Relicensing Study 3.3.20

Ichthyoplankton Entrainment Assessment at the Northfield Mountain Project

Study Report

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

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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*.

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 life stages 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 the study plan to quantify entrainment of various life stages 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.

The ichthyoplankton entrainment study followed Study Plan 3.3.20 as approved by FERC and commenced on May 28, 2015 and continued through July 17, 2015. Over the course of the study, 23 entrainment samples and 12 validation samples were collected, processed and analyzed to determine an 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. However, American Shad spawning strategy includes broadcasting large numbers of eggs which experience high natural mortality. Fecundity estimates are higher for broadcast spawners (150,000-500,000 eggs per American shad female) who do not build protective nests to guard their young from predators. As such, the survival fractions for species with these types of reproduction strategies tend to be lower. Based on the entrainment estimates and published survival fractions, the number of equivalent juvenile and adults lost to entrainment at the Northfield Mountain Project was estimated to be 696 juvenile shad and 94 adult American shad. To put these numbers into perspective, the number of American shad passed in 2015 at the Turners Falls Gatehouse fishway and the Vernon fishway were 58,079 and 39,791, respectively.

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LIST OF ABBREVIATIONS

AELs	adult equivalent losses
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
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

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.

2 STUDY SITE

Key features of the Northfield Mountain Project consists of: a) an upper reservoir and dam/dikes; b) an intake; c) pressure shaft; d) an underground powerhouse; and c) a tailrace. The Turners Falls Impoundment (TFI) (Connecticut River) serves as a lower reservoir. 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. 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.

Pressure Shaft

The pressure conduit system consists of a reinforced concrete intake portal, a 200 foot long concrete lined transition section, a portal 55 feet wide by 80 feet high, an inclined concrete-lined pressure shaft that connects the intake and manifold shaft (31 feet diameter, 853 feet long, inclined 50º from the horizontal), concrete-lined manifold formed by branching of the pressure shaft into two 22 foot diameter conduits and then into four 14 foot diameter tunnels which lead to four steel-lined penstocks (340 feet long, diameter decreases from 14 to 9.5 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 msl and the roof is at 190 feet mean sea level (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).

Tailrace Tunnel

Water flows between the powerhouse and the TFI via the tailrace 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. The tunnel discharges during generation through a concrete exit structure into the TFI. The exit structure includes a transition from the horseshoe shape into a trapezoidal shape. A floating boom is provided across the exit channel to provide a barrier to large debris and boaters.

The trapezoidal trash rack 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 square feet (ft^2). The bar thickness is 0.75 inches, with a clear-spacing of 6 inches.

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. The ichthyoplankton entrainment study was conducted on May 28, 2015 and continued through July 17, 2015 during pump-back operations.

3.1 Entrainment Sampling

In accordance with the approved study plan, entrainment sampling to collect American shad eggs and larvae was accomplished by tapping off existing piping inside of the powerhouse at the Northfield Mountain Project Unit 2 that supplies water from the Connecticut River to the upper reservoir. The water collected 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). Approximately 100-200 cubic meters of intake water at a rate of 3 and 3 ½ gallons per second were filtered for each sample. Collection time for each sample was just over two (2) hours.

Intake water from Unit 2 was diverted through a four-inch diameter flexible hose to an entrainment sampling tank. An inline Signet® digital flow meter was mounted in the hose to record the volume of water sampled. The hose's 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 and subsequently sorted. The Northfield Mountain Project typically pumped between 6 and 7 hours during the night allowing for up to two samples per evening.

At least once per week samples were collected every two (2) hours during a pumping cycle. These were designated as ***Random*** samples because the number of pumps operated during sampling was not controlled. In addition, pump-back operations were manipulated to specifically sample operations with 1 2, 3, and 4 pumps running (***Scenario*** samples). Sample collection was initiated at least 30 minutes after the pumping cycle began to ensure the water was well mixed.

Scenario 1: 1 pump operational (Unit 2)
Scenario 2: 2 pumps operational (Unit 2 and one other)
Scenario 3: 3 pumps operational (Unit 2 and two others)
Scenario 4: All 4 pumps operational

Figure 3.1-1: Ichthyoplankton Entrainment Collection Set Up for Collection of American Shad Eggs and Larvae at the Northfield Mountain Project, 2015

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 collected for each scenario (1, 2, 3 and 4 units pumping). Ichthyoplankton samples were collected in front of the intake racks in 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. Data were collected on June 6, 10, 18 and 19 under 4, 3, 2, and 1 unit, respectively. The bongo nets were towed in a straight line starting at the intake/tailrace at mid-depth 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 was rinsed down with water into the cod-end collection jars. The samples were preserved with a 10% formalin solution in appropriately labeled jars and transported back to the sorting room for analysis. Three replicate samples were collected for each scenario.

