Relicensing Study 3.3.20

Ichthyoplankton Entrainment Assessment at the Northfield Mountain Project

2016 Study Report

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

Prepared for:

FirstLight Power Resources

Prepared by:

Kleinschmidt

Gomez and Sullivan Engineers

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EXECUTIVE SUMMARY

FirstLight Hydro Generating Company (FirstLight) is the current licensee of the Northfield Mountain Pumped Storage Project (Northfield Mountain Project, FERC No. 2485) and the Turners Falls Hydroelectric Project (Turners Falls Project, FERC No. 1889). FirstLight has initiated with the Federal Energy Regulatory Commission (FERC, the Commission) the process of relicensing the Northfield Mountain and Turners Falls Projects using FERC's Integrated Licensing Process (ILP). The current licenses for the Northfield Mountain and Turners Falls Projects were issued on May 14, 1968 and May 5, 1980, respectively, with both set to expire on April 30, 2018. This report documents the results of Study No. 3.3.20 *Ichthyoplankton Entrainment Assessment at the Northfield Mountain Project* that was conducted during 2015 and 2016.

The February 21, 2014 FERC Study Plan Determination Letter (SPDL) did not require FirstLight to conduct ichthyoplankton sampling in the vicinity of the Northfield Mountain Project intake (tailrace) to quantitatively determine the level of entrainment of early lifestages of American Shad. On March 13, 2014, the United States Fish and Wildlife Service (USFWS) filed a notice of study dispute relating to this determination. On April 8, 2014, the Study Dispute Panel held a meeting at the Northfield Mountain Project Visitors Center to resolve the dispute. In the end, USFWS, FERC and FirstLight collaborated on a study plan to quantify entrainment of various lifestages of American Shad ichthyoplankton at the Northfield Mountain Project and the Study Dispute Panel was suspended without issuing a finding. FirstLight filed the study plan on October 16, 2014. FERC approved the plan in its study plan determination issued January 22, 2015.

In 2015, FirstLight conducted the ichthyoplankton entrainment study from May 28 to June 17 in accordance with the approved study plan. Over the course of the 2015 study, 23 entrainment samples and 12 validation samples were collected, processed and analyzed to estimate the number of American Shad eggs and larvae entrained at the Northfield Mountain Project. The shad ichthyoplankton densities in samples collected in entrainment and offshore at the Northfield Mountain Project were low, most likely because shad spawning did not occur in the proximity of the Northfield Mountain Project tailrace. When extrapolated to the volume of water pumped during the study period from May 28 to July 17, 2015 just over 3 million shad eggs and 500,000 shad larvae were estimated to have been entrained at the Northfield Mountain Project in 2015. Based on the entrainment estimates and published survival fractions (Crecco et al 1983), the number of equivalent juvenile and adults lost to entrainment at the Northfield Mountain Project in 2015 was estimated to have been 696 juvenile shad or 94 adult American shad.

Several stakeholders requested a second year of study and due to annual variability and the typical patchy distribution of ichthyoplankton and late start of the 2015 study, FirstLight performed a second year of study in 2016. Entrainment and offshore sampling was initiated on May 11, 2016 and continued at weekly intervals through July 29, 2016; 47 entrainment samples and 33 offshore (validation) samples were collected. Based on sample counts and the total volume of water pumped at Northfield Mountain Project during the 2016 study period, an estimated 9.5 million shad eggs and 5.4 million shad larvae were estimated to have been entrained the Northfield Mountain Project in 2016. Applying published survival fractions, the numbers of equivalent juvenile and adults lost to entrainment at the Northfield Mountain Project were estimated to be 2,093 juvenile shad or 578 adult American Shad. To put these numbers into perspective, the numbers of American Shad passed in 2016 at the Turners Falls Gatehouse fishway and the Vernon fishway were 54,069 and 35,807, respectively and the 2016 juvenile shad index of abundance was the highest ever recorded.

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LIST OF ABBREVIATIONS

AELs	adult equivalent losses
C	Celsius
cfs	cubic feet per second
CI	confidence interval
CTDEEP	Connecticut Department of Energy and Environmental Protection
DO	dissolved oxygen
FERC	Federal Energy Regulatory Commission
FirstLight	FirstLight Hydro Generating Company
ft^2	square feet
ILP	Integrated Licensing Process
m^3	cubic meters
µS/cm	micro Siemens per centimeter
mg/L	milligrams per liter
mm	millimeter
msl	mean sea level
No.	number
Northfield Mountain Project	Northfield Mountain Pumped Storage Project
PAD	Pre-Application Document
PSP	Proposed Study Plan
QA/QC	Quality Assurance/Quality Control
RSP	Revised Study Plan
SD1	Scoping Document 1
SD2	Scoping Document 2
SPDL	Study Plan Determination Letter
TFI	Turners Falls Impoundment
TL	total length
Turners Falls Project	Turners Falls Hydroelectric Project
USFWS	United States Fish and Wildlife Service
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. This report documents the results of Study No. 3.3.20 *Ichthyoplankton Entrainment Assessment at the Northfield Mountain Project*.

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

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

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

On March 13, 2014, the United States Fish and Wildlife Service (USFWS) filed a notice of study dispute relating to the FERC SPDL not to require FirstLight to conduct ichthyoplankton sampling in the vicinity of the Northfield Mountain Project intake (tailrace) to quantitatively determine the level of entrainment of early life stages of American Shad. Following USFWS letter, the following activities occurred relative to the study dispute:

- On March 26, 2014, a conference call was held with FirstLight, USFWS and FERC to discuss the notice of study dispute.
- On March 28, 2014, FirstLight filed with FERC information relative to Northfield Mountain Project Pumping.
- On March 31, 2014 FERC issued a Notice of Dispute Resolution Panel Meeting and Technical Conference.

- On April 1, 2014, a conference call was held with FirstLight, USFWS and FERC to further discuss the study dispute.
- On April 3, 2014, FirstLight filed with FERC two reports from the 1990s relevant to the Study Dispute Panel's consideration of the dispute.
- On April 7, 2014, FirstLight filed with FERC "Comments and Information of FirstLight Hydro Generating Company Regarding Notice of Study Dispute" relating to USFWS's exercise of Federal Power Act section 18 authority as it pertains to the study dispute.
- On April 8, 2014, the Study Dispute Panel held its meeting at the Northfield Mountain Project Visitors Center.
- On April 8, 2014, following the study dispute panel meeting, a meeting was held with FirstLight, USFWS and FERC to discuss the possibility of a mutually agreeable solution that would alleviate the need for a Director's determination on the study dispute.
- On April 14, 2014, FirstLight filed with FERC drawings and photographs of the Northfield Mountain Project relevant to study methodology discussed by FirstLight, USFWS, and FERC.
- On April 15, 2014, FirstLight filed with FERC Dye testing information conducted at the Northfield Mountain Project.
- On April 22, 2014, a conference call was held with FirstLight, USFWS and FERC to further discuss a mutually agreeable study plan.
- On May 1, 2014, the USFWS filed a Response to the FirstLight's April 7, 2014 filing.
- On May 2, 2014, the USFWS filed with FERC a conceptual framework for assessing ichthyoplankton entrainment at the Northfield Mountain Project. In addition, in a separate May 2, 2014 letter to FERC, USFWS stated that if FERC accepts the proposed study plan framework and requires FirstLight to conduct the study, USFWS will consider the dispute resolved.
- On May 2, 2014, FirstLight filed with FERC a letter supporting USFWS's proposed study.
- On May 2, 2014, FERC suspended the Dispute Resolution Panel.

In the end, USFWS, FERC and FirstLight collaborated on the study plan to quantify entrainment of various life stages of American Shad ichthyoplankton (eggs, yolk-sac and post yolk-sac larvae) at the Northfield Mountain Project. FirstLight submitted the study plan on October 16, 2014, and FERC approved the plan with modifications in its January 22, 2015 study plan determination. Specifically, FERC modified the study plan by recommending that FirstLight (1) include river discharge in its analyses of ichthyoplankton density and entrainment rates; and (2) examine the relationship between entrainment and intake water volume.

1.1 Study Goals and Objectives

In 2015, FirstLight conducted the ichthyoplankton entrainment study from May 28 to June 17. The report describing the 2015 study results was filed with FERC on March 1, 2016. On April 25, 2016 FirstLight had a conference call with NMFS, USFWS, FERC and MADFW to discuss the 2015 ichthyoplankton study. A number of stakeholders requested a second year of study. Due to starting the study late in 2015 coupled with annual variability and the typical patchy distribution of ichthyoplankton, FirstLight performed a second year of study in 2016, which is reported herein. As identified in the Study Plan, the purpose of this study is to quantify entrainment of American Shad ichthyoplankton at the Northfield Mountain Project. The objectives of this study are to:

- Calculate the number of American Shad eggs and larvae entrained at the Northfield Mountain Project;

- Estimate the loss of adult and juvenile shad equivalents based on shad egg and larvae entrainment at the Northfield Mountain Project;
- Compare entrainment rates with one through four units pumping; and
- Determine the temporal distribution of entrainment within the prevailing pumping period.

In their comments on the 2015 report, several stakeholders requested that FirstLight calculate ichthyoplankton entrainment based on pumping operation during the shad ichthyoplankton period under FirstLight's proposal to expand the Upper Reservoir's operating range. The modeling for this scenario is in development, and FirstLight will include the results of the ichthyoplankton entrainment projection based on this scenario in a future filing with FERC.

