Juvenile American Shad Assessment in the Connecticut River from Holyoke Dam to Bellows Falls Dam, 2017-2018

Steven Mattocks and Brian Keleher

Massachusetts Division of Fisheries and Wildlife (MassWildlife)

Field Headquarters Office, Westborough, MA 01581; Connecticut Valley District Office, Belchertown, MA 01007

Kenneth Sprankle

U.S. Fish and Wildlife Service

Connecticut River Fish and Wildlife Conservation Office, Sunderland, MA 01375

Introduction

American Shad *Alosa sapidissima* are anadromous fish that serve important ecological roles as forage for freshwater and marine fish, birds, and terrestrial mammals, and can support both recreational and commercial fisheries (ASMFC 2009, McDermott et al. 2015). They are the largest species in the family *Clupeidae* (herrings) and make annual spring migrations up rivers to spawn. Main stem dam construction disrupted annual spawning migrations beginning in the early 1800s resulting in population declines (Gephard and McMenemy 2004, Limburg and Waldman 2009, Mattocks et al. 2017). More recently, American Shad populations in New England and throughout the Atlantic coast have declined over the past several decades and were considered to be at an all-time low in 2007 by the American Shad Stock Assessment Subcommittee (SASC) due to excessive total mortality, habitat loss and degradation, and habitat access impediments (ASMFC 2007, ASMFC 2010, CRASC 2017). Further, they have been identified as a "species of greatest conservation need" by Massachusetts and other New England state agencies (MDFW 2015).

The Connecticut River Atlantic Salmon Commission (CRASC) coordinates restoration and management activities for American Shad and has a minimum annual run target to the river mouth of 1.7 million fish, with subsequent minimum escapement targets at main stem dams including targeted tributaries based on available habitat (CRASC 2017). Annual adult shad counts at Holyoke Dam have been relatively high since 2012 but remain lower than restoration minimum targets, particularly upstream of the Turners Falls Dam in Massachusetts and the Vernon Dam in Vermont/New Hampshire. While fish passage systems have improved to varying degrees in recent decades, it is unclear how main stem dams may affect the reproductive potential of the population (both spatially and temporally) as measured by juvenile production.

Movement patterns and life history traits are important considerations for managing and restoring anadromous species. American Shad are batch spawners, with historical rates of iteroparity in the Connecticut River estimated to average approximately 38% from the 1960s to early 1970s (Leggett 1976, Leggett et al. 2004), while more recent rates are estimated to range from 3-10% (CRASC 2017). Causes for this decline have not been definitively determined but are believed to include elevated mortality from ineffective downstream passage measures at hydropower facilities, as well as passage delays at barriers during upstream and downstream migration (direct and indirect mortality) (Mathur 1994; Castro-Santos and Letcher 2010; CRASC 2017). Adult American Shad migrations from marine waters to the Connecticut River peak in May, with spawning occurring primarily from mid-May through late June (Leggett et al. 2004). Subsequently, juveniles typically develop in late June and July, and spend several months feeding before emigrating to marine waters in late fall (Crecco et al. 1983; O'Donnell and Letcher 2008). Juvenile shad length increases throughout the summer season until late fall, after which growth is insignificant (O'Donnell and Letcher 2008). Primary triggers for emigration are believed to be associated with declining autumn temperatures, with size having some effect

although not a limiting factor (O'Leary and Kynard 1986, Limburg 1996). Juvenile American Shad peak migration movements have been shown to occur in late afternoon and early evening (O'Leary and Kynard 1986), and primarily follow the river channel during outmigration (Kynard et al. 2003). The timing of downstream movement has implications for survival, as the ability to transition to salt water becomes impaired at low (<10° C) water temperatures (Zydlewski et al. 2003).

The American Shad's complex life history coupled with multiple hydropower dams and a large pumped storage hydropower facility on the main stem Connecticut River has negative consequences to migrating adults (up and down running), return spawner reproductive potential, juvenile production (spatial coverage and density), and juvenile outmigration success. Juvenile shad mortality from larger main stem hydropower turbines may range widely depending on turbine design and operations and include other project sources of mortality such as spill at dam/gate structures (Franke et al. 1997). In the case of the Northfield Mountain Pumped Storage facility, with a pumping capacity of 15,000 CFS to its storage reservoir, there is no expectation of any survival for entrained eggs, larvae or juvenile shad (LMS 1993). Thus, understanding spatial ecology and quantifying natural and anthropogenic sources of mortality is essential to managing sustainable populations.

The ASMFC Amendment 3 for American Shad Management (2010) plan included, among other plan objectives: Maximize the number of juvenile recruits emigrating from freshwater stock complexes. As part of this plan's listed strategies, juvenile shad productivity and population structure data are an important component needed for development of sustainable fishery management plan. The ASMFC plan further identified potential threats including but not limited to: barriers to migration (need for safe, timely, effective migration), water withdrawals- "especially at pumped storage facilities" with concerns for associated delays in fish movement past the facility, and impingement or entrainment at intakes causing mortality or injury. The Connecticut River American Shad Management Plan (CRASC 2017) similarly prioritizes the need to establish safe, effective, and timely downstream fish passage measures for juvenile shad that maximize through/pass project survival. The CRASC plan also notes the important ecological contributions juvenile shad have while in freshwater.

Currently, the only juvenile American Shad monitoring effort on the Connecticut River is conducted by the Connecticut Department of Energy and Environmental Protection (CTDEEP) through the use of fixed beach seine stations (CTDEEP 2017). The Juvenile Abundance Index (JAI) dates back to 1974 and serves as a long term indicator of juvenile shad abundance for the observed year class, however, it is limited by spatial (downstream of Holyoke Dam) and statistical (fixed stations) components. Because this survey is conducted below the Holyoke Dam, the localized effects of upstream dams on juvenile American Shad productivity and

emigration are unclear, and specifically, how main stem dams affect habitat use and production in inter-dam habitat sections.

Currently on the main stem river, the Turners Falls Dam Project, Northfield Mountain Pumped Storage Project (NMPS), Vernon Dam Project and Bellows Falls Dam Project are all in the Federal Energy Regulatory Commission (FERC) relicensing process and are located within the historical range of American Shad. Several recent FERC-required relicensing study reports have provided data on direct short-term (24 hour) mortality impacts on juvenile shad from balloon tag studies with indirect impacts less clearly defined due to challenges in maintaining control groups and the use of smallest available radio tags.

Goals

This collaborative study aims to better understand juvenile American Shad productivity in the Connecticut River from Holyoke Dam (rkm 139) to Bellows Falls Dam (rkm 280) through several metrics (abundance, size, condition) across various dammed sections of the river. In addition, we aim to provide supportive evidence for ongoing juvenile abundance index surveys conducted by CTDEEP and CRASC. These efforts will provide baseline data for juvenile shad production, habitat use, and condition, and will ultimately inform local and regional management agencies and restoration efforts.

