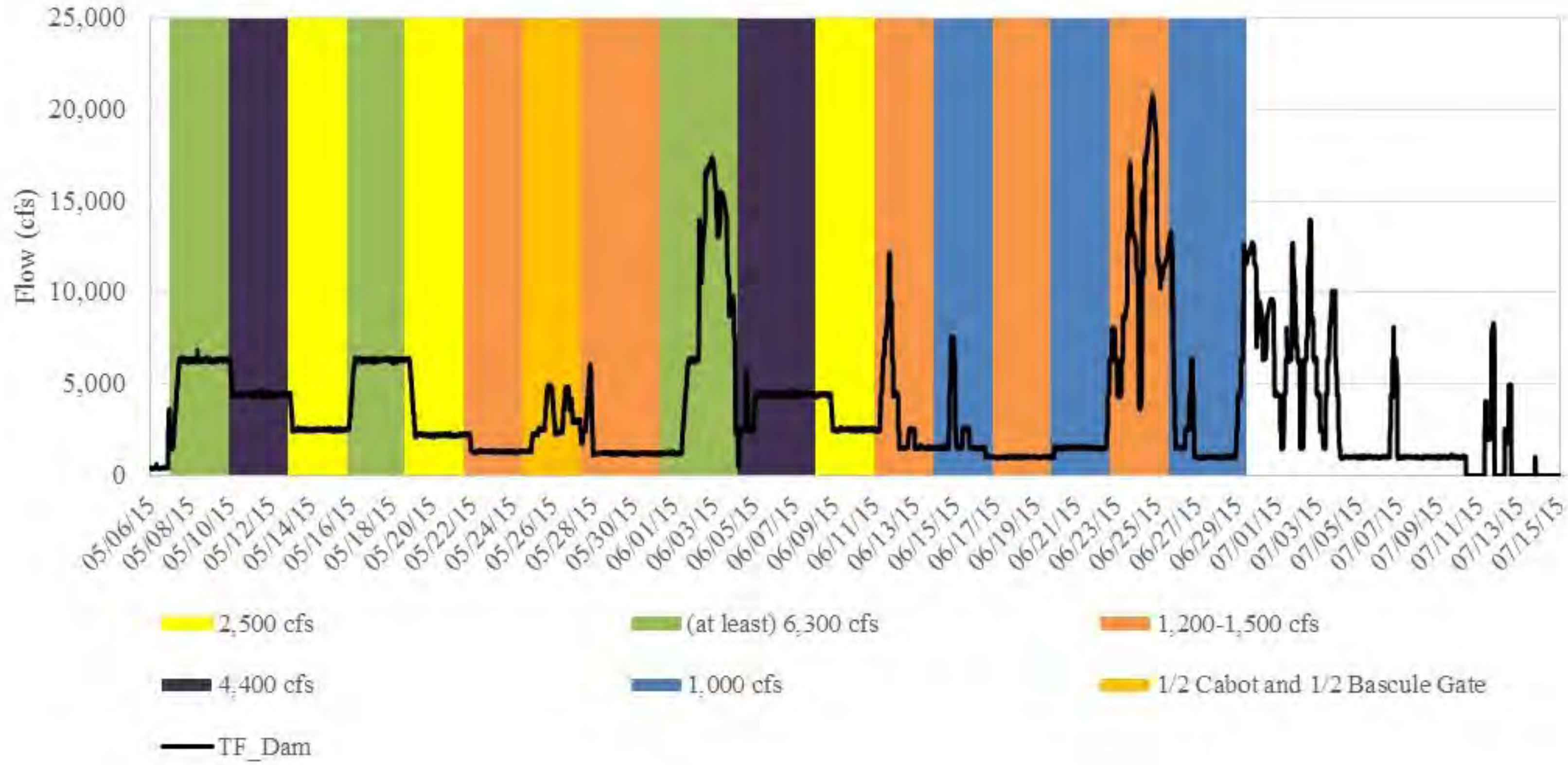


Figure 4.3-7. Discharge to the TF bypass reach during the adult shad study. Colored bars indicate the scheduled flow scenario.

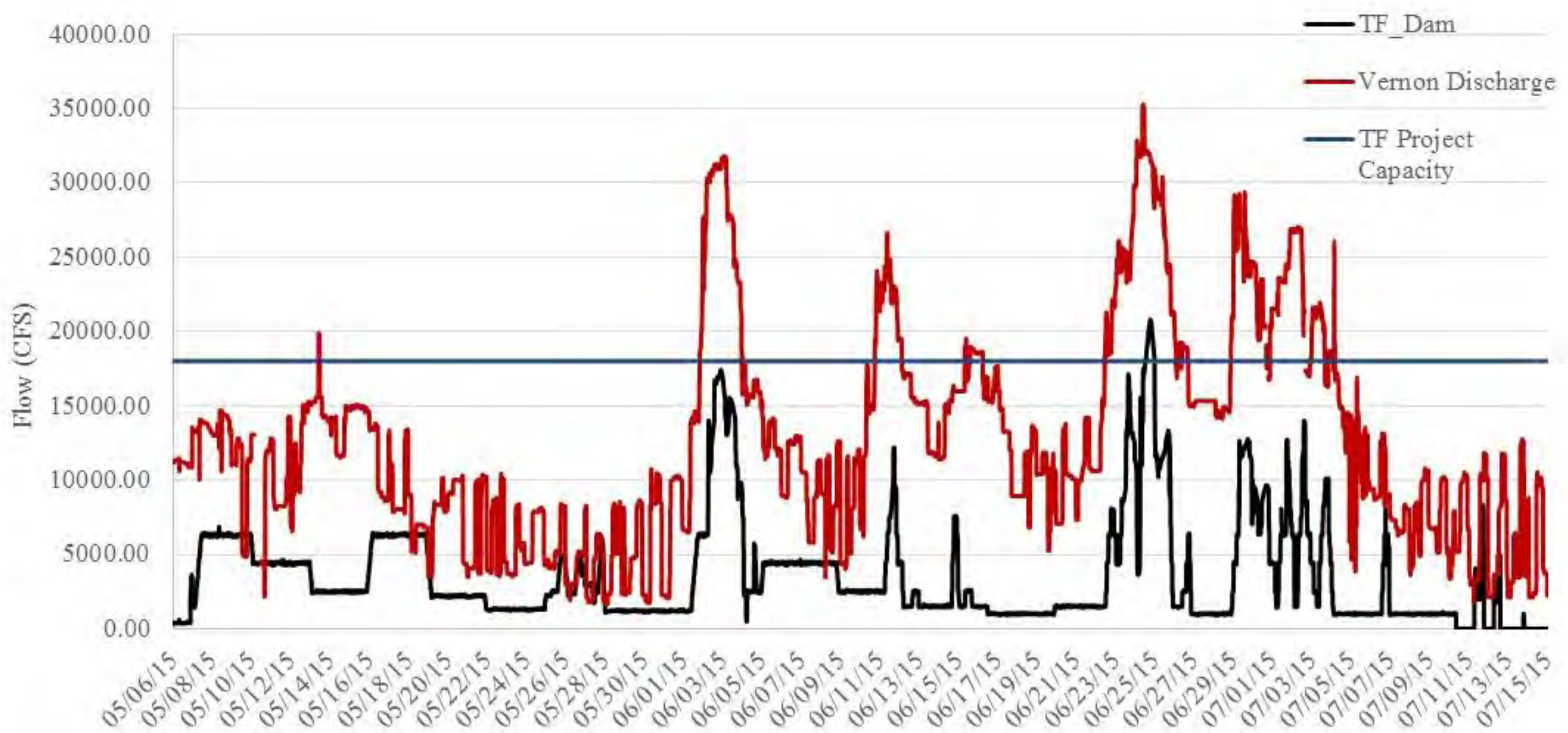


Figure 4.3-8. Discharge at the TFD and Vernon Project during the adult shad study.

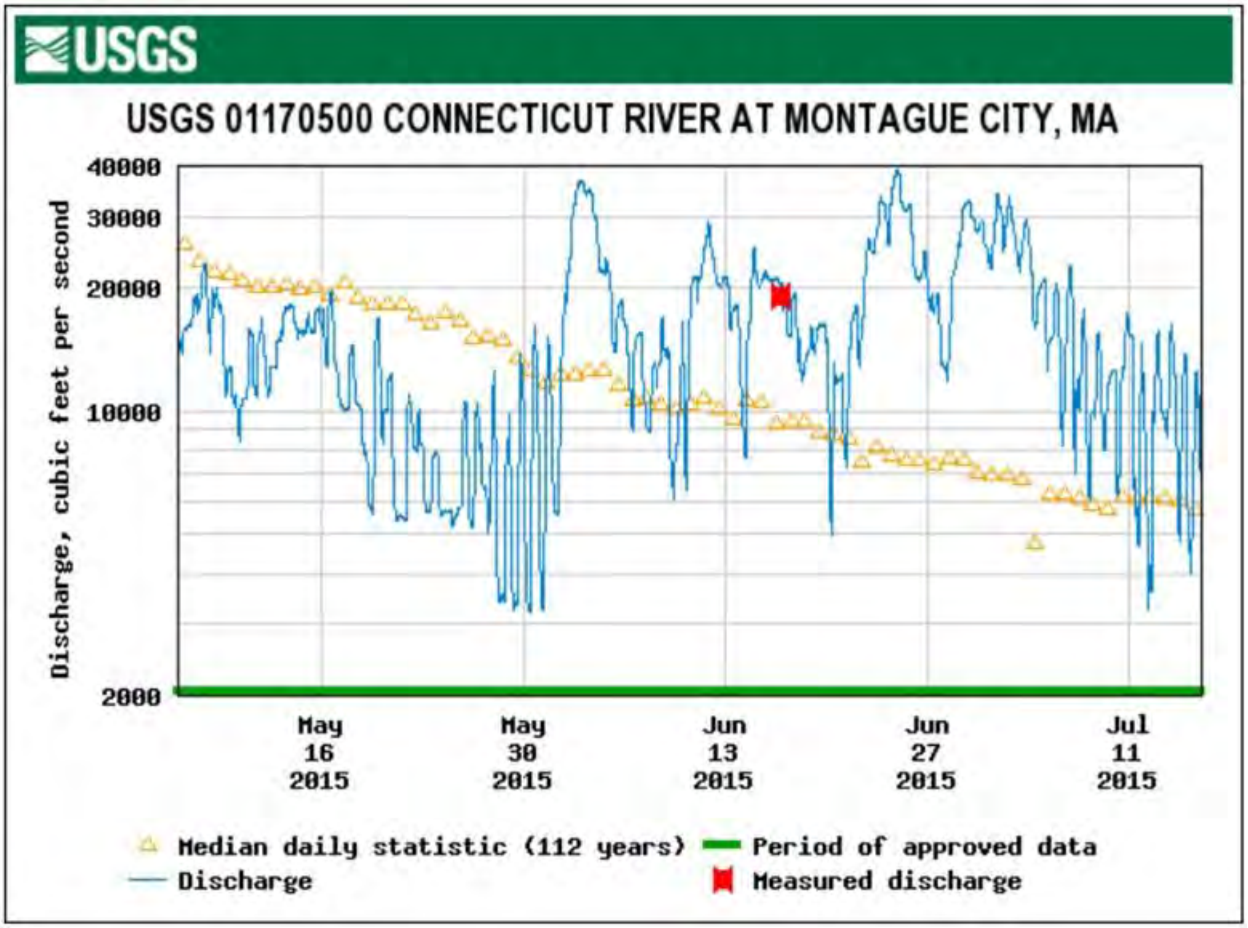


Figure 4.3-9. River flow as measured at the USGS Station 01170500 Connecticut River at Montague City, MA.

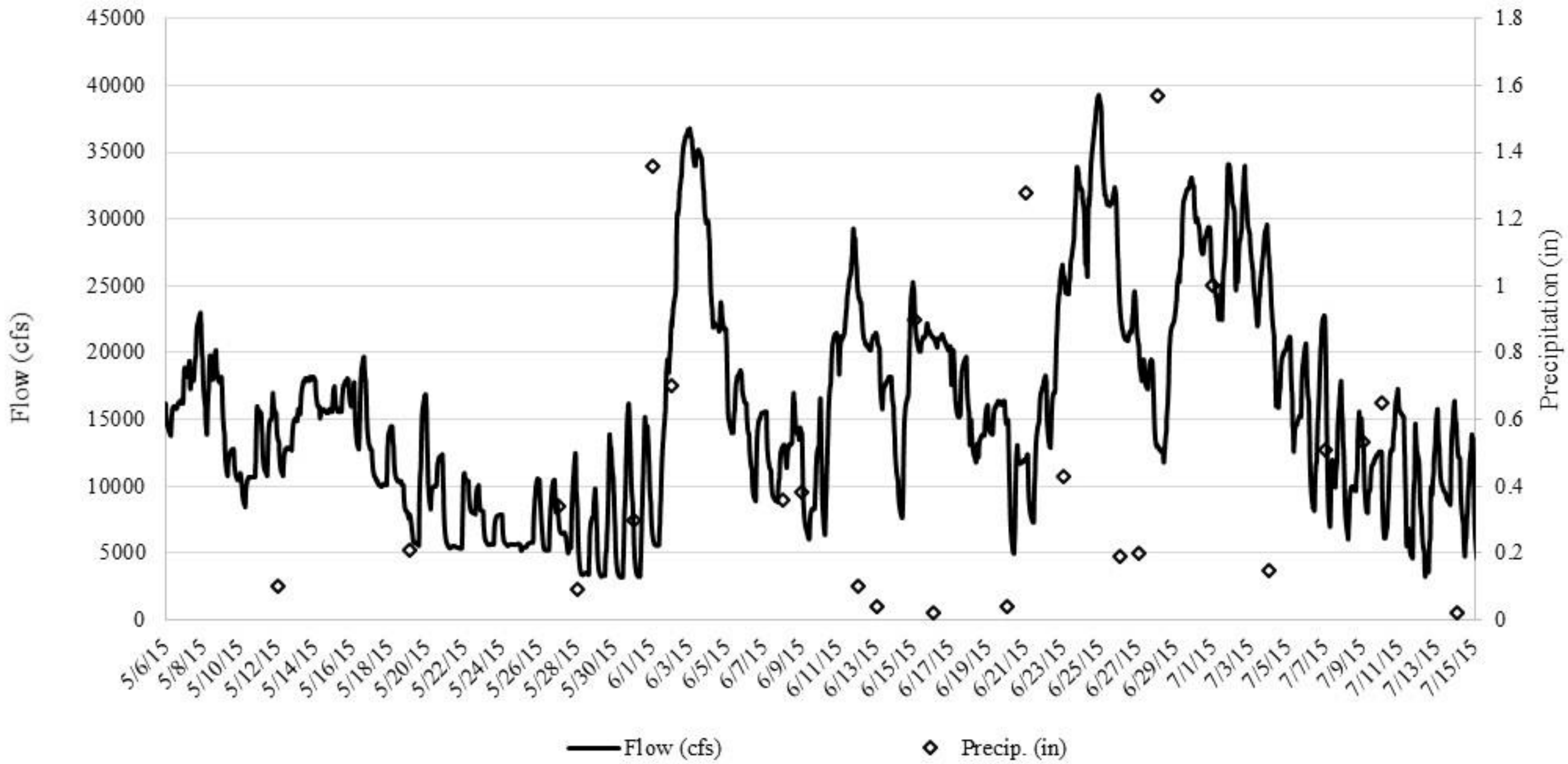


Figure 4.3-10. Connecticut River flow (gage 01170500 Montague City, MA) and precipitation during the adult shad study.

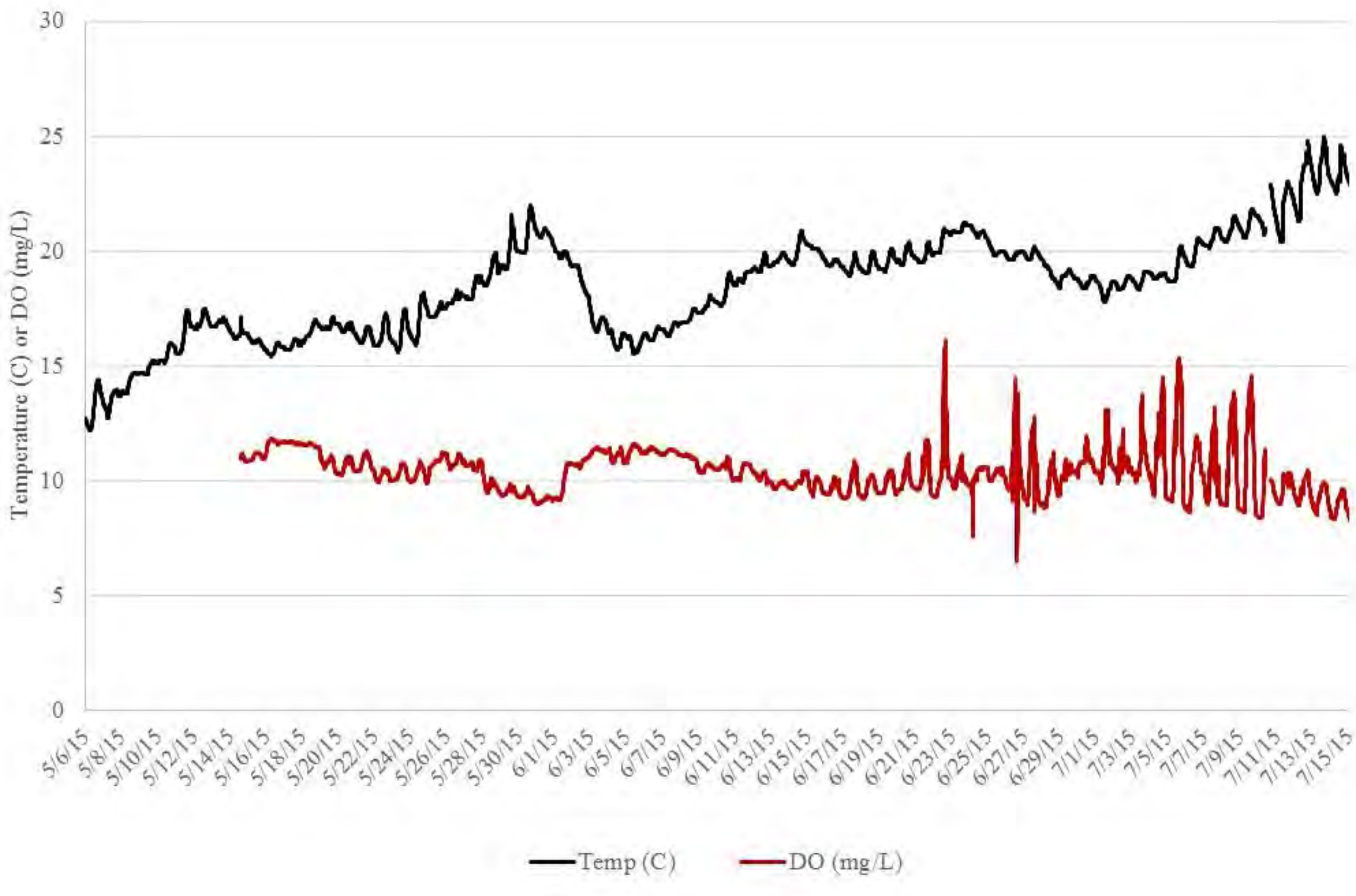


Figure 4.3-11. Dissolved oxygen and water temperature within the TF bypass reach during the adult shad study.

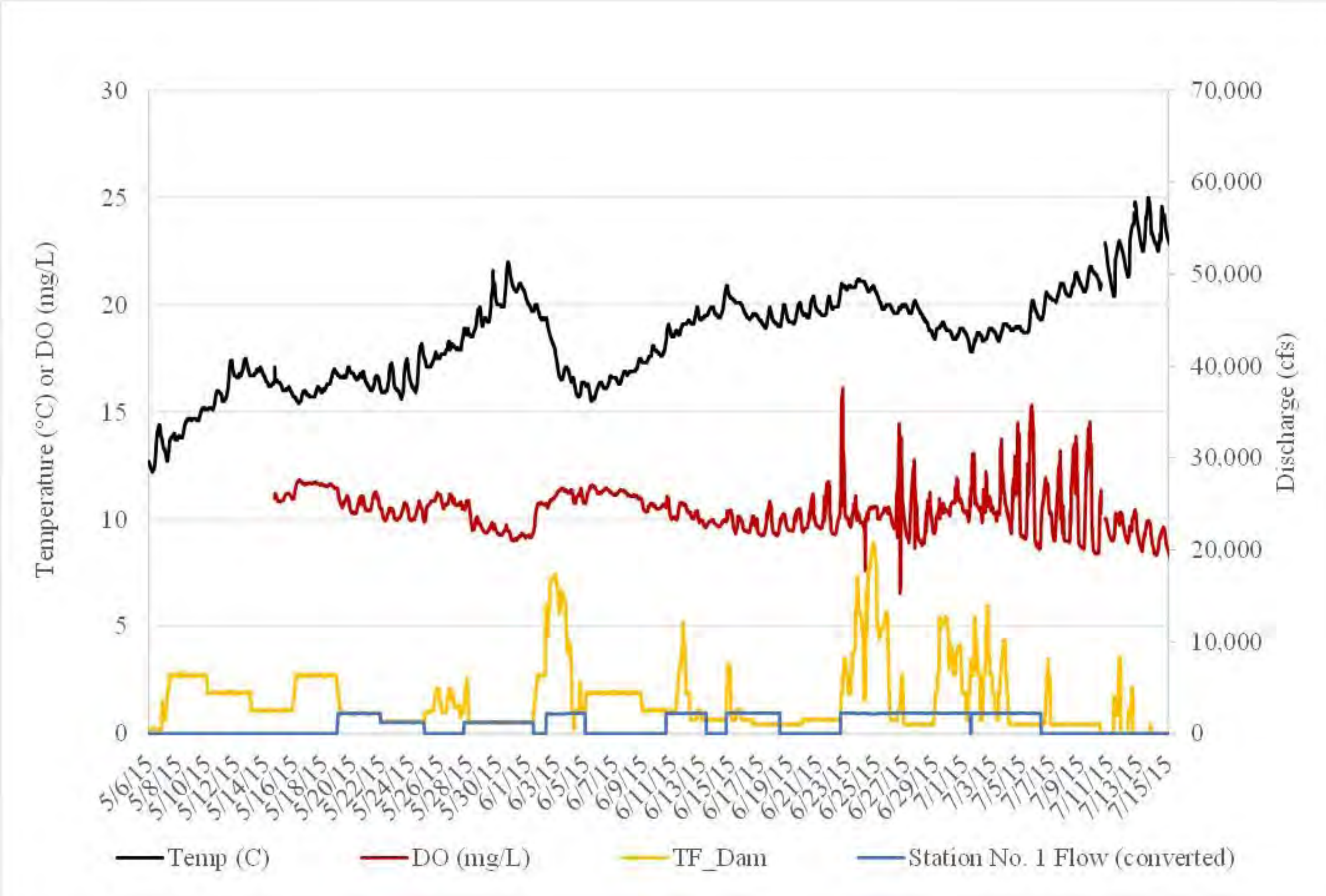


Figure 4.3-12. Water Temperature and Dissolved Oxygen in the TF Bypass Reach relative to discharge at the TF Dam and Station No. 1 operation

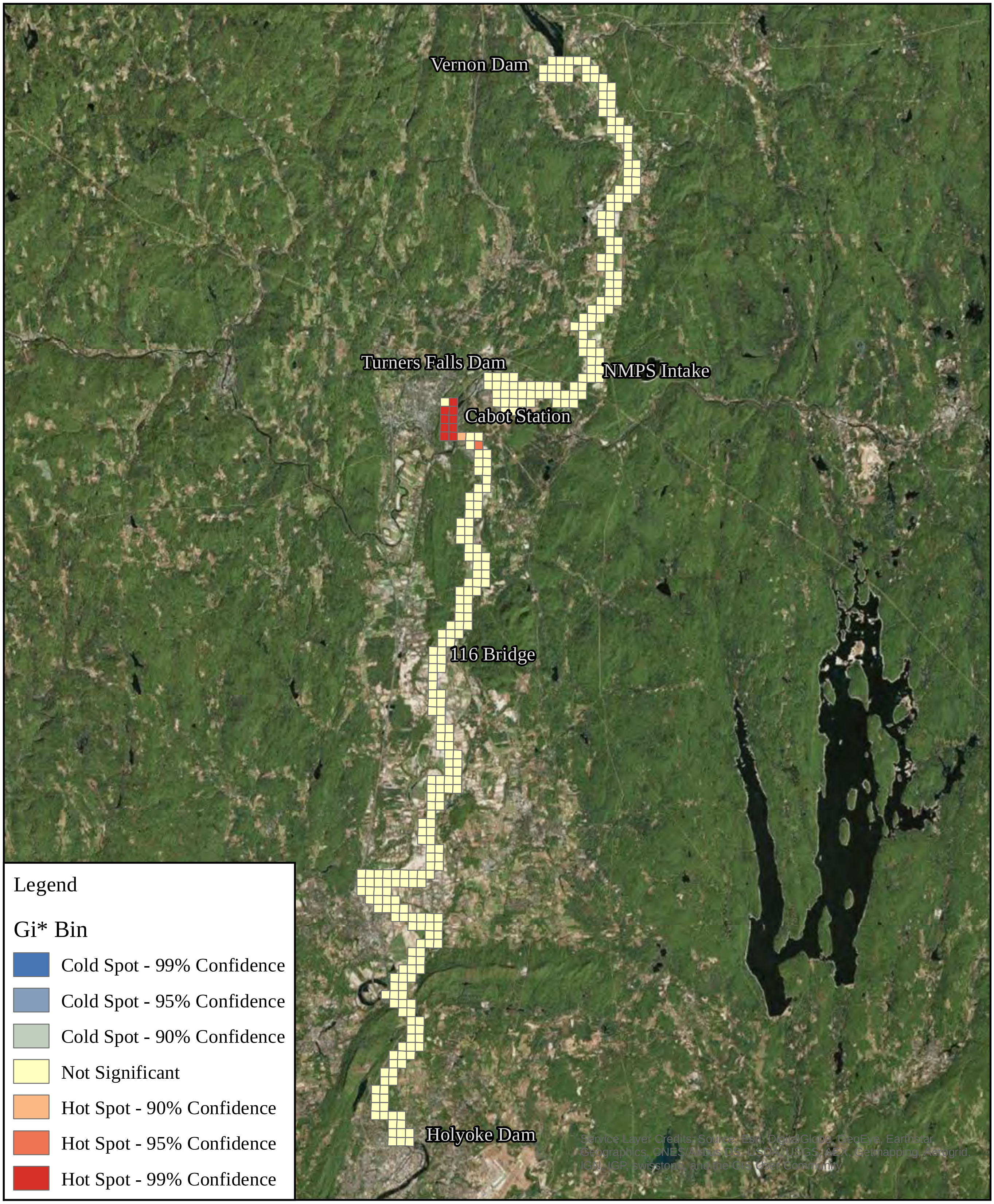
4.4 Mobile Tracking and Evaluation of Mortality

A total of 33 mobile tracking surveys were conducted over 9 weeks between May 15, and July 7, 2015 (Table 4.4-1). Approximately 110 search hours yielded a total of 549 recaptures of fish locations during the survey. A single fish may have multiple recapture events. A detailed record of the mobile tracking results is located in Appendix B – Mobile Tracking Matrix. The Mobile Tracking Matrix includes test fish frequency and identification code, release site location and date, the location and date of observed test fish (Reaches 1-4 as described in Figure 2-1), passage routes (upstream and downstream migration), final recapture location and date, and final fate of the test fish.

The Getis-Ord Gi* Hot Spot Analysis revealed mortality hotspots in the vicinity of Cabot Station and the Deerfield River Confluence (Figure 4.4-1). Approximately 14% of all mortality detections occurred in this area, while the remaining initial mortality detections were spread throughout the study area. An examination of the upstream-most locations of shad detected in mobile-tracking surveys (Figure 4.4-2) revealed that the majority of mobile-tracked fish were detected further upstream at fixed stations, with the largest number reaching their maximum upstream location at the Cabot Station tailrace farfield (T6) (Figure 4.4-3). The upstream-most locations of mobile-tracked shad were explored with a Getis-Ord Gi* Hot Spot Analysis using the Optimized Hot Spot tool in ArcGIS to determine if there were any spatial clustering patterns in where individual fish reached their upstream migration limits; however, low spatial variability of fish locations resulting from many fish reaching their maximum upstream extent at the Cabot Station tailrace far-field (T6) prevented the analysis from calculating hot spots.

Table 4.4-1. Mobile tracking surveys conducted during the 2015 adult shad Study.

Week	Date	Survey Area
1	5/15/2015	Turners Falls Impoundment
2	5/20/2015	Sunderland Bridge to Holyoke Dam
	5/20/2015	Cabot Station to Sunderland Bridge
	5/21/2015	Turners Falls Impoundment
3	5/27/2015	Sunderland Bridge to Holyoke Dam
	5/27/2015	Cabot Station to Sunderland Bridge
	5/28/2015	Cabot Station to Sunderland Bridge
	5/28/2015	Turners Falls Impoundment
4	6/3/2015	Cabot Station to Holyoke Dam
	6/3/2015	Turners Falls Impoundment
	6/4/2015	Sunderland Bridge to Hatfield S-Curve
	6/4/2015	Cabot Station to Sunderland Bridge
5	6/9/2015	Turners Falls Impoundment
	6/9/2015	Cabot Station to Sunderland Bridge
	6/10/2015	Sunderland Bridge to Holyoke Dam
	6/11/2015	Sunderland Bridge to Hatfield S-Curve
	6/11/2015	Cabot Station to Sunderland Bridge
6	6/16/2015	Cabot Station to Sunderland Bridge
	6/16/2015	Sunderland Bridge to Hatfield S-Curve
	6/17/2015	Turners Falls Impoundment
	6/18/2015	Cabot Station to Sunderland Bridge
	6/18/2015	Hatfield S-Curve to Holyoke Dam
7	6/22/2015	Cabot Station to Sunderland Bridge
	6/23/2015	Sunderland Bridge to Hatfield S-Curve
	6/24/2015	Turners Falls Impoundment
	6/25/2015	Sunderland Bridge to Holyoke Dam
8	6/29/2015	Hatfield S-Curve to Holyoke Dam
	6/29/2015	Cabot Station to Hatfield S-Curve
	6/30/2015	Cabot Station to Hatfield S-Curve
	6/30/2015	Turners Falls Impoundment
9	7/6/2015	Turners Falls Impoundment
	7/6/2015	Cabot Station to Hatfield S-Curve
	7/7/2015	Cabot Station to Holyoke Dam



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Miles

Figure 4.4-1: Optimized Hotspot Analysis for the first mobile-tracking mortality detections of adult American Shad.

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Figure 4.4-2: Upstream-most mobile-tracking locations of Holyoke-tagged American Shad.

N

0 2.25 4.5 9 Miles

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Figure 4.4-3: Upstream-most locations of mobile-tracked Holyoke-tagged American Shad.

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0 2.25 4.5 9 Miles

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4.5 Data Reduction

In total, there were 1,034 tagged fish in the Connecticut River during the spring of 2015. There were shad, Sea Lamprey and 6 Atlantic Salmon tagged by the USGS. Of those fish, 449 were dual tagged, 451 were PIT tagged only, and 134 were radio tagged only. The resulting data collection effort produced 19,177,280 detections and following data reduction, the final recaptures dataset was 16,784,468 detections, a reduction of approximately 12.5%. The algorithm itself removed 9.7% of the detections as false positive, while the other data reduction steps removed the remaining 2.8%. The single most important predictor for the algorithm was detection history and its derived components. It was the pattern of hit to missed detections that drove the belief in a record as being true or false positive. A snapshot of both a good (Figure 4.5-1) and bad (Figure 4.5-2) detection is provided. For Orion receiver sites, the algorithm removed between 3.57% and 59.24% of the records (Table 4.5-1), while the algorithm removed between 0 and 21% (Table 4.5-2) for Lotek receiver sites.

During the false positive removal, it was discovered that Lotek receivers using frequency switching could not detect the mortality status of the tag due to the randomizer setting used on the tag. The Sigma-8 tags incorporated a pulse randomizer that adds or subtracts 500 milliseconds to a pulse as a means of reducing the chance of collisions. However, receivers round to the nearest second, which means over time the tag will either add or subtract a second and the detection history will shift (random walk). This shift is evident in the detection history of the good detection (Figure 4.5-1) and is what is responsible for creating the wave pattern within the record. When scanning multiple frequencies with a Lotek receiver, we found that the shift in the detection history will occur by the time the receiver returns to the original frequency. Therefore, the pulse randomizer prohibited the researcher from determining the mortality status of a tag with Lotek receivers. However, mortality was assessed during mobile tracking, and a record of the fish’s mortality would preclude it from statistical analysis.

Following algorithm and SQL false positive removal, a final MS Access recaptures database was constructed with tables describing recaptures (fish ID, receiver ID, and time stamp), a master tag table, a master receiver table, and flow data. The database was used to manage all data for the individual models as well as to construct primary raw data counts.

Table 4.5-1: The number of true and false positive detections identified by the algorithm with percent (%) removal of records for sited with Orion receivers

Site	Location	True Positive	False Positive	Percent Removal
5	Cabot Tailrace	1,722,734	359,824	17.28%
7	Cabot FW Entrance	9,967	664	6.25%
8	Cabot Forebay	7,061,616	504,385	6.67%
9	Cabot Bypass	3,093,486	114,403	3.57%
11	Smead Island	76,272	35,159	31.55%
12	Rawson Island	154,107	223,935	59.24%
13	Lower Canal	311,364	120,002	27.82%
15	Conte Discharge	587,252	96,296	14.09%
17	Station No. 1 Forebay	441,074	142,642	24.44%
18	DS of Station No. 1	160,368	14,149	8.11%
21	Upper Canal	515,612	55,641	9.74%
22	DS Gatehouse	329,260	80,752	19.70%
25	NMPS Intake	290,175	15,775	5.16%
29	Lower Cabot FW	4,805	293	5.75%
30	Spillway Entrance Dipole	9,205	756	7.59%
31	Upper Reservoir	0	0	No fish
33	Deerfield Conf	8,799	1,279	12.69%

Table 4.5-2: The number of true and false positive detections identified by the algorithm with percent (%) removal of records for sites with Lotek receivers.

Station	Name	True Positive	False Positive	Percent Removal
1	Red Cliff	73,012	3,235	4.24%
2	Sunderland Bridge	129,155	4,353	3.26%
3	Montague Wastewater	356,831	1,224	0.34%
6	Cabot Farfield	604,607	2,010	0.33%
14	Conte Intake	333,472	4,531	1.34%
16	Station No. 1 Tailrace	2,981	13	0.43%
19	Dam RR	42,343	10,927	20.51%
20	Dam RL	588,916	31,168	5.03%
23	Impoundment	120,708	37,927	23.91%
24	Gill Bank	196,956	1,104	0.56%
26	Shearer RL	49,586	638	1.27%
27	Shearer RR	26,502	243	0.91%

149.780 25	5/13/2015 3:17:05 AM	True	11011110000
149.780 25	5/13/2015 3:17:07 AM	True	10111100000
149.780 25	5/13/2015 3:17:12 AM	True	00000111111
149.780 25	5/13/2015 3:17:14 AM	True	00001111111
149.780 25	5/13/2015 3:17:16 AM	True	00011111111
149.780 25	5/13/2015 3:17:18 AM	True	00111111111
149.780 25	5/13/2015 3:17:20 AM	True	01111111110
149.780 25	5/13/2015 3:17:22 AM	True	11111111100
149.780 25	5/13/2015 3:17:24 AM	True	11111111000
149.780 25	5/13/2015 3:17:26 AM	True	11111110000
149.780 25	5/13/2015 3:17:28 AM	True	11111100000
149.780 25	5/13/2015 3:17:31 AM	True	00000111110
149.780 25	5/13/2015 3:17:33 AM	True	00001111100
149.780 25	5/13/2015 3:17:35 AM	True	00011111001
149.780 25	5/13/2015 3:17:37 AM	True	00111110011
149.780 25	5/13/2015 3:17:39 AM	True	01111100110
149.780 25	5/13/2015 3:17:45 AM	True	11100110100

Figure 4.5-1: True detections as identified by the false positive reduction algorithm. Note detection history string with apparent wave pattern through time.

FreqCode	timeStamp	detHist	lagB	lagF	ReClass
149.800 89	5/4/2015 7:09:41 PM	00000100000	0	66525	False
149.800 89	5/5/2015 1:38:26 PM	00000100000	66525	13326	False
149.800 89	5/5/2015 5:20:32 PM	00000100000	13326	71041	False
149.800 89	5/6/2015 1:04:33 PM	00000100000	71041	14182	False
149.800 89	5/6/2015 5:00:55 PM	00000100000	14182	17896	False
149.800 89	5/6/2015 9:59:11 PM	00000100000	17896	32477	False
149.800 89	5/7/2015 7:00:28 AM	00000100000	32477	777	False
149.800 89	5/7/2015 7:13:25 AM	00000100000	777	2122	False
149.800 89	5/7/2015 7:48:47 AM	00000100000	2122	113156	False
149.800 89	5/8/2015 3:14:43 PM	00000100000	113156	242966	False
149.800 89	5/11/2015 10:44:09 AM	00000100000	242966	23008	False
149.800 89	5/11/2015 5:07:37 PM	00000100000	23008	16499	False
149.800 89	5/11/2015 9:42:36 PM	00000100000	16499	21940	False
149.800 89	5/12/2015 3:48:16 AM	00000100000	21940	42644	False
149.800 89	5/12/2015 3:39:00 PM	00000100000	42644	34239	False
149.800 89	5/13/2015 1:09:39 AM	00000100000	34239	64578	False
149.800 89	5/13/2015 7:05:57 PM	00000100000	64578	24134	False
149.800 89	5/14/2015 1:48:11 AM	00000100000	24134	407371	False

Figure 4.5-2: False positive detection as identified by the algorithm. Note large, infrequent, and random lags between detections and poor detection history string.

4.5.1 Event Enumeration

The brute force piecewise linear regression algorithm identified the lagged break between detections that signified new behavior. This behavior of interest occurs when an individual fish leaves the station of interest only to return to it again. Table 4.5.1-1 lists the breaks in seconds for each reach. A python script then enumerated the presence event of each detection. Of particular interest was Cabot ladder, Spillway ladder and Gatehouse ladder. These breaks identified when an animal rejected an attempt to enter or climb the ladder and tried again at a later time. The event identifier worked very well at the entrance to Cabot ladder, however manual editing was required for recaptures further up the ladder as the lag between the entrance and exit was often longer than break specified. Manual editing was also required for the Spillway, Gatehouse, and the downstream bypass entrance. Following event enumeration, overlapping events were discovered when a reach consisting of Yagi antennas had events for the same fish when it was also identified in a limiting reach consisting of dipole and PIT antennas. It was hypothesized that the broader Yagi antennas were picking up detections of a fish while it was within the ladder. Another Python script identified these overlapping detections, and they were subsequently removed from statistical analysis via SQL query criteria. Figures for each reach can be found below, where the red lines in each plot are the piecewise regression segments that minimize error over the dataset.

Table 4.5.1-1: Breaks in seconds for each reach

Reach	Seconds
Canal	3120
Cabot Ladder	960
Station No. 1 Forebay	390
Deerfield	7290
Lower River	5940
Spillway Ladder	450
Lower Bypass	1410
Cabot Forebay	2850
Gatehouse Entrance	1650
Station No. 1 Tailrace	300
Downstream Bypass	3060
NFM Intake	870
Gatehouse Ladder	420
US NFM Intake	1110
Upper Bypass	5910
Cabot Powerhouse	6090
DS NFM Intake	5910

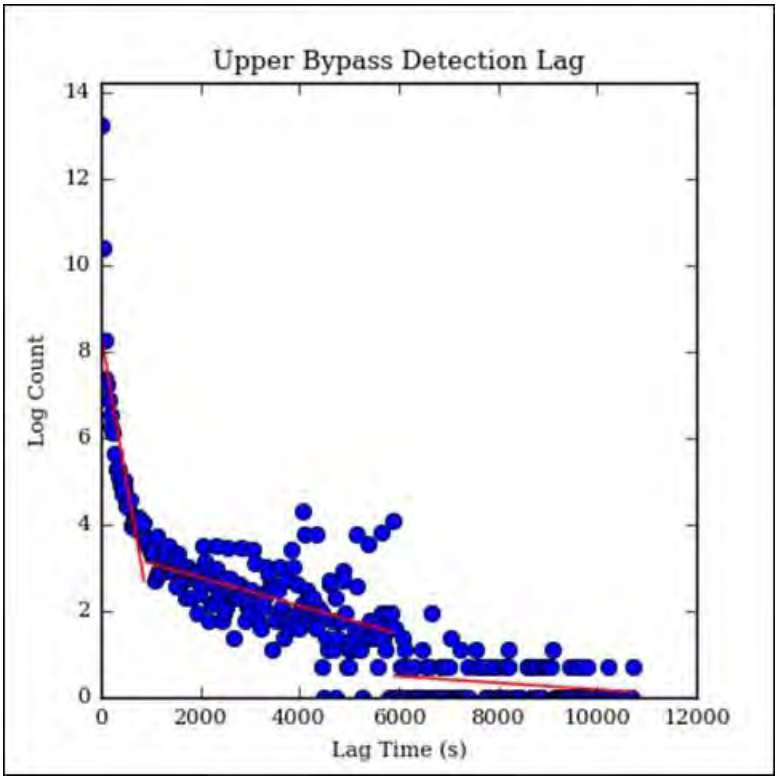

Figure 4.5.1-1: Results of the brute force piecewise linear regression, with the three behavioral equations that minimize regression error for the Upper Bypass reach (receivers T19 and T20)

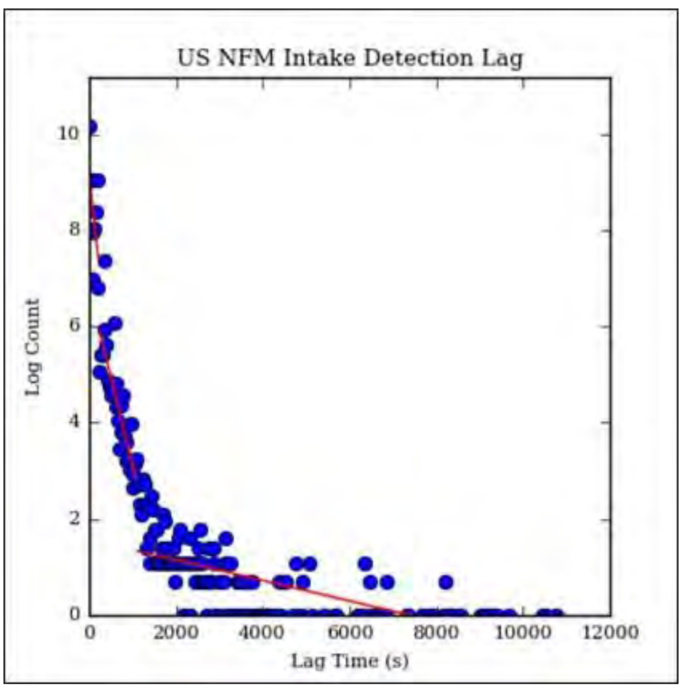

Figure 4.5.1-2: Results of the brute force piecewise linear regression, with the three behavioral equations that minimize regression error for the reach upstream of NMPS Intake (receiver T26 and T27)

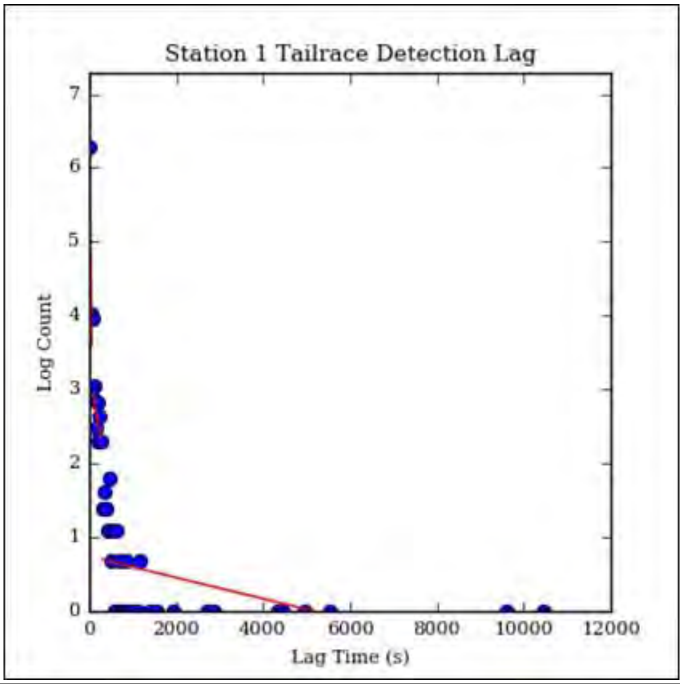

Figure 4.5.1-3: Results of the brute force piecewise linear regression, with the three behavioral equations that minimize regression error for Station No. 1 Tailrace (receiver T16)

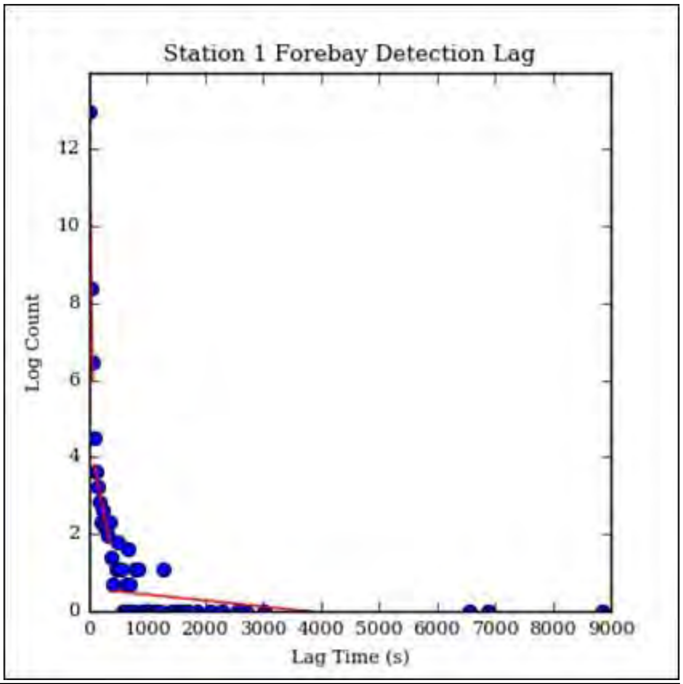

Figure 4.5.1-4: Results of the brute force piecewise linear regression, with the three behavioral equations that minimize regression error for the Station No. 1 Forebay (receiver T17)

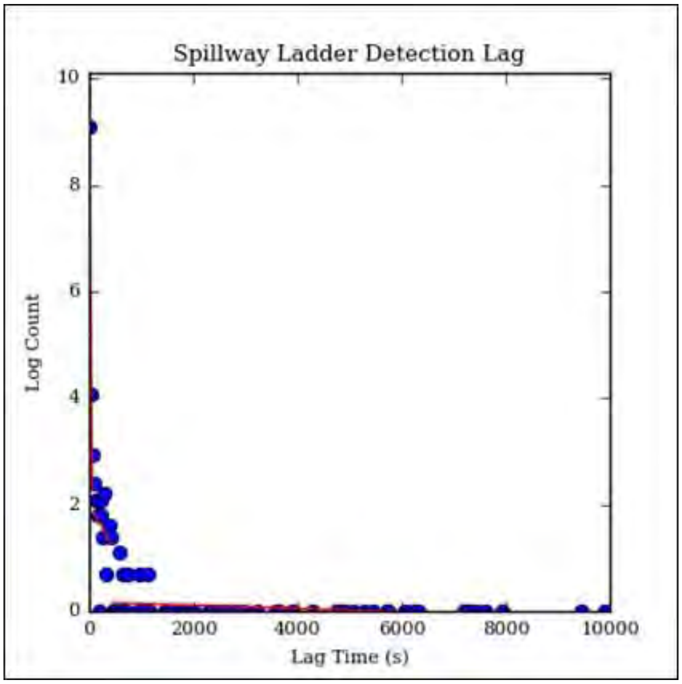

Figure 4.5.1-5: Results of the brute force piecewise linear regression, with the three behavioral equations that minimize regression error for the Spillway Ladder (receivers T30, P21, P22, P23S1, P23TP, P24 and P25)

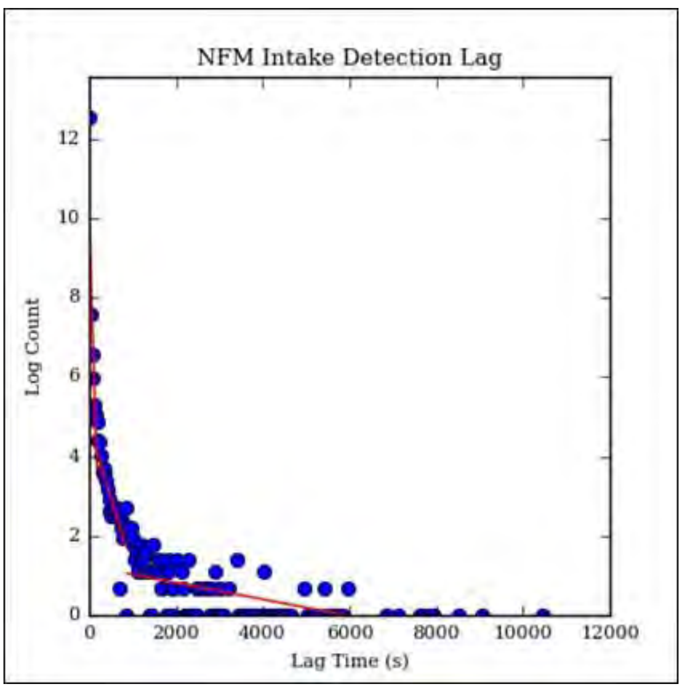

Figure 4.5.1-6: Results of the brute force piecewise linear regression, with the three behavioral equations that minimize regression error for the NMPS Intake (receivers T25)

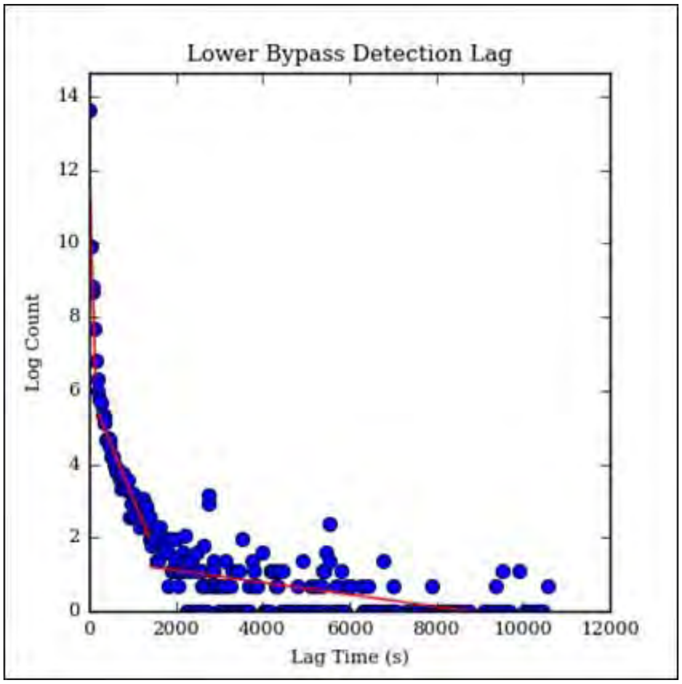

Figure 4.5.1-7: Results of the brute force piecewise linear regression, with the three behavioral equations that minimize regression error for the Lower Bypass reach (receivers T11, T15, T12W and T12E)

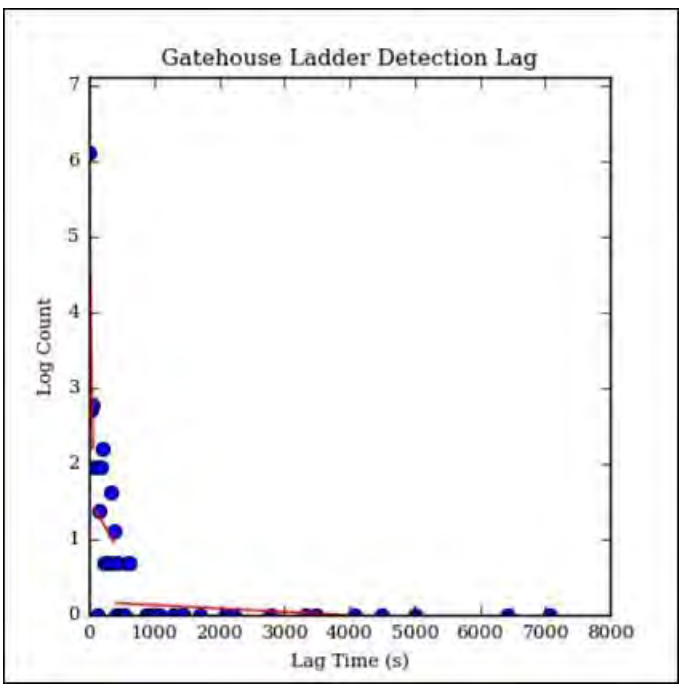

Figure 4.5.1-8: Results of the brute force piecewise linear regression, with the three behavioral equations that minimize regression error for the Gatehouse Ladder (receivers P34, P34Z, P21, P32 and P33)

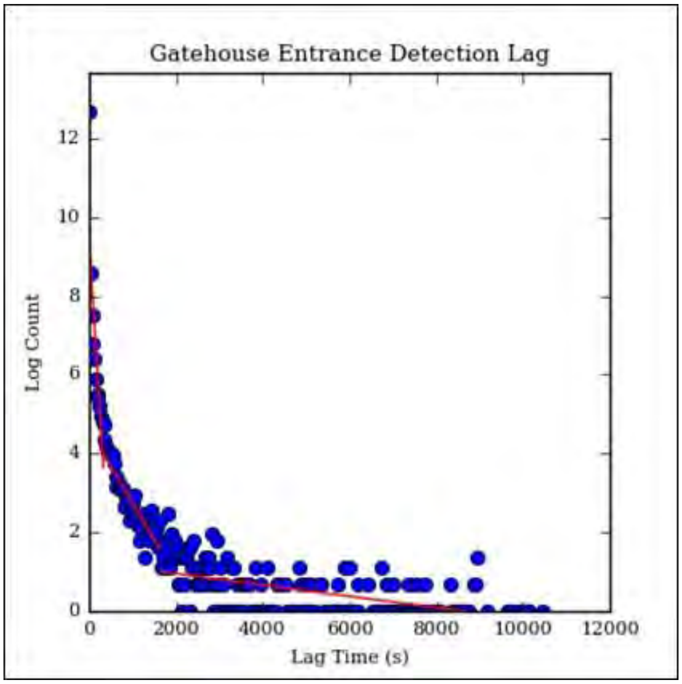

Figure 4.5.1-9: Results of the brute force piecewise linear regression, with the three behavioral equations that minimize regression error for the Gatehouse Entrance Yagi (receiver T22)

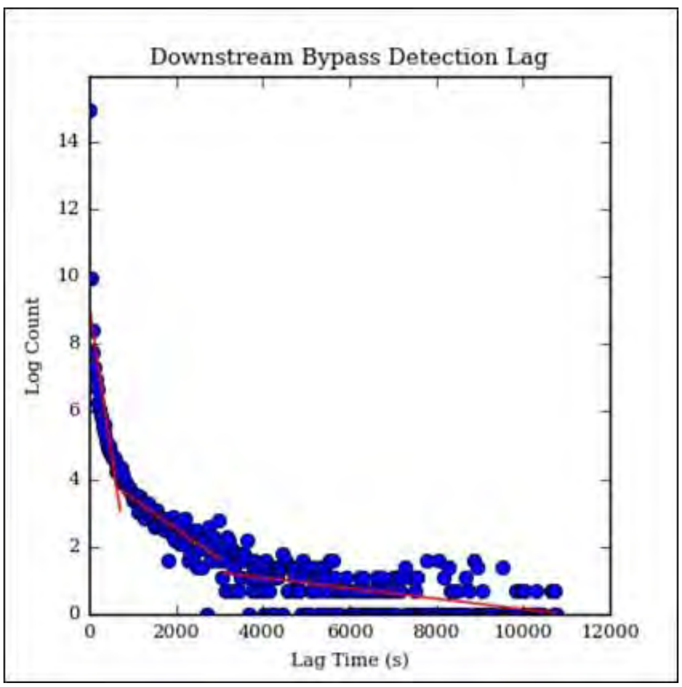

Figure 4.5.1-10: Results of the brute force piecewise linear regression, with the three behavioral equations that minimize regression error for the Downstream Bypass reach (receivers T9 and P13)

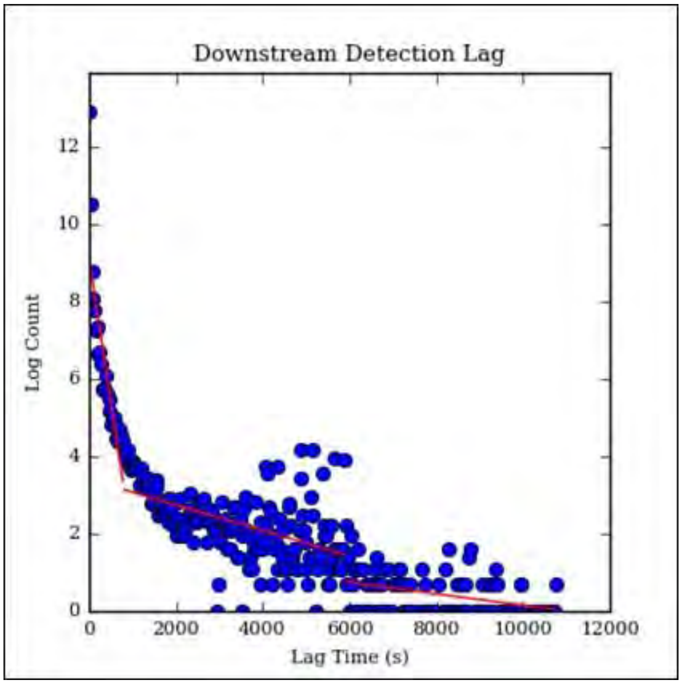

Figure 4.5.1-11: Results of the brute force piecewise linear regression, with the three behavioral equations that minimize regression error for the Downstream (lower river) Reach (receivers T1, T2 and T3)

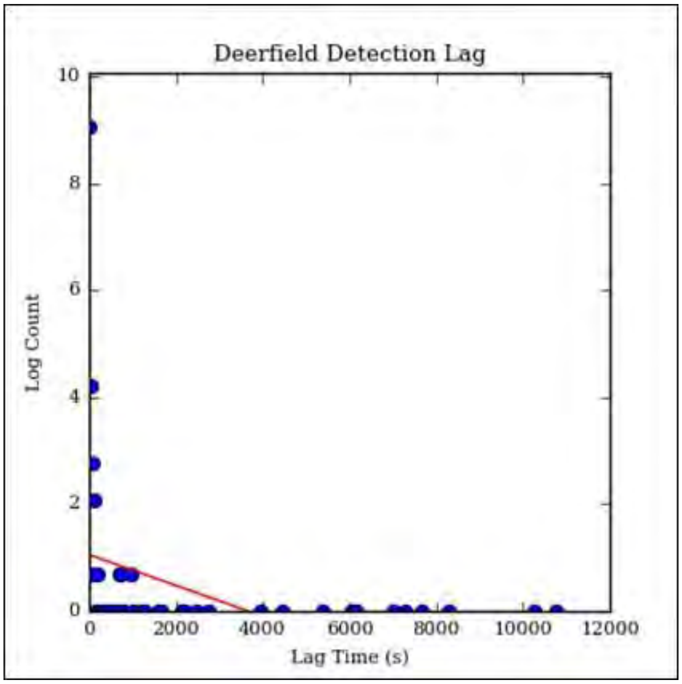

Figure 4.5.1-12: Results of the brute force piecewise linear regression, with the three behavioral equations that minimize regression error for the Deerfield River (receiver T33)

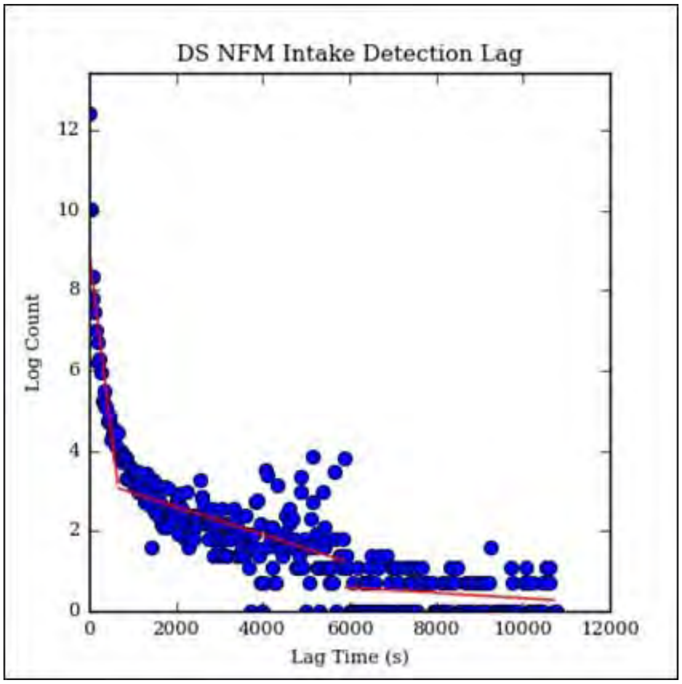

Figure 4.5.1-13: Results of the brute force piecewise linear regression, with the three behavioral equations that minimize regression error for the reach downstream of the NMPS intake (receivers T24 and T23)

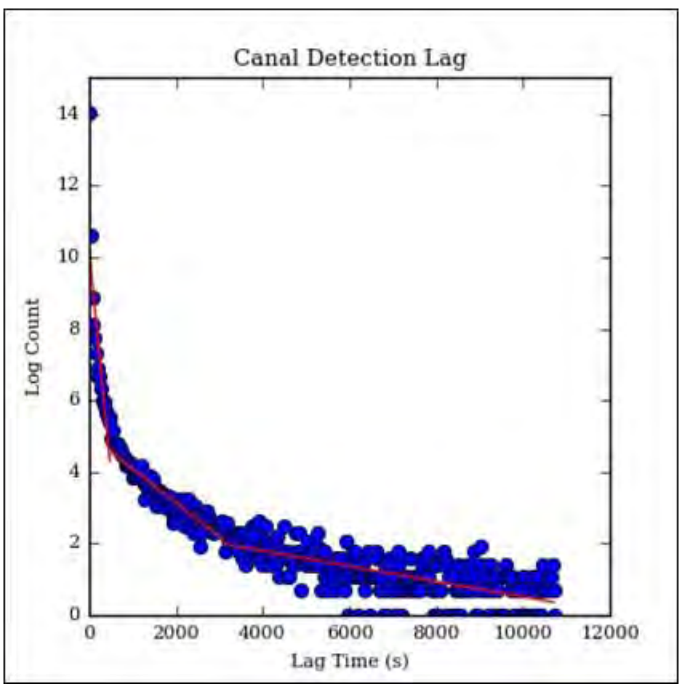

Figure 4.5.1-14: Results of the brute force piecewise linear regression, with the three behavioral equations that minimize regression error for the Canal (receivers T13, T14, T18 and T21)

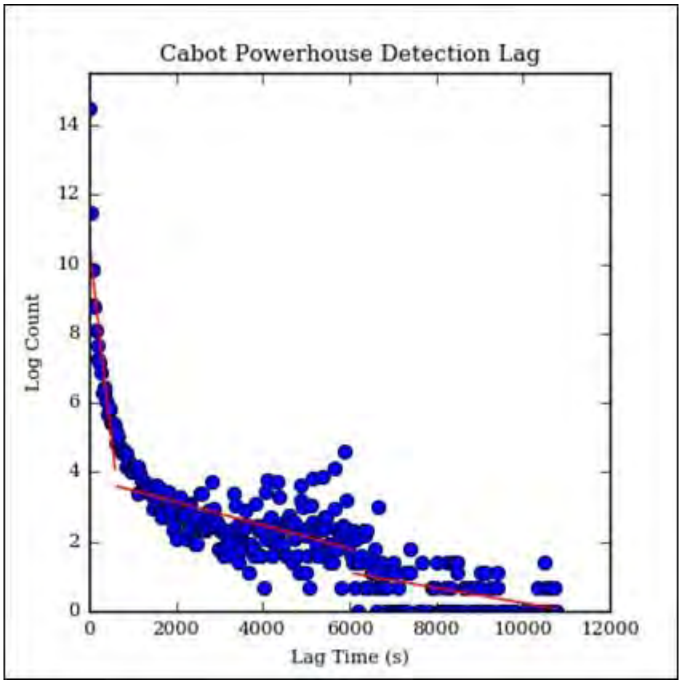

Figure 4.5.1-15: Results of the brute force piecewise linear regression, with the three behavioral equations that minimize regression error for the Cabot Tailrace (receivers T5 and T6)

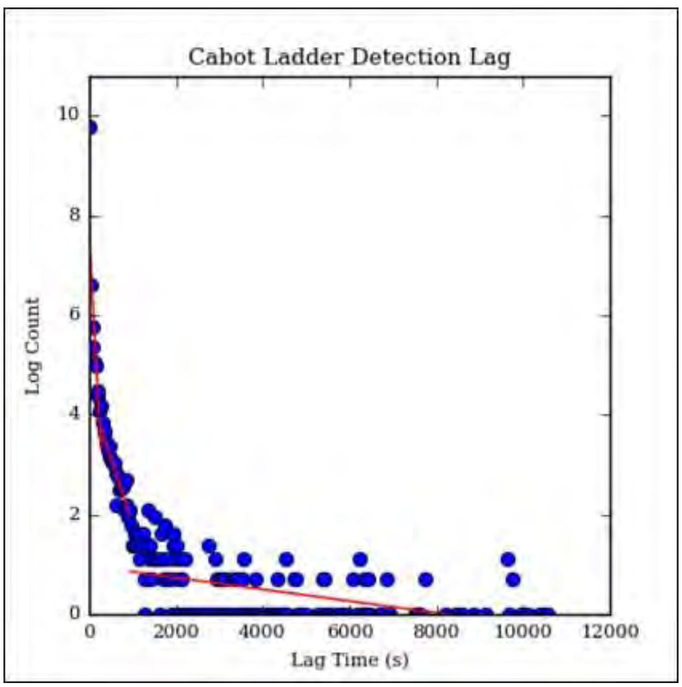

Figure 4.5.1-16: Results of the brute force piecewise linear regression, with the three behavioral equations that minimize regression error for the Cabot Ladder (receivers T7, P111, P112, T29 and P12)

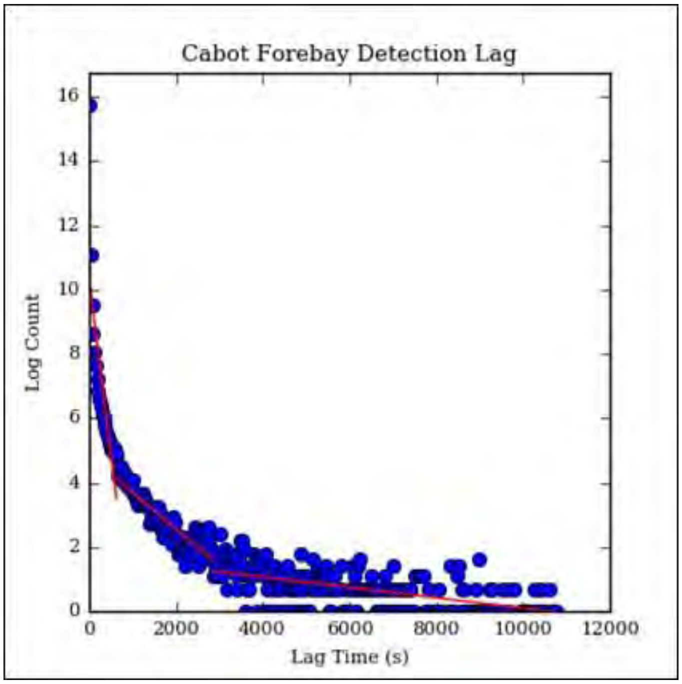

Figure 4.5.1-17: Results of the brute force piecewise linear regression, with the three behavioral equations that minimize regression error for the Cabot Forebay (receivers T8)

4.6 Adult Shad Migration and Emigration within the Connecticut River – Holyoke to Vernon

The following sections discuss the migration and emigration of tagged Adult American Shad within the Connecticut River from Holyoke to Vernon. The subsections were designed so that they follow the migratory route of an Adult American Shad from passage at Holyoke through either of the Turners Falls fish ladders. After passage at the Turners Falls Project, fish migrate through the Turners Falls Impoundment where they may pass Northfield Mountain intake in either migratory direction. Once fish were emigrating, we attempted to understand downstream route selection at TFD, along with downstream passage through the power canal. Every potential avenue for passage was explored and assessed with appropriate statistical techniques designed to answer questions of efficiency, route selection and delay.

4.6.1 Holyoke to Montague

The first analysis tracked dual tagged shad from Holyoke moving through the lower river up to the project (Figure 4.6.1-1). In total, Kleinschmidt released 215 dual tagged shad at Holyoke, the detection histories of 164 recaptured shad were used in the MSM analysis, and 162 in the time-to-event analysis. The MSM and time-to-event analyzed movement and delay, respectively.