2 STUDY SITE

The Northfield Mountain Project consists of: a) an upper reservoir and dam/dikes; b) an intake in the upper reservoir; c) pressure shaft; d) an underground powerhouse; and e) a tailrace/intake in the lower reservoir. The Turners Falls Impoundment (TFI) (Connecticut River) serves as a lower reservoir. During generation, water flows from the upper reservoir via the intake channel, through the pressure shaft to the powerhouse and then the tailrace tunnel delivers the water back to the TFI. Key features are described further below.

Turners Falls Impoundment

The TFI, formed by the Turners Falls Dam, extends upstream approximately 20 miles to the base of Vernon Dam in Vernon, VT. To provide storage capacity for the Northfield Mountain Project, the Turners Falls Impoundment elevation may vary, per the FERC license, from a minimum elevation of 176.0 feet msl to a maximum elevation of 185.0 feet msl; this constitutes a 9 foot fluctuation as measured at the Turners Falls Dam. The impoundment has a surface area of approximately 2,110 acres and a gross storage volume of approximately 21,500 acre-feet at elevation 185.0 feet msl (as measured at Turners Falls Dam).

Northfield Mountain Intake/Tailrace Tunnel

During pumping operation, water is pumped from the TFI through a tailrace tunnel to the powerhouse cavern and then through the pressure shaft to the upper reservoir. A floating boom is provided across the intake channel to provide a barrier to large debris and boaters. The trapezoidal trashrack opening has the following dimensions: top width: 99’-6”, bottom width: 74’4”, depth: 48’-0”, resulting in a gross area opening of 4,400 ft2. The bar thickness is 0.75 inches, with a clear-spacing of 6 inches. The intake structure includes a transition from the trapezoidal shape into a horseshoe shaped tunnel. There are four draft tubes connected by a manifold to a common tailrace tunnel. The tailrace tunnel is concrete lined, horseshoe shaped and 5,136 feet long, with a maximum width of 33 feet and a height of 31 feet.

Powerhouse

The underground powerhouse is 328 feet long and 70 feet wide. The floor of the spherical valve gallery is at elevation 56 feet mean sea level (msl) and the roof is at 190 feet msl. It contains four reversible pump/turbines operating at gross heads ranging from 753 to 824.5 feet. The electrical capacities of the units during the study period were as follows: Unit 1: 267.9 MW, Unit 2: 291.7 MW, Unit 3: 291.7 MW and Unit 4: 291.7 MW, for a total station nameplate capacity of 1,143 MW. When operating in a pumping mode, the approximate hydraulic capacity is 15,200 cfs (3,800 cfs/pump). Alternatively, when operating in a generation mode, the approximate hydraulic capacity is 20,000 cfs (5,000 cfs/turbine).

Pressure Shaft

During pumping, water from the powerhouse enters the pressure conduit system which consists of four steel-lined penstocks (340 feet long, diameter increased from 9.5 to 14 feet). These penstocks come together into two 22 foot diameter conduits and then into concrete-lined manifold. An inclined concrete-lined pressure shaft 31 feet diameter, 853 feet long, inclined 50º from the horizontal) connects the manifold to a 200 foot long concrete lined transition section and then to the upper reservoir intake portal. From here, water enters the upper reservoir.

3 METHODS

Ichthyoplankton monitoring at the Northfield Mountain Project consisted of both entrainment and river sampling to determine the number of American Shad larvae and eggs that are withdrawn from the Connecticut River and pumped to the upper reservoir. In 2016, entrainment and river sampling during pumping operations were initiated on May 11 (calendar week 20 of 2016) and generally continued at weekly intervals through July 29 (calendar week 31 of 2016). During the first year of study (2015), operations at the Northfield Mountain Project were intentionally manipulated such that sample collection occurred during 1, 2, 3, and 4-pump operations. For the 2016 study, no attempt was made to schedule sampling during specific pumping scenarios.

3.1 Entrainment Sampling

Similar to 2015, entrainment sampling to collect American Shad eggs and larvae in 2016 was accomplished by tapping off existing piping for Unit 2 in the Northfield Mountain powerhouse that supplies water from the Connecticut River to the upper reservoir. The water diverted at the tap represented the raw water pumped through the system. PVC and rubber piping, a digital flow meter, a 1,000-liter plastic tank, and a 0.333 mm mesh plankton net were utilized to construct the sampling system (Figure 3.1-1). In 2016, the goal was to filter approximately 50 cubic meters (m^3) of intake water per sample to assess the temporal trends in entrainment during the approximately 6-hour pumping period each night. Intake water was diverted to the entrainment sampler at a rate of approximately 3-3.5 gallons per second, which allowed for each sample to be collected in about one hour. Entrainment sample collection was initiated at least ½-hour after the pumping cycle began to allow for the water to be well-mixed. As such, 3 to 5 replicates (50 m^3 each) were collected each sampling night.

Intake water from Unit 2 was diverted through a four-inch diameter flexible hose to a 1,000-liter entrainment sampling tank. An inline Signet® digital flow meter was mounted in the hose to record the volume of water sampled. The hose discharge was directed into a conical 0.333 mm mesh plankton net suspended in a 1,000-liter plastic tank. The plastic tank was designed with an overflow system. Once sufficient volume was obtained, the net was removed from the sampling tank and its contents rinsed into the cod-end collection jar with fresh water. The sample jar was then removed from the plankton net and the contents preserved with a 10% formalin solution for subsequent sorting in the laboratory.

3.2 Sample Validation

To validate that ichthyoplankton collection densities were representative of densities in the intake tunnel, paired samples from inside of the powerhouse (entrainment) and from the intake/tailrace channel (offshore) were generally collected each week. No offshore samples were collected during the week beginning May 22, 2016 as the bongo nets could not be retrieved following deployment on the night of May 24, 2016 (or early morning May 25).

Ichthyoplankton samples were collected near the entrance to the intake/tailrace channel with weighted 60-cm diameter paired bongo nets with 0.333 mm mesh deployed from a boat. The general location of the tows is shown in Figure 3.2-1. The bongo nets were generally towed obliquely[1] in a straight line from downstream to upstream for approximately six minutes or until at least 100 cubic meters of river water was sampled. General Oceanics flowmeters were suspended in the center of each net to measure the volume of river water filtered during each tow. Once the target volume was obtained based on time towed, the nets were hauled onto the boat and the contents from the net with the highest volume were rinsed down with water into the cod-end collection jars; the contents of the other net were discarded. Three replicate tows

[1] The 2015 report submitted to FERC in February 2016 incorrectly stated that the bongo system was towed at mid-depth. The net was towed in an oblique pattern during both years of study, such that the bongos were first deployed to sample near-bottom and gradually raised towards the surface to allow for the entire water column to be sampled.

were performed on each sampling night. The samples were preserved with a 10% formalin solution in appropriately labeled jars and transported back to the sorting room for analysis.

3.3 Sample Processing

Samples were sorted with the aid of a dissecting microscope by biologists trained in ichthyoplankton identification. American Shad larvae and eggs were removed from the samples, identified, and enumerated. Larvae and eggs of Blueback Herring and American Shad in the Connecticut River are not easily distinguishable. However, Blueback Herring numbers are very low; therefore, any alosine eggs and larvae were assumed to be American Shad.

A quality control (QC) program designed to ensure that the Average Outgoing Quality Limit for sorting and identification is greater than 90% was followed. To accomplish this, one sample from each series of ten samples processed by a single individual was randomly selected to be re-sorted. No one was allowed to perform a quality assurance/quality control (QA/QC) on his or her own samples. The person checking the sample (the QA/QC-er) re-processed the sample to determine what percentage of both larvae and eggs was missed, if any. If the percentage missed in either category was equal to or greater than 10%, the following QA/QC procedure was followed until a "passing" QA/QC was obtained: Starting with samples sorted prior to the failed QA/QC, samples were re-sorted in sequential order, working back, until a 'passing' QA/QC was obtained (i.e., Number found by QA/QC individual was less than 10% of total eggs or larvae in the sample). The process was repeated with subsequently sorted samples, sequentially until a passing QA/QC was obtained. Any larvae or egg found during the QA/QC process was added to the totals on the corresponding data sheet and included in the entrainment estimates.

All sorting data, as well as field data, were entered into a Microsoft Access database developed specifically for this study. All data entered were verified for accuracy against the original data sheets prior to commencement of analyses, which are described below.

3.4 Entrainment Data Analysis Methods

Sample Densities

The densities of shad eggs and larvae in each of the entrainment and offshore samples were calculated by dividing the sample count by sample volume to express organism density in count per cubic meter (1).

$$\rho_{si} = \frac{x_{si}}{v_s} \qquad (1)$$

Where ρ_{si} is the density of lifestage i (eggs or larvae) in sample s (org/m^3); x_{si} is the count of organisms of lifestage i in sample s (org); and v_s is the volume of sample s (m^3). There is no uncertainty associated with an individual sample density as there is a single count and single volume that are considered for the density calculation.