Objectives

(1) Establish juvenile shad index survey above Holyoke Dam and contrast metrics with current monitoring efforts (CTDEEP) to ground-truth survey data and inform future monitoring priorities;

(2) Evaluate juvenile shad metrics across three dam segments and coinciding (nested) impoundment zones across time and space; and

(3) Determine juvenile shad habitat use across space and time to inform management practices and research needs

Methods

Study Sites

Holyoke (rkm 139), Turners Falls (rkm 198), Vernon (rkm 228), and Bellows Falls (rkm 280) are consecutive, main stem dams located on the Connecticut River from Massachusetts to New Hampshire/Vermont (Figure 1). The Holyoke to Turners Falls, Turners Falls to Vernon, and Vernon to Bellows Falls dam sections are 57.3, 31.7, and 50.2 km in length, respectively. The

Northfield Mountain Pumped Storage hydropower facility is located between the Turners Falls Dam and the Vernon Dam (Figure 1).

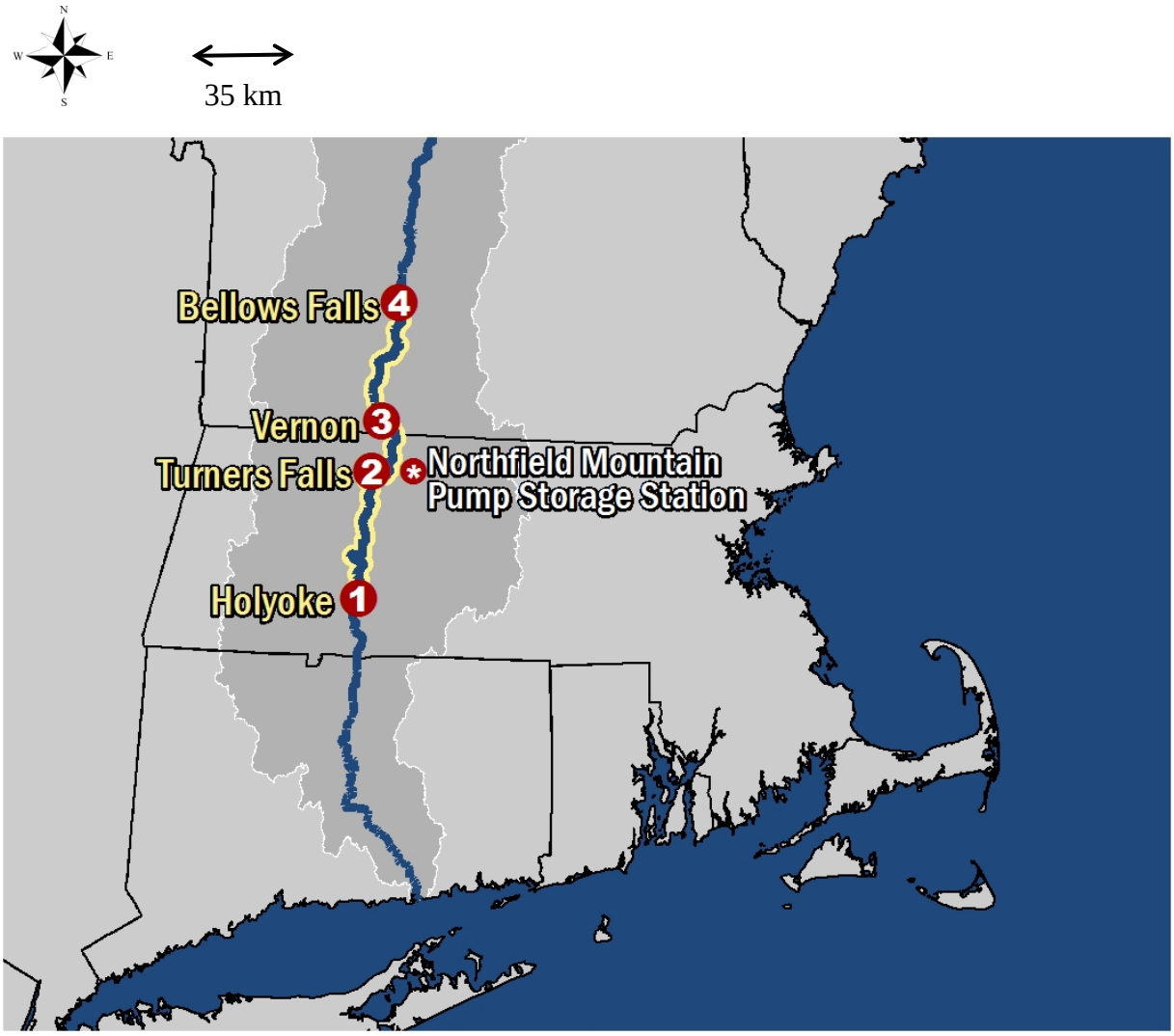

Figure 1: Map of the Connecticut River with main stem dams and habitat sections sampled for juvenile American Shad (highlighted yellow), from Holyoke Dam to Bellows Falls Dam.

Each dam section was further delineated by habitat sections referred to as ‘impoundment zones’, which were classified by ‘lower’, ‘middle’, and ‘upper impoundments’, as well as ‘riverine’, depending on the length and habitat conditions of each segment. The Holyoke section was the only dam section with four impoundment zones that included a riverine section (north of Rt. 116 Bridge). Both the Holyoke impoundment and Vernon impoundment zones were assigned three impoundment zones (lower, middle, and upper) due to their length and logistic considerations/sampling time constraints, while the shorter length of the Turners Falls impoundment only required two impoundment zones.