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 from 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 project. 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

Entrainment and offshore sample densities for each sample and species/lifestage were calculated by dividing the sample count by sample volume to express organism density in count per cubic meter (1). Only samples with non-zero counts were calculated

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

Where ρ_{si} is the density of species/lifestage i in sample s (org/m^3), x_{si} is the count of organisms of species/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 measure.

Weekly Sample Densities

Equation (2) calculates a weekly mean entrainment density and the uncertainty is accounted for with Equation (3). The mean count 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 count and 95% CI were estimated with a generalized linear model assuming a Negative Binomial distribution.

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

Where $\rho_{wi}$is the density of species lifestage i in week w and is expressed in units of x/m^3, $\bar{x}_{wi}$ is the mean count of species 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 species/lifestage i in week w, $\delta\bar{x}_{wi}$ is the 95% CI of the mean count of species/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 respectively and $Z_{a/2}$ is the z-score for the 95% confidence level α.

Comparison of Offshore vs Entrainment Samples

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

Calculation of Flow

Operations data that measured flow in cubic feet per second were provided by FirstLight. The extrapolation requires the total amount of water pumped during a given calendar week. Therefore, the pumping rate was transformed to a volume of water pumped with Equation (6):

$$Q_i' = Q_i * 0.0283168 * s_i \quad (6)$$

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 ($^{m^3/s}/_{ft^3/s}$). An MS Access aggregate query summed the weekly volume of water pumped. With weekly densities and flow known, extrapolations are computed next.

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 daily water volume pumped was calculated based on daily average flow rates obtained from Northfield Mountain Project personnel. 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 (7)).

$$x_{wi}' = \rho_{wi} Q_w' \quad (7)$$

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 ρ_{wi} was calculated. Equation (8) calculates the error associated with each weekly estimate x_{wi}'.

$$\delta x_{wi}' = |Q_w'| * \delta \rho_{wi} \quad (8)$$

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 (6) and (3) respectively. The weekly extrapolation estimates the number of individuals of lifestage i lost to the population 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 NFM 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 NFM, the weekly estimates of 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 (9)):

$$AEL_j = \sum_{j=1}^{n} S_{ij} x'_{wi} p_j \tag{9}$$

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 species/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 (10))

$$S_{ij} = \prod_{i=1}^{j} S_k \tag{10}$$

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 covering all of the lifestages required for this assessment (Table 3.4.1). Both sources reported mortality rather than survival. Mortality was converted to survival with equation **Error! Reference source not found.** (Haddon 2011):

$$S_k = \frac{N_k}{N_i} = e^{-(M_k + F_k)} \tag{11}$$

Where M_k is the natural mortality rate at lifestage k, F_k is the fishing mortality at lifestage k, 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, CTDEEP, 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 must be accounted for with the estimate of AEL_j ((12) :

$$\delta AEL_{wj} = \sqrt{\left(\frac{\delta x'_{wi}}{x'_{wi}}\right)^2 + \left(\frac{\delta p_j}{p_j}\right)^2} * |AEL_{wj}| \tag{12}$$

Where δAEL_j is the uncertainty in the estimated AEL_j, $\delta x'_{wi}$ is the 95% CI of the weekly w extrapolation of species/lifestage i (8), x'_{wi} is the weekly w extrapolation of species/lifestage i (7), 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 returning 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 MS 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.

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

Lifestage (k)	M_k	F_k	S_k	Source
Egg	0.496	0	0.609	EPA 2004
Larvae 1	0.273	0	0.760	Crecco *et al.* 1983
Larvae 2	0.15	0	0.861	Crecco *et al.* 1983
Larvae 3	0.096	0	0.901	Crecco *et al.* 1983
Larvae 4	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: Crecco *et al*., 1983 Lifestages Specific Mortality Rate 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
Note: F_k is the instantaneous rate of fishing mortality at lifestage k
Note: S_k is the lifestage specific survival fraction

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0 0.025 0.05 0.1 Miles

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

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4 RESULTS

Over the course of the study, 23 entrainment samples and 12 validation samples were collected from May 28 to June 26, 2015. Water quality information, including water temperature, dissolved oxygen (DO), pH and conductivity, collected on each date of sampling is presented in Table 4.0-1 for entrainment and Table 4.0.2 for validation samples. During sampling the water temperature ranged from 15.0ºC to 24.4ºC, DO ranged from 4.8 to 10.01 mg/L, pH ranged from 6.5 to 7.8 and conductivity 78 to 138.7 µcm/s 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. Compared to the period from 1975-2014[1] the flow was lower than average at the start of the study but higher than average for the remainder of the study.