Weekly Sample Densities

Equation (2) calculates a weekly mean entrainment density and the uncertainty is accounted for with Equation (3). The mean counts with 95% confidence intervals (CI) were calculated assuming a Poisson distribution using a generalized linear model with count as the dependent variable and week as a factor. The Poisson distribution assumes that the count variance equals the mean. If this assumption failed, the mean counts and 95% CI were estimated with a generalized linear model assuming a Negative Binomial distribution.

$$\rho_{wi} = \frac{e^{\bar{x}_{wi}}}{\bar{v}_w} \qquad (2)$$

Where ρ_{wi} is the density of lifestage i in week w and is expressed in units of x/m^3; $\bar{x}_{wi}$ is the mean count of lifestage i in week w (x); and $\bar{v}_w$ is the mean sample volume (m^3) in week w. Equation (3) estimates the uncertainty in ρ_{wi} and assumes that the errors associated with count $\bar{x}_{wi}$ and sample volume $\bar{v}_w$ are uncorrelated and random.

$$\delta\rho_{wi} = \sqrt{\left(\frac{\delta\bar{x}_{wi}}{\bar{x}_{wi}}\right)^2 + \left(\frac{\delta\bar{v}_w}{\bar{v}_w}\right)^2} * |\rho_{wi}| \quad (3)$$

Where $\delta\rho_{wi}$ is the 95% CI of the mean density of lifestage i in week w; $\delta\bar{x}_{wi}$ is the 95% CI of the mean count of lifestage i in week w (Equation (4)); and $\delta\bar{v}_w$ is the 95% CI of volume in week w (Equation (5)).

$$\delta\bar{x}_{wi} = Z_{a/2} * \frac{\sigma_{x_{wi}}}{\sqrt{n}} \quad (4)$$

$$\delta\bar{v}_w = Z_{a/2} * \frac{\sigma_{v_w}}{\sqrt{n}} \quad (5)$$

Where $\sigma_{x_{wi}}$ and σ_{v_w} are the standard deviation of weekly counts (x) and volume (v), respectively, and $Z_{a/2}$ is the Z-score for the 95% confidence level (α). If the precision of the weekly sample densities cannot be estimated, a more traditional extrapolation method is warranted. First, weekly sample densities given with Equation 6 are calculated.

$$\bar{\rho}_{wi} = \frac{\sum x_{si}}{\sum v_s} \quad (6)$$

Where $\bar{\rho}_{wi}$ is the weekly density of the i^{th} species and lifestage, x_{si} is the count of the i^{th} species and lifestage in sample s and v_s is the volume of water pumped in sample s. Following the calculation of each weekly density, a linear spline interpolated daily organism densities (org/m^3) between weekly observations. The spline method interpolates a linear function between observations and assumes that observations taken closer together are more similar than those taken further apart. Following the calculation of daily densities, the estimate was extrapolated by multiplying the daily density by the daily summed pumping flow.

Comparison of Offshore and Entrainment Samples

Following the calculation of weekly entrainment and offshore densities by lifestage, the sample type (entrainment or offshore) with the maximum density estimate served as the weekly extrapolation density. Based on the number of samples, direct comparisons were made with an aggregate query in Microsoft Access that determined the maximum weekly lifestage density. Following this comparison, operations data were manipulated as described below for the weekly extrapolation.

Calculation of Flow

Northfield Mountain operations data for the duration of the entrainment sampling program were provided by FirstLight as hourly flow rates (cfs). As the entrainment extrapolation requires the total amount of water pumped during a given calendar week, the flow rate was transformed to a volume of water pumped (Equation (7)).

$$Q_i' = Q_i * 0.0283168 * s_i \quad (7)$$

Where Q_i' is the volume of water pumped (m^3) per Northfield Mountain Project time interval i; Q_i is the Northfield Mountain Project reported flow rate in ft^3/s; s_i is the duration of the i^{th} Northfield Mountain Project time interval in seconds; and the conversion factor is expressed in units of cubic meter per second per cubic foot per second ($\left.{m^3/s}\middle/{ft^3/s}\right.$). A Microsoft Access aggregate query summed the weekly volume of water pumped that was used to extrapolate weekly entrainment estimates.

Weekly Extrapolation of Entrainment Estimates

Entrainment estimates for American Shad eggs and larvae were derived based on the extrapolation of raw counts using a volumetric ratio and summing of weekly estimates derived from samples. The weekly entrainment estimate was calculated by multiplying the organism density ρ_{wi} (org/m^3) by the volume of water pumped in a given week (m^3) (Equation (8)).

$$x_{wi}' = \rho_{wi} Q_w' \tag{8}$$

Where x_{wi}' is the weekly estimate of organisms entrained during pumping operations; ρ_{wi} is the weekly entrainment density expressed in $\ln(x_{wi})\,/m^3$; and Q_w' is the sum of water pumped during week w. While there is no error associated with Q_w', the error associated with each weekly estimate ρ_{wi} was calculated. Equation (9) calculates the error associated with each weekly estimate x_{wi}'.

$$\delta x_{wi}' = |Q_w'| * \delta \rho_{wi} \tag{9}$$

Where $\delta x_{wi}'$ is the uncertainty of the weekly extrapolation, and the weekly volume Q_w' and density uncertainty $\delta \rho_{wi}$ were derived with Equations (7) and (3), respectively. The weekly extrapolation estimates the number of individuals of lifestage i entrained due to pumping operations at the Northfield Mountain Project while the Adult Equivalent Model estimates the number of equivalent adults that are lost to recruitment.

Equivalent Adult Estimates

The numbers of entrained American Shad larvae and eggs during sampling at Northfield Mountain were converted into adult equivalents. Adult equivalent losses (AELs) are estimates of the number of entrained organisms removed from the population that otherwise would have survived to some future age, or age of equivalence. To estimate AELs for Northfield Mountain, the weekly estimates of entrained larvae and eggs (x_{wi}') were multiplied by the survival fraction at the age of equivalence i and the proportion p of returning adults that belong to lifestage i (Equation (10)):

$$AEL_j = \sum_{j=1}^{n} S_{ij} x_{wi}' p_j \tag{10}$$

Where AEL_j is the expected number of adult equivalents of lifestage j lost due to pumping operations; S_{ij} is the survival fraction of organisms of starting lifestage i surviving to lifestage j; x_{wi}' is the extrapolated number of organisms of lifestage i during week w; and p_j is the expected proportion of returning equivalent adults of lifestage j.

Survival rates of early lifestages are often expressed on a lifestage-specific basis so that the fraction surviving from any particular lifestage i to adulthood or age of equivalence j is expressed as the product of survival fractions for all lifestages (k) through which a fish must pass before reaching age of equivalence j (Equation (11)).

$$S_{ij} = \prod_{i=1}^{j} S_k \tag{11}$$

Where S_{ij} where is the survival fraction from the starting age i to the age of equivalence j and S_k is the survival rate at age k. Lifestage-specific survival rates were compiled from (EPA 2004) and Crecco et al. 1983 (Table 3.4.1). Both sources reported mortality rather than survival. Mortality was converted to survival with Equation 12 (Haddon, 2011):

$$S_k = \frac{N_k}{N_i} = e^{-(M_k+F_k)} \tag{12}$$

Where M_k is the natural mortality rate at lifestage k; F_k is the fishing mortality at lifestage k; and N_k is the number expected to survive to lifestage k assuming N_i is the number of fish alive at lifestage i.

The Connecticut Department of Energy and Environmental Protection (CT DEEP) collects life history parameters from adult American Shad as they pass through the Holyoke lift and uses scales to estimate the age of the fish. The ages of equivalence are based on the list of ages identified by the CT DEEP over a 5-year period from 2010 – 2014 (J. Benway, CT DEEP, personal communication, 12/2015). The yearly counts by age introduce uncertainty into the proportion of returning adults p belonging to the age of equivalence j. The 95% CI for the proportion of each age class was calculated assuming a multinomial distribution. The uncertainty associated with x'_{wi} and p_j was accounted for with Equation (13).

$$\delta AEL_{wj} = \sqrt{\left(\frac{\delta x'_{wi}}{x'_{wi}}\right)^2 + \left(\frac{\delta p_j}{p_j}\right)^2} * |AEL_{wj}| \tag{13}$$

Where δAEL_{wj} is the uncertainty in the estimated AEL_j; $\delta x'_{wi}$ is the 95% CI of the weekly (w) extrapolation of lifestage i; x'_{wi} is the weekly w extrapolation of lifestage i; δp_j is the 95% CI for the proportion of the j^{th} age of equivalence; and p_j is the proportion of the j^{th} lifestage that are expected to return to the Holyoke lift. The AEL model was implemented to take advantage of its inherent looping and hash table indexing capabilities. Following computation, results were imported into the Microsoft Access project database. An aggregate query then summed the number of equivalent adults over each week to obtain the number of equivalent adults for each recruitment age lost to entrainment in 2016.