The median flow experienced by fish while in the downstream portion of the study area was 12,700 cfs at Montague (Table 4.6.1-1). The state table (Table 4.6.1-2) displays the raw number of transitions among states within each exposure hour, and is read as from (row) to (column). When a fish transitions between non-adjacent states, it moves undetected through a telemetry station, hence reach detection probability can be inferred from these tables. In the state table, fish were recaptured at Montague 1,071 times within an hour, and were found to migrate from Montague towards the project 101 times and from Montague to somewhere downstream (either Canoe Club or Sunderland) 48 times. The state table also provides a sense of residence time within each site. When a marked fish did not transition from one site to another site within an hour, it was counted as a "from-to" transition at the same site. The "Project" site had the largest count, with fish remaining within this site for an hour, 5,157 times. The Canoe Club (T1) had the lowest residence time with only 514 from-to hourly counts. Therefore, fish traveling upstream from Holyoke remained around the "Project" site approximately ten times longer than they did at downstream sites such as the Canoe Club or Sunderland.

The MSM allows for a descriptive analysis of fish movement between states in response to flow or other factors of interest. The MSM produces the joint probability that a fish will survive, transition from and be detected next at all other sites. Therefore, we can ask, given our current location, where will we end up next? All of the transition probabilities between lower river and project states at varying Montague flows are displayed in (Appendix D, Table D-1.1-1). In general, fish detected at Sunderland were most likely to be detected next at Montague, and the probability of these detections increased with flow at the Montague Gage. Once a fish reached Montague, the probability of a fish surviving, transitioning and being detected next at the "Project" site was 72% at 7,070 cfs (25th percentile flow, Appendix D, Table D-1.1-1). At 17,100 cfs (75th percentile), this probability was 65%. Fish naturally move upstream through this reach seeking passage and or spawning (see Study No. 3.3.6), but seem to be affected by increasing flow. As flows increase from 7,070 cfs (25th percentile) to 17,100 cfs (75th percentile), movements downstream (sum of Sunderland and Canoe Club) from Montague increased from 28% to 36%. In total, of the 162 fish analyzed with the MSM model, 107 were detected within the project area and 9 state transitions occurred from the project area to another location upstream (Power Canal, TFI, etc.).

While the MSM is useful for describing where a fish will transition to and be detected next, it does little to describe how the population of tagged individuals moved through this reach with respect to time. Time-to-event analysis provides us with a more complete picture of this process. To simplify this analysis, recaptures at the Canoe Club (T1), Sunderland (T2) and Montague (T3) receivers were grouped into a *staging* state. Recaptures at receivers upstream of Montague (Deerfield: T33, Smead Island: T11, Conte Tailrace: T15, Cabot Tailrace: T6 and T5) were grouped into a *passing* state. Cox proportional hazards regression modeling examines the time to our event of interest, which is when a fish undergoes a *staging-passing* transition. The 162 dual tagged fish analyzed with time-to-event made 114 successful forays into the project area from lower river receivers. These events may include multiple forays for the same fish. The fish appear to have experienced a similar distribution of flows from Montague during the day as they did at night (Appendix D, Figure D-2.1-1). The best model estimated a hazard ratio of 2.8239 suggesting that a fish is 2.8 times more likely to experience the event during the day than at night. Of the population of shad available to pass into the project, 50% did so within 232 hours during the day (Figure 4.6.1-2). A majority (75%) of the 162 tagged fish experienced the event within 400 hours with few fish arriving after that. The null model loses confidence after 1000 hours and shows the last transition to occur after 1400 hours.

Table 4.6.1-1. Flow Quantiles for MSM Downstream Model

Quantile	Natural Logarithm (ln) of Flow	Flow (cfs)
0%	8.06	3,180
25%	8.86	7,070
50%	9.45	12,700
75%	9.75	17,100
100%	10.55	38,100

Table 4.6.1-2: State Table displaying the transitions from (row) to (column) at each hour exposure for fish in the MSM Downstream Model.

From	Canoe Club	Sunderland	Montague	Project	Upstream Passage
Canoe Club	514	8	2	8	0
Sunderland	30	818	62	14	0
Montague	8	40	1071	101	0
Project	3	8	92	5157	9

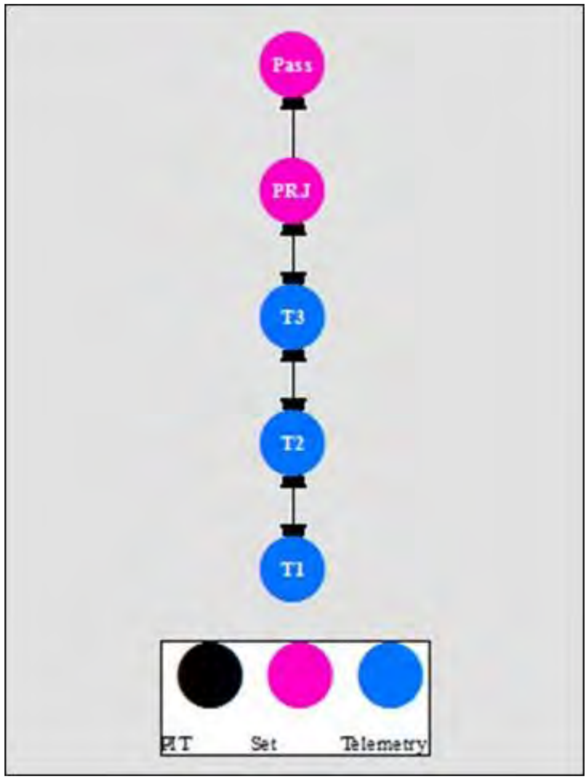

Figure 4.6.1-1. Telemetry subnetwork used for the MSM model downstream of the Turners Falls Project. Note the PRJ set includes all telemetry receivers (PIT and Radio) considered to be within the Turners Falls Project, and the Pass set includes all telemetry receivers considered to be within the Turners Falls Impoundment and Power Canal, Montague is station T3, Sunderland (T2) and Canoe Club (T1).

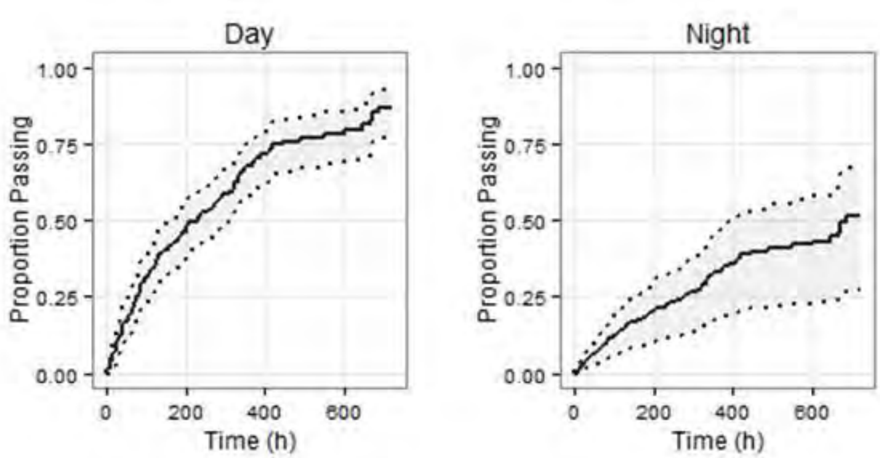

Figure 4.6.1-2: Kaplan Meier curves for the lower river to project area migration times during the day and at night.

4.6.2 Montague Spoke

Once fish arrive at Montague, they are faced with a complex array of migratory choices. They may turn left and attempt the Deerfield River (T33) or the western channel of Smead Island (T11). If they turn right and approach the project, the fish can transition into the Cabot Station tailrace (T5 and T6) with eventual transition into the bypass reach (T15) or the Cabot ladder (P111, P112, T7, T29, P12). This specific section will discuss transitions into the Cabot Tailrace, Bypass Reach, Smead Island and Deerfield, with Cabot ladder attraction discussed in the next section. Of the 215 dual tagged shad released at Holyoke, detection histories from 105 recaptured fish within the Montague Spoke network (Figure 4.6.2-1) were used in the MSM model. Unlike the previous model, flow was broken up into two components: Cabot discharge (Appendix D, Figure D-1.2-1) and bypass flow (Appendix D, Figure D-1.2-2). Bypass flow is the sum of Station No. 1 discharge and spill at TFD. The flows experienced by fish within the Montague spoke MSM model are reflective of the scheduled flow releases with the exception of a few recaptures when the bypass reach experienced large spill events in late June.

The state table (Table 4.6.2-2) shows 58 transitions into the Cabot Tailrace from Montague, 4 from the Deerfield River (T33), 16 from the west channel of Smead Island (T11) and 13 from the Bypass Reach (T15). Interestingly, there were 39 forays into the west channel of Smead Island and only 14 into the Deerfield River. The best MSM model incorporated Cabot discharge, Bypass Flow and diurnal cues, thus examination of each transition probability table is difficult because multiple transition probability tables were warranted to explore different combinations of covariate levels (Appendix D, Tables D-1.2-1 though D-1.2-8). One should be thorough when examining these transition probability tables, because there are circumstances where a low number of transitions occurred. This resulted in wider confidence intervals and reduced the precision of the estimate. Transition probabilities from the Deerfield River suffered because of this. The state table only shows 14 forays into the Deerfield River, however there was more combinations of flow and diurnal cues than there were observations and the precision for these estimates was low.

The probability that fish will survive, transition to and be detected within the Deerfield River from Montague does not appear to change significantly with flow and ranges from 6% at low flow (Appendix D, Table D-1.2-1, 25th Cabot, 25th Bypass) to 9% at high flow (Appendix D, Table D-1.2-3, 75th Cabot, 75th Bypass) with overlapping confidence intervals. Transition into the Deerfield River from the Cabot Tailrace was also low (<1%) and did not change as flow increased. Transition into the Deerfield River from the west channel of Smead Island was lowest at low flow 4%, (Appendix D, Table D-1.2-1, 25th Cabot, 25th Bypass), but was 11% during high flow events (Appendix D, Table D-1.2-3, 75th Cabot, 75th Bypass). Once fish entered the Deerfield River, time-to-event analysis assessed time to escape. A Kaplan-Meier curve (Figure 4.6.2-2) was fit to the detection histories of 11 shad that made 13 successful escapes, meaning that one or more fish made multiple forays into the Deerfield River and multiple escape attempts. Further, no successful escape-events occurred after 20 hours. Of the 11 fish analyzed with time-to-event, only 8 escaped, however 50% of the escapes occurred within 9.1 hours.

The 39 forays into the west channel of Smead Island are interesting because it was not previously thought of as a preferred migratory route. The probability that a fish will transition to Smead Island from Montague increases from 7% at low flow (Appendix D, Table D-1.2-1, 25th Cabot, 25th Bypass) to 26% at high flow (Appendix D, Table D-1.2-3, 75th Cabot, 75th Bypass). Heat maps were constructed to show the probability of survival, transition and detection at Smead Island from Montague at a range of flows during day (Figure 4.6.2-3) and night (Figure 4.6.2-4). As Cabot Discharge increases, the probability that fish transitioned to the west channel of Smead Island from the tailrace increased. Transition into the west channel from the Cabot Tailrace increased from 2% (Appendix D, Table D-1.2-1) at low flow to 13% (Appendix D, Table D-1.2-3) at high flow. Once in the west channel, the probability that fish transitioned into the Bypass Reach increased from 23% at low flow to 46% at high flow. High Cabot discharges seem to encourage a portion of the population to travel around Smead Island, and a combination of high bypass and high Cabot discharge seemed to increase passage into the Bypass Reach from the western channel. However, the largest contribution of fish into the Bypass Reach came from the Cabot tailrace with 48 forays compared to 13 from Smead Island and 20 undetected from Montague (state table, Table 4.6.2-2).

A majority of fish (74%) from Montague survived, transitioned and were detected next at the Cabot Tailrace at low flow (Appendix D, Table D-1.2-1, 25th Cabot, 25th Bypass), however this proportion declined to only 44% at high flow (Appendix D, Table D-1.2-3, 75th Cabot, 75th Bypass). Heat maps show the range of transition probabilities during the day (Figure 4.6.2-5) and night (Figure 4.6.2-6). They suggest that fish were less likely to survive, transition to and be detected within the tailrace during high flow events, and that upstream migration was sensitive to bypass flow conditions. However, due to the low number of observed events during high bypass flow conditions, one must interpret estimates using bypass flow outside of the scheduled releases with caution. As fish moved into the Cabot tailrace, they were available to transition into the Bypass Reach, Cabot ladder, or go back downstream.

Table 4.6.2-1. Flow Quantiles for MSM Montague Model

Quantile	Cabot Discharge ln(cfs)	Cabot Discharge cfs	Bypass Flow ln(cfs)	Bypass Flow cfs
0%	2.78	16	6.89	979
25%	7.75	2,327	7.82	2,500
50%	8.83	6,814	8.30	4,035
75%	9.34	11,375	8.57	5,275
100%	9.53	13,731	9.88	19,479

Table 4.6.2-2. State Table displaying the transitions from (row) to (column) at each hour exposure for fish in the MSM Montague Model.

From	To: Montague	Deerfield	Smead Island	Cabot Tailrace	Bypass
Montague	1,072	10	17	58	20
Deerfield	9	18	0	4	0
Smead Island	8	3	137	16	13
Cabot Tailrace	68	1	13	1,323	48
Bypass	13	0	9	56	1,011

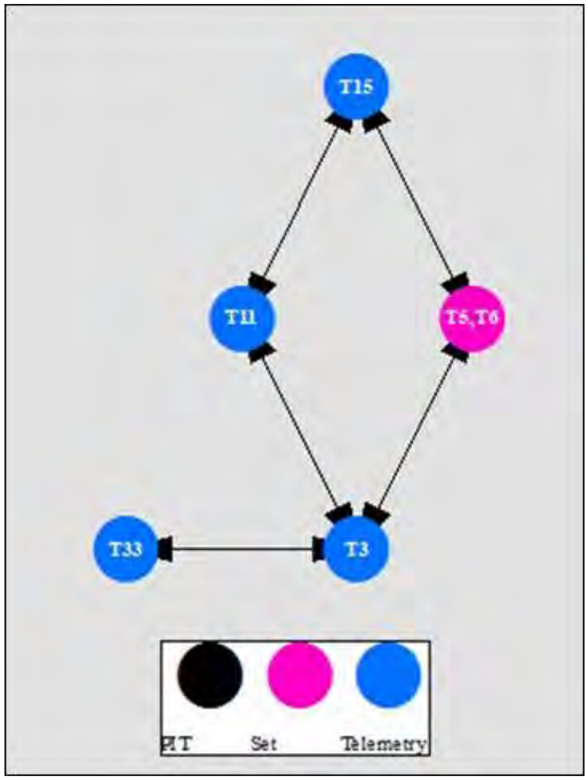

Figure 4.6.2-1. Telemetry subnetwork used in the Montague Spoke model. The Montague Waste Water treatment plant Yagi antenna is located at T3, the entrance to the Deerfield River is located at T33, T11 is the western channel of Smead Island, the Cabot Tailrace consists of receivers T5 and T6 and the bypass reach is receiver T15.

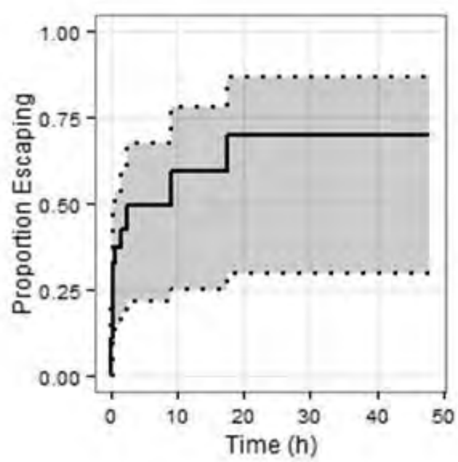

Figure 4.6.2-2: Kaplan Meier curve of time to escape the Deerfield River

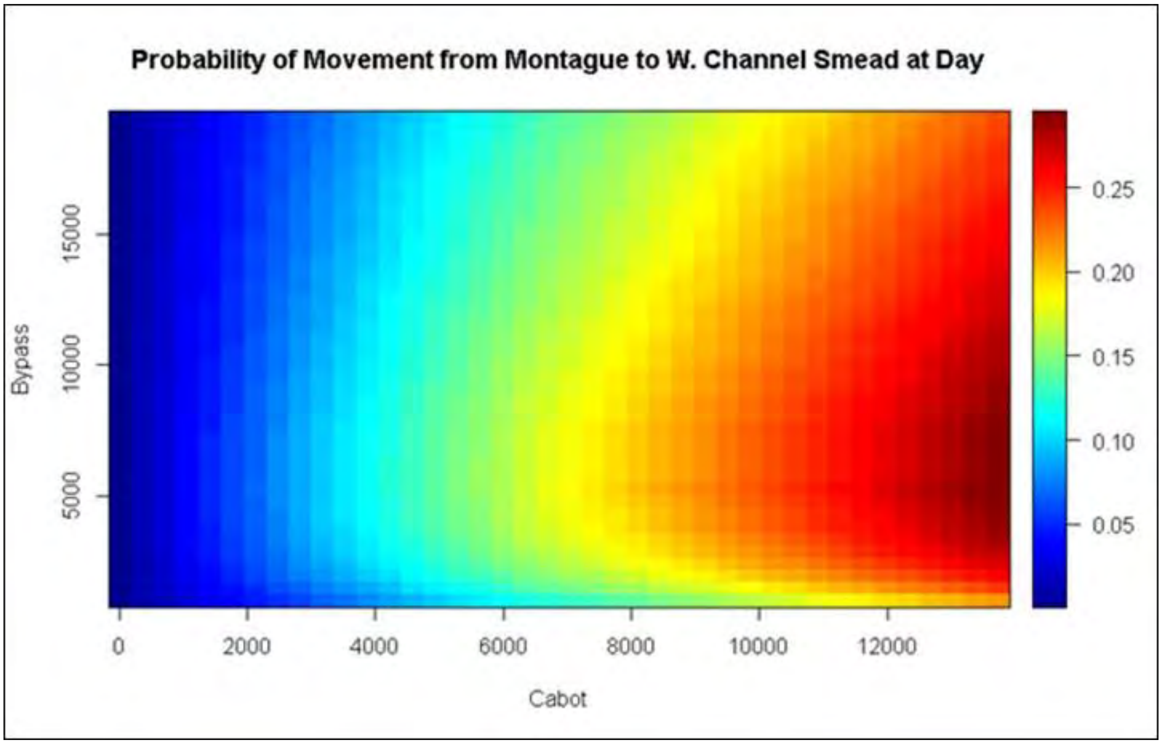

Figure 4.6.2-3: Probability heat map at various Bypass and Cabot flows (cfs) during the day

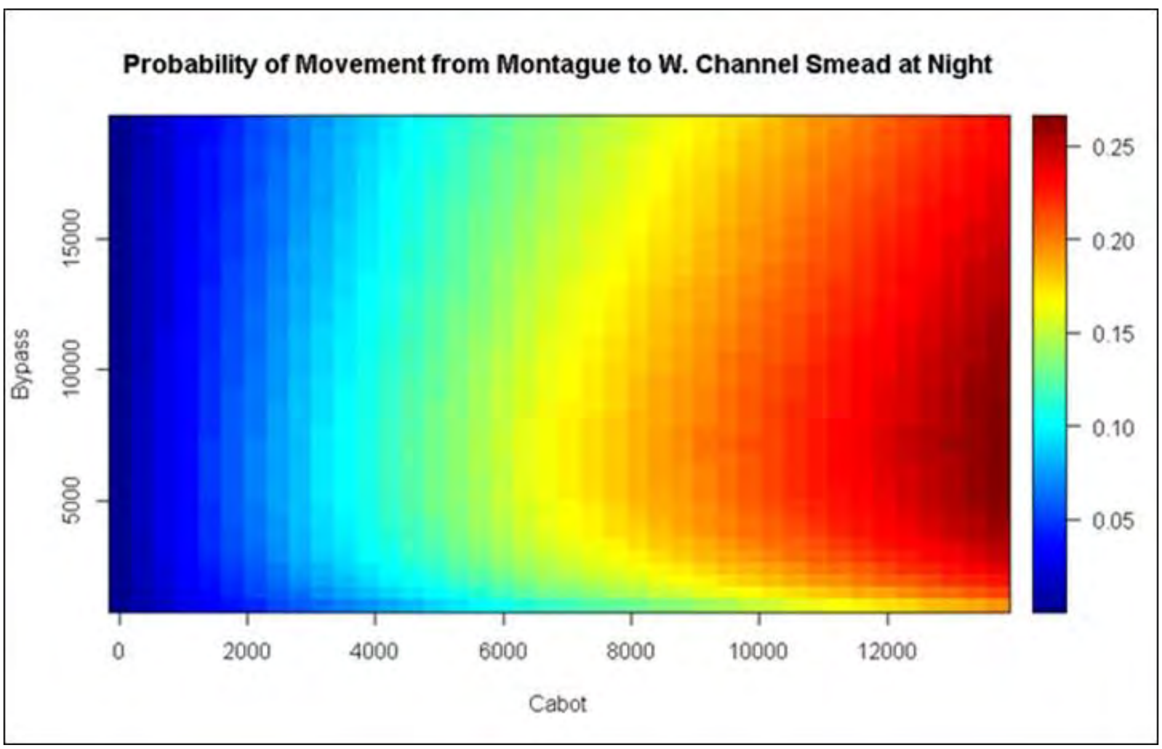

Figure 4.6.2-4: Probability heat map at various Bypass and Cabot flows (cfs) at night

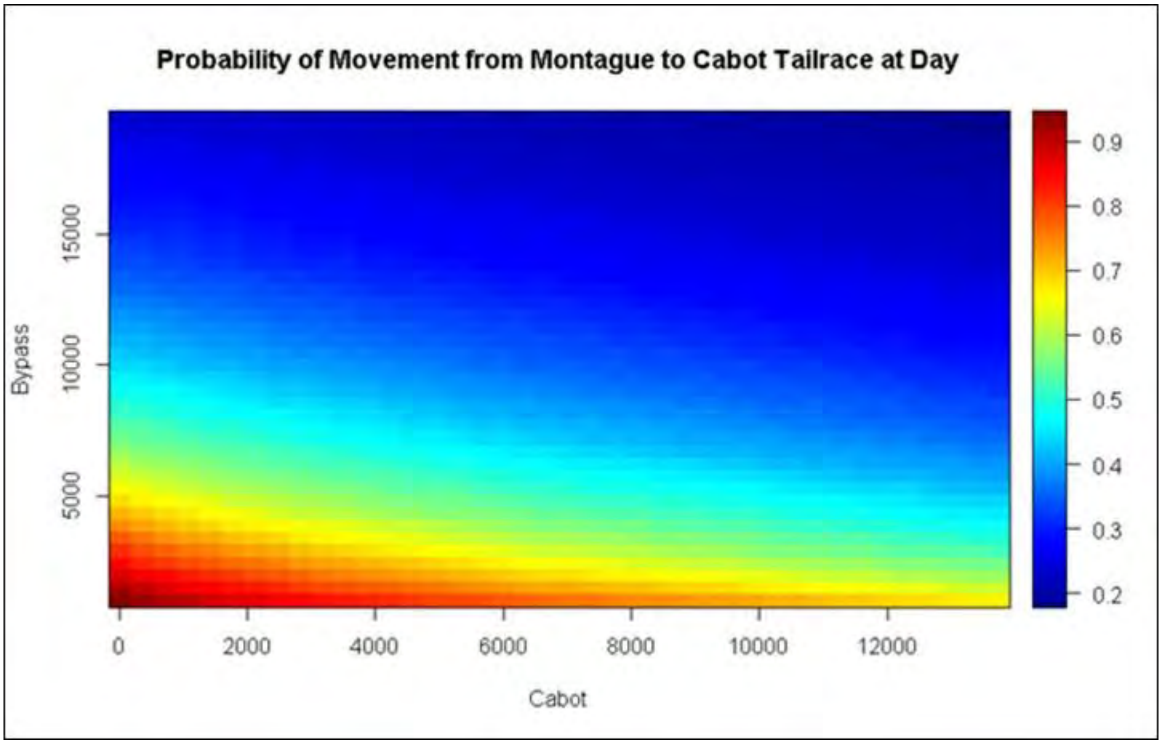

Figure 4.6.2-5: Probability heat map at various Bypass and Cabot flows (cfs) during the day. Given that there were very few observations during the extreme bypass flow event (> 7500 cfs) one should interpret transition probabilities in this range with caution.

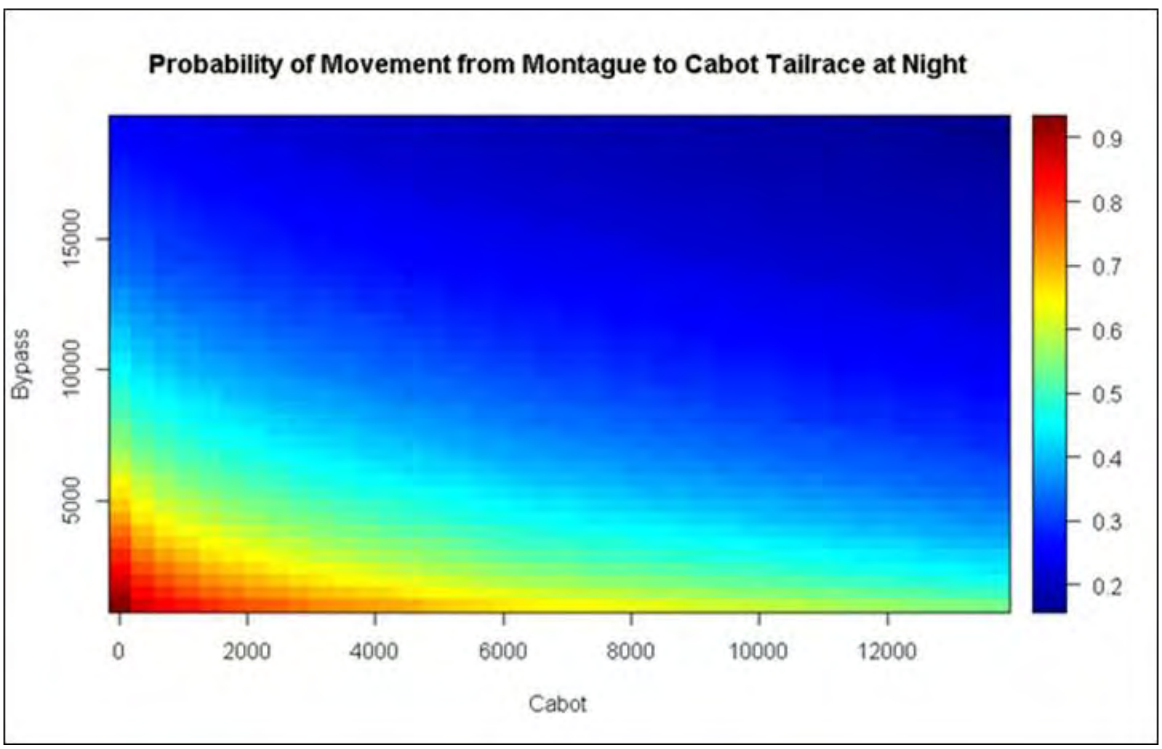

Figure 4.6.2-6: Probability heat map at various Bypass and Cabot flows (cfs) at night

4.6.3 Cabot Ladder Attraction

There are three primary migratory routes available for shad that arrive at the Cabot Tailrace. They may attempt the Cabot ladder, continue on their upstream migration through the bypass reach, or they may reach the upstream extent of their migration and turn around. Movement within the reach was assessed with an MSM model, while time-to-event was assessed with Cox proportional hazards regression modeling.

The Cabot ladder MSM attraction model (Figure 4.6.3-1) used the known detection histories from 107 dual tagged shad released at Holyoke that met the assumptions of the test, and were detected within the Cabot Tailrace (T5 and T6), Bypass Reach (T15, T12E and T12W), Downstream (T33, T3 and T2) and-or Cabot ladder (P111, P112, T7, T29, P12). This analysis included telemetry receivers further up the bypass reach where two extra fish were found to have passed through the region of the Montague Spoke analysis undetected. If fish were only recaptured within the ladder, they were removed from analysis as they did not provide information on state transition. The median flows experienced by fish in the Cabot ladder attraction flow model were 6,815 cfs at Cabot Station and 4,309 cfs in the Bypass Reach (Table 4.6.3-1). The resulting histograms (Appendix D, Figure D-1.3-1 and Figure D-1.3-2) were log transformed to conform to the data analysis procedure as written in Jackson (2011). The state table (Table 4.6.3-2) displays the raw number of transitions among states within each exposure hour, and is read as the number of transitions from a state (row) to another (column). When a fish transitions between non-adjacent states, it moves undetected through a telemetry station.

The state table counts 137 forays into Cabot ladder, with 120 from the tailrace, 8 from downstream receivers and 9 from the bypass reach. This number of forays differed from the sum of the number of forays per fish according to the raw recapture data. This was due to the limitation of counting process data used. The event enumerator procedure quantified more than one ladder event in a row before the fish ever visited another state. With counting process data, if the fish does not leave a state between subsequent detections, then the model will not enumerate a new foray. Regardless, the state table indicated relatively high detection probability through the tailrace with 87% (120/137) of the forays detected at T5 or T6. Fish arrived at the Cabot ladder throughout the day, with two distinct peaks occurring between 0500 and 0900 and between 1600 and 1900 (Figure 4.6.3- 2). The saturated model, (Model 9) incorporated flow from Cabot discharge and the Bypass reach with diurnal cues. From the Cabot Tailrace, the probability that a fish survived, transitioned and was detected next in Cabot ladder was similar at low flow (52%) (25^{th} Cabot, 25^{th} Bypass and Appendix D, Table D-1.3-1) and high flow (54%) (75^{th} Cabot, 75^{th} Bypass, (Appendix D, Table D-1.3-3), where $0.52\ (0.41{,}0.63) \approx 0.54\ (0.42{,}0.64)$. The highest probabilities of transitioning into the Cabot ladder from Cabot Tailrace (60%) occurred when Cabot discharge was high and bypass flow was low (Appendix D, Table D.1.3-1), probability from Cabot Tailrace to Cabot ladder when 75^{th} Cabot, 25^{th} Bypass and when 100^{th} Cabot, 25^{th} Bypass). Heat maps were constructed showing the probability of surviving, transitioning and being detected next within the Cabot ladder from Holyoke at a range of flows for day (Figure 4.6.3-3) and night (Figure 4.6.3-4).

The MSM model also quantified the expected number of visits (forays) into Cabot ladder under differing flow regimes (Appendix D, Table D-1.3-9 and D-1.3-10). During the day at low flow (25^{th} Cabot, 25^{th} Bypass), about 8.22 visits per fish are expected. The number of visits rises to 12.11 when Cabot was at the 100^{th} flow percentile and the bypass flow remained low at the 25^{th} percentile. Greater Cabot flows appear to produce more attraction water for the ladder, causing fish to attempt more forays. As the bypass flow increased, the expected number of forays into Cabot ladder decreased. At the 25^{th} Cabot and 75^{th} Bypass flow, 7.2 forays were expected. Overall, the number of expected forays into the ladder decreased with bypass flow, with the highest proportion occurring when bypass flow was low (25^{th} percentile) (Appendix D, Table D-1.3-9).

While the MSM model describes the overall transition probabilities into the ladder, it does not account for the rate of movement. In other words, with MSM alone, we do not know if shad were delayed along their journey. Two separate time-to-event models were created for Cabot ladder Attraction. The first assessed time-to-first foray, while the second assessed time-to-attraction for all Cabot ladder attraction events (*n* forays per fish) that incorporated time-varying covariates.

For time to first Cabot ladder Foray, dual tagged volitional fish from Holyoke were used. Volitional means that this model only incorporates fish that made at least one attempt at entering the ladder. Any recaptures after the first attempt at the Cabot ladder were removed from the analysis. Further, the model required fish to be detected at Montague prior to the first detection at the Cabot ladder. Two fish were removed from this analysis that were not detected at Montague. In total 43 dual tagged volitional fish from Holyoke were used to assess the overall time until first foray to the ladder (P111, P112, T7, T30, and P12) from Montague (T3). The flows experienced by fish assessed with time-to-event at Cabot Station are in (Appendix D, Figure D-2.2-1) and the bypass flow in (Appendix D, Figure D-2.2-2).

The best model (4) had significant terms for Cabot Generation and diurnal cues. The estimated hazard ratio for Cabot Generation was 1.09, suggesting a fish was 1.09 times more likely to migrate towards the ladder as flow increased by 1000 cfs. The estimated hazard ratio for diurnal cues was 5.011 suggesting that fish were over 5 times more likely to experience the event during the day than at night. According to the model, 50% of the fish that completed their first foray during the day did so within 7.55 hours, while 50% of the fish to reach Cabot ladder during the night did so within 148.0 hours after detection at Montague (Figure 4.6.3-5). Note that movement towards Cabot improved (higher hazard ratio) with increasing flow.

The time-to-Cabot ladder attraction analysis was complex because there are multiple avenues of migration or intervening states (Deerfield River, Lower River, Bypass Reach, west channel of Smead Island and Cabot ladder). According to the state table from the Cabot Tailrace movement model, 62 transitions occurred towards the lower river, 52 up the bypass reach and 120 into the Cabot ladder from the Cabot Tailrace. Competing risks were included in the event data and were censored at transition. There were 45 fish recaptured within the tailrace that made subsequent visits to Cabot ladder, the bypass reach, and/or areas downstream of the tailrace (either up the Deerfield or into the lower river). In total, the time-to-Cabot ladder attraction counted 114 ladder events, with 60 events into the bypass reach and another 60 downstream. These occurrences are very similar to the results of Montague Spoke which had different assumptions and data requirements, and modeled a slightly different cohort of fish.

The fish experienced similar Cabot flow scenarios during the day and night (Appendix D, Figure D-2.3-1) with this trend continuing with bypass reach flows (Appendix D, Figure D-2.3-2). The model incorporating interaction effects of Bypass Flow and diurnal cues was the best (Figure 4.6.3-6). The hazard ratio for diurnal cues was very high and suggests that fish were 10.94 times more likely to become attracted to Cabot ladder during the day than at night. The best model also found a negative relationship with bypass flow. Fish were less likely (0.69) to experience attraction as bypass flow increases by 1000 cfs. Overall attraction into Cabot ladder is low because the site also competes with other migratory pathways (competing risks). Figure 4.6.3-7 shows that, compared to fish approaching the bypass reach or turning back downstream, the relative rate of attraction into the Cabot ladder was very high. While the overall rate of attraction into the bypass reach or fish turning around and swimming back downstream was relatively low. Attraction rates into the Deerfield River were relatively high, but overall attraction was low.

Table 4.6.3-1: Flow Quantiles for MSM Cabot Attraction

	Cabot Discharge		Bypass Flow	
Quantile	ln(cfs)	cfs	ln(cfs)	cfs
0%	2.74	15	6.85	945
25%	7.75	2,325	7.82	2,500
50%	8.83	6,815	8.37	4,309
75%	9.34	11,380	8.60	5,409
100%	9.53	13,756	9.88	19,503

Table 4.6.3-2. State Table displaying the transitions from (row) to (column) at each hour exposure

	To			
From	Downstream	Bypass	Cabot Tailrace	Cabot Ladder
Downstream	1,095	32	61	8
Bypass	20	1,165	71	9
Cabot Tailrace	62	52	1,118	120
Cabot ladder	13	16	106	48

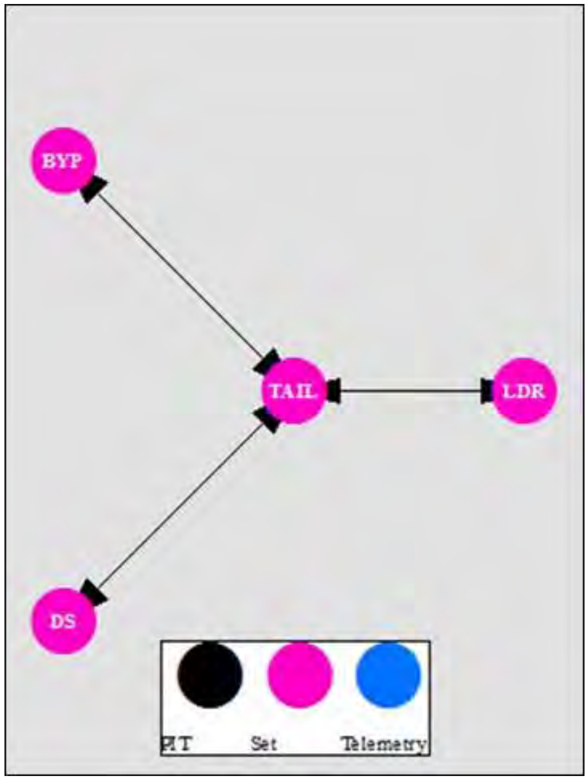

Figure 4.6.3-1. Telemetry subnetwork used during the Cabot Ladder Attraction assessment.

The tailrace (TAIL) set consisted of receivers T5 and T6. The downstream state (DS) consisted of receivers T33, T3 and T2. The Bypass state (BYP) consisted of receivers T15, T12E and T12W. The ladder state (LDR) consisted of receivers T7, P111, P112, T29 and P12.

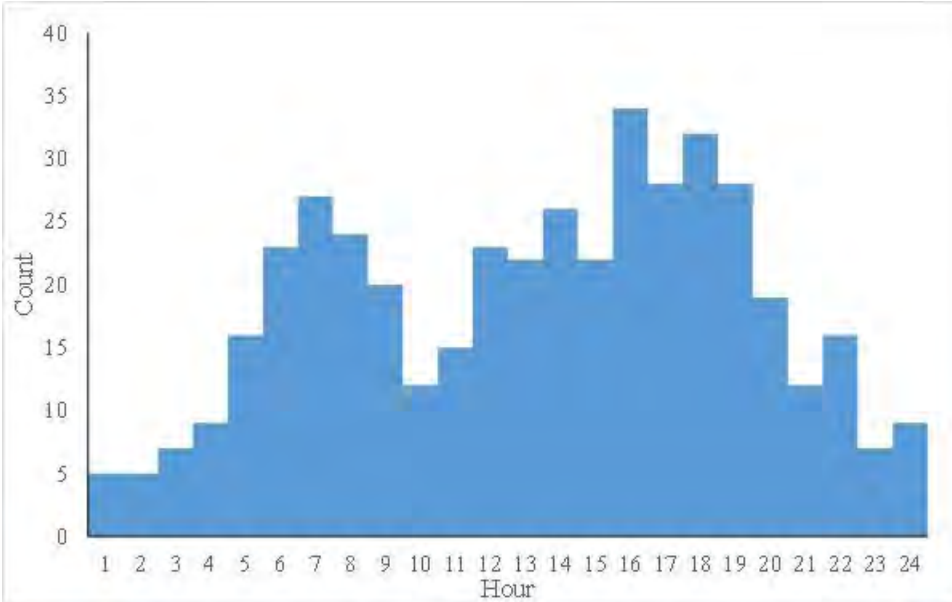

Figure 4.6.3-2. Time of arrival for dual tagged fish at Cabot Ladder.

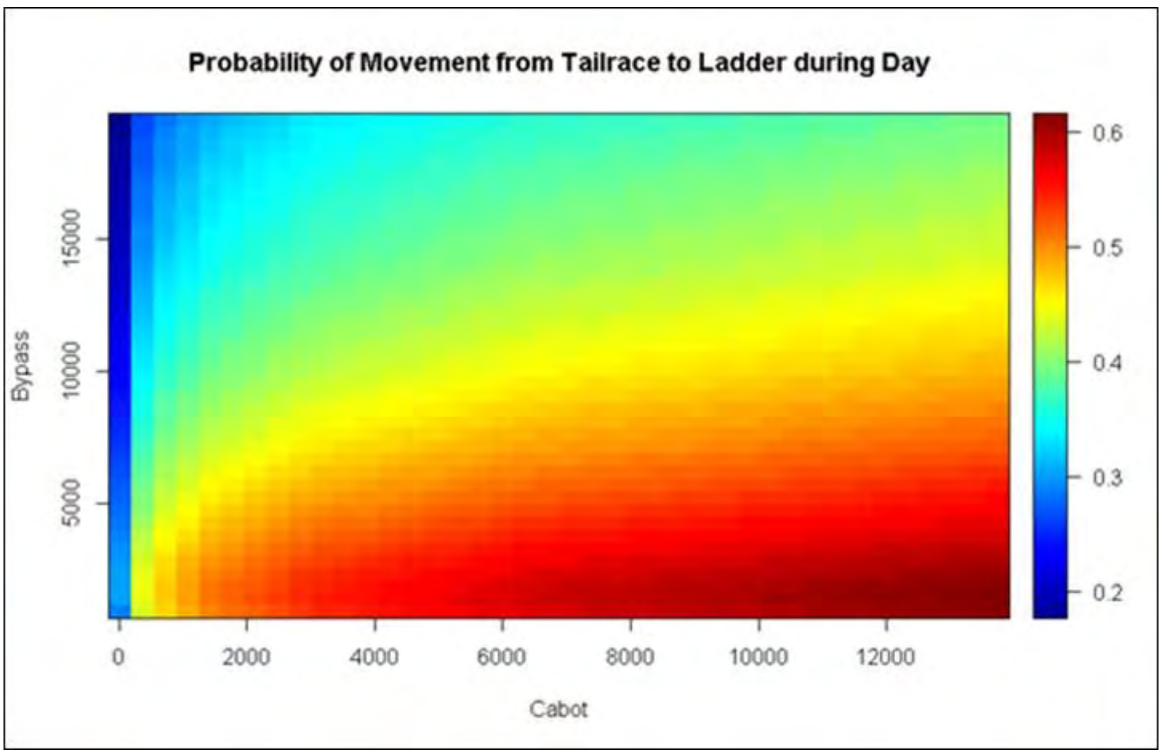

Figure 4.6.3-3: Probability heat map at various Bypass and Cabot flows during the day

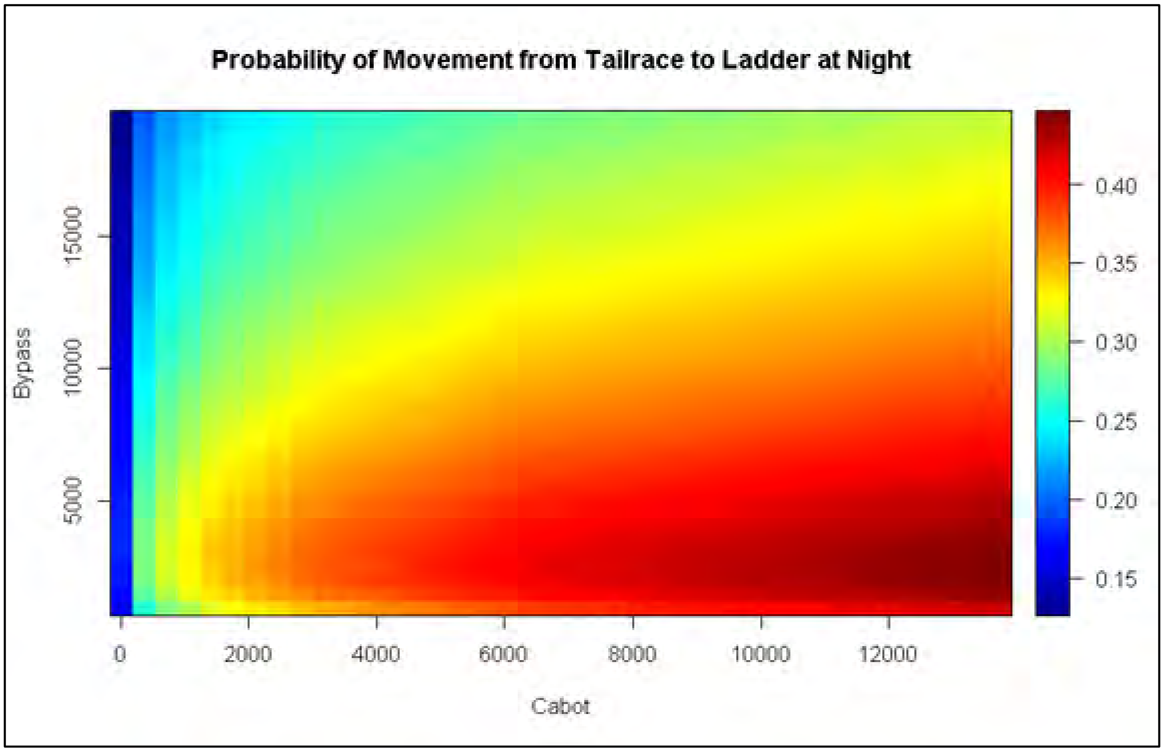

Figure 4.6.3-4: Probability heat map at various Bypass and Cabot flows during the night

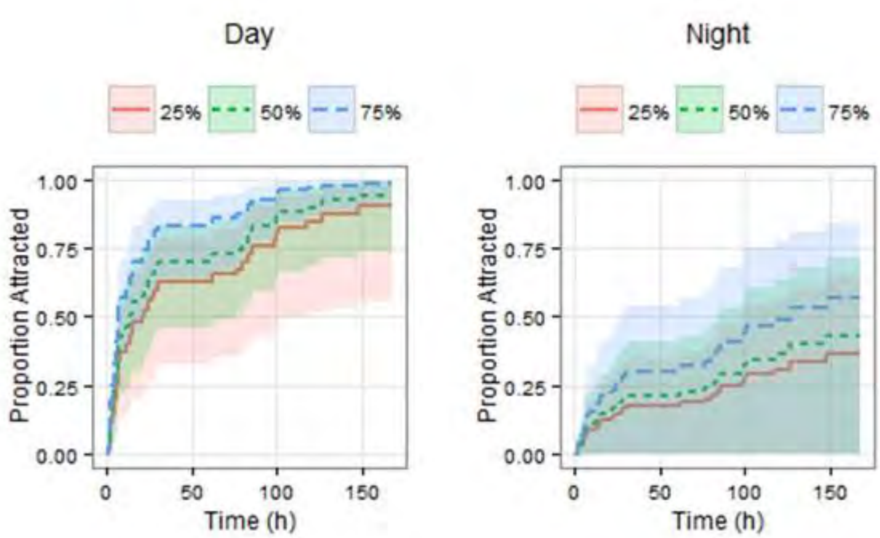

Figure 4.6.3-5: Cabot ladder first foray Model 4, incorporating diurnal cues with confidence interval.

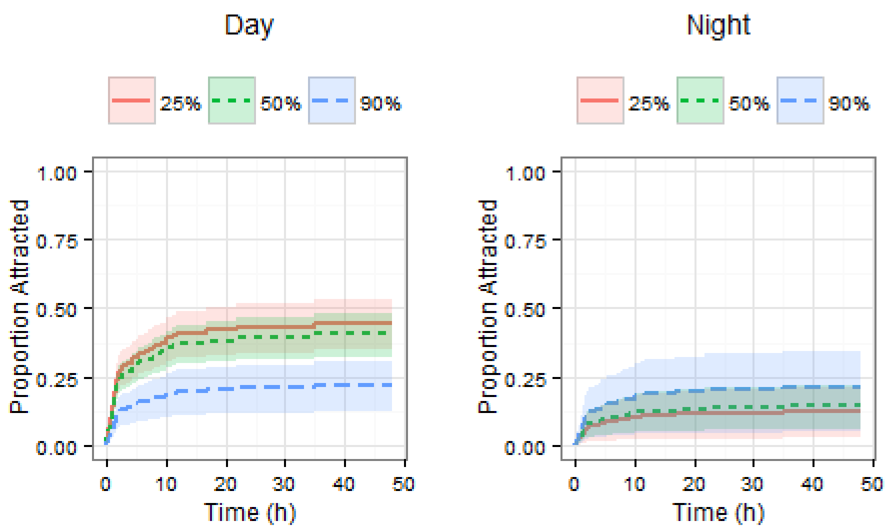

Figure 4.6.3-6: Cabot ladder attraction during the day and at night incorporating Bypass flow.

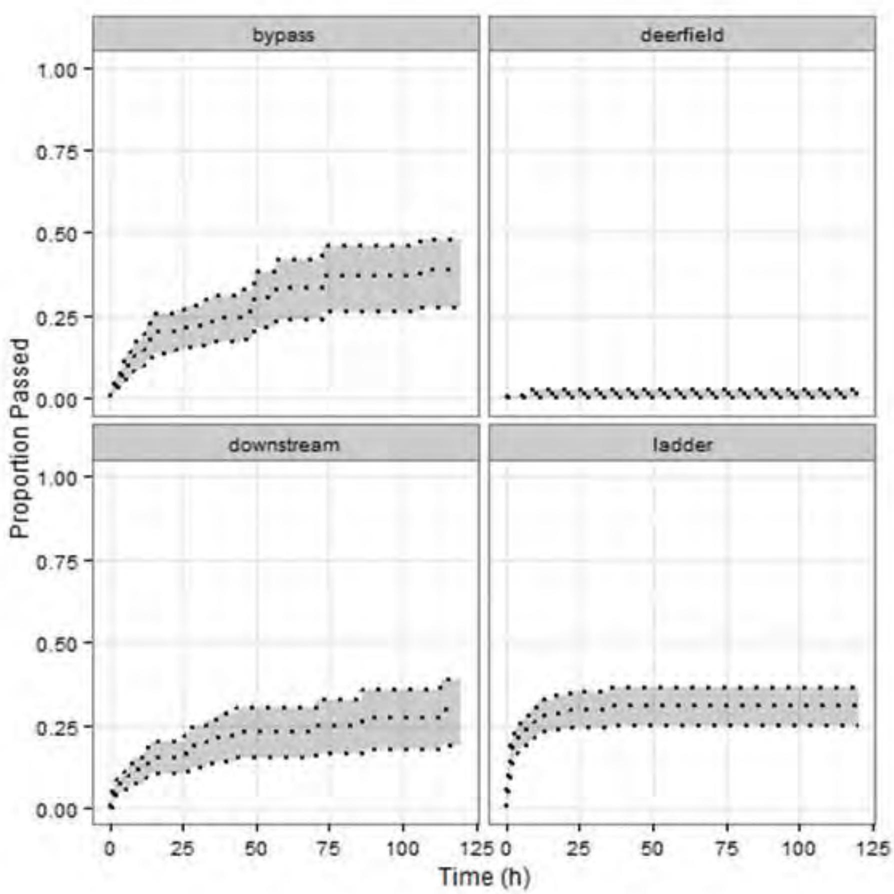

Figure 4.6.3-7: Time-to-event for competing risks within Cabot Tailrace.

4.6.4 Cabot Ladder Efficiency

Not all fish that approached and used the Cabot ladder were successful in their passage event. A CJS model was used to assess the efficiency of the entrance and the internal and overall efficiency of Cabot ladder, while time-to-event was used to evaluate ladder delay.

The best CJS model was fully time dependent (see Appendix D, Section 3.1 for a discussion on model selection) and combined the PIT (P111, P112) and dipole (T7) entrance antennas into one station. The entrance efficiency passage rate (survival) between the tailrace and entrance antenna was 66.8%, which was in line with the MSM estimates of Cabot ladder attraction. The survival rate between the entrance and next antenna (T29) was 100%, and the survival rate between T29 and Cabot ladder exit PIT (P12) was only 15.3%. However, all fish that passed Cabot ladder were recaptured within the Canal/Gatehouse ladder complex (P12 – Canal = 100%). The overall efficiency of the Cabot ladder, including entrance efficiency, was 10.2% (Appendix D, Table D-3.1-2). When not accounting for the entrance efficiency, the overall rate was 15.3%. While the overall efficiency was low, fish were also delayed within the Cabot ladder.

While the CJS model describes the overall efficiency of the ladder, it does not account for the rate of movement. In other words, with CJS alone, we do not know if shad were significantly delayed within the Cabot ladder. In total, 103 dual tagged and PIT tagged only fish from Holyoke attempted the ladder with 16 successful attempts. Time-to-event analysis showed that there were no successful attempts after fish were in the ladder for 40 hours according to the Kaplan Meier Plot (Figure 4.6.4-1).

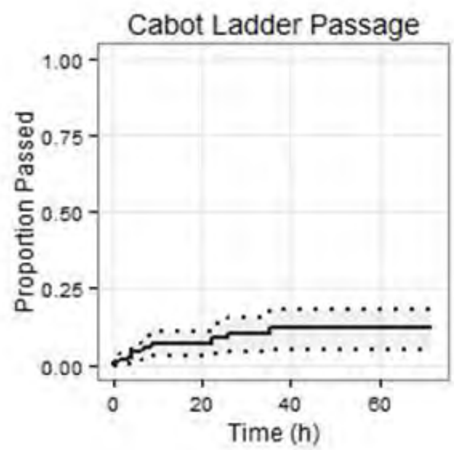

Figure 4.6.4-1: Time to Cabot Ladder passage.

4.6.5 Bypass Reach

As fish move upstream and pass Cabot Station, they are faced with a meandering path of islands, including Rawson Island. The western channel of Rawson provides passage through to the TF spillway. On the eastern side of Rawson Island fish are faced with a natural barrier known as Rock Dam.

The analysis of fish moving through Rawson Island telemetry subnetwork (Figure 4.6.5-1) incorporated recaptures from 95 dual tagged shad released at Holyoke. The median flow experienced by fish while in the Rawson portion of the study area was 4,407 cfs (Table 4.6.5-1).

Under low bypass flows (25^{th} percentile), fish downstream had the highest probability (45%) of surviving, transitioning and being detected next at T12W (Rawson Island West) (Appendix D, Table D-1.5-1). This probability decreased with increasing flow to a minimum of 25% at the 75^{th} percentile flow. The probability of fish surviving, transitioning from T12W and being detected next upstream remained relatively stable (0.16 to 0.21) between the 25^{th} and 75^{th} percentile flow. As flow increased, fish downstream were more likely to be detected on the eastern side of Rawson Island (T12E) with a minimum probability of 18% at 25^{th} percentile flow to a probability of 55% at the 75^{th} percentile flow. However, migration upstream from the eastern side of Rawson had the lowest probability of success. Fish from T12E had a very low probability (2%) of surviving, transitioning to and being detected next upstream at all flows.

In summary it appears that as bypass flows increase, fish become more attracted to the eastern channel of Rawson Island, however there was relatively little upstream success from the eastern channel. Fish attracted to the eastern channel likely encounter Rock Dam, move back downstream slightly where they may attempt passage through the west channel. As flow increases, fish in the west channel were more likely to survive, transition and be detected next upstream. This suggests Rock Dam is a significant barrier to upstream migration. Further, after examination of the state table (Table 4.6.5-2), fish did not spend much time within the western channel as evident in the T12W – T12W transition count.

Table 4.6.5-1. Flow Quantiles for MSM Rawson Island Model

Quantile	ln(Flow)	Flow (cfs)
0%	6.85	945
25%	7.84	2,545
50%	8.39	4,407
75%	8.74	6,241
100%	9.88	19,503

Table 4.6.5-2: State Table displaying the transitions from (row) to (column) at each hour exposure for fish in the MSM Rawson Island Model.

	To			
From	**Downstream**	**T12W**	**T12E**	**Upstream**
Downstream	2,160	21	22	17
T12W	16	57	23	9
T12E	19	24	240	1
Upstream	19	3	0	767

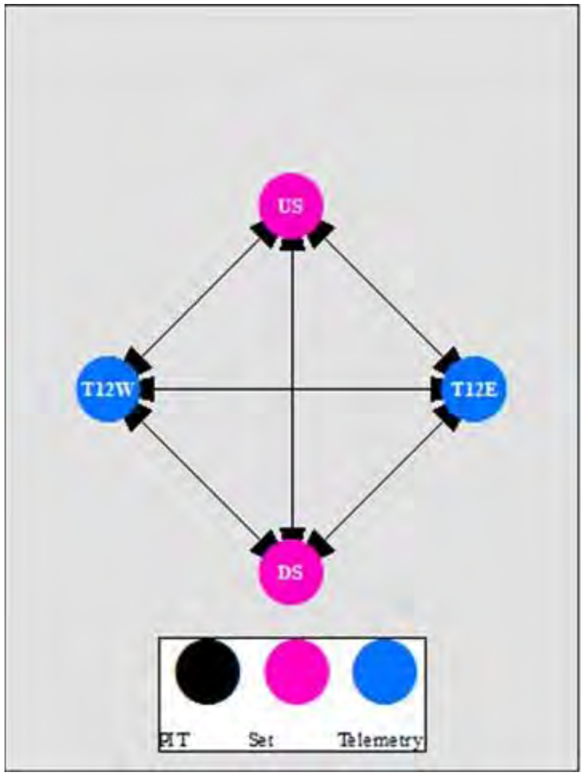

Figure 4.6.5-1: Rawson Island sub network model. The downstream set included receivers T6, T11 and T15 while the upstream set consisted of receivers T20 and T19.

4.6.6 Spillway Ladder Attraction

As fish migrate up the bypass reach and arrive at the Turners Falls spillway, they may attempt the Spillway ladder or turn back around and start their emigration. An MSM model was used to assess movement and attraction towards the ladder whereas time-to-event was used to evaluate migratory delay within the bypass reach (time-to-first foray) and time-to-attraction.

The Spillway ladder MSM attraction model included information from the recaptures of 57 dual tagged fish released at Holyoke known to be within the lower and upper bypass reaches (Figure 4.6.6-1). The median flow experienced by fish while in the Spillway ladder portion of the study was 4,420 cfs in the Bypass Reach (Table 4.6.6-1). The resulting histogram (Appendix D, Figure D-1.6-1) was log transformed to conform to the data analysis procedure as written in Jackson (2011). Fish approached the Spillway ladder throughout the day, but counts peaked between 1300 and 1700 (Figure 4.6.6-2). The state table (Table 4.6.6-2) displays the raw number of transitions among states within each exposure hour, and is read as from (row) to (column). When a fish transitions between non-adjacent states, it moves undetected through a telemetry station.

The best MSM model (See Appendix D, Section D-1.6) incorporated flow from the Bypass Reach. Once detected at the base of the Turners Falls Dam, the probability that a fish continued to the Spillway ladder at lower flow (2,569 cfs) was 65%, however this dropped to 41% at higher flow (6,226) (Appendix D, Table D-1.6-1). High flow within the bypass reach appeared to prohibit attraction to the ladder, at the maximum bypass flow (19,503 cfs) the probability that a fish survived transition from the base of the Turners Falls Dam and was detected within the ladder was only 17%. However, there were a low number of observations at this high spillage flow and the confidence interval was wide, stretching between 2 and 58%. Therefore, results at the 100% flow should be interpreted with caution. The expected number of forays (*envisits*) into spillway ladder ranged from 3.47 at low flow (25^{th} Bypass) to 2.47 at high flow (75^{th} percentile) (Appendix D, Table D-1.6-2).

The MSM model only tells half of the story, we do not know the rate of movement within the bypass reach, or how quickly fish were attracted to the ladder once in the spillway. To answer these questions, two time-to-event analyses were conducted. The first assessed time-to-first foray, while the second assessed time-to-attraction for fish once they arrived at the base of the Turners Falls Dam (antennas T19 and T20).

For the first foray into Spillway ladder, volitional dual tagged shad from Holyoke recaptured at Montague and then again anywhere within the ladder were used. For this analysis the clock started when fish were first recaptured at Montague and ended at the first recapture within the ladder. There were 11 dual tagged volitional fish from Holyoke that made at least one attempt on Spillway ladder that were detected at Montague. Fish appeared to experience the same or similar bypass flows during the night as they did during the day (Appendix D, Figure D-2.5-1). The null model suggests that 50% of the tracked fish will experience the event within 94.4 hours compared with 7.55 hours for fish first arriving at Cabot ladder from Montague (Figure 4.6.6-3). Due to the small sample size of fish from Montague (11), the confidence intervals are fairly wide.

The time-to-Spillway ladder attraction assessment incorporated detection histories from the 34 dual tagged volitional fish recaptured in the lower bypass (T15, T12E and T12W), spillway (T19 and T20) and spillway ladder (T30, P21, P22, P23SL, P23TP, P24 and P25). In total, 34 dual tagged fish made at least 17 successful attempts into Spillway ladder from the spillway, however they also rejected the Spillway ladder and retreated to the lower bypass reach 20 times. The total number of fish for this assessment was larger than the time-to-first foray model because individuals passed through Montague undetected. As with other reaches, the fish appear to have experienced the same or similar flow regimes during the day as they did at night (Appendix D, Figure D-2.6-1). The best model incorporated diurnal cues (see Appendix D, Section 2.4 for more detail). The model suggested that fish were more 7.3 times more likely to enter the spillway ladder during the day than at night (Figure 4.6.6-4).

Table 4.6.6-1: Flow Quantiles for MSM Spillway Attraction

	Bypass	
Quantile	**ln(cfs)**	**cfs**
0%	6.85	945
25%	7.85	2,569
50%	8.39	4,420
75%	8.74	6,226
100%	9.88	19,503

Table 4.6.6-2: State Table displaying the transitions from (row) to (column) at each hour exposure in the MSM Spillway Attraction Model.

	To		
From	**Downstream**	**Tailrace**	**Spillway Ladder**
Lower Bypass	1409	26	3
Turners Falls Spillway	21	827	22
Spillway Ladder	1	19	14

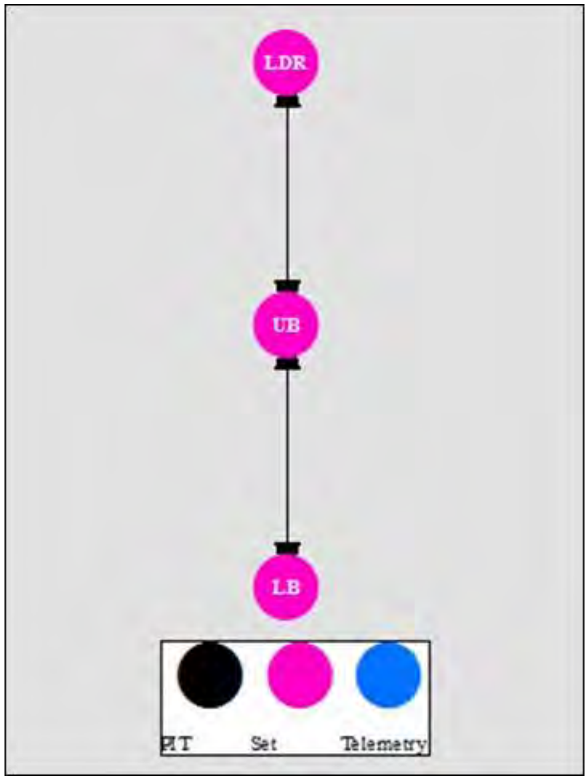

Figure 4.6.6-1: Spillway Attraction sub network consisted of three locations, lower bypass (LB), upper bypass (UB) and Spillway Ladder (LDR). LB consisted of stations T6, T11, T15, T12E and T12W, UB consisted of T20 and T19 and LDR consisted of P30, P21, P22, P23SL, P23TP, P24 and P25.

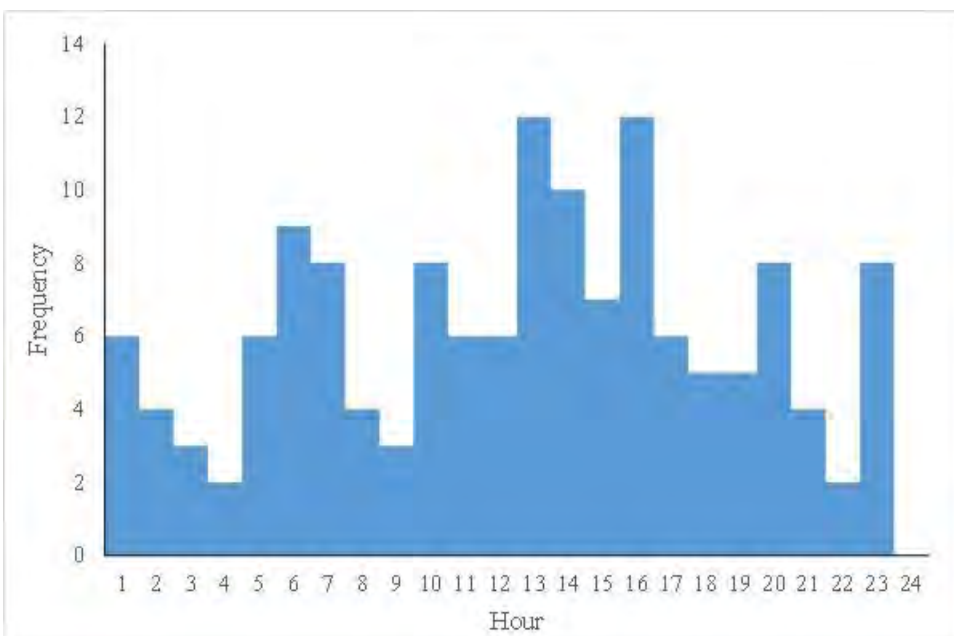

Figure 4.6.6-2: Time of arrival for fish using Spillway Ladder

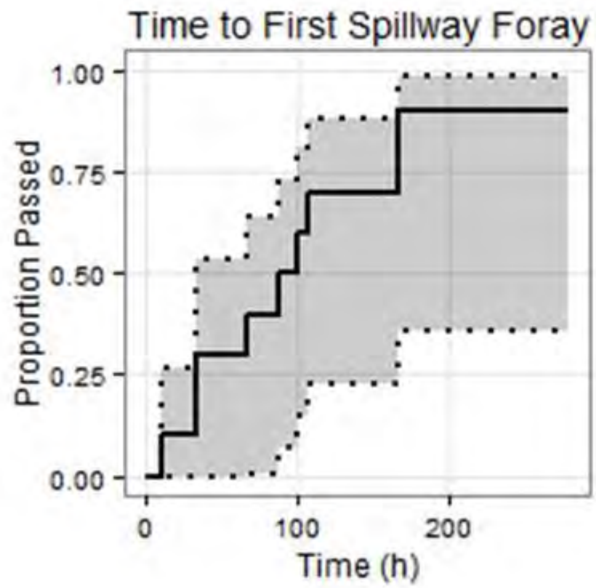

Figure 4.6.6-3: Kaplan-Meier curve of the time to first Spillway ladder from Montague

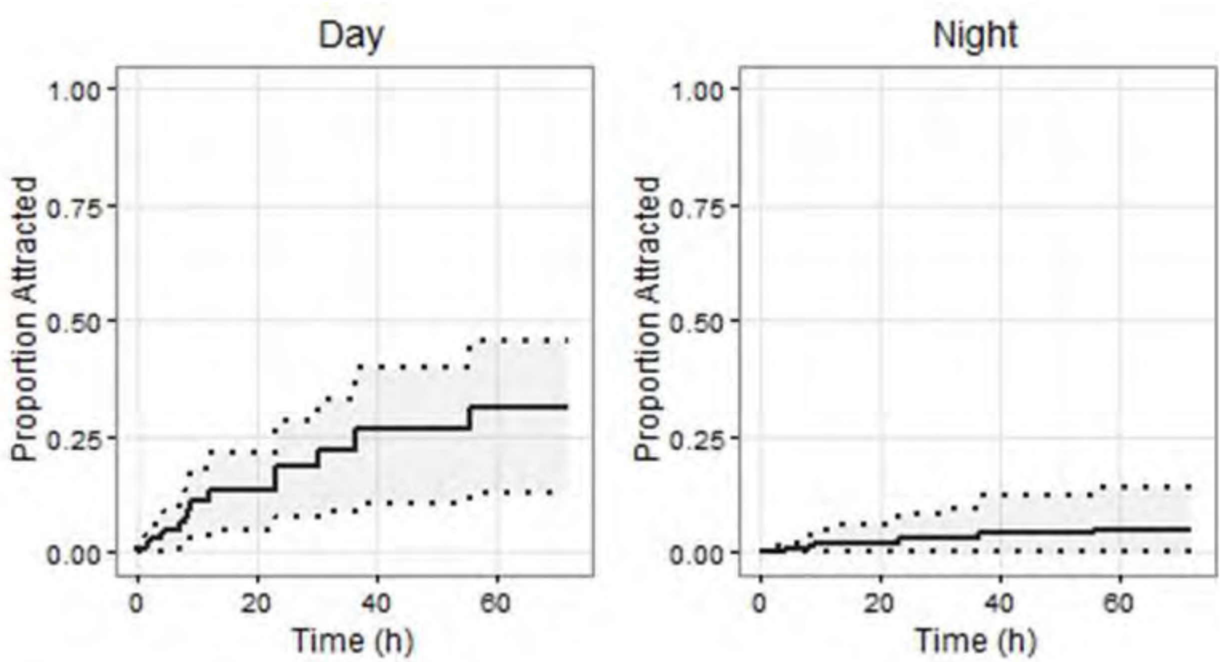

Figure 4.6.6-4: Spillway ladder attraction, incorporating diurnal cues

4.6.7 Spillway Ladder Efficiency

Once fish are attracted towards the Spillway ladder, they must successfully pass if they are to spawn in the Connecticut River upstream of the Turners Falls Dam. A CJS model assessed the overall and entrance efficiency of the Spillway ladder, while time-to-passage quantified overall ladder delay.

The best CJS model combined the entrance PIT antennas (P21, P22) with the entrance dipole (T30) into one station with passage rates to all other stations analyzed. The spillway entrance efficiency (of the dual tagged and PIT tagged only fish known to be in the spillway) was 91.5%. The passage rate (survival) from the entrance to the first PIT reader (P23SL) was 64.7%. The rate from P23SL to the turning pool (P23TP) was 61.3%. Ninety percent of the fish arriving at the turning pool passed to P24, and from P24 to P25, passage rate was 100%. Overall, the ladder had an efficiency of 32.7% which includes entrance efficiency (Appendix D, Table D-3.2-2). Without entrance efficiency, the ladder efficiency was 36%.