4.1 Entrainment Sampling

Entrainment sampling was conducted at least once per week and samples were collected every two (2) hours during a pumping cycle. Samples were collected while the number of pumps operating during sampling was not controlled. These were designated as ***Random*** samples (Table 4.1-1). Pump-back operations were also manipulated to specifically sample operations with 1 2, 3, and 4 pumps running (***Scenario*** samples) (Table 4.1-1).

The entrainment sample densities are simply the number of shad eggs and larvae in the sample divided by the sample volume. Densities are expressed in units of organisms per 100 m^3. Densities ranged from 0 to 31 shad eggs per 100 m^3 (Table 4.1-2). No larvae were counted in entrainment samples. To validate that entrainment ichthyoplankton densities were representative of densities in the intake tunnel, entrainment and offshore samples were collected for each pumping scenario (1, 2, 3 and 4 units pumping).

4.2 Offshore Sampling

Offshore sampling was conducted adjacent to Northfield Mountain intake on evenings corresponding with the special unit scenarios (6/9/2015 4 units, 6/10/2015 3 units, 6/18/2015 2 units and 6/19/2015 1 unit). In all samples, counts were low; however, a larvae was identified in week 24 on 6/10/2015 during three units pumping (Table 4.2-1). Densities in the offshore samples are expressed as the number of organisms per 100 m^3. While the volume of water sampled was similar to the entrainment samples, overall shad egg densities collected near the intake were lower than those collected in the entrainment samples.

4.3 Entrainment Estimate

Both the entrainment and offshore densities were used to calculate weekly entrainment estimates. With multiple samples taken 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. Mean counts were not assessed in weeks where no ichthyoplankton were identified. 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). Therefore, a generalized linear model assuming a negative binomial distribution was used to model the mean count and CI, with week as a factor (Table 4.3-2).

To describe the mean weekly entrainment rate, a Negative Binomial regression was applied. The test, which was analogous to a traditional analysis of variance, looked for significant difference in mean count over

[1] Although the USGS Gage has been active since 1905, a more recent period was selected to reflect climate change and the development of flood control facilities in the basin above the Turners Falls Dam prior to 1975.

each week. The only week that was significantly different from the other weeks was Week 24, at the a = 0.10 level (p = 0.096) (Table 4.3-2). Therefore, the CI reported is at the 1-a = 0.90. The offshore model was significant; however, only at the intercept (p = 0.005). The mean count of eggs in Week 25 is no different from the mean count of eggs in Week 24, nor are the mean counts of larvae in Week 24 different from the mean counts of eggs in Week 24. The regressions applied here are analogous to an analysis of variance. The intercept value was significant and represents the mean count at Week 22. The only other row that was significant was Week 24. Therefore, the mean count at Week 24 was higher than Weeks 22, 23, 25 and 26. Taking into account significant estimates, the weekly mean counts by sample type, week and life stage are found in Table 4.3-3. Based on this model, weekly entrainment densities were calculated (Table 4.3-4 and Figure 4.3-1).

Due to the low numbers of eggs and larvae collected, offshore and entrainment counts were not statistically compared. Thus, the count of organisms applied to the extrapolation was calculated as the maximum weekly average count by week and lifestage (Table 4.3-4). After dividing the weekly average counts by the weekly average sample volume and accounting for error around the estimates, density (ρ) in org/m^3 by week and lifestage is also reported in Table 4.3-4.

Weekly extrapolated estimates of entrainment were calculated (Table 4.3-5) using the actual flow of water pumped at the Northfield Mountain Project per week and the calculated weekly densities on weeks where shad eggs and larvae were collected in either the entrainment or offshore samples.

4.4 Equivalent Adult Estimates

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 CTDEEP per 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 entrainment samples are provided in Table 4.4-2. The total number of equivalent juvenile and adult American shad lost to entrainment of ichthyoplankton at the Northfield Mountain Project in 2015 was estimated to be 696 juveniles and 94 adult American shad.