Table 3.4-1. Lifestage Specific Mortality Rates with Converted Survival Fractions

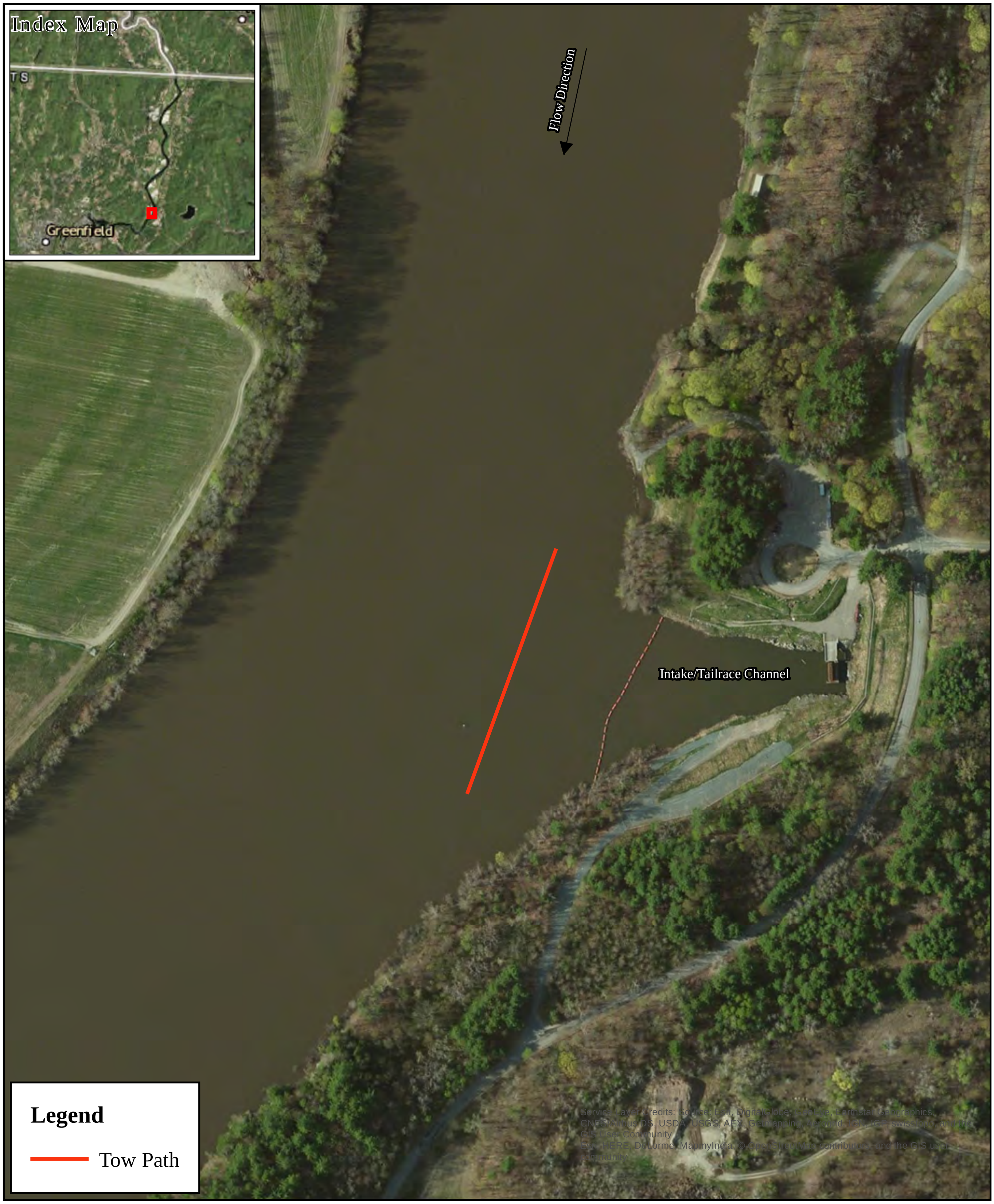
Lifestage (k)	M_k	F_k	S_k	Source
Egg	0.496	0	0.609	EPA 2004
Larvae 1 (L1)	0.273	0	0.760	Crecco *et.al.*, 1983
Larvae 2 (L2)	0.15	0	0.861	Crecco *et. al.*, 1983
Larvae 3 (L3)	0.096	0	0.901	Crecco *et. al.*, 1983
Larvae 4 (L4)	0.060	0	0.942	Crecco *et. al.*, 1983
Juvenile	7.4	0	6.113×10^{-4}	EPA 2004
Age 1	0.3	0	0.741	EPA 2004
Age 2	0.3	0	0.741	EPA 2004
Age 3	0.3	0	0.741	EPA 2004
Age 4	0.54	0.21	0.472	EPA 2004
Age 5	1.02	0.21	0.292	EPA 2004
Age 6	1.5	0.21	0.181	EPA 2004

Note: from Crecco et. al., 1983, the lifestages specific mortality rates were averaged across 1979 – 1982.

Note: L1 larvae correspond to fish between 10.0 and 13.0 mm, L2 fish between 13.0 and 18.0 mm, L3 fish between 18.0 and 21.0 mm and L4 fish are between 21.0 and 23.0 mm.

Note: M_k is the instantaneous rate of natural mortality at lifestage k; F_k is the instantaneous rate of fishing mortality at lifestage k; and S_k is the lifestage specific survival fraction.

Figure 3.1-1: Ichthyoplankton Entrainment Sampling System for Collection of American Shad Eggs and Larvae at the Northfield Mountain Project.



Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)
Ichthyoplankton Entrainment Assessment
at the NorthfieldMountain Project
Relicensing Study 3.3.20

N

0 0.025 0.05 0.1 Miles

Figure 3.2-1: General Location of Ichthyoplankton Entrainment Verification Samples

Path: W:\gis\studies\3_3_20\Maps\Figure 3_2_1.mxd

4 RESULTS

Over the course of the study, 47 entrainment samples and 33 validation (offshore) samples were collected between May 11 (calendar week 20 of 2016) and July 29, 2016 (calendar week 31 of 2016). Water quality information, including water temperature, dissolved oxygen (DO), pH and conductivity, collected on each date of sampling, as well as operational status of the Northfield Mountain Project, is presented in Table 4.0-1 for entrainment and Table 4.0.2 for validation samples. During sampling, the water temperature ranged from 11.7^{o}C to 26.8^{o}C, DO ranged from 6.5 to 11.7 mg/L, pH ranged from 7.1 to 8.4 and conductivity 63 to 157 µS/cm for entrainment and validation samples combined. Figure 4.0-1 shows the Connecticut River flow as measured at the United States Geological Survey gage in Montague City, MA (Gage No. 01170500) during the sampling period.

4.1 Entrainment Densities

Weekly densities, based on the total number of organisms collected and total volume of water sampled each week of entrained shad eggs and larvae are presented in Table 4.1-1. Eggs were first observed in entrainment samples collected on June 2 (Week 23) and remained present in samples collected through July 8, 2016 (Week 28). Egg density peaked during Week 24 (June 8), when a maximum density of 15.3 eggs per 100 m3 was observed.

Larval observations appeared somewhat more sporadic as larvae were absent from 50% of the samples collected. Shad larvae were first observed in entrainment samples collected on May 25 and peak density occurred on June 8, 2016 (Week 24). Shad larvae were not observed in any samples collected after July 8, 2016 (Week 28). Weekly larval densities ranged from 0 to 11.5 shad larvae per 100 m^3.

The temporal distribution of shad egg and larval entrainment was assessed by summing hourly (based on start hour) densities for each lifestage (eggs and larvae) across weeks (Table 4.1-2). There was no temporal distribution throughout the sampling period.

There does not appear to be a trend with river flow and entrainment density. The daily non-zero organism densities (org/m^3) were matched with the daily average flow at the Montague USGS gage and graphed (Figure 4.1-1). There does not appear to be a trend with river flow and entrainment at Northfield as the Pearson correlation coefficient was low for eggs ($r = 0.49$) and larvae ($r = -0.35$).

4.2 Verification (Offshore) Densities

Verification (offshore) sampling was conducted adjacent to Northfield Mountain intake/tailrace channel each evening that entrainment samples were collected. No verification samples were collected during Week 22 as one of the nets was torn during the first tow and could not be replaced until the following week. Weekly densities of shad eggs and larvae in verification samples are presented in Table 4.2-1. Throughout the 2016 study period, only one shad egg was observed in the verification samples, which was collected on May 18 (Week 21).

Larval observations were also scarce, with larvae only observed in samples collected during Weeks 24 (June 8) and 25 (June 17). The density of shad larvae in the verification samples collected during Week 24 was 0.311 larvae per 100 m^3 and for Week 25 was nearly 11 larvae per 100 m^3. No larvae were collected after June 17, 2016 (Week 25).

4.3 Entrainment Estimate

Both the entrainment and offshore densities were used to calculate weekly entrainment estimates. With multiple samples collected per night and week, uncertainty in organism density was taken into account. It is assumed that organism density within the river is variable in space and time. The entrainment density should reflect that natural variability. Therefore, the weekly mean count and 95% CI were modeled with a generalized linear model. Count data are traditionally modeled assuming a Poisson distribution; however, sample counts at the Northfield Mountain Project violated the assumption of the variance equaling the mean (Table 4.3-1). As in 2015 a generalized linear model assuming a negative binomial distribution was used to model the mean count and CI, with week as a factor.

To describe the mean weekly entrainment rate, we applied a negative binomial regression to the larval entrainment data. The test, which was analogous to a traditional analysis of variance, looked for significant difference in mean count over each week. However, neither the intercept (Table 4.3-2) nor any week of the larval entrainment data were significant. Therefore, a negative binomial distribution was fit to the entire entrainment dataset (Figure 4.3-1). While excellent fit was achieved (note very high agreement between empirical and theoretical distributions), the overabundance of samples with 0 counts meant the distribution was not informative for extrapolation purposes. Both the median and lower 95% confidence interval were zero, meaning our estimate would be zero. This result prompted the use of a more traditional entrainment estimate.