Along with overall ladder efficiency, time-to-event assessed delay within Spillway ladder. Of the 35 dual and PIT tagged fish released from Holyoke that were recaptured in Spillway ladder, 16 successfully passed out of 87 attempts. As evident in the Kaplan-Meier curve (Figure 4.6.7-1), no more successful passage events occurred after 10 hours. Overall, fish ascended Spillway ladder more quickly than at the Cabot ladder. However, these results should be suspect given the low rates of recapture at the Spillway ladder entrance.

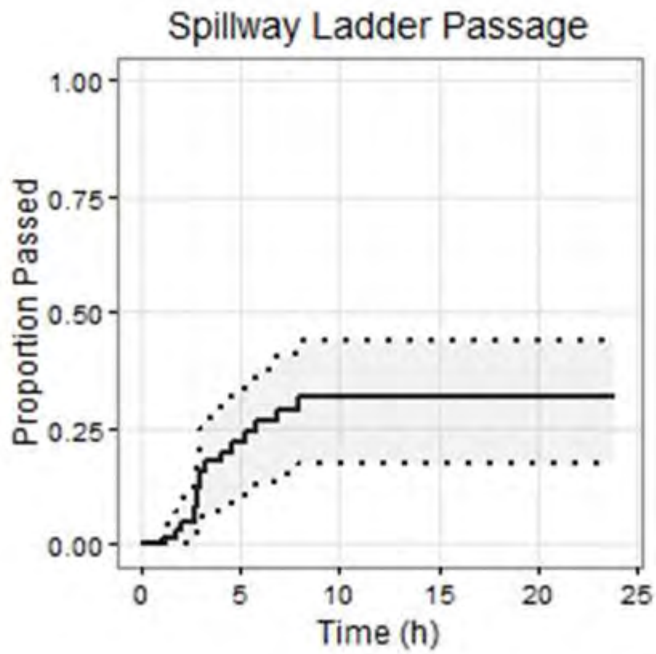

Figure 4.6.7-1: Time to spillway ladder passage

4.6.8 Upstream Migration through the Canal

As fish pass Cabot ladder and enter the canal, they have a number of migratory decisions. If they move downstream, they enter the Cabot Forebay area, which is in close proximity to the downstream bypass. Presumably fish can pass through the downstream bypass and fall back down into the Cabot Tailrace. If fish in the canal continue upstream, they may be attracted to the Station No. 1 Forebay, further delaying their upstream progress. The last hurdle for upstream passage through the canal is at the Gatehouse ladder, where fish that successfully pass enter into the Turners Falls Impoundment.

The analysis of fish migrating upstream through the canal included recaptures from 60 dual tagged shad released at Holyoke or Cabot that were assumed to be upstream obligated (Figure 4.6.8-1). Upstream obligated fish were those fish released into the canal, or those that successfully passed Cabot ladder and have yet to spawn. The median flow experienced by fish while in the Cabot Canal was 6,564 cfs (Table 4.6.8-1).

An examination of the state table (Table 4.6.8-2) suggests that fish used the lower canal and Cabot Forebay more than the upper canal. The state table counted 2,087, 2,950 and 2,462 recaptures within an hour at the downstream bypass, Cabot Forebay and the lower canal sites, respectively. In contrast, fish were recaptured 545 and 234 times within an hour at the upper canal and Gatehouse Yagi sites. This suggests a considerable amount of time spent in the lower portions of the canal and around the Cabot Forebay. The state table also indicates a large amount of milling between the downstream bypass, Cabot Forebay and lower canal. In total, marked fish made 813 transitions into the Cabot Forebay from the downstream bypass, and 866 total forays from the Forebay towards the downstream bypass. Further, fish were found to make 365 transitions from the Forebay and into the lower canal and 407 from the lower canal and back into the Forebay. All these transitions were from only 60 dual tagged shad released at Holyoke or directly into the power canal.

An MSM model was fit to the state table, which found that fish in the lower canal (T13 and T14) were decreasingly likely to survive, transition to, or be detected next in the upper canal (T18 and T21) as flow increased (probability = 0.21 at 25% flow, decreasing to 0.11 at 75% flow, Appendix D, Table D-1.4-1). Fish that arrived in the upper canal were most likely detected next at the lower canal site (probability = 0.31 at 25% flow, increasing to 0.63 at 75% flow, Appendix D, Table D-1.4-1). As flow increased in the canal, fish appeared to abandon the upper portion of the canal in favor of the lower canal and the Cabot Forebay. The estimated number of forays at the Gatehouse ladder ranged from 9.35 to 0.46, as flows increased from the 25^{th} to 75^{th} percentile (Appendix D, Table D-1.4-2). Of the 26 dual tagged fish from Holyoke or released into canal that were recaptured at T22, 18 were recaptured somewhere within Gatehouse ladder. While the MSM model is appropriate for examining where fish went in the canal, it does not describe the rate of movement. Time-to-event was used to evaluate time-to-arrival at the Gatehouse entrance Yagi antenna (T22), which assessed the overall delay within the canal. Time-to-event was also used to evaluate time-to-escape Station No. 1 Forebay, and time-to-escape Cabot Forebay as fish may become trapped and delayed within these reaches.

For the time-to-upper canal arrival model, only those fish obligated to move upstream were used (Holyoke and Canal released fish). In total, the overall model identified 60 recaptured fish, making 122 successful forays up to the Yagi antenna at the entrance to the Gatehouse ladder over 295 different attempts. Generally, the fish experienced the same flow at night as during the day (Appendix D, Figure D-2.9-1). Opposing day/night KM curves with flows representing the 25^{th}, 50^{th} and 75^{th} percentile Cabot flows were constructed. Fish were delayed less during low flow (25^{th} percentile flow) (Figure 4.6.8-2).

While in the canal, fish may get attracted towards the Station No. 1 forebay, or fail to migrate out of the Cabot Forebay as evident with the considerable milling shown in the MSM state table (Table 4.6.8-2). At the Station No. 1 Forebay, six fish were detected within the Forebay. They made 7 successful attempts exits from the Forebay indicating that a fish swam back in and exited again. The resulting KM survival curve suggests that fish exit Station No. 1 Forebay within 15 hours (Figure 4.6.8-3).

The second location where fish were delayed was the Cabot Forebay. From the Forebay, fish may choose to transition upstream through the canal or to the downstream bypass entrance. In total, there was 52 fish making 387 transitions towards the bypass entrance and 931 attempts towards the upper canal reaches, suggesting substantial milling at the Forebay. Fish did not migrate upstream after 48 hours of being in front of the Forebay (Figure 4.6.8-4).

As upstream obligated fish enter the canal, considerable milling occurred between the lower canal, Cabot Forebay, and the downstream bypass area as evident with the MSM state transitions. Fish may take as long as 48 hours to leave the Forebay area. Furthermore, fish in the upper canal were found to abandon the reach in favor of the lower canal as flow increased. The overall time for fish to move up the canal to the area of the Gatehouse entrance (arrival at T22) was significantly affected by canal flow, with high flows reducing the rate at which shad experienced the event.

Table 4.6.8-1. Flow Quantiles for the MSM Upstream Canal Model

Quantile	ln(Flow)	Flow
0%	3.69	40
25%	8.11	3,340
50%	8.79	6,564
75%	9.39	12,016
100%	9.84	18,691

Table 4.6.8-2: State Table displaying the transitions from (row) to (column) at each hour exposure for fish in the MSM Upstream Canal Model.

From	To						
	Downstream Bypass	Cabot Forebay	Lower Canal	Upper Canal	Gatehouse Yagi	Gatehouse Ladder	Upstream Passage
Downstream Bypass	2,087	813	38	0	0	0	0
Cabot Forebay	866	2950	365	3	0	0	0
Lower Canal	17	407	2,462	93	0	0	0
Upper Canal	1	2	83	545	118	0	0
Gatehouse Yagi	0	0	0	107	234	15	1
Gatehouse Ladder	0	0	0	1	5	7	10

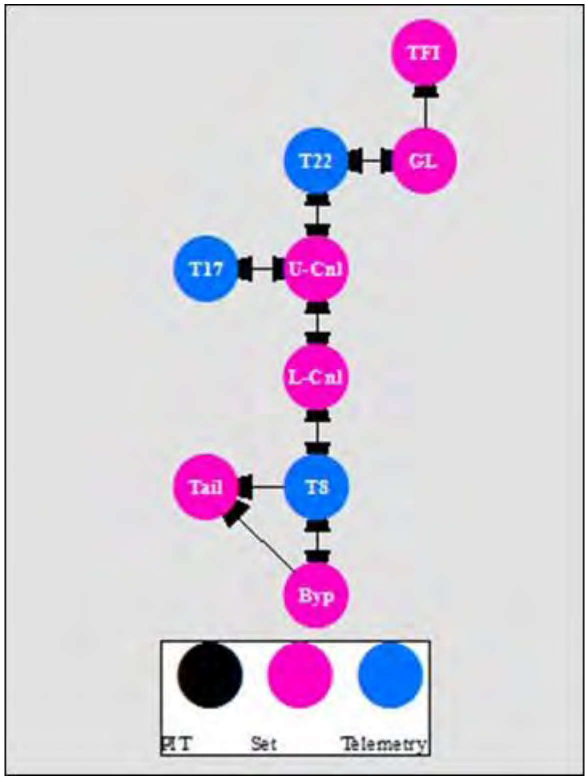

Figure 4.6.8-1. Upstream canal migration subnetwork.

Note the network was fairly complicated with sets of receivers at the downstream bypass (T9 and P13), Cabot Tailrace (T5 and T6), Lower Canal (T13 and T14), Upper Canal (T18 and T21), Gatehouse Ladder (P34, P31 and P32) and the TFI (P33, T23, T24, T25, T26 and T27).

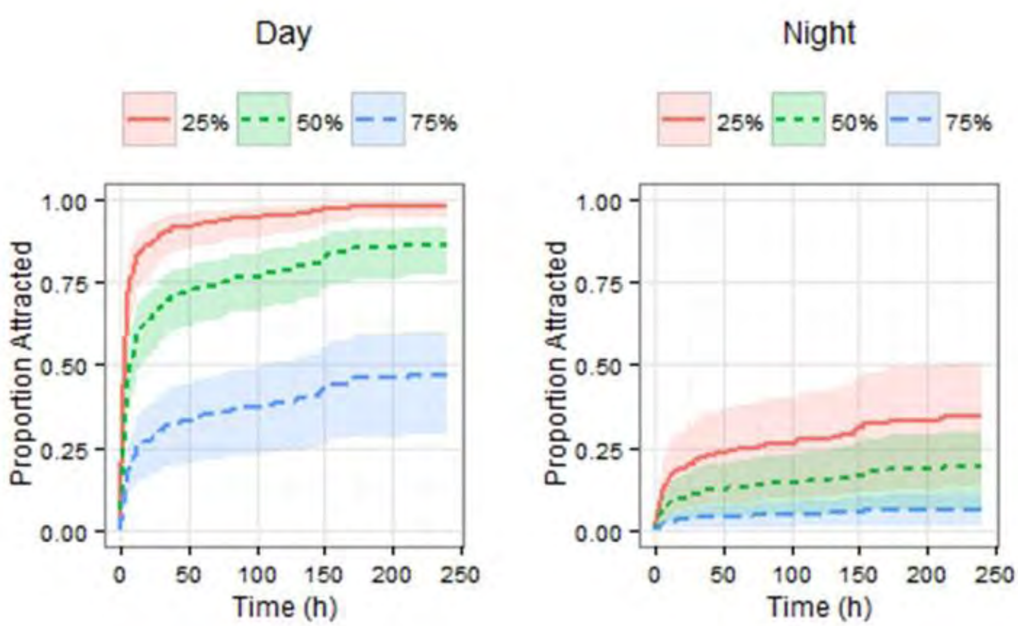

Figure 4.6.8-2: Time to overall upstream canal passage under different flow regimes.

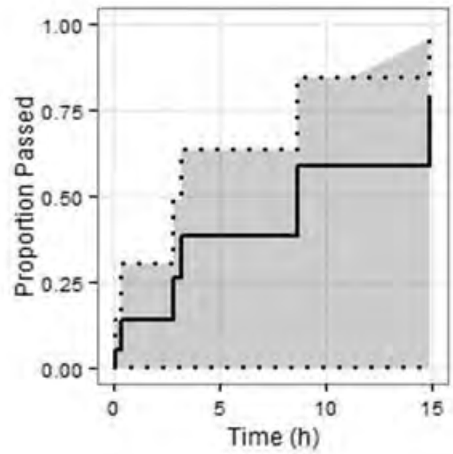

Figure 4.6.8-3: Time to escape Station No. 1 Forebay

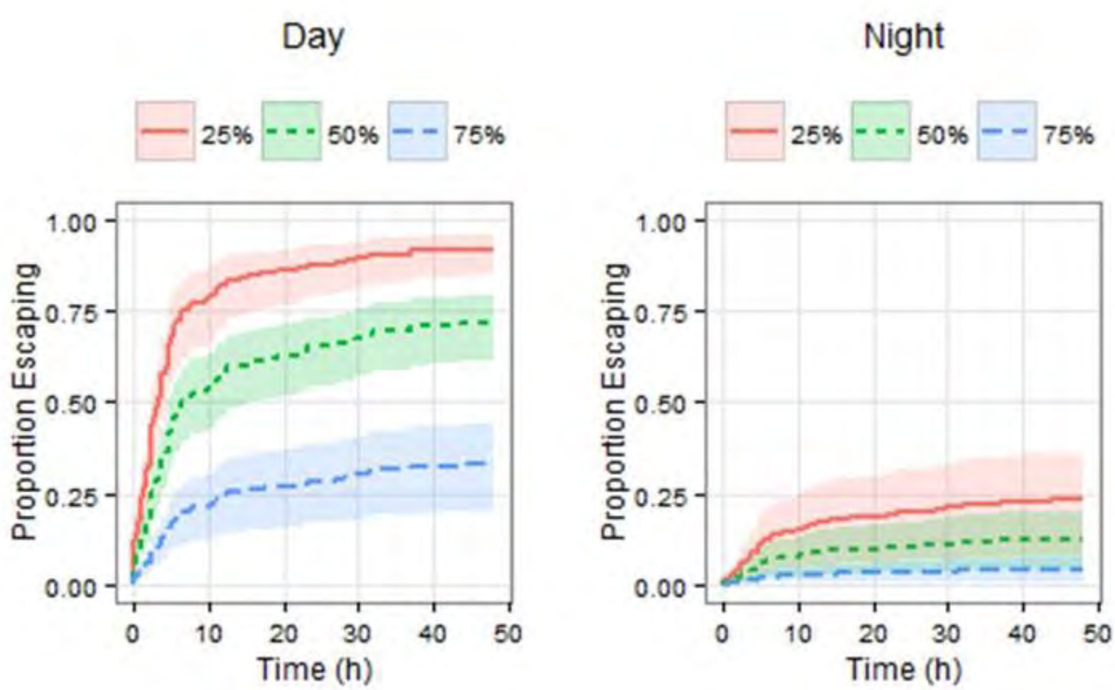

Figure 4.6.8-4: Time to escape Cabot Forebay under different flow regimes.

4.6.9 Gatehouse Ladder

For those fish that pass via Cabot or Spillway ladder and successfully migrate up to the head of the power canal, they next encounter the Gatehouse ladder. The entrance efficiency of Gatehouse ladder was assessed with an MSM model (see Appendix D, Table D-1.4), internal efficiency was assessed with a CJS model, and passage delay was assessed with time-to-event. Fish approached the Gatehouse ladder during the daylight hours with peak counts occurring between 1400 and 1700 (Figure 4.6.9-1).

The best MSM model incorporated Cabot Canal discharge (Appendix D, Table D-1.4). Given the poor performance of P34Z and low recapture rates at P34, the best estimate of the efficiency of the Gatehouse ladder entrance was tested on transitions from the Gatehouse Yagi antenna (T22). At the 25th Cabot Canal flow, the probability that a fish will survive, transition from T22 and be detected within the Gatehouse ladder (P34, P31, P32 or P33) is 11% which rises to 15% at the 75th percentile Appendix D (Table D-1.4-1). At the 100th percentile there is no passage into the Gatehouse ladder from the Gatehouse Yagi (T22). While the entrance efficiency from the Gatehouse Yagi was low, fish that entered had a good chance of passing into the impoundment. The internal efficiency of Gatehouse ladder was assessed with a CJS mark recapture model. The probability of passage through the Gatehouse ladder was high at 76.9% (Appendix D, Table D-3.3-2). Time-to-event for passage at Gatehouse ladder was not quantified because P34Z was non-operational, therefore we did not know when the clock started.

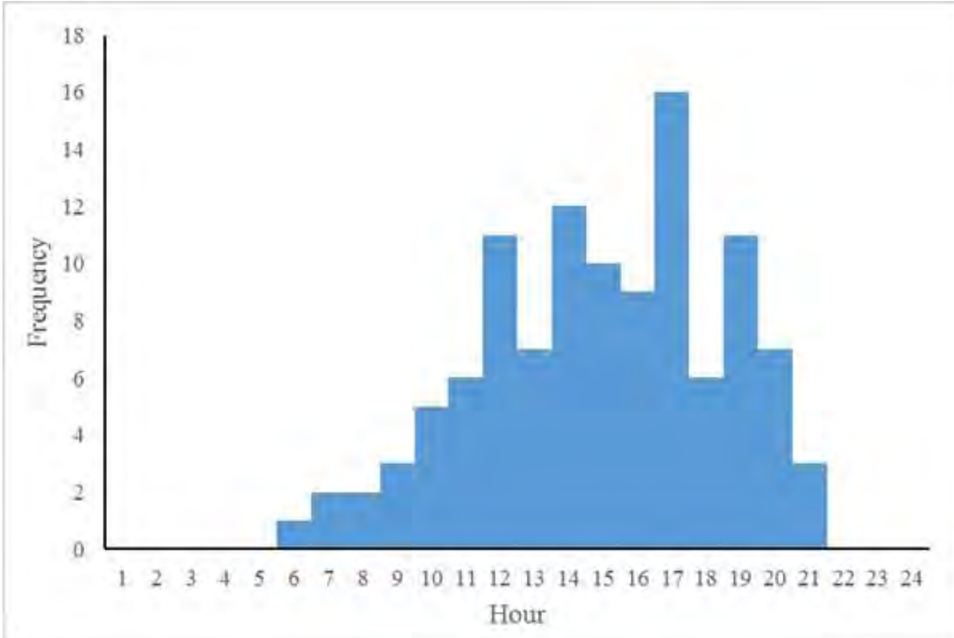

Figure 4.6.9-1: Count of arrival time at Gatehouse Ladder.

4.6.10 Upstream Migration through the TFI Impoundment

As fish enter the impoundment to continue upstream, they may become attracted to the NMPS Intake or be affected by its operation and incur delay on their way to Vernon.

The MSM analysis of fish moving upstream in the Turners Falls Impoundment included recaptures from 204 shad detected within the impoundment telemetry subnetwork (Figure 4.6.10-1). The median NMPS Project operational flow experienced by fish in the TFI during pumping was -6,699 cfs and 2,536 cfs during generation (Table 4.6.10-1). Pumping operations are discussed first.

The joint probability of a fish surviving, transitioning from the downstream of the intake and being detected within the NMPS intake was 33% at the 25th percentile pumping flow. As pumping increased (75th percentile), the probability of detection next at the intake decreased to 15% (Appendix D, Table D-1.7-1) (Figure 4.6.10-2). The probability that a fish survived, transitioned to, and was detected at Shearer Farms (T26 & T27) from downstream of the intake (T23 or T24) was 53% at the 25th percentile pumping flow and 60% at the 75th percentile pumping flow.

During the daytime, when NMPS was idle, fish downstream of the intake (T24) had a 68% chance of surviving, transitioning to and being detected next at Shearer farms (T26 and T27). At nighttime during idle operations, fish downstream of the intake (T24) were still most likely to be detected next at Shearer Farm (60%) (Appendix D, Table D-1.7-2) When NMPS was idle, fish had a 24% chance of transitioning, surviving and being detected at the intake from downstream during the day. This percentage was 9% at night during idle. During generation, fish had a 72% chance of surviving, transitioning and being detected next at Shearer Farms from downstream of the NMPS intake (T23, T24) and only a 19% chance of transitioning into the intake at 25th percentile discharge. When discharge was high (75th percentile), there was little change in the transition rates from downstream of the intake to Shearer Farms (75%) and the probability of transitioning into the intake decreased to 14% (Appendix D, Table D-1.7-4).

Time-to-event analysis quantified delay for fish attracted towards the NMPS intake, and time to upstream migration. A total of 32 fish were attracted towards the intake, making 53 successful escape attempts, meaning that some fish made multiple forays into the intake area (Figure 4.6.10-3). For the time to Shearer Farms model, 142 fish made 228 forays from downstream of the NMPS intake. The estimated hazard ratio during the day was 1.18, suggesting fish were approximately 1.2 times more likely to experience the event during the day than at night (Figure 4.6.10-4). These results suggest some delay during upstream migration, milling around the intake, or at least some sort of attraction while moving upstream.

No fish were found to be detected within the Upper Reservoir suggesting that there was no entrainment of adult shad at the NMPS Project. Approximately 50% of those fish attracted to the intake were able to escape within approximately 20 hours.

Table 4.6.10-1. Flow Quantiles for MSM Impoundment Model

	Pump		Gen	
Quantile	**Scaled flow**	**cfs**	**Scaled flow**	**cfs**
0%	-1.00	13,950	0.0002	4
25%	-0.71	9,887	0.14	2,360
50%	-0.48	6,699	0.15	2,536
75%	-0.24	3,346	0.31	5,301
100%	-0.002	24	1.00	16,917

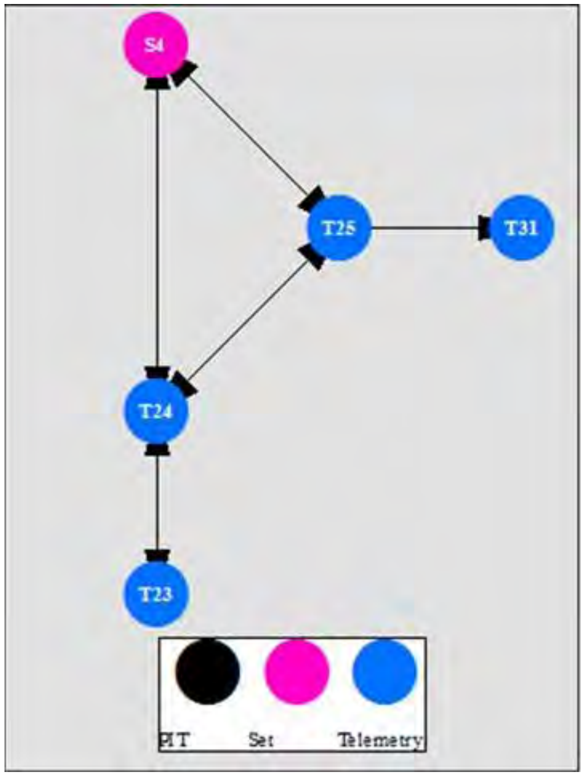

Figure 4.6.10-1. Impoundment subnetwork showing states in the MSM model.

The lower impoundment was T23, downstream of NMPS intake (T24), NMPS intake (T25) and upstream of NMPS intake (T26 and T27) along with NMPS Upper Reservoir (T31)

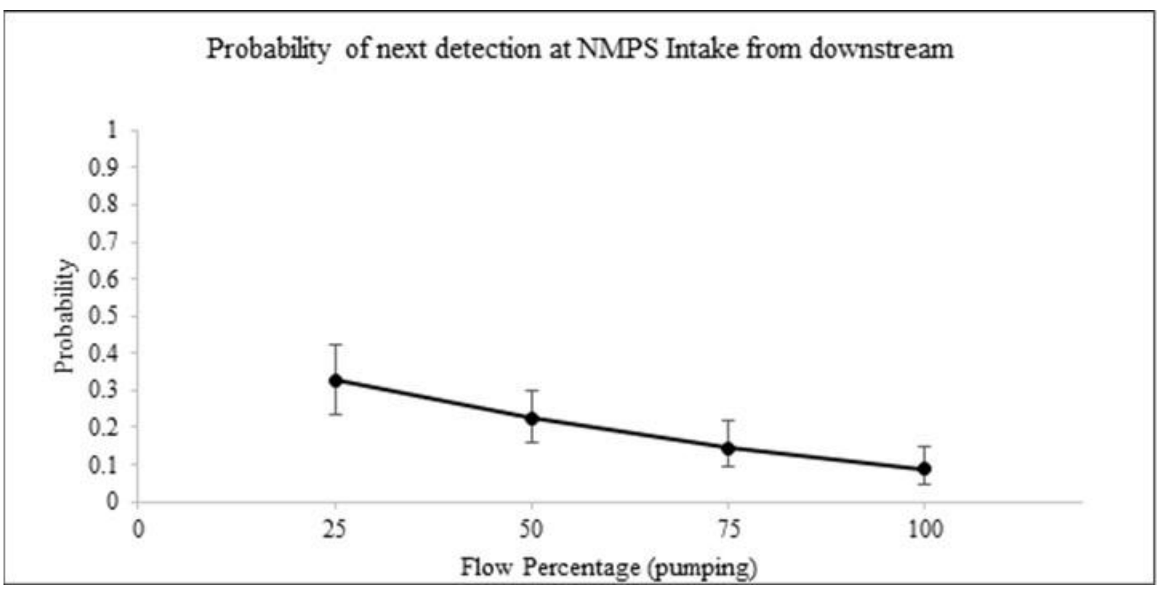

Figure 4.6.10-2. Probability of fish being next detected at NMPS Intake at varying pumping scenarios in the MSM Impoundment Model.

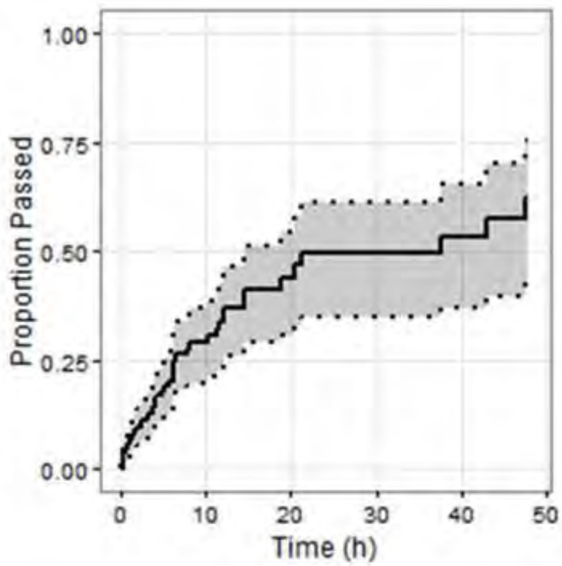

Figure 4.6.10-3: Time to escape NMPS intake

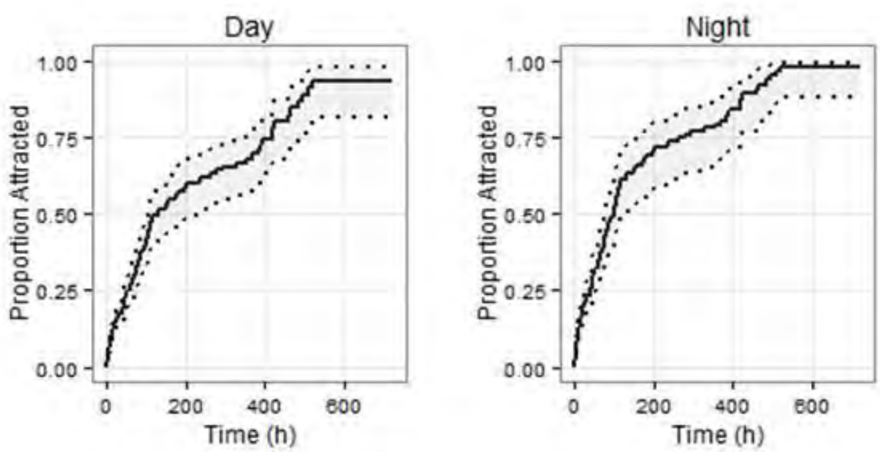

Figure 4.6.10-4: Time to upstream migration at Shearer Farms (T26 & T27) within TFI from downstream of the NMPS intake (T23 & T24).

4.6.11 Downstream Migration through the TFI Impoundment

As fish begin their downstream movement, they will inevitably pass NMPS Project intake and their migration may be delayed or they may risk entrainment.

Time-to-event analysis was performed for those fish migrating downstream through the Turners Falls Impoundment. Only downstream obligated fish (those released at TransCanada) were used for this analysis. Overall, 95% of fish successfully emigrated downstream from Vernon passed NMPS with 62 successful events (i.e., emigration past the NMPS intake). According to the Kaplan-Meier curve, approximately 50% of the fish reached the area of the impoundment below NMPS intake (T23 and T24) within 25 hours and 75% of the population passed within 100 hours (Figure 4.6.11-1).

As with the upstream migrants, a small portion of the fish were attracted to the NMPS intake. A total of 10 fish made 15 successful escape events suggesting some milling in front of the intake. According to the Kaplan-Meier curve, 50% escaping within 6.42 hours and 75% escape within 20 hours and approximately 95% of fish pass within 36 hours (Figure 4.6.11-2).

Transition probabilities (Appendix D, Table D-1.7-4) indicated that for fish detected at Shearer Farm, movement downstream increased with increasing NMPS Project generation (from 93% to 97%; from 25% to 75% discharge); however, attraction toward the intake decreased with increasing generation (from 7% to 3%; from 25% discharge to 75% discharge). Entrainment did not occur at NMPS intake during upstream or downstream migratory efforts. While there was some evidence of milling in front of the intake, most fish appeared to avoid or ignore this structure and continued migrating.

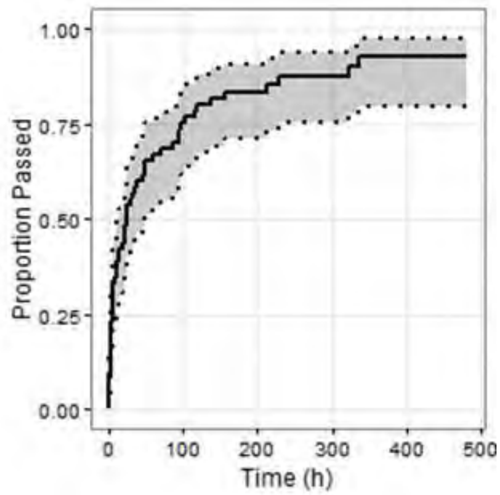

Figure 4.6.11-1: Time to migrate past NMPS intake from Shearer Farm

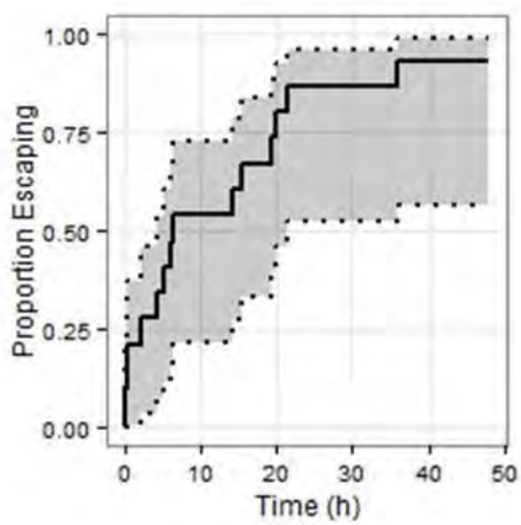

Figure 4.6.11-2: Time to escape the NMPS intake

4.6.12 Downstream Migratory Route Choice at Turners Falls Dam

As fish continue their emigration and approach Turners Falls Dam, they can pass via spill over the dam or enter the canal through the gatehouse. The downstream passage MSM model incorporated information from 165 downstream obligated fish (those released into the impoundment or from TransCanada projects) in the downstream passage telemetry subnetwork (Figure 4.6.12-1). The median flow experienced by fish during downstream passage in the canal was 6,223 cfs and the median flow experienced at TF Dam was 2,462 cfs (Table 4.6.12-1).

Transition probabilities (Appendix D, Table D-1.8-2) show which migratory routes are preferred for fish passing downstream at the Turners Falls Project. Fish detected in the TFI have a 0.74 probability of surviving, transitioning and being detected next at the Gatehouse entrance Yagi and/or canal and a 0.26 probability of being detected next at the Turners Falls Spillway.

The catch-curve mortality estimate (Appendix D, Table D-4-1) for those fish that pass over the Turners Falls Dam and spill was 0.03 fish per day, compared to the 'natural' mortality rate of only 0.01 fish per day. The natural mortality rate was derived from fish tagged and released at Holyoke that did not pass any structure.

Table 4.6.12-1: Flow Quantiles for MSM Downstream passage at Turners Falls Dam

	Canal		TF Dam	
Quantile	**Ln(flow)**	**cfs**	**Ln(flow)**	**cfs**
0%	5.86	350	6.25	516
25%	8.19	3,619	7.18	1,307
50%	8.74	6,223	7.81	2,462
75%	9.53	13,746	8.65	5,736
100%	9.84	18,691	9.94	20,818

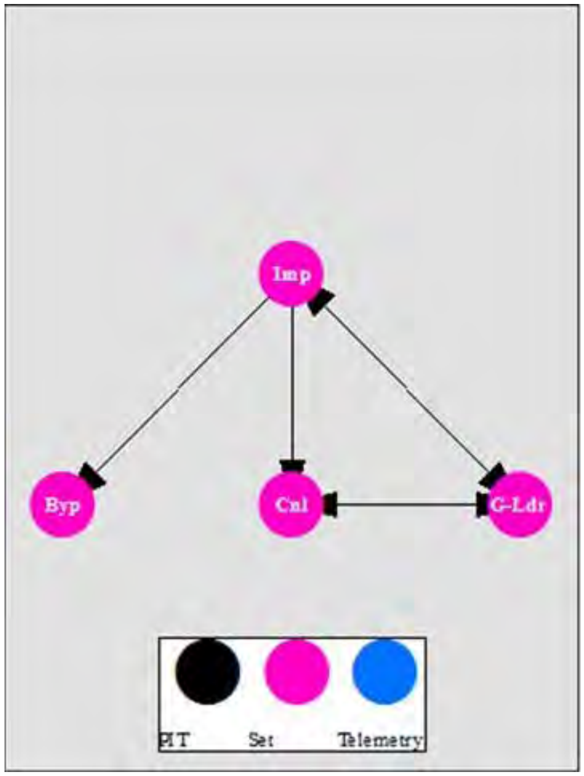

Figure 4.6.12-1. Downstream Passage MSM subnetwork.

The Impoundment state (Imp) consisted of receivers T26, T27, T25, T24 and T23. The Bypass state (Byp) consisted of receivers T20, T19, T12W, T12E and T15. The Gatehouse Ladder (G-Ldr) state consisted of P33, P32, P31, and P34 and the canal (Cnl) state consisted of receivers T22, T21 and T18.

4.6.13 Downstream Migration through the Canal

Fish entering the canal during their downstream migration must continue to the Cabot Forebay, past the Station No. 1 Forebay, before finding the preferred passage route at the downstream bypass sluice. The MSM analysis of fish moving downstream through the canal included 86 fish moving through the telemetry subnetwork (Figure 4.6.13-1). The median flow experienced by fish in the Cabot canal downstream model was 9,184 cfs (Table 4.6.13-1).

Of the 86 fish that utilized the canal during their downstream effort, three transitioned from the upper canal to the Cabot Tailrace and one transitioned from the lower canal to the Cabot Tailrace with no detections at any additional receivers in the Cabot Forebay. Therefore those four fish have no confirmed passage route through the canal. Thirty nine fish survived, transitioned and were detected in the tailrace from the downstream bypass for an overall downstream bypass rate of 45%. Twenty eight fish transitioned from Cabot Forebay to the Cabot Tailrace, and as a result the estimated rate of entrainment at Cabot Station was 32% (28/86). If we sum all of the Cabot Tailrace transition counts, 67 of the 86 fish known to be in the canal passed downstream for an overall canal rate of 82%.

The time-to-event analysis was able to utilize 98 fish migrating downstream into the canal. For the overall model, 98 fish made 80 successful attempts (defined as making it from the Gatehouse to the Cabot Station downstream bypass (P13) or the Cabot Tailrace (T6 and T5)). According to the model, 50% of the sample group experienced the event after 23.1 hours of being in the canal (Figure 4.6-13-2).

There are two locations within the canal that fish may have trouble navigating. These include the Station No. 1 Forebay and the Cabot Forebay areas. Only five emigrating fish were detected within the Station No. 1 Forebay and four escaped. Given the low sample sizes, regression models failed to find fit, however a KM curve was fit to the data and found that 50% of the population were able to escape after 14 hours (Figure 4.6.13-3).

The MSM state table revealed a significant amount of milling between the Cabot Forebay and its neighboring reaches, similar to the upstream obligated fish in the canal (Table 4.6.8-2). The state table (Table 4.6.13-2) counted 37 passing through the turbines from the Forebay, 745 events towards the bypass entrance, and 135 upstream in the canal. The probability that fish in the Cabot Forebay will survive, transition to and be detected next at the downstream bypass remained unchanged as flow increases from the 25th to 75th percentile canal flow (Appendix D, Table D-1.9-1). Fish in the Cabot Forebay were less likely to be next detected in the lower canal as flows increased (17% at 25th flow decreasing to 14% at 75th flow). Fish in the Cabot Forebay had an increased likelihood of being detected next in the Cabot Tailrace as flows increased (2% at 25th flow increasing to 5% at 75th flow).

Fish at the Downstream Bypass were most likely to be detected next at the Cabot Forebay, though the probability of next detection decreased with increases in flow (93% at 25th percentile flow decreasing to 97% at 100th percentile flow; (Appendix D, Table D-1.9-1). Fish at the Downstream Bypass were rarely detected next in the lower canal, with a probability of detection of 0.03 for all flows. Fish at the Downstream Bypass were increasingly likely to be next detected at the Cabot Tailrace as flows increased (4% at 25th percentile flow increasing to12% at 100th percentile flow).

In summary, fish are more likely to move downstream in the canal as flows increase. However, extensive milling occurs within the Forebay as fish attempt to find downstream passage. Fish will visit the Cabot Forebay and Downstream Bypass as much as 17 and 14 times respectively during low flow scenarios (25%). As flows increase, the expected number of visits decrease, however it appears that fish eventually find a passage route and pass downstream equally as well during all flow scenarios.

A null time-to-event model was fit to each competing avenue of escape from the Cabot Forebay (travel through the powerhouse, escape upstream, or downstream bypass entrance) and their respective KM curves were graphed (Figure 4.6.13-4). The resulting curves suggest of those fish available to pass towards the downstream bypass reach, most do so relatively quickly with 50% transitioning within 1.77 hours, while

50% of those abandoning the Forebay and migrating back upstream do so within 22.5 hours. There appears to be movement from the Forebay through the powerhouse (entrainment), and those fish that do choose this route do so very quickly.

The downstream canal model assessed passage efficiency of the downstream bypass. Of the 76 fish to appear at the bypass entrance (T9) 40 passed downstream via the bypass (P13) or were recaptured in the tailrace (T6 and T5) for an overall efficiency of 52%. These 76 fish abandoned the bypass for any location upstream 716 times, suggesting milling at this location. The resulting KM curves (Figure 4.6.13-5) shows low passage efficiency and large delay through the downstream bypass with fish abandoning the bypass and escaping upstream in relatively high numbers very quickly.

Overall, once in the canal, 50% of the fish pass downstream within 23 hours, however a portion remained in the canal after 10 days. The multistate model indicated that fish were more likely to move downstream in the canal as flows increased. Milling occurred within the Cabot Forebay as fish attempted to find downstream passage. It does appear that fish have more success locating the downstream bypass as canal flows increase. The analysis of time-to-event data suggests that a small cohort of fish are attracted to the Station No. 1 forebay. Of those fish in the Cabot forebay, 50% leave within 14 hours, and a proportion remained after 400 hours. The multi-state model suggests there is movement between the Cabot Forebay and bypass entrance. Fish may quickly move to the bypass, but they also quickly move back to the Forebay. Fish do pass downstream, but do so after many events.

Catch-curve mortality estimates were calculated for those fish that passed via the powerhouse and downstream bypass structures (Appendix D, Table D-4-1). The mortality rate for those fish passing via powerhouse was 0.02 fish per day, while those fish passing via downstream bypass was 0.01 fish per day. The mortality rate for fish passing via downstream bypass was not different from the mortality of fish released at Holyoke that did not pass any structure (0.01 fish per day).

Table 4.6.13-1. Flow Quantiles for the MSM Downstream Canal Model.

Quantile	ln(Flow)	Flow
0%	3.69	40
25%	8.37	3,340
50%	9.13	6,564
75%	9.70	12,016
100%	9.84	18,691

Table 4.6.13-2. State Table displaying the transitions from (row) to (column) at each hour exposure in the MSM Downstream Canal Model.

	To					
From	**Upper Canal**	**Station 1 Forebay**	**Lower Canal**	**Cabot Forebay**	**Downstream Bypass**	**Cabot Tailrace**
Upper Canal	1,575	6	92	0	0	3
Station 1 Forebay	3	641	2	0	0	0
Lower Canal	19	0	1,148	198	9	1
Cabot Forebay	1	0	118	3,048	599	24
Downstream Bypass	0	0	17	547	1,410	39

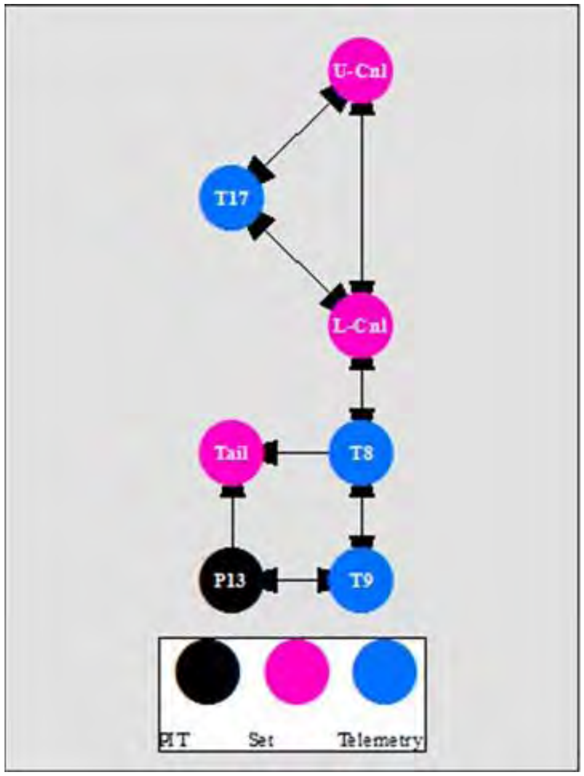

Figure 4.6.13-1. Downstream migrating canal model. The upper canal (U-Cnl) consisted of receivers T22, T21, and T18. The Lower canal (L-Cnl) consisted of T14 and T13 and the Tailrace consisted of T5 and T6.

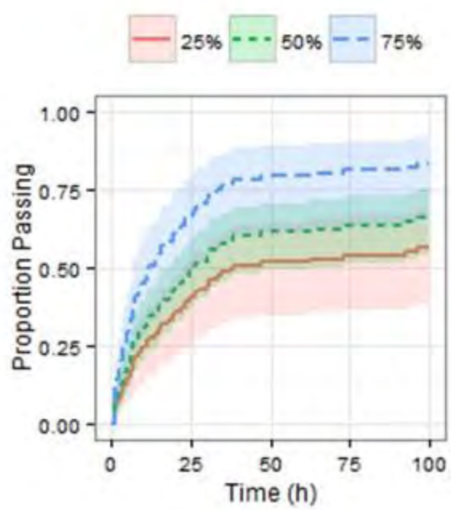

Figure 4.6.13-2: Time to downstream bypass arrival after passing into the Canal via the Gatehouse.

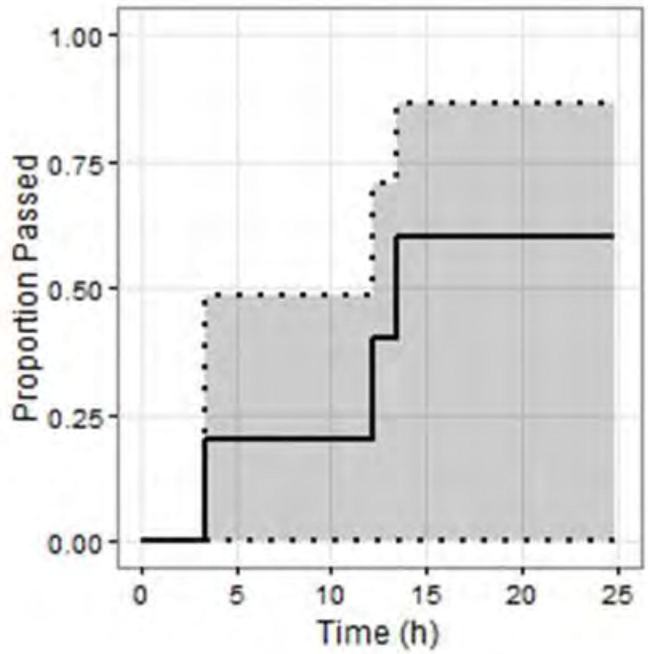

Figure 4.6.13-3: Time to escape Station No. 1 forebay.

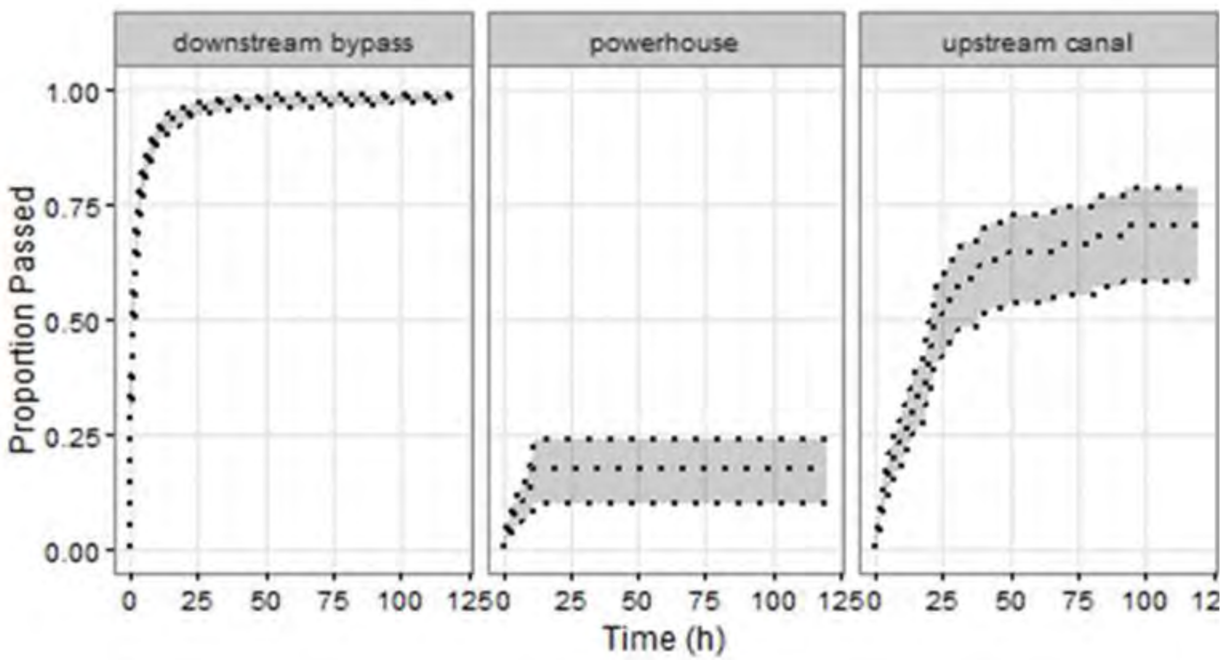

Figure 4.6.13-4: Downstream canal Cabot Forebay competing risk KM curves, proportion passed through time

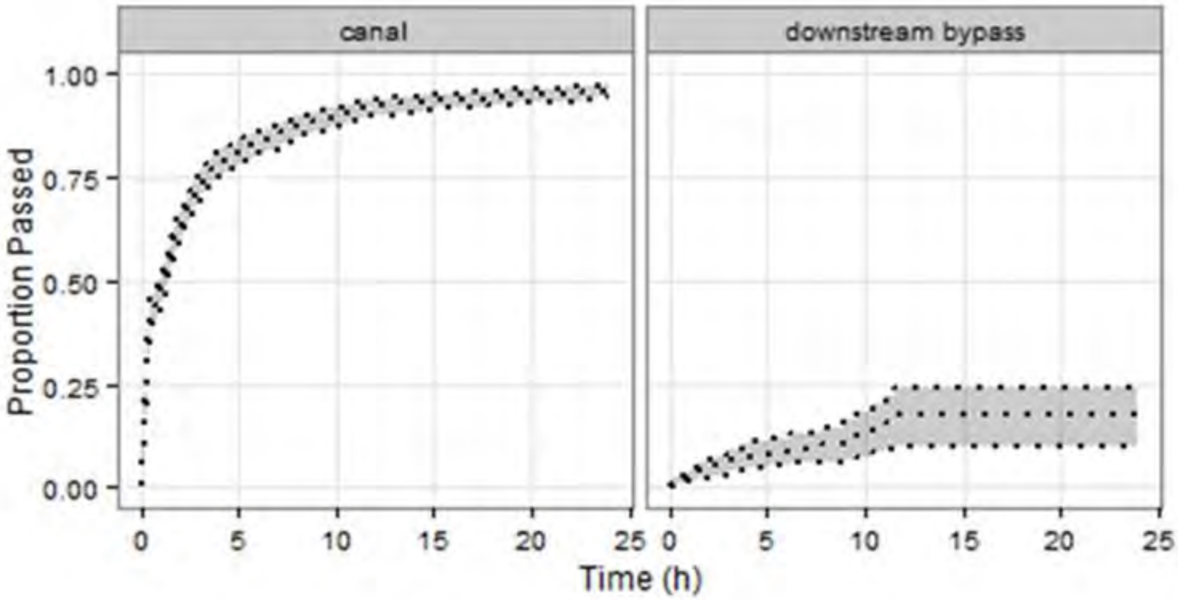

Figure 4.6.13-5: Time to downstream passage across either passage route

4.7 Turners Falls Fishway Passage

Upstream fish passage facilities at the Turners Falls Project have been in operation since 1980. The complex consists of three fish ladders: Cabot fish ladder adjacent to Cabot Station; Spillway fish ladder at Turners Falls Dam; and Gatehouse fish ladder at the upstream end of the power canal. In 2015, the Cabot fishway became operational on May 6, the spillway fishway on May 7, and the Gatehouse fishway on May 8. The fishways were closed for the season on July 6, 2015 after consultation with Massachusetts Division of Fisheries and Wildlife (MADFW) and U.S. Fish and Wildlife Services (FWS). Historical assessments of the Turners Falls passage structures are discussed in detail in Exhibit E of the Final License Application (FirstLight, 2016).

The 2015 daily and cumulative shad counts from Cabot fish ladder, Spillway fish ladder and Gatehouse fish ladder are presented in Figures 4.7-1, 4.7-2 and 4.7-3, respectively. Cabot Station fish ladder passed a total of 47,588 Shad throughout the two month period and experienced a daily maximum count of 5,066 fish on May 12, 2015 (Figure 4.7-1). Spillway fish ladder passed a total of 41,836 American Shad throughout the two month and experienced a daily maximum count of 4,414 fish on May 13, 2015 (Figure 4.7-2). Gatehouse fish ladder passed a total of 58,079 American Shad throughout the two-month period and experienced a daily maximum count of 6,395 fish on May 13, 2015 (Figure 4.7-3). Each fish ladder recorded the highest daily totals of fish throughout the month of May, followed by a slowdown of passage in the beginning of June and another small surge of passage in mid-June. Gatehouse fish ladder recorded no count data from June 18, 2015 to June 21, 2015.

The number of American Shad counted in 2015 passing through the Spillway fishway was higher relative to the number counted at the Cabot fishway than in previous years of operation. This may be the result of manipulating flow in the bypass reach during the season. Flow released at TFD sometimes exceeded the discharge from Cabot Station, a condition, which normally only occurs when inflow to the project exceeds twice the hydraulic capacity of generating facilities, plus fish passage flows, a relatively rare occurrence during the upstream passage season.

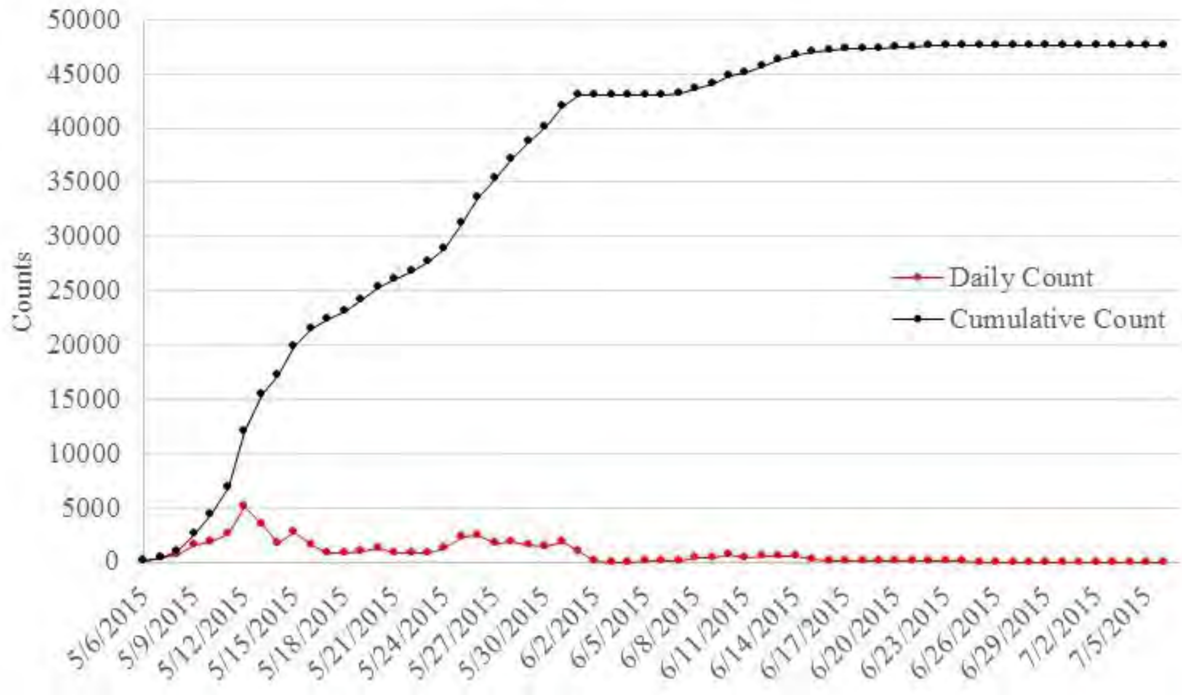

Figure 4.7-1: Daily and cumulative shad counts at Cabot fish ladder.

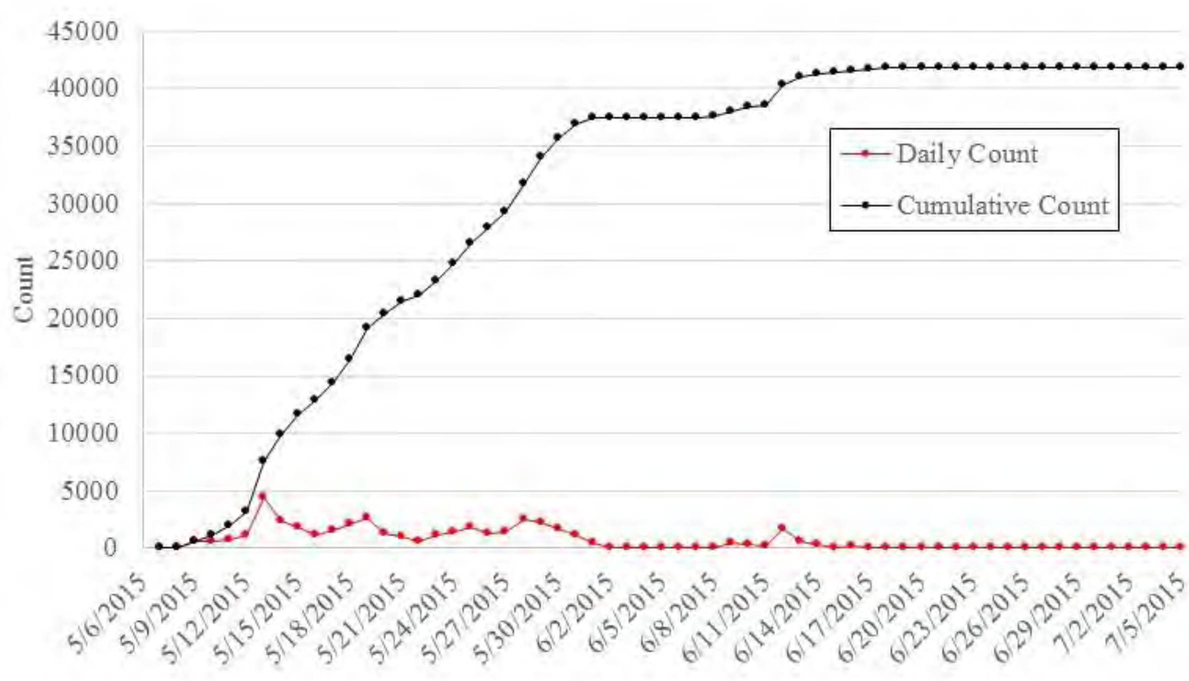

Figure 4.7-2: Daily and cumulative shad counts at Spillway fish ladder.

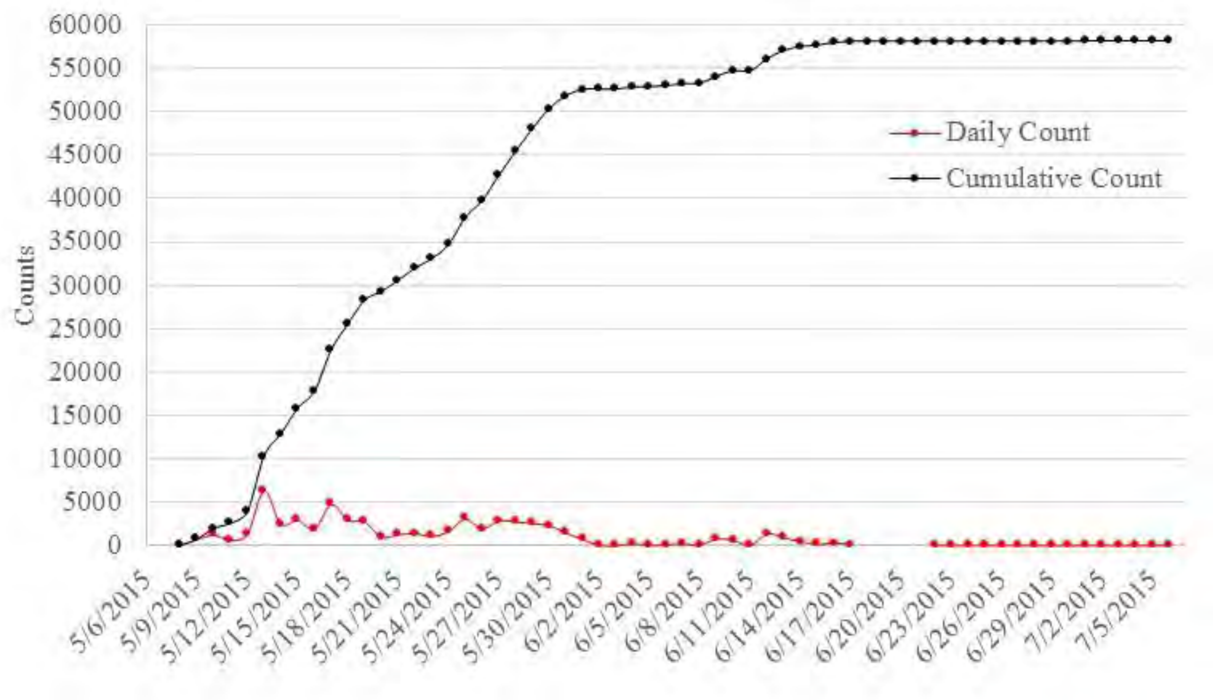

Figure 4.7-3: Daily and cumulative shad counts at Gatehouse fish ladder.

5 DISCUSSION & CONCLUSIONS

Data Analysis

The 2015 adult shad study yielded adequate results by which to achieve the stated objectives of the study. The study achieved these objectives through the use of radio and PIT telemetry methods. The analysis of radio telemetry data took a statistical driven approach, as requested by stakeholders. To understand the migration of adult American Shad through the project and answer the specific objectives of this study, a combination of four statistical and analytical methods were used. Hot spot analyses identified spatial clusters in the mobile tracking data, providing a distribution of points on a map, which can identify significant use of an area by a population of tracked fish. The multi-state Markov (MSM) models identified routes of passage via transition probability tables and enumerated the expected number of visits (forays) to receivers of interest. This allowed determination of where a fish survive, transition to and be detected next given its current location and provided valuable information for all of the required objectives. The Cox Proportional Hazards and time-to-event analysis determined any instances of delayed migration. This analysis was used to explain how a population of fish moved through a telemetered reach in time, and attempted to determine if movement rates were a function of change in system state. The Cormack-Jolly-Seber (CJS) open population mark recapture model assessed the internal efficiencies of ladders. This model incorporated the presence/absence of a fish within a telemetered reach and provided an unbiased estimate of survival, or successful passage through a ladder. Each one of these statistical procedures has its own set of data requirements, assumptions and limitations that are explained in detail in Section 3.3. The power of these analyses comes from the use of all four procedures in combination to understand what will likely happen to fish moving through the project under a variety of operational and flow conditions.

The three step data reduction method provided a quantifiable method of data reduction that reduced the number of arbitrary decisions. The algorithm developed for this study provided a quantifiable first round of data reduction, and the output allowed adjustments to the final posterior probability equation within MS Access. The SQL reduction methods reduced arbitrary decisions and the visual inspection provided an excellent QAQC protocol. With the visual inspection tool, improbable movement between reaches could be readily identified. For example, these include fish with good detections in the bypass reach only to be detected within the canal a short time later without evidence of the fish using a ladder. These improbable movements, deemed “cross chatter” were subsequently removed from the analysis. We consider the final dataset to be robust and defensible. There are only a few locations where the algorithm and SQL procedures removed a significant amount of data. These areas include Rawson Island and Station No. 1 tailrace. Fish moving through Rawson Island, especially the west channel, did so relatively quickly which may have reduced the algorithm’s ability to identify a good detection considering it needs subsequent detections in series. This hypothesis was corroborated by the large number of fish that moved undetected through the west channel and later recaptured in the upper bypass reach. A fish moving quickly through any reach would not display subsequent detections in series. The large removal of records at the Station No. 1 tailrace was due to fish detections prior to fish release, indicating that the Station No. 1 tailrace antenna was picking up signals during the tagging process. In all, three fish were removed from the analysis in their entirety. These included two fish from TransCanada (NA-SHD-0916 and NA-SHD-0920) and one fish released at Holyoke (KA-SHD-0017). The TransCanada fish successfully passed through the project but were subsequently detected again in the impoundment without any upstream passage. All of the detections for these fish appeared to be good and the removal was necessary considering there was no evidence to suggest any hits were bad. The Holyoke released fish was removed from analysis because it had near perfect detection at all receivers at all times. Further, the detection history was nearly perfect with no wave pattern, suggesting improbable hit detections.

The final recaptures database is at the limit of what MS Access can handle. With over 16 million records it is just under the 2 GB table size limit. If telemetry projects were to get larger, new methods of data management would be required, and ease of use would suffer. As a result of the large database size, the recaptures table was streamlined with extraneous fields removed. This included receiver dB power readings and other ancillary fields. However, we were able to manage data for all fish and receivers at once in one database, greatly improving the reliability of the input data provided to the statistical analyses. Without having to perform complex joins and unions between separate database tables, the analyst was assured the correct data were provided to the statistical procedures. With a robust data management procedure providing accurate input data, each study objective was analyzed with its own statistical procedure.

Bypass Flow Events

As evident in the flow histograms for the multi-state and time-to-event analysis, there were low-frequency high-flow events during the study period, and observations within the bypass reach during these events suffered with low numbers of recaptures. One should interpret statistics in the upper quartile (75^{th} – 100^{th} percentile) of bypass flow with caution. They were included in the appendix tables for completeness, however they were not reported on as more often than not confidence intervals were wide and they were of limited use.

Upstream Migration

Approximately 50% of the tagged fish reached the Turners Falls Project area within 232 hours after release from Holyoke. Fish abandoned the project area and moved downstream during high flow events. Upstream movement was also reduced during these high flows, suggesting an unwillingness of shad to migrate upstream during these events. The rate of movement was more affected by day/night than flow, which aligns with the biological consensus that American Shad migrate during the day and spawn at night. Fish were 2.8 times more likely to experience project arrival during the day than at night.

Once upstream migrating fish arrived at Montague, they were faced with a complicated array of migratory pathways. Fish may choose to migrate into the Deerfield River, bypass the Cabot tailrace and around the western channel of Smead Island, they may choose to enter the tailrace or they may pass undetected directly up the bypass reach. Flow complicates their choices, and the fish appear to minimize energy expenditure by finding areas of refuge during high flow. Fish preferred to move into the Cabot Tailrace during times of low flow. However, as Cabot discharge increased, a greater number of fish moved though the west channel of Smead Island, either as an alternate route of passage or an area of flow refuge. During high flow events, upstream movement decreased. During higher flows from the Bypass Reach, fish tended toward Smead Island, suggesting this area may be a flow refuge.

Attraction towards the Cabot ladder is also a complex, flow-dependent process. Attraction to the Cabot ladder increased as Cabot discharge increased, suggesting the discharge from the powerhouse provides attraction flow. However, as flow from the Bypass Reach increased, the overall attraction to the Cabot ladder was lower. As Bypass Reach flow increased further, movement from the Cabot Tailrace into the Bypass Reach decreased.

The overall Cabot ladder efficiency was low. The CJS model estimated overall efficiency at only 10.2%. The ladder segment between receivers T29 and P12 exhibited the lowest rates of only 15.3%. Further, the Kaplan-Meier survival curve suggested that fish abandon attempts after 40 hours with the last successful passage attempt after 30 hours. While the success rate is low, the time to first foray was only 7.44 hours. If a fish does not choose to attempt Cabot ladder, they may continue their migration upstream through the bypass reach.

Rawson Island represents a migratory hurdle that all fish must pass on their route through the Bypass Reach towards Spillway ladder. It appears that fish milled between the eastern and western channels of Rawson Island, with relatively little upstream success from the eastern channel where the Rock Dam poses a significant barrier to upstream migration. Further, passed through the western channel relatively quickly. After fish migrated past Rawson Island, they were able to approach and use Spillway ladder.

Of the fish that approached Spillway ladder from Montague, 50% did so within 94.4 hours. The time to first foray suggests fish spend roughly four days ascending the bypass reach before they find the Spillway ladder. Once in the upper bypass reach, it appears that fish have trouble being attracted to the Spillway ladder entrance during high flow scenarios as evident with the low transition probabilities towards the ladder as flow increases. The overall efficiency of the Spillway ladder was 32.7%.

If a fish can successfully find and pass either the Cabot or Spillway ladders, they are faced with a challenging migratory scenario once in the canal. Fish in the canal exhibited considerable milling within the lower canal – Cabot Forebay – downstream bypass area. Fish took as long as 48 hours to leave the Forebay area. Further, fish in the upper canal were found to abandon the reach in favor of the lower canal as flow increases. The overall time for fish to move up the canal to the area of the Gatehouse entrance (arrival at T22) was significantly affected by Canal Flow, with higher flows reducing the rate at which shad experience the event. Fish attracted to the Station No. 1 Forebay take upwards of 15 hours to leave.

Once fish arrive at the upstream end of the canal, they reach the Gatehouse ladder, designed to pass fish into the Turners Falls Impoundment. The Gatehouse ladder was the best performing ladder of the three with an overall efficiency was 76.9%. Overall, 50% of the successful attempts occurring within 1.5 hours. However, due to recapture issues at the entrance antenna, the estimated passage time may be negatively biased and underestimated.

Fish were attracted to the NMPS intake less during increased pumping. Their movement upstream remained relatively consistent with probability of a fish surviving, transitioning and being detected at Shearer Farm between 53 and 60%. During the day, attraction toward the intake decreased with increasing generation operations. Overall, movement upstream decreased slightly with increasing NMPS discharges.

Downstream Migration

For downstream migrating fish, movement downstream decreased slightly with increasing Northfield operations, however attraction towards the intake also decreased with increasing operations. For those emigrants attracted towards the intake, 50% of the population were able to escape within one day, while 25% remained in the intake area after two days. About 75% of the downstream migrants emigrated within four days from Shearer Farms to downstream of the NMPS intake. The segment of the downstream migrating population attracted to the intake are able to leave the area after two days.

Once fish arrive at Turners Falls Dam, they are faced with two primary passage routes. Most fish (75%) entered the Turners Falls Power Canal, and the remaining fish (25%) passed over the Spillway into the bypass reach.

Approximately 50% of the fish that entered the canal passed downstream within 23 hours, however a portion remained in the canal up to 10 days. Fish were more likely to move downstream in the canal as flows increased. However, milling occurred within the Cabot Forebay as fish attempt to find downstream passage. Fish seemed to locate the downstream bypass better as canal flows increased. A small cohort of fish were attracted to the Station No. 1 forebay. Of those fish in the Station No. 1 forebay, 50% leave within 14 hours. The multi-state model suggests there is movement between the Cabot Forebay and bypass entrance. Fish often quickly moved to the downstream bypass, but they also moved back to the Forebay after approaching the bypass. Fish passed downstream through the bypass sluice, but typically after a number of forays. In total, 32% will pass through Cabot Powerhouse and become entrained while 45% will pass via the downstream bypass sluice.