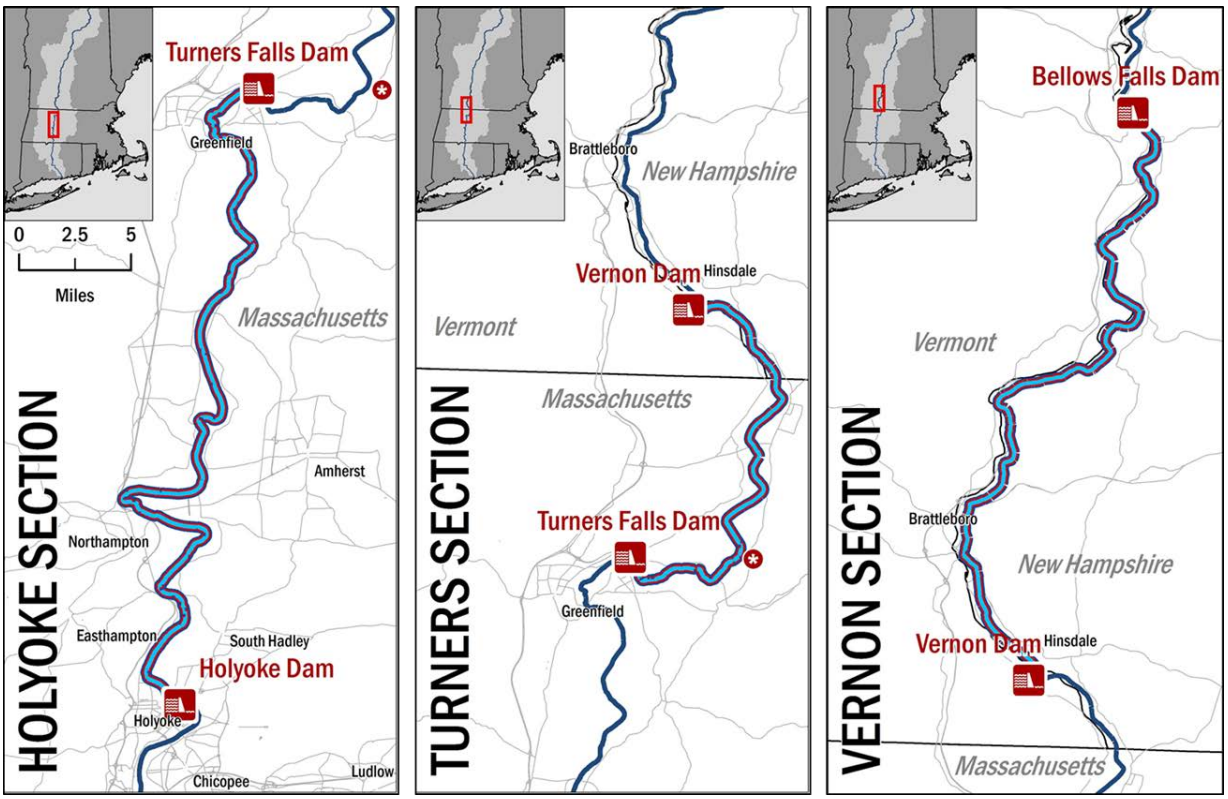

Figure 2: Map panels of each dam section sampled (Holyoke, Turners, and Vernon).

Fish Sampling

Electrofishing surveys were conducted in 2017 from August 22 to October 18 and in 2018 from August 8 to November 1, with sampling beginning 20 minutes after sunset and continuing until 5 sampling runs were completed, typically concluding by 10:00 pm. Three electrofishing boats using pulsed DC current and standardized waveform (Smith Root, Midwest Lakes) were used with two netters located at the bow. Juvenile shad were netted, identified by date, run #, dam section, and impoundment zone for next day processing, and immediately placed on ice and either frozen for later processing or refrigerated and processed the following day. Total length (mm) and weight (g) were recorded on all juvenile shad.

Dam sections were surveyed sequentially, generally in a downstream to upstream order, with one section being sampled per sampling night and typically two sampling nights per week. We used a random number generator in Microsoft Excel (2010) to select sampling locations delineated by 0.5 river kilometer (rkm) cells. Electrofishing runs began at the most upstream selected site for each dam section, and followed a zig-zag pattern across the river from shoreline to shoreline in a downstream direction. GPS tracks were recorded and stored using WGS 1983 Geographic Coordinate System. Paired electrofishing runs with MDFW and USFWS boats and crews were conducted to test sampling effort and efficiency and were conducted over multiple sampling days both years.

Metric Calculations

Catch rates of juvenile shad are represented by Catch-Per-Unit-Effort (CPUE), which was calculated as the total number of shad captured per minute of electrofishing for each run.

Fish length was measured as the total length (TL) of fish in millimeters (mm), measured on a standard wood measuring board. Weights were recorded for all fish, which were measured to the nearest tenth of a gram (g).

Fish condition was calculated using Fulton's *K*, which represents approximate fish condition or relative health at any given time. Fulton's *K* represents morphometric and physiological changes in body condition that are often correlated with fat and protein content and are typically indicative of foraging success. Fulton's *K* is calculated as:

$$K = (W/L^3)100$$

where $\boldsymbol{W}$ is fish weight in grams, and $\boldsymbol{L}$ is fish length in mm.

Results

There were no detected differences in comparisons of juvenile shad catch rates among the three electrofishing boats/crew (ANOVA P = 0.385) or in later individual paired sample comparisons

(Mann-Whitney Rank Sum P = 0.791; P = 0.222; P = 0.377). We captured a total of 1,006 juvenile shad in 2017, and 4,130 in 2018. In 2017, the Vernon Dam section (upstream of Vernon Dam to Bellows Falls Dam) had the highest CPUE, while in 2018 the Holyoke Dam section had the highest CPUE (Table 1). In 2017, high CPUE values in the Vernon section were largely driven by high values in the lower impoundment zone, while in 2018 no discernable pattern was observed. In 2018, high CPUE values in the Holyoke section were largely driven by high catch rates in the Oxbow, and to a lesser extent in the middle Holyoke impoundment.

Table 1: Mean and SD of CPUE (# fish/minute) from electrofishing runs across dam sections are reported. Total number of electrofishing runs for each dam section in 2017 and 2018 are also included (no runs below Holyoke in 2017).

	Mean CPUE	**SD CPUE**	**# of Runs**	**Mean CPUE**	**SD CPUE**	**# of Runs**
Dam Section		**2017**			**2018**	
Below Holyoke	-	-	-	1.596	1.383	18
Holyoke	0.540	0.753	78	3.096	3.925	98
Turners	0.141	0.396	39	1.183	1.869	50
Vernon	1.404	1.416	31	1.666	2.218	51

CPUE values were highly variable as indicated by standard deviation values. Overall, catch rates were a great deal higher in 2018 compared to 2017, despite higher numbers of adult shad runs in 2017 in Holyoke and Turners sections (Table 2). CPUE was logged for further comparison across dam sections and impoundment zones (Figure 3).

Table 2: Adult American Shad passage counts at each main stem dam in 2017 and 2018.