With this information in mind, we developed an extrapolation that mirrors a more traditional method that simply multiplies the daily sample density by the total volume of water pumped. This method cannot give us an estimate of precision. We interpolated organism densities (org/m^3) between observations with a linear spline for 2016 (Figure 4.3-2). Note the spline method interpolates a linear function between observations. This method assumes that observations taken closer together are more similar than those taken further apart. The 2016 entrainment estimate was 9,540,864 eggs and 5,385,760 L4 larvae (Table 4.3-2).

4.4 Equivalent Adult Estimates

Similar to 2015, the estimate of equivalent adults by lifestage incorporated the proportion of 3, 4, 5, and 6-year-old adults returning to Holyoke between 2010 and 2014 (J. Benway CT DEEP pers. comm. 12/2015). The age with the highest proportion of returning adults was five (5) with just over 40% (Table 4.4-1). Results of the equivalent juvenile and adult determinations for American Shad observed in the 2016 entrainment samples are provided in Table 4.4-2. To be conservative, it was assumed that all larvae entrained at Northfield Mountain during 2016 were of lifestage L4 as this class exhibits the highest lifestage-specific survival amongst the various stages of shad larvae. The total number of equivalent juvenile and adult American Shad lost due to entrainment of eggs and larvae at the Northfield Mountain Project in 2016 was estimated to be 2,093 juveniles or 578 adult American Shad.

4.5 Shad Spawning in TFI

A companion American Shad spawning study was conducted in the TFI during 2015 (Study No. 3.3.6 *Impact of Project Operations on Shad Spawning, Spawning Habitat and Egg Deposition in the Area of the Northfield Mountain and Turners Falls Projects*). The only area where shad were detected spawning in the TFI was just below the Vernon Dam at the downstream end of Stebbins Island (Figure 4.5-1). Spawning was observed over an approximately 39-acre area at this location. As part of Study No. 3.3.6, American Shad eggs and larvae were collected at the Stebbins Island spawning site and the densities from May 19 to June 18, 2015 ranged from 7 to 101 per 100 m^3 (*see* Study Report No. 3.3.6).

Table 4.0-1. Northfield Mountain Project Entrainment Sample Collection Information

Week No.	Sample Date	Sample No.	Start Time	Duration (hr:min)	No. of Pumps	Water Temp. (ºC)	DO (mg/L)	pH	Conductivity (µS/cm)
20	5/11/2016	1	0:31	1:11	2	11.69	11.4	7.95	98
		2	2:14	1:07	2	11.86	11.65	7.99	99
		3	3:28	1:08	1	11.86	11.51	7.79	99
21	5/18/2016	4	0:45	1:07	2	13.25	10.93	7.77	102
		5	1:53	1:07	3	12.99	10.73	7.81	102
		6	3:05	1:13	3	12.85	10.76	7.81	101
		7	4:20	1:20	1	12.70	10.77	7.8	101
22	5/25/2016	8	0:40	0:59	4	15.08	10.12	7.83	97
		9	1:40	1:01	4	*	*	*	*
		10	2:42	1:01	4	*	*	*	*
		11	3:44	0:57	3	*	*	*	*
		12	4:42	1:03	2	*	*	*	*
23	6/2/2016	13	2:45	1:10	2	21.78	8.28	7.57	122
		14	4:00	1:08	3	21.67	9.26	7.48	122
		15	5:10	1:07	1	21.57	8.11	7.48	121
24	6/8/2016	16	1:30	1:10	1	22.04	8.05	7.44	124
		17	2:43	1:05	2	21.99	8.04	7.48	124
		18	3:50	1:10	3	21.91	8.01	7.49	124
		19	5:03	1:10	3	21.86	8.05	7.49	124
25	6/17/2016	20	0:50	1:08	3	21.66	9.17	7.31	124
		21	3:19	1:06	4	20.73	9.29	7.74	123
		22	4:28	1:07	2	20.64	9.25	7.71	123
26	6/23/2016	23	1:28	1:05	2	22.18	8.64	7.51	137
		24	2:35	1:05	3	22.37	9.11	7.73	143
		25	3:42	1:08	2	22.23	9.14	7.78	144
		26	4:50	1:08	1	22.14	9.07	7.77	144
27	6/29/2016	27	0:40	1:08	1	23.99	7.92	7.63	147
		28	1:50	1:06	2	24.11	8.04	7.63	146
		29	2:58	1:08	3	24.19	8.11	7.65	146
		30	4:08	1:10	1	24.05	8.00	7.64	146
28	7/8/2016	31	0:55	1:01	2	25.90	8.75	7.95	141
		32	1:57	1:07	3	25.88	8.71	8.16	140
		33	3:05	1:10	4	25.79	8.7	8.12	140
		34	4:16	1:09	3	25.68	8.69	8.11	138
29	7/15/2016	35	23:45**	1:10	1	24.55	8.39	7.95	140
		36	0:55	1:09	2	24.82	9.04	8.13	142
		37	2:05	1:04	3	24.82	8.85	8.13	143

Week No.	Sample Date	Sample No.	Start Time	Duration (hr:min)	No. of Pumps	Water Temp. (ºC)	DO (mg/L)	pH	Conductivity (µS/cm)
		38	3:10	1:02	4	24.72	8.94	8.13	142
		39	4:12	1:05	2	24.72	8.80	8.13	141
30	7/20/2016	40	0:27	1:15	1	25.36	8.81	8.20	157
		41	1:42	1:14	2	25.16	8.80	8.20	157
		42	2:56	1:14	2	25.02	8.65	8.18	155
		43	4:10	1:15	2	24.91	8.70	8.20	154
31	7/29/2016	44	0:40	1:04	2	26.25	8.35	8.40	146
		45	1:45	1:07	3	26.22	8.22	8.11	145
		46	2:55	1:09	3	26.33	8.32	8.14	144
		47	4:05	1:07	2	26.37	8.28	8.13	143

** No measurements recorded; water quality meter malfunctioned.*

*** Sample initiated on night of 7/14, but completed on 7/15/2016.*

Table 4.0-2. Northfield Mountain Project Validation (Offshore) Sample Collection Information

Week No.	Sample Date	Water Temp. (°C)	DO (mg/L)	pH	Conductivity (µS/cm)	Sample No.	Start Time	Duration (minutes)	Depth (ft)	Sample Volume (m^3)	No. of Pumps
20	5/11/2016	12.3	10.3	7.05	63	1	2:35	7	35	105	2
						2	3:15	7	35	116	2
						3	3:46	7	35	117	2
21	5/18/2016	13.5	9.62	7.26	77	4	1:18	6	20	198	2
						5	1:44	6	18	164	2
						6	2:03	6	20	106	2
22	6/2/2016	21.9	7.75	7.38	100	7	2:21	6	20	100	2
						8	2:57	6	19.2	101	2
						9	3:12	6	20	105	2
23	6/10/2016	20.3	7.65	7.55	112	10	3:03	5	-	111	2
						11	3:19	6	-	105	2
						12	3:36	6	-	106	1
24	6/17/2016	20.8	7.89	7.47	117	13	0:59	6	22.4	137	3
						14	1:14	6	23.7	116	3
						15	1:31	6	24	112	3
25	6/23/2016	22.3	7.61	7.47	102	16	2:05	6	25	157	2
						17	2:20	6	23.2	148	2
						18	2:33	6	25	140	2
26	6/29/2016	24	7.18	7.57	118	19	3:55	6	-	142	4
						20	4:16	6	-	213	3
						21	-	6	-	130	3
27	7/8/2016	26.5	7.36	7.62	131	22	1:15	6	20	118	2
						23	1:35	6	20	106	2
						24	2:03	6	20	120	3
28	7/15/2016	25.4	6.92	7.7	132	25	0:00	6	17	150	1
						26	0:19	6	20	104	1

Week No.	Sample Date	Water Temp. (ºC)	DO (mg/L)	pH	Conductivity (µS/cm)	Sample No.	Start Time	Duration (minutes)	Depth (ft)	Sample Volume (m^3)	No. of Pumps
						27	0:34	6	23	127	2
29	7/20/2016	25.7	7.18	7.5	140	28	0:45	6	20	117	1
						29	1:01	6	20	122	1
						30	1:15	6	20	114	1
30	7/29/2016	26.8	6.51	7.49	129	31	0:56	6	20	115	1
						32	1:11	6	20	111	1
						33	1:24	6	20	100	1

"-" no data recorded

Table 4.1-1. 2016 Weekly Densities of American Shad Ichthyoplankton Observed in Entrainment Samples

Week No.	Lifestage	Count	Sample Volume (m^3)	Density (No./100 m^3)
20	E	0	150	0.000
	L	0		0.000
21	E	0	201	0.000
	L	0		0.000
22	E	0	250	0.000
	L	2		0.800
23	E	20	148	13.514
	L	17		11.486
24	E	31	202	15.347
	L	5		2.475
25	E	2	150	1.333
	L	2		1.333
26	E	1	150	0.667
	L	0		0.000
27	E	1	250	0.400
	L	0		0.000
28	E	1	200	0.500
	L	2		1.000
29	E	0	256	0.000
	L	0		0.000
30	E	0	200	0.000
	L	0		0.000
31	E	0	200	0.000
	L	0		0.000