Summary

Less than half the American Shad lifted upstream of Holyoke Dam approach the Turners Falls Project as many of these may spawn below the Project. Once at the Project, fish are faced with a route selection and appear to choose pathways that minimize energy expenditure with fish finding refuge behind Smead Island during high flow. While a proportion of fish use Smead Island as a flow refuge, they overwhelmingly prefer the Cabot Tailrace for their route towards the bypass reach. Delays occur at Rock Dam where there was very little successful movement upstream, and fish will use the west channel of Rawson Island to reach the spillway. Fish appear to be attracted towards Cabot ladder more than Spillway ladder (they can find the entrance at greater flows), but the overall success in the Cabot ladder is much lower. High spill flows are an issue at the entrance to Spillway ladder, and fish appear to not be able to find the entrance during high flow. Once in the canal, fish mill in front of Cabot Forebay, and some abandon their migration at the head of the canal during high flows. Fish were found to fall back and make numerous attempts at the Gatehouse ladder from the Gatehouse Yagi antenna (T22). Passage through Gatehouse ladder is relatively successful. Once in the impoundment, a large proportion of the fish will successfully migrate through the project. A small percentage are attracted towards NMPS intake but they are able to leave relatively quickly. During their emigration, fish overwhelmingly choose to migrate through the canal, where they mill at the Cabot Forebay before passing through the downstream bypass (45%) or through Cabot Powerhouse (32%) or undetected. Of the 86 fish, 67 passed downstream for an overall canal rate of 82%.

6 LITERATURE CITED

Beeman, J. W., & Perry, R. W. (2012). Telemetry Techniques: A User Guide for Fisheries Research. In N. Adams, J. Beeman, & J. Eiler (Eds.). American Fisheries Society.

Budy, P., G. P. Thiede, N. Bouwes, C. E. Petrosky, and H. Schaller. (2002). Evidence linking delayed mortality of Snake River salmon to their earlier hydropower system experience. North American Journal of Fisheries Management 22:35–51.

Cooch, E., & White, G. (2006). Program MARK: A Gentle Introduction. Available in. pdf format for free download at http://www.phidot.org/software/mark/docs/book.

FirstLight. (2016). Final Application for New License for Major Water Power Project – Existing Dam, Northfield Project, Exhibit E Environmental Report. Filed with FERC April 29, 2016.

Jackson, C. H. (2011). Multi-State Models for Panel Data: The {msm} Package for {R}. Journal of Statistical Software, 38(8), 1-29.

Kieffer, M.C. & B. Kynard. (2012). Spawning and Non-spawning Migrations, Spawning and the Effect of River Regulation on Spawning Success of Connecticut River Shortnose Sturgeon. Pages 73-113 *in* Kynard, B., P. Bronzi and H Rosenthal. Life History and Behaviour of Connecticut River Shortnose and Other Sturgeon. World Sturgeon Conservation Society: Special Publication, No. 4, (2012).

Lebreton, J.-D., Burnham, K. P., Clobert, J., & Anderson, D. R. (1992). Modeling Survival and Testing Biological Hypotheses Using Marked Animals: A Unified Approach with Case Studies. Ecological monographs, 62(1), 67-118.

Marsland, S. (2009). Machine Learning: An Algorithmic Perspective. Boca Raton, Florida: CRC Press, Taylor and Francis Group.

Miranda, L.E., and B.W. Bettoli. (2007). Mortality. Pages 229–277 *in* C. S. Guy and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Ott, R. L., & Longnecker, M. (2001). An Introduction to Statistical Methods and Data Analysis (5th ed.). Pacific Grove, CA: Duxbury.

Richert, W., & Pedro-Coelho, L. (2013). Building Machine-Learning Systems with Python. Birmingham, UK: Packt Publishing.

Stone, J. V. (2013). Bayes' Rule: A Tutorial Introduction to Bayesian Analysis. Lexington, KY: Sebtel Press.

TransCanada. (2016). ILP Study 21, American Shad Telemetry Study, Study Report, prepared by Normandeau Associates.

Weather Underground. (2016). History for Orange, MA. Accessed [Online] August 5, 2016 URL: https://www.wunderground.com/history/airport/KORE/2015/5/6/CustomHistory.html?dayend=15&monthend=7&yearend=2015&req_city=&req_state=&req_statename=&reqdb.zip=&reqdb.magic=&reqdb.wmo=

APPENDIX A - TELEMETRY NETWORK CALIBRATION AND EQUIPMENT EFFECTIVENESS

APPENDIX A: 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 test tag that was used was # 900_230000014404, and this tag was not used when tagging any adult shad. A summary of each individual 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
P111	Cabot Entrance River Right	2 to 3	Tested strong
P112	Cabot Entrance River Left	3 to 4	Tested strong
P12	Cabot Fishway Exit	3 to 5	Tested strong
P13	Cabot Bypass	1 to 2	Some non-detectable areas in the middle of antenna
P21	Spillway Entrance River Right	1 to 2	Some non-detectable areas in the middle of antenna
P22	Spillway Entrance River Left	1 to 2	Some non-detectable areas in the middle of antenna
P23	Spillway Lower and 1st Turning Pool	2 to 3	Tested strong
P24	Spillway 2nd Turning Pool	3 to 4	Tested strong
P25	Spillway Window	1 to 2	Some non-detectable areas in the middle of antenna
P31	Gatehouse 1st Vertical Slot	1 to 2	Tested Strong – Some non-detectable areas due to size of antenna
P32	Gatehouse 2nd Vertical Slot	1 to 2	Tested strong – Some non-detectable areas due to size of antenna
P33	Gatehouse Viewing Window	1 to 2	Tested strong
P34	Gatehouse Entrance	<1	Never able to tune correctly – very inconsistent

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 3.2.1-1 of the main report. Orion receivers output an average power number for each contact, which is recorded in decibel levels (dBm). 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.

Station: Red Cliffe Canoe Club

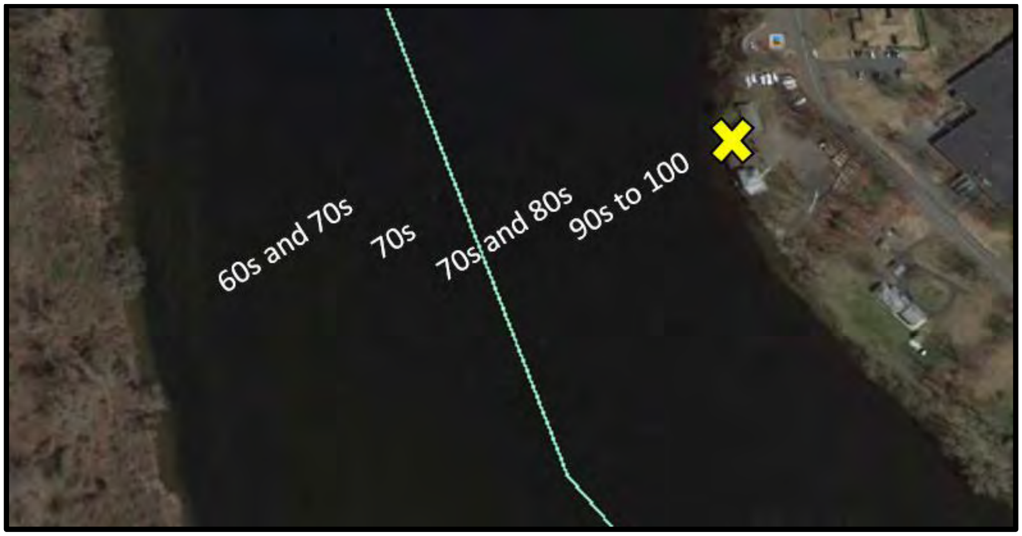

Figure 1: The large yellow X marks the approximate placement of the yagi antenna and the Lotek receiver used to detect fish moving across the width of the river at River Mile 86.5. The radio test tag produced power levels ranging from 60s to 100 db with highest powers located near the bank and attenuating slightly toward the far bank of the river.

Station: Rt. 116 Bridge Sunderland

Figure 2: The large yellow X marks the approximate placement of the two yagi antennas and the Lotek receiver used to detect fish moving across the width of the river at River Mile 111. The radio test tag produced power levels ranging from 60s to 100 db with highest powers located near the middle of the river closest to the yagi antennas and attenuating slightly farthest from the approximate 45° angle of the detection zones.

Station: Montague Wastewater

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 119.5. The radio test tag produced power levels ranging from 70s to 110 db with highest powers located near the bank of the river closest to the yagi antennas and attenuating slightly toward the far bank.

Station: Deerfield River Confluence

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 Deerfield River confluence at River Mile 119.5. The radio test tag produced power levels ranging from -70s to -90s db with highest powers located closest to the yagi antennas near Cabot Station and attenuating slightly further out in the tail waters.

Station: Cabot Tailrace

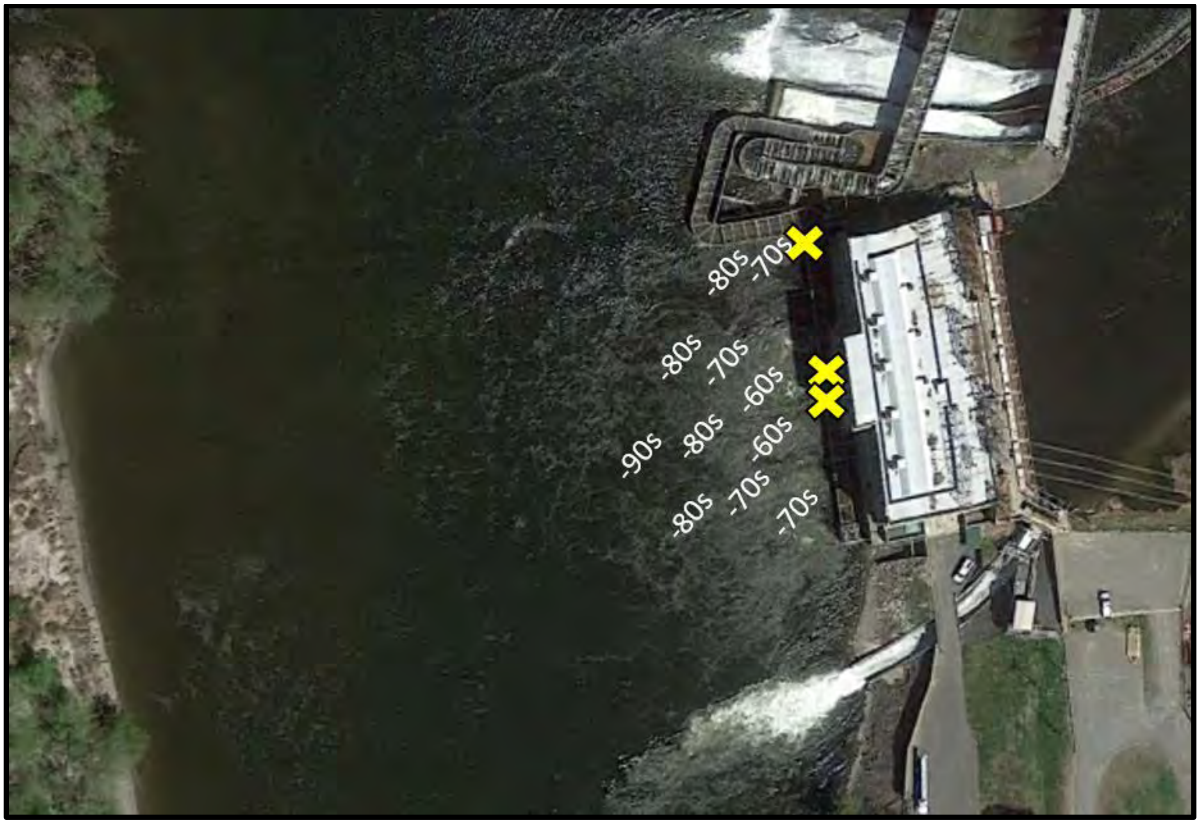

Figure 5: The large yellow X's mark the approximate placement of the two yagi antennas and the dipole antenna along with the Orion receiver used to detect fish moving Cabot Station Tailrace at River Mile 120. The radio test tag produced power levels ranging from -60s to -90s db with highest powers located closest to the yagi antennas near Cabot Station and attenuating slightly further out in the tail waters. The dipole antenna was located at the entrance to the Cabot fish ladder and produced power levels ranging from -70 to -80.

Station: Cabot far field

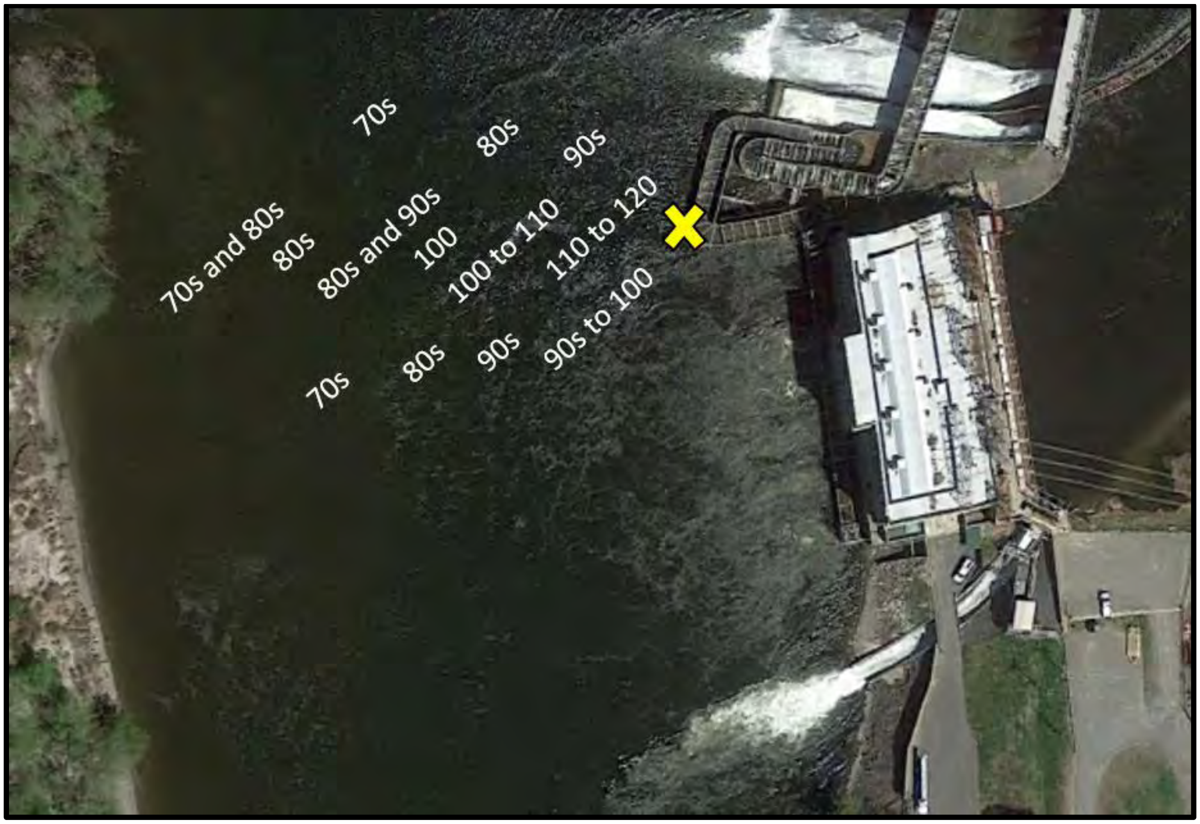

Figure 6: The large yellow X marks the approximate placement of the yagi antenna and the Lotek receiver used to detect fish moving across the width of the river passing Cabot Station at River Mile 120. The radio test tag produced power levels ranging from 70 to 120 db with highest powers located closest to the yagi antenna near the first bend in the Cabot Station Fish Ladder and attenuating toward the far bank of the river.

Station: Cabot Station Forebay

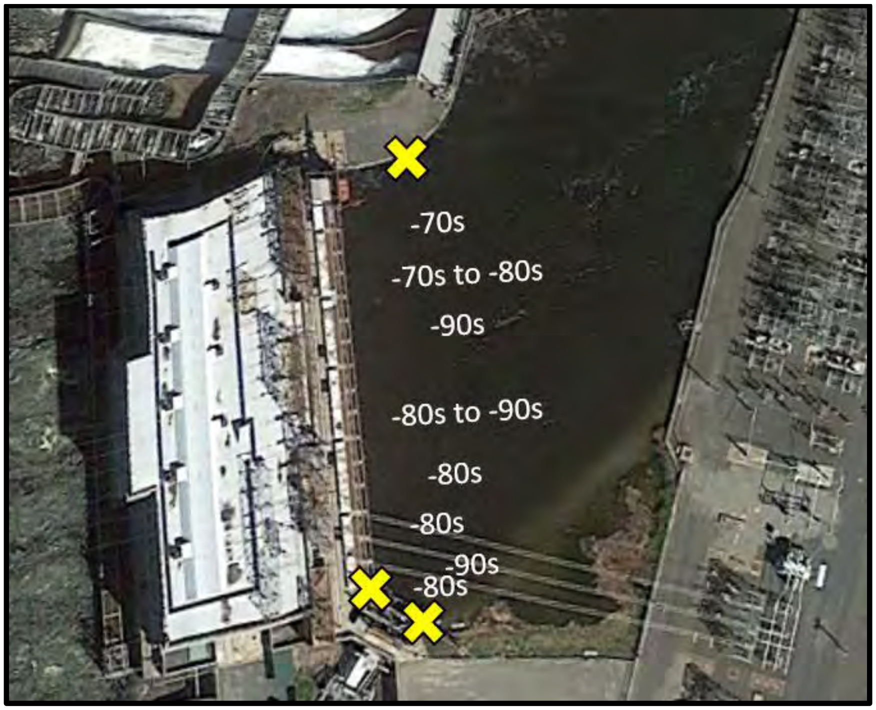

Figure 7: The large yellow X's mark the approximate location of the yagi antennas and the dipole antenna along with the Orion receiver used to detect fish moving across the width of the Cabot Station Forebay and through the bypass. The radio test tag produced power levels ranging from -70 to -90 with highest powers located closest to the yagi antennas and attenuated in the middle of the Cabot Station Forebay. The dipole antenna produced power levels ranging from -80 to -90 right immediately in front of the bypass.

Station: Rawson Island

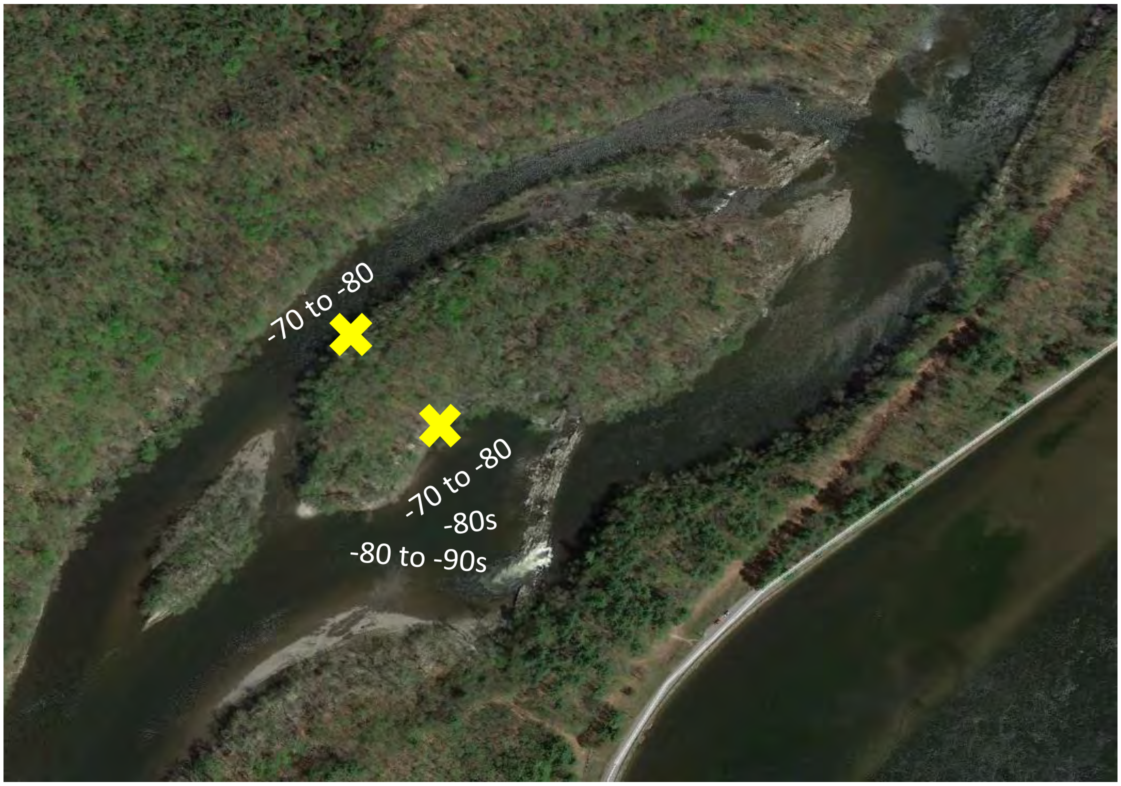

Figure 8: The large yellow X's mark the approximate placement of the yagi antennas and the Orion receivers used to detect fish moving across either side of Rawson Island at River Mile 120.5. The radio test tag produced power levels ranging from -70s to -90s with highest powers located closest to the yagi antennas and attenuated in the toward the far bank of the river.

Station: Station No. 1 Forebay

Figure 9: The large yellow X marks the approximate placement of the yagi antenna and the Lotek receiver used to detect fish within the Station No.1 tailrace at River Mile 121. The radio test tag produced power levels ranging from -70 to -90 with highest powers located closest to the yagi antennas and attenuated in the middle of the Cabot Station Forebay.

Station: Station No. 1 Tailrace

Figure 10: The large yellow X marks the approximate placement of the yagi antenna and the Lotek receiver used to detect fish within the Station No.1 tailrace at River Mile 121. The radio test tag produced power levels ranging from 70s to 100 with highest powers located closest to the yagi antennas and attenuating in the middle of the Station No. 1 Forebay.

Station: Below Turners Falls Dam river right

Figure 11: The large yellow X marks the approximate placement of the yagi antenna and the Orion receiver used to detect fish below the Turners Falls dam at River Mile 122. The radio test tag produced power levels ranging from -80 to -100s with highest powers located closest to the yagi antennas and attenuated farther out from the antenna. Not shown in this photo is a dipole antenna that was located at the entrance to the Spillway fish ladder. This antenna produced strong power levels ranging from -70 to -90.

Station: Below Turners Falls Dam river left

Figure 12: The large yellow X marks the approximate placement of the yagi antenna and the Orion receiver used to detect fish below Turners Falls Dam at River Mile 122. The radio test tag produced power levels ranging from -80 to -90s with highest powers located closest to the yagi antennas and attenuated farther out from the antenna.

Station: Upstream end of Canal

Figure 13: The large yellow X marks the approximate placement of the yagi antenna and the Orion receiver used to detect fish in the upstream end of the canal at River Mile 122. The radio test tag produced power levels ranging from -70 to -90s with highest powers located closest to the yagi antennas and attenuated farther out from the antenna.

Station: Turners Falls Impoundment

Figure 14: The large yellow X marks the approximate placement of the yagi antenna and the Lotek receiver used to detect fish below in the Turners Falls Impoundment at River Mile 122. The radio test tag produced power levels ranging from 80 to 120s with highest powers located closest to the yagi antennas and attenuated farther out from the antenna near the far bank of the river.

Station: Gill Bank

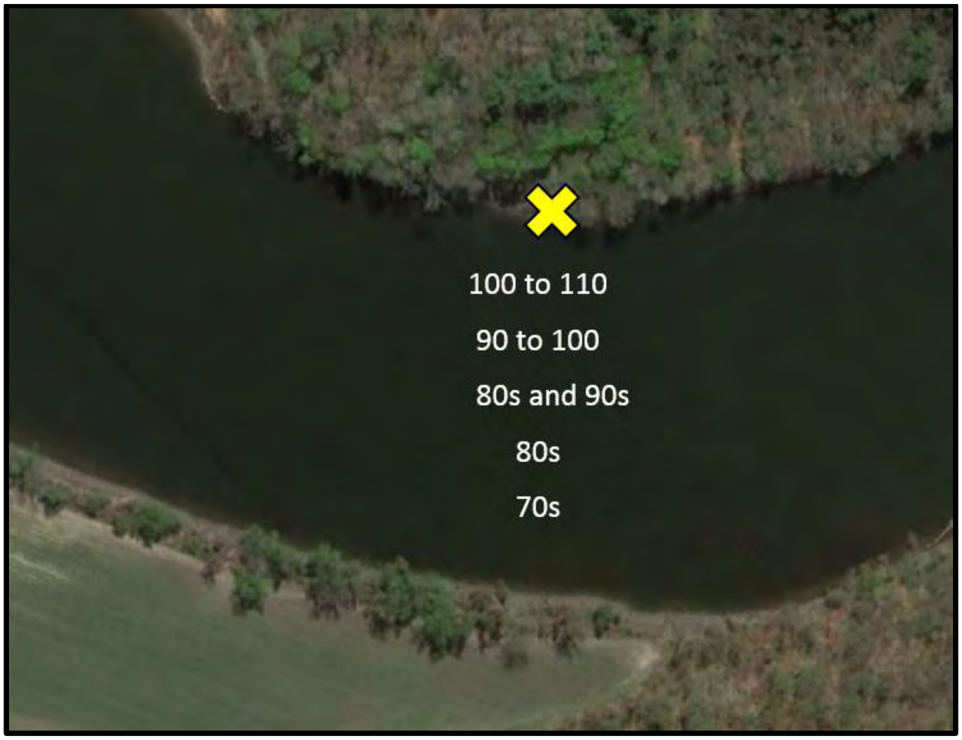

Figure 15: The large yellow X marks the approximate placement of the yagi antenna and the Lotek receiver used to detect fish below in the Gill Bank area at River Mile 126.5. The radio test tag produced power levels ranging from 70 to 110 with highest powers located closest to the yagi antennas and attenuated farther out from the antenna near the far bank of the river.

Station: NMPS Intake

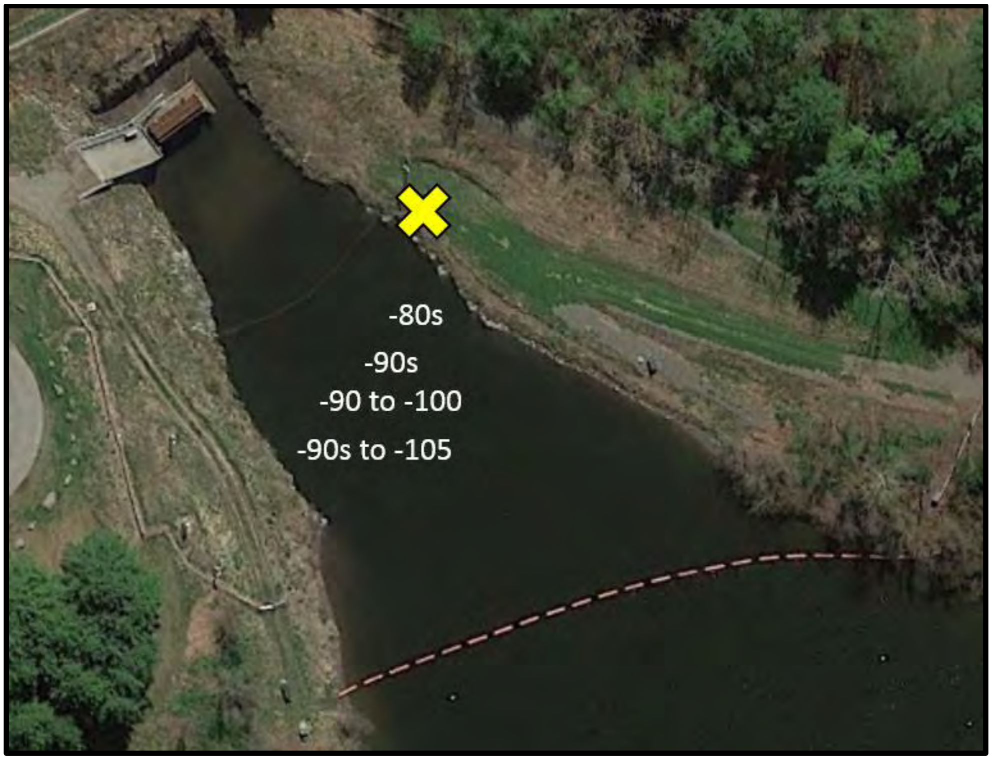

Figure 16: The large yellow X marks the approximate placement of the yagi antenna and the Orion receiver used to detect fish at the NMPS Intake at River Mile 127. The radio test tag produced power levels ranging from -80 to -105 with highest powers located closest to the yagi antennas and attenuated farther out from the antenna near the far bank of the intake.

Station: Shearer Farms

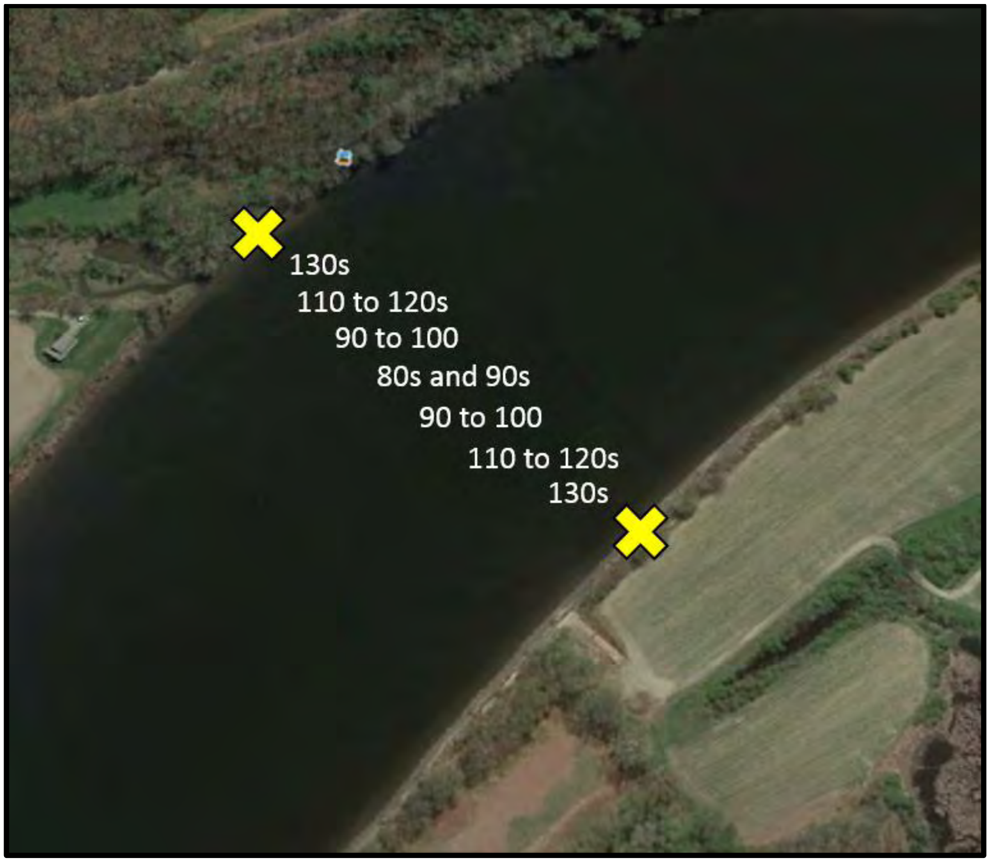

Figure 17: The large yellow X's mark the approximate placement of the yagi antennas and the Lotek receiver used to detect fish crossing Shearer Farms at River Mile 127.5. The radio test tag produced power levels ranging from 80s to 130s with highest powers located closest to the yagi antennas and attenuated farther out toward the middle of the river.

Equipment Effectiveness

Equipment and data files were inspected upon download, and noted for malfunctions or errors. Field notes and raw data files were reviewed to create a calendar depicting the number of days in which no contacts were detected, or telemetry receivers were malfunctioning (Table 2). Table 2 shows the number of days and percentage of the 61 day study in which receivers were malfunctioning (red highlights). Malfunctions included loss of power, data corruption, and hardware/software glitches. Some data files revealed days in which no contacts were recorded (orange highlights).

Table 2. Calendar of sampling season, depicting the number of days in which no contacts were received (orange) or telemetry receivers were malfunctioning (red).

	Station ID																																											
Date	**T1**	**T2**	**T3**	**T33**	**T5**	**T6**	**T7**	**P111**	**P112**	**P12**	**T29**	**T8**	**T9**	**P13**	**T11**	**T12**	**T13**	**T14**	**T15**	**T18**	**T16**	**T17**	**T30**	**P21**	**P22**	**P23 SL**	**P23 TP**	**P24**	**P25**	**P34 Z**	**T19**	**T20**	**T21**	**T22**	**P34**	**P31**	**P32**	**P33**	**T23**	**T24**	**T25**	**T31**	**T26**	**T27**
5/6/15																																												
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7/1/15																																												
7/2/15																																												
7/3/15																																												
7/4/15																																												
7/5/15																																												
Station ID	**T1**	**T2**	**T3**	**T33**	**T5**	**T6**	**T7**	**P111**	**P112**	**P12**	**T29**	**T8**	**T9**	**P13**	**T11**	**T12**	**T13**	**T14**	**T15**	**T18**	**T16**	**T17**	**T30**	**P21**	**P22**	**P23 SL**	**P23 TP**	**P24**	**P25**	**P34 Z**	**T19**	**T20**	**T21**	**T22**	**P34**	**P31**	**P32**	**P33**	**T23**	**T24**	**T25**	**T31**	**T26**	**T27**
Total Days Monitoring	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61
# days no detections	0	0	3	20	0	5	32	26	27	34	37	8	10	19	7	26	0	0	0	6	12	11	28	41	35	39	39	36	16	36	0	0	0	0	32	31	38	36	0	3	3	0	0	0
# days disabled	17	6	0	7	20	0	0	0	0	9	0	0	0	12	2	0	0	4	10	15	0	0	16	11	22	1	1	9	42	14	31	8	0	0	19	5	3	6	7	0	22	0	15	11

% disabled	28	10	0	11	33	0	0	0	0	15	0	0	0	20	3	0	0	7	16	25	0	0	26	18	36	2	2	15	69	23	51	13	0	0	31	8	5	10	11	0	36	0	25	18

APPENDIX B - FISH HISTORY MATRIX

Fish ID	Release Date	Release Location	Upstream Migration			Downstream Migration							Comment
			Cabot Ladder	Spillway Ladder	Gatehouse	Bascule Gate	Taintor Gate	Gatehouse	Spillway Ladder	Cabot Ladder	Cabot Powerhouse	Downstream Bypass	
149.720 100	5/26/2015	Holyoke Dam											all hits false positive
149.720 101	5/26/2015	Holyoke Dam											fish only recaptured in bypass reach, T15, T6
149.720 102	5/26/2015	Holyoke Dam											only recaptured at T1
149.720 103	5/26/2015	Holyoke Dam											only recaptured at T1
149.720 104	5/26/2015	Holyoke Dam											only recaptured at T1
149.720 20	5/6/2015	Holyoke Dam	attempt										fish swam up bypass, attempted Cabot ladder
149.720 21	5/6/2015	Holyoke Dam											recaptured at T2
149.720 22	5/6/2015	Holyoke Dam											all hits false positive
149.720 23	5/6/2015	Holyoke Dam											only recaptured at T6
149.720 24	5/6/2015	Holyoke Dam											fish swam up bypass reach
149.720 25	5/6/2015	Holyoke Dam	complete	attempt									fish swam up bypass reach, attempted Spillway ladder, completed Cabot ladder, never escaped Canal
149.720 26	5/6/2015	Holyoke Dam											only recaptured at T2
149.720 27	5/6/2015	Holyoke Dam											recaptured at T2 and T6
149.720 28	5/6/2015	Holyoke Dam											no recaptures
149.720 29	5/6/2015	Holyoke Dam	attempt										swam up bypass, attempted Cabot ladder
149.720 30	5/6/2015	Holyoke Dam											only recaptured at T6
149.720 31	5/6/2015	Holyoke Dam											fish swam up bypass, nosed up to dam but did not attempt either ladder
149.720 32	5/6/2015	Holyoke Dam		complete									fish swam up bypass, complete passage history on Spillway and Gatehouse ladder, swam out of study area
149.720 33	5/6/2015	Holyoke Dam	attempt	complete				complete			complete		fish swam up bypass, attempted Cabot ladder, then attempted Spillway ladder, was successful, swam into TFI, downstream through Canal and escaped to T3
149.720 34	5/6/2015	Holyoke Dam											no recaptures, all removed as false positive
149.720 35	5/12/2015	Holyoke Dam											fish swam up bypass
149.720 36	5/12/2015	Holyoke Dam											fish swam up bypass, nosed up to dam but did not attempt either ladder
149.720 37	5/12/2015	Holyoke Dam											fish only recaptured in bypass reach at T6
149.720 38	5/12/2015	Holyoke Dam											no recaptures
149.720 39	5/12/2015	Holyoke Dam											only recaptured at T6
149.720 40	5/12/2015	Holyoke Dam											swam up bypass, recaptured at T6 then T1
149.720 41	5/12/2015	Holyoke Dam	attempt										swam up bypass, multiple attempts at Cabot ladder
149.720 42	5/12/2015	Holyoke Dam											no recaptures
149.720 43	5/12/2015	Holyoke Dam											only recaptured at T6
149.720 44	5/12/2015	Holyoke Dam											released into Canal, never escaped
149.720 45	5/13/2015	Cabot Power Canal										complete	released into Canal, eventually escaped via downstream bypass
149.720 46	5/13/2015	Cabot Power Canal			complete	complete							released into Canal, migrated upstream to TFI, escaped via bascule into bypass
149.720 47	5/13/2015	Cabot Power Canal									complete		released into Canal, did not migrate to TFI, eventually escaped via Cabot powerhouse to T3
149.720 48	5/13/2015	Cabot Power Canal										complete	released into Canal, immediately migrated downstream via downstream bypass
149.720 49	5/13/2015	Cabot Power Canal										complete	released into Canal, delay at Cabot forebay, eventually found bypass and passed via downstream bypass
149.720 50	5/15/2015	TF Impoundment			complete			complete			complete		released into Canal, migrated upstream through Gatehouse ladder into TFI, escaped back downstream through Gatehouse, eventually passed through Cabot powerhouse
149.720 51	5/15/2015	TF Impoundment											released into TFI, migrated north, never back down
149.720 52	5/15/2015	TF Impoundment						complete			complete		released into TFI, migrated into Canal through Gatehouse, passed downstream through Cabot powerhouse
149.720 53	5/15/2015	TF Impoundment						complete			complete		released into TFI, migrated into Canal through Gatehouse, passed downstream through Cabot powerhouse
149.720 54	5/15/2015	TF Impoundment						complete			complete		released into TFI, migrated into Canal through Gatehouse, passed downstream through Cabot powerhouse
149.720 55	5/15/2015	TF Impoundment											released into TFI, never migrated downstream
149.720 56	5/15/2015	TF Impoundment						complete			complete		released into TFI, migrated into Canal through Gatehouse, passed downstream through Cabot powerhouse
149.720 57	5/16/2015	TF Impoundment						complete				complete	released into TFI, migrated into Canal through Gatehouse, significant delay at Cabot forebay, eventually passed via downstream bypass
149.720 58	5/16/2015	TF Impoundment						complete					released into TFI, migrated into Canal through Gatehouse, never passed downstream of Canal, at T8 through end of study
149.720 59	5/15/2015	TF Impoundment				complete							released into TFI, passed into bypass reach via bascule gate, detected at T20, fish found its way out of study area
149.720 60	5/16/2015	TF Impoundment				complete							released into TFI, passed into bypass reach via bascule gate, spent a lot of time making its way out of the bypass reach
149.720 61	5/15/2015	TF Impoundment						complete			complete		released into TFI, escaped via Gatehouse into Canal, escaped Canal via Cabot powerhouse, minimal delay in Canal
149.720 62	5/16/2015	TF Impoundment						complete				complete	released into TFI, escaped via Gatehouse into Canal, escaped Canal via downstream bypass, minimal delay trying to find downstream passage
149.720 63	5/16/2015	TF Impoundment						complete			complete		released into TFI, escaped via Gatehouse into Canal, escaped Canal via Cabot powerhouse, minimal delay in Canal, evidence of delay at forebay
149.720 64	5/16/2015	TF Impoundment						complete				complete	released into TFI, escaped via Gatehouse into Canal, escaped Canal via downstream bypass, long delay at forebay trying to find passage
149.720 65	5/16/2015	TF Impoundment				complete?							released into TFI, escaped via bascule
149.720 66	5/16/2015	TF Impoundment						complete				complete	released into TFI, escaped via Gatehouse, escaped Canal via downstream bypass, minimal delay at forebay
149.720 67	5/16/2015	TF Impoundment				complete							released into TFI, escaped via bascule then hung out in Cabot Tailrace
149.720 68	5/19/2015	Cabot Power Canal										complete	released into Canal, never went upstream, long delay before passing via downstream bypass
149.720 69	5/19/2015	Cabot Power Canal										complete	released into Canal, never went upstream, long delay before passing via downstream bypass
149.720 70	5/19/2015	Cabot Power Canal										complete	released into Canal, never went upstream, long delay before passing via downstream bypass
149.720 71	5/19/2015	Cabot Power Canal										complete	released into Canal, never went upstream, long delay before passing via downstream bypass
149.720 72	5/19/2015	Cabot Power Canal									complete		released into Canal, never went upstream, long delay before passing via powerhouse
149.720 73	5/19/2015	Cabot Power Canal										complete	released into Canal, never went upstream, minimal delay before passing via downstream bypass
149.720 74	5/19/2015	Holyoke Dam											no recaps
149.720 75	5/19/2015	Holyoke Dam											released at Holyoke, made it up to Sunderland
149.720 76	5/19/2015	Holyoke Dam											released at Holyoke, only recaptured at the T1
149.720 77	5/19/2015	Holyoke Dam											released at Holyoke, only recaptured at the T1
149.720 78	5/19/2015	Holyoke Dam											released at Holyoke, only recaptured at T6
149.720 79	5/19/2015	Holyoke Dam											released at Holyoke, only recaptured at Sunderland
149.720 80	5/19/2015	Holyoke Dam											released at Holyoke, made it up to bypass - T6
149.720 81	5/19/2015	Holyoke Dam											released at Holyoke, swam up bypass, escaped via Deerfield, migrated back downstream
149.720 82	5/19/2015	Holyoke Dam											no recaps
149.720 83	5/19/2015	Holyoke Dam											no recaps

149.720 84	5/22/2015	TF Impoundment											released in TFI, never swam back down
149.720 85	5/22/2015	TF Impoundment				complete ?							released in TFI, unknown how it got into bypass reach, dead looking lags at T20 however alive at T15
149.720 86	5/22/2015	TF Impoundment											released in TFI, never swam back down
149.720 87	5/22/2015	TF Impoundment						complete			complete		released in TFI, escaped to Canal after a while via Gatehouse, minimal delay at forebay and passed via Cabot powerhouse, alive at T2
149.720 88	5/22/2015	TF Impoundment						complete			complete		released in TFI, escaped to Canal after a long time via Gatehouse, minimal delay at forebay, passed via Cabot powerhouse, alive at T2
149.720 89	5/22/2015	TF Impoundment						complete				complete	released in TFI, escaped via Canal through Gatehouse, minimal delay at forebay until it found downstream passage
149.720 90	5/22/2015	TF Impoundment				complete							released in TFI, escaped via bascule gate, swam downstream via bypass
149.720 91	5/23/2015	TF Impoundment											released in TFI, never swam back down
149.720 92	5/23/2015	TF Impoundment				complete							released in TFI, somehow made it into bypass reach, assuming via bascule, definitely alive at T15
149.720 93	5/23/2015	TF Impoundment											released in TFI, never swam back down
149.720 94	5/23/2015	TF Impoundment											released in TFI, looks like swam up and out of project
149.720 95	5/23/2015	TF Impoundment				complete							released in TFI, escaped via bascule gate and looks like it died
149.720 96	5/23/2015	TF Impoundment											released in TFI, never swam out
149.720 97	5/23/2015	TF Impoundment						complete				complete	released in TFI, escaped via Gatehouse, significant delay at forebay before finding downstream bypass
149.720 98	5/23/2015	TF Impoundment											released in TFI, never swam out
149.720 99	5/23/2015	TF Impoundment				complete							released in TFI, passed via bascule
149.720 161	5/10/2015	Pauchaug Brook Boat Launch											no recaptures
149.720 162	5/10/2015	Pauchaug Brook Boat Launch				complete							Normandeau fish, passed via bascule gate, migrated through bypass and out of project
149.720 163	5/10/2015	Pauchaug Brook Boat Launch						complete					Normandeau fish, passed through Gatehouse into Canal, significant delay at forebay, never escaped Canal
149.720 164	5/10/2015	Pauchaug Brook Boat Launch						complete				complete	Normandeau fish, passed through Gatehouse into Canal, nosed into Station 1 forebay, then at Cabot forebay, minimal delay passed via bypass then out of project
149.720 165	5/10/2015	Pauchaug Brook Boat Launch						complete			complete		Normandeau fish, passed through Gatehouse into Canal, passed through powerhouse to bypass reach, delay in Cabot forebay
149.720 166	5/14/2015	Pauchaug Brook Boat Launch				complete							Normandeau fish, passed via bascule, ping ponged around bypass for a while before migrating downstream
149.720 167	5/14/2015	Pauchaug Brook Boat Launch		attempt				complete				complete	Normandeau fish, passed through Gatehouse into Canal, passed through powerhouse into bypass reach, then swam back up to Spillway ladder before heading downstream
149.720 168	5/14/2015	Pauchaug Brook Boat Launch						complete			complete		Normandeau fish, passed through Gatehouse into Canal, passed through powerhouse into bypass reach, significant delay at forebay
149.720 169	5/14/2015	Pauchaug Brook Boat Launch						complete				complete	Normandeau fish, passed through Gatehouse into Canal, passed into bypass reach via downstream bypass
149.720 170	5/14/2015	Pauchaug Brook Boat Launch						complete			complete		Normandeau fish, passed through Gatehouse into Canal, passed through powerhouse into bypass reach, minor delay at forebay
149.720 171	5/28/2015	Pauchaug Brook Boat Launch						complete			complete		Normandeau fish, passed through Gatehouse into Canal, passed through powerhouse into bypass reach, significant delay at forebay
149.720 172	5/28/2015	Pauchaug Brook Boat Launch											Normandeau fish, only recaptured at T24
149.720 173	5/28/2015	Pauchaug Brook Boat Launch						complete		complete			Normandeau fish, passed through Gatehouse, hung out in Station 1 forebay for a long time, then it looks like it escaped Canal through Cabot Ladder
149.720 174	5/28/2015	Pauchaug Brook Boat Launch						complete					Normandeau fish, passed through Gatehouse, looks like it died in the Canal
149.720 175	5/28/2015	Pauchaug Brook Boat Launch						complete				complete	Normandeau fish, passed through Gatehouse, nosed into Station 1 forebay, passed via downstream bypass, minimal delay at Cabot forebay
149.720 181	5/17/2015	Old Ferry Boat Ramp											no recaptures
149.720 182	5/17/2015	Old Ferry Boat Ramp											no recaptures
149.720 183	5/17/2015	Old Ferry Boat Ramp											no recaptures
149.720 184	5/17/2015	Old Ferry Boat Ramp											Normandeau fish, bounced around TFI, never escaped
149.720 185	5/17/2015	Old Ferry Boat Ramp											no recaptures
149.720 186	5/24/2015	Old Ferry Boat Ramp					complete						Normandeau fish, looks like it passed via taintor gates (T19) hung out at T20 for a long time after that, eventually migrated downstream and out of project
149.720 187	5/24/2015	Old Ferry Boat Ramp											no recaptures
149.720 188	5/24/2015	Old Ferry Boat Ramp											no recaptures
149.720 189	5/24/2015	Old Ferry Boat Ramp											no recaptures
149.720 190	5/24/2015	Old Ferry Boat Ramp											no recaptures
149.720 191	5/24/2015	Old Ferry Boat Ramp											no recaptures
149.720 192	5/28/2015	Pauchaug Brook Boat Launch											no recaptures
149.780 20	5/6/2015	Holyoke Dam											released at Holyoke, recaptured at Sunderland and T6
149.780 21	5/6/2015	Holyoke Dam											no recaptures
149.780 22	5/6/2015	Holyoke Dam	attempt										released at Holyoke, attempted Cabot ladder
149.780 23	5/6/2015	Holyoke Dam											released at Holyoke, swam up Deerfield, spent all its time there, swam back downstream
149.780 24	5/6/2015	Holyoke Dam	attempt	attempt									released at Holyoke, swam up bypass, attempted Cabot, attempted Spillway, incomplete on both, swam back down
149.720 25	5/6/2015	Holyoke Dam	attempt										released at Holyoke, attempted Cabot ladder late in the game, bounced around bypass reach and up Deerfield for a while
149.780 26	5/6/2015	Holyoke Dam		complete	complete			complete				complete	released at Holyoke, swam up bypass reach, completed Spillway and Gatehouse ladder, hung out in TFI, escaped via Gatehouse into Canal, escaped via downstream bypass w/ minimal delay
149.780 27	5/6/2015	Holyoke Dam											no recaptures
149.780 28	5/6/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
149.780 29	5/6/2015	Holyoke Dam											released at Holyoke, recaptured in bypass reach at T6 and T5
149.780 30	5/12/2015	Holyoke Dam											released at Holyoke, only recaptured at T2
149.780 31	5/12/2015	Holyoke Dam											released at Holyoke, only recaptured at T6
149.780 32	5/12/2015	Holyoke Dam											released at Holyoke, only recaptured at T6
149.780 33	5/12/2015	Holyoke Dam											no recaptures
149.780 34	5/12/2015	Holyoke Dam	complete		complete	complete							released at Holyoke, completed Cabot and Gatehouse ladders, immediately escaped downstream via bascule and hung out by T12E, no evidence of passage through Canal!!!
149.780 35	5/12/2015	Holyoke Dam											released at Holyoke, only recaptured at T6
148.780 36	5/12/2015	Holyoke Dam		attempt									released at Holyoke, swam up bypass, attempted Spillway but did not succeed, eventually swam out from bypass reach
148.780 37	5/12/2015	Holyoke Dam											released at Holyoke, swam up bypass, ended up at Montague
148.780 38	5/12/2015	Holyoke Dam	attempt										released at Holyoke, nosed into Cabot ladder, did not succeed, immediately swam back downstream
148.780 39	5/13/2015	Cabot Power Canal									complete	attempt	released in Canal, didn't escape, spent entire time in forebay, was not successful at downstream bypass, eventually passed via Cabot powerhouse and swam out
148.780 40	5/13/2015	Cabot Power Canal									complete		released in Canal, large delay at forebay, eventually passed via Cabot powerhouse, ended up in Deerfield River

148.780 41	5/13/2015	Cabot Power Canal									complete		released in Canal, explored Canal, got fed up and eventually passed via powerhouse and was recaptured again at Montague
149.780 42	5/13/2015	Cabot Power Canal			complete			complete			complete		released in Canal, escaped upstream via Gatehouse ladder, hung out in TFI, came back down via Gatehouse, minimal delay at forebay and passed via Cabot powerhouse
149.780 43	5/13/2015	Cabot Power Canal								complete			released in Canal, bounced around for a while, last Canal hit at T14 then at T5
148.780 64	5/19/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
148.780 65	5/19/2015	Holyoke Dam											released at Holyoke, bounced around bypass reach
148.780 66	5/19/2015	Holyoke Dam	attempt										released at Holyoke, nosed into Cabot ladder and did not success, bounced around bypass reach for a while afterwards
148.780 67	5/19/2015	Holyoke Dam											no recaptures
148.780 68	5/19/2015	Holyoke Dam											released at Holyoke, recaptured at Sunderland and T1, never reached project
149.780 69	5/19/2015	Holyoke Dam											released at Holyoke, only recaptured at T1 and T6
149.780 70	5/19/2015	Holyoke Dam											released at Holyoke, recaptured at Sunderland and T1, never reached project
149.780 71	5/19/2015	Holyoke Dam											no recaptures
149.780 72	5/19/2015	Holyoke Dam	attempt										released at Holyoke, attempted Cabot ladder, failed, then hung out at T6
149.780 73	5/19/2015	Holyoke Dam											released at Holyoke, only recaptured at T6
149.780 74	5/22/2015	TF Impoundment											removed all as false positive, no recaptures
149.780 75	5/22/2015	TF Impoundment											no recaptures
149.780 76	5/22/2015	TF Impoundment						complete					released in Canal, immediately swam downstream via Gatehouse then out of Canal via downstream bypass with minimal delay
149.780 77	5/22/2015	TF Impoundment											released into TFI, never escaped
149.780 78	5/22/2015	TF Impoundment						complete			complete		released into TFI, escaped into Canal through Gatehouse, escaped Canal via powerhouse, still alive at T1, minimal delay in Canal
149.780 79	5/26/2015	Holyoke Dam	attempt										released at Holyoke, attempted Cabot ladder was not successful, fish in bypass reach for extended time after attempt
149.780 80	5/26/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
149.780 81	5/26/2015	Holyoke Dam	attempt										released at Holyoke, attempted Cabot ladder was not successful, fish in bypass reach for extended time after attempt
149.780 82	5/26/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
149.780 83	5/26/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
149.780 84	6/8/2015	Holyoke Dam											released at Holyoke, swam up bypass, then swam back down to Sunderland
149.780 85	6/8/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
149.780 86	6/8/2015	Holyoke Dam											released at Holyoke, made it up to Montague then swam back downstream
149.780 87	6/8/2015	Holyoke Dam											released at Holyoke, swam up to T6
149.780 88	6/8/2015	Holyoke Dam											no recaptures
149.780 89	6/8/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
149.780 90	6/8/2015	Holyoke Dam											no recaptures
149.780 91	6/8/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
149.780 92	6/8/2015	Holyoke Dam											released at Holyoke, only recaptured at Sunderland
149.780 93	6/8/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
149.780 94	6/8/2015	Holyoke Dam											no recaptures
149.780 95	6/8/2015	Holyoke Dam											no recaptures
149.780 96	6/8/2015	Holyoke Dam											no recaptures
149.780 97	6/8/2015	Holyoke Dam											no recaptures
149.780 98	6/8/2015	Holyoke Dam											no recaptures
149.800 100	6/8/2015	Holyoke Dam											released at Holyoke, only recaptured at T6
149.800 101	5/26/2015	Holyoke Dam	attempt	attempt									released at Holyoke, attempted Cabot and Spillway ladder with no success
149.800 102	6/8/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
149.800 103	6/8/2015	Holyoke Dam											no recaptures
149.800 20	5/6/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
149.800 21	5/6/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
149.800 22	5/6/2015	Holyoke Dam											released at Holyoke, only recaptured at T6
149.800 23	5/6/2015	Holyoke Dam	attempt										released at Holyoke, multiple failed attempts at Cabot ladder, swam around bypass reach after that
149.800 24	5/6/2015	Holyoke Dam	attempt										released at Holyoke, multiple failed attempts at Cabot Ladder, swam around bypass reach after that
149.800 25	5/6/2015	Holyoke Dam											released at Holyoke, recaptured at T6 then at T1 on its way out
149.800 26	5/6/2015	Holyoke Dam											released at Holyoke, only recaptured at T6
149.800 27	5/6/2015	Holyoke Dam											released at Holyoke, bounced around bypass reach and into Deerfield river
149.800 28	5/6/2015	Holyoke Dam	attempt										released at Holyoke, only recaptured at entrance to Cabot Ladder
149.800 29	5/6/2015	Holyoke Dam											released at Holyoke, recaptured at Sunderland and T1, never reached project
149.800 30	5/6/2015	Holyoke Dam	complete		complete			complete				complete	released at Holyoke, successfully passed Cabot Ladder with minimal delay, migrated through Canal with minimal delay, passed Gatehouse ladder with no delay, hung out in TFI, escaped via Gatehouse back into Canal and migrated through downstream bypass and back downstream with minimal delay
149.800 31	5/6/2015	Holyoke Dam											released at Holyoke, only recaptured in Cabot Tailrace
149.800 32	5/6/2015	Holyoke Dam	attempt										released at Holyoke, attempted Cabot ladder, swam around in bypass after that and back out
149.800 33	5/6/2015	Holyoke Dam											fish removed from analysis due to unreasonable pattern of strong detections
149.800 34	5/6/2015	Holyoke Dam											released at Holyoke, swam into bypass but didn't do anything else
149.800 35	5/12/2015	Holyoke Dam											released at Holyoke, recaptured at T1 and Cabot tailrace
149.800 36	5/12/2015	Holyoke Dam											released at Holyoke, only recaptured at T6
149.800 37	5/12/2015	Holyoke Dam	attempt										released at Holyoke, attempted Cabot ladder but failed, swam around bypass reach after that and back out
149.800 38	5/12/2015	Holyoke Dam											released at Holyoke, recaptured at T6 and T1
149.800 39	5/12/2015	Holyoke Dam											released at Holyoke, only recaptured at T6
149.800 40	5/12/2015	Holyoke Dam											released at Holyoke, bounced around bypass reach
149.800 41	5/12/2015	Holyoke Dam											released at Holyoke, only recaptured at Sunderland and T6
149.800 42	5/12/2015	Holyoke Dam											released at Holyoke, seen in mainstem and T6
149.800 43	5/12/2015	Holyoke Dam	complete		complete	complete							released at Holyoke, multiple attempts at Cabot, eventually passed, no delay in Canal through Gatehouse ladder, escaped TFI via bascule gate and hung out in bypass till end of study
149.800 44	5/12/2015	Holyoke Dam											released at Holyoke, swam up bypass reach then hung out beneath the dam at T19
149.800 45	5/13/2015	Cabot Power Canal	complete							complete		complete	released at Cabot however compelling reason to accept detections at T15 and T5 day of release (late afternoon) - looks like fish escaped and re-entered Canal
149.800 46	5/13/2015	Cabot Power Canal									complete		released in Canal, eventually downstream through powerhouse
149.800 47	5/13/2015	Cabot Power Canal			complete			complete			complete		released in Canal, escaped upstream via Gatehouse ladder, hung out in TFI, came back down via Gatehouse, no delay, passed through powerhouse

149.800 48	5/13/2015	Cabot Power Canal			complete			complete			complete		released in Canal, some delay getting to Gatehouse ladder, no delay in ladder, hung out in TFI, escaped via Gatehouse to Canal, minimal delay at forebay until passage through powerhouse
149.800 49	5/13/2015	Cabot Power Canal										complete	released into Canal, significant delay at forebay until fish eventually passes via downstream bypass
149.800 50	5/15/2015	TF Impoundment				complete							released into TFI, eventually made it downstream into bypass reach (T6) however was not recaptured anywhere else, looks odd
149.800 51	5/15/2015	TF Impoundment						complete			complete		released into TFI, eventually escaped via Gatehouse into Canal, then powerhouse at Cabot with no delay
149.800 52	5/15/2015	TF Impoundment											released into TFI, ever escaped
149.800 53	5/15/2015	TF Impoundment				complete							released into TFI, escaped over bascule gate into bypass, migrated downstream and through project
149.800 54	5/15/2015	TF Impoundment				complete							released into TFI, immediately escaped over bascule into bypass then hung out there bounding around till end of study
149.800 55	5/16/2015	TF Impoundment				complete?		complete					released into TFI, escaped via Gatehouse because fish was definitely recaptured at T22 on 5/29 - then it was in bypass reach on 6/2 (T15) unknown how it passed
149.800 56	5/15/2015	TF Impoundment						complete				complete	released into TFI, escaped via Gatehouse then through downstream bypass, experienced delays at forebay, migrated out of project
149.800 57	5/15/2015	TF Impoundment											released into TFI, never escaped
149.800 58	5/15/2015	TF Impoundment											released into TFI, never escaped
149.800 59	5/16/2015	TF Impoundment						complete				complete	released into TFI, immediately escaped into Canal through Gatehouse, however faced very long delay at forebay and eventually passed via downstream bypass
149.800 60	5/16/2015	TF Impoundment											released into TFI, never escaped
149.800 61	5/16/2015	TF Impoundment						complete			complete		released into TFI, escaped into Canal via Gatehouse, nosed into Station 1 but was not entrained, eventually found Cabot powerhouse and passed via forebay
149.800 62	5/16/2015	TF Impoundment						complete			complete		released into TFI, escaped via Gatehouse into Canal, minimal delay at forebay and passed through powerhouse
149.800 63	5/16/2015	TF Impoundment											released into TFI, appears to have migrated north and not back out
149.800 64	5/16/2015	TF Impoundment				complete							released into TFI, immediately escaped into bypass reach through bascule gate, migrated out of project
149.800 65	5/16/2015	TF Impoundment				complete							released into TFI, immediately escaped into bypass reach through bascule gate, migrated out of project
149.800 66	5/19/2015	Cabot Power Canal			complete			complete			complete		released in Canal, escaped through Gatehouse ladder minimal delay, escaped TFI via Gatehouse, attempted Station 1, escaped via Cabot powerhouse with no delay in Canal
149.800 67	5/19/2015	Cabot Power Canal										complete	released in Canal, never escaped forebay, tons of delay
149.800 68	5/19/2015	Cabot Power Canal										complete	released into Canal, never escaped, eventually found downstream bypass
149.800 69	5/19/2015	Cabot Power Canal											released into Canal, never escaped
149.800 70	5/19/2015	Cabot Power Canal										complete	released into Canal, escaped via downstream bypass, bounced around bypass reach and went up Deerfield, then migrated out of project area
149.800 71	5/19/2015	Cabot Power Canal			complete								released into Canal, took a long time making it to Gatehouse ladder, eventually passed into TFI where it wasted no time migrating out of project to not return
149.800 72	5/19/2015	Holyoke Dam											released at Holyoke, made it to bypass
149.800 73	5/19/2015	Holyoke Dam											no recaptures
149.800 74	5/19/2015	Holyoke Dam											no recaptures
149.800 75	5/19/2015	Holyoke Dam											no recaptures
149.800 76	5/19/2015	Holyoke Dam											no recaptures
149.800 77	5/19/2015	Holyoke Dam											released at Holyoke, migrated to T5
149.800 78	5/19/2015	Holyoke Dam	attempt										released at Holyoke, attempted Cabot ladder, hung out in bypass for remainder
149.800 79	5/19/2015	Holyoke Dam											released at Holyoke, only recaptured at T6
149.800 80	5/19/2015	Holyoke Dam											released at Holyoke, migrated up to bypass, hung out for a while and then migrated back out of project
149.800 81	5/19/2015	Holyoke Dam				complete							recaptured in TFI, possible downstream passage over bascule gate into bypass reach where it stayed for remainder of study
149.800 82	5/22/2015	TF Impoundment											released in TFI, only recaptured at T23
149.800 83	5/22/2015	TF Impoundment			complete			complete					released in impoundment, escaped to Canal via Gatehouse, hung out in Canal for a long time, then swam back upstream passed via Gatehouse ladder and stayed in TFI for remainder
149.800 84	5/22/2015	TF Impoundment				complete							released in TFI, passed via bascule then fish bounced around bypass reach
149.800 85	5/22/2015	TF Impoundment						complete			complete		released in TFI, migrated through Gatehouse into Canal, appears to have passed via powerhouse, many false positives
149.800 86	5/22/2015	TF Impoundment											released in TFI, never migrated out
149.800 87	5/22/2015	TF Impoundment				complete							released in TFI, passed over bascule gate and looks like it died right under receiver (T20)
149.800 88	5/23/2015	TF Impoundment							complete				released in TFI, picked up at Spillway entrance dropper (T30), appears to have used Spillway ladder to migrate downstream
149.800 89	5/23/2015	TF Impoundment											no recaptures
149.800 90	5/23/2015	TF Impoundment											released into TFI, never escaped, hung out by NMPS intake through end of study but was not entrained
149.800 91	5/23/2015	TF Impoundment						complete			complete		released into TFI, hung out there for a while, escaped via Gatehouse to Canal, then Cabot powerhouse to bypass reach, minimal delay at forebay
149.800 92	5/23/2015	TF Impoundment						complete			complete		released into TFI, hung out there for a while, escaped via Gatehouse to Canal, then Cabot powerhouse to bypass reach, minimal delay at forebay
149.800 93	5/23/2015	TF Impoundment				complete							released into TFI, passed bascule then hung out in bypass through end of study
149.800 94	5/23/2015	TF Impoundment						complete			complete		released into TFI, hung out there for a while, escaped via Gatehouse to Canal, then Cabot powerhouse to bypass reach, minimal delay at forebay
149.800 95	5/23/2015	TF Impoundment						complete					released into TFI, escaped via Gatehouse into Canal then it looks like it died
149.800 96	5/26/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
149.800 97	5/26/2015	Holyoke Dam											released at Holyoke, recaptured at T1 > Sunderland > T1 > migrated out of study
149.800 98	5/26/2015	Holyoke Dam											no recaptures
149.800 99	5/26/2015	Holyoke Dam											released at Holyoke, fish nosed into bypass reach then migrated out and hung out by Sunderland till end of study
149.800 161	5/30/2015	Old Ferry Boat Ramp											no recaptures
149.800 163	5/24/2015	Old Ferry Boat Ramp						complete			complete		Normandeau fish, migrated through Gatehouse then through powerhouse, no delay in Canal, out of study area
149.800 166	5/10/2015	Pauchaug Brook Boat Launch						complete			complete		Normandeau fish, migrated through Gatehouse, then through powerhouse, minimal delay at forebay,
149.800 167	5/10/2015	Pauchaug Brook Boat Launch						complete			complete		Normandeau fish, migrated through Gatehouse, then through powerhouse, no delay in Canal
149.800 168	5/10/2015	Pauchaug Brook Boat Launch						complete			complete		Normandeau fish, migrated through Gatehouse, then through powerhouse, significant delay in Canal
149.800 169	5/10/2015	Pauchaug Brook Boat Launch						complete				complete	Normandeau fish, migrated through Gatehouse, then through bypass reach, significant delay at forebay
149.800 170	5/10/2015	Pauchaug Brook Boat Launch						complete					Normandeau fish, migrated through Gatehouse, then stuck at forebay through end of study
149.800 171	5/14/2015	Pauchaug Brook Boat Launch						complete			complete		Normandeau fish, migrated through Gatehouse, then through powerhouse, delay at forebay
149.800 172	5/14/2015	Pauchaug Brook Boat Launch											Normandeau fish, only recaptured at T24
149.700 173	5/14/2015	Pauchaug Brook Boat Launch											no recaptures
149.800 174	5/14/2015	Pauchaug Brook Boat Launch				complete							Normandeau fish, passed via bascule, hung out in bypass after