Dam	**2017**	**2018**
Holyoke	536,670	275,232
Turners	48,727	43,146
Vernon	28,682	31,725

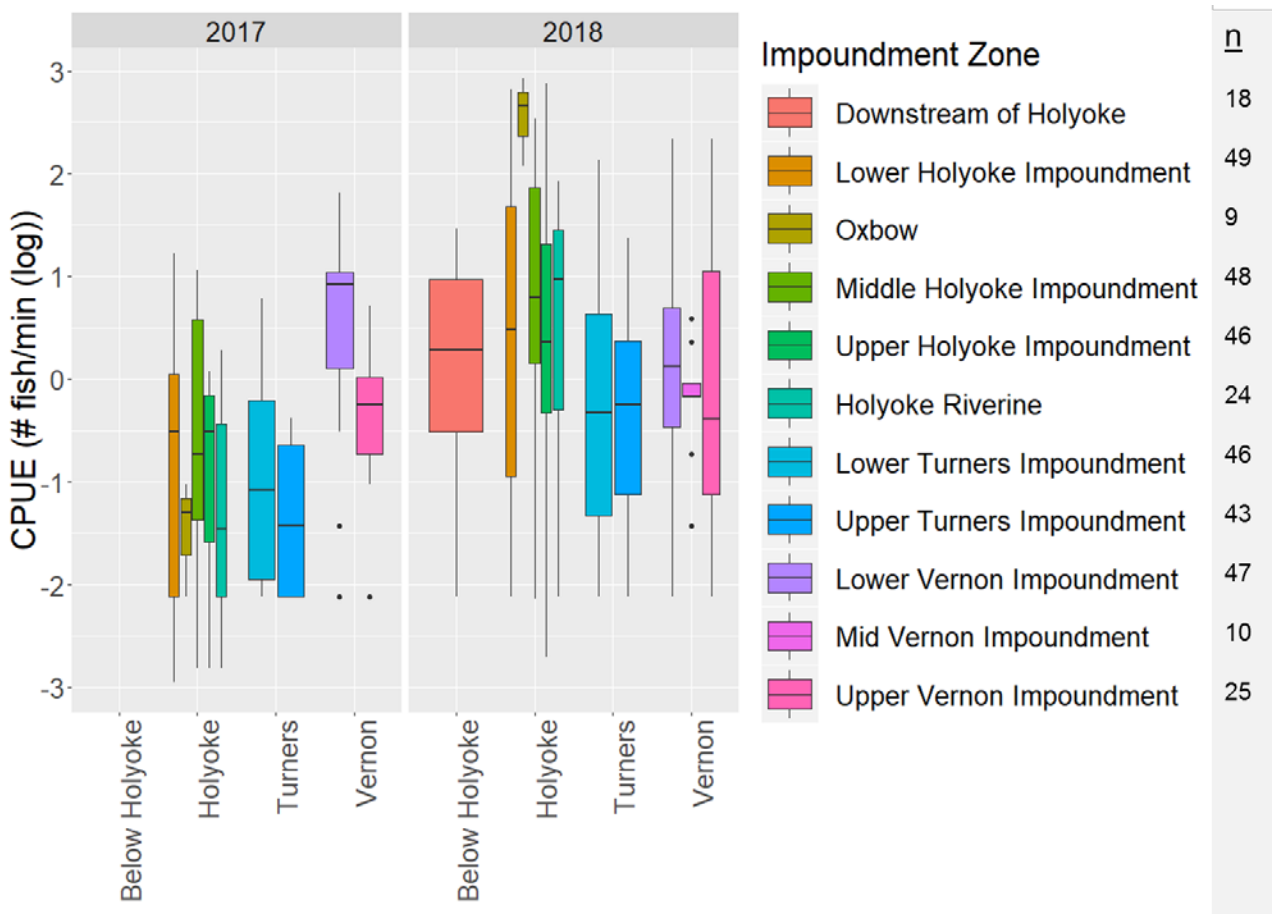

Figure 3: Box plots with logged CPUE (# fish/minute) across impoundment and dam section (x-axis) zone for 2017 and 2018. Black horizontal lines are median values, and boxes are 25th and 75th percentile values. Black dots are values < or > 1.5 * IQR.

In general, CPUE declined through time (2017 and 2018 data combined) except for the Vernon section (Figure 4). CPUE declined sharply through time below and within the Holyoke dam section; however this declining trend weakens with each upstream section. Turners section CPUE declined slightly, and in the Vernon section there was no apparent decline in CPUE through time.