Table 4.1-2. Temporal distribution of eggs and larvae entrained at Northfield Mountain Project during 2016 study period

Lifestage	Start Hour	Organism Count	Sample Volume (m^3)	Density (#/100 m^3)
Egg	23:00	0	55	0.00
	0:00	1	451	0.22
	1:00	8	401	2.00
	2:00	10	450	2.22
	3:00	8	402	1.99
	4:00	11	500	2.20
	5:00	18	98	18.37
Larvae	23:00	0	55	0.00
	0:00	0	451	0.00
	1:00	1	401	0.25
	2:00	12	450	2.67
	3:00	4	402	1.00
	4:00	8	500	1.60
	5:00	3	98	3.06

Table 4.2-1. 2016 Weekly Densities of American Shad Ichthyoplankton Observed in Verification (Offshore) Samples

Week No.	Lifestage	Count	Sample Volume (m^3)	Density (No./100 m^3)
20	E	0	338	0.000
	L	0		0.000
21	E	1	468	0.214
	L	0		0.000
23	E	0	306	0.000
	L	0		0.000
24	E	0	322	0.000
	L	1		0.311
25	E	0	365	0.000
	L	40		10.959
26	E	0	445	0.000
	L	0		0.000
27	E	0	485	0.000
	L	0		0.000
28	E	0	344	0.000
	L	0		0.000
29	E	0	381	0.000
	L	0		0.000
30	E	0	353	0.000
	L	0		0.000
31	E	0	326	0.000
	L	0		0.000

Table 4.3-1. Weekly Mean Count and Variance by Sample Type, Week and Lifestage for Ichthyoplankton Data Collected at Northfield Mountain Project

Sample Type	Week No.	Lifestage	Mean Count ($\bar{x}$)	Variance	n
Entrainment	20	E	0.00	0.00	3
Entrainment	21	E	0.00	0.00	4
Entrainment	22	E	0.00	0.00	5
Entrainment	23	E	6.67	9.33	3
Entrainment	24	E	7.75	20.92	4
Entrainment	25	E	0.67	0.33	3
Entrainment	26	E	0.33	0.33	3
Entrainment	27	E	0.20	0.20	5
Entrainment	28	E	0.25	0.25	4
Entrainment	29	E	0.00	0.00	5
Entrainment	30	E	0.00	0.00	4
Entrainment	31	E	0.00	0.00	4
Entrainment	20	L	0.00	0.00	3
Entrainment	21	L	0.00	0.00	4
Entrainment	22	L	0.40	0.80	5
Entrainment	23	L	5.67	14.33	3
Entrainment	24	L	1.25	0.92	4
Entrainment	25	L	0.67	0.33	3
Entrainment	26	L	0.00	0.00	3
Entrainment	27	L	0.00	0.00	5
Entrainment	28	L	0.50	0.33	4
Entrainment	29	L	0.00	0.00	5
Entrainment	30	L	0.00	0.00	4
Entrainment	31	L	0.00	0.00	4
Offshore	20	E	0.00	0.00	3
Offshore	21	E	0.33	0.33	3
Offshore	23	E	0.00	0.00	3
Offshore	24	E	0.00	0.00	3
Offshore	25	E	0.00	0.00	3
Offshore	26	E	0.00	0.00	3
Offshore	27	E	0.00	0.00	3
Offshore	28	E	0.00	0.00	3
Offshore	29	E	0.00	0.00	3
Offshore	30	E	0.00	0.00	3
Offshore	31	E	0.00	0.00	3
Offshore	20	L	0.00	0.00	3
Offshore	21	L	0.00	0.00	3
Offshore	23	L	0.00	0.00	3
Offshore	24	L	0.33	0.33	3
Offshore	25	L	13.33	277.33	3
Offshore	26	L	0.00	0.00	3
Offshore	27	L	0.00	0.00	3
Offshore	28	L	0.00	0.00	3
Offshore	29	L	0.00	0.00	3
Offshore	30	L	0.00	0.00	3
Offshore	31	L	0.00	0.00	3

Table 4.3-2. Negative Binomial Generalized Linear Model for Count Data for Ichthyoplankton Collected at Northfield Mountain Project. Note the larval entrainment model was not informative prompting fit of a single distribution to describe all entrainment events.

Model	Parameter	Estimate	Std. Error	Z value	p
Entrainment (L)	Intercept	1.999906	2.251958	0.974	0.330
	Week 23	3.083299	2.326116	1.383	0.167
	Week 24	2.571527	2.321933	-0.217	0.828
	Week 25	0.500024	2.648782	-0.690	0.490
	Week 28	0.500024	2.780136	-0.690	0490

Table 4.3-3. Weekly summed extrapolation of eggs and larvae

Week	Pump Volume	Eggs	Larvae
20	28,076,201	0	0
21	27,426,911	0	31,460
22	32,482,856	475,417	607,953
23	32,276,214	3,586,034	2,812,422
24	20,731,612	2,965,183	887,935
25	37,561,327	1,732,921	586,827
26	35,508,448	380,183	122,861
27	35,466,926	252,059	38,168
28	33,978,988	128,776	257,553
29	31,669,228	20,291	40,582
30	45,303,677	0	0

Table 4.4-1. The Equivalent Adult Proportions Based on Shad Returning to Holyoke Dam from 2010 to 2014

Age	Proportion	95% CI
3	0.085	[0.065,0.104]
4	0.398	[0.379,0.418]
5	0.405	[0.385,0.424]
6	0.107	[0.088,0.127]
7	0.005	[0.000,0.025]

Table 4.4-2. The Estimate of Equivalent Juvenile (J) and Adult American Shad Loss Due to Entrainment of Eggs and Larvae at Northfield Mountain Project in 2016

Starting Lifestage	Equivalent Loss by Stage/Age (years)					
	J	3	4	5	6	7
Egg	1,987	69	152	45	2	0
Larvae 4	106	237	70	3	0	0
Total	**2,093**	**306**	**222**	**48**	**2**	**0**

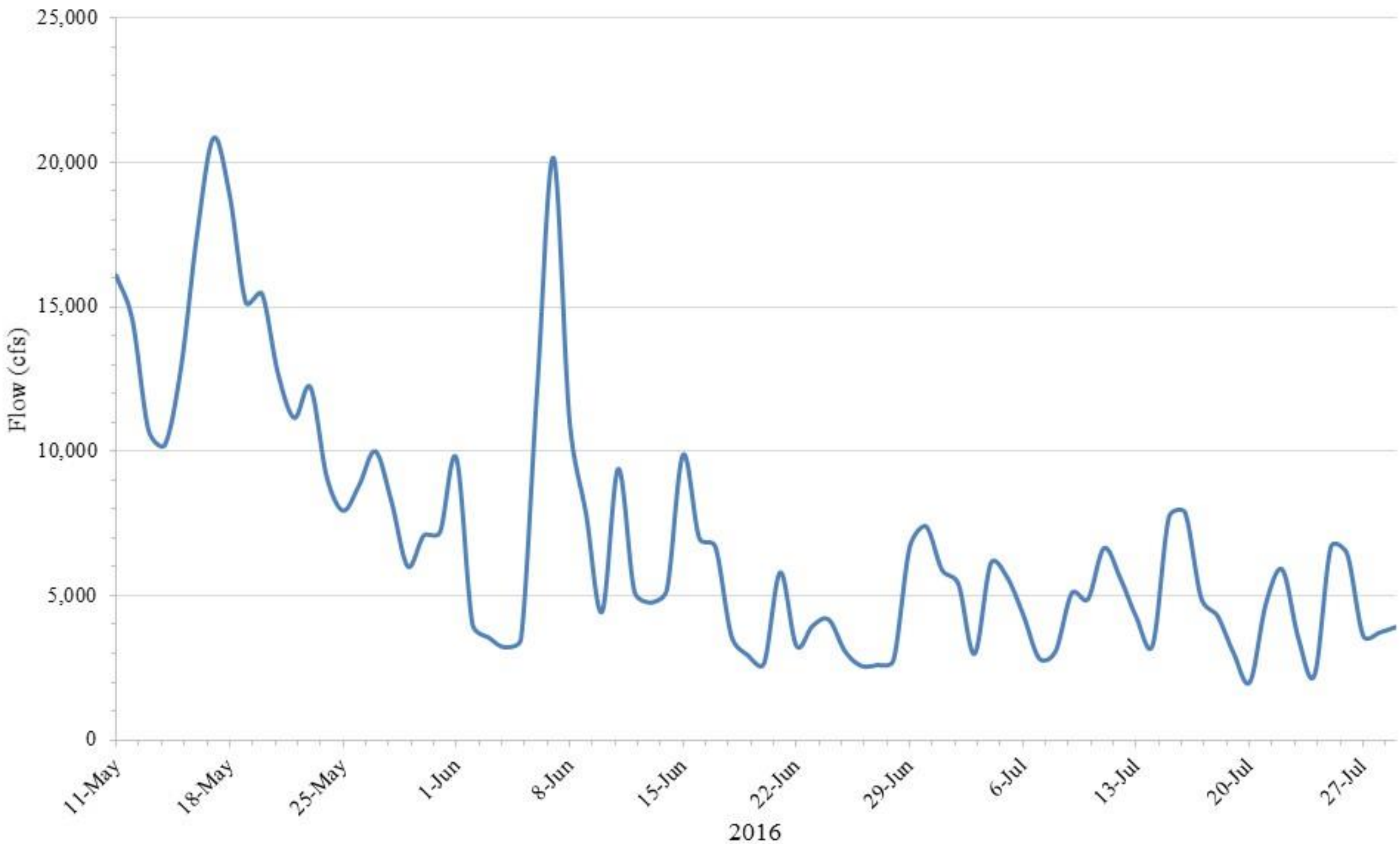


Figure 4.0-1: Connecticut River 15-Minute Flow at the Montague USGS Gage during the Northfield Mountain Project 2016 Ichthyoplankton Study