149.800 175	5/14/2015	Pauchaug Brook Boat Launch						complete					Normandeau fish, passed via Gatehouse, then hung out in Canal, dead?
149.800 176	5/28/2015	Pauchaug Brook Boat Launch				complete							Normandeau fish, passed via bascule, hung out in bypass after
149.800 177	5/28/2015	Pauchaug Brook Boat Launch						complete			complete		Normandeau fish, passed via Gatehouse, passed via powerhouse, no delay in Canal, looks like it's dead at Montague
149.800 178	5/28/2015	Pauchaug Brook Boat Launch						complete				complete	Normandeau fish, passed via Gatehouse, passed via bypass
149.800 179	5/28/2015	Pauchaug Brook Boat Launch						complete					Normandeau fish, passed via Gatehouse into Canal where it looks like it died
149.800 180	5/28/2015	Pauchaug Brook Boat Launch						complete					Normandeau fish, passed via Gatehouse into Canal where it looks like it died
149.800 186	5/17/2015	Old Ferry Boat Ramp											no recaptures
149.800 187	5/17/2015	Old Ferry Boat Ramp				complete							Normandeau fish, passed via bascule hung out in bypass then out of project
149.800 188	5/17/2015	Old Ferry Boat Ramp											no recaptures
149.800 189	5/17/2015	Old Ferry Boat Ramp						complete			complete		Normandeau fish, passed via Gatehouse then powerhouse, delay at forebay before passing through Cabot powerhouse
149.800 190	5/17/2015	Old Ferry Boat Ramp											no recaptures
149.800 191	5/24/2015	Old Ferry Boat Ramp											Normandeau fish, only recaptured at S4
149.800 192	5/24/2015	Old Ferry Boat Ramp						complete			complete		Normandeau fish, passed via Gatehouse, passed via powerhouse, no delay in Canal,
149.800 193	5/24/2015	Old Ferry Boat Ramp				complete							Normandeau fish, passed via Spillway, ping-ponged between T19 and T20 - looks like it's dead
149.800 194	5/24/2015	Old Ferry Boat Ramp						complete			complete		Normandeau fish, passed via Gatehouse, passed via powerhouse, delay at forebay, then out of study area
149.800 195	5/24/2015	Old Ferry Boat Ramp						complete			complete		Normandeau fish, passed via Gatehouse, passed via powerhouse, minimal delay at forebay
150.440 100	5/26/2015	Holyoke Dam											released at Holyoke, only recaptured at T1 and Sunderland
150.440 101	5/26/2015	Holyoke Dam											no recaptures
150.440 102	5/26/2015	Holyoke Dam											released at Holyoke, recaptured at T1 > Sunderland > T1 > migrate out of study
150.440 103	6/8/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
150.440 104	6/8/2015	Holyoke Dam	complete		complete								released at Holyoke, multiple attempts at Cabot ladder, eventually passed, no delay in Canal through Gatehouse ladder, migrated out of project (Vernon)
150.440 105	6/8/2015	Holyoke Dam											no recaptures
150.440 106	6/8/2015	Holyoke Dam											no recaptures
150.440 167	5/28/2015	Pauchaug Brook Boat Launch											Normandeau fish, once in TFI ping ponged around NFM intake
150.440 168	5/24/2015	Old Ferry Boat Ramp						complete					Normandeau fish, migrated through Gatehouse into Canal, never escaped Canal
150.440 171	5/10/2015	Pauchaug Brook Boat Launch											Normandeau fish, migrated into TFI and set
150.440 172	5/10/2015	Pauchaug Brook Boat Launch						complete				complete	Normandeau fish, migrated through Gatehouse into Canal and out via bypass, minimal delay
150.440 173	5/10/2015	Pauchaug Brook Boat Launch				complete							Normandeau fish, passed via bascule into bypass reach then migrated out of study area
150.440 174	5/10/2015	Pauchaug Brook Boat Launch						complete				complete	Normandeau fish, passed into Canal via Gatehouse, then out bypass, significant delay at forebay
150.440 175	5/10/2015	Pauchaug Brook Boat Launch											no recaptures
150.440 176	5/14/2015	Pauchaug Brook Boat Launch											no recaptures
150.440 177	5/14/2015	Pauchaug Brook Boat Launch											no recaptures
150.440 178	5/14/2015	Pauchaug Brook Boat Launch											no recaptures
150.440 179	5/14/2015	Pauchaug Brook Boat Launch											no recaptures
150.440 180	5/14/2015	Pauchaug Brook Boat Launch											no recaptures
150.440 191	5/17/2015	Old Ferry Boat Ramp											no recaptures
150.440 192	5/17/2015	Old Ferry Boat Ramp						complete			complete		Normandeau fish, migrated through Gatehouse into Canal, significant delay at forebay before passing through Cabot powerhouse, swam out of project
150.440 193	5/17/2015	Old Ferry Boat Ramp				complete							Normandeau fish, passed via spill into bypass, hung out for a while
150.440 194	5/17/2015	Old Ferry Boat Ramp						complete			complete		Normandeau fish, migrated through Gatehouse into Canal, delay at forebay before passing through Cabot powerhouse, then out of project
150.440 195	5/17/2015	Old Ferry Boat Ramp											no recaptures
150.440 196	5/24/2015	Old Ferry Boat Ramp						complete					Normandeau fish, migrated through Gatehouse, never escaped forebay
150.440 197	5/24/2015	Old Ferry Boat Ramp											no recaptures
150.440 198	5/24/2015	Old Ferry Boat Ramp				complete							Normandeau fish, passed via spill (bascule?) and ping ponged between T15 and T12E
150.440 199	5/24/2015	Old Ferry Boat Ramp											no recaptures
150.440 20	5/6/2015	Holyoke Dam	attempt										released at Holyoke, multiple attempts at Cabot ladder, never passed, then migrated back out of project
150.440 200	5/24/2015	Old Ferry Boat Ramp						complete			complete		Normandeau fish, migrated through Gatehouse, passed via Cabot powerhouse, almost no delay, went into Station 1 forebay but turned around
150.440 201	5/30/2015	Old Ferry Boat Ramp											no recaptures
150.440 202	5/30/2015	Old Ferry Boat Ramp						complete			complete		Normandeau fish, migrated through Gatehouse, significant delay at forebay, eventually passed via Cabot powerhouse
150.440 203	5/30/2015	Old Ferry Boat Ramp											no recaptures
150.440 204	5/30/2015	Old Ferry Boat Ramp											no recaptures
150.440 205	5/30/2015	Old Ferry Boat Ramp											no recaptures
150.440 21	5/6/2015	Holyoke Dam	attempt										released at Holyoke, multiple attempts at Cabot ladder, all failed, migrated out
150.440 22	5/6/2015	Holyoke Dam											no recaptures
150.440 23	5/6/2015	Holyoke Dam											no recaptures
150.440 24	5/6/2015	Holyoke Dam	attempt										released at Holyoke, multiple attempts at Cabot ladder, all failed, hung out in bypass for a long time before beginning outmigration
150.440 25	5/6/2015	Holyoke Dam											released at Holyoke, hung out in bypass reach, nosed into Deerfield then back downstream
150.440 26	5/6/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
150.440 27	5/6/2015	Holyoke Dam	attempt										released at Holyoke, bounced around bypass for a while, attempted Cabot ladder then started outmigration
150.440 28	5/6/2015	Holyoke Dam											no recaptures
150.440 29	5/6/2015	Holyoke Dam											released at Holyoke, bounced around bypass then left
150.440 30	5/6/2015	Holyoke Dam	attempt										released at Holyoke, bounced around bypass, attempted ladder, then outmigrated
150.440 31	5/6/2015	Holyoke Dam											released at Holyoke, made it to bypass
150.440 32	5/6/2015	Holyoke Dam	attempt	attempt									released at Holyoke, attempted Spillway ladder and Cabot ladder, no success, outmigrated after spending some time in bypass reach
150.440 33	5/6/2015	Holyoke Dam											released at Holyoke, only recaptured at T1 and Sunderland
150.440 34	5/6/2015	Holyoke Dam											released at Holyoke, bounced around bypass looks like it died up at T20
150.440 35	5/6/2015	Holyoke Dam	attempt										released at Holyoke, multiple attempts at Cabot Ladder, all failures, hung out in bypass for a while before outmigration
150.440 36	5/12/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
150.440 37	5/12/2015	Holyoke Dam	attempt										released at Holyoke, attempted Cabot Ladder, bounced around bypass before out-migrating
150.440 38	5/12/2015	Holyoke Dam											no recaptures
150.440 39	5/12/2015	Holyoke Dam	attempt										released at Holyoke, attempted Cabot ladder, then outmigrated shortly thereafter
150.440 40	5/12/2015	Holyoke Dam											released at Holyoke, only recaptured at T1

150.440 41	5/12/2015	Holyoke Dam											no recaptures
150.440 42	5/12/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
150.440 43	5/12/2015	Holyoke Dam											no recaptures
150.440 44	5/12/2015	Holyoke Dam											no recaptures
150.440 45	5/12/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
150.440 46	5/13/2015	Cabot Power Canal										complete	released in Cabot, never escaped Canal, significant delay at forebay before escaping via downstream bypass
150.440 47	5/13/2015	Cabot Power Canal											released in Canal, never escaped Canal, significant delay at forebay
150.440 48	5/13/2015	Cabot Power Canal										complete	released in Canal, nosed into Station 1 forebay, hung out at Cabot forebay and eventually passed via downstream bypass, significant delay at forebay
150.440 49	5/13/2015	Cabot Power Canal								complete			released in Canal, escaped via Cabot ladder downstream, hung out in bypass reach after that, never outmigrated
150.440 50	5/13/2015	Cabot Power Canal									complete		released in Canal, never escaped upstream, eventually passed via powerhouse, significant delay at forebay
150.440 51	5/15/2015	TF Impoundment						complete			complete		released in TFI, immediately migrated downstream through Gatehouse, significant delay at forebay and finally passed via powerhouse
150.440 52	5/15/2015	TF Impoundment											released in TFI, never escaped
150.440 53	5/15/2015	TF Impoundment											released in TFI, appears to migrate north and not come back
150.440 54	5/15/2015	TF Impoundment											no recaptures
150.440 55	5/15/2015	TF Impoundment				complete							released in impoundment, immediately outmigrated via bascule passed downstream through bypass after delay at T20
150.440 56	5/15/2015	TF Impoundment						complete				complete	released in TFI, passed downstream into Canal through Gatehouse, then through downstream bypass, minimal delay at forebay
150.440 57	5/15/2015	TF Impoundment						complete				complete	released in TFI, passed downstream into Canal through Gatehouse, then through downstream bypass, minimal delay at forebay
150.440 58	5/16/2015	TF Impoundment						complete					released in TFI, passed downstream into Canal through Gatehouse, never escaped Canal
150.440 59	5/15/2015	TF Impoundment				complete							released in TFI, recaptured at T15, assumed to pass via bascule gate - eventually outmigrated
150.440 60	5/16/2015	TF Impoundment						complete				complete	released in TFI, passed into Canal through Gatehouse, delay at forebay before finding downstream passage
150.440 61	5/16/2015	TF Impoundment						complete					released in TFI, passed into Canal through Gatehouse, never escaped Canal
150.440 62	5/16/2015	TF Impoundment						complete			complete		released in TFI, passed into Canal through Gatehouse, minimal delay at forebay before passing through powerhouse
150.440 63	5/16/2015	TF Impoundment						complete			complete		released in TFI, passed into Canal through Gatehouse, no delay at forebay before passing through powerhouse
150.440 64	5/16/2015	TF Impoundment						complete			complete		released in TFI, passed into Canal through Gatehouse, no real delay at forebay before passing through powerhouse
150.440 65	5/16/2015	TF Impoundment						complete			complete		released in TFI, passed into Canal through Gatehouse, significant delay at forebay before passing through powerhouse
150.440 66	5/16/2015	TF Impoundment				complete							released in TFI, immediately passed via bascule and looks like it died
150.440 67	5/19/2015	Cabot Power Canal									complete		released in Canal, never migrated north, eventually passed via powerhouse
150.440 68	5/19/2015	Cabot Power Canal										complete	released in Canal, never migrated north, minimal delay at forebay before passing via downstream bypass, out-migrated through Holyoke
150.440 69	5/19/2015	Cabot Power Canal									complete		released in Canal, never migrated north, delay at forebay before passing through powerhouse, looks like its dead and ping ponging between T5 and T6
150.440 70	5/19/2015	Cabot Power Canal									complete		released in Canal, nosed into Station 1 forebay, then migrated back to forebay, significant delay before passing through Cabot powerhouse and then out of project
150.440 71	5/19/2015	Cabot Power Canal									complete		released in Canal, delay at forebay until passed through Cabot powerhouse, downstream migration after that
150.440 72	5/19/2015	Cabot Power Canal			attempt						complete		released in Canal, attempted Gatehouse ladder, dropped back, significant delay in forebay until passing through powerhouse with downstream migration after that
150.440 73	5/19/2015	Holyoke Dam											released at Holyoke, eventually nosed into bypass reach and hung out by Cabot tailrace
150.440 74	5/19/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
150.440 75	5/19/2015	Holyoke Dam											no recaptures
150.440 76	5/19/2015	Holyoke Dam											no recaptures
150.440 77	5/19/2015	Holyoke Dam											no recaptures
150.440 78	5/19/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
150.440 79	5/19/2015	Holyoke Dam											no recaptures
150.440 80	5/19/2015	Holyoke Dam	complete		attempt							complete	released at Holyoke, completed Cabot ladder, attempted Gatehouse, dropped back through Canal, significant delay in Canal and forebay, eventual passage through downstream bypass
150.440 81	5/19/2015	Holyoke Dam											no recaptures
150.440 82	5/22/2015	TF Impoundment						complete			complete		released in TFI, migrated through Gatehouse into Canal, minimal delay at forebay and passed through powerhouse, nosed into Deerfield before migrating out of project
150.440 83	5/22/2015	TF Impoundment				complete?							released in TFI, ended up in bypass reach, assumed to pass via bascule gate, fish migrates out through project
150.440 84	5/22/2015	TF Impoundment				complete?							released in TFI, ended up in bypass reach, assumed to pass via bascule gate
150.440 85	5/22/2015	TF Impoundment											released in TFI, looks like it migrated north and never came back
150.440 86	5/22/2015	TF Impoundment											released in TFI, looks like it migrated north and never came back
150.440 87	5/22/2015	TF Impoundment						complete			complete		released in TFI, migrated into Canal through Gatehouse, minimal delay at forebay before passing through Cabot powerhouse, then outmigrated from project
150.440 88	5/22/2015	TF Impoundment						complete			complete		released in TFI, migrated into Canal through Gatehouse, minimal delay at forebay before passing through Cabot powerhouse, then outmigrated from project
150.440 89	5/23/2015	TF Impoundment											released in TFI, never escaped
150.440 90	5/23/2015	TF Impoundment						complete			complete		released in TFI, migrated into Canal through Gatehouse, minimal delay at forebay before passing through Cabot powerhouse, then outmigrated from project
150.440 91	5/23/2015	TF Impoundment											released in TFI, never migrated out
150.440 92	5/23/2015	TF Impoundment											released in TFI, never migrated out
150.440 93	5/23/2015	TF Impoundment						complete				complete	released in TFI, migrated into Canal through Gatehouse, minimal delay at forebay before passing through downstream bypass, then outmigrated from project
150.440 94	5/23/2015	TF Impoundment						complete				complete	released in TFI, migrated into Canal through Gatehouse, minimal delay at forebay before passing through downstream bypass, then outmigrated from project
150.440 95	5/23/2015	TF Impoundment				complete							released into TFI, passed into bypass reach via bascule, then looks like it died
150.440 96	5/23/2015	TF Impoundment						completer				complete	released in TFI, migrated into Canal through Gatehouse, minimal delay at forebay before passing through downstream bypass, then outmigrated from project
150.440 97	5/26/2015	Holyoke Dam											released at Holyoke, recaptured at T1 then Sunderland then T1 and out of project
150.440 98	5/26/2015	Holyoke Dam											released at Holyoke, recaptured only at T1
150.440 99	6/8/2015	Holyoke Dam											released at Holyoke, recaptured only at T1
150.540 100	5/26/2015	Holyoke Dam											released at Holyoke, recaptured only at T1
150.540 101	5/26/2015	Holyoke Dam											no recaptures
150.540 161	5/14/2015	Pauchaug Brook Boat Launch											no recaptures

150.540 162	5/14/2015	Pauchaug Brook Boat Launch											no recaptures
150.540 163	5/14/2015	Pauchaug Brook Boat Launch											no recaptures
150.540 164	5/14/2015	Pauchaug Brook Boat Launch											no recaptures
150.540 165	5/14/2015	Pauchaug Brook Boat Launch											no recaptures
150.540 176	5/10/2015	Pauchaug Brook Boat Launch											fish removed from analysis due to unreasonable pattern of strong detections
150.540 177	5/10/2015	Pauchaug Brook Boat Launch						complete			complete		Normandeau fish, migrated into Canal through Gatehouse, then through powerhouse with minimal delay at forebay
150.540 178	5/10/2015	Pauchaug Brook Boat Launch						complete			complete		Normandeau fish, migrated into Canal through Gatehouse, nosed into Station 1, delay at forebay before passing through powerhouse
150.540 179	5/10/2015	Pauchaug Brook Boat Launch						complete			complete		Normandeau fish, migrated into Canal through Gatehouse, then through powerhouse with minimal delay at forebay
150.540 180	5/10/2015	Pauchaug Brook Boat Launch						complete			complete		Normandeau fish, migrated into Canal through Gatehouse, then through powerhouse with delay at forebay
150.540 181	5/24/2015	Old Ferry Boat Ramp											no recaptures
150.540 182	5/24/2015	Old Ferry Boat Ramp						complete			complete		Normandeau fish, migrated into Canal through Gatehouse, then through powerhouse with significant delay at forebay
150.540 183	5/24/2015	Old Ferry Boat Ramp											no recaptures
150.540 184	5/24/2015	Old Ferry Boat Ramp						complete					Normandeau fish, migrated into Canal through Gatehouse, then hung out in Canal till end
150.540 185	5/24/2015	Old Ferry Boat Ramp						complete			complete		Normandeau fish, migrated into Canal through Gatehouse, then through powerhouse with significant delay at forebay
150.540 196	5/17/2015	Old Ferry Boat Ramp						complete			complete		Normandeau fish, migrated into Canal through Gatehouse, then through powerhouse with significant delay at forebay
150.540 197	5/17/2015	Old Ferry Boat Ramp											no recaptures
150.540 198	5/17/2015	Old Ferry Boat Ramp											no recaptures
150.540 199	5/17/2015	Old Ferry Boat Ramp											no recaptures
150.540 20	5/6/2015	Holyoke Dam		complete	complete								released at Holyoke, poked around bypass reach for a while before finding Spillway ladder, then pass via Gatehouse ladder and out of impoundment, did not come back
150.540 200	5/17/2015	Old Ferry Boat Ramp											no recaptures
150.540 201	5/30/2015	Old Ferry Boat Ramp											no recaptures
150.540 202	5/30/2015	Old Ferry Boat Ramp											Normandeau fish, only recaptured in TFI
150.540 203	5/30/2015	Old Ferry Boat Ramp											no recaptures
150.540 204	5/30/2015	Old Ferry Boat Ramp											no recaptures
150.540 205	5/30/2015	Old Ferry Boat Ramp				complete							Normandeau fish, pass downstream via bascule then hung out in bypass reach through end of survey
150.540 21	5/6/2015	Holyoke Dam	attempt										released at Holyoke, attempted Cabot ladder, failed then hung out in bypass reach
150.540 22	5/6/2015	Holyoke Dam	attempt										released at Holyoke, multiple attempts at Cabot ladder, all unsuccessfully, spent a lot of time in bypass reach until it out-migrated
150.540 23	5/6/2015	Holyoke Dam		attempt									released at Holyoke, multiple failed attempts at Spillway ladder, then migrated out of system
150.540 24	5/6/2015	Holyoke Dam											no recaptures
150.540 25	5/6/2015	Holyoke Dam	attempt										released at Holyoke, multiple failed attempts at Cabot ladder then migrated out of system
150.540 26	5/6/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
150.540 27	5/6/2015	Holyoke Dam											released at Holyoke, only recaptured at Sunderland and T1
150.540 28	5/6/2015	Holyoke Dam											no recaptures
150.540 29	5/6/2015	Holyoke Dam	attempt										released at Holyoke, multiple failed attempts at Cabot ladder, the migrated out of system
150.540 30	5/6/2015	Holyoke Dam											released at Holyoke, only recaptured at Sunderland and Montague
150.540 31	5/6/2015	Holyoke Dam	attempt										released at Holyoke, multiple failed attempts at Cabot ladder and hung out in bypass reach
150.540 32	5/6/2015	Holyoke Dam											no recaptures
150.540 33	5/6/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
150.540 34	5/6/2015	Holyoke Dam											no recaptures
150.540 35	5/6/2015	Holyoke Dam											no recaptures
150.540 36	5/12/2015	Holyoke Dam											no recaptures
150.540 37	5/12/2015	Holyoke Dam											no recaptures
150.540 38	5/12/2015	Holyoke Dam	attempt										released at Holyoke, attempted Cabot ladder, failed, swam up Deerfield, then outmigrated from study area
150.540 39	5/12/2015	Holyoke Dam	attempt										released at Holyoke, multiple failed attempts at Cabot ladder, then outmigrated from study areas
150.540 40	5/12/2015	Holyoke Dam											released at Holyoke, nosed into bypass reach then back out
150.540 41	5/12/2015	Holyoke Dam	attempt	complete									released at Holyoke, multiple failed attempts at Cabot ladder, no delay at Spillway or Gatehouse ladder, then up through TFI and out of project area, did not come back
150.540 42	5/12/2015	Holyoke Dam											no recaptures
150.540 43	5/12/2015	Holyoke Dam	attempt										released at Holyoke, multiple failed attempts at Cabot then bounced around bypass reach, then outmigrated from project area
150.540 44	5/12/2015	Holyoke Dam											released at Holyoke, bounced around bypass reach and back out
150.540 45	5/13/2015	Cabot Power Canal										complete	released at Cabot, did not migrate north through Canal, significant delay at forebay until it passed through downstream bypass
150.540 46	5/13/2015	Cabot Power Canal						attempt				complete	released at Cabot, attempted Gatehouse ladder, delay at forebay until fish passed via downstream bypass
150.540 47	5/13/2015	Cabot Power Canal										complete	released at Cabot, did not migrate north through Canal, delay at forebay until it passed via downstream bypass, then fish went up Deerfield before out-migrating
150.540 48	5/13/2015	Cabot Power Canal										complete	released at Cabot, did not migrate north through Canal, significant delay at forebay until it passed via downstream bypass, then outmigrated
150.540 49	5/13/2015	Cabot Power Canal			complete								released at Cabot, hung out for a while before migrating up through Gatehouse, hung out in TFI till end of survey
150.540 50	5/15/2015	TF Impoundment						complete			complete		released in TFI, passed into Canal through Gatehouse, then passed through powerhouse with minimal delay at forebay
150.540 51	5/15/2015	TF Impoundment						complete				complete	released in TFI, passed into Canal through Gatehouse, then passed through downstream bypass after significant delay at forebay
150.540 52	5/15/2015	TF Impoundment						complete			complete		released in TFI, passed into Canal through Gatehouse, then passed though powerhouse after delay at forebay
150.540 53	5/16/2015	TF Impoundment						complete				complete	released in TFI, passed into Canal through Gatehouse, then passed through downstream bypass after significant delay at forebay
150.540 54	5/15/2015	TF Impoundment											released in TFI, migrated north and never came back
150.540 55	5/16/2015	TF Impoundment						complete			complete		released in TFI, passed into Canal through Gatehouse, then passed though powerhouse, no real delay at forebay
150.540 56	5/16/2015	TF Impoundment				complete							released in TFI, passed via spill (bascule?) into bypass reach
150.540 57	5/16/2015	TF Impoundment											released in TFI, never escaped
150.540 58	5/16/2015	TF Impoundment				complete							released in TFI, passed downstream via spill (bascule?) into bypass reach then outmigrated from project
150.540 59	5/16/2015	TF Impoundment											released in TFI, outmigrated north from project did not come back
150.540 60	5/16/2015	TF Impoundment	attempt					complete			complete		released in TFI, passed downstream into Canal via Gatehouse, passed through powerhouse after minimal delay at forebay, then it tried to get back up into Canal at Cabot but failed before it outmigrated from project

150.540 61	5/15/2015	TF Impoundment						complete			complete		released in TFI, passed downstream into Canal via Gatehouse, then through powerhouse after minimal delay at forebay
150.540 62	5/16/2015	TF Impoundment				complete?							released in TFI, assumed pass via spill (bascule?) fish recaptured in bypass
150.540 63	5/15/2015	TF Impoundment				complete?							released in TFI, assumed pass via spill (bascule?) fish escaped to Deerfield and never came back
150.540 64	5/15/2015	TF Impoundment				complete							released in TFI, passed downstream via spill, bounced around bypass reach
150.540 65	5/15/2015	TF Impoundment						complete					released in TFI, passed into Canal via Gatehouse, looks like it died in Canal and got hung up at T14
150.540 66	5/19/2015	Cabot Power Canal										complete	released in Cabot, sparse history but detected at downstream bypass
150.540 67	5/19/2015	Cabot Power Canal										complete	released in Cabot, did not migrate north through Canal, found downstream bypass after delay at forebay, then outmigrated through study area
150.540 68	5/19/2015	Cabot Power Canal									complete		released in Cabot, did not migrate north through Canal, eventually passed via powerhouse after significant delay at forebay
150.540 69	5/19/2015	Cabot Power Canal											released in Cabot, did not migrate at all, probably dead
150.540 70	5/19/2015	Cabot Power Canal										complete	released in Cabot, did not migrate north through Canal, eventually passed via downstream bypass after significant delay at forebay
150.540 71	5/19/2015	Cabot Power Canal									complete		released in Cabot, nosed into Station 1 forebay, back downstream and pass through powerhouse after significant delay at forebay
150.540 72	5/19/2015	Cabot Power Canal										complete	released in Cabot, did not migrate north through Canal, eventually passed via downstream bypass after significant delay at forebay
150.540 73	5/19/2015	Holyoke Dam											no recaptures
150.540 74	5/19/2015	Holyoke Dam											no recaptures
150.540 75	5/19/2015	Holyoke Dam											released at Holyoke, nosed up into bypass reach and over into Deerfield, eventually came back out
150.540 76	5/19/2015	Holyoke Dam	attempt										released at Holyoke, failed attempt at Cabot ladder, bounced around bypass after that before out-migrating from project
150.540 77	5/19/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
150.540 78	5/19/2015	Holyoke Dam											no recaptures
150.540 79	5/19/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
150.540 80	5/19/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
150.540 81	5/19/2015	Holyoke Dam	attempt										released at Holyoke, only recaptured at entrance to Cabot ladder, no where else, looks funny
150.540 82	5/22/2015	TF Impoundment											released in TFI, migrated north and never came back
150.540 83	5/22/2015	TF Impoundment											released in TFI, only recaptured at T23
150.540 84	5/22/2015	TF Impoundment						complete			complete		released in TFI, passed into Canal through Gatehouse, passed through powerhouse with minimal delay at forebay
150.540 85	5/22/2015	TF Impoundment											released in TFI, hung out in front of intake for remainder of study
150.540 86	5/22/2015	TF Impoundment											released in TFI, did not migrate out
150.540 87	5/22/2015	TF Impoundment						complete					released in TFI, passed into Canal through Gatehouse, did not get out of Canal
150.540 88	5/22/2015	TF Impoundment				complete							released in TFI, passed via spill, looks like it's dead between T20 / T19
150.540 89	5/23/2015	TF Impoundment											released in TFI, migrated north and never came back
150.540 90	5/23/2015	TF Impoundment											released in TFI, only recaptured at T23
150.540 91	5/23/2015	TF Impoundment						complete					released in TFI, passed into Canal through Gatehouse, never escaped forebay
150.540 92	5/23/2015	TF Impoundment				complete							released in TFI, passed into bypass via spill, outmigrated through project
150.540 93	5/23/2015	TF Impoundment						complete			complete		released in TFI, passed into Canal through Gatehouse after minimal delay at forebay, then bounced around bypass for a while before out-migrating
150.540 94	5/23/2015	TF Impoundment				complete?							released in TFI, got into bypass reach, assume via bascule gate (T20)
150.540 95	5/23/2015	TF Impoundment											released in TFI, never escaped
150.540 96	5/23/2015	TF Impoundment						complete					released in TFI, passed into Canal via Gatehouse, turned into Station 1 forebay and hung out there for remainder of study
150.540 97	5/26/2015	Holyoke Dam											released at Holyoke, only recaptured at T1
150.540 98	5/26/2015	Holyoke Dam											released at Holyoke, only recaptured at T1 and Sunderland before out-migrating
150.540 99	6/8/2015	Holyoke Dam											no recaptures

APPENDIX C - MOBILE TRACKING MATRIX

Fish ID	Release Site	Release Date	Mobile Tracking Zone Detections Upstream Migration					Mobile Tracking Zone Detections Downstream Migration					Final Recapture Date	Final Detection Zone	Time in Study Area (days)	Fate
			1	2	Route through Project (DNP - Did Not Pass)	3	4	4	3	Route through Project (DNP - Did Not Pass)	2	1				
149.720 162	Pauchaug Brook Boat Launch	5/10/2015			DNP					Bascule Gate		6/25/2015	6/25/2015	1	46	Died in Study Area
149.720 166	Pauchaug Brook Boat Launch	5/14/2015			DNP					Bascule Gate	7/6/2015		7/6/2015	2	54	Died in Study Area
149.720 167	Pauchaug Brook Boat Launch	5/14/2015			DNP					Gatehouse/Cabot Powerhouse		6/29/2015	6/29/2015	1	46	Died in Study Area
149.720 169	Pauchaug Brook Boat Launch	5/14/2015			DNP			6/3/2015		Gatehouse/Downstream Bypass			6/3/2015	4	21	Left Study Area
149.720 170	Pauchaug Brook Boat Launch	5/14/2015			DNP		5/21/2015		6/3/2015	Gatehouse/Cabot Powerhouse			6/3/2015	3	21	Left Study Area
149.720 171	Pauchaug Brook Boat Launch	5/28/2015			DNP					Gatehouse/Cabot Powerhouse		6/18/2015	6/18/2015	1	21	Died in Study Area
149.720 173	Pauchaug Brook Boat Launch	5/28/2015			DNP					Gatehouse/Cabot Ladder	6/29/2015		6/29/2015	2	32	Left Study Area
149.720 175	Pauchaug Brook Boat Launch	5/28/2015			DNP					Gatehouse/Downstream Bypass	7/6/2015		7/6/2015	2	40	Died in Study Area
149.720 182	Old Ferry Boat Ramp	5/17/2015			DNP			6/3/2015		DNP			6/3/2015	4	18	Died in Study Area
149.720 184	Old Ferry Boat Ramp	5/17/2015			DNP				6/17/2015	DNP			6/17/2015	3	31	Died in Study Area
149.720 191	Old Ferry Boat Ramp	5/24/2015			DNP			7/6/2015		DNP			7/6/2015	4	44	Died in Study Area
149.720 24	Holyoke Dam	5/6/2015			DNP					DNP	5/20/2015	5/27/2015	5/27/2015	1	21	Left Study Area
149.720 26	Holyoke Dam	5/6/2015			DNP					DNP		6/3/2015	6/29/2015	1	55	Died in Study Area
149.720 27	Holyoke Dam	5/6/2015		6/3/2015	DNP					DNP			7/6/2015	2	62	Died in Study Area
149.720 30	Holyoke Dam	5/6/2015		6/4/2015	DNP					DNP			6/4/2015	2	30	Left Study Area
149.720 32	Holyoke Dam	5/6/2015			Spillway Ladder/Gatehouse Ladder	6/9/2015				DNP			7/6/2015	3	61	Died in Study Area
149.720 33	Holyoke Dam	5/6/2015			Spillway Ladder/Gatehouse Ladder				6/3/2015	Gatehouse/Cabot Powerhouse			6/3/2015	3	29	Left Study Area
149.720 36	Holyoke Dam	5/12/2015	5/20/2015		DNP					DNP	6/4/2015		6/4/2015	2	24	Left Study Area
149.720 38	Holyoke Dam	5/12/2015			DNP					DNP		6/18/2015	6/18/2015	1	37	Left Study Area
149.720 39	Holyoke Dam	5/12/2015			DNP					DNP		6/18/2015	6/18/2015	1	38	Died in Study Area
149.720 41	Holyoke Dam	5/12/2015	5/20/2015	5/27/2015	DNP					DNP			5/27/2015	2	16	Left Study Area
149.720 42	Holyoke Dam	5/12/2015			DNP					DNP		6/10/2015	6/10/2015	1	30	Died in Study Area
149.720 47	Cabot Power Canal	5/13/2015			DNP					Cabot Powerhouse		6/10/2015	6/10/2015	1	29	Left Study Area
149.720 49	Cabot Power Canal	5/13/2015			DNP					Downstream Bypass		5/27/2015	6/29/2015	1	48	Died in Study Area
149.720 50	TF Impoundment	5/15/2015			DNP					Gatehouse/Cabot Powerhouse		6/11/2015	6/11/2015	1	28	Died in Study Area
149.720 51	TF Impoundment	5/15/2015			DNP			6/30/2015		DNP			6/30/2015	4	46	Died in Study Area
149.720 52	TF Impoundment	5/15/2015			DNP					Gatehouse/Cabot Powerhouse		6/3/2015	6/29/2015	1	46	Died in Study Area
149.720 54	TF Impoundment	5/15/2015			DNP			6/3/2015	6/9/2015	Gatehouse/Cabot Powerhouse	6/16/2015		7/6/2015	2	53	Died in Study Area
149.720 55	TF Impoundment	5/15/2015			DNP				6/3/2015	DNP			6/30/2015	3	46	Died in Study Area
149.720 56	TF Impoundment	5/15/2015			DNP					Gatehouse/Cabot Powerhouse	6/29/2015		6/29/2015	2	46	Died in Study Area
149.720 57	TF Impoundment	5/15/2015			DNP					Gatehouse/Downstream Bypass	5/29/2015	6/18/2015	6/18/2015	1	35	Died in Study Area
149.720 59	TF Impoundment	5/15/2015			DNP					Bascule Gate		5/27/2015	6/25/2015	1	42	Died in Study Area
149.720 64	TF Impoundment	5/16/2015			DNP					Gatehouse/Downstream Bypass	6/18/2015		6/18/2015	2	34	Died in Study Area
149.720 65	TF Impoundment	5/16/2015			DNP					Bascule Gate	6/3/2015		6/3/2015	2	19	Died in Study Area
149.720 66	TF Impoundment	5/16/2015			DNP					Gatehouse/Downstream Bypass		5/20/2015	6/18/2015	1	34	Died in Study Area
149.720 69	Cabot Power Canal	5/19/2015			DNP					Downstream Bypass	6/3/2015		6/3/2015	2	16	Died in Study Area
149.720 70	Cabot Power Canal	5/19/2015			DNP					Downstream Bypass		6/3/2015	6/18/2015	1	30	Died in Study Area
149.720 71	Cabot Power Canal	5/19/2015			DNP					Downstream Bypass	6/22/2015		7/6/2015	2	49	Died in Study Area
149.720 75	Holyoke Dam	5/19/2015		5/29/2015	DNP					DNP			5/29/2015	2	10	Left Study Area
149.720 79	Holyoke Dam	5/19/2015	5/20/2015	6/3/2015	DNP					DNP			6/10/2015	2	22	Left Study Area
149.720 80	Holyoke Dam	5/19/2015			DNP					DNP		6/25/2015	6/25/2015	1	38	Left Study Area
149.720 81	Holyoke Dam	5/19/2015	6/4/2015		DNP					DNP		6/11/2015	6/11/2015	1	23	Left Study Area
149.720 82	Holyoke Dam	5/19/2015	5/27/2015		DNP					DNP			5/27/2015	1	8	Left Study Area
149.720 83	Holyoke Dam	5/19/2015	5/27/2015		DNP					DNP			5/27/2015	1	8	Left Study Area
149.720 84	TF Impoundment	5/22/2015			DNP				6/24/2015	DNP			6/30/2015	3	39	Left Study Area
149.720 85	TF Impoundment	5/22/2015			DNP		6/3/2015			Bascule Gate		6/10/2015	6/18/2015	1	27	Died in Study Area
149.720 86	TF Impoundment	5/22/2015			DNP				6/17/2015	DNP			6/17/2015	3	26	Died in Study Area
149.720 87	TF Impoundment	5/22/2015			DNP			6/9/2015		Gatehouse/Cabot Powerhouse		6/18/2015	6/18/2015	1	27	Died in Study Area
149.720 88	TF Impoundment	5/22/2015			DNP			6/3/2015		Gatehouse/Cabot Powerhouse		7/7/2015	7/7/2015	1	47	Died in Study Area
149.720 90	TF Impoundment	5/22/2015			DNP					Bascule Gate		5/27/2015	5/27/2015	1	5	Left Study Area
149.720 91	TF Impoundment	5/23/2015			DNP	6/3/2015				DNP			6/9/2015	3	17	Died in Study Area
149.720 93	TF Impoundment	5/23/2015			DNP	6/3/2015				DNP			7/6/2015	3	44	Died in Study Area
149.720 96	TF Impoundment	5/23/2015			DNP	6/24/2015				DNP			6/24/2015	3	32	Died in Study Area
149.720 99	TF Impoundment	5/23/2015			DNP	6/3/2015				Bascule Gate			6/3/2015	3	12	Left Study Area
149.780 20	Holyoke Dam	5/6/2015	5/20/2015	6/3/2015	DNP					DNP			7/6/2015	2	62	Remained in the Study Area
149.780 22	Holyoke Dam	5/6/2015		5/20/2015	DNP					DNP			6/29/2015	2	55	Died in Study Area
149.780 23	Holyoke Dam	5/6/2015			DNP					DNP		6/16/2015	7/7/2015	1	63	Died in Study Area
149.780 26	Holyoke Dam	5/6/2015			Spillway Ladder/Gatehouse Ladder		6/3/2015			Gatehouse/Downstream Bypass		6/25/2015	6/25/2015	1	50	Left Study Area
149.780 29	Holyoke Dam	5/6/2015			DNP					DNP		7/7/2015	7/7/2015	1	63	Died in Study Area
149.780 31	Holyoke Dam	5/12/2015	5/27/2015		DNP					DNP			5/27/2015	1	15	Left Study Area
149.780 34	Holyoke Dam	5/12/2015			Cabot Ladder/Gatehouse Ladder					Bascule Gate	6/11/2015		6/11/2015	2	31	Died in Study Area
149.780 36	Holyoke Dam	5/12/2015		5/27/2015	DNP					DNP	6/10/2015		6/10/2015	2	29	Left Study Area
149.780 37	Holyoke Dam	5/12/2015			DNP					DNP	7/7/2015		7/7/2015	2	56	Died in Study Area
149.780 40	Cabot Power Canal	5/13/2015			DNP					Cabot Powerhouse	6/22/2015		6/22/2015	2	41	Died in Study Area
149.780 42	Cabot Power Canal	5/13/2015			Gatehouse Ladder					Gatehouse/Cabot Powerhouse	6/10/2015		6/10/2015	2	29	Died in Study Area
149.780 65	Holyoke Dam	5/19/2015	5/20/2015	5/27/2015	DNP					DNP		6/25/2015	6/25/2015	1	38	Died in Study Area

149.780 66	Holyoke Dam	5/19/2015		5/27/2015	DNP					DNP		7/7/2015	7/7/2015	1	50	Left Study Area
149.780 70	Holyoke Dam	5/19/2015			DNP					DNP		6/4/2015	6/25/2015	1	38	Died in Study Area
149.780 72	Holyoke Dam	5/19/2015		5/29/2015	DNP					DNP		6/18/2015	6/25/2015	1	38	Died in Study Area
149.780 77	TF Impoundment	5/22/2015			DNP				6/17/2015	DNP			6/24/2015	3	33	Died in Study Area
149.780 79	Holyoke Dam	5/26/2015	5/27/2015		DNP					DNP			5/27/2015	1	1	Left Study Area
149.780 81	Holyoke Dam	5/26/2015		5/29/2015	DNP					DNP		6/29/2015	7/7/2015	1	43	Left Study Area
149.780 84	Holyoke Dam	6/8/2015			DNP					DNP		6/29/2015	6/29/2015	1	22	Died in Study Area
149.780 86	Holyoke Dam	6/8/2015			DNP					DNP		6/29/2015	6/29/2015	1	22	Died in Study Area
149.800 101	Holyoke Dam	5/26/2015			DNP					DNP	7/7/2015		7/7/2015	2	42	Died in Study Area
149.800 161	Old Ferry Boat Ramp	5/30/2015			DNP			7/6/2015		DNP			7/6/2015	4	38	Died in Study Area
149.800 163	Old Ferry Boat Ramp	5/24/2015			DNP					Gatehouse/Cabot Powerhouse		6/25/2015	6/25/2015	1	32	Left Study Area
149.800 166	Pauchaug Brook Boat Launch	5/10/2015			DNP					Gatehouse/Cabot Powerhouse		6/18/2015	6/18/2015	1	39	Died in Study Area
149.800 167	Pauchaug Brook Boat Launch	5/10/2015			DNP					Gatehouse/Cabot Powerhouse		6/16/2015	6/29/2015	1	51	Died in Study Area
149.800 168	Pauchaug Brook Boat Launch	5/10/2015			DNP					Gatehouse/Cabot Powerhouse	7/7/2015		7/7/2015	2	58	Died in Study Area
149.800 170	Pauchaug Brook Boat Launch	5/10/2015			DNP			6/3/2015		Gatehouse			6/3/2015	4	25	Remained in the Study Area
149.800 172	Pauchaug Brook Boat Launch	5/14/2015			DNP				6/30/2015	DNP			6/30/2015	3	47	Died in Study Area
149.800 173	Pauchaug Brook Boat Launch	5/14/2015			DNP			6/9/2015		DNP			6/9/2015	4	27	Died in Study Area
149.800 176	Pauchaug Brook Boat Launch	5/28/2015			DNP					Bascule Gate		6/4/2015	6/25/2015	1	29	Died in Study Area
149.800 177	Pauchaug Brook Boat Launch	5/28/2015			DNP					Gatehouse/Cabot Powerhouse	6/18/2015		6/18/2015	2	22	Died in Study Area
149.800 178	Pauchaug Brook Boat Launch	5/28/2015			DNP					Gatehouse/Downstream Bypass		6/18/2015	6/18/2015	1	21	Died in Study Area
149.800 180	Pauchaug Brook Boat Launch	5/28/2015			DNP			6/9/2015		Gatehouse			6/9/2015	4	13	Died in Study Area
149.800 189	Old Ferry Boat Ramp	5/17/2015			DNP					Gatehouse/Cabot Powerhouse		6/3/2015	6/10/2015	1	24	Died in Study Area
149.800 192	Old Ferry Boat Ramp	5/24/2015			DNP					Gatehouse/Cabot Powerhouse		6/10/2015	6/10/2015	1	18	Died in Study Area
149.800 195	Old Ferry Boat Ramp	5/24/2015			DNP					Gatehouse/Cabot Powerhouse	7/6/2015		7/6/2015	2	44	Died in Study Area
149.800 20	Holyoke Dam	5/6/2015			DNP					DNP		6/25/2015	6/25/2015	1	50	Died in Study Area
149.800 23	Holyoke Dam	5/6/2015			DNP					DNP		6/3/2015	6/3/2015	1	29	Left Study Area
149.800 24	Holyoke Dam	5/6/2015	5/20/2015		DNP					DNP			5/27/2015	1	21	Left Study Area
149.800 28	Holyoke Dam	5/6/2015			DNP					DNP		6/18/2015	6/18/2015	1	44	Died in Study Area
149.800 32	Holyoke Dam	5/6/2015			DNP					DNP		5/27/2015	5/27/2015	1	21	Left Study Area
149.800 34	Holyoke Dam	5/6/2015			DNP					DNP		5/20/2015	5/20/2015	1	14	Left Study Area
149.800 35	Holyoke Dam	5/12/2015			DNP					DNP		6/25/2015	6/25/2015	1	45	Died in Study Area
149.800 38	Holyoke Dam	5/12/2015			DNP					DNP		5/20/2015	5/20/2015	1	9	Left Study Area
149.800 41	Holyoke Dam	5/12/2015	5/27/2015		DNP					DNP			5/27/2015	1	15	Left Study Area
149.800 42	Holyoke Dam	5/12/2015			DNP					DNP	5/28/2015	6/10/2015	6/10/2015	1	30	Left Study Area
149.800 43	Holyoke Dam	5/12/2015	5/20/2015		Cabot Ladder/Gatehouse Ladder					Bascule Gate			5/20/2015	1	8	Left Study Area
149.800 45	Cabot Power Canal	5/13/2015			Cabot Ladder					Downstream Bypass		5/27/2015	5/27/2015	1	14	Died in Study Area
149.800 47	Cabot Power Canal	5/13/2015			Gatehouse Ladder		6/3/2015			Gatehouse/Cabot Powerhouse	6/29/2015		6/29/2015	2	47	Left Study Area
149.800 49	Cabot Power Canal	5/13/2015			DNP					Downstream Bypass		5/20/2015	5/20/2015	1	8	Left Study Area
149.800 51	TF Impoundment	5/15/2015			DNP		5/21/2015			Gatehouse/Cabot Powerhouse	7/7/2015		7/7/2015	2	53	Died in Study Area
149.800 52	TF Impoundment	5/15/2015			DNP				6/24/2015	DNP			6/30/2015	3	46	Died in Study Area
149.800 55	TF Impoundment	5/16/2015			DNP					Unknown	6/3/2015		6/3/2015	2	19	Left Study Area
149.800 57	TF Impoundment	5/15/2015			DNP				6/24/2015	DNP			6/24/2015	3	40	Died in Study Area
149.800 58	TF Impoundment	5/15/2015			DNP			6/3/2015	6/24/2015	DNP			6/24/2015	3	40	Died in Study Area
149.800 59	TF Impoundment	5/16/2015			DNP					Gatehouse/Downstream Bypass		6/3/2015	6/29/2015	1	45	Died in Study Area
149.800 60	TF Impoundment	5/16/2015			DNP			6/9/2015		DNP			6/9/2015	4	25	Left Study Area
149.800 61	TF Impoundment	5/16/2015			DNP					Gatehouse/Cabot Powerhouse	6/18/2015		6/23/2015	2	38	Died in Study Area
149.800 63	TF Impoundment	5/16/2015			DNP	5/21/2015		6/30/2015		DNP			7/6/2015	4	52	Died in Study Area
149.800 65	TF Impoundment	5/16/2015			DNP					Bascule Gate		7/7/2015	7/7/2015	1	53	Died in Study Area
149.800 69	Cabot Power Canal	5/19/2015			DNP					DNP		6/16/2015	6/16/2015	1	29	Died in Study Area
149.800 70	Cabot Power Canal	5/19/2015			DNP					Downstream Bypass	6/3/2015	6/10/2015	6/10/2015	1	23	Left Study Area
149.800 72	Holyoke Dam	5/19/2015		5/27/2015	DNP					DNP			5/27/2015	2	9	Left Study Area
149.800 80	Holyoke Dam	5/19/2015			DNP					DNP	6/11/2015		6/11/2015	2	23	Left Study Area
149.800 81	Holyoke Dam	5/19/2015			DNP					DNP		6/3/2015	6/3/2015	1	16	Left Study Area
149.800 83	TF Impoundment	5/22/2015			Gatehouse Ladder				6/24/2015	Gatehouse Ladder			6/30/2015	3	39	Died in Study Area
149.800 84	TF Impoundment	5/22/2015			DNP					Bascule Gate		6/4/2015	7/6/2015	1	46	Remained in the Study Area
149.800 85	TF Impoundment	5/22/2015			DNP					Gatehouse/Cabot Powerhouse	6/16/2015		7/7/2015	2	46	Remained in the Study Area
149.800 86	TF Impoundment	5/22/2015			DNP				6/24/2015	DNP			6/24/2015	3	33	Died in Study Area
149.800 88	TF Impoundment	5/23/2015			DNP					Spillway Ladder	6/11/2015		7/6/2015	2	45	Died in Study Area
149.800 89	TF Impoundment	5/23/2015			DNP					Unknown		6/10/2015	6/10/2015	1	19	Left Study Area
149.800 91	TF Impoundment	5/23/2015			DNP	5/28/2015				Gatehouse/Cabot Powerhouse		7/7/2015	7/7/2015	1	46	Died in Study Area
149.800 92	TF Impoundment	5/23/2015			DNP		5/28/2015			Gatehouse/Cabot Powerhouse		6/16/2015	6/16/2015	1	25	Left Study Area
149.800 93	TF Impoundment	5/23/2015			DNP					Bascule Gate		6/10/2015	6/25/2015	1	34	Died in Study Area
149.800 99	Holyoke Dam	5/26/2015	5/27/2015		DNP					DNP		6/25/2015	6/25/2015	1	30	Died in Study Area
150.440 100	Holyoke Dam	5/26/2015	5/27/2015		DNP					DNP			6/3/2015	1	9	Left Study Area
150.440 102	Holyoke Dam	5/26/2015	5/27/2015		DNP					DNP			5/27/2015	1	1	Left Study Area
150.440 167	Pauchaug Brook Boat Launch	5/24/2015			DNP				6/30/2015	DNP			6/30/2015	3	37	Died in Study Area
150.440 171	Pauchaug Brook Boat Launch	5/10/2015			DNP			6/3/2015		DNP			7/6/2015	4	58	Died in Study Area
150.440 172	Pauchaug Brook Boat Launch	5/10/2015			DNP		5/21/2015			Gatehouse/Downstream Bypass			5/21/2015	4	12	Left Study Area

150.440 175	Pauchaug Brook Boat Launch	5/10/2015			DNP			6/30/2015		DNP			6/30/2015	4	51	Died in Study Area
150.440 191	Old Ferry Boat Ramp	5/17/2015			DNP			6/30/2015		DNP			6/30/2015	4	44	Died in Study Area
150.440 198	Old Ferry Boat Ramp	5/24/2015			DNP					Bascule Gate	6/29/2015		6/29/2015	2	36	Died in Study Area
150.440 200	Old Ferry Boat Ramp	5/24/2015			DNP					Gatehouse/Cabot Powerhouse	7/6/2015		7/6/2015	2	44	Died in Study Area
150.440 202	Old Ferry Boat Ramp	5/30/2015			DNP					Gatehouse/Cabot Powerhouse	6/22/2015		6/22/2015	2	24	Died in Study Area
150.440 21	Holyoke Dam	5/6/2015			DNP					DNP		5/27/2015	5/27/2015	1	21	Left Study Area
150.440 25	Holyoke Dam	5/6/2015		5/20/2015	DNP					DNP			5/27/2015	2	22	Left Study Area
150.440 29	Holyoke Dam	5/6/2015			DNP					DNP	6/4/2015		6/4/2015	2	30	Left Study Area
150.440 30	Holyoke Dam	5/6/2015		5/20/2015	DNP					DNP			5/20/2015	2	15	Left Study Area
150.440 38	Holyoke Dam	5/12/2015	5/20/2015		DNP					DNP			5/20/2015	1	9	Left Study Area
150.440 39	Holyoke Dam	5/12/2015		5/27/2015	DNP					DNP			5/27/2015	2	16	Left Study Area
150.440 48	Cabot Power Canal	5/13/2015			DNP					Downstream Bypass	6/22/2015		6/22/2015	2	41	Died in Study Area
150.440 50	Cabot Power Canal	5/13/2015			DNP					Cabot Powerhouse	6/10/2015	6/10/2015	7/7/2015	1	56	Remained in the Study Area
150.440 52	TF Impoundment	5/15/2015			DNP				6/3/2015	DNP			6/24/2015	3	40	Left Study Area
150.440 55	TF Impoundment	5/15/2015			DNP					Bascule Gate	6/22/2015		6/22/2015	2	39	Died in Study Area
150.440 56	TF Impoundment	5/15/2015			DNP					Gatehouse/Downstream Bypass		6/29/2015	6/29/2015	1	46	Died in Study Area
150.440 58	TF Impoundment	5/16/2015			DNP			6/3/2015		Gatehouse			6/3/2015	4	19	Left Study Area
150.440 59	TF Impoundment	5/15/2015			DNP	5/28/2015				Bascule Gate			5/28/2015	3	14	Left Study Area
150.440 61	TF Impoundment	5/16/2015			DNP		5/21/2015			DNP			5/21/2015	4	6	Left Study Area
150.440 62	TF Impoundment	5/16/2015			DNP					Gatehouse/Cabot Powerhouse	6/16/2015		6/22/2015	2	38	Died in Study Area
150.440 63	TF Impoundment	5/16/2015			DNP					Gatehouse/Cabot Powerhouse		6/18/2015	6/18/2015	1	33	Died in Study Area
150.440 67	Cabot Power Canal	5/19/2015			DNP					Cabot Powerhouse	6/22/2015		6/22/2015	2	35	Died in Study Area
150.440 68	Cabot Power Canal	5/19/2015			DNP					Downstream Bypass		5/27/2015	5/27/2015	1	8	Left Study Area
150.440 69	Cabot Power Canal	5/19/2015			DNP					Cabot Powerhouse	6/22/2015		6/22/2015	2	35	Died in Study Area
150.440 70	Cabot Power Canal	5/19/2015			DNP					Cabot Powerhouse		6/25/2015	7/7/2015	1	50	Remained in the Study Area
150.440 71	Cabot Power Canal	5/19/2015			DNP					Cabot Powerhouse	6/3/2015		6/9/2015	2	22	Died in Study Area
150.440 73	Holyoke Dam	5/19/2015		6/3/2015	DNP					DNP			6/3/2015	2	16	Left Study Area
150.440 82	TF Impoundment	5/22/2015			DNP	6/3/2015				Gatehouse/Cabot Powerhouse		6/25/2015	6/25/2015	1	34	Died in Study Area
150.440 84	TF Impoundment	5/22/2015			DNP					Bascule Gate	6/3/2015	6/10/2015	7/6/2015	1	46	Died in Study Area
150.440 85	TF Impoundment	5/22/2015			DNP	6/3/2015				DNP			6/3/2015	3	13	Left Study Area
150.440 87	TF Impoundment	5/22/2015			DNP					Gatehouse/Cabot Powerhouse	6/3/2015	6/10/2015	6/25/2015	1	35	Died in Study Area
150.440 88	TF Impoundment	5/22/2015			DNP		5/28/2015			Gatehouse/Cabot Powerhouse			6/3/2015	4	13	Left Study Area
150.440 89	TF Impoundment	5/23/2015			DNP		6/9/2015			DNP			6/30/2015	4	38	Died in Study Area
150.440 90	TF Impoundment	5/23/2015			DNP					Gatehouse/Cabot Powerhouse	7/7/2015		7/7/2015	2	45	Died in Study Area
150.440 91	TF Impoundment	5/23/2015			DNP				6/30/2015	DNP			6/30/2015	3	38	Died in Study Area
150.440 93	TF Impoundment	5/23/2015			DNP					Gatehouse/Downstream Bypass		6/18/2015	6/25/2015	1	33	Died in Study Area
150.440 97	Holyoke Dam	5/26/2015	5/27/2015		DNP					DNP	6/10/2015		6/10/2015	2	15	Left Study Area
150.540 176	Pauchaug Brook Boat Launch	5/10/2015			DNP			6/3/2015		DNP			6/3/2015	4	25	Left Study Area
150.540 177	Pauchaug Brook Boat Launch	5/10/2015			DNP					Gatehouse/Cabot Powerhouse	7/7/2015		7/7/2015	2	58	Died in Study Area
150.540 178	Pauchaug Brook Boat Launch	5/10/2015			DNP			6/3/2015		Gatehouse/Cabot Powerhouse	6/18/2015		6/29/2015	2	51	Died in Study Area
150.540 179	Pauchaug Brook Boat Launch	5/10/2015			DNP					Gatehouse/Cabot Powerhouse	6/18/2015		6/22/2015	2	44	Died in Study Area
150.540 180	Pauchaug Brook Boat Launch	5/10/2015			DNP					Gatehouse/Cabot Powerhouse		6/16/2015	6/16/2015	1	38	Died in Study Area
150.540 182	Old Ferry Boat Ramp	5/24/2015			DNP					Gatehouse/Cabot Powerhouse	6/29/2015		7/7/2015	2	44	Died in Study Area
150.540 196	Old Ferry Boat Ramp	5/17/2015			DNP					Gatehouse/Cabot Powerhouse	6/16/2015		7/6/2015	2	51	Died in Study Area
150.540 201	Old Ferry Boat Ramp	5/30/2015			DNP			6/30/2015		DNP			6/30/2015	4	31	Died in Study Area
150.540 205	Old Ferry Boat Ramp	5/30/2015			DNP					Bascule Gate	6/3/2015		7/6/2015	2	38	Died in Study Area
150.540 21	Holyoke Dam	5/6/2015			DNP					DNP	5/27/2015		5/27/2015	2	21	Left Study Area
150.540 22	Holyoke Dam	5/6/2015			DNP					DNP	6/18/2015		6/18/2015	2	44	Left Study Area
150.540 27	Holyoke Dam	5/6/2015	5/20/2015		DNP					DNP			5/20/2015	1	14	Left Study Area
150.540 31	Holyoke Dam	5/6/2015		5/20/2015	DNP					DNP	6/16/2015		6/16/2015	2	42	Left Study Area
150.540 32	Holyoke Dam	5/6/2015		5/20/2015	DNP					DNP			5/20/2015	2	15	Left Study Area
150.540 38	Holyoke Dam	5/12/2015	5/20/2015	5/27/2015	DNP					DNP			5/27/2015	2	16	Left Study Area
150.540 40	Holyoke Dam	5/12/2015			DNP					DNP	6/16/2015		6/16/2015	2	36	Left Study Area
150.540 41	Holyoke Dam	5/12/2015			Spillway Ladder/Gatehouse Ladder		6/9/2015	7/6/2015		DNP			7/6/2015	4	56	Died in Study Area
150.540 43	Holyoke Dam	5/12/2015			DNP					DNP	6/4/2015		6/4/2015	2	24	Left Study Area
150.540 44	Holyoke Dam	5/12/2015			DNP					DNP		6/10/2015	7/7/2015	1	57	Died in Study Area
150.540 45	Cabot Power Canal	5/13/2015			DNP					Downstream Bypass		6/16/2015	6/25/2015	1	44	Died in Study Area
150.540 46	Cabot Power Canal	5/13/2015			DNP					Downstream Bypass	6/22/2015		7/7/2015	2	55	Died in Study Area
150.540 47	Cabot Power Canal	5/13/2015			DNP					Downstream Bypass		7/7/2015	7/7/2015	1	56	Died in Study Area
150.540 48	Cabot Power Canal	5/13/2015			DNP					Downstream Bypass	5/29/2015		5/29/2015	2	16	Left Study Area
150.540 49	Cabot Power Canal	5/13/2015			Gatehouse Ladder				6/24/2015	DNP			7/6/2015	3	54	Died in Study Area
150.540 52	TF Impoundment	5/15/2015			DNP					Gatehouse/Cabot Powerhouse	5/29/2015		6/22/2015	2	39	Died in Study Area
150.540 54	TF Impoundment	5/15/2015			DNP			6/9/2015		DNP			7/6/2015	4	53	Left Study Area
150.540 56	TF Impoundment	5/16/2015			DNP					Bascule Gate	7/7/2015		7/7/2015	2	52	Died in Study Area
150.540 57	TF Impoundment	5/16/2015			DNP			6/9/2015		DNP			6/9/2015	4	25	Died in Study Area
150.540 58	TF Impoundment	5/16/2015			DNP					Bascule Gate		5/27/2015	5/27/2015	1	11	Left Study Area
150.540 60	TF Impoundment	5/16/2015			DNP			6/3/2015		Gatehouse/Cabot Powerhouse			6/3/2015	4	19	Left Study Area
150.540 61	TF Impoundment	5/15/2015			DNP				6/3/2015	Gatehouse/Cabot Powerhouse			6/3/2015	3	20	Left Study Area
150.540 62	TF Impoundment	5/16/2015			DNP					Bascule Gate	6/3/2015		6/16/2015	2	32	Died in Study Area
150.540 63	TF Impoundment	5/15/2015			DNP					Bascule Gate	6/22/2015		6/22/2015	2	39	Died in Study Area

150.540 65	TF Impoundment	5/15/2015			DNP				5/28/2015	Gatehouse			5/28/2015	3	14	Left Study Area
150.540 67	Cabot Power Canal	5/19/2015			DNP					Downstream Bypass		5/20/2015	6/16/2015	1	29	Left Study Area
150.540 68	Cabot Power Canal	5/19/2015			DNP					Cabot Powerhouse	6/3/2015		7/7/2015	2	49	Died in Study Area
150.540 70	Cabot Power Canal	5/19/2015			DNP					Downstream Bypass		6/25/2015	6/29/2015	1	42	Left Study Area
150.540 71	Cabot Power Canal	5/19/2015			DNP					Cabot Powerhouse	6/22/2015		7/7/2015	2	49	Remained in the Study Area
150.540 72	Cabot Power Canal	5/19/2015			DNP					Downstream Bypass	6/3/2015		6/3/2015	2	16	Left Study Area
150.540 75	Holyoke Dam	5/19/2015	5/20/2015		DNP					DNP	6/4/2015		6/4/2015	2	17	Left Study Area
150.540 76	Holyoke Dam	5/19/2015		6/3/2015	DNP					DNP		6/25/2015	6/25/2015	1	38	Died in Study Area
150.540 77	Holyoke Dam	5/19/2015	5/20/2015		DNP					DNP			5/20/2015	1	2	Left Study Area
150.540 78	Holyoke Dam	5/19/2015			DNP					DNP		6/25/2015	6/25/2015	1	37	Died in Study Area
150.540 79	Holyoke Dam	5/19/2015			DNP					DNP		6/25/2015	6/25/2015	1	37	Died in Study Area
150.540 83	TF Impoundment	5/22/2015			DNP				6/17/2015	DNP			6/24/2015	3	33	Died in Study Area
150.540 84	TF Impoundment	5/22/2015			DNP					Gatehouse/Cabot Powerhouse	7/7/2015		7/7/2015	2	46	Died in Study Area
150.540 85	TF Impoundment	5/22/2015			DNP		5/28/2015			DNP			5/28/2015	4	7	Left Study Area
150.540 86	TF Impoundment	5/22/2015			DNP				6/24/2015	DNP			6/24/2015	3	33	Died in Study Area
150.540 92	TF Impoundment	5/23/2015			DNP		6/3/2015			Bascule Gate		6/18/2015	6/29/2015	1	38	Died in Study Area
150.540 94	TF Impoundment	5/23/2015			DNP					Bascule Gate	7/6/2015		7/6/2015	2	45	Died in Study Area
150.540 95	TF Impoundment	5/23/2015			DNP				6/17/2015	DNP			6/17/2015	3	25	Died in Study Area
150.540 98	Holyoke Dam	5/26/2015	5/27/2015		DNP					DNP		6/10/2015	6/10/2015	1	16	Left Study Area

APPENDIX D – STATISTICAL RESULTS

Appendix D: Statistical Model Selection and Results Tables and Figures

D-1 MULTI-STATE MARKOV

Multi-state Markov (MSM) modeling quantifies movement between states (locations) in continuous time. The resulting transition probabilities are the joint probability of a marked animal surviving, transitioning and being detected next at a receiver. To reduce negative bias resulting from low detection probabilities, telemetered reaches were aggregated together whenever possible because it was highly unlikely for a fish to transfer through multiple receivers without being detected. Each reach has a state table that incorporates movement from all individuals and by counting the number of times that a transition is made from a state (row) to another state (column). The count of individuals from and to the same site represent the number of times marked animals were recaptured within an hour. Large from-to counts at a particular site means that animals spent considerable time at a site before transitioning. Transitions are assumed to be instantaneous, and are never recounted. This table is useful to describe the total number of forays into specific reaches, however it should be noted that it is representative of the entire population and not individual fish, and may represent more than 1 foray per fish. To fit an MSM model to this state table, we let R calculate the initial transition probability matrix using the *crudeinits* function. These initial probabilities are then fed to the *msm* function, and a likelihood optimizer based upon the Newton-Raphson method quantified state transition intensities. There were instances when the quasi-Newton method failed to converge. In these cases, an optimizer based on simulated annealing was applied. A series of models were fit to each location incorporating diurnal cues and operations data (flow) in a method analogous to multiple regression. The best model was determined using a likelihood ratio procedure where nested models (smaller > larger) were tested against each other. When models were not comparable with the likelihood ratio, the model with the lower AIC score was considered better. The null hypothesis for the likelihood ratio procedure specified no difference between nested models. If the result was significant, we rejected the null hypothesis and concluded that the more complex model explained a significantly larger amount of variance than the simpler model, thus the more complex model was better. Once we were satisfied we had an appropriate model to describe movement, we used the *pnext* and *envisits* functions to describe the probability that an animal will survive, transition to and be detected at the next state given its current location and the expected number of visits (forays) to a station respectively. Of interest to the study team were the state table, *pnext* table, and *envisits* table (when number of forays was required).

After finding the best model, the *pnext* tables were constructed. These tables provide information on the probability of the next detection occurring at a telemetry station given a known previous detection at another station. The probability is presented in decimal form with upper and lower confidence intervals in parenthesis below. Again, this probability is the joint probability of a marked animal surviving, transitioning and being detected.

Selected reaches include the expected number of forays tables which are read in the same manner as detection probability tables.

Within each reach, there is a histogram of flow experienced by fish in that particular area during the time of this study. Some histograms may have been log transformed to conform to the data analysis procedure as written in Jackson (2011).

D-1.1 Lower River to Project: Holyoke to Montague

Four models were created for the MSM Downstream analysis. Model 1 included time in decimal days with no covariates and had an AIC value of 2588.68. Model 2 included time in decimal days with ln(Flow) as a covariate and had an AIC value of 2590.95. Model 3 included time in decimal days with diurnal cues as a covariate and had an AIC value of 2584.08. Model 4 included time in decimal days with ln(Flow) and diurnal cues as additive covariates and had an AIC value of 2590.22. Likelihood ratio tests revealed that Model 2 was significantly better than Model 1 ($p = 0.03$), Model 3 was significantly better than Model 1 ($p = 0.003$), Model 4 was significantly better than Model 2 ($p = 0.01$), and Model 4 was not significantly better than Model 3 ($p = 0.09$). Models 2 and 3 could not be tested with a likelihood ratio procedure because they were not nested. While model 3 had a lower AIC value, the number of state transition observations was critically low at night and values without infinite confidence intervals could not be estimated. Therefore, Model 3 is considered the best model for this analysis.

The resulting transition probability (*pnext*) table can be found below (Table D-1.1-1). Overall, confidence intervals around each estimate were fairly tight, therefore the reliability of these estimates remains relatively high.

Table D-1.1-1. Probability of fish moving between states at varying Montague flows in the MSM Downstream Model.

Beginning State at Flow		Probability of Next State				Project Passage
		Canoe Club	Sunderland	Montague	Project	
25% Flow	Canoe Club	0	0.51 (0.24, 0.73)	0.08 (0.01, 0.39)	0.42 (0.18, 0.64)	0
	Sunderland	0.30 (0.20, 0.41)	0	0.55 (0.43, 0.64)	0.15 (0.09, 0.25)	0
	Montague	0.02 (0.005, 0.08)	0.26 (0.18, 0.34)	0	0.72 (0.62, 0.79)	0
	Project	0.03 (0.01, 0.11)	0.1 (0.05, 0.18)	0.78 (0.66, 0.86)	0	0.09 (0.04,0.17)
50% Flow	Canoe Club	0	0.41 (0.20, 0.64)	0.11 (0.02, 0.34)	0.48 (0.25, 0.69)	0
	Sunderland	0.28 (0.20, 0.37)	0	0.61 (0.51, 0.69)	0.12 (0.06, 0.20)	0
	Montague	0.04 (0.02, 0.10)	0.28 (0.21, 0.36)	0	0.68 (0.59, 0.75)	0
	Project	0.03 (0.01, 0.10)	0.06 (0.03, 0.13)	0.84 (0.74, 0.89)	0	0.08 (0.04, 0.15)
75% Flow	Canoe Club	0	0.35 (0.13, 0.62)	0.14 (0.03, 0.43)	0.51 (0.23, 0.73)	0
	Sunderland	0.26 (0.17, 0.38)	0	0.64 (0.51, 0.74)	0.10 (0.05, 0.20)	0
	Montague	0.07 (0.03, 0.13)	0.29 (0.21, 0.37)	0	0.65 (0.55, 0.73)	0
	Project	0.02 (0.01, 0.09)	0.04 (0.01, 0.12)	0.86 (0.74, 0.91)	0	0.07 (0.03, 0.16)
100% Flow	Canoe Club	0	0.20 (0.02, 0.66)	0.25 (0.02, 0.81)	0.55 (0.07, 0.90)	0
	Sunderland	0.21 (0.08, 0.44)	0	0.73 (0.48, 0.88)	0.06 (0.01, 0.21)	0

Montague	0.20 (0.05, 0.51)	0.29 (0.15, 0.47)	0	0.51 (0.28, 0.68)	0
Project	0.02 (0.00, 0.23)	0.01 (0.00, 0.01)	0.91 (0.61, 0.97)	0	0.06 (0.01, 0.30)

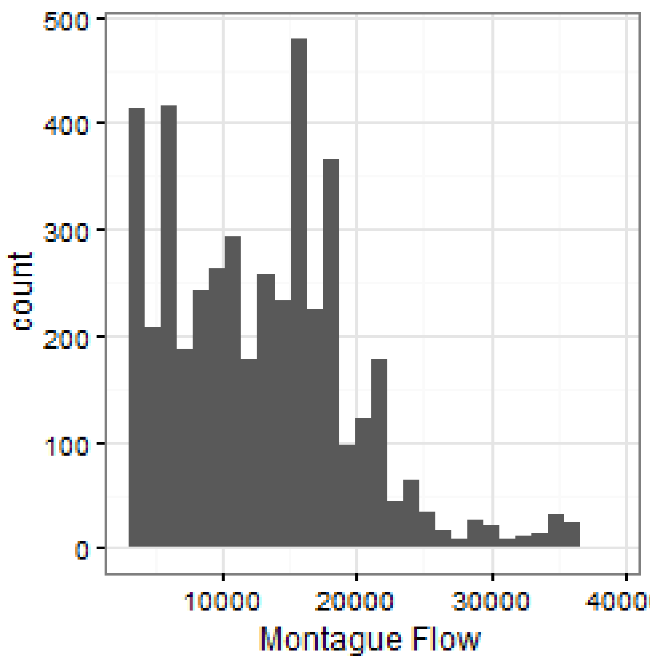

Figure D-1.1-1. Flow at Montague experienced by fish in the MSM Downstream Model

D-1.2 The Montague Reach

Nine models were created for the MSM Montague analysis. Model 1, the null model, included time in decimal days with no covariates and had an AIC value of 2138. Model 2, which included time in decimal days with Station 1 operations as a covariate, did not converge. Model 3 included time in decimal days with Cabot discharge as a covariate and had an AIC value of 2110. Model 4 included time in decimal days with Bypass flow as a covariate and had an AIC value of 2093. Model 5 included time in decimal days with diurnal cues as a covariate and had an AIC value of 2108. Model 6 included time in decimal days with Cabot discharge and Bypass flow as covariates and had an AIC value of 2054. Model 7 included time in decimal days with Cabot discharge and diurnal cues as covariates and had an AIC value of 2077. Model 8 included time in decimal days with Bypass flow and diurnal cues as covariates and had an AIC value of 2055. Model 9, the saturated model, included time in decimal days with Cabot discharge, Bypass flow, and diurnal cues as covariates and had an AIC value of 2036. Likelihood ratio tests revealed that Models 3, 4, & 5 were significantly better than Model 1 ($p < 0.001$) and Model 9 was significantly better than Models

6, 7, & 8 ($p < 0.001$). Overall, as evidenced by the lowest AIC value of 2036, the saturated model (9) was the best descriptor of movement around the Montague Spoke and into the Bypass Reach.

The resulting transition probability (*pnext*) table can be found below (in tables Table D-1.2-1 through Table D-1.2-8). Careful examination of each table is warranted as there were some flow combinations that produced a low number of transitions resulting in wide confidence intervals. When the interval is especially wide, the estimate is deemed unreliable for those specific transitions. However, while some estimates are unreliable, a majority are within an acceptable range. Some examples of wide confidence intervals are transitions from the Deerfield River. Note on Table D-1.2-1. Transition from the Deerfield to Montague was estimated at 89%, however the resulting confidence interval was very wide and ranged between 13% and 100%. Therefore, one would be 95% certain that in future studies under similar circumstances that this transition estimate would be between these two bounds.