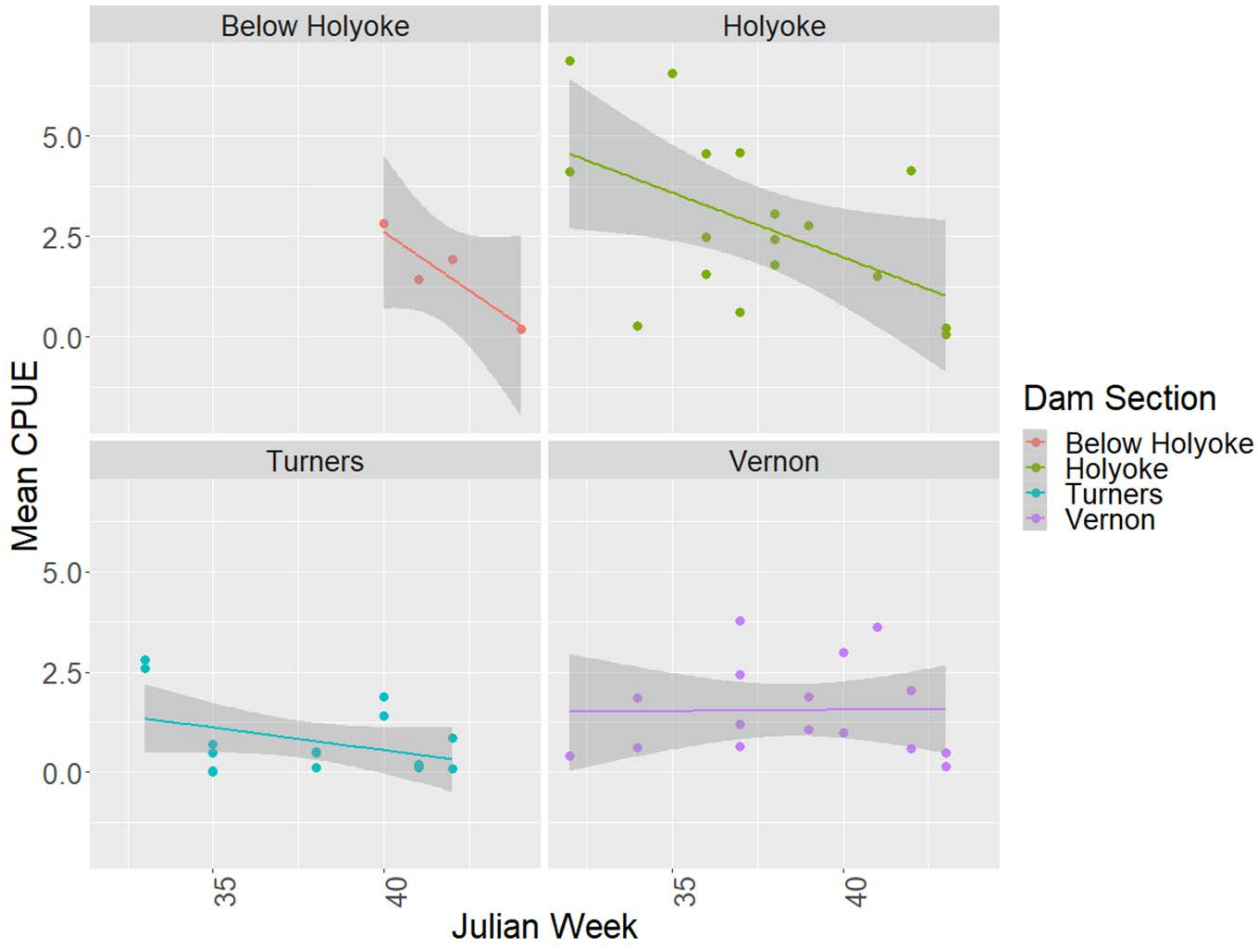

Figure 4: CPUE values (# fish/minute) across Julian week for each dam section, with 95% confidence intervals (shaded). Data is aggregated by Julian Day, with each point representing average CPUE values across dam section for each sample day.

The dissipating trend of declining CPUE through time in an upstream direction corresponds with increasing fish size (total length) through time (upstream direction). Length increases sharply through time in the uppermost section (Bellows), and this effect declines with each downstream dam section (Figure 5). Vernon Dam section has mild to moderate increases in length over time, while Holyoke Dam section show very little increase in length over time.

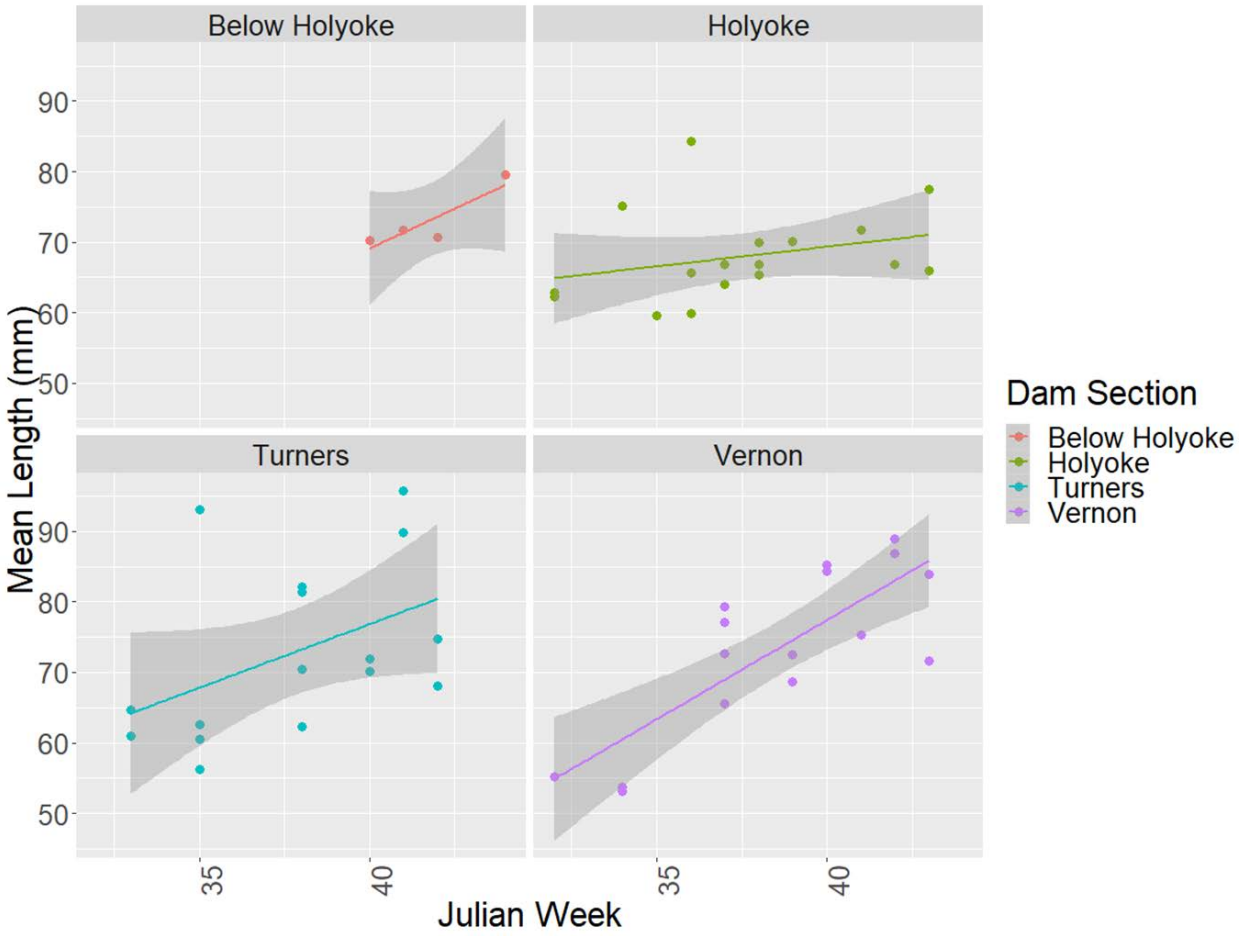

Figure 5: Juvenile American Shad size (total length) across Julian week for each dam section, with 95% confidence intervals (shaded). Data is aggregated by Julian day, with each point representing the average length values across each dam section for each sample day.