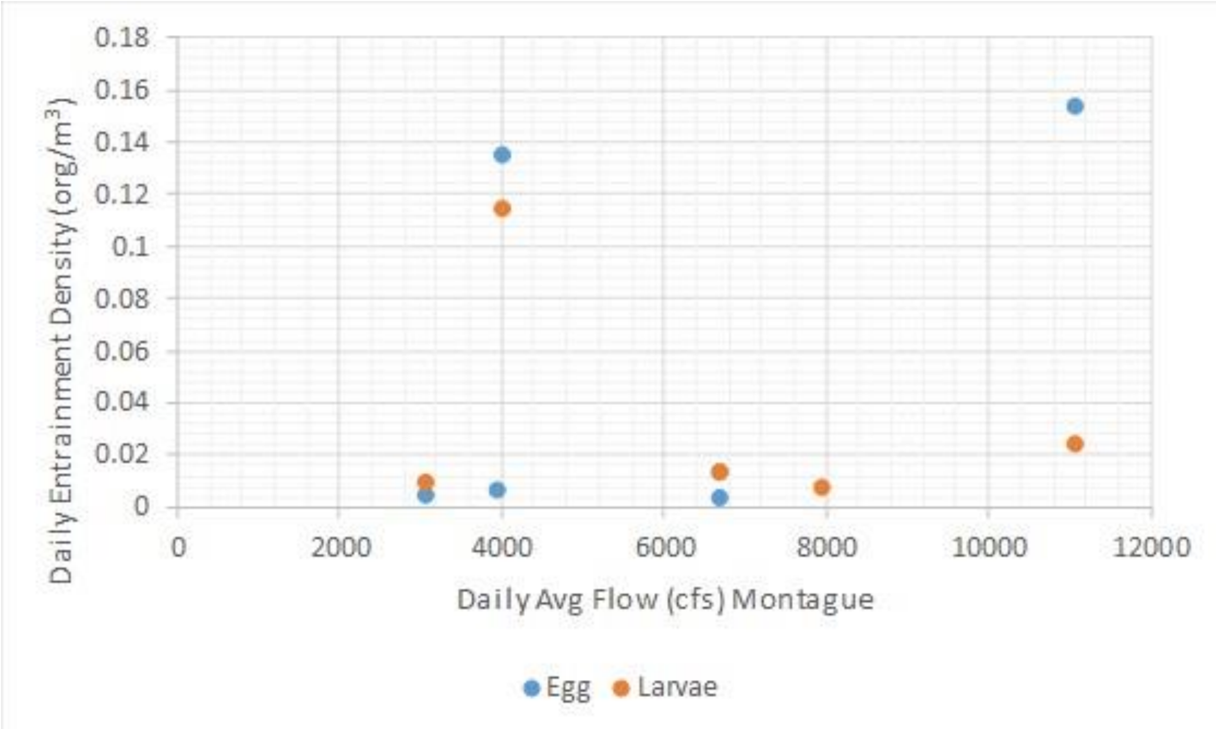


Figure 4.1-1: The 2016 daily entrainment density at Northfield Mountain Project matched with the daily average flow at Montague gage.

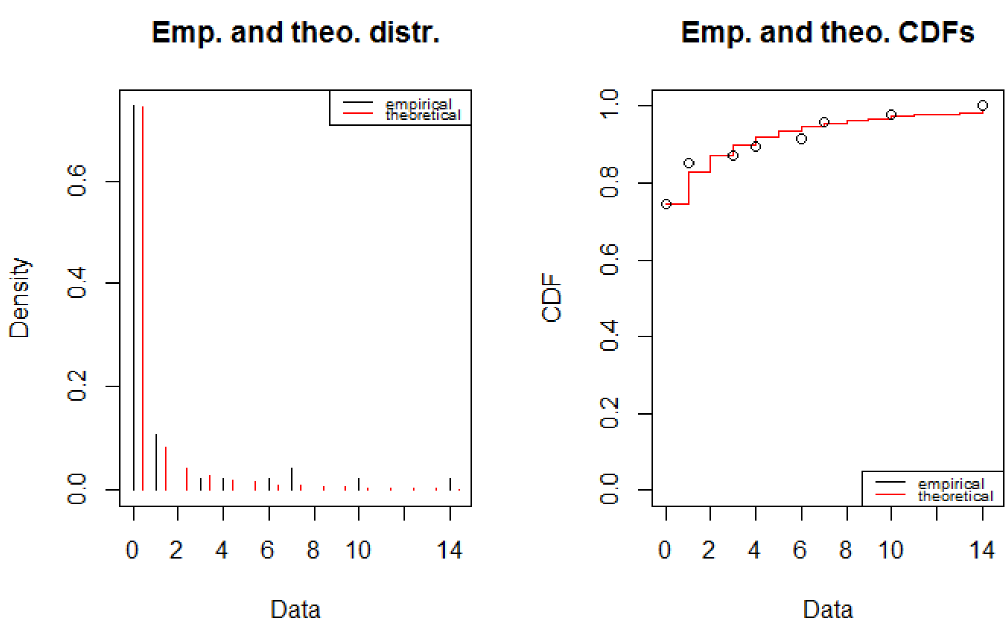


Figure 4.3-1 Negative binomial fit to 2016 data.

Note observed and theoretical counts match up very well. However, the overabundance of zero count samples in 2016 resulted in an uninformative distribution prompting the use of more traditional methods.

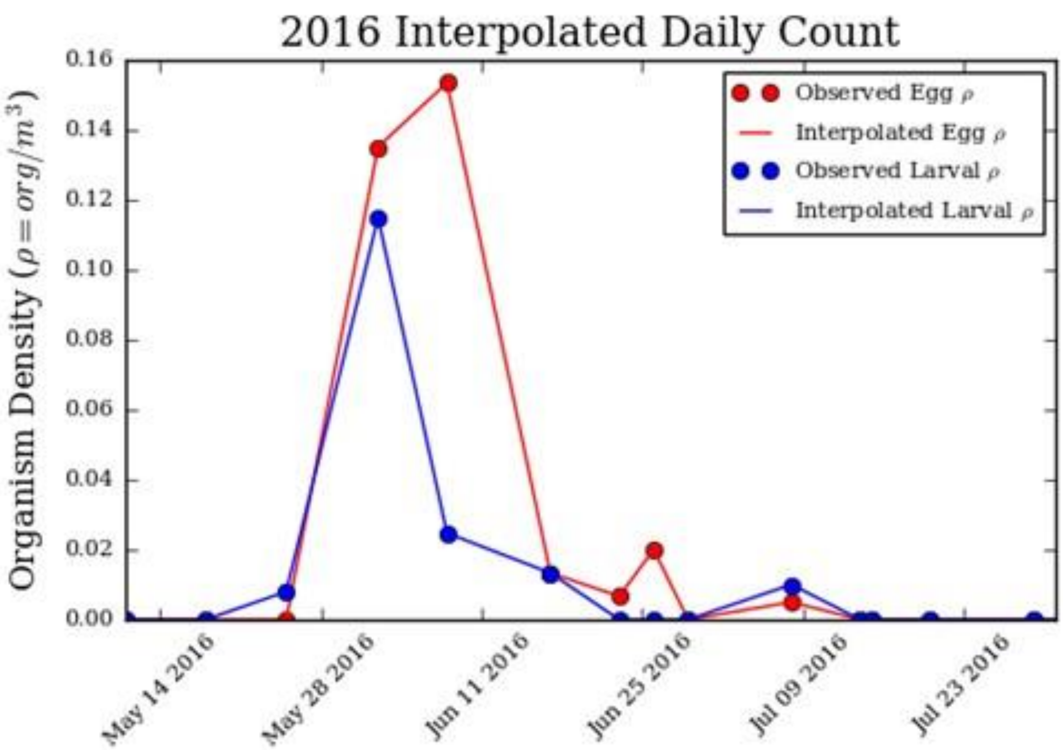
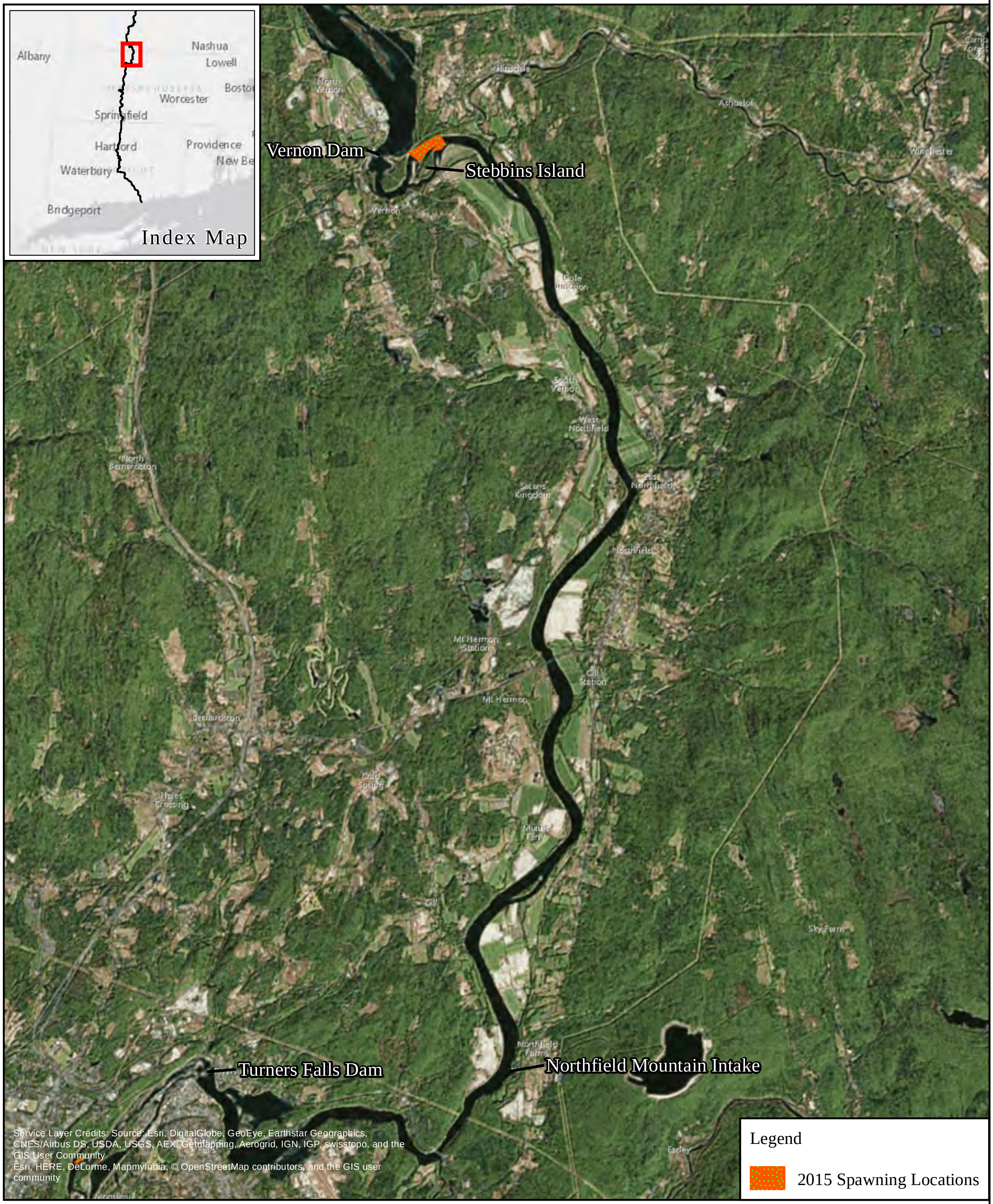