4.5 Shad Spawning in TFI

A companion American shad spawning study was conducted in the TFI concurrent with this entrainment study (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

Sample Number	Rep	Date	Duration	No. of Pumps	Water Temperature (ºC)	DO (mg/L)	pH	Conductivity (µcm/s)
1	1	5/28/2015	2:46	3	18.8	5.9	7.1	107.7
2	2	5/28/2015	2:05	3	19.5	5.7	7.2	112.6
3	1	6/5/2015	2:16	3	16.6	6.5	7.2	93.1
4	2	6/5/2015	2:19	3	15.0	7.2	7.1	82.0
5	1	6/9/2015	2:16	4	17.3	6.7	7.2	84.0
6	2	6/9/2015	2:20	4	17.2	6.8	7.3	85.6
7	1	6/10/2015	2:13	3	17.8	6.3	7.3	86.3
8	2	6/10/2015	2:04	3	18.1	6.6	7.3	87.9
9	1	6/11/2015	2:16	1-3	17.8	6.4	7.2	91.4
10	2	6/11/2015	2:30	3	18.4	6.3	7.3	96.0
11	1	6/16/2015	1:55	1-3	19.5	6.3	7.1	87.1
12	2	6/16/2015	2:03	1-4	19.0	6.6	7.2	81.3
13	1	6/18/2015	1:58	2	19.3	6.3	7.3	88.2
14	2	6/18/2015	2:13	2	19.2	6.4	7.3	90.4
15	1	6/19/2015	2:20	1	19.4	6.2	7.2	89.2
16	2	6/19/2015	2:30	1	19.0	6.5	7.3	90.9
17	1	6/26/2015	2:08	1-3	20.1	6.5	7.2	90.6
18	2	6/26/2015	2:13	3	19.5	6.7	7.3	80.6
19	1	7/1/2015	2:07	1-2	19.7	6.4	7.2	83.0
20	2	7/1/2015	2:19	3	17.8	6.3	7.3	94.0
21	1	7/8/2015	2:14	4	20.5	5.7	7.1	103.0
22	2	7/8/2015	2:30	4	20.6	5.8	7.3	103.2
23	1	7/17/2015	2:02	1	24.4	4.8	7.5	138.7

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

Sample Number	Date	Begin Time	Duration (minutes)	Depth (ft)	Water Temp. (ºC)	DO (mg/L)	pH	Conductivity (µcm/s)	Volume (m^3)	No. of Pumps
1	6/9/2015	1:40	6	24	17.2	9.5	6.5	78	107	4
2	6/9/2015	2:01	6	24	17.2	9.5	6.5	78	102	4
3	6/9/2015	2:17	6	24	17.2	9.5	6.5	78	105	4
4	6/10/2015	1:40	6	22	17.6	9.6	7.4	82	108	3
5	6/10/2015	1:51	6	22	17.6	9.6	7.4	82	112	3
6	6/10/2015	2:04	6	20	17.6	9.6	7.4	82	148	3
7	6/18/2015	1:10	10	20.2	19.12	10.01	7.8	94	147	2
8	6/18/2015	1:35	10	17.5	19.12	10.01	7.8	94	196	2
9	6/18/2015	2:00	10	20.8	19.12	10.01	7.8	94	156	2
10	6/19/2015	1:00	10	27.5	18.97	9.95	7.2	95	194	1
11	6/19/2015	1:25	10	21.1	18.97	9.95	7.2	95	178	1
12	6/19/2015	1:40	10	20.9	18.97	9.95	7.2	95	173	1

Table 4.1-1. Dates, Regime and Number of Pumps Operating During Entrainment Sampling at Northfield Mountain Project, May 28 through July 17, 2015

Sample Number	Rep	Date	Regime	Number of Pumps
1	1	5/28/2015	Random	3
2	2	5/28/2015	Random	3
3	1	6/5/2015	Random	3
4	2	6/5/2015	Random	3
5	1	6/9/2015	Scenario	4
6	2	6/9/2015	Scenario	4
7	1	6/10/2015	Scenario	3
8	2	6/10/2015	Scenario	3
9	1	6/11/2015	Random	1-3
10	2	6/11/2015	Random	3
11	1	6/15/2015	Random	1-3
12	2	6/15/2015	Random	1-4
13	1	6/18/2015	Scenario	2
14	2	6/18/2015	Scenario	2
15	1	6/19/2015	Scenario	1
16	2	6/19/2015	Scenario	1
17	1	6/26/2015	Random	1-3
18	2	6/26/2015	Random	3
19	1	7/1/2015	Random	1-2
20	2	7/1/2015	Random	3
21	1	7/8/2015	Random	4
22	2	7/8/2015	Random	4
23	1	7/17/2015	Random	1

Table 4.1-2. Northfield Mountain Project American Shad Ichthyoplankton Entrainment Densities