Table D-1.2-1. Probability of fish moving between states at 25 % Bypass flows at varying Cabot Discharge flows during the day.

Beginning State at Flow		Probability of Next State				
		Montague	Deerfield	Smead Island	Cabot Tailrace	Bypass Reach
25% Cabot Discharge 25% Bypass Flow	Montague	0	0.061 (0.02, 0.19)	0.07 (0.01, 0.24)	0.74 (0.54, 0.83)	0.13 (0.06, 0.23)
	Deerfield	0.89 (0.13, 1.00)	0	0	0.11 (0.00, 0.87)	0
	Smead Island	0.15 (0.02, 0.66)	0.04 (0.01, 0.10)	0	0.57 (0.22, 0.76)	0.23 (0.08, 0.41)
	Cabot Tailrace	0.51 (0.35, 0.64)	0.006 (0.00, 0.08)	0.02 (0.02, 0.11)	0	0.46 (0.31, 0.60)
	Bypass Reach	0.12 (0.04, 0.28)	0	0.04 (0.01, 0.14)	0.84 (0.66, 0.93)	0
50% Cabot Discharge 25% Bypass Flow	Montague	0	0.08 (0.03, 0.19)	0.16 (0.08, 0.30)	0.64 (0.48, 0.75)	0.11 (0.05, 0.22)
	Deerfield	0.57 (0.13, 0.93)	0	0	0.43 (0.07, 0.87)	0
	Smead Island	0.24 (0.06, 0.58)	0.04 (0.01, 0.15)	0	0.42 (0.18, 0.67)	0.31 (0.12, 0.53)
	Cabot Tailrace	0.51 (0.38, 0.63)	0.006 (0.00, 0.09)	0.09 (0.03, 0.19)	0	0.39 (0.27, 0.51)
	Bypass Reach	0.10 (0.03, 0.24)	0	0.05 (0.01, 0.18)	0.85 (0.67, 0.93)	0
75% Cabot Discharge 25% Bypass Flow	Montague	0	0.09 (0.03, 0.22)	0.24 (0.12, 0.39)	0.57 (0.41, 0.70)	0.10 (0.04, 0.21)
	Deerfield	0.36 (0.03, 0.92)	0	0	0.64 (0.08, 0.97)	0
	Smead Island	0.28 (0.07, 0.60)	0.03 (0.00, 0.22)	0	0.35 (0.14, 0.61)	0.34 (0.11, 0.63)
	Cabot Tailrace	0.47 (0.34, 0.61)	0.006 (0.00, 0.11)	0.19 (0.09, 0.34)	0	0.33 (0.21, 0.45)
	Bypass Reach	0.09 (0.03, 0.26)	0	0.06 (0.01, 0.21)	0.85 (0.65, 0.93)	0

Beginning State at Flow		Probability of Next State				
		Montague	Deerfield	Smead Island	Cabot Tailrace	Bypass Reach
100% Cabot Discharge 25% Bypass Flow	Montague	0	0.10 (0.04, 0.23)	0.27 (0.15, 0.45)	0.54 (0.36, 0.68)	0.09 (0.04, 0.21)
	Deerfield	0.30 (0.02, 0.90)	0	0	0.70 (0.10, 0.98)	0
	Smead Island	0.30 (0.08, 0.64)	0.03 (0.00, 0.24)	0	0.32 (0.11, 0.58)	0.35 (0.10, 0.66)
	Cabot Tailrace	0.45 (0.29, 0.58)	0.006 (0.00, 0.11)	0.24 (0.11, 0.43)	0	0.31 (0.18, 0.43)
	Bypass Reach	0.09 (0.02, 0.26)	0	0.06 (0.01, 0.24)	0.85 (0.62, 0.94)	0

Table D-1.2-2. Probability of fish moving between states at 50 % Bypass flows at varying Cabot Discharge flows during the day.

Beginning State at Flow		Probability of Next State				
		Montague	Deerfield	Smead Island	Cabot Tailrace	Bypass Reach
25% Cabot Discharge 50% Bypass Flow	Montague	0	0.06 (0.02, 0.16)	0.07 (0.02, 0.25)	0.65 (0.49, 0.75)	0.22 (0.13, 0.32)
	Deerfield	0.90 (0.21, 1.00)	0	0	0.10 (0.00, 0.79)	0
	Smead Island	0.19 (0.03, 0.65)	0.11 (0.04, 0.21)	0	0.36 (0.15, 0.50)	0.34 (0.13, 0.47)
	Cabot Tailrace	0.59 (0.46, 0.69)	0.01 (0.002, 0.06)	0.01 (0.001, 0.11)	0	0.39 (0.28, 0.49)
	Bypass Reach	0.18 (0.09, 0.30)	0	0.08 (0.03, 0.20)	0.74 (0.59, 0.84)	0
50% Cabot Discharge 50% Bypass Flow	Montague	0	0.08 (0.04, 0.17)	0.18 (0.10, 0.29)	0.55 (0.43, 0.66)	0.18 (0.11, 0.31)
	Deerfield	0.60 (0.20, 0.89)	0	0	0.40 (0.11, 0.80)	0
	Smead Island	0.27 (0.10, 0.52)	0.09 (0.03, 0.22)	0	0.24 (0.13, 0.35)	0.41 (0.23, 0.58)
	Cabot Tailrace	0.60 (0.48, 0.69)	0.01 (0.00, 0.07)	0.07 (0.03, 0.15)	0	0.33 (0.24, 0.43)
	Bypass Reach	0.15 (0.08, 0.26)	0	0.10 (0.05, 0.22)	0.75 (0.61, 0.84)	0
75% Cabot Discharge 50% Bypass Flow	Montague	0	0.09 (0.04, 0.20)	0.26 (0.15, 0.39)	0.49 (0.36, 0.61)	0.16 (0.09, 0.28)
	Deerfield	0.39 (0.06, 0.87)	0	0	0.61 (0.13, 0.94)	0
	Smead Island	0.31 (0.11, 0.56)	0.08 (0.02, 0.26)	0	0.19 (0.09, 0.31)	0.43 (0.19, 0.64)
	Cabot Tailrace	0.56 (0.42, 0.67)	0.01 (0.00, 0.10)	0.14 (0.06, 0.28)	0	0.29 (0.19, 0.40)

Beginning State at Flow		Probability of Next State: Montague	Deerfield	Smead Island	Cabot Tailrace	Bypass Reach
	Bypass Reach	0.13 (0.06, 0.25)	0	0.11 (0.04, 0.26)	0.75 (0.59, 0.86)	0
100% Cabot Discharge 50% Bypass Flow	Montague	0	0.10 (0.04,0.21)	0.29 (0.17, 0.46)	0.46 (0.32, 0.58)	0.15 (0.08, 0.26)
	Deerfield	0.32 (0.03, 0.88)	0	0	0.68 (0.13, 0.97)	0
	Smead Island	0.32 (0.11, 0.61)	0.07 (0.01, 0.30)	0	0.17 (0.07, 0.30)	0.43 (0.18, 0.68)
	Cabot Tailrace	0.54 (0.38, 0.67)	0.01 (0.00, 0.12)	0.18 (0.07, 0.36)	0	0.27 (0.16, 0.37)
	Bypass Reach	0.13 (0.05, 0.27)	0	0.12 (0.04, 0.30)	0.75 (0.57, 0.86)	0

Table D-1.2-3. Probability of fish moving between states at 75 % Bypass flows at varying Cabot Discharge flows during the day.

Beginning State at Flow		Probability of Next State: Montague	Deerfield	Smead Island	Cabot Tailrace	Bypass Reach
25% Cabot Discharge 75% Bypass Flow	Montague	0	0.06 (0.02, 0.17)	0.08 (0.02, 0.25)	0.58 (0.42, 0.70)	0.28 (0.17, 0.41)
	Deerfield	0.90 (0.21, 1.00)	0	0	0.096 (0.00, 0.79)	0
	Smead Island	0.20 (0.03, 0.66)	0.17 (0.05, 0.34)	0	0.25 (0.09, 0.44)	0.38 (0.15, 0.55)
	Cabot Tailrace	0.63 (0.48, 0.74)	0.02 (0.00, 0.09)	0.01 (0.00, 0.07)	0	0.34 (0.23, 0.46)
	Bypass Reach	0.21 (0.11, 0.36)	0	0.11 (0.04, 0.30)	0.68 (0.51, 0.80)	0
50% Cabot Discharge 75% Bypass Flow	Montague	0	0.08 (0.03, 0.19)	0.18 (0.10, 0.30)	0.50 (0.35, 0.62)	0.24 (0.14, 0.35)
	Deerfield	0.61 (0.22, 0.89)	0	0	0.39 (0.11, 0.78)	0
	Smead Island	0.27 (0.11, 0.53)	0.13 (0.06, 0.27)	0	0.16 (0.07, 0.30)	0.44 (0.26, 0.61)
	Cabot Tailrace	0.64 (0.49, 0.74)	0.02 (0.002, 0.13)	0.05 (0.02, 0.16)	0	0.29 (0.19, 0.41)
	Bypass Reach	0.17 (0.09, 0.3)	0	0.15 (0.07, 0.29)	0.68 (0.52, 0.80)	0
75% Cabot Discharge	Montague	0	0.09 (0.04, 0.21)	0.26 (0.15, 0.40)	0.44 (0.31, 0.56)	0.21 (0.12, 0.33)
	Deerfield	0.40 (0.06, 0.88)	0	0	0.60 (0.12, 0.94)	0
	Smead Island	0.30 (0.11, 0.59)	0.11 (0.03, 0.33)	0	0.13 (0.05, 0.26)	0.46 (0.21, 0.67)

Beginning State at Flow		Probability of Next State				
		Montague	Deerfield	Smead Island	Cabot Tailrace	Bypass Reach
	Cabot Tailrace	0.61 (0.41, 0.73)	0.02 (0.00, 0.17)	0.12 (0.04, 0.31)	0	0.26 (0.15, 0.39)
	Bypass Reach	0.16 (0.07, 0.29)	0	0.16 (0.07, 0.33)	0.68 (0.51, 0.80)	0
100% Cabot Discharge 75% Bypass Flow	Montague	0	0.09 (0.03, 0.21)	0.30 (0.16, 0.45)	0.41 (0.27, 0.54)	0.20 (0.11, 0.32)
	Deerfield	0.33 (0.03, 0.86)	0	0	0.67 (0.14, 0.97)	0
	Smead Island	0.31 (0.11, 0.60)	0.11 (0.02, 0.34)	0	0.11 (0.04, 0.25)	0.46 (0.21, 0.69)
	Cabot Tailrace	0.59 (0.37, 0.73)	0.02 (0.0009, 0.23)	0.15 (0.04, 0.36)	0	0.24 (0.13, 0.37)
	Bypass Reach	0.15 (0.06, 0.30)	0	0.17 (0.06, 0.36)	0.68 (0.49, 0.82)	0

Table D-1.2-4. Probability of fish moving between states at 100 % Bypass flows at varying Cabot Discharge flows during the day.

Beginning State at Flow		Probability of Next State				
		Montague	Deerfield	Smead Island	Cabot Tailrace	Bypass Reach
25% Cabot Discharge 100% Bypass Flow	Montague	0	0.03 (0.00, 0.23)	0.05 (0.01, 0.30)	0.23 (0.06, 0.53)	0.68 (0.32, 0.88)
	Deerfield	0.92 (0.08, 1.00)	0	0	0.08 (0.00, 0.92)	0
	Smead Island	0.09 (0.00, 0.69)	0.62 (0.08, 0.95)	0	0.02 (0.00, 0.25)	0.27 (0.02, 0.79)
	Cabot Tailrace	0.75 (0.02, 0.92)	0.08 (0.00, 0.98)	0	0	0.17 (0.00, 0.43)
	Bypass Reach	0.31 (0.03, 0.83)	0	0.42 (0.04, 0.91)	0.27 (0.03, 0.71)	0
50% Cabot Discharge 100% Bypass Flow	Montague	0	0.05 (0.01, 0.25)	0.14 (0.03, 0.40)	0.20 (0.06, 0.44)	0.61 (0.29, 0.84)
	Deerfield	0.67 (0.04, 0.99)	0	0	0.33 (0.01, 0.96)	0
	Smead Island	0.13 (0.01, 0.53)	0.52 (0.09, 0.88)	0	0.01 (0.00, 0.17)	0.34 (0.05, 0.75)
	Cabot Tailrace	0.76 (0.01, 0.93)	0.08 (0.00, 0.98)	0.02 (0.00, 0.28)	0	0.14 (0.00, 0.42)
	Bypass Reach	0.24 (0.02, 0.75)	0	0.50 (0.07, 0.91)	0.26 (0.04, 0.63)	0
75% Cabot Discharge	Montague	0	0.06 (0.01, 0.30)	0.21 (0.05, 0.51)	0.19 (0.05, 0.43)	0.55 (0.23, 0.80)
	Deerfield	0.46 (0.01, 0.99)	0	0	0.54 (0.01, 0.99)	0

Beginning State at Flow		Probability of Next State				
		Montague	Deerfield	Smead Island	Cabot Tailrace	Bypass Reach
	Smead Island	0.15 (0.13, 0.65)	0.47 (0.08, 0.85)	0	0.01 (0.00, 0.13)	0.36 (0.06, 0.76)
	Cabot Tailrace	0.75 (0.01, 0.93)	0.08 (0.00, 0.99)	0.04 (0.00, 0.50)	0	0.13 (0.01, 0.37)
	Bypass Reach	0.21 (0.02, 0.77)	0	0.54 (0.07, 0.92)	0.25 (0.03, 0.64)	0
100% Cabot Discharge 100% Bypass Flow	Montague	0	0.06 (0.01, 0.36)	0.24 (0.06, 0.55)	0.18 (0.05, 0.40)	0.53 (0.20, 0.78)
	Deerfield	0.39 (0.01, 0.98)	0	0	0.61 (0.02, 0.99)	0
	Smead Island	0.16 (0.01, 0.66)	0.45 (0.08, 0.84)	0	0.009 (0.00, 0.13)	0.37 (0.07, 0.79)
	Cabot Tailrace	0.74 (0.01, 0.93)	0.08 (0.00, 0.99)	0.05 (0.00, 0.56)	0	0.12 (0.00, 0.34)
	Bypass Reach	0.20 (0.01, 0.73)	0	0.55 (0.08, 0.92)	0.25 (0.04, 0.63)	0

Table D-1.2-5. Probability of fish moving between states at 25 % Bypass flows at varying Cabot Discharge flows at night.

Beginning State at Flow		Probability of Next State				
		Montague	Deerfield	Smead Island	Cabot Tailrace	Bypass Reach
25% Cabot Discharge 25% Bypass Flow	Montague	0	0.18 (0.05, 0.46)	0.07 (0.01, 0.29)	0.65 (0.36, 0.82)	0.11 (0.03, 0.32)
	Deerfield	0.97 (0.15, 1.00)	0	0	0.03 (0.00, 0.85)	0
	Smead Island	0.09 (0.01, 0.44)	0.02 (0.00, 0.10)	0	0.73 (0.37, 0.88)	0.16 (0.06, 0.36)
	Cabot Tailrace	0.38 (0.19, 0.61)	0.003 (0.00, 0.07)	0.03 (0.00, 0.19)	0	0.59 (0.33, 0.77)
	Bypass Reach	0.21 (0.08, 0.46)	0	0.10 (0.02, 0.32)	0.69 (0.43, 0.85)	0
50% Cabot Discharge 25% Bypass Flow	Montague	0	0.24 (0.08, 0.48)	0.15 (0.04, 0.37)	0.53 (0.29, 0.73)	0.08 (0.02, 0.28)
	Deerfield	0.85 (0.35, 0.98)	0	0	0.15 (0.02, 0.65)	0
	Smead Island	0.15 (0.04, 0.40)	0.02 (0.00, 0.11)	0	0.59 (0.30, 0.80)	0.23 (0.09, 0.43)
	Cabot Tailrace	0.37 (0.18, 0.58)	0.003 (0.00, 0.06)	0.14 (0.04, 0.37)	0	0.49 (0.26, 0.68)
	Bypass Reach	0.17 (0.06, 0.40)	0	0.12 (0.03, 0.36)	0.70 (0.04, 0.85)	0
75% Cabot	Montague	0	0.26 (0.09, 0.54)	0.21 (0.07, 0.49)	0.46 (0.21, 0.67)	0.07 (0.02, 0.24)

Beginning State at Flow		Probability of Next State				
		Montague	Deerfield	Smead Island	Cabot Tailrace	Bypass Reach
	Deerfield	0.70 (0.28, 0.94)	0	0	0.30 (0.06, 0.72)	0
	Smead Island	0.19 (0.05, 0.47)	0.02 (0.00, 0.14)	0	0.52 (0.22, 0.76)	0.27 (0.10, 0.54)
	Cabot Tailrace	0.33 (0.17, 0.52)	0.002 (0.00, 0.09)	0.28 (0.11, 0.53)	0	0.39 (0.20, 0.60)
	Bypass Reach	0.16 (0.05, 0.38)	0	0.14 (0.03, 0.41)	0.70 (0.39, 0.86)	0
100% Cabot Discharge 25% Bypass Flow	**Montague**	0	0.26 (0.08, 0.55)	0.24 (0.07, 0.54)	0.43 (0.20, 0.65)	0.07 (0.01, 0.24)
	Deerfield	0.63 (0.19, 0.91)	0	0	0.37 (0.09, 0.81)	0
	Smead Island	0.20 (0.06, 0.50)	0.02 (0.00, 0.14)	0	0.49 (0.21, 0.75)	0.28 (0.09, 0.57)
	Cabot Tailrace	0.30 (0.15, 0.49)	0.002 (0.00, 0.10)	0.35 (0.13, 0.61)	0	0.35 (0.17, 0.57)
	Bypass Reach	0.15 (0.05, 0.37)	0	0.14 (0.03, 0.43)	0.70 (0.41, 0.87)	0

Table D-1.2-6. Probability of fish moving between states at 50 % Bypass flows at varying Cabot Discharge flows at night.

Beginning State at Flow		Probability of Next State				
		Montague	Deerfield	Smead Island	Cabot Tailrace	Bypass Reach
25% Cabot Discharge 50% Bypass Flow	**Montague**	0	0.18 (0.05, 0.45)	0.07 (0.01, 0.28)	0.57 (0.30, 0.78)	0.18 (0.05, 0.40)
	Deerfield	0.97 (0.19, 1.00)	0	0	0.03 (0.00, 0.81)	0
	Smead Island	0.12 (0.02, 0.49)	0.07 (0.01, 0.29)	0	0.53 (0.24, 0.74)	0.27 (0.10, 0.49)
	Cabot Tailrace	0.46 (0.24, 0.66)	0.005 (0.00, 0.17)	0.02 (0.00, 0.16)	0	0.51 (0.28, 0.71)
	Bypass Reach	0.27 (0.10, 0.54)	0	0.17 (0.04, 0.44)	0.56 (0.30, 0.76)	0
50% Cabot Discharge 50% Bypass Flow	**Montague**	0	0.24 (0.08, 0.47)	0.16 (0.05, 0.41)	0.46 (0.02, 0.66)	0.14 (0.04, 0.36)
	Deerfield	0.86 (0.36, 0.98)	0	0	0.14 (0.02, 0.64)	0
	Smead Island	0.19 (0.07, 0.43)	0.06 (0.01, 0.24)	0	0.39 (0.02, 0.59)	0.36 (0.17, 0.55)
	Cabot Tailrace	0.46 (0.24, 0.65)	0.01 (0.00, 0.22)	0.11 (0.03, 0.29)	0	0.43 (0.22, 0.64)
	Bypass Reach	0.22 (0.08, 0.45)	0	0.22 (0.07, 0.50)	0.56 (0.32, 0.77)	0

Beginning State at Flow		Probability of Next State				
		Montague	Deerfield	Smead Island	Cabot Tailrace	Bypass Reach
75% Cabot Discharge 50% Bypass Flow	Montague	0	0.25 (0.09, 0.49)	0.23 (0.07, 0.48)	0.39 (0.20, 0.61)	0.12 (0.03, 0.31)
	Deerfield	0.72 (0.34, 0.93)	0	0	0.28 (0.07, 0.66)	0
	Smead Island	0.23 (0.08, 0.47)	0.06 (0.00, 0.27)	0	0.32 (0.15, 0.54)	0.39 (0.18, 0.61)
	Cabot Tailrace	0.41 (0.19, 0.61)	0.01 (0.00, 0.24)	0.22 (0.07, 0.50)	0	0.36 (0.17, 0.54)
	Bypass Reach	0.20 (0.07, 0.46)	0	0.24 (0.08, 0.56)	0.55 (0.28, 0.75)	0
100% Cabot Discharge 50% Bypass Flow	Montague	0	0.26 (0.09, 0.53)	0.26 (0.08, 0.53)	0.37 (0.16, 0.58)	0.11 (0.03, 0.32)
	Deerfield	0.65 (0.02, 0.92)	0	0	0.35 (0.08, 0.76)	0
	Smead Island	0.25 (0.08, 0.53)	0.06 (0.00, 0.29)	0	0.30 (0.11, 0.51)	0.40 (0.18, 0.63)
	Cabot Tailrace	0.39 (0.17, 0.61)	0.01 (0.00, 0.28)	0.28 (0.08, 0.57)	0	0.33 (0.14, 0.52)
	Bypass Reach	0.19 (0.06, 0.45)	0	0.25 (0.08, 0.57)	0.55 (0.29, 0.77)	0

Table D-1.2-7. Probability of fish moving between states at 75 % Bypass flows at varying Cabot Discharge flows at night.

Beginning State at Flow		Probability of Next State				
		Montague	Deerfield	Smead Island	Cabot Tailrace	Bypass Reach
25% Cabot Discharge 75% Bypass Flow	Montague	0	0.18 (0.05, 0.48)	0.07 (0.01, 0.29)	0.51 (0.23, 0.71)	0.24 (0.07, 0.49)
	Deerfield	0.97 (0.19, 1.00)	0	0	0.03 (0.00, 0.81)	0
	Smead Island	0.14 (0.02, 0.55)	0.12 (0.01, 0.47)	0	0.40 (0.13, 0.65)	0.33 (0.11, 0.62)
	Cabot Tailrace	0.51 (0.26, 0.70)	0.01 (0.00, 0.34)	0.02 (0.00, 0.17)	0	0.47 (0.22, 0.68)
	Bypass Reach	0.30 (0.09, 0.59)	0	0.23 (0.06, 0.56)	0.47 (0.22, 0.69)	0
50% Cabot Discharge 75% Bypass Flow	Montague	0	0.23 (0.08, 0.47)	0.17 (0.05, 0.39)	0.41 (0.19, 0.63)	0.19 (0.05, 0.42)
	Deerfield	0.87 (0.32, 0.99)	0	0	0.13 (0.01, 0.69)	0
	Smead Island	0.21 (0.06, 0.46)	0.10 (0.02, 0.41)	0	0.28 (0.10, 0.52)	0.41 (0.19, 0.65)
	Cabot Tailrace	0.51 (0.23, 0.72)	0.008 (0.00, 0.42)	0.09 (0.02, 0.28)	0	0.40 (0.16, 0.58)

Beginning State at Flow		Probability of Next State				
		Montague	Deerfield	Smead Island	Cabot Tailrace	Bypass Reach
	Bypass Reach	0.24 (0.08, 0.52)	0	0.29 (0.08, 0.58)	0.47 (0.23, 0.71)	0
75% Cabot Discharge 75% Bypass Flow	Montague	0	0.25 (0.08, 0.51)	0.24 (0.07, 0.51)	0.36 (0.15, 0.57)	0.16 (0.05, 0.39)
	Deerfield	0.73 (0.26, 0.95)	0	0	0.27 (0.05, 0.73)	0
	Smead Island	0.24 (0.08, 0.51)	0.09 (0.16, 0.40)	0	0.23 (0.08, 0.47)	0.44 (0.20, 0.68)
	Cabot Tailrace	0.47 (0.19, 0.67)	0.01 (0.00, 0.45)	0.19 (0.04, 0.48)	0	0.34 (0.12, 0.55)
	Bypass Reach	0.22 (0.07, 0.51)	0	0.32 (0.11, 0.62)	0.46 (0.21, 0.70)	0
100% Cabot Discharge 75% Bypass Flow	Montague	0	0.25 (0.08, 0.56)	0.26 (0.08, 0.57)	0.33 (0.14, 0.53)	0.15 (0.04, 0.40)
	Deerfield	0.67 (0.18, 0.93)	0	0	0.33 (0.06, 0.82)	0
	Smead Island	0.25 0.07, 0.52)	0.09 (0.01, 0.38)	0	0.21 (0.07, 0.41)	0.45 (0.17, 0.68)
	Cabot Tailrace	0.44 (0.16, 0.65)	0.007 (0.0, 0.41)	0.24 (0.05, 0.58)	0	0.31 (0.10, 0.52)
	Bypass Reach	0.21 (0.05, 0.48)	0	0.33 (0.10, 0.65)	0.46 (0.20, 0.70)	0

Table D-1.2-8. Probability of fish moving between states at 100 % Bypass flows at varying Cabot Discharge flows at night.

Beginning State at Flow		Probability of Next State				
		Montague	Deerfield	Smead Island	Cabot Tailrace	Bypass Reach
25% Cabot Discharge 100% Bypass Flow	Montague	0	0.11 (0.01, 0.54)	0.06 (0.00, 0.31)	0.22 (0.04, 0.53)	0.62 (0.16, 0.89)
	Deerfield	0.98 (0.06, 1.00)	0	0	0.02 (0.0, 0.94)	0
	Smead Island	0.08 (0.14, 0.64)	0.58 (0.03, 0.98)	0	0.04 (0.00, 0.50)	0.30 (0.01, 0.85)
	Cabot Tailrace	0.69 (0.00, 0.91)	0.04 (0.00, 0.99)	0.01 (0.00, 0.14)	0	0.26 (0.00, 0.63)
	Bypass Reach	0.31 (0.01, 0.92)	0	0.57 (0.03, 0.96)	0.13 (0.01, 0.51)	0
50% Cabot Discharge	Montague	0	0.15 (0.02, 0.60)	0.14 (0.022, 0.48)	0.19 (0.03, 0.46)	0.52 (0.11, 0.84)
	Deerfield	0.89 (0.05, 1.00)	0	0	0.11 (0.00, 0.95)	0
	Smead Island	0.12 (0.003, 0.63)	0.49 (0.03, 0.95)	0	0.02 (0.00, 0.36)	0.37 (0.03, 0.83)

Beginning State at Flow		Probability of Next State: Montague	Deerfield	Smead Island	Cabot Tailrace	Bypass Reach
	Cabot Tailrace	0.70 (0.00, 0.91)	0.04 (0.00, 0.99)	0.04 (0.00, 0.49)	0	0.22 (0.00, 0.59)
	Bypass Reach	0.23 (0.01, 0.87)	0	0.66 (0.06, 0.97)	0.12 (0.01, 0.50)	0
75% Cabot Discharge 100% Bypass Flow	Montague	0	0.17 (0.02, 0.62)	0.20 (0.03, 0.59)	0.17 (0.03, 0.42)	0.46 (0.14, 0.82)
	Deerfield	0.78 (0.03, 1.00)	0	0	0.22 (0.00, 0.97)	0
	Smead Island	0.14 (0.01, 0.68)	0.44 (0.03, 0.92)	0	0.02 (0.00, 0.29)	0.40 (0.03, 0.86)
	Cabot Tailrace	0.68 (0.00, 0.90)	0.04 (0.00, 1.00)	0.08 (0.00, 0.71)	0	0.20 (0.00, 0.51)
	Bypass Reach	0.19 (0.01, 0.86)	0	0.70 (0.07, 0.97)	0.11 (0.01, 0.47)	0
100% Cabot Discharge 100% Bypass Flow	Montague	0	0.18 (0.02, 0.63)	0.23 (0.03, 0.67)	0.16 (0.03, 0.41)	0.44 (0.08, 0.82)
	Deerfield	0.72 (0.02, 1.00)	0	0	0.28 (0.00, 0.98)	0
	Smead Island	0.15 (0.01, 0.66)	0.42 (0.03, 0.92)	0	0.02 (0.00, 0.22)	0.41 (0.04, 0.85)
	Cabot Tailrace	0.66 (0.00, 0.89)	0.04 (0.00, 1.00)	0.10 (0.00, 0.77)	0	0.19 (0.00, 0.50)
	Bypass Reach	0.18 (0.01, 0.85)	0	0.71 (0.08, 0.97)	0.11 (0.01, 0.46)	0

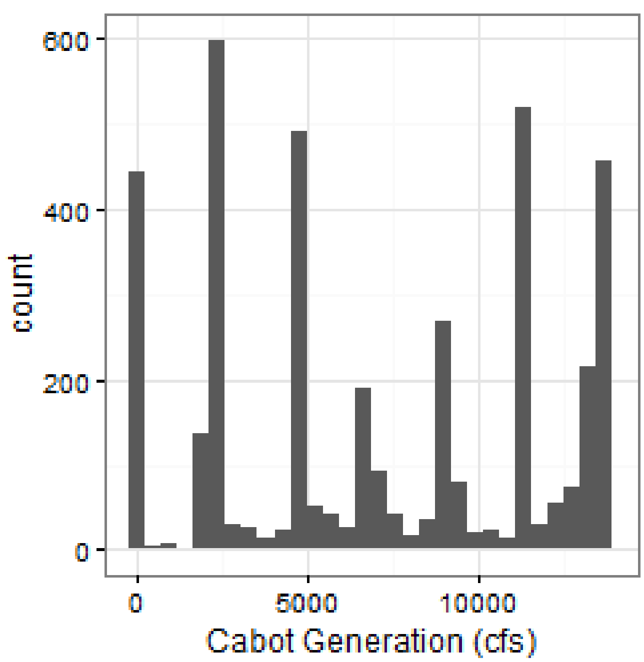

Figure D-1.2-1. Cabot discharge experienced by fish in the MSM Montague Model

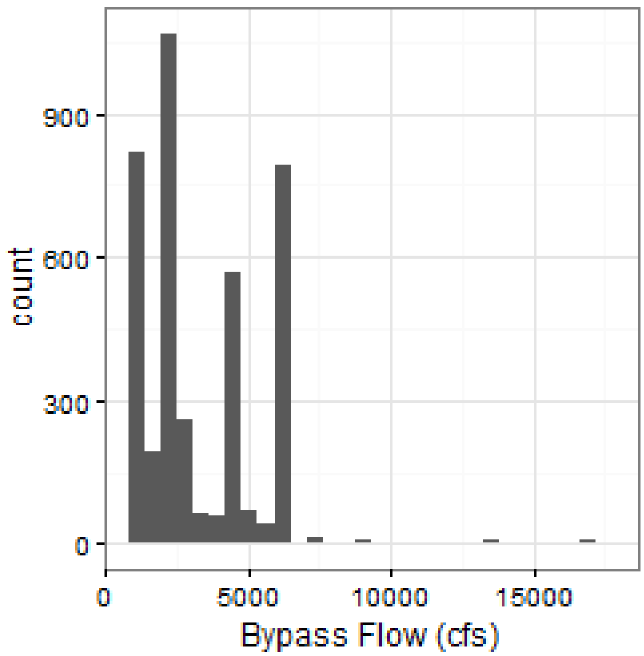

Figure D-1.2-2: Bypass Flow experienced by fish in the MSM Montague Model

D-1.3 Cabot Ladder Attraction

Nine models were created for the MSM Cabot ladder attraction analysis. Model 1 included time in decimal days and had an AIC value of 2401. Model 2, which included time in decimal days and included Cabot generation as a covariate had an AIC value of 2316. Model 3 included time in decimal days and included Bypass Flow as a covariate had an AIC value of 2335. Model 4 included time in decimal days and included Station No. 1 operations as a covariate had an AIC value of 2313. Model 5 included time in decimal days and incorporated diurnal cues as a covariate had an AIC value of 2303. Model 6 included time in decimal days and was an additive model with Bypass flow and Cabot generation as covariates had an AIC value of 2276. Model 7 included time in decimal days and was an additive model incorporating Cabot generation and diurnal cues as covariates had an AIC value of 2236. Model 8 included time in decimal days and was an additive model that incorporated Bypass flow and diurnal cues as covariates with an AIC value of 2243. Model 9 included time in decimal days and was a saturated model that incorporated Cabot generation, Bypass flow and diurnal cues as covariates and had an AIC value of 2201. Likelihood ratio tests revealed that Models 2, 3, and 4 are significantly better than Model 1 ($p < 0.001$) and Model 9 was significantly better than Models 6, 7, and 8 ($p < 0.001$). Overall, Model 9, the saturated model incorporating flow from Cabot discharge and the Bypass Reach with diurnal cues is the best model with the lowest AIC value of 2201.

Table D-1.3-1: Probability of fish moving through states at 25% Bypass flows and varying Cabot flows during the daytime.

Beginning State at Flow		Probability of Next State			
		Downstream	Bypass	Cabot Tailrace	Cabot Ladder
25% Cabot Flow 25% Bypass Flow	Downstream	0	0.27 (0.17, 0.39)	0.71 (0.57, 0.81)	0.02 (0.01, 0.10)
	Bypass	0.10 (0.04, 0.23)	0	0.84 (0.67, 0.92)	0.06 (0.02, 0.20)
	Cabot Tailrace	0.23 (0.15, 0.33)	0.25 (0.17, 0.34)	0	0.52 (0.41, 0.63)
	Cabot Ladder	0.07 (0.02, 0.22)	0.08 (0.03, 0.22)	0.84 (0.65, 0.92)	0
50% Cabot Flow 25% Bypass Flow	Downstream	0	0.30 (0.19, 0.44)	0.6 (0.51, 0.78)	0.03 (0.01, 0.12)
	Bypass	0.10 (0.04, 0.21)	0	0.83 (0.66, 0.91)	0.07 (0.02, 0.22)
	Cabot Tailrace	0.21 (0.14, 0.29)	0.22 (0.15, 0.30)	0	0.57 (0.47, 0.66)
	Cabot Ladder	0.04 (0.02, 0.11)	0.08 (0.03, 0.16)	0.88 (0.77, 0.93)	0
75% Cabot Flow 25% Bypass Flow	Downstream	0	0.32 (0.19, 0.48)	0.65 (0.48, 0.77)	0.03 (0.01, 0.13)
	Bypass	0.10 (0.04, 0.23)	0	0.83 (0.63, 0.92)	0.08 (0.02, 0.26)
	Cabot Tailrace	0.20 (0.14, 0.29)	0.20 (0.14, 0.29)	0	0.60 (0.50, 0.68)
	Cabot Ladder	0.03 (0.01, 0.11)	0.08 (0.03, 0.18)	0.89 (0.77, 0.94)	0
100% Cabot Flow 25% Bypass Flow	Downstream	0	0.33 (0.20, 0.50)	0.64 (0.46, 0.78)	0.03 (0.01, 0.12)
	Bypass	0.10 (0.04, 0.25)	0	0.83 (0.60, 0.92)	0.08 (0.02, 0.26)
	Cabot Tailrace	0.20 (0.13, 0.28)	0.20 (0.13, 0.28)	0	0.60 (0.50, 0.69)
	Cabot Ladder	0.03 (0.01, 0.09)	0.07 (0.03, 0.19)	0.90 (0.77, 0.95)	0

Table D-1.3-2: Probability of fish moving between states at 50% Bypass flows and varying Cabot flows during the daytime.

Beginning State at Flow		Probability of Next State			
		Downstream	Bypass	Cabot Tailrace	Cabot Ladder
25% Cabot Flow	Downstream	0	0.35 (0.24, 0.46)	0.61 (0.49, 0.71)	0.04 (0.01, 0.13)
	Bypass	0.20 (0.11, 0.32)	0	0.70 (0.57, 0.80)	0.10 (0.04, 0.22)

Beginning State at Flow		Probability of Next State			
		Downstream	Bypass	Cabot Tailrace	Cabot Ladder
	Cabot Tailrace	0.31 (0.24, 0.40)	0.19 (0.13, 0.27)	0	0.49 (0.40, 0.58)
	Cabot Ladder	0.13 (0.06, 0.24)	0.14 (0.07, 0.26)	0.73 (0.59, 0.83)	0
50% Cabot Flow 50% Bypass Flow	**Downstream**	0	0.39 (0.28, 0.51)	0.56 (0.44, 0.67)	0.05 (0.02, 0.13)
	Bypass	0.19 (0.11, 0.30)	0	0.69 (0.56, 0.79)	0.12 (0.06, 0.24)
	Cabot Tailrace	0.29 (0.22, 0.37)	0.17 (0.11, 0.24)	0	0.54 (0.46, 0.62)
	Cabot Ladder	0.08 (0.04, 0.15)	0.14 (0.07, 0.23)	0.79 (0.67, 0.85)	0
75% Cabot Flow 50% Bypass Flow	**Downstream**	0	0.41 (0.28, 0.53)	0.54 (0.41, 0.66)	0.05 (0.02, 0.15)
	Bypass	0.18 (0.10, 0.32)	0	0.68 (0.53, 0.80)	0.13 (0.06, 0.26)
	Cabot Tailrace	0.28 (0.21, 0.37)	0.16 (0.10, 0.23)	0	0.56 (0.47, 0.65)
	Cabot Ladder	0.06 (0.02, 0.16)	0.13 (0.06, 0.26)	0.81 (0.66, 0.90)	0
100% Cabot Flow 50% Bypass Flow	**Downstream**	0	0.42 (0.28, 0.55)	0.53 (0.38, 0.67)	0.05 (0.02, 0.15)
	Bypass	0.19 (0.10, 0.31)	0	0.68 (0.53, 0.79)	0.13 (0.05, 0.27)
	Cabot Tailrace	0.28 (0.20, 0.37)	0.15 (0.10, 0.22)	0	0.57 (0.47, 0.66)
	Cabot Ladder	0.05 (0.02, 0.15)	0.13 (0.05, 0.30)	0.81 (0.63, 0.90)	0

Table D-1.3-3: Probability of fish moving through states at 75% Bypass flow and varying Cabot flows during the daytime.

Beginning State at Flow		Probability of Next State			
		Downstream	Bypass	Cabot Tailrace	Cabot Ladder
25% Cabot Flow 75% Bypass Flow	**Downstream**	0	0.38 (0.26, 0.51)	0.57 (0.43, 0.69)	0.05 (0.02, 0.14)
	Bypass	0.25 (0.14, 0.38)	0	0.62 (0.48, 0.75)	0.12 (0.05, 0.25)
	Cabot Tailrace	0.35 (0.26, 0.46)	0.17 (0.11, 0.26)	0	0.47 (0.37, 0.57)
	Cabot Ladder	0.16 (0.08, 0.27)	0.17 (0.09, 0.29)	0.67 (0.54, 0.79)	0
50 % Cab	**Downstream**	0	0.42 (0.30, 0.55)	0.52 (0.38, 0.63)	0.06 (0.02, 0.14)

	Bypass	0.24 (0.13, 0.37)	0	0.61 (0.47, 0.73)	0.14 (0.07, 0.28)
	Cabot Tailrace	0.33 (0.24, 0.43)	0.15 (0.09, 0.24)	0	0.52 (0.42, 0.62)
	Cabot Ladder	0.09 (0.04, 0.21)	0.17 (0.10, 0.30)	0.74 (0.59, 0.84)	0
75% Cabot Flow 75% Bypass Flow	**Downstream**	0	0.44 (0.32, 0.57)	0.49 (0.36, 0.62)	0.06 (0.02, 0.16)
	Bypass	0.24 (0.13, 0.38)	0	0.61 (0.44, 0.74)	0.15 (0.07, 0.29)
	Cabot Tailrace	0.32 (0.22, 0.43)	0.14 (0.08, 0.22)	0	0.54 (0.42, 0.64)
	Cabot Ladder	0.07 (0.02, 0.21)	0.17 (0.07, 0.37)	0.76 (0.55, 0.87)	0
100% Cabot Flow 75% Bypass Flow	**Downstream**	0	0.45 (0.33, 0.59)	0.48 (0.34, 0.60)	0.07 (0.02, 0.17)
	Bypass	0.24 (0.13, 0.39)	0	0.61 (0.44, 0.74)	0.16 (0.07, 0.31)
	Cabot Tailrace	0.31 (0.21, 0.43)	0.14 (0.08, 0.22)	0	0.55 (0.43, 0.66)
	Cabot Ladder	0.07 (0.02, 0.21)	0.16 (0.06, 0.38)	0.77 (0.54, 0.89)	0

Table D-1.3-4: Probability of fish moving through states at 100% Bypass flow and varying Cabot flows during the daytime.

Beginning State at Flow		**Probability of Next State**			
		Downstream	**Bypass**	**Cabot Tailrace**	**Cabot Ladder**
25% Cabot Flow 100% Bypass Flow	**Downstream**	0	0.55 (0.20, 0.79)	0.31 (0.11, 0.59)	0.15 (0.02, 0.58)
	Bypass	0.60 (0.12, 0.89)	0	0.20 (0.04, 0.47)	0.20 (0.02, 0.79)
	Cabot Tailrace	0.60 (0.29, 0.84)	0.07 (0.02, 0.26)	0	0.33 (0.12, 0.61)
	Cabot Ladder	0.34 (0.05, 0.82)	0.36 (0.06, 0.79)	0.29 (0.06, 0.65	0
50% Cabot Flow 100% Bypass Flow	**Downstream**	0	0.57 (0.24, 0.81)	0.26 (0.09, 0.52)	0.16 (0.03, 0.54)
	Bypass	0.57 (0.14, 0.88)	0	0.19 (0.04, 0.51)	0.23 (0.02, 0.76)
	Cabot Tailrace	0.57 (0.25, 0.81)	0.06 (0.01, 0.22)	0	0.36 (0.14, 0.66)
	Cabot Ladder	0.23 (0.02, 0.77)	0.40 (0.05, 0.84)	0.36 (0.06, 0.75)	0
75 % Cab	**Downstream**	0	0.59 (0.25, 0.81)	0.24 (0.08, 0.51)	0.17 (0.03, 0.58)

Beginning State at Flow		Probability of Next State: Downstream	Bypass	Cabot Tailrace	Cabot Ladder
	Bypass	0.56 (0.13, 0.87)	0	0.19 (0.04, 0.48)	0.25 (0.02, 0.77)
	Cabot Tailrace	0.56 (0.23, 0.82)	0.06 (0.01, 0.24)	0	0.38 (0.14, 0.68)
	Cabot Ladder	0.19 (0.01, 0.77)	0.41 (0.04,0.88)	0.39 (0.06, 0.78)	0
100% Cabot Flow 100% Bypass Flow	Downstream	0	0.59 (0.24, 0.83)	0.24 (0.08, 0.48)	0.17 (0.03, 0.56)
	Bypass	0.56 (0.11, 0.87)	0	0.19 (0.04, 0.49)	0.25 (0.02, 0.79)
	Cabot Tailrace	0.55 (0.22, 0.80)	0.06 (0.01, 0.23)	0	0.39 (0.14, 0.70)
	Cabot Ladder	0.18 (0.01, 0.79)	0.42 (0.05, 0.89)	0.40 (0.05, 0.79)	0

Table D-1.3-5: Probability of fish moving through states at 25% Bypass flows and varying Cabot flows during the nighttime.

Beginning State at Flow		Probability of Next State: Downstream	Bypass	Cabot Tailrace	Cabot Ladder
25% Cabot Flow 25% Bypass Flow	Downstream	0	0.14 (0.04, 0.37)	0.72 (0.45, 0.88)	0.14 (0.04, 0.37)
	Bypass	0.13 (0.05, 0.29)	0	0.84 (0.66, 0.93)	0.02 (0.00, 0.17)
	Cabot Tailrace	0.21 (0.11, 0.36)	0.42 (0.26, 0.60)	0	0.37 (0.22, 0.53)
	Cabot Ladder	0.20 (0.04, 0.54)	0.08 (0.01, 0.30)	0.72 (0.37, 0.90)	0
50% Cabot Flow 25% Bypass Flow	Downstream	0	0.16 (0.04, 0.42)	0.67 (0.38, 0.84)	0.17 (0.05, 0.42)
	Bypass	0.13 (0.05, 0.29)	0	0.84 (0.63, 0.93)	0.03 (0.00, 0.18)
	Cabot Tailrace	0.20 (0.11, 0.35)	0.38 (0.24, 0.56)	0	0.41 (0.25, 0.57)
	Cabot Ladder	0.12 (0.03, 0.33)	0.08 (0.02, 0.28)	0.80 (0.55, 0.92)	0
75% Cabot Flow 25% Bypass Flow	Downstream	0	0.17 (0.05, 0.41)	0.65 (0.34, 0.83)	0.18 (0.06, 0.44)
	Bypass	0.13 (0.05, 0.30)	0	0.84 (0.63, 0.93)	0.03 (0.00, 0.19)
	Cabot Tailrace	0.20 (0.10, 0.34)	0.36 (0.23, 0.53)	0	0.44 (0.28, 0.60)
	Cabot Ladder	0.10 (0.03, 0.30)	0.08 (0.02, 0.25)	0.83 (0.58, 0.93)	0

Beginning State at Flow		Probability of Next State: Downstream	Bypass	Cabot Tailrace	Cabot Ladder
100% Cabot Flow 25% Bypass Flow	Downstream	0	0.17 (0.05, 0.43)	0.64 (0.35, 0.83)	0.19 (0.05, 0.48)
	Bypass	0.13 (0.05, 0.31)	0	0.84 (0.60, 0.93)	0.03 (0.00, 0.22)
	Cabot Tailrace	0.20 (0.10, 0.34)	0.36 (0.21, 0.51)	0	0.45 (0.28, 0.61)
	Cabot Ladder	0.09 (0.02, 0.27)	0.08 (0.02, 0.29)	0.84 (0.59, 0.93)	0

Table D-1.3-6: Probability of fish moving between states at 50% Bypass flows and varying Cabot flows during the nighttime.

Beginning State at Flow		Probability of Next State: Downstream	Bypass	Cabot Tailrace	Cabot Ladder
25% Cabot Flow 50% Bypass Flow	Downstream	0	0.18 (0.06, 0.44)	0.59 (0.33, 0.78)	0.24 (0.08, 0.46)
	Bypass	0.26 (0.12, 0.46)	0	0.70 (0.47, 0.84)	0.04 (0.01, 0.23)
	Cabot Tailrace	0.30 (0.17, 0.48)	0.34 (0.20, 0.51)	0	0.36 (0.22, 0.51)
	Cabot Ladder	0.31 (0.09, 0.64)	0.12 (0.02, 0.40)	0.57 (0.25, 0.81)	0
50% Cabot Flow 50% Bypass Flow	Downstream	0	0.19 (0.06, 0.45)	0.53 (0.27, 0.72)	0.27 (0.10, 0.52)
	Bypass	0.25 (0.11, 0.46)	0	0.70 (0.46, 0.84)	0.04 (0.01, 0.25)
	Cabot Tailrace	0.29 (0.16, 0.45)	0.31 (0.18, 0.46)	0	0.40 (0.25, 0.57)
	Cabot Ladder	0.20 (0.07, 0.47)	0.13 (0.03, 0.36)	0.67 (0.39, 0.84)	0
75% Cabot Flow 50% Bypass Flow	Downstream	0	0.20 (0.07, 0.48)	0.51 (0.26, 0.73)	0.29 (0.11, 0.57)
	Bypass	0.25 (0.11, 0.46)	0	0.71 (0.44, 0.84)	0.05 (0.01, 0.29)
	Cabot Tailrace	0.28 (0.15, 0.45)	0.29 (0.16, 0.46)	0	0.43 (0.27, 0.60)
	Cabot Ladder	0.16 (0.05, 0.42)	0.13 (0.03, 0.39)	0.71 (0.42, 0.86)	0
100% Cabot Flow 50% Bypass Flow	Downstream	0	0.21 (0.07, 0.48)	0.50 (0.24, 0.72)	0.30 (0.11, 0.57)
	Bypass	0.25 (0.11, 0.46)	0	0.70 (0.44, 0.84)	0.05 (0.01, 0.29)
	Cabot Tailrace	0.28 (0.15, 0.46)	0.28 (0.16, 0.45)	0	0.44 (0.27, 0.60)

Beginning State at Flow		Probability of Next State			
		Downstream	Bypass	Cabot Tailrace	Cabot Ladder
	Cabot Ladder	0.15 (0.04, 0.40)	0.13 (0.03, 0.40)	0.72 (0.43, 0.88)	0

Table D-1.3-7: Probability of fish moving between states at 75% Bypass flows and varying Cabot flows during the nighttime.

Beginning State at Flow		Probability of Next State			
		Downstream	Bypass	Cabot Tailrace	Cabot Ladder
25% Cabot Flow 75% Bypass Flow	Downstream	0	0.19 (0.05, 0.47)	0.53 (0.26, 0.74)	0.28 (0.10, 0.58)
	Bypass	0.33 (0.14, 0.58)	0	0.63 (0.35, 0.80)	0.05 (0.01, 0.31)
	Cabot Tailrace	0.35 (0.19, 0.54)	0.30 (0.16, 0.47)	0	0.35 (0.20, 0.52)
	Cabot Ladder	0.36 (0.10, 0.73)	0.14 (0.02, 0.492)	0.50 (0.21, 0.75)	0
50% Cabot Flow 75% Bypass Flow	Downstream	0	0.20 (0.06, 0.44)	0.47 (0.24, 0.70)	0.32 (0.13, 0.60)
	Bypass	0.32 (0.13, 0.55)	0	0.62 (0.37, 0.81)	0.05 (0.01, 0.29)
	Cabot Tailrace	0.33 (0.18, 0.52)	0.27 (0.14, 0.45)	0	0.39 (0.23, 0.58)
	Cabot Ladder	0.25 (0.07, 0.54)	0.15 (0.03, 0.46)	0.60 (0.31, 0.81)	0
75% Cabot Flow 75% Bypass Flow	Downstream	0	0.21 (0.07, 0.48)	0.44 (0.20, 0.66)	0.34 (0.14, 0.63)
	Bypass	0.32 (0.13, 0.56)	0	0.62 (0.37, 0.80)	0.06 (0.01, 0.33)
	Cabot Tailrace	0.32 (0.16, 0.50)	0.26 (0.13, 0.43)	0	0.42 (0.25, 0.61)
	Cabot Ladder	0.20 (0.05, 0.49)	0.15 (0.04, 0.50)	0.65 (0.33, 0.85)	0
100% Cabot Flow 75% Bypass Flow	Downstream	0	0.21 (0.07, 0.48)	0.43 (0.20, 0.68)	0.35 (0.13, 0.65)
	Bypass	0.32 (0.13, 0.57)	0	0.62 (0.34, 0.80)	0.06 (0.01, 0.33)
	Cabot Tailrace	0.32 (0.17, 0.52)	0.25 (0.12, 0.45)	0	0.42 (0.25, 0.60)
	Cabot Ladder	0.18 (0.05, 0.47)	0.15 (0.03, 0.46)	0.66 (0.34, 0.87)	0

Table D-1.3-8: Probability of fish moving between states at 100% Bypass flows and varying Cabot flows during the nighttime.

Beginning State at Flow		Probability of Next State			
		Downstream	Bypass	Cabot Tailrace	Cabot Ladder
25% Cabot Flow 100% Bypass Flow	Downstream	0	0.20 (0.02, 0.62)	0.21 (0.03, 0.56)	0.60 (0.12, 0.93)
	Bypass	0.74 (0.20, 0.96)	0	0.19 (0.02, 0.57)	0.07 (0.00, 0.67)
	Cabot Tailrace	0.61 (0.26, 0.87)	0.14 (0.02, 0.44)	0	0.25 (0.07, 0.54)
	Cabot Ladder	0.61 (0.07, 0.96)	0.22 (0.01, 0.80)	0.17 (0.01, 0.57)	0
50% Cabot Flow 100% Bypass Flow	Downstream	0	0.20 (0.02, 0.65)	0.17 (0.02, 0.50)	0.63 (0.11, 0.95)
	Bypass	0.73 (0.16, 0.95)	0	0.19 (0.03, 0.512)	0.08 (0.00, 0.75)
	Cabot Tailrace	0.59 (0.25, 0.85)	0.12 (0.02, 0.42)	0	0.28 (0.08, 0.60)
	Cabot Ladder	0.48 (0.03, 0.94)	0.28 (0.01, 0.88)	0.24 (0.02, 0.68)	0
75% Cabot Flow 100% Bypass Flow	Downstream	0	0.20 (0.02, 0.61)	0.16 (0.02, 0.52)	0.65 (0.14, 0.95)
	Bypass	0.72 (0.15, 0.94)	0	0.19 (0.03, 0.56)	0.09 (0.00, 0.69)
	Cabot Tailrace	0.58 (0.22, 0.85)	0.12 (0.02, 0.42)	0	0.30 (0.09, 0.65)
	Cabot Ladder	0.42 (0.03, 0.94)	0.31 (0.01, 0.87)	0.27 (0.02, 0.72)	0
100% Cabot Flow 100% Bypass Flow	Downstream	0	0.20 (0.02, 0.62)	0.15 (0.02, 0.50)	0.65 (0.15, 0.94)
	Bypass	0.72 (0.17, 0.94)	0	0.19 (0.03, 0.58)	0.09 (0.00, 0.69)
	Cabot Tailrace	0.58 (0.22, 0.85)	0.12 (0.02, 0.43)	0	0.31 (0.09, 0.65)
	Cabot Ladder	0.40 (0.02, 0.91)	0.32 (0.01, 0.90)	0.29 (0.02, 0.72)	0

Table D-1.3-9: Expected visits (forays) in the MSM Cabot Ladder Attraction Model during the day.

Bypass Flow	Cabot Discharge	Expected Visits			
		Downstream	Bypass	Cabot Tailrace	Cabot Ladder
25%	25%	4.51 (3.44, 6.18)	5.77 (4.58, 7.59)	15.18 (12.73, 18.19)	8.22 (6.01, 11.12)
	50%	4.67 (3.61, 6.14)	6.20 (4.91, 7.88)	17.69 (14.55, 21.23)	10.48 (7.96, 13.83)

	75%	4.71 (3.7, 6.38)	6.37 (4.98, 8.38)	18.91 (14.88, 23.21)	11.66 (8.59, 15.83)
	100%	4.73 (3.63, 6.34)	6.43 (5, 8.68)	19.37 (15.39, 23.58)	12.11 (8.6, 16.46)
50%	25%	4.90 (4.03, 6.01)	4.78 (4.01, 5.85)	10.73 (8.96, 12.77)	5.87 (4.61, 7.61)
	50%	5.11 (4.19, 6.3)	5.33 (4.43, 6.44)	12.56 (10.55, 15.22)	7.54 (5.93, 9.76)
	75%	5.19 (4.13, 6.48)	5.57 (4.53, 7.03)	13.49 (10.59, 16.48)	8.43 (6.03, 11.18)
	100%	5.22 (4.17, 6.58)	5.66 (4.65, 7.17)	13.84 (11, 17.48)	8.77 (6.33, 12.18)
75%	25%	4.94 (3.95, 6.27)	4.51 (3.69, 5.56)	9.05 (7.3, 11.06)	5.01 (3.72, 6.82)
	50%	5.17 (4.16, 6.5)	5.10 (4.22, 6.26)	10.58 (8.53, 13.14)	6.44 (4.75, 8.58)
	75%	5.27 (4.1, 6.86)	5.36 (4.3, 6.89)	11.37 (8.65, 14.69)	7.20 (5.07, 10.14)
	100%	5.30 (4.05, 6.88)	5.45 (4.32, 7.1)	11.67 (8.8, 15.29)	7.50 (5.33, 11.02)
100%	25%	4.88 (2.44, 10.93)	4.21 (2.48, 8.92)	3.16 (1.61, 6.65)	2.59 (1.12, 9.33)
	50%	5.25 (2.59, 11.37)	4.93 (2.99, 10.94)	3.57 (1.89, 8.3)	3.26 (1.4, 11.7)
	75%	5.43 (2.77, 12.34)	5.30 (3.22, 11.25)	3.82 (1.95, 9.38)	3.65 (1.45, 11.4)
	100%	5.50 (2.92, 12.46)	5.44 (3.27, 12.38)	3.92 (1.98, 9.69)	3.81 (1.6, 13.46)

Table D-1.3-10: Expected visits (forays) in the MSM Cabot Ladder Attraction Model at night.

		Expected Visits			
Bypass Flow	**Cabot Discharge**	**Downstream**	**Bypass**	**Cabot Tailrace**	**Cabot Ladder**
25%	25%	1.98 (1.27, 3.18)	2.84 (1.75, 4.56)	5.80 (3.96, 8.13)	2.40 (1.44, 4.2)
	50%	1.86 (1.27, 2.93)	2.80 (1.76, 4.5)	6.12 (4.3, 8.95)	2.85 (1.7, 4.93)
	75%	1.81 (1.26, 2.97)	2.78 (1.67, 4.74)	6.28 (4.28, 9.18)	3.09 (1.76, 5.54)

	100%	1.79 (1.23, 2.84)	2.77 (1.77, 4.82)	6.34 (4.4, 9.8)	3.18 (1.86, 5.82)
50%	25%	2.43 (1.66, 3.67)	2.15 (1.34, 3.61)	4.31 (3.02, 6.19)	2.21 (1.29, 3.93)
	50%	2.31 (1.62, 3.54)	2.20 (1.35, 3.77)	4.61 (3.21, 6.72)	2.60 (1.61, 4.61)
	75%	2.26 (1.54, 3.56)	2.21 (1.36, 3.94)	4.78 (3.13, 7.23)	2.81 (1.67, 5.22)
	100%	2.25 (1.56, 3.64)	2.22 (1.34, 3.92)	4.85 (3.24, 7.23)	2.89 (1.61, 5.2)
75%	25%	2.63 (1.79, 4.4)	1.97 (1.22, 3.49)	3.80 (2.53, 5.84)	2.20 (1.21, 4.24)
	50%	2.52 (1.72, 4.01)	2.05 (1.23, 3.56)	4.09 (2.76, 6.34)	2.58 (1.52, 4.78)
	75%	2.48 (1.7, 3.86)	2.09 (1.23, 3.89)	4.26 (2.71, 6.49)	2.78 (1.54, 5.11)
	100%	2.46 (1.64, 4.19)	2.10 (1.24, 3.93)	4.33 (2.75, 6.87)	2.86 (1.57, 5.66)
100%	25%	4.44 (1.77, 15.81)	1.96 (0.78, 6.59)	1.88 (0.9, 5.01)	3.46 (0.76, 16.59)
	50%	4.44 (1.85, 14.34)	2.26 (0.87, 7.01)	2.08 (0.87, 6.21)	3.78 (0.93, 15.15)
	75%	4.45 (1.68, 18.26)	2.43 (0.98, 7.8)	2.22 (0.92, 7.88)	3.95 (1.01, 20.33)
	100%	4.45 (1.84, 17.83)	2.49 (0.94, 8.1)	2.28 (0.94, 9.06)	4.02 (0.92, 20.11)

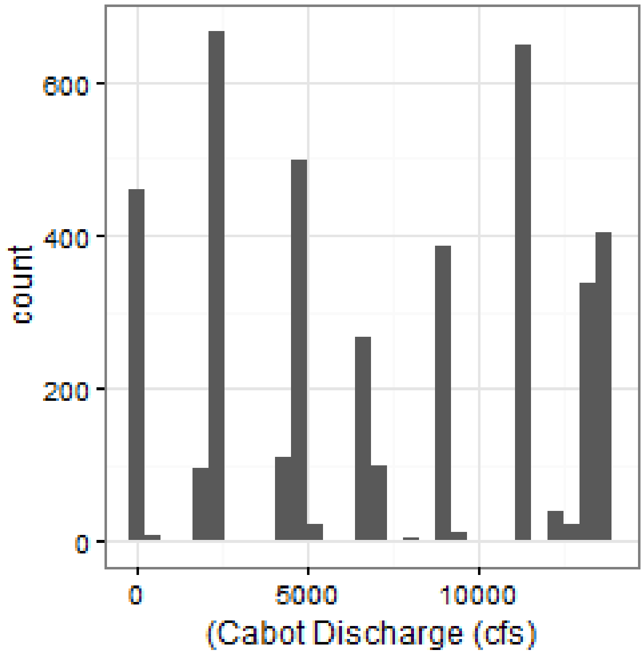

Figure D-1.3-1 Cabot discharge experienced by fish in the MSM Cabot Attraction Model

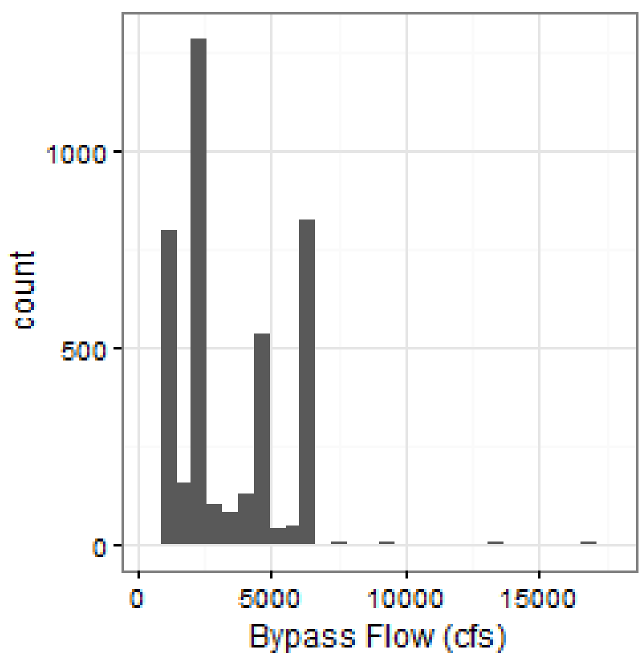

Figure D-1.3-2 Bypass flow experienced by fish in the MSM Cabot Attraction Model

D-1.4 Upstream Migration through Canal

Two models were created for the MSM Upstream Canal analysis. Model 1 included time in decimal days with no covariates and had an AIC value of 668. Model 2 included time in decimal days with Cabot Canal flow as a covariate and had an AIC value of 404. A likelihood ratio test revealed that Model 2 was significantly better than Model 1 ($p < 0.001$).

Table D-1.4-1. Probability of fish moving between states at various Cabot Canal flows in the MSM Upstream Canal Model (continued on next page).

Beginning State at Flow		Probability of Next State						
		Downstream Bypass	Cabot Forebay	Lower Canal	Upper Canal	Gatehouse Yagi	Gatehouse Ladder	Upstream Passage
25% Flow	Downstream Bypass	0	0.95 (0.94-0.97)	0.05 (0.03-0.06)	0	0	0	0
	Cabot Forebay	0.70 (0.67-0.73)	0	0.29 (0.26-0.32)	0	0	0	0
	Lower Canal	0.04 (0.02-0.06)	0.75 (0.70-0.78)	0	0.21 (0.17-0.25)	0	0	0
	Upper Canal	0.001 (0.00-0.11)	0.00 (0.00-0.09)	0.31 (0.22-0.38)	0	0.69 (0.55-0.76)	0	0
	Gatehouse Yagi	0	0	0	0.89 (0.00-0.93)	0	0.11 (0.00-0.19)	0.00 (0.00-1.00)
	Gatehouse Ladder	0	0	0	0.05 (0.00-0.60)	0.02 (0.00-0.70)	0	0.93 (0.22-0.99)
50% Flow	Downstream Bypass	0	0.96 (0.94-0.97)	0.05 (0.03-0.06)	0	0	0	0
	Cabot Forebay	0.70 (0.67-0.73)	0	0.29 (0.27-0.32)	0	0	0	0
	Lower Canal	0.03 (0.02-0.05)	0.81 0.77-0.84)	0	0.16 (0.12-0.20)	0	0	0
	Upper Canal	0	0.01 (0.00-0.06)	0.47 (0.39-0.55)	0	0.52 (0.43-0.59)	0	0
	Gatehouse Yagi	0	0	0	0.86 (0.44-0.92)	0	0.12 (0.00-0.20)	0.00 (0.00-1.00)
	Gatehouse Ladder	0	0	0	0.09 (0.01-0.42)	0.32 (0.08-0.66)	0	0.59 (0.25-0.84)

Table D-1.4-1. Probability of fish moving between states at various flows in the MSM Upstream Canal Model.

Beginning State at Flow		Probability of Next State						
		Downstream Bypass	Cabot Forebay	Lower Canal	Upper Canal	Gatehouse Yagi	Gatehouse Ladder	Upstream Passage
75% Flow	Downstream Bypass	0	0.96 (0.03-0.97)	0.04 (0.03-0.06)	0	0	0	0
	Cabot Forebay	0.70 (0.66-0.73)	0	0.30 (0.27-0.33)	0	0	0	0
	Lower Canal	0.02 (0.01-0.05)	0.86 (0.81-0.89)	0	0.11 (0.09-0.16)	0	0	0
	Upper Canal	0.12 (0.11-0.12)	0.03 (0.00-0.11)	0.63 (0.49-0.72)	0	0.33 (0.23-0.43)	0	0
	Gatehouse Yagi	0	0	0	0.84 (0.02-0.93)	0	0.15 (0.00-0.32)	0.00 (0.00-0.97)
	Gatehouse Ladder	0	0	0	0.04 (0.00-0.61)	0.89 (0.23-0.99)	0	0.07 (0.00-0.48)
100% Flow	Downstream Bypass	0	0.95 (0.93-0.97)	0.04 (0.03-0.07)	0	0	0	0
	Cabot Forebay	0.69 (0.65-0.74)	0	0.29 (0.25-0.34)	0.003 (0.000-0.02)	0	0	0
	Lower Canal	0.02 (0.00-0.05)	0.88 (0.03-0.91)	0	0.09 (0.07-0.13)	0	0	0
	Upper Canal	0.02 (0.00-0.48)	0.09 (0.00-0.51)	0.67 (0.26-0.80)	0	0.22 (0.07-0.32)	0	0
	Gatehouse Yagi	0	0	0	0.00 (0.00-0.85)	0	0.00 (0.00-0.27)	0.99 (0.00-1.00)
	Gatehouse Ladder	0	0	0	0.01 (0.00-0.87)	0.98 (0.08-0.99)	0	0

Table D-1.4-2. Expected visits (forays) in the MSM Upstream Canal Model.

Canal Flow	Expected Visits						
	Downstream Bypass	Cabot Forebay	Lower Canal	Upper Canal	Gatehouse Yagi	Gatehouse Ladder	Upstream Passage
25%	37.99 (12.58-115.07)	52.90 (17.51-162.37)	21.012 (6.32-58.71)	12.07 (1.42-29.76)	8.22 (0.99-22.52)	9.35 (0.00-2.75)	0.87 (0.40-10.99)
50%	63.92 (20.42-81.29)	89.72 (28.83-112.67)	34.57 (10.46-42.85)	11.00 (1.84-15.43)	5.92 (0.98-8.89)	0.78 (0.00-1.30)	0.46 (0.19-0.99)
75%	78.77 (36.84-86.86)	111.38 (53.33-119.78)	41.37 (18.85-44.99)	7.73 (2.47-10.30)	2.95 (0.85-4.59)	0.46 (0.00-1.01)	0.03 (0.00-0.85)
100%	51.04 (37.28-77.66)	72.40 (53.69-108.39)	25.67 (19.35-39.20)	2.69 (2.04-5.77)	0.58 (0.26-1.45)	0.00 (0.00-0.29)	0.58 (0.00-0.79)

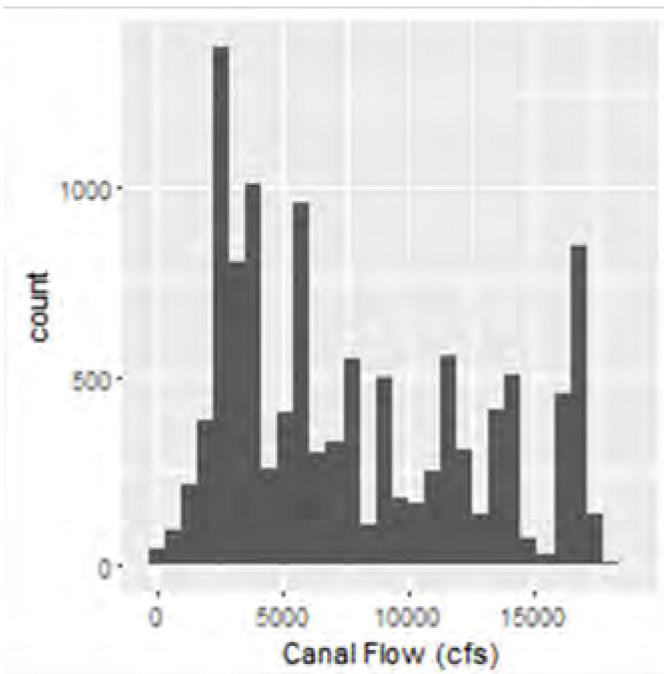

Figure D-1.4-1. Flow in Cabot Canal experienced by fish in the MSM Upstream Canal Model

D-1.5 Rawson Island

Four models were created for the MSM Rawson Island analysis. Model 1 included time in decimal days with no covariates and had an AIC value of 899. Model 2 included time in decimal days with ln(BypassFlow) as a covariate and had an AIC value of 896. Model 3 included time in decimal days with Station No. 1 Operations as a covariate and had an AIC value of 878. Model 4 included time in decimal days with diurnal cues as a covariate and had an AIC value of 894. Likelihood ratio tests revealed that Model 2 was significantly better than Model 1 (P = 0.02), Model 3 was not significantly better than Model

1, and Model 4 was not significantly better than Model 2. Overall, Model 2 was the best model as it incorporates bypass flow with an AIC value of 896.

Table D-1.5-1. Probability of fish moving between states at varying flows in the MSM Rawson Island Model.