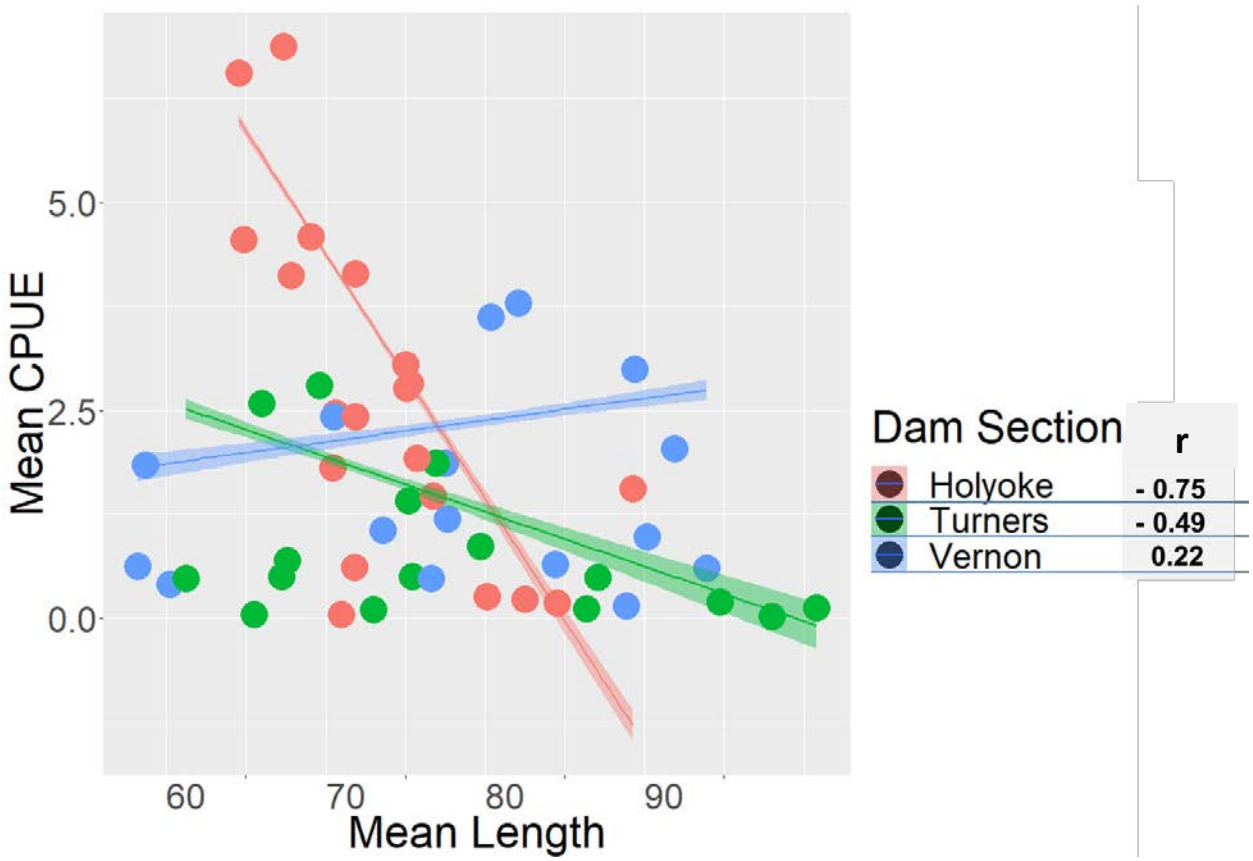

Figure 6: Scatterplot of mean CPUE and mean length values for Holyoke (red), Turners (green), and Vernon (blue) dam sections. Data was aggregated by Julian day, thus each point represents the average CPUE or length value per sample day.

Mean CPUE and mean lengths were plotted across dam section for both years of data (Figure 6). Pearson's r correlation coefficients were calculated for each dam section as a proxy measure for determining density dependent growth. Mean CPUE and mean lengths were highly correlated (negative) in the Holyoke section (-0.75), while not highly correlated in the Turners section but still with a negative effect (-0.49), and not at all correlated in the Vernon section (0.22) with the effect changing to positive.

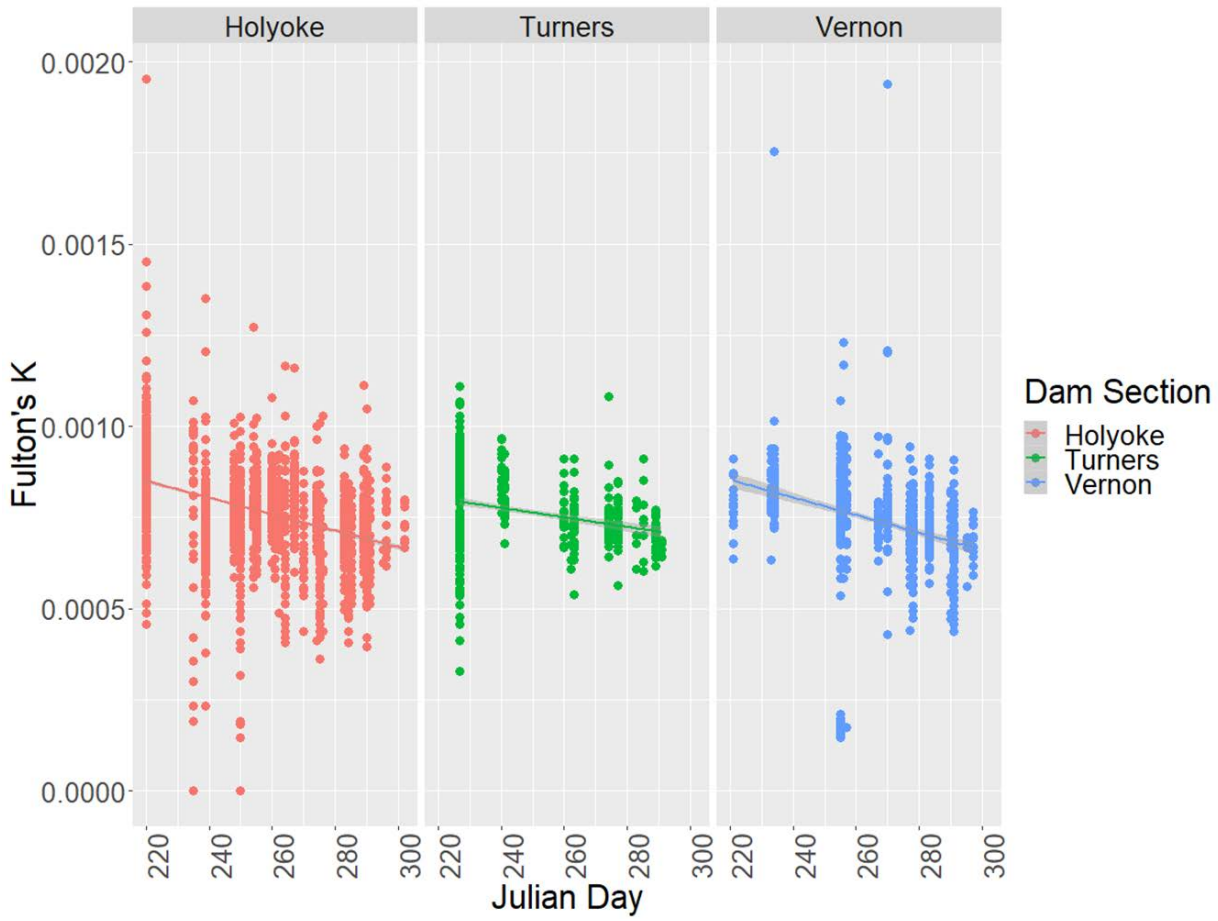

Figure 7: Fulton's *K* values through time (Julian Day) for 2017 and 2018 (data combined), across all dam sections. Regression lines were added for each dam section.