Sample No.	Date	Rep	Life Stage	Count	Volume	Density (x 100m3)	Northfield Mountain Generation			
							Unit 1	Unit 2	Unit 3	Unit 4
1	5/28/2015	1	Egg	5	100.12	5	on	on	off	on
2	5/28/2015	2	Egg	1	100.68	1	on	on	off	on
3	6/5/2015	1	Egg	2	100.01	2	off	on	on	on
4	6/5/2015	2	Egg	3	100.45	3	on	on	on	on
5	6/9/2015	1	Egg	5	100.4	5	on	on	on	on
6	6/9/2015	2	Egg	3	102.9	3	on	on	on	on
7	6/10/2015	1	Egg	3	111.18	3	on	on	on	on
8	6/10/2015	2	Egg	4	100.76	4	off	on	on	on
9	6/11/2015	1	Egg	12	100.28	12	off	on	on	on
10	6/11/2015	2	Egg	31	100	31	off	on	on	on
11	6/16/2015	1	Egg	3	100.13	3	off	on	on	on
12	6/16/2015	2	Egg	8	100.09	8	on	on	on	on
13	6/18/2015	1	Egg	0	100.2	0	on	on	off	off
14	6/18/2015	2	Egg	2	100.22	2	on	on	off	off
15	6/19/2015	1	Egg	1	101.31	1	off	on	off	off
16	6/19/2015	2	Egg	2	107.21	2	off	on	off	off
17	6/26/2015	1	Egg	0	100.09	0	off	on	on	on
18	6/26/2015	2	Egg	1	100.89	1	off	on	on	on
19	7/1/2015	1	Egg	0	99.92	0	off	on	on	on
20	7/1/2015	2	Egg	0	100.04	0	off	on	on	on
21	7/8/2015	1	Egg	0	100.26	0	on	on	on	on
22	7/8/2015	2	Egg	0	100.03	0	on	on	on	on
23	7/17/2015	1	Egg	0	100.19	0	off	on	off	off

Table 4.2-1. Northfield Mountain Project American Shad Ichthyoplankton Densities in Offshore Samples

Sample Number	Date	Time	Life Stage	Count	Volume (m^3)	Density (x 100 m^3)
1	6/9/2015	1:40	E	3	107	2.80
1	6/9/2015	1:40	L	0	107	0.00
2	6/9/2015	2:01	E	0	102	0.00
2	6/9/2015	2:01	L	0	102	0.00
3	6/9/2015	2:17	E	0	105	0.00
3	6/9/2015	2:17	L	0	105	0.00
4	6/10/2015	1:40	E	0	108	0.00
4	6/10/2015	1:40	L	1	108	0.93
5	6/10/2015	1:51	E	0	112	0.00
5	6/10/2015	1:51	L	0	112	0.00
6	6/10/2015	2:04	E	0	148	0.00
6	6/10/2015	2:04	L	0	148	0.00
7	6/17/2015	1:10	E	0	147	0.00
7	6/17/2015	1:10	L	0	147	0.00
8	6/17/2015	1:35	E	0	196	0.00
8	6/17/2015	1:35	L	0	196	0.00
9	6/17/2015	2:00	E	1	156	0.64
9	6/17/2015	2:00	L	0	156	0.00
10	6/19/2015	1:00	E	2	194	1.03
10	6/19/2015	1:00	L	0	194	0.00
11	6/19/2015	1:25	E	2	178	1.12
11	6/19/2015	1:25	L	0	178	0.00
12	6/19/2015	1:40	E	2	173	1.16
12	6/19/2015	1:40	L	0	173	0.00

Table 4.3-1. 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	22	E	3.00	8.00	2
Entrainment	23	E	2.50	0.50	2
Entrainment	24	E	9.67	120.67	6
Entrainment	25	E	2.67	7.87	6
Entrainment	26	E	0.50	0.50	2
Offshore	24	E	3.0	NA	1
Offshore	24	L	1.0	NA	1
Offshore	24	E	1.75	0.25	4

Table 4.3-2. Negative Binomial Generalized Linear Model for Count Data for Ichthyoplankton Collected at Northfield Mountain Project

Model	Parameter	Estimate	Std. Error	Z value	p
Entrainment	Intercept	1.39	0.53	2.62	0.00879
Entrainment	Week 23	-0.13	0.76	-0.18	0.86055
Entrainment	Week 24	0.98	0.59	1.66	0.09602
Entrainment	Week 25	-0.09	0.61	-0.14	0.88732
Entrainment	Week 26	-0.98	0.88	-1.12	0.26314
Offshore	Intercept	1.39	0.50	2.78	0.00556
Offshore	Week 25 (E)	-0.37	0.58	-0.64	0.52104
Offshore	Week 24 (L)	-0.69	0.86	-0.80	0.42349