Beginning State at Flow		Probability of Next State			
		Downstream	T12W	T12E	Upstream
25% Flow	Downstream	0	0.45 (0.31, 0.61)	0.18 (0.09, 0.32)	0.37 (0.24, 0.51)
	T12W	0.38 (0.23, 0.54)	0	0.46 (0.29, 0.62)	0.16 (0.07, 0.34)
	T12E	0.39 (0.21, 0.59)	0.58 (0.36, 0.75)	0	0.02 (0.00, 0.21)
	Upstream	0.92 (0.56, 0.99)	0.08 (0.01, 0.44)	0	0
50% Flow	Downstream	0	0.34 (0.22, 0.45)	0.39 (0.26, 0.52)	0.27 (0.17, 0.40)
	T12W	0.33 (0.21, 0.47)	0	0.49 (0.34, 0.62)	0.19 (0.10, 0.31)
	T12E	0.43 (0.29, 0.57)	0.55 (0.39, 0.68)	0	0.02 (0.00, 0.15)
	Upstream	0.88 (0.65, 0.96)	0.12 (0.04, 0.35)	0	0
75% Flow	Downstream	0	0.25 (0.15, 0.36)	0.55 (0.42, 0.68)	0.20 (0.12, 0.31)
	T12W	0.29 (0.18, 0.44)	0	0.50 (0.33, 0.64)	0.21 (0.10, 0.37)
	T12E	0.45 (0.28, 0.60)	0.53 (0.36, 0.67)	0	0.02 (0.00, 0.16)
	Upstream	0.84 (0.61, 0.95)	0.16 (0.05, 0.39)	0	0
100% Flow	Downstream	0	0.25 (0.15, 0.36)	0.55 (0.42, 0.68)	0.20 (0.12, 0.31)
	T12W	0.29 (0.18, 0.44)	0	0.50 (0.33, 0.64)	0.21 (0.10, 0.37)
	T12E	0.45 (0.28, 0.60)	0.53 (0.36, 0.67)	0	0.02 (0.00, 0.16)
	Upstream	0.84 (0.61, 0.95)	0.16 (0.05, 0.39)	0	0

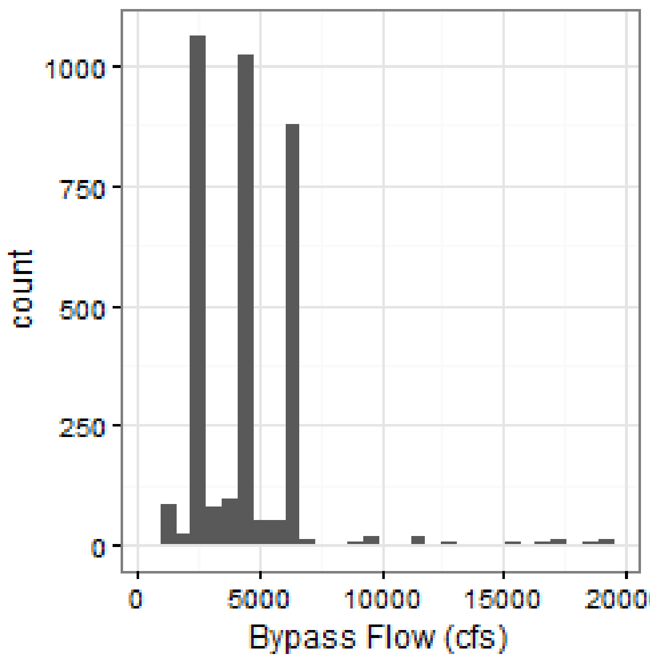

Figure D-1.5-1: Flow in the Bypass Reach experienced by fish in the MSM Rawson Model

D-1.6 Attraction to the Spillway Fish Ladder

Four models were created for the MSM Spillway Ladder Attraction analysis. Model 1 included time in decimal days with no covariates and had an AIC value of 485. Model 2, which included time decimal days with Bypass flow as a covariate had an AIC value of 483. Model 3 included time in decimal days and incorporated diurnal cues as a covariate had an AIC value of 485. Model 4, which included time in decimal days and incorporated Bypass flow and diurnal cues as covariates had an AIC value of 485. Likelihood ratio test concluded that Model 2 performed significantly better than Model 1 (p = 0.02), and Model 3 was not significantly better than Model 1 (p = 0.05). Model 4 was not significantly better than Model 2 (p = 0.12). Overall, Model 2 was deemed the best model (AIC = 483), showing that flow effects entrance into the spillway ladder.

Table D-1.6-1: Probability of fish moving between states at varying Bypass flows in the MSM Spillway Attraction Model.

Beginning State at Flow		Probability of Next State		
		Downstream	Tailrace	Spillway ladder
25% Flow	Downstream	0	0.74 (0.41, 0.92)	0.26 (0.08, 0.59)
	Tailrace	0.35 (0.16, 0.59)	0	0.65 (0.41, 0.84)
	Spillway Ladder	0.08 (0.01, 0.45)	0.92 (0.55, 0.99)	0
50% Flow	Downstream	0	0.92 (0.69, 0.98)	0.08 (0.02, 0.31)
	Tailrace	0.49 (0.35, 0.64)	0	0.51 (0.36, 0.65)

	Spillway Ladder	0.002 (0.00, 1.00)	1.00 (0.00, 1.00)	0
75% Flow	**Downstream**	0	0.97 (0.76, 0.99)	0.03 (0.00, 0.24)
	Tailrace	0.59 (0.40, 0.75)	0	0.41 (0.25, 0.60)
	Spillway Ladder	0.0002 (0.00, 1.00)	1.00 (0.00, 1.00)	0
100% Flow	**Downstream**	0	1.00 (0.79, 1.00)	0.002 (0.00, 0.21)
	Tailrace	0.83 (0.42, 0.98)	0	0.17 (0.02, 0.58)
	Spillway Ladder	0 (0.00, 1.00)	1.00 (0.00, 1.00)	0

Table D-1.6-2: Expected visits (forays) in the MSM Spillway Attraction Model.

Bypass Flow	**Expected Visits**		
	Downstream	**Tailrace**	**Spillway Ladder**
25%	1.82 (1.1, 3.29)	4.82 (2.66, 7.88)	3.47 (1.69, 6.38)
50%	2.51 (1.9, 4.34)	5.53 (3.02, 7.31)	2.80 (1.44, 4.43)
75%	3.32 (2.4, 5.46)	6.17 (3.81, 9.01)	2.47 (1.24, 5.23)
100%	7.95 (2.7, 4,096.43)	10.23 (4.46, 3,951.62)	1.59 (0.32, 1,299.82)

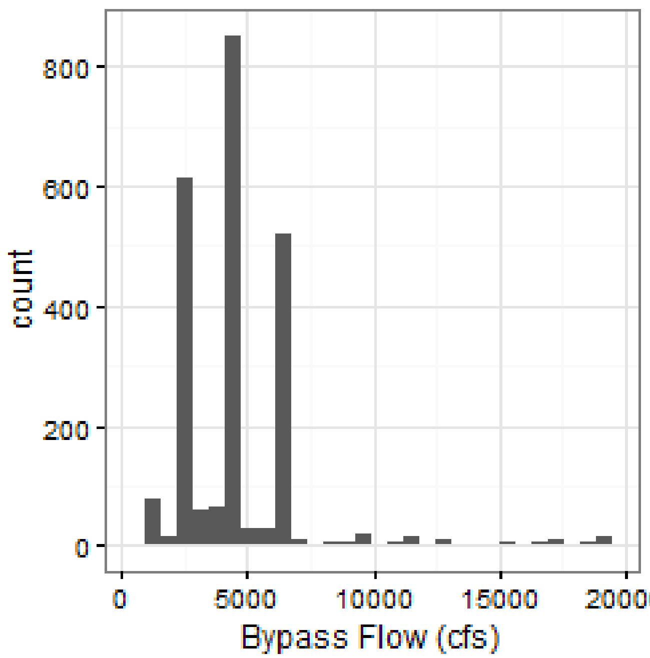

Figure D-1.6-1: Flow in the Bypass Reach experienced by fish in the MSM Spillway Attraction Model, before and after log transformation

D-1.7 Turners Falls Impoundment

Four models were created for the MSM Impoundment analysis. Model 1 included time in decimal days and had an AIC value of 4119. Model 2, which included time in decimal days and included scaled flow as a covariate had an AIC value of 2415. Model 3, which included time in decimal days and included diurnal cues as a covariate had an AIC value of 3990. Model 4 included time in decimal days and was a saturated model that incorporated scaled flow and diurnal cues as covariates and had an AIC value of 3936. Likelihood ratio tests concluded that Model 2 was significantly better than Model 1 ($p < 0.001$) and Model 3 was significantly better than Model 1 ($p < 0.001$). Overall, Model 4, the saturated model incorporating scaled flow and diurnal cues was the best model with an AIC value of 3936.

Table D-1.7-1. Probability of fish moving through states at various pumping flows at NMPS during the nighttime in the MSM Impoundment Model.

Beginning State at Flow		Probability of Next State			
		Lower Impoundment	DS NMPS Intake	NMPS Intake	Shearer Farms
25% Pumping Flow	Lower Impoundment	0	0.99 (0.82, 1.00)	0	0.01 (0.00, 0.18)
	DS NMPS Intake	0.14 (0.08, 0.22)	0	0.33 (0.23, 0.42)	0.53 (0.43, 0.63)
	NMPS Intake	0.02 (0.00, 0.13)	0.82 (0.61, 0.92)	0	0.16 (0.06, 0.34)
	Shearer Farms	0.13 (0.07, 0.22)	0.56 (0.45, 0.68)	0.30 (0.20, 0.42)	0
50 %	Lower Impoundment	0	0.98 (0.81, 1.00)	0	0.02 (0.00, 0.19)

	DS NMPS Intake	0.19 (0.13, 0.27)	0	0.23 (0.16, 0.30)	0.58 (0.50, 0.67)
	NMPS Intake	0.05 (0.01, 0.19)	0.79 (0.59, 0.89)	0	0.16 (0.07, 0.32)
	Shearer Farms	0.17 (0.11, 0.26)	0.69 (0.60, 0.77)	0.14 (0.08, 0.21)	0
75% Pumping Flow	**Lower Impoundment**	0	0.97 (0.78, 1.00)	0	0.03 (0.00, 0.22)
	DS NMPS Intake	0.25 (0.18, 0.34)	0	0.15 (0.10, 0.22)	0.60 (0.51, 0.68)
	NMPS Intake	0.10 (0.03, 0.29)	0.73 (0.50, 0.85)	0	0.17 (0.07, 0.36)
	Shearer Farms	0.20 (0.13, 0.28)	0.75 (0.66, 0.82)	0.05 (0.03, 0.09)	0
100% Pumping Flow	**Lower Impoundment**	0	0.94 (0.66, 0.99)	0	0.06 (0.01, 0.34)
	DS NMPS Intake	0.31 (0.22, 0.41)	0	0.09 (0.05, 0.15)	0.60 (0.49, 0.69)
	NMPS Intake	0.21 (0.07, 0.47)	0.63 (0.38, 0.80)	0	0.16 (0.05, 0.36)
	Shearer Farms	0.22 (0.14, 0.33)	0.77 (0.64, 0.84)	0.02 (0.01, 0.04)	0

Table D-1.7-2. Probability of fish moving through states during no operations during the day and night in the MSM Impoundment Model.

Beginning State at Flow		**Probability of Next State**			
		Lower Impoundment	**DS NMPS Intake**	**NMPS Intake**	**Shearer Farms**
No Operations Daytime	**Lower Impoundment**	0	0.99 (0.91, 1.00)	0	0.01 (0.0, 0.09)
	DS NMPS Intake	0.07 (0.05, 0.11)	0	0.24 (0.19, 0.30)	0.68 (0.63, 0.74)
	NMPS Intake	0.05 (0.02, 0.12)	0.78 (0.68, 0.85)	0	0.17 (0.10, 0.25)
	Shearer Farms	0.20 (0.15, 0.27)	0.68 (0.60, 0.74)	0.12 (0.07, 0.18)	0
No Operations Nighttime	**Lower Impoundment**	0	0.94 (0.65, 0.99)	0	0.06 (0.01, 0.35)
	DS NMPS Intake	0.31 (0.22, 0.42)	0	0.09 (0.05, 0.16)	0.60 (0.48, 0.69)
	NMPS Intake	0.21 (0.07, 0.48)	0.63 (0.37, 0.81)	0	0.16 (0.05, 0.35)
	Shearer Farms	0.22 (0.14, 0.33)	0.77 (0.66, 0.85)	0.02 (0.01, 0.05)	0

Table D-1.7-3. Probability of fish moving through states at various discharge flows at NMPS Intake during the nighttime in the MSM Impoundment Model.

Beginning State at Flow		Probability of Next State			
		Lower Impoundment	DS NMPS Intake	NMPS Intake	Shearer Farms
25% Discharge Flow	Lower Impoundment	0	0.91 (0.55, 0.99)	0	0.09 (0.01, 0.45)
	DS NMPS Intake	0.35 (0.23, 0.47)	0	0.07 (0.03, 0.13)	0.58 (0.46, 0.69)
	NMPS Intake	0.30 (0.10, 0.61)	0.55 (0.28, 0.76)	0	0.14 (0.04, 0.36)
	Shearer Farms	0.22 (0.13, 0.36)	0.77 (0.63, 0.86)	0.01 (0.00, 0.02)	0
50% Discharge Flow	Lower Impoundment	0	0.90 (0.53, 0.99)	0	0.10 (0.01, 0.47)
	DS NMPS Intake	0.35 (0.23, 0.48)	0	0.06 (0.03, 0.13)	0.58 (0.45, 0.70)
	NMPS Intake	0.31 (0.11, 0.64)	0.55 (0.26, 0.77)	0	0.14 (0.04, 0.41)
	Shearer Farms	0.22 (0.12, 0.36)	0.77 (0.63, 0.87)	0.009 (0.00, 0.03)	0
75% Discharge Flow	Lower Impoundment	0	0.85 (0.33, 0.99)	0	0.15 (0.01, 0.67)
	DS NMPS Intake	0.40 (0.26, 0.56)	0	0.04 (0.02, 0.10)	0.56 (0.40, 0.69)
	NMPS Intake	0.44 (0.13, 0.80)	0.44 (0.15, 0.73)	0	0.12 (0.02, 0.35)
	Shearer Farms	0.23 (0.12, 0.41)	0.76 (0.59, 0.88)	0.004 (0.00, 0.01)	0
100% Discharge Flow	Lower Impoundment	0	0.42 (0.00, 0.99)	0	0.58 (0.01, 1.00)
	DS NMPS Intake	0.57 (0.27, 0.82)	0	0.01 (0.02, 0.038)	0.42 (0.18, 0.71)
	NMPS Intake	0.90 (0.35, 0.99)	0.08 (0.00, 0.51)	0	0.03 (0.00, 0.37)
	Shearer Farms	0.26 (0.08, 0.59)	0.74 (0.41, 0.92)	0	0

Table D-1.7-4. Probability of fish moving through states at various discharge flows at NMPS Intake during the daytime in the MSM Impoundment Model.

Beginning State at Flow		Probability of Next State			
		Lower Impoundment	DS NMPS Intake	NMPS Intake	Shearer Farms
25% Discharge	Lower Impoundment	0	0.98 (0.92, 1.00)	0	0.02 (0.00, 0.08)
	DS NMPS Intake	0.09 (0.06, 0.13)	0	0.19 (0.15, 0.24)	0.72 (0.66, 0.77)

	NMPS Intake	0.08 (0.04, 0.16)	0.75 (0.64, 0.83)	0	0.17 (0.11, 0.26)
	Shearer Farms	0.22 (0.16, 0.29)	0.71 (0.64, 0.77)	0.07 (0.04, 0.11)	0
50% Discharge Flow	Lower Impoundment	0	0.98 (0.91, 1.00)	0	0.02 (0.00, 0.09)
	DS NMPS Intake	0.09 (0.06, 0.13)	0	0.19 (0.15, 0.24)	0.72 (0.67, 0.77)
	NMPS Intake	0.09 (0.04, 0.17)	0.74 (0.63, 0.83)	0	0.17 (0.10, 0.27)
	Shearer Farms	0.22 (0.16, 0.29)	0.71 (0.64, 0.78)	0.06 (0.04, 0.11)	0
75% Discharge Flow	Lower Impoundment	0	0.97 (0.87, 0.99)	0	0.03 (0.01, 0.13)
	DS NMPS Intake	0.11 (0.07, 0.16)	0	0.14 (0.10, 0.19)	0.75 (0.68, 0.80)
	NMPS Intake	0.14 (0.06, 0.27)	0.69 (0.55, 0.79)	0	0.17 (0.09, 0.30)
	Shearer Farms	0.24 (0.17, 0.32)	0.73 (0.64, 0.80)	0.03 (0.02, 0.06)	0
100% Discharge Flow	Lower Impoundment	0	0.80 (0.16, 0.99)	0	0.20 (0.01, 0.84)
	DS NMPS Intake	0.21 (0.10, 0.39)	0	0.04 (0.01, 0.09)	0.75 (0.57, 0.87)
	NMPS Intake	0.64 (0.16, 0.95)	0.27 (0.04, 0.69)	0	0.08 (0.01, 0.35)
	Shearer Farms	0.28 (0.12, 0.50)	0.72 (0.50, 0.87)	0.002 (0.00, 0.01)	0

Table D-1.7-5 Expected visits (forays) at varying operational scenarios in the MSM Impoundment Model.

Diel Period	Operations Scenario	Expected Visits Lower Impoundment	DS NMPS Intake	NMPS Intake	Shearer Farms
Day	No Operations	2.46 (2.00, 3.12)	10.91 (9.75, 12.15)	3.42 (2.72, 4.32)	7.95 (7.11, 8.92)
Night	No Operations	4.97 (3.83, 6.47)	10.83 (8.6, 13.13)	1.02 (0.57, 1.77)	6.85 (5.17, 9.52)
Night	25% Pump	4.58 (3.34, 6.58)	19.14 (15.01, 22.96)	9.25 (6.5, 12.74)	12.06 (9.02, 15.41)
	50% Pump	4.83 (3.78, 6.42)	15.28 (12.42, 17.99)	4.43 (3.14, 6.22)	9.77 (7.63, 12.32)
	75% Pump	4.93	12.64	2.09	8.07

		(3.83, 6.28)	(10.53, 15.01)	(1.4, 3.07)	(6.52, 10.15)
	100% Pump	4.97 (3.82, 6.68)	10.84 (8.54, 13.25)	1.03 (0.57, 1.81)	6.85 (5.07, 9.25)
Day	**25% Discharge**	2.42 (1.96, 3.03)	9.46 (8.54, 10.54)	2.21 (1.71, 2.8)	7.07 (6.39, 7.87)
	50% Discharge	2.42 (1.94, 2.98)	9.37 (8.42, 10.39)	2.14 (1.64, 2.74)	7.01 (6.34, 7.83)
	75% Discharge	2.37 (1.88, 3.1)	8.16 (7.17, 9.24)	1.32 (0.96, 1.85)	6.25 (5.53, 7.09)
	100% Discharge	2.22 (1.37, 3.97)	5.23 (3.53, 7.16)	0.20 (0.08, 0.53)	4.41 (3.2, 6.61)
Night	**25% Discharge**	4.98 (3.7, 6.97)	10.01 (7.64, 12.65)	0.69 (0.36, 1.42)	6.32 (4.59, 9.45)
	50% Discharge	4.98 (3.74, 6.97)	9.95 (7.79, 12.73)	0.67 (0.32, 1.31)	6.29 (4.56, 9.48)
	75% Discharge	5.01 (3.46, 7.72)	9.16 (6.86, 12.08)	0.42 (0.18, 1.02)	5.86 (3.7, 10.29)
	100% Discharge	5.35 (2.39, 10.96)	6.78 (3.83, 11.13)	0.06 (0.01, 0.28)	6.27 (1.95, 13.35)

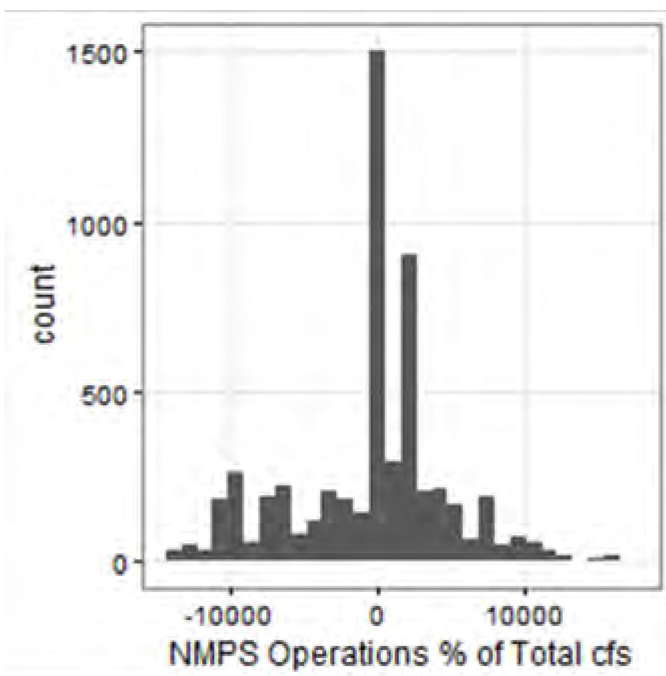

Figure D-1.7-1 NMPS operations experienced by fish in the MSM Impoundment Model

D-1.8 Downstream Passage at Turners Falls Dam

Five models were created for the MSM downstream passage analysis. Model 1 included time in decimal days and had an AIC value of 1093. Model 2, which included time in decimal days and incorporated Cabot canal flow as a covariate had an AIC value of 1101. Model 3, which included time in decimal days and incorporated spill flow as a covariate had an AIC value of 1101. Model 4, which included time in decimal days and incorporated diurnal cues as a covariate did not converge. Model 5, which included time in decimal days and incorporated both Cabot canal and TF Dam flows as covariates did not converge. Likelihood ratio tests concluded that Models 2 and 3 are not significantly better than Model 1 (9 = 0.559, p = 0.580), respectively. Overall, Model 1, the reduced model, which includes decimal days was the best model with an AIC value of 1093.

Below is the state table (Table D-1.8-1) displaying the raw number of transitions among states within each exposure hour, and is read as from (row) to (column). When a fish transitions between non adjacent states, it moves undetected through a telemetry station.

Table D-1.8-1: State Table displaying the transitions from (row) to (column) at each hour exposure in the MSM Downstream Passage Model.

	To			
From	**Impoundment**	**Gatehouse Ladder**	**Gatehouse-Canal**	**Spillway**
Impoundment	3,272	0	91	32
Gatehouse Ladder	1	1	1	0
Gatehouse-Canal	4	2	1,297	3
Spillway	0	0	0	0

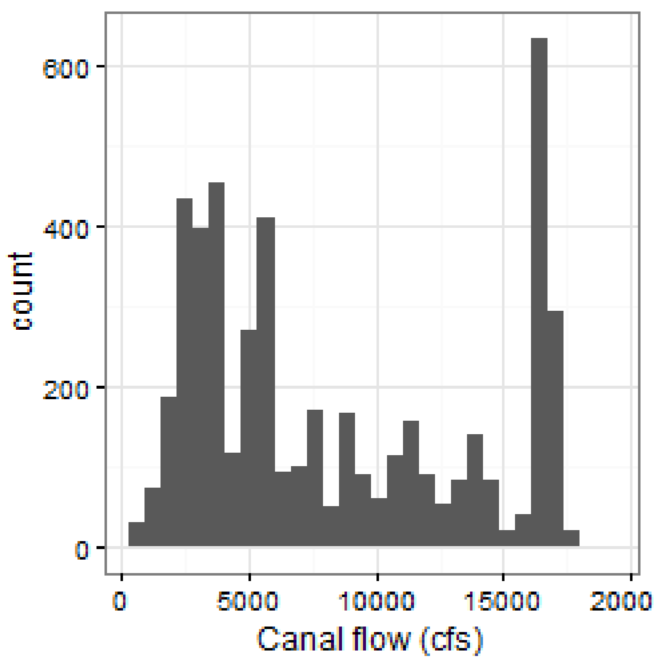

Figure D-1.8-1 Flow in Cabot Canal experienced by fish in the MSM Downstream Passage Model, both before and after log transformation.

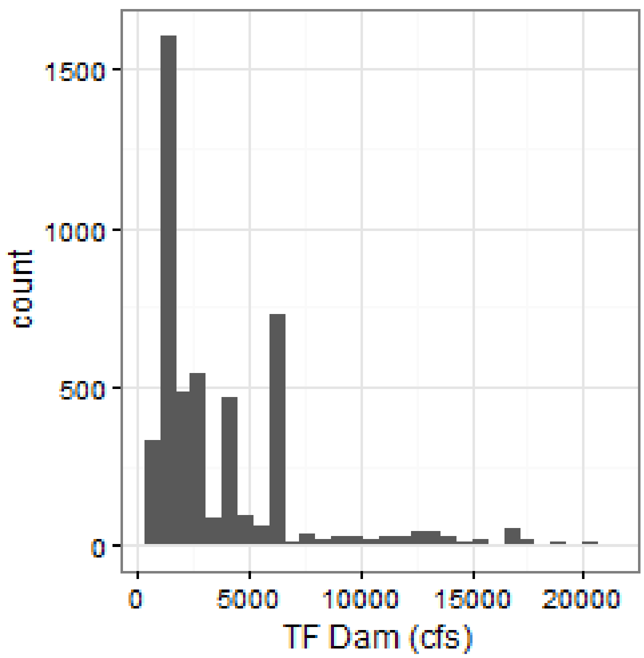

Figure D-1.8-1: Flow at Turners Falls Dam experienced by fish in the MSM Downstream Passage Model, both before and after log transformation.

Table D-18-2. Probability of fish moving through states (all flows) during downstream passage.

Beginning State at Flow		**Probability of Next State**			
		Impoundment	**Gatehouse ladder**	**Gatehouse-canal**	**Spillway**
All Flows	**Impoundment**	0	0	0.74 (0.66,0.81)	0.26 (0.19,0.34)
	Gatehouse Ladder	0.50 (0.06,0.95)	0	0.50 (0.045,0.94)	0
	Gatehouse-canal	0.44 (0.16,0.72)	0.22 (0.05,0.58)	0	0.33 (0.10,0.65)
	Spillway	0	0	0	0

D-1.9 Downstream Migrating Canal

Three models were created for the MSM Downstream Canal analysis. Model 1included time in decimal days with no covariates and had an AIC value of 1446. Model 2 included time in decimal days with Cabot Canal flow as a covariate and had an AIC value of 1294. Model 3 included time in decimal days with diurnal cues as a covariate; the model did not converge, suggesting that there were not enough observations at certain times of the day to develop a proper estimate. A likelihood ratio test revealed that Model 2 was significantly better than Model 1 ($p < 0.001$).

Table D-1.9-1. Probability of fish moving between states at various flows in the MSM Downstream Canal Model (continued on next page).

Beginning State at Flow		Probability of Next State					
		Upper Canal	Station 1 Forebay	Lower Canal	Cabot Forebay	Downstream Bypass	Cabot Tailrace
25% Flow	Upper Canal	0	0.07 (0.03, 0.19)	0.88 (0.73, 0.94)	0	0	0.05 (0.01, 0.15)
	Station 1 Forebay	1.00 (0.00, 1.00)	0	0 (0.00, 1.00)	0	0	0
	Lower Canal	0.09 (0.06, 0.14)	0	0	0.88 (0.81, 0.92)	0.02 (0.01, 0.06)	0.004 (0.00, 0.04)
	Cabot Forebay	0.001 (0.00, 0.01)	0	0.17 (0.14, 0.20)	0	0.82 (0.80, 0.84)	0.02 (0.01, 0.04)
	Downstream Bypass	0	0	0.03 (0.02, 0.05)	0.93 (0.90, 0.95)	0	0.04 (0.03, 0.07)
50% Flow	Upper Canal	0	0.06 (0.03, 0.13)	0.91 (0.83, 0.95)	0	0	0.03 (0.01, 0.09)
	Station 1 Forebay	1.00 (0.00, 1.00)	0	0.00 (0.00, 1.00)	0	0	0
	Lower Canal	0.08 (0.05, 0.12)	0	0	0.88 (0.81, 0.91)	0.04 (0.02, 0.08)	0.005 (0.00, 0.03)
	Cabot Forebay	0.001 (0.00, 0.01)	0	0.15 (0.13, 0.18)	0	0.81 (0.78, 0.84)	0.03 (0.02, 0.05)
	Downstream Bypass	0	0	0.03 (0.02, 0.05)	0.90 (0.87, 0.92)	0	0.07 (0.05, 0.10)

Table D-1.9-2. Probability of fish moving between states at various flows in the MSM Downstream Canal Model (continued).

Beginning State at Flow		Probability of Next State					
		Upper Canal	Station 1 Forebay	Lower Canal	Cabot Forebay	Downstream Bypass	Cabot Tailrace
75% Flow	Upper Canal	0	0.05 (0.02, 0.12)	0.93 (0.84, 0.97)	0	0	0.02 (0.00, 0.08)
	Station 1 Forebay	0.50 (0.09, 0.91)	0	0.50 (0.09, 0.91)	0	0	0
	Lower Canal	0.07 (0.03, 0.13)	0	0	0.86 (0.76, 0.91)	0.07 (0.03, 0.14)	0.005 (0.00, 0.07)

	Cabot Forebay	0.002 (0.00, 0.02)	0	0.14 (0.11, 0.17)	0	0.81 (0.76, 0.84)	0.05 (0.03, 0.08)
	Downstream Bypass	0	0	0.03 (0.01, 0.06)	0.87 (0.81, 0.90)	0	0.11 (0.07, 0.16)
100% Flow	**Upper Canal**	0	0.05 (0.02, 0.14)	0.93 (0.83, 0.97)	0	0	0.02 (0.00, 0.09)
	Station 1 Forebay	0.06 (0.00, 0.93)	0	0.94 (0.07, 1.00)	0	0	0
	Lower Canal	0.06 (0.03, 0.13)	0	0	0.85 (0.73, 0.91)	0.08 (0.03, 0.17)	0.005 (0.00, 0.09)
	Cabot Forebay	0.002 (0.00, 0.02)	0	0.14 (0.11, 0.17)	0	0.80 (0.75, 0.84)	0.06 (0.04, 0.09)
	Downstream Bypass	0	0	0.03 (0.01, 0.06)	0.86 (0.79, 0.90)	0	0.12 (0.08, 0.18)

Table D-1.9-3. Expected visits (forays) in the MSM Downstream Canal Model.

	Expected Visits					
Canal Flow	**Upper Canal**	**Station 1 Forebay**	**Lower Canal**	**Cabot Forebay**	**Downstream Bypass**	**Cabot Tailrace**
25%	0.54 (0.29, 1.32)	0.12 (0.04, 0.54)	4.51 (3.08, 7.12)	16.65 (10.3, 26.82)	13.68 (8.27, 22.44)	0.99 (0.92, 1.00)
50%	0.32 (0.17, 0.53)	0.08 (0.03, 0.18)	2.97 (2.39, 3.68)	10.11 (7.62, 12.56)	8.36 (6.15, 10.39)	1.00 (0.99, 1.00)
75%	0.19 (0.1, 0.42)	0.06 (0.02, 0.16)	2.26 (1.81, 2.83)	6.88 (4.81, 8.88)	5.70 (3.95, 7.38)	1.00 (1.00, 1.00)
100%	0.15 (0.07, 0.41)	0.05 (0.02, 0.16)	2.13 (1.68, 2.74)	6.26 (4.2, 8.51)	5.19 (3.45, 7.14)	1.00 (1.00, 1.00)

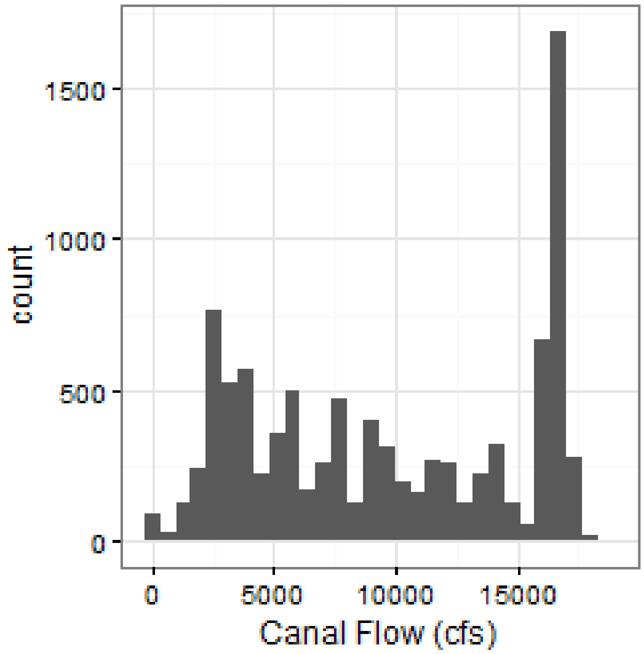

Figure D-1.9-1 Flow in Cabot Canal experienced by fish in the MSM Downstream Canal Model

D-2 COX PROPORTIONAL HAZARDS REGRESSION MODELING:

The assessment of time to event (delay) was carried out with Cox Proportional Hazards regression analysis within the survival analysis framework. Survival estimates are an essential compliment to multivariate regression models for time-to-event data, both for prediction and covariate effects (Thomas & Reyes, 2014). Recaptures data for each sub-model were formatted into the "counting process" style and imported into R for use with the *survival* package. Competing models were fit in a procedure analogous to multiple regression modeling, where individual 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 doesn't explain more variance than it does. In other words, the null hypothesis 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 (hazard) of the event occurring. If for example, the model described attraction towards a ladder with a time varying covariate of flow and the hazard ratio > 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 < 1.0 than the instantaneous risk decreases, and the proportion of fish to have passed into the structure at time (t) decreases, thus delay is incurred. The "best" model minimized AIC scores and/or had a significant omnibus statistic ($p < 0.05$) and informative hazard estimate ($HR \neq 1.0$).

D-2.1 Lower River to Project

The lower river to project modeled assessed time to project migration from release. The model incorporated dual tagged fish released at Holyoke. The downstream "staging" location consisted of receivers T1, T2 and T3 while the project "passing" receivers consisted of T33, T11, T15, T6 and T5. Out of the fish released, 162 dual tagged fish made 114 successful events into the project area from lower river receivers. These events may include multiple forays for the same fish, which means that some event durations may have been smaller because the clock started when fish first arrived in the lower river from the project and then swam back upstream. The fish appear to have experienced the same flows from Montague during the day as they did at night.

Two competing models were constructed for the Lower River to Project assessment. The first fit Montague Flow, a continuous time varying covariate (AIC = 983.67). The omnibus likelihood ratio (LR) test statistic was not significant ($p = 0.6461$) suggesting the model is poor and is not better than chance. Further, the estimated hazard ratio (HR) is 1.00 and not significant ($p = 0.643$) suggesting that there is no effect on the rate at which animals will migrate upstream after a unit increase in discharge. The second model added a time varying categorical covariate to the model (AIC = 966.67), which was highly significant (LR $p < 0.001$) suggesting the model is better than chance. The estimated HR was 2.8239 was significant ($p < 0.001$) suggesting a fish is 2.8 times more likely to experience the event during the day than at night (Figure D-2.1-2). According to AIC scores, the second model was the best.

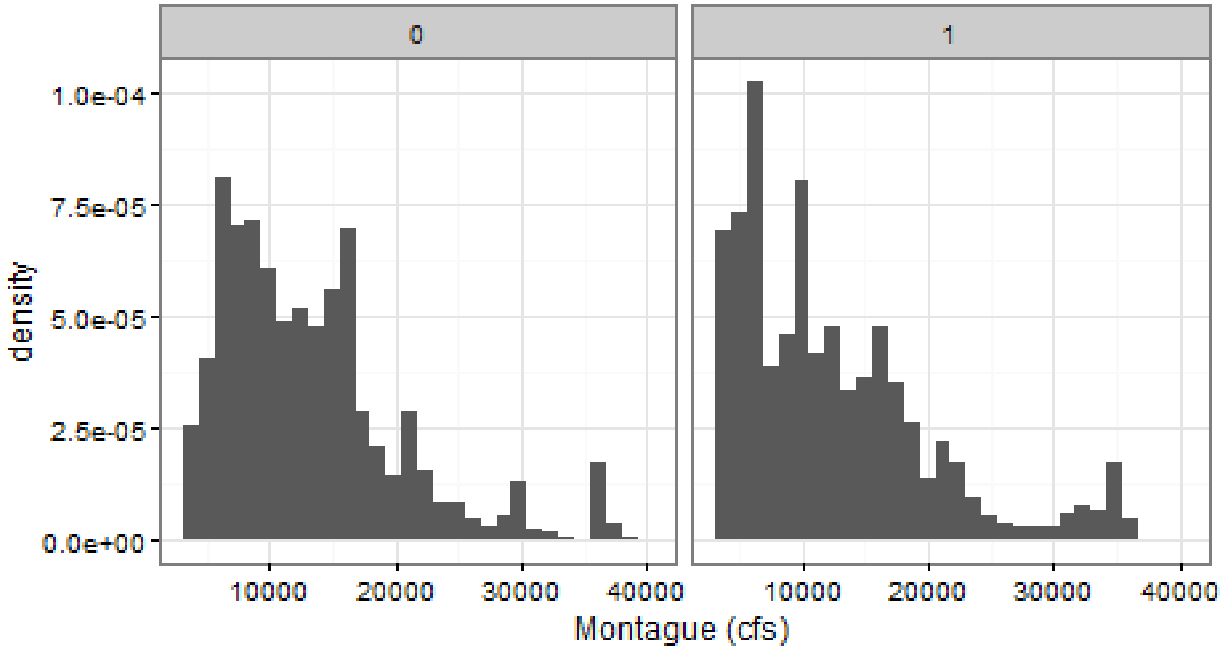

Figure D-2.1-1: Lower River to Project Model 1, Montague flows day and night

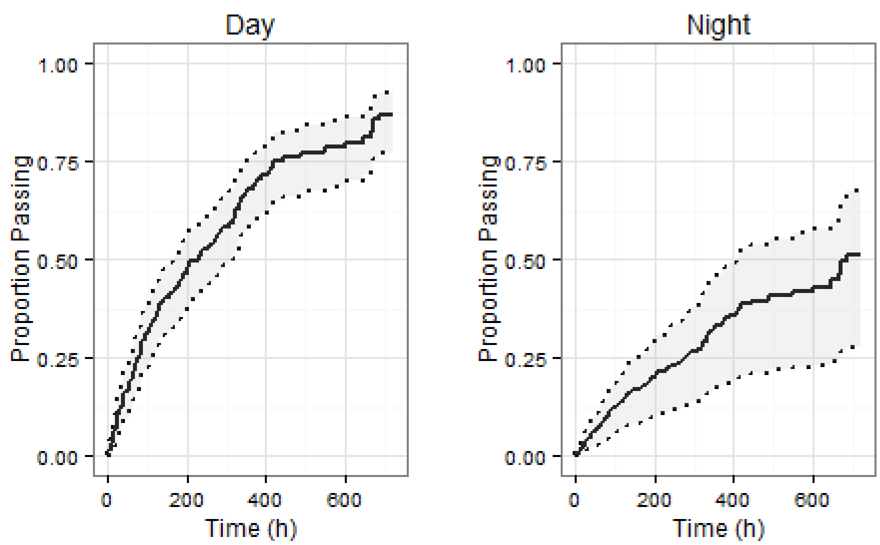

Figure D-2.1-2: Kaplan Meier curves for the lower river to project area migration times during the day and at night.

D-2.2 Cabot Ladder First Foray

For time to first Cabot Ladder Foray, dual tagged volitional fish from Holyoke were used. Volitional simply means that this model only incorporates fish that made at least 1 attempt at the ladder. Any recaptures after the first at the Cabot Ladder were removed from the analysis. Further, it only concerned recaptures between the first recapture at Montague and the first recapture at Cabot Ladder. If a fish was not detected at Montague before first being detected at Cabot Ladder than it has been removed from this analysis. (43 out of 45). In total 43 dual tagged volitional fish from Holyoke were used to assess the overall delay until first foray from Montague (T3). Considering these were volitional fish, and each visited the ladder at least once, there was 43 successful events. There does not appear to be a trend between the Cabot Generation flows experienced by fish during the night vs day time. This trend followed through with flows coming from the Bypass Reach. The range of flows were much smaller within the bypass reach, however the multiple peaks suggest operational scenarios.

The procedure fit 3 models, the first of which incorporated Cabot Generation flows (AIC = 237.7553), and was significant (LR p = 0.006). While the estimated hazard ratio was significant (p = 0.008), it was 1.000 suggesting that Cabot Generation has no effect on the risk of an event occurring. The second model incorporated bypass flows (AIC = 244.6905). The LR test was not significant (p = 0.541) suggesting the model was not better than chance at explaining variance. The estimated hazard ratio (0.9999) was not significant (p = 0.541) suggesting that Bypass Flow did not affect the risk of a fish experiencing its first foray. The third model attempted to fit diurnal cues as a categorical time varying covariate (AIC = 233.5124). Unlike the previous two models, the likelihood ratio test was significant (p < 0.001). The estimated hazard ratio (5.4238) was also significant (p = 0.005) suggesting that fish are 5.4 times more likely to experience their first foray into the Cabot Ladder from Montague during the day than at night. The best model was model 3. Its LR omnibus test was significant suggesting it was the only model better than chance, and it also had the lowest AIC.

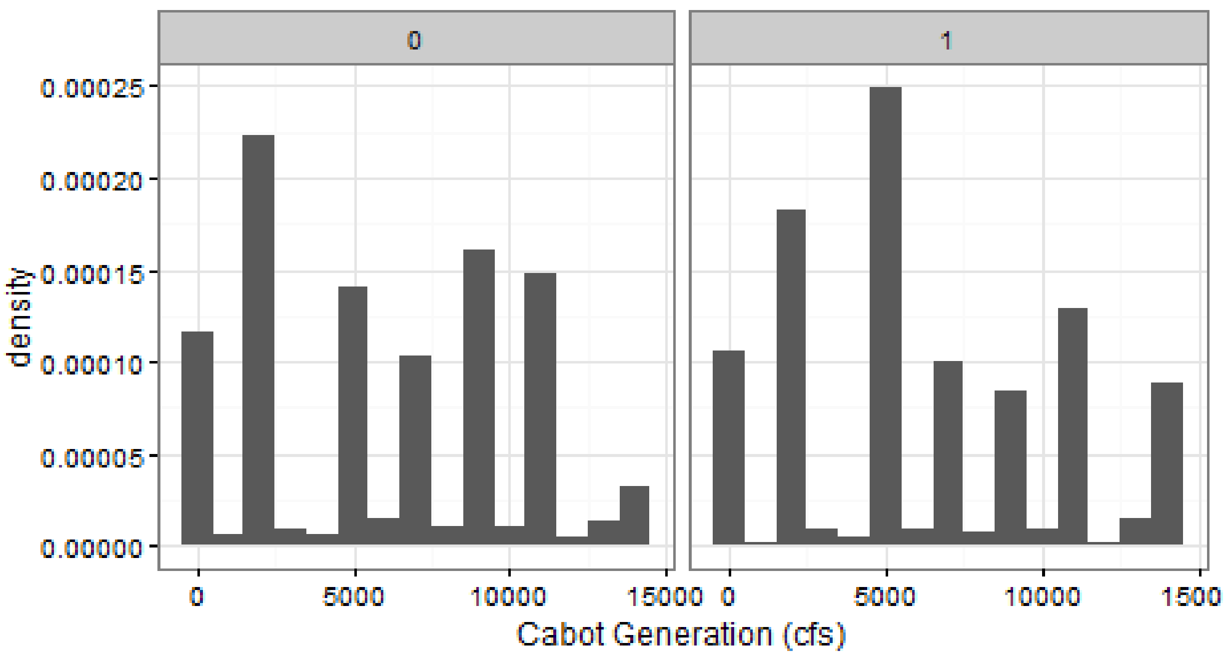

Figure D-2.2-1: Cabot ladder first foray, Cabot Generation Flow day and night. On the figures, 1 = day and 0 = night.

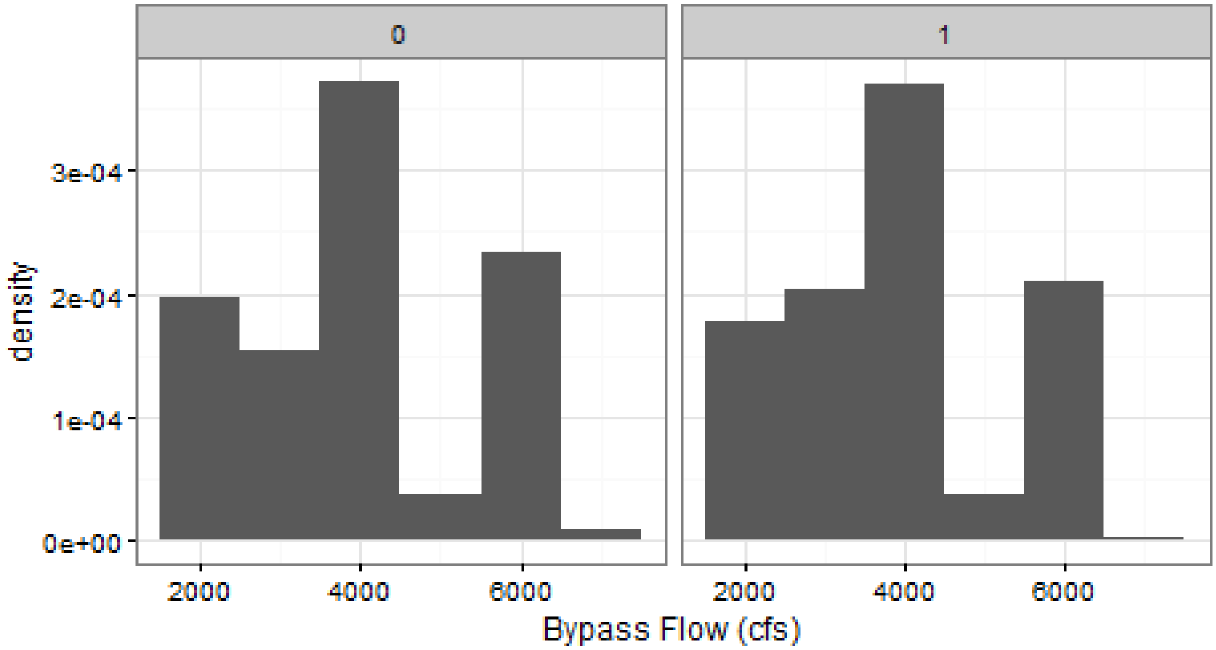

Figure D-2.2-2: Cabot ladder first foray, Bypass flows day and night. On the figures, 1 = day and 0 = night.

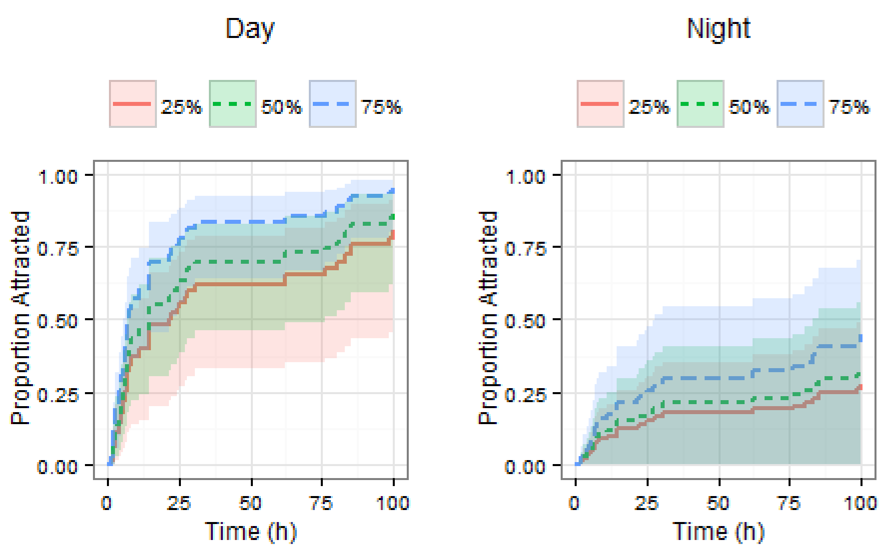

Figure D-2.2-3: Cabot ladder first foray Model 4, incorporating diurnal cues with confidence intervals

D-2.3 Cabot Ladder Attraction

Given the complexity of the river adjacent to the Cabot tailrace, there are significant avenues of migration and intervening states (Deerfield River, Lower River, Bypass Reach, west channel of Smead Island and Cabot Ladder). According the state table from the Cabot Tailrace movement model, 62 transitions occurred towards the lower river, 52 up the bypass reach and 120 into the Cabot Ladder. The competing risks were included in the event data. There were 45 fish recaptured within the tailrace that made subsequent visits to Cabot Ladder, the bypass reach, and/or made trips somewhere downstream of the tailrace (either up the Deerfield or into the lower river). In total, 114 ladder events occurred with 60 events into the bypass reach and another 60 downstream, matching very closely with the state table for Montague Spur (Multi-state model), which had different assumptions and data requirements, and modeled a slightly different cohort of fish. The fish experienced similar Cabot flow scenarios during the day and night with this trend continuing with bypass reach flows.

Four competing models were fit to the counting data for Cabot Ladder attraction. The first model fit Cabot generation flow (AIC = 1310.976), was significant at the a = 0.10 level (LR, p = 0.0567). Suggesting the model is better than chance if our tolerance of committing a type II error is 10%. Further, the estimated hazard ratio of 1.000 was also significant at the 0.10 (p = 0.592). While significant (at the a = 0.10), the estimate is 1.000, meaning that the hazard ratio does not increase or decrease as flow increases and decreases. There is no effect in the hazard ratio caused by Cabot Generation. The second model fit Bypass flow (AIC = 1307.119) and was significant (LR, p = 0.0062) and explains more variation in the data than it does not. The estimated hazard ratio of 0.9998 was significant (p = 0.008) suggesting there is a slight negative effect associated with Bypass Flow. As flow through the bypass reach increases, the hazard ratio decreases, meaning that the risk of an animal getting attracted towards the ladder decreases. The fourth model (AIC = 1300.28) fit diurnal cues, a time varying categorical covariate. The omnibus statistic (LR, p < 0.001) was significant suggesting the model was better than chance. Further, the estimated hazard ratio 2.57 was significant (p = 0.02), suggesting fish were 1.88 times more likely to experience passage from the tailrace to the ladder during the day than at night.

Considering that both bypass flow and diurnal cues were significant, two more models were created to assess additive and interaction effects between them. The first of these models assessed additive effects (AIC = 1292.414) and was significant (LR, p < 0.001). The estimated hazard ratio (2.564) for diurnal cue categorical covariate was significant (p < 0.001). The estimated hazard (0.9998) ratio for bypass flow was also significant (p < 0.001). Therefore as flows decreased and it was daytime, the hazard ratio increased, meaning passage was far more likely. The final model looked for interaction effects between bypass flow and day/night (AIC = 1163.304). The final model was highly significant (LR, p < 0.001) suggesting the model was much better than chance. Diurnal cues were significant (HR = 10.915, p = 0.002) as well as the interaction effect between day/night and flow (HR = 0.999, p = 0.03), however bypass flow alone was not (HR = 1.001, p = 0.3518). This suggests that during the day, bypass flows have a larger negative effect on the fish than at night.

According to these results, the final model was the best. It was better than chance, had significant explanatory powers, and the lowest AIC score.

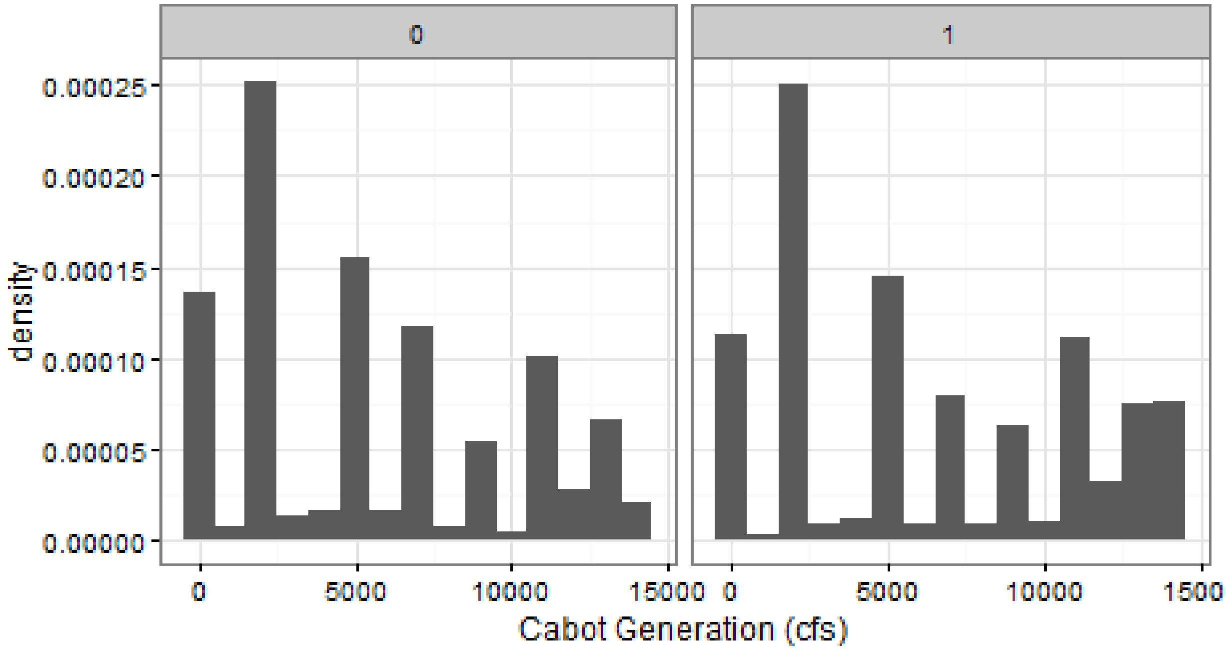

Figure D-2.3-1: Cabot Ladder attraction, Cabot Generation day and night

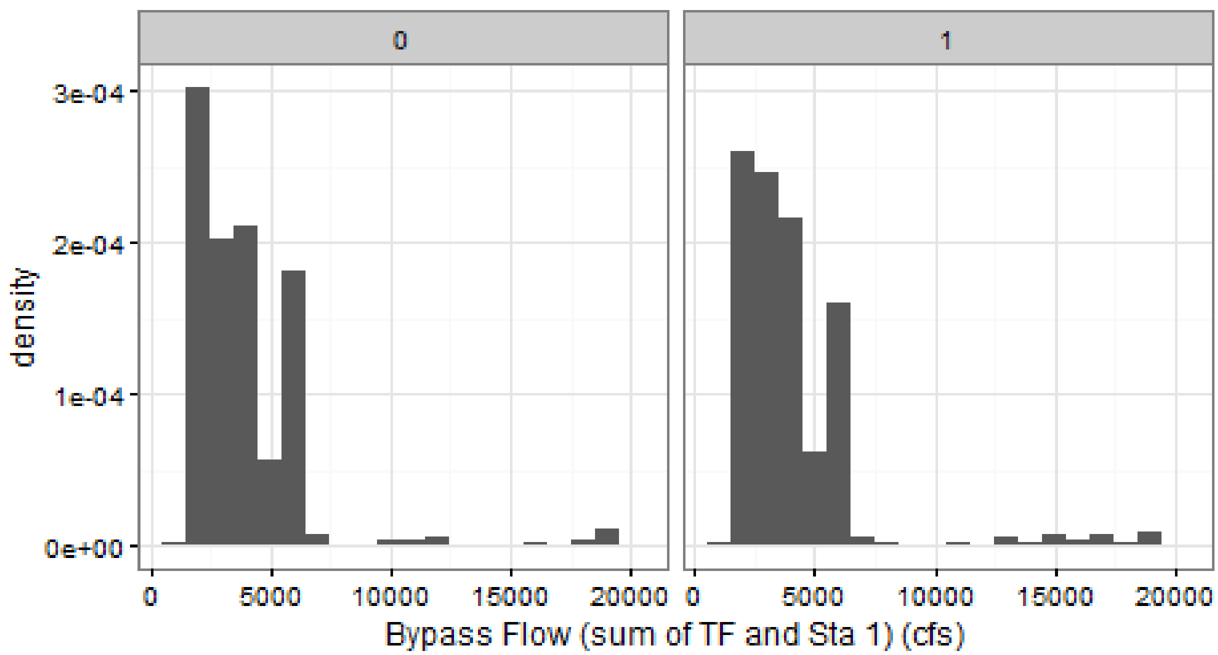

Figure D-2.3-2: Cabot Ladder attraction, Bypass flow day and night

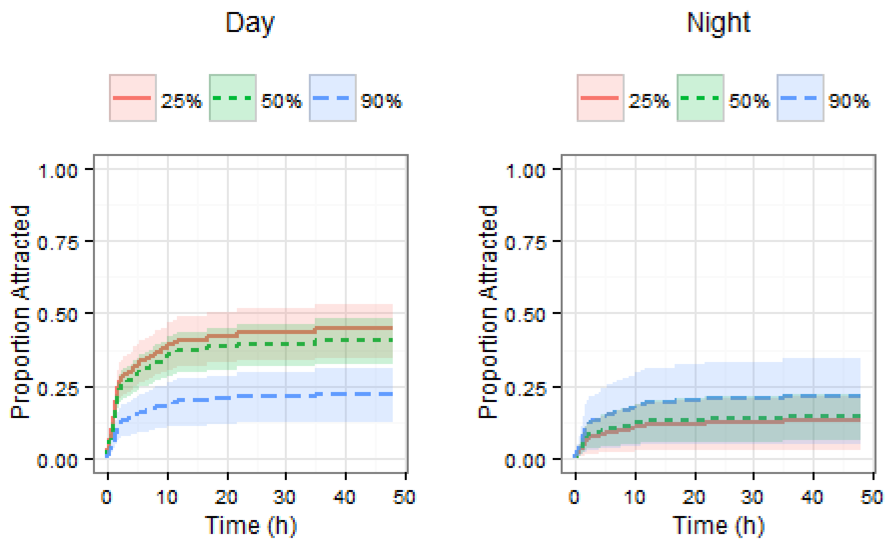

Figure D-2.3-3: Cabot ladder attraction during the day and at night incorporating Bypass flow.

D-2.4 Cabot Ladder Time to Passage

In total, 103 dual tagged and pit tagged only volitional fish from Holyoke were found to attempt Cabot ladder a combined 408 times, but only 16 attempts were successful. Further there were no successful attempts after 40 hours within the ladder according to the Kaplan Meier plot (Figure D-2.4-1).

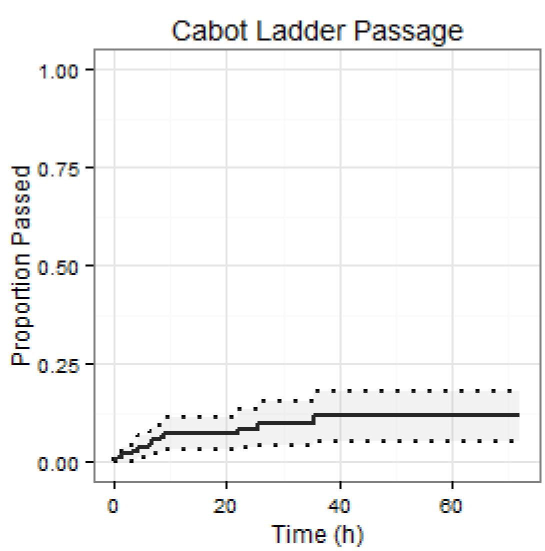

Figure D-2.4-1: Cabot ladder passage; proportion through time

D-2.5 Spillway Ladder First Foray

For the first foray into Spillway Ladder, volitional dual tagged shad from Holyoke recaptured at Montague and then again anywhere within the ladder were used. For this analysis the clock started when fish were first recaptured at Montague and ended the first recapture within the ladder. In total there were 11 dual tagged volitional fish from Holyoke that made at least 1 attempt on Spillway Ladder from Montague. Fish appeared to experience the same or similar bypass flows during the night as they did during the day.

Two models were fit to the data, the first attempted to fit flow (AIC = 119.54). However, the omnibus likelihood ratio test was not significant ($p = 0.1183$), suggesting the model was not better than chance. The estimated hazard ratio was 1.0004 and significant at the a = 0.10 level ($p = 0.09$). However, with the LR test not significant, low significance on the covariate estimate, and HR close to 1, it is suggested that flow does not affect the instantaneous risk of fish arriving at the ladder from Montague. The second model attempted to fit a time varying categorical covariate describing diurnal cues (AIC = 113.1744). The omnibus LR test was significant $p = 0.003$, however the estimated hazard ratio (4.080) was not ($p = 0.998$) suggesting that fish are equally as likely to experience the event from Montague during the day as they are at night.

Therefore, the null model is appropriate to describe the time to first foray at Spillway Ladder from Montague. The null model suggests that 50% of the population will experience the event after 94.4 hours compared with 7.55 hours for fish first arriving at Cabot Ladder from Montague. Due to the small sample size of fish from Montague (11) the confidence intervals are fairly wide.

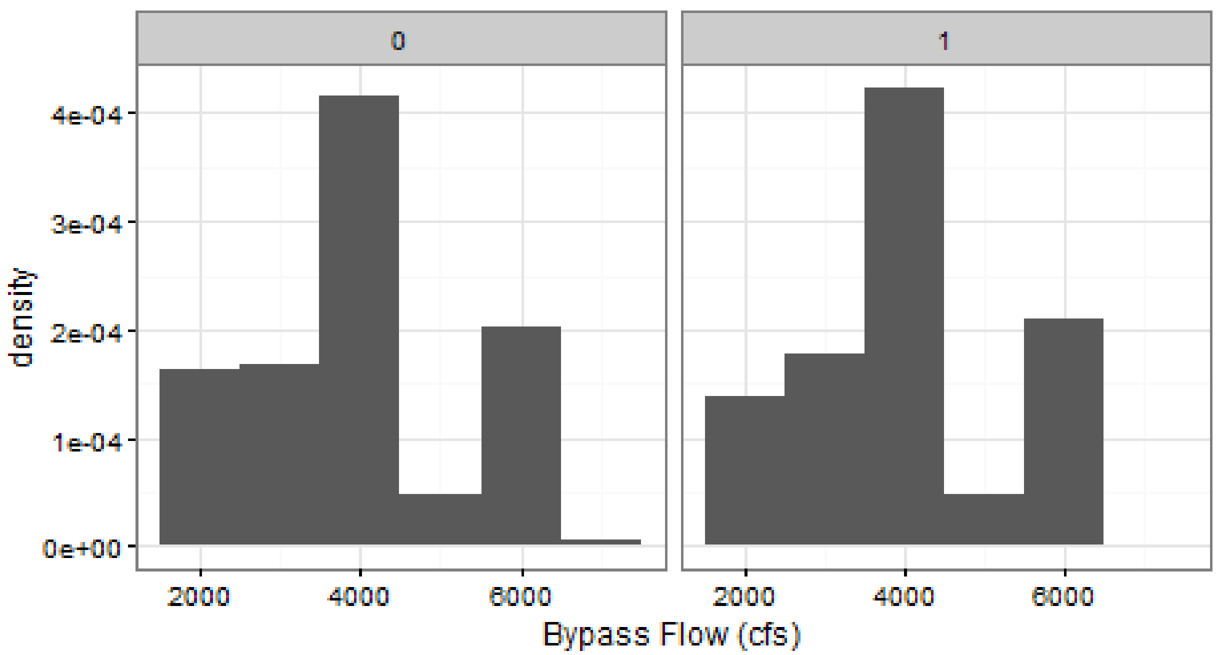

Figure D-2.5-1: Spillway ladder first foray, Bypass flow day and night

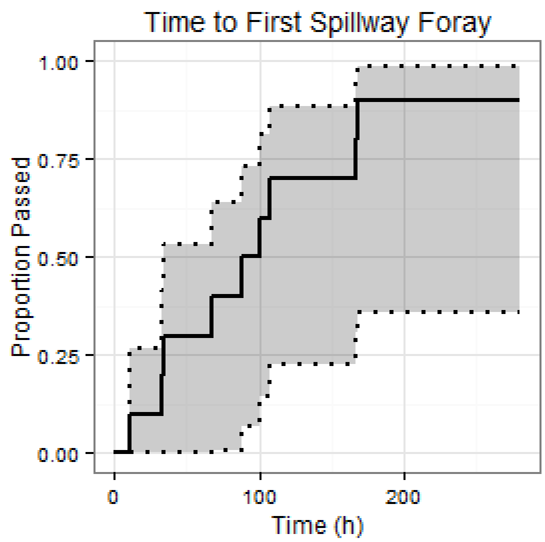

Figure D-2.5-2: Kaplan-Meier survival curve of the Spillway ladder first foray model with confidence intervals.

D-2.6 Spillway Ladder Attraction

Dual tagged volitional fish from Holyoke recaptured in the lower bypass (T15, T12E, T12W), upper bypass (T19 and T20) and Spillway ladder (T30, P11, P12, P23SL, P23TP, P24 and P25) were used for this analysis. In total, 34 dual tagged fish from Montague made at least 17 successful attempts at Spillway Ladder from the upper bypass, however they also rejected the spillway ladder and retreated to the lower bypass 20 times. As with other reaches, the fish appear to have experienced the same or similar flow regimes during the day as they did at night.

Two models were fit to the data, the first (AIC = 142.156) attempted to fit Bypass Flow to ladder attraction and was significant at the $a = 0.10$ level (LR, p = 0.078). The estimated hazard ratio (0.9997) was less than 1, but not significant (0.143). If this term was significant, an increase in bypass flow would reduce the instantaneous risk of a fish being attracted to the Spillway Ladder. The second model (AIC = 138.7397) attempted to fit diurnal cues, a time varying categorical covariate. Overall, the omnibus LR statistic was significant (p = 0.01) suggesting the model is better than chance. The estimated hazard ratio of 7.297 was significant at the $a = 0.10$ level (p = 0.055), suggesting that fish are 7.297 times more likely to be attracted towards the ladder during the day than at night. The best model was model 2, which incorporated diurnal cues.

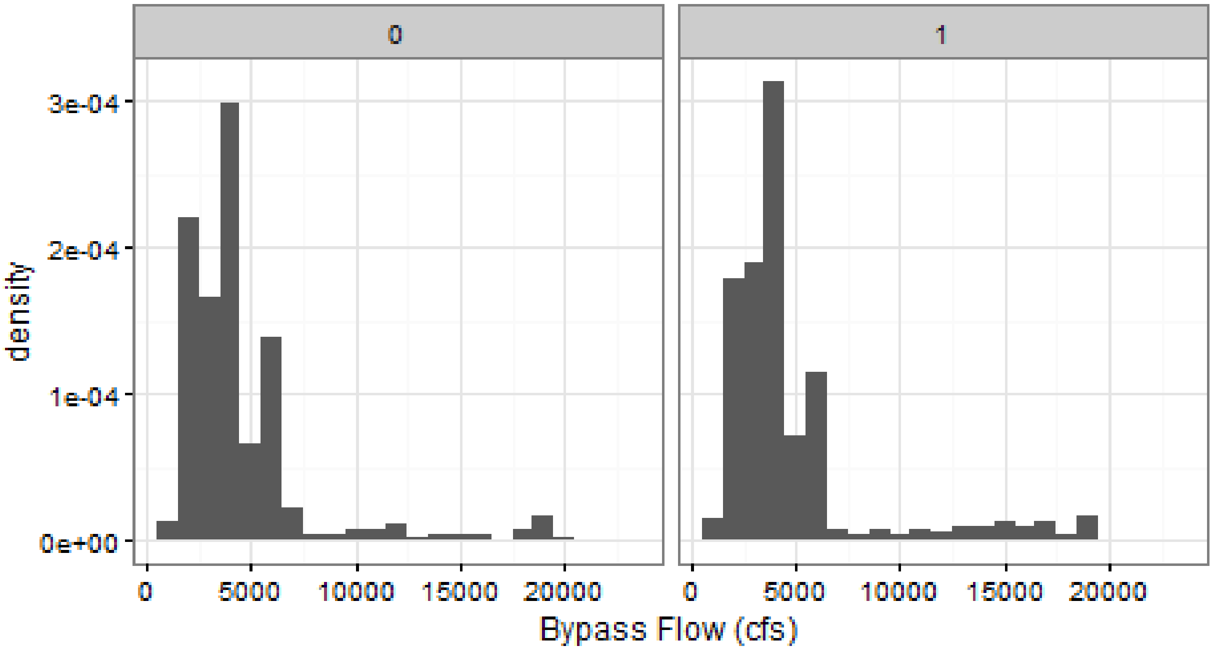

Figure D-2.6-1: Spillway ladder attraction, Bypass Flow day and night

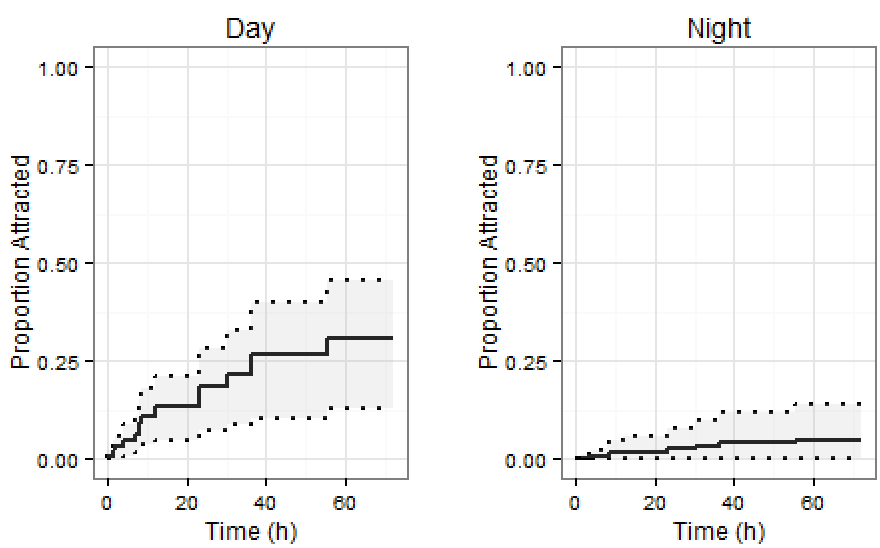

Figure D-2.6-2: Spillway ladder attraction, incorporating diurnal cues

D-2.7 Spillway Ladder Time to Passage

Of the 35 dual and pit tagged fish released from Holyoke that were recaptured in Spillway Ladder, 16 successfully passed out of 87 attempts. As evident in the Kaplan-Meier curve (Figure D-2.7-1), no more successful passaged occurred after 10 hours. Overall, fish ascended Spillway ladder quicker than Cabot ladder. However, these results should be suspect given the low rates of recapture at the Spillway Ladder entrance.