Figure 4.3-2 Interpolated daily sample density (organisms per cubic meter of water) for 2016 data.
Note that the interpolation method reproduces empirical data while providing a linear function between observations.



FirstLight Power Resources

Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)
Ichthyoplankton Entrainment Assessment
at the NorthfieldMountain Project
Relicensing Study 3.3.20

N

0 0.75 1.5 3 Miles

Figure 4.5-1:
Shad Spawning Location
Identified in
Turners Falls Impoundment

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5 DISCUSSION

In the Connecticut River from mid-May through mid-June, American Shad spawn mostly at night when water temperatures are between 14ºC and 23ºC (Crecco & Savoy, 1987; Marcy, 2004). Water temperature is considered to be the major variable controlling egg development and the timing of spawning (Savoy *et al.*, 2004). Shad eggs hatch in 8 to 12 days at 13-15°C, 6 to 8 days at 17°C, and 3 days at 24°C (Savoy *et al.*, 2004). Newly hatched shad larvae (7-10 mm total length (TL)) occur during May and June and remain near the river bottom until the yolk sac is nearly absorbed about 3 to 4 days later (Savoy *et al.*, 2004). Subsequent to yolk absorption, shad larvae (10-12 mm TL) are transported by river currents into eddies and backwater areas where current velocities are relatively low (Crecco *et al.*, 1983).

A study to determine locations of shad spawning was conducted in 2015. Results indicated that shad spawn just downstream of Vernon Dam near Stebbins Island well upstream of the Northfield Mountain Project intake/tailrace. Densities of shad eggs and larvae at the upriver spawning site were higher than those found at the Northfield Mountain Project in 2015. Lower shad ichthyoplankton densities at the Northfield Mountain Project may be explained by the location of the actual spawning area far upstream of the Northfield intake in the TFI. Researchers have reported that fertilized shad eggs roll along the bottom for 1.6-6.4 km (Savoy *et al.*, 2004).

2016

While the shad ichthyoplankton densities in samples collected at the Northfield Mountain Project were low, when extrapolated by the volume of water pumped at night during the spawning season, approximately 9.5 million shad eggs and 5.4 million shad larvae were estimated to be entrained at the Northfield Mountain Project in 2016. However, to put these numbers in perspective, American Shad spawning strategy includes broadcasting large numbers of eggs which experience high natural mortality. American Shad spawn between 150,000-500,000 eggs per female, and fecundity increases with age, length, and weight (Savoy *et al.*, 2004). Fecundity estimates are higher for broadcast spawners, which do not build protective nests to guard their young from predators. As such, the survival fractions for young produced by broadcast spawners tend to be low.

Since only about 1 out of every 100,000 eggs survives to become a spawning adult, high fecundity is critical for sustaining the stock (Savoy *et al.*, 2004). American Shad eggs in the Connecticut River experienced annual mortality ranging from 24% to 44% per day between 1979 and 1987 (Savoy & Crecco, 1988). As a consequence, between 5% and 19% of the fertilized eggs survive to hatching (Savoy & Crecco, 1988). American Shad larval mortality rates are highest (17-26% per day) among first-feeding larvae, and then decline throughout larval development (Crecco *et al.*, 1983). The larval stage for American Shad lasts between 4 and 6 weeks, during which the larvae grow fairly rapidly (0.4 mm day) to about 22-26 mm TL (Savoy & Crecco, 1988). Based on the 1979-1984 survivorship data, 60-80% of newly hatched larvae die within 3 to 7 days after feeding begins.

The number of equivalent juvenile and adults lost to entrainment at the Northfield Mountain Project was estimated to be 2,093 juvenile shad or 578 adult American Shad for the 2016 spawning season based on the entrainment estimates and published survival fractions discussed above. To put these numbers into perspective, the number of American Shad passed in 2016 at the Turners Falls Gatehouse fishway and the Vernon fishway were 54,069 and 35,807, respectively.

Comparison of 2015 and 2016

In 2015, FirstLight conducted the ichthyoplankton entrainment study from May 28 to June 17 in accordance with the approved study plan. Over the course of the 2015 study, 23 entrainment samples and 12 validation samples were collected, processed and analyzed to estimate of the American Shad eggs and larvae entrained at the Northfield Mountain Project. The shad ichthyoplankton densities in samples collected in entrainment and offshore at the Northfield Mountain Project were low most likely because shad spawning did not occur in the proximity of the Northfield Mountain Project tailrace. However, when extrapolated by the volume of water pumped during the study period from May 28 to July 17, 2015 just over 3 million shad eggs and 500,000 shad larvae were estimated to be entrained at the Northfield Mountain Project in 2015. Based on the entrainment estimates and published survival fractions, the number of equivalent juvenile and adults lost to entrainment at the Northfield Mountain Project in 2015 was estimated to be 696 juvenile shad or 94 adult American shad.

The higher shad ichthyoplankton densities recorded in 2016 coincided with the highest Connecticut River juvenile index of abundance recorded. Since 1978, the CT DEEP has conducted seine studies to estimate an annual index of juvenile shad abundance in the Connecticut River at a number of sites from Holyoke, MA to Essex, CT between July and October. The annual juvenile index of abundance has shown no trend over time and during the 38 years of sampling the arithmetic mean CPUE averaged 47. The 2015 annual juvenile index of abundance arithmetic mean CPUE was 37.9 which indicated a moderate year class (J. Benway CT DEEP *pers. comm*. 11/2016). In 2016 the arithmetic mean CPUE was 262.3 which was the highest index ever recorded (J. Benway CT DEEP *pers. comm*. 11/2016). The next highest arithmetic mean CPUE was 105.8 in 1994 (J. Benway CT DEEP *pers. comm*. 11/2016). Juvenile indices have been positively correlated with recruitment levels of adult females returning to the Connecticut River 4-6 years later Savoy *et al*., 2004). The higher entrainment rates at the Northfield Mountain Project in 2016 did not seem to have an effect on the subsequent year class strength of the Connecticut River juvenile shad. June river flow, water temperature, and zooplankton availability have been linked to year class strength (Savoy *et al*., 2004). Dominant year-class strength of shad is most likely to occur when lower than normal June flows are coupled with moderate spawning stocks (Savoy *et al*., 2004).

6 LITERATURE CITED

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