Table 4.3-3. Mean Count and Precision of Estimate by Sample Type, Week and Lifestage for Ichthyoplankton Data Collected at Northfield Mountain Project

Sample Type	Week	Lifestage	Mean Count ($\bar{x}$)	Precision +/- ($\delta\bar{x}$)
Entrainment	Week 22	E	4.00	2.39
Entrainment	Week 23	E	4.00	2.39
Entrainment	Week 24	E	11.00	2.64
Entrainment	Week 25	E	4.00	2.39
Entrainment	Week 26	E	4.00	2.39
Offshore	Week 24	E	4.00	2.28
Offshore	Week 24	L	4.00	2.28
Offshore	Week 25	E	4.00	2.28

Table 4.3-4. Extrapolated Count and Precision by Week and Lifestage with Calculated Density and Precision for Ichthyoplankton Data Collected at Northfield Mountain Project

Week	Lifestage	Count ($\bar{x}$)	Precision ($\delta\bar{x}$)	Density (ρ) (org/m^3)	Precision ($\delta\rho$)
22	E	4.00	2.39	0.0398	0.0238
23	E	4.00	2.39	0.0399	0.0238
24	E	11.00	2.64	0.1072	0.0259
24	L1	4.00	2.28	0.0352	0.0205
25	E	4.00	2.39	0.0394	0.0235
26	E	4.00	2.39	0.0398	0.0238

Table 4.3-5. Estimated Extrapolated Weekly Entrainment Estimates at Northfield Mountain Project by Lifestage

Week	Life Stage	Flow (100 m^3) (Q)	Density (#/100m3) (ρ)	Density Precision ($\delta\rho$)	Extrapolated Count (x')	Extrapolated Precision ($\delta x'$)
22	E	48,701.56	3.98	2.38	193,832	115,909
23	E	49,043.40	3.99	2.38	195,683	116,723
24	E	148,760.55	10.72	2.59	1,594,713	385,289
24	L1	148,760.55	3.52	2.05	523,637	304,959
25	E	89,986.23	3.94	2.35	354,545	211,467
26	E	35,851.83	3.98	2.38	142,690	85,327

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 and Adult American Shad Loss Caused by Entrainment of Eggs and Larvae at Northfield Mountain Project in 2015

Age of Equivalency	AEL	δAEL
J	696.17	294.91
3	23.99	11.77
4	53.23	22.73
5	15.79	6.74
6	0.76	0.35