Fulton's *K* values show apparent declining trends through time across all three dam sections (Figure 7). Rates of decline appear similar across dam section, but this was not specifically tested. Condition values will be tested statistically once more data are collected.

Both Connecticut and Massachusetts surveys resulted in higher CPUE in 2018 compared to 2017 (Figure 8). This proportional increase in both surveys suggests they are tracking similar trends in juvenile shad production, and can likely be used to complement one another in terms of informing juvenile shad production, although more data are needed to confirm this trend.

Electrofishing runs were also conducted below the Holyoke dam in 2018 (n=18) to determine if differences in CPUE (compared to above Holyoke Dam) were present below the Holyoke Dam, which could potentially complicate data interpretation. Catch rates below Holyoke Dam appear similar in magnitude compared with samples above the dam, suggesting no major differences, although this was not directly tested.

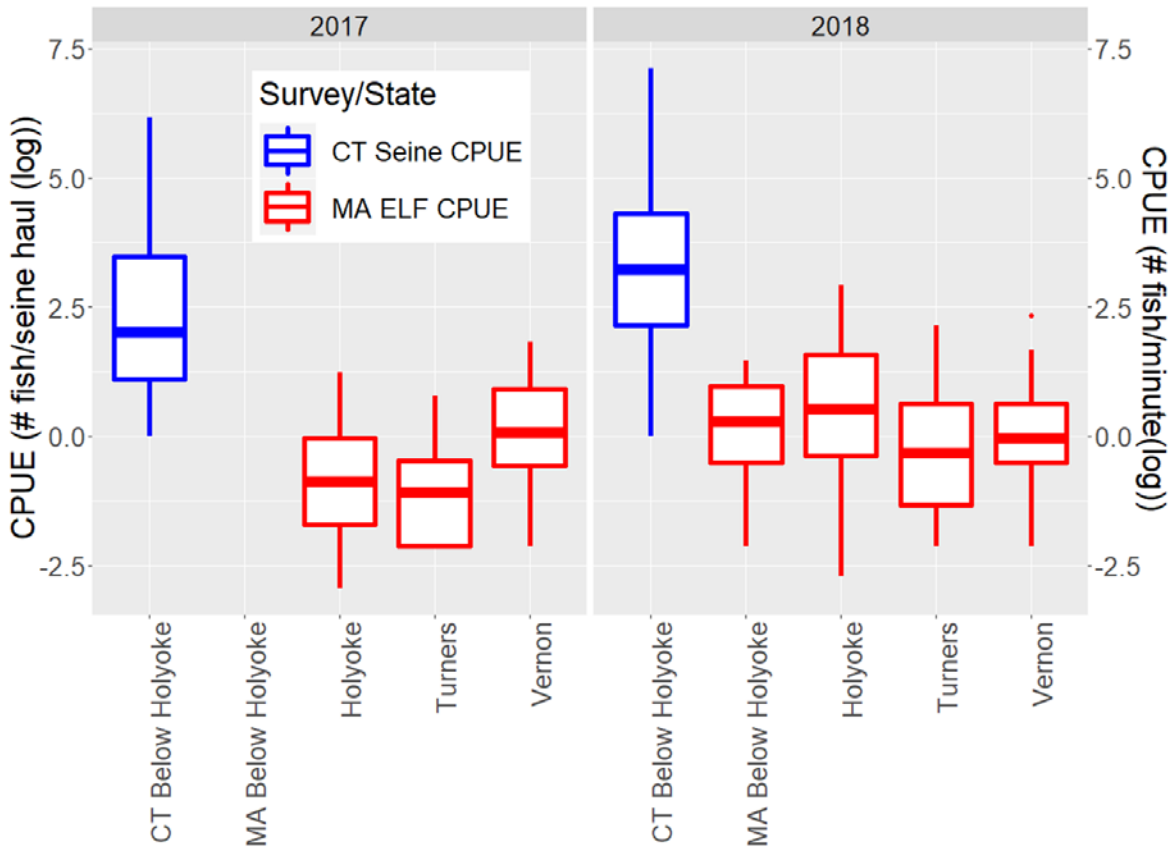

Figure 8: Box plots comparing CT seine surveys (blue) with MA electrofishing surveys (red) in 2017 and 2018 (logged). CPUE is contrasted across dam sections for MA electrofishing survey (x-axis). Note that units are different (CT: # fish/seine haul; MA: # fish/minute), thus caution should be used when comparing indices directly.

Discussion

Boat electrofishing surveys conducted by MDFW and USFWS appear to be proportional and complimentary to CTDEEP seine surveys (note the different scales/indices). Shad CPUE via electrofishing was variable across dam section, yet consistently similar in scale compared to seine data. Both surveys saw an increase in juvenile shad CPUE from 2017 to 2018.

Our data suggests strong density dependence effects in the Holyoke Dam section, but not the Vernon or Turners section. This is made clear by the differences in CPUE and total length across time for each dam section (Figure 4, 5), as well as the direct relationship between CPUE and total length (Figure 6). Density dependent effects are known to arise among organisms with limited resources within their environment, such as environments where high abundances of juvenile forage fish occur with a limited food supply. This effect is important in controlling

unlimited growth in species and habitats, and can also be used to gauge if populations are growing to their full potential and if natural mortality rates can occur to provide sufficient forage for freshwater predators such as Striped Bass *Morone saxatilis* and Smallmouth Bass *Micropterus dolomieu*.

Juvenile American Shad in the lowermost dam section (Holyoke) show very little increase in length through time, while also displaying strong decreases in CPUE through time. This effect is reversed upstream, such that the uppermost dam section (Vernon) shows a substantial increase in length through time coupled with relatively constant catch rates (CPUE) through time. These observations are indicative of density dependent population effects, where the Holyoke Dam section retains a high number of adult American Shad, largely due to lack of sufficient adult passage above Turner's Falls Dam (next consecutive dam). This appears to result in high initial abundances of juvenile shad and increased mortality associated with density dependent effects.

Juvenile shad in the Holyoke Dam section obtain greater lengths at slower rates, and likely experience high mortality rates as suggested by rapidly reduced CPUE across time. This observed effect shows evidence which strongly supports the goal of improved fish passage at Turner's Falls Dam to benefit the reproductive capacity of this population. Despite nearly double the number of adults making it above Holyoke in 2017 compared to 2018, an even smaller percentage of adults made it above the Turners Dam in 2017 (9.1%) compared to 2018 (15.7%). Turner's Falls Dam appears to be the primary barrier for increasing adult and juvenile numbers upstream of the Holyoke Dam section. This has significant consequences for upstream ecosystems that depend on reliable pulses of forage fish for over-summer growth, as well as juveniles moving downstream into the estuary and the marine environment. To realize these juvenile production benefits, the cumulative impacts of downstream passage mortality at hydroelectric facilities (four facilities in the case of juveniles upstream of Vernon) must be controlled. This passage mortality concern for out migrating, spent adult shad has the same critical importance for addressing the depressed repeat spawner component of this population. Higher passage rates of adult shad at Turner's Falls Dam section likely would result in more dispersed catch rates throughout the impoundment zones with more even and efficient use of available river habitat. This includes the expectation that density dependent effects would decrease in the Holyoke section and increase in both sections above (Turners and Vernon).