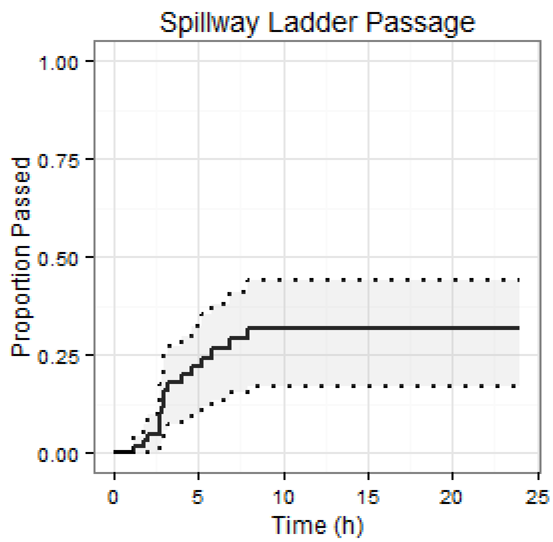

Figure D-2.7-1: Spillway ladder passage; proportion through time

D-2.8 Downstream Canal

Dual tagged fish from the upstream TransCanada project and those released into the Turners Falls Impoundment were used for the upstream Canal models. For the overall model, 98 fish made 80 successful attempts (defined as making it to P13 or the Cabot Tailrace (T6 and T5)). The fish appear to have experienced the same canal flows during the day as they did at night (Figure D-2.8-1).

Two models were fit to the data, the first attempted to fit Canal discharge, a continuous time varying covariate (AIC = 595.1202). The model was significant (LR, p = 0.013) suggesting it was better than chance. Further, the estimated HR of 1.05 was also significant (p = 0.0145). The second model (AIC = 599.626) fit diurnal cues, a time varying categorical covariate. The model was significant (LR, p = 0.013) suggesting it was better than chance. However, the estimated hazard ratio (1.3587) was not significant (p = 0.205) suggesting that there is no diurnal effect on time to event. Fish will experience the event equally as much during the day as the night. Given that the first model was significant and had an effect, it was deemed the best model to describe overall emigration rates from the canal. The resulting KM (Figure D-2.8-2) shows that the rate of travel towards the Bypass sluice was higher at higher flows.

There are two locations within the canal that the downstream cohort may have issues with navigating. These include the Station 1 Forebay and Cabot Forebay area. According to the results of the MSM, a significant amount of milling or back and forth movement exists between the Cabot Forebay and its neighboring reaches. The first of these sub-canal models was the Station 1 Forebay model. A successful escape attempt occurred when fish moved between the station 1 forebay or the mid canal (T18, T13, T14). Only 5 downstream fish were caught within the Forebay and 4 escaped. The fish experienced roughly the same canal flows during the day and night (Figure D-2.8-3).

Given the low sample sizes regression models failed to find fit. However, the resulting Kaplan-Meier curve shows that 50% of the population escape the Forebay at approximately 14 hours (Figure D-2.8-4).

The second canal subreach was the Cabot Forebay model. According to results of the MSM model significant milling occurs between the Forebay, downstream bypass and upper canal reaches. In total 87 fish were found to use this location, with 37 passing through the turbines from the Cabot Forebay, 745 events towards the bypass entrance, and 135 upstream in the canal. Fish experienced roughly the same flow at night as during the day (Figure D-2.8-5).

Two models were fit to this region, the first attempted to fit canal flows to time to event data (AIC = 444.9941). The LR test was highly significant ($p < 0.001$) suggesting the model was much better than chance. The estimated HR (1.13) was also highly significant ($p < 0.001$). Suggesting the instantaneous risk of fish experiencing the event (movement away from the Forebay) increases with a 1000 cfs increase in flow. The second model fit diurnal cues (AIC 462.1881), however it was not significant (HR, $p = 0.437$). Further, the estimated hazard ratio associated with day/night (0.767) was not significant ($p = 0.432$), suggesting there is no effect due to day/night. The first model with a lower AIC and significant HR was deemed the best (Figure D-2.8-6).

A null model was fit to each competing risk (travel through powerhouse, escape upstream, downstream bypass entrance) and their respective KM curves were graphed (Figure D-2.8-7). The resulting curves suggest of those fish available to pass towards the downstream bypass reach, most do so relatively quickly, while those abandoning the Forebay and migrate back upstream do so after quite some time. There appears to be little movement from the Forebay through the powerhouse, and those fish that do choose this route do so very quickly.

The final downstream canal subreach model assessed passage efficiency of the downstream bypass. Of the 76 fish to appear at the bypass entrance (T9) 40 passed downstream via P13 or were recaptured in the tailrace (T6 and T5). Of those 76 fish, they abandoned the bypass for any location upstream 716 times, suggesting an incredible amount of milling at this location. Two Cox models were fit to the data, the first attempted Canal discharge (AIC = 430.402). The model was significant at the $a = 0.10$ level (LR, $p = 0.06103$) as was the estimated hazard ratio ($p = 0.0642$). The HR was 1.05 suggesting a positive effect with flow. The second model (AIC = 431.5529) fit diurnal cues but was not significant (LR, $p = 0.1246$). The resulting KM curves (Figure 4.7.9-7) shows low passage efficiency and large delay through the bypass reach with fish abandoning the bypass and escaping upstream in relatively high numbers very quickly. Given that the model was not significant at the $a = 0.05$, a null model with competing risks was fit to the time to event data and plotted in Figure D-2.8-8. The resulting KM figures show fish abandoning the bypass reach in favor of the canal and forebay region quicker than those fish passing downstream via the bypass.

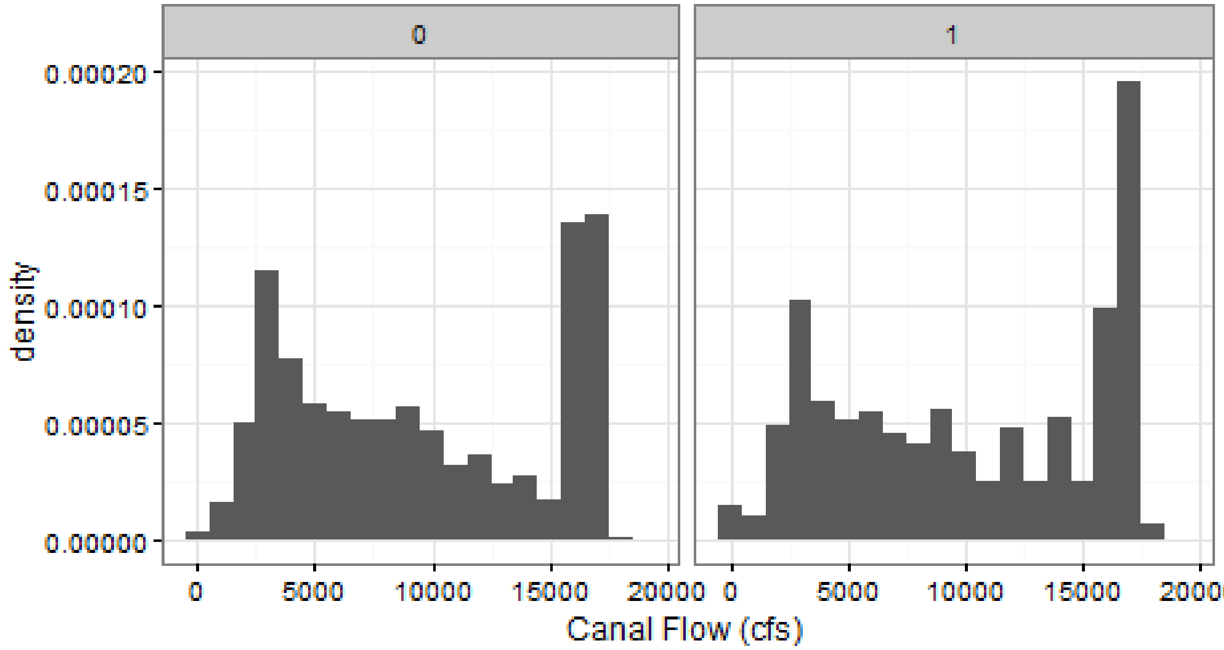

Figure D-2.8-1: Downstream canal, canal flow day and night

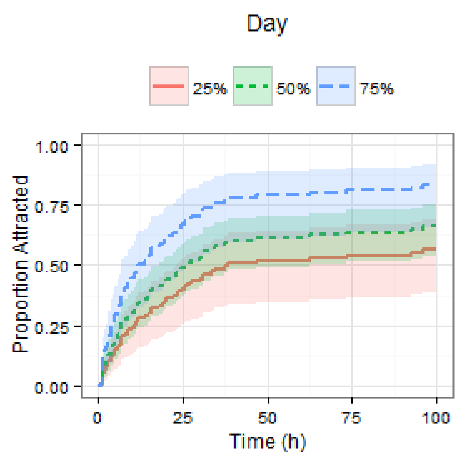

Figure D-2.8-2: Time to downstream bypass arrival after passing into the Canal via the Gatehouse

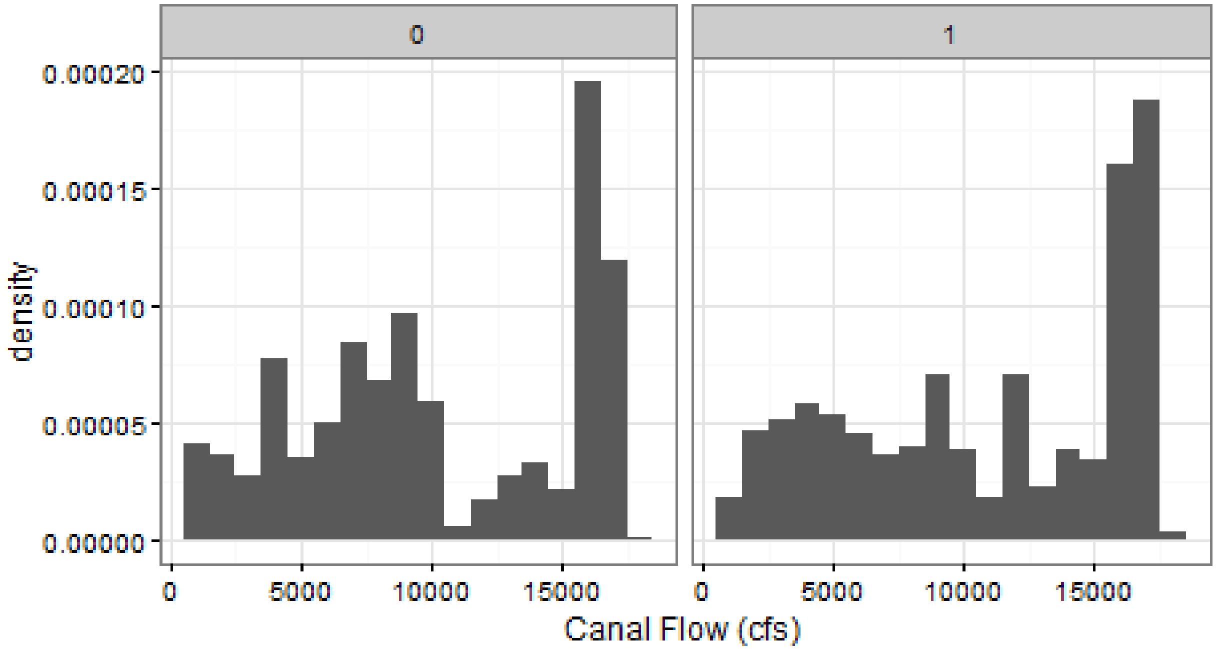

Figure D-2.8-3: Downstream canal Station No 1 Model, Flows day and night

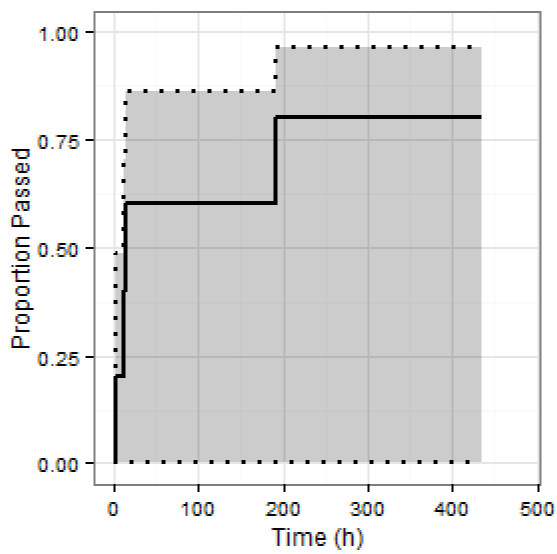

Figure D-2.8-4: Downstream Canal Station No. 1 KM Curve proportion escaped Forebay

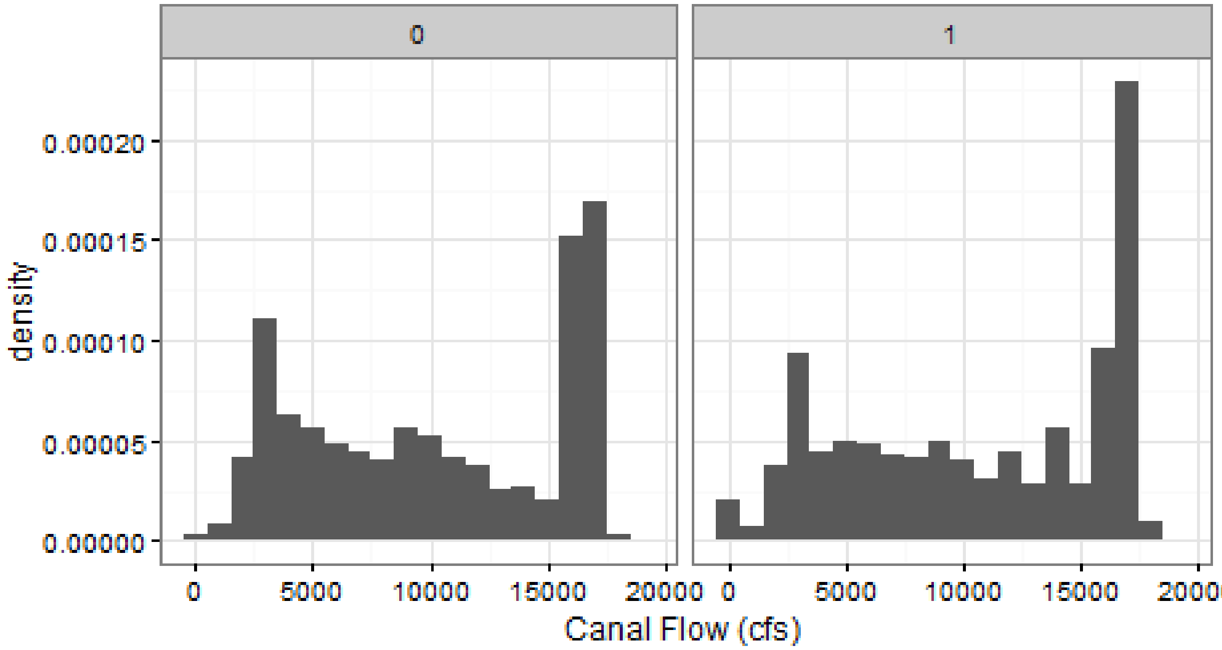

Figure D-2.8-5: Downstream canal Cabot Forebay Model, Flows day and night

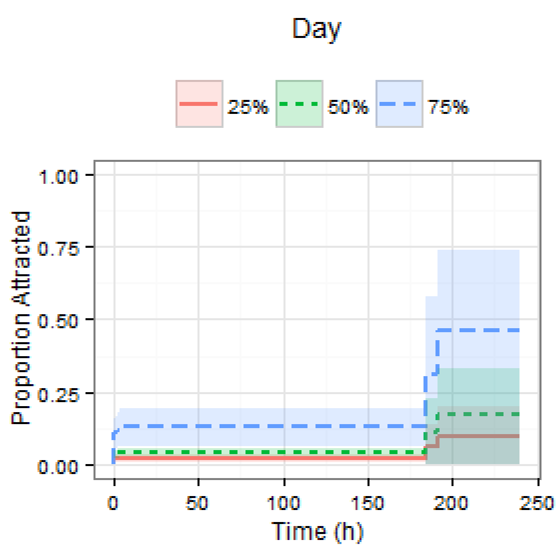

Figure D-2.8-6: Time-to-passage through Cabot Powerhouse from Cabot Forebay

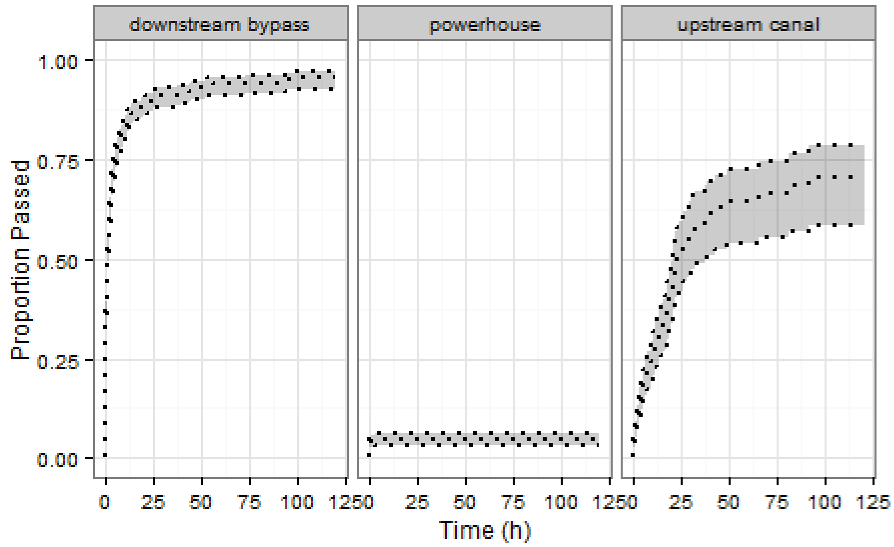

Figure D-2.8-7: Downstream canal Cabot Forebay competing risk KM curves, proportion passed through time

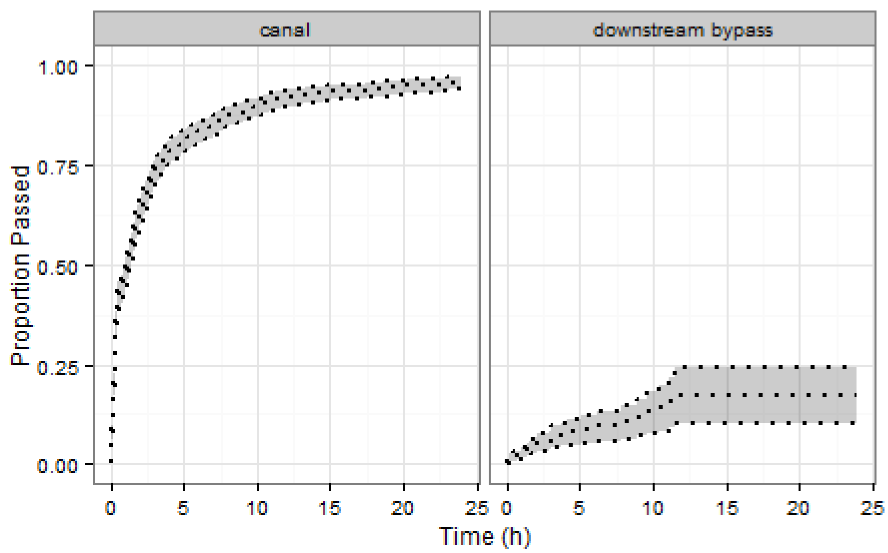

Figure D-2.8-8: Downstream canal Cabot Forebay downstream bypass KM curve

D-2.9 Upstream Canal

For the upstream canal model, only those fish obligated to move upstream were used (Holyoke and Canal released fish). In total, the overall model identified 60 recaptured fish, making 122 successful forays up to the Yagi antenna at the entrance to the Gatehouse Ladder over 295 different attempts. Generally, the fish experienced the same flow at night as during the day (Figure D-2.9-1).

A total of four models were fit to the data, the first of which attempted to fit Canal discharge (AIC = 1022.066). The model was highly significant (LR, $p < 0.001$) suggesting it was better than chance. The estimated HR of 0.8219 was also significant ($p < 0.001$) suggesting a decrease in the hazard ratio with a unit increase in flow. The second model fit diurnal cues (AIC = 1035.946) and was significant (LR, p <

0.001). Diurnal cues was significant (p < 0.001) with an estimated hazard ratio of 8.319 suggesting that fish are 8.3 times more likely to experience the event during the day than at night. The third model assessed additive effects between flow and diurnal cues (AIC = 962.5227) and was significant (LR, p < 0.001). Further, both the estimated hazard ratios for flow (0.81) and Daytime (0.945) were significant (p < 0.001 and p < 0.001 respectively). As flow increases the rate at which fish experience the event are reduced. The fourth model attempted to fit interaction effects between flow and diurnal cues (AIC = 964.0577). The model was significant (LR, p < 0.001). Cabot flow (HR = 0.999, p = 0.03) and Daytime (HR = 6.493, p = 0.004) were significant, but the interaction effect was not (HR = 1.00, p = 0.526). Given that the third model had the lowest AIC score, the overall upstream canal time to event was described as an additive model with flow and diurnal cues (Figure D-2.9-2).

The second upstream canal submodel to be fit looked at time to event of fish escaping the Cabot Forebay. The first model attempted to fit flow (AIC = 5050.431). The model was significant (LR, p < 0.001) suggesting it was better than chance. The estimated HR (0.9599) was significant (P < 0.001). The second model fit diurnal cues to the data (AIC = 5059.72). This model was significant (LR, p = 0.012). The estimated hazard ratio (1.312) was significant (p = 0.014) suggesting a fish was 1.3 times more likely to experience an event during the day than at night. The third model attempted to fit flow and diurnal cues as additive effects (AIC = 5045.551). This model was significant (LR, p = < 0.001). The fourth model attempted to fit flow and diurnal cues as interacting effects (AIC = 5045.42) and was significant (LR, p < 0.001). The estimated HR (1.03) for diurnal cues was not significant (p = 0.86), while the estimated HR (0.93) was significant (p = 0.001). The interaction estimated HR (1.039) was not significant (p = 0.14). The fourth model, with the lowest AIC scores was best (Figure D-2.9-3).

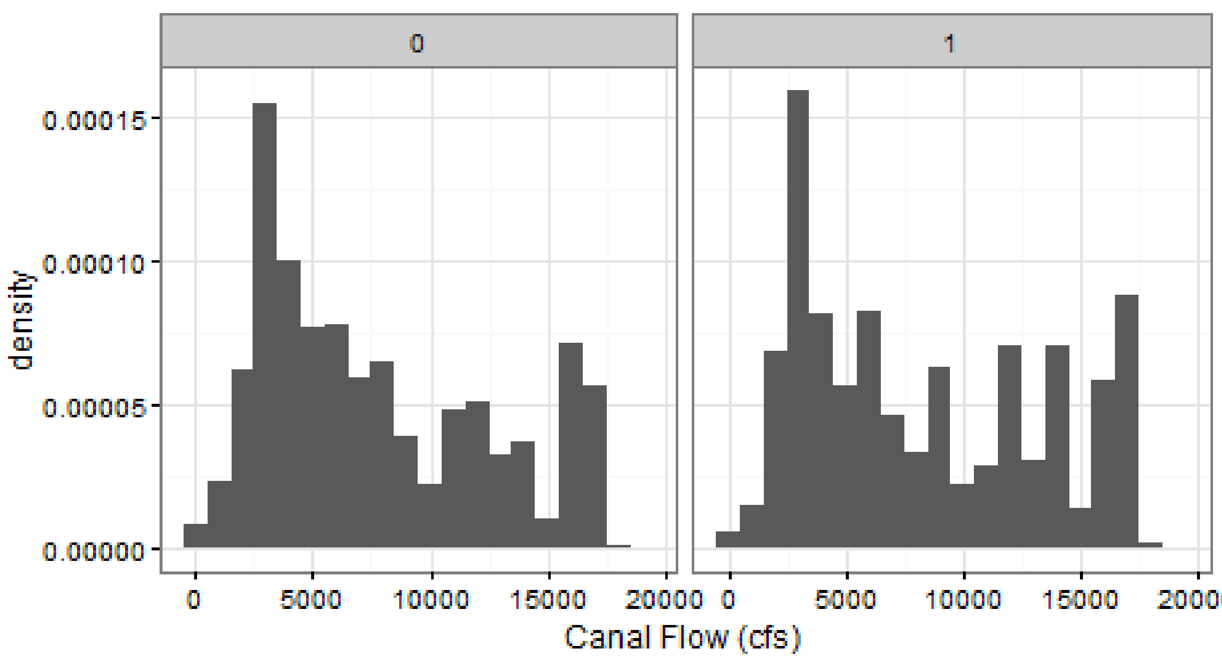

Figure D-2.9-1: Upstream canal; canal flow day and night

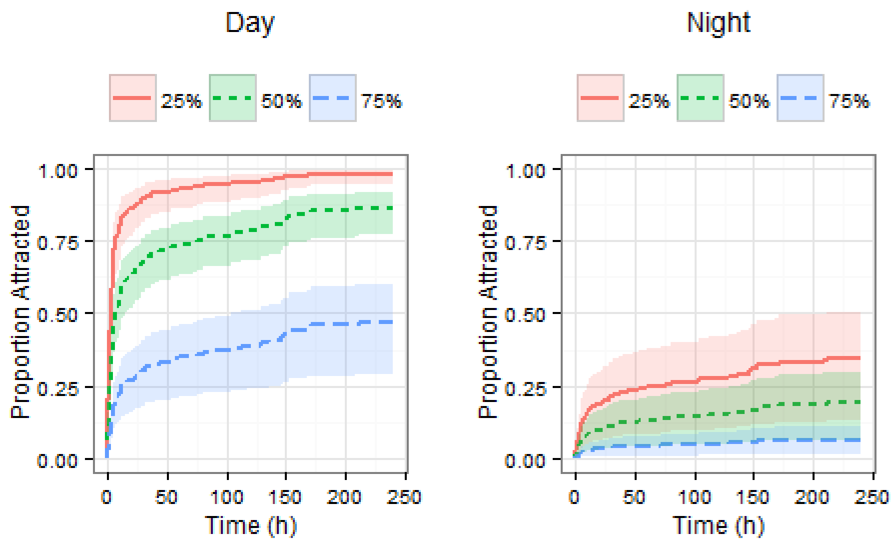

Figure D-2.9-2: Overall time to event – fish moving downstream through canal

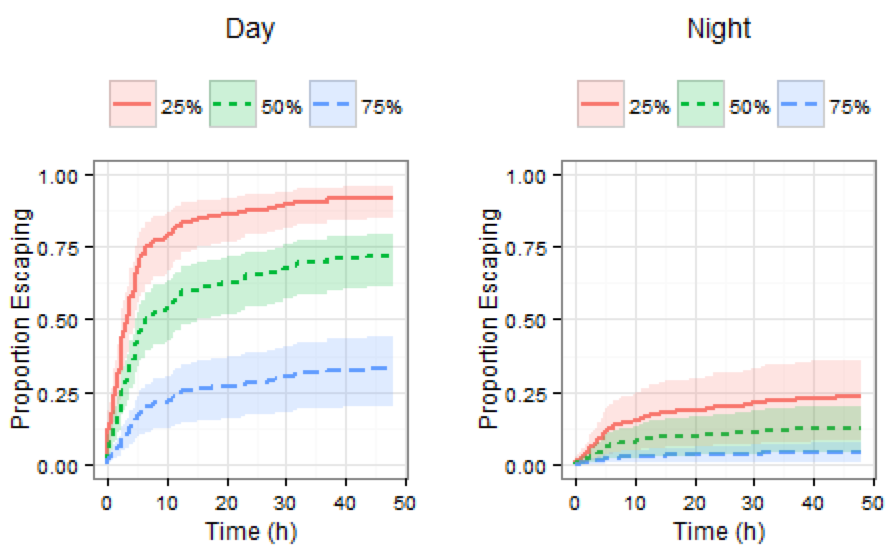

Figure D-2.9-3: Time to fish leaving escaping the forebay

D-2.10 Upstream Impoundment

Like the upstream and downstream canal models, the upstream and downstream Turners Falls impoundment TTE models were broken up into upstream and downstream obligated fish. Upstream obligated fish are those released into the Impoundment or those that migrated into it from the canal, while downstream obligated fish are those released upstream at Trans Canada. The first model looked to assess time to upstream migration. The event in consideration was movement from downstream of the NMPS intake to upstream of the intake. In total, 142 fish made 228 forays up to Shearer farms suggesting significant milling. Also, 45 fish made an attempt from downstream of the intake (T23/T24) towards the intake (T25). Fish experienced different operations at night than during the day as expected (Figure D-2.10-1).

Two models were fit to the counting process data. The first attempted to fit operations to time to event (AIC = 2648.803). The model was not significant (LR, p = 0.9295) suggesting it was not better than chance. The second model attempted to fit diurnal cues (AIC = 2643.598). The model was significant (p = 0.0248) with an LR = 0.02 and a hazard ratio of 1.18. With the lower AIC score, the second model was deemed the best (Figure D-2.10-2).

During their upstream migration within the impoundment, fish may get attracted towards the NMPS intake and have their upstream migration delayed. In the time to escape the intake model, 32 fish were found to be present, making 53 successful escape attempts (either upstream or downstream). Two models were fit to this dataset, the first of which attempted to find a relationship with flow (AIC = 467.3068). The model was not significant (LR, p = 0.723) suggesting it was not better than chance. The second model attempted to fit diurnal cues (AIC = 467.143). This model was also not significant (LR, p = 0.5912). Given neither model was better than chance, the best descriptor of time to escape was the null model (Figure D-2.10-3).

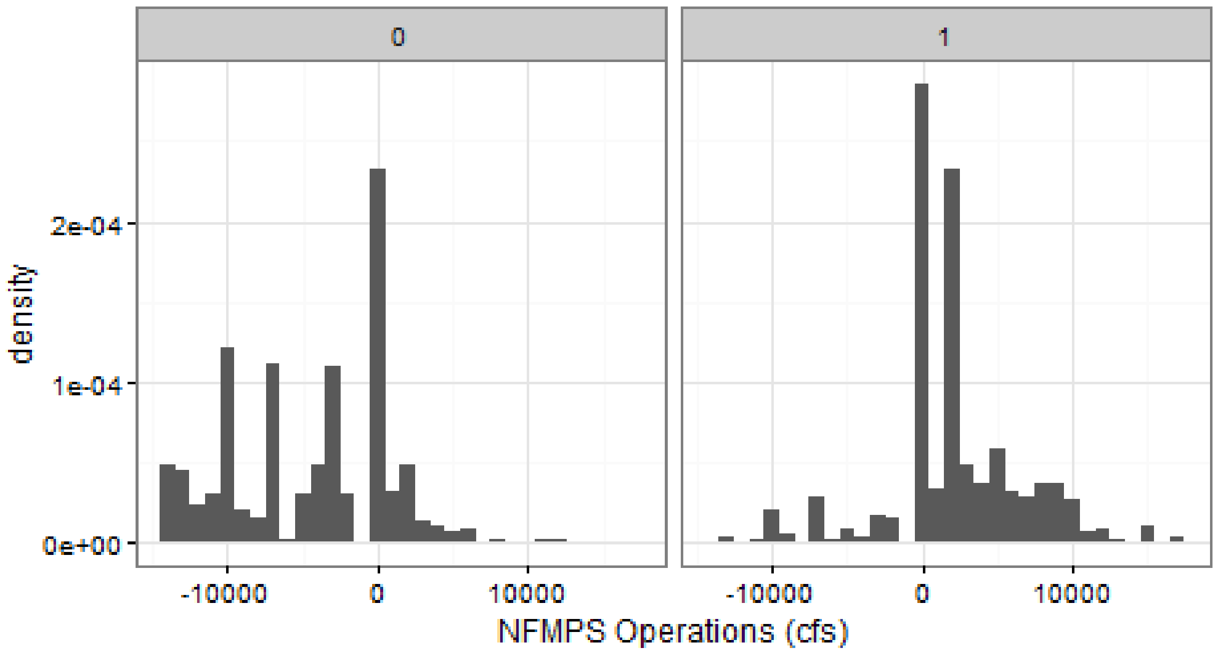

Figure D-2.10-1: Upstream Impoundment Model, NMPS Operations day and night

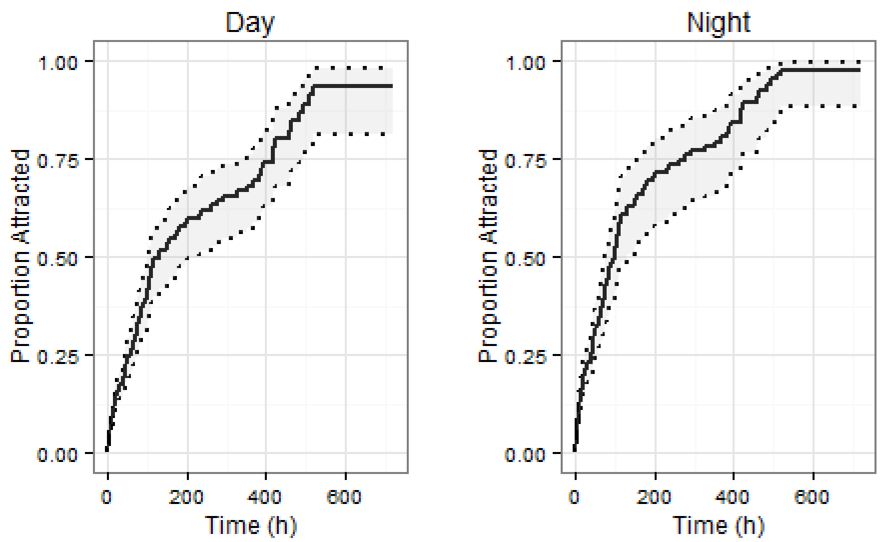

Figure D-2.10-2: Upstream Impoundment Model; time to upstream migration

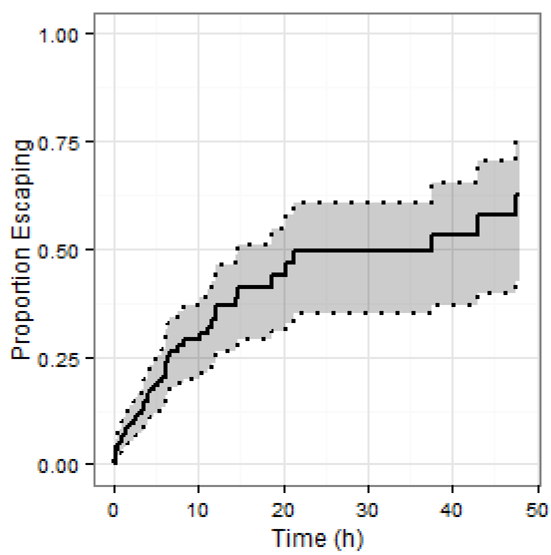

Figure D-2.10-3: Upstream Impoundment NMPS Model; proportion vs time

D-2.11 Downstream Impoundment

The final project segment to be assessed with time to event analysis considered those animals migrating downstream through the Turners Falls Impoundment. Only downstream obligated (those released at Trans Canada) were used for this analysis. Overall, 59 fish made it downstream from Vernon with 62 successful events. The events considered for analysis here was travel passed the NMPS intake. As with the upstream migrants, the downstream fish experienced much different flow at night than during the day (Figure D-2.11-1).

Two models were fit to assess downstream time to event. The first attempted to fit NMPS operations (AIC = 415.1303), but was not significant (LR, p = 0.339). The second model attempted to fit diurnal cues (AIC = 415.8301) and was also not significant (LR, p = 0.6453). Therefore, the null model was used to describe time to event (Figure D-2.11-2).

As with the upstream migrants, a portion of the population are attracted to the NMPS intake and fail to continue their migration. A total of 10 fish made 15 successful escape events suggesting there was milling in front of the intake. Two models were fit to the data, the first of which looked for a relationship with flow (AIC = 64.73). This model was not significant (LR, p = 0.654). The second model attempted to fit diurnal cues (AIC = 64.91) but was also not significant (LR, p = 0.863). Therefore, the null model was appropriate to describe time to escape (Figure D-2.11-3).

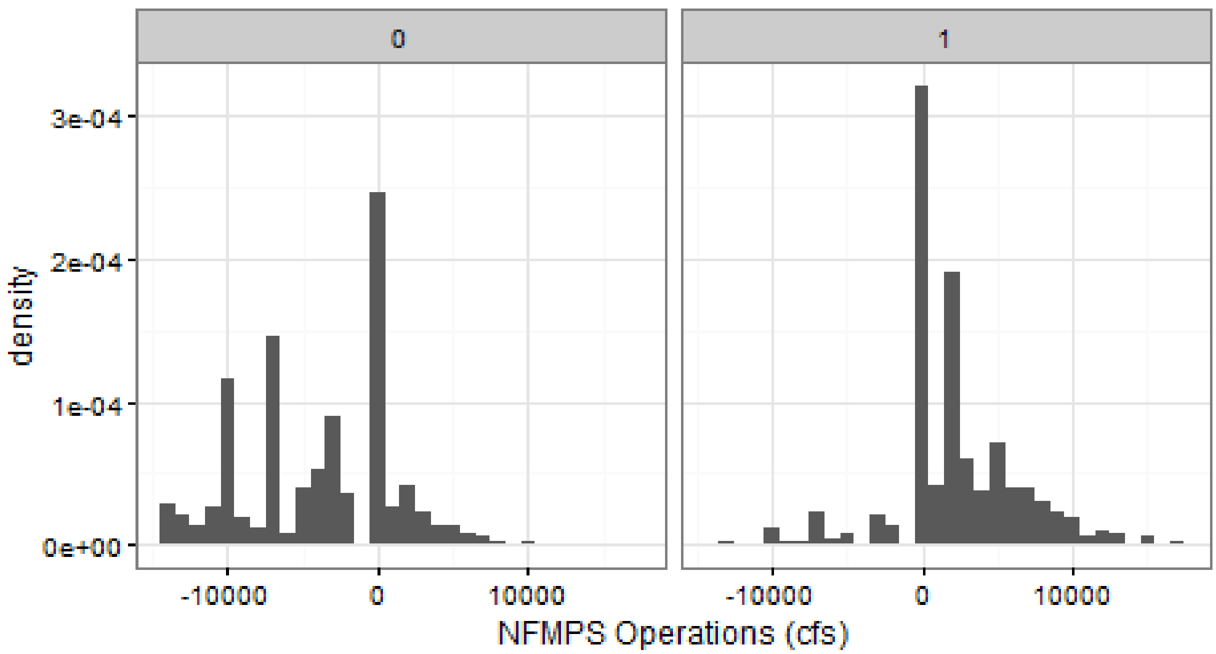

Figure D-2.11-1: Downstream Impoundment Model; NMPS flow day and night

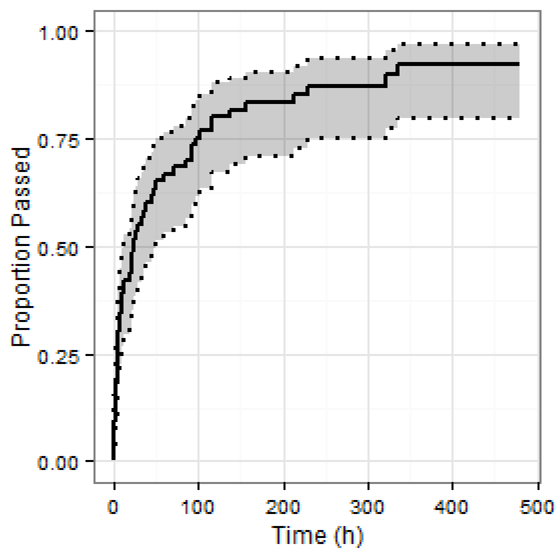

Figure D-2.11-2: Downstream Impoundment Model; time to pass NMPS

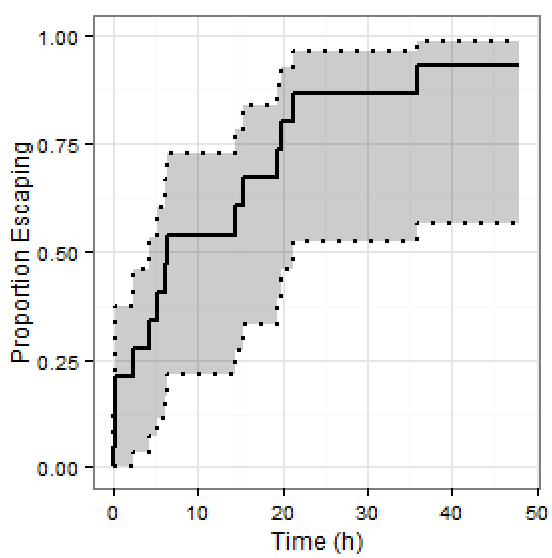

Figure D-2.11-3: Downstream Impoundment NMPS model; time to escape

D-3 INTERNAL LADDER EFFICIENCY

Mark recapture theory assessed the internal efficiency of each ladder to produce unbiased estimates of passage success (passage). Four competing models were analyzed for the Cabot Ladder, Spillway, and Gatehouse in an attempt to find the smallest with most explanatory power: the saturated model included time dependent passage and recapture ($\phi(t)p(t)$,), the second model (2) was time dependent passage$\phi(t)$ and independent recapture ($p(.)$), the third (3) was time independent passage ($\phi(.)$) and last (4) time dependent recapture ($p(t)$), and time independent passage and recapture. $\phi(.)p(.)$. Passage and recapture estimates are reported for the model with the lowest AIC value.

D-3.1 Cabot Ladder

The saturated model with each receiver station (entrance (P111 and P112), T7, T29, P12, and canal recapture) considered separately did not pass the goodness of fit GOF test. However, a model that combined the entrance and T7 sites passed GOF, and was used for the remaining analysis. The saturated model (ϕ(t)p(t)) had the lowest AIC value (Table D-3.1-1).

Table D-3.1-2 shows the passage estimates between each receiver station within the ladder. Successful passage through the entire ladder was the product of the passage estimates between each receiver station. The overall efficiency of the Cabot ladder including entrance efficiency was 10.2% (Table D-3.1-2). When not accounting for the entrance efficiency, the overall rate was 15.3%. Recapture rates at each receiver ranged from 24% to 100% (Table D-3.1-3).

Table D-3.1-1: Model output for the Cabot Ladder.

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Number of Parameters	Deviance
Saturated {ϕ(t)p(t)}	445.8	0	1	1	5	8.1
2 {ϕ(.)p(t)}	472.9	27.1	0	0	5	35.2
3 {ϕ(t)p(.)}	489.0	43.1	0	0	4	53.3
4 {ϕ(.)p(.)}	534.1	88.3	0	0	2	102.5

Table D-3.1-2: Cabot ladder passage estimates.

Receiver	Passage (%)	Standard Error (%)	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Tailrace – Entrance+T7	66.8	4.0	58.8	74.8
Entrance –T29	100	0	59.0	100
T29 –P12	15.3	3.5	9.2	23.0
P12 –Canal	100	0	100	100

Table D-3.1-3. Cabot ladder recapture estimates.

Parameter	Recapture (%)	Standard Error (%)	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Entrance+T7	97.3	2.7	88.7	99.8
T29	23.9	4.2	16.3	32.7
P12	62.5	12.1	38.2	83.1
Passage	100	00	100	100

D-3.2 Spillway Fishway

The saturated model with each receiver station separate (entrance, T30, P23SL, P23TP, P24, P25, and recapture within Gatehouse Ladder) passed the GOF test; however, recapture rates were low at the entrance. A model was created which combined the entrance and T30 into a single station, and this model was used for the remaining analysis. The saturated model ($\phi(t)p(t)$ had the lowest AIC value (Table D-3.2-1). Passage through the Spillway Fishway was 32.7% (Table D-3.2-2) when accounting for entrance efficiency and 36% when entrance efficiency is not accounted for. Recapture rates at each receiver ranged from 6% to 100% (Table D-3.2-3).

Table D-3.2-1: Model output for the Spillway Fishway.

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Number of Parameters	Deviance
Saturated{ϕ(t)p(t)}	220.5	0	1.0	1.0	7	4.3
2 {ϕ(.)p(t)}	233.5	12.9	0	0	4	23.9
3 {ϕ(t)p(.)}	290.7	70.2	0	0	5	78.9
4 {ϕ(.)p(.)}	305.3	84.8	0	0	2	99.9

Table D-3.2-2: Spillway Fishway passage estimates.

Parameter	Passage (%)	Standard Error (%)	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Spillway - Entrance+T30	91.5	13.5	69.5	100
Entrance -P23SL	64.7	11.6	45.8	84.2
P23SL - P23TP	61.3	10.0	42.0	82.7
P23TP - P24	90.0	9.5	62.8	99.4
P24 -P25	100	0	88.7	100
P25 -Passage	100	0	88.7	100
Passage through the Spillway Fishway	32.7			

Table D-3.2-3: Spillway Fishway recapture estimates.

Parameter	Recapture (%)	Standard Error (%)	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Entrance+T30	37.9	9.0	22.9	56.1
P23SL	100	0	89.3	100
P23TP	56.3	12.4	32.4	78.3
P24	100	0	88.7	100
P25	6.3	6.1	0.4	24.8
Passage	100	0	88.7	100

D-3.3 Gatehouse Fishway

The model with each receiver station (entrance, P34, P31, P32, P33, and passage into TFI) separate passed the GOF test; however, there was an optimization error when analyzing the saturated model. A model was created without P34, and this model was used for the remaining analysis. The saturated model ($\phi(t)p(t)$ had the lowest AIC value (Table D-3.3-1). Passage through the Gatehouse Fishway was 76.9% (Table D-3.3-2). Recapture rates at each receiver ranged from 95% to 100% (Table D-3.3-3).

Table D-3.3-1: Model output for the Gatehouse.

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Number of Parameters	Deviance
{ϕ(t)p(t)}	166.6	0	0.9	1.0	5	0.3
{ϕ(t)p(.)}	171.6	5.1	0.1	0.1	4	7.5
{ϕ(.)p(t)}	178.6	12.1	0	0	3	16.6
{ϕ(.)p(.)}	184.0	17.4	0	0	2	23.9

Table D-3.3-2: Gatehouse passage estimates.

Parameter	Passage (%)	Standard Error (%)	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Entrance -P31	84.8	4.1	75.7	91.6
P31- P32	93.9	3.0	86.2	98.2
P32 -P33	96.6	2.4	89.9	99.4
P33 - Passage	100	0	96.9	100
Passage through the Gatehouse	76.9			

Table D-3.3-3 Gatehouse recapture estimates.

Parameter	Recapture (%)	Standard Error (%)	Lower 95% Confidence Interval	Upper 95% Confidence Interval
P31	96.8	2.2	90.4	99.5
P32	95.0	2.8	87.5	98.7
P33	100	0	96.9	100
Passage	100	0	96.9	100

In summary, Cormack Jolly Saber models were successfully fit to all ladders. However, in each case recapture rates at the entrances were low requiring the modeler to aggregate the entrance PIT and dipole antenna (Cabot and Spillway Ladder) or remove the entrance PIT altogether (Gatehouse Ladder). The low rates of recapture at the entrance to each ladder complicated the analysis of the ladders overall time to passage and may introduce negative bias to the estimate of time to event. While bias may be an issue, the estimated confidence intervals around each passage estimate were reasonable.

D-4 CATCH CURVE MORTALITY ASSESSMENT

The baseline daily mortality rate of mobile-tracked fish that did not interact with the Turners Falls Project was -0.01 (Table D-4-1; Figure D-4-1). Similarly, the instantaneous daily mortality rate for fish that did pass project features ranged from 1% to 3% (Table D-4-1). Mobile-tracked fish that passed the Turners Falls Project via spill over a bascule gate exhibited an instantaneous daily mortality rate of 3% (Figure D-4-2) and a mortality rate per river mile of 3% (Figure D-4-3). Fish that died after passing via spill travelled an average of 13 miles over an average of 21 days before mortality signals emitted from the tags were detected. Mobile-tracked fish that passed through the Cabot Station Powerhouse exhibited a daily mortality rate of 2% (Figure D-4-4). Most of the mortality detections from these fish occurred at the confluence of the Deerfield River in a pool where deep water could have obscured mortality signals from being detected earlier in the study period. As such, mortality rates per river mile could not be accurately assessed. Mobile-tracked fish that passed through the downstream bypass at Cabot Station exhibited an instantaneous daily mortality rate of 1% (Figure D-4-5) and a mortality rate per river mile of 2% (Figure D-4-6). Fish that died after passing via the downstream bypass travelled an average of 15 miles over an average of 28 days before being observed emitting a mortality signal. Mobile-tracked fish that passed through both Gatehouse and Cabot Station Powerhouse exhibited an instantaneous daily mortality rate of 3% (Figure D-4-7) and a mortality rate per river mile of 4% (Figure D-4-8). Fish that died after passing through both structures travelled an average of 11 miles over an average of 24 days before being observed emitting a mortality signal. Mobile-tracked fish that passed through both Gatehouse and the downstream bypass exhibited an instantaneous daily mortality rate of 3% (Figure D-4-9) and a mortality rate per river mile of 2% (Figure D-4-10). Fish that died after passing through both of these structures travelled an average of 22 miles over an average of 21 days before mortality signals were detected. To conform with the convention of mortality estimates, the antilog (e^{-z}) of instantaneous mortality rate is the survival rate (*S*), and mortality is 1-*S*.

Table D-4-1. Instantaneous Daily Mortality rate regression model statistics.

Downstream Passage Structure	Mortality Rate	Regression Model Statistics					
				Intercept		Slope	
		F	Significance F	Coefficient	P-value	Coefficient	P-Value
None	Daily	446.88	< 0.001	4.33	< 0.001	-0.01	< 0.001
Bascule Gate	Daily	871.57	< 0.001	3.14	< 0.001	-0.03	< 0.001
	Per River Mile	260.16	< 0.001	3.00	< 0.001	-0.03	< 0.001
Cabot Powerhouse	Daily	64.58	< 0.001	1.94	< 0.001	-0.02	< 0.001
Downstream Bypass	Daily	323.40	< 0.001	2.82	< 0.001	-0.01	< 0.001
	Per River Mile	227.12	< 0.001	2.74	< 0.001	-0.02	< 0.001
Gatehouse and Cabot Powerhouse	Daily	988.95	< 0.001	3.85	< 0.001	-0.03	< 0.001
	Per River Mile	1550.70	< 0.001	3.58	< 0.001	-0.04	< 0.001

Gatehouse and Downstream Bypass	Daily	162.55	< 0.001	2.61	< 0.001	-0.03	< 0.001
	Per River Mile	76.06	< 0.001	2.51	< 0.001	-0.02	< 0.001

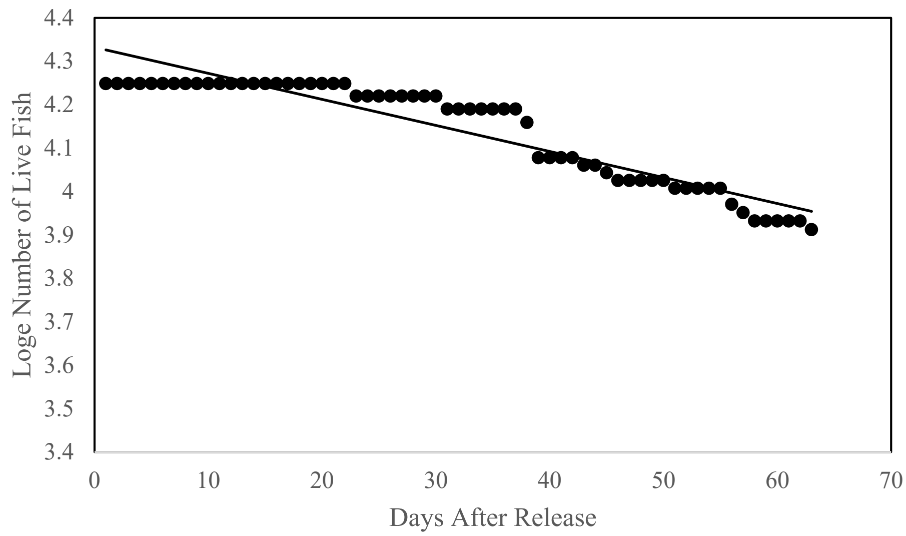

Figure D-4-1. Regression plot used to calculate instantaneous daily mortality rate for fish released at Holyoke that did not pass through any project features.

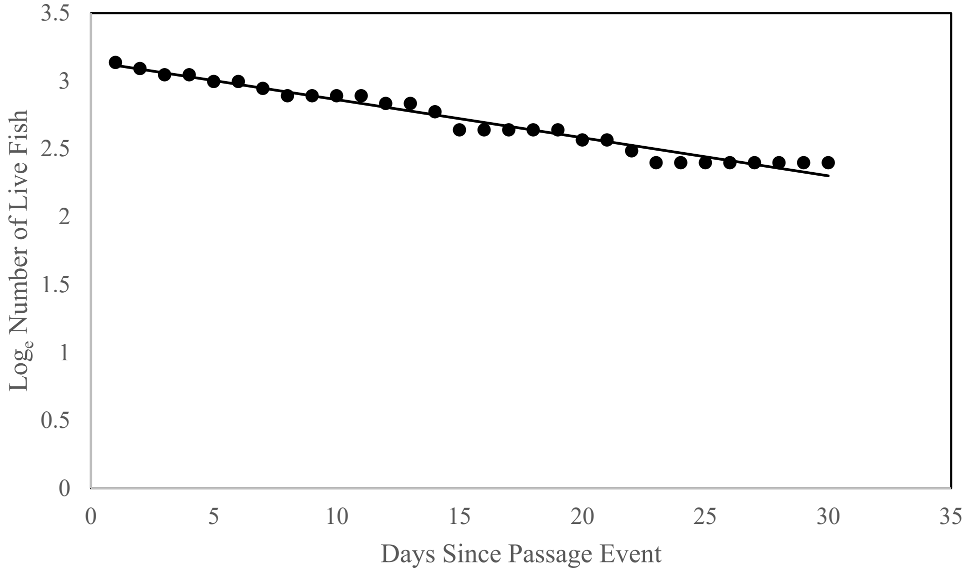

Figure D-4-2. Regression plot used to calculate daily mortality rate for fish passing via bascule gates.

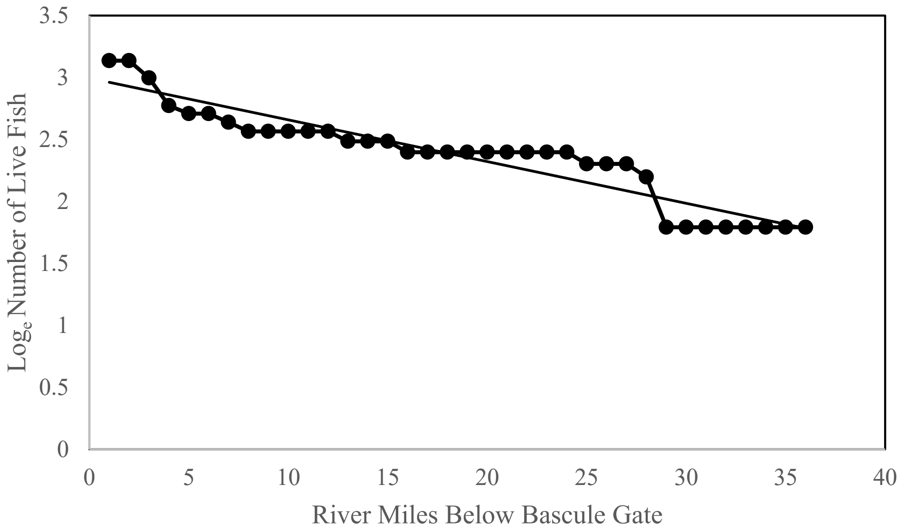

Figure D-4-3: Regression plot used to calculate mortality rate per river mile for fish passing via bascule gates.

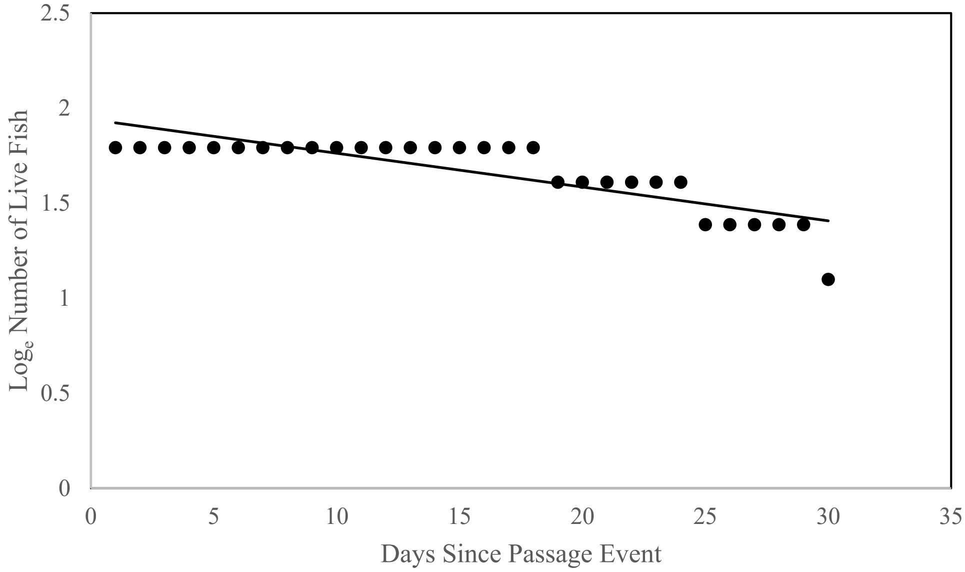

Figure D-4-4. Regression plot used to calculate daily mortality rate for fish passing through Cabot Powerhouse.

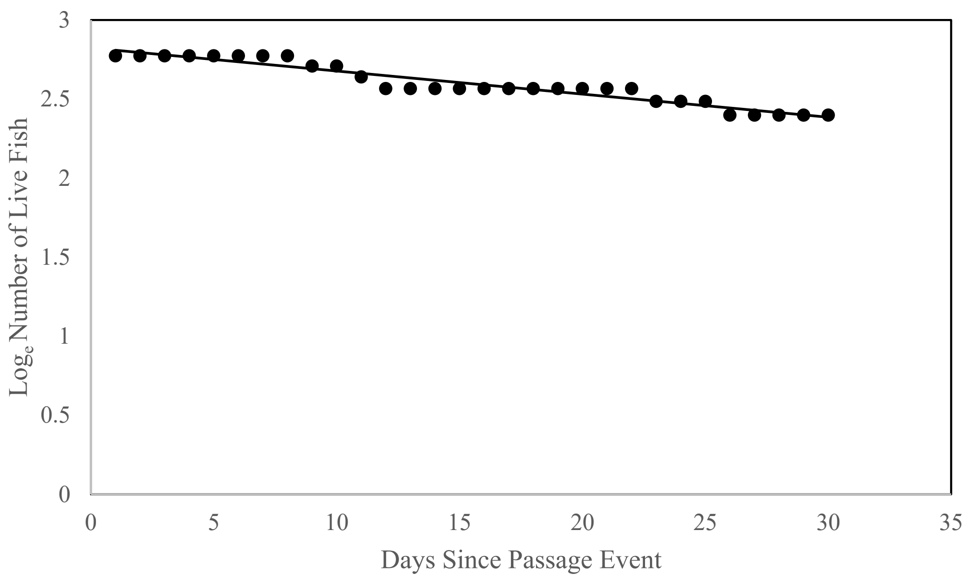

Figure D-4-5: Regression plot used to calculate daily mortality rate for fish passing via the downstream bypass at Cabot Station.

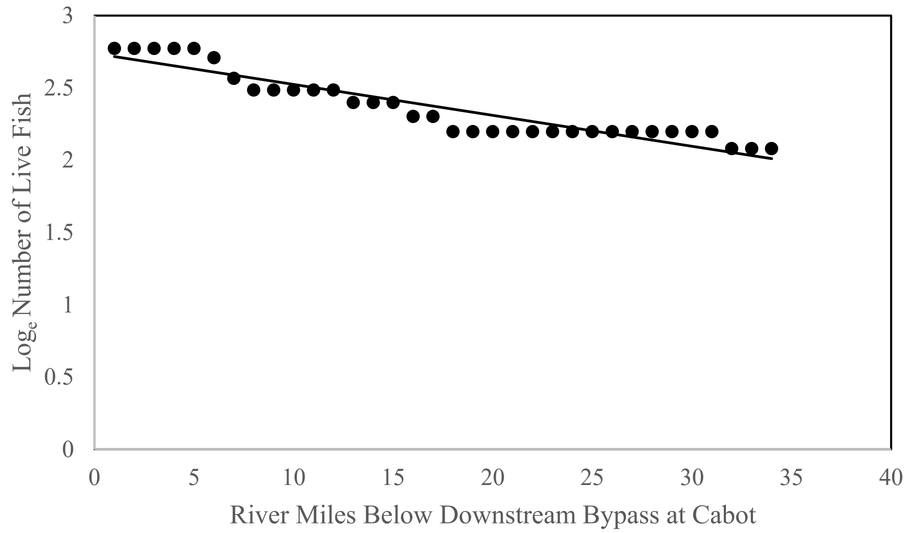

Figure D-4-6: Regression plot used to calculate mortality rate per river mile for fish passing via the downstream bypass at Cabot Station.

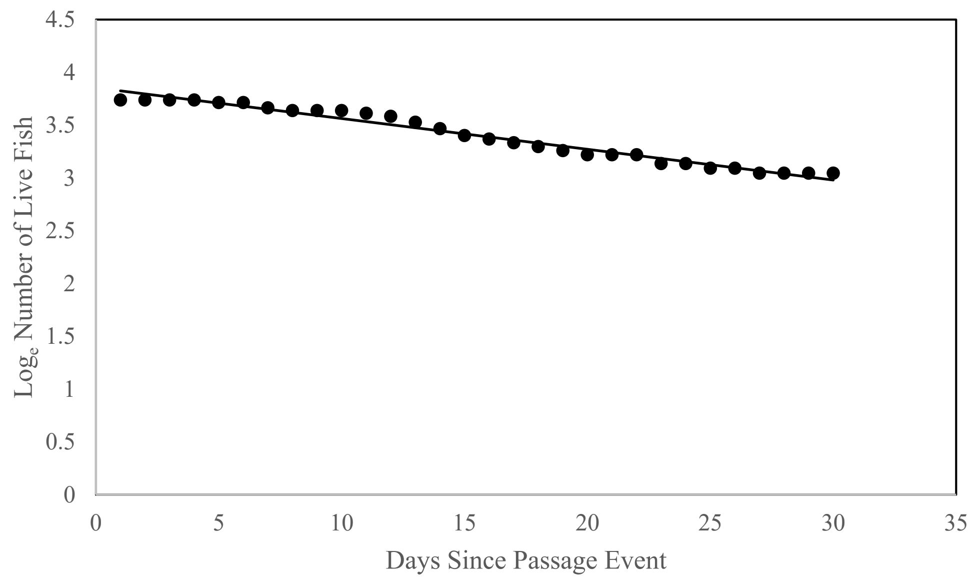

Figure D-4-7: Regression plot used to calculate daily mortality rate for fish passing through both Gatehouse and Cabot Powerhouse.

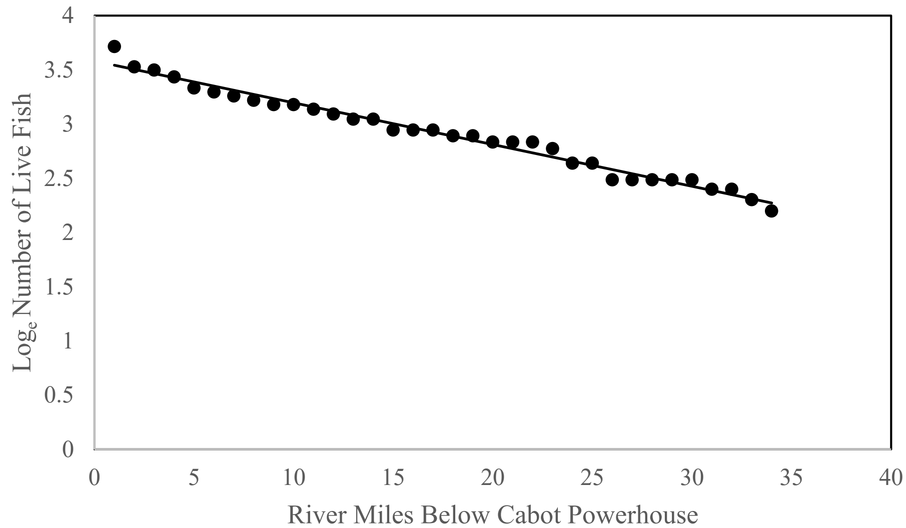

Figure D-4-8: Regression plot used to calculate mortality rate per river mile for fish passing through both Gatehouse and Cabot Powerhouse.

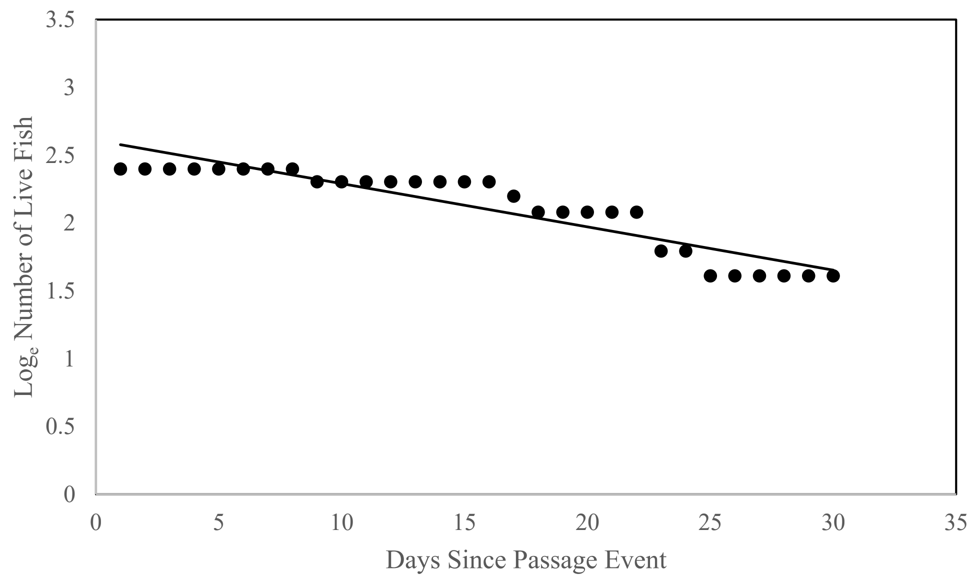

Figure D-4-9: Regression plot used to calculate daily mortality rate for fish passing through both Gatehouse and the downstream bypass at Cabot Station.

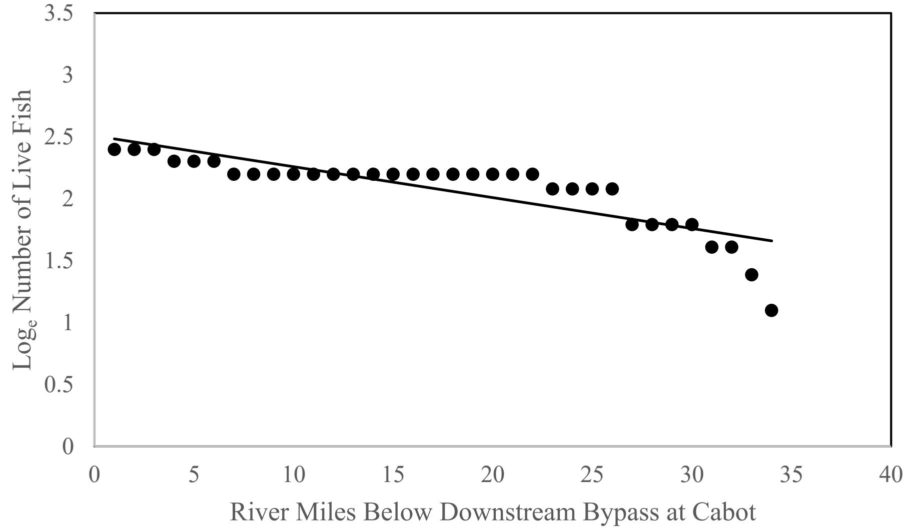

Figure D-4-10: Regression plot used to calculate mortality rate per river mile for fish passing through both Gatehouse and the downstream bypass at Cabot Station.