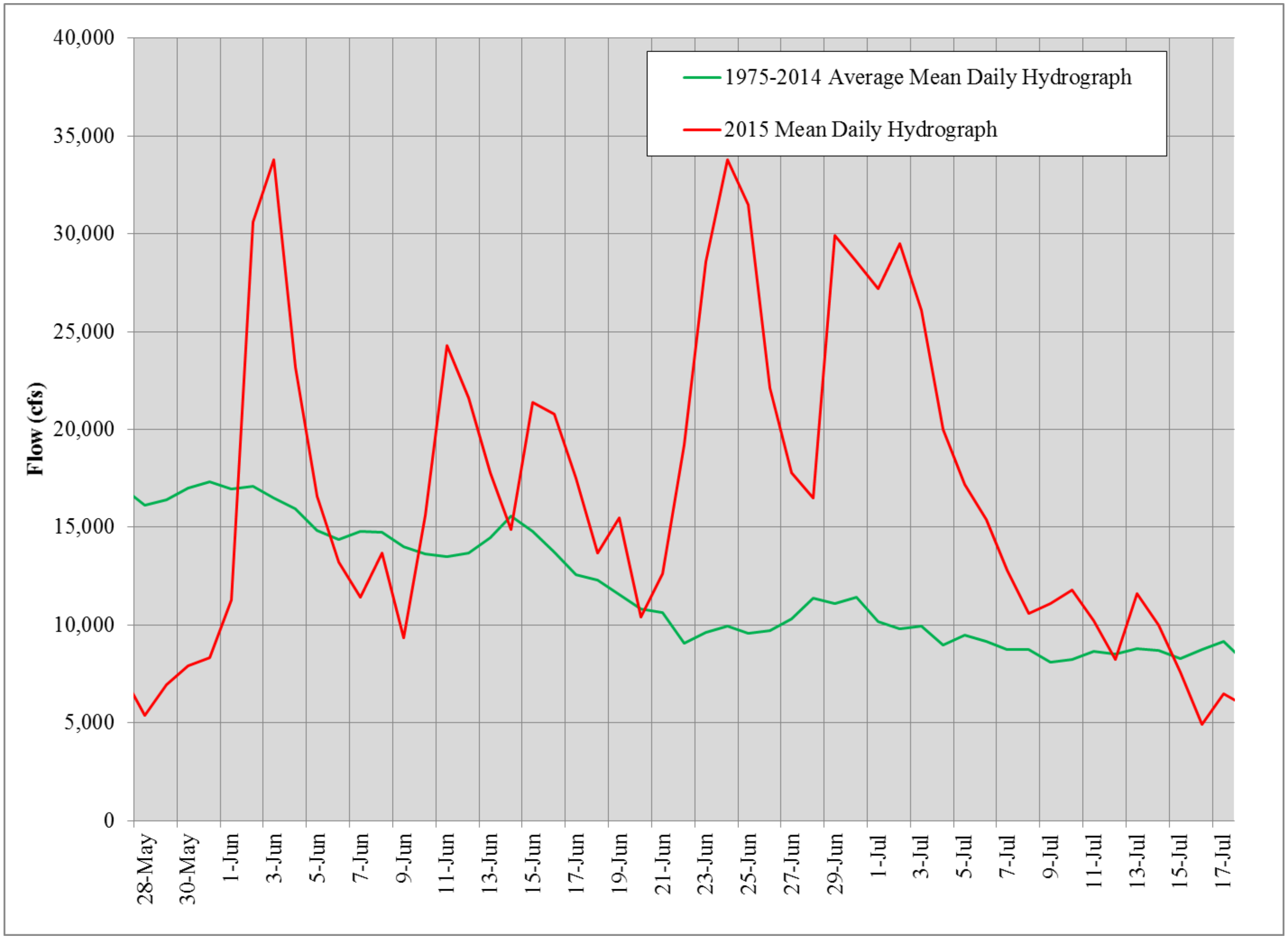


Figure 4.0-1: Connecticut River Flow at the Montague USGS Gage during the Northfield Mountain Project Ichthyoplankton Study