This summary report provides novel evidence of strong density dependent effects observed in the lower dam section (Holyoke to Turners Falls), mild to moderate density dependent effects in the middle dam section (Turners Falls to Vernon), and virtually no observed density dependence in the upper dam section (Vernon to Bellows Falls). More efficient passage of adult shad, particularly at the Turner's Dam Fishway, is needed, with corresponding downstream passage protections for spent adults. Suitable passage/protection of juvenile shad passing by/through all hydropower facilities must be properly developed and assessed. Further, data reported here confirms the importance of the stratified electrofishing survey and shows the value in monitoring juvenile shad productivity upstream of the Holyoke dam.

References

[ASMFC] Atlantic States Marine Fisheries Commission. 2007. American shad stock assessment for peer review, Volume 1 and Volume 2. Stock Assessment Report No. 07-01. Washington, D.C.

[ASMFC] Atlantic States Marine Fisheries Commission. 2009. Atlantic Coast Diadromous fish habitat: a review of utilization, threats, recommendations, for conservation and research needs. Washington, D.C.

[ASMFC] Atlantic States Marine Fisheries Commission. 2010. Amendment 3 to the Interstate Fishery Management Plan for Shad and River Herring (American Shad Management). Washington, DC.

Castro-Santos, T. and B. H. Letcher. 2010. Modeling migratory energetics of Connecticut River American Shad (Alosa sapidissima): implications for the conservation of an iteroparous anadromous fish. Canadian Journal of Fisheries and Aquatic Science, 67: 806-830.

[CRASC] Connecticut River Atlantic Salmon Commission. 2017. Connecticut River American Shad Management Plan. Sunderland, Massachusetts.

Crecco, V.A., Savoy, T.F., Gunn, L. 1983. Daily mortality rates of larval and juvenile American shad Alosa sapidissima in the Connecticut River with changes in year-class strength. Canadian Journal of Fisheries and Aquatic Sciences 40: 1719–1728.

[CTDEEP] Connecticut Department of Energy and Environmental Protection. Roberts, Jacqueline. 2017. Survey of Alosines and Other Important Forage Species in the Connecticut and Thames Rivers. Bureau of Natural Resources, Hartford, CT.

Franke, G.F., D.R. Webb, R.K. Fisher, D. Mathur, P.N. Hopping, P.A. March, M.R. Headrick, I.T. Laczo, Y. Ventikos, and F. Sotiropoulios. 1997. "Development of environmentally advanced hydropower turbine system concepts", Voith Hydro, Inc. Report No. 2677-0141. Prepared for the USDOE (Idaho) Contract No. DE-AC07-96ID13382. Page 17 of 26

Gephard, S. and J. McMenemy. 2004. An overview of the program to restore Atlantic salmon and other diadromous fishes to the Connecticut River with notes on the current status of these species in the river. Pages 287-317 in P. M. Jacobson, D. A. Dixon, W. C. Leggett, B.C. Marcy, Jr., R.R. Massengill, editors. The Connecticut River Ecological Study (1965-1973) revisited: ecology of the lower Connecticut River 1973-2000. American Fisheries Society, Monograph 9, Bethesda, Maryland.

Leggett, W. C. 1976. The American shad (Alosa sapidissima), with special reference to its migration and population dynamics in the Connecticut River. Page 169-225 in D. Merriman and L. M Thorpe, editors; The Connecticut River Ecological Study, The Impact of a Nuclear Power Plant. American Fisheries Society, Monograph 1, Bethesda, Maryland.

Leggett, W. C., T. F. Savoy, and C. A. Thomichek. 2004. The impact of enhancement initiatives on the structure and dynamics of the Connecticut River population of American Shad. Pages 391-405 in P. M. Jacobson, D. A. Dixon, W. C. Leggett, B.C. Marcy, Jr., R.R. Massengill, editors. The Connecticut River Ecological Study (1965-1973) revisited: ecology of the lower Connecticut River 1973-2000. American Fisheries Society, Monograph 9, Bethesda, Maryland.

Limburg, Karen E. 1996. Growth and migration of 0-year American shad (Alosa sapidissima) in the Hudson River estuary: otolith microstructural analysis. Can. J. Fish. Aquat. Sci. 53: 220-238.

Limburg K.E., and Waldman J.R. 2009. Dramatic declines in North Atlantic diadromous fishes. BioScience 59: 955–965.

[LMS] Lawler, Matusky and Skelly Engineers. 1993. Northfield Mountain Pumped Storage. Facility 1992 American Shad Studies. Draft Report. FERC Project 2485. Prepared for Northeast Utilities Service Company, Berlin, Connecticut.

Mathur, D, P. Heisey, and D. A. Robinson. 1994. Turbine passage mortality of juvenile American shad at a low-head hydroelectric dam. Transactions of the American Fisheries Society 123:108-111.

Mattocks, S., C. J. Hall, A. Jordaan. 2017. Damming, Lost Connectivity, and the Historical Role of Anadromous Fish in Freshwater Ecosystem Dynamics. Bioscience 67: 713-728.

[MDFW] Massachusetts Division of Fisheries and Wildlife. 2015. Massachusetts State Wildlife Action Plan. Westborough, MA.

McDermott, S. P., N. C. Bransome, S. E. Sutton, B. E. Smith, J. S. Link, and T. J. Miller. 2015. Quantifying alosine prey in the diets of marine piscivores in the Gulf of Maine. Journal of Fish Biology 86: 1811- 1829.

O'Donnell, M. J. and B. H. Letcher. 2008. Size and age distributions of juvenile Connecticut River American Shad above Hadley Falls: Influence on outmigration representation and timing. River Research and Applications 24: 929-940.

O'Leary, J. A. and B. Kynard. 1986. Behavior, length, and sex ratio of seaward migrating juvenile American shad and blueback herring in the Connecticut River. Transactions of the American Fisheries Society Volume 115, Issues 4, pages 529-536.

Zydlewski, J., S. D. McCormick and J. G. Kumkel. 2003. Late migration and seawater entry is physiologically disadvantageous for American Shad juveniles. Journal of Fish Biology. Volume 63