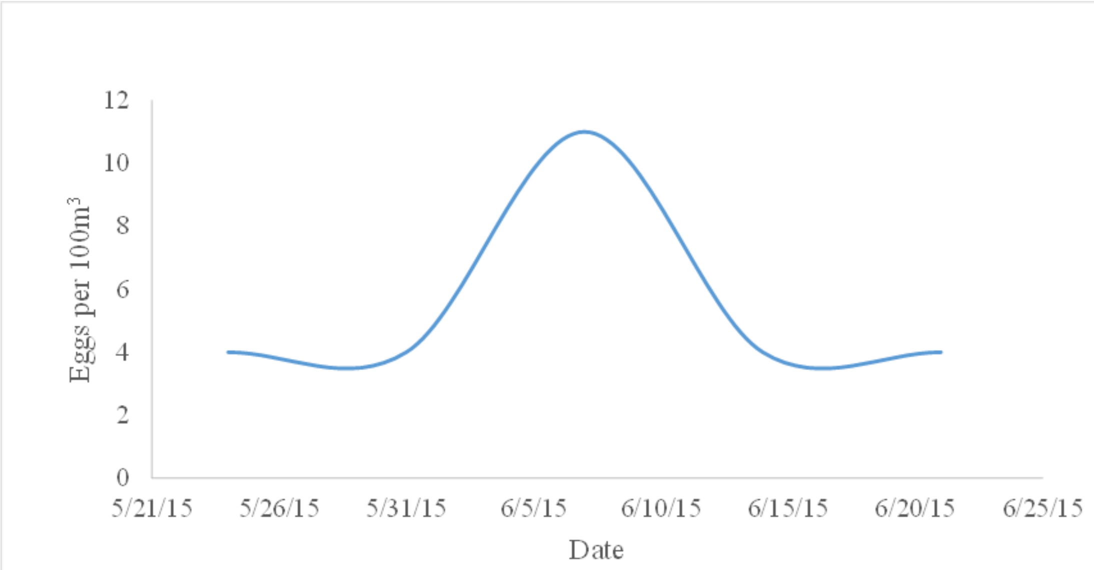
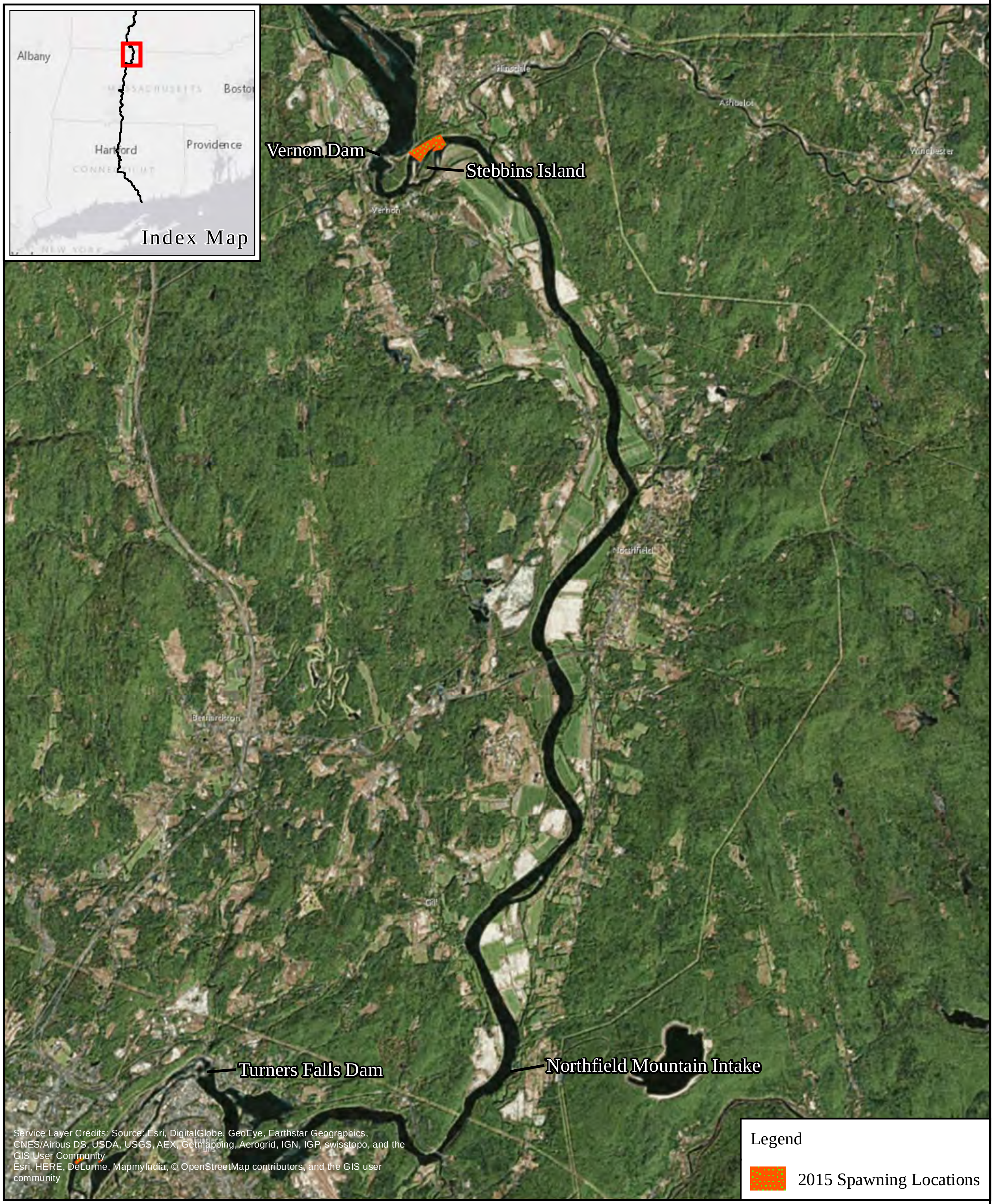


Figure 4.3-1: Weekly Northfield Mountain Project Weekly Egg Densities in Entrainment Samples



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

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

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5 DISCUSSION

American shad eggs and larvae were entrained at the Northfield Mountain Project. 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-l5°C, 6 to 8 days at l7°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 concurrent with this entrainment study. 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. Lower shad ichthyoplankton densities at the Northfield Mountain Project are most likely 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).

While the shad ichthyoplankton densities in samples collected at the Northfield Mountain Project were low, when extrapolated by the volume of water pumped during the spawning season just over 3 million shad eggs and 500,000 shad larvae were estimated to be entrained at the Northfield Mountain Project in 2015. 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 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 annually was estimated to be 696 juvenile shad and 94 adult American shad for the 2015 shad 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 2015 at the Turners Falls Gatehouse fishway and the Vernon fishway were 58,079 and 39,791, respectively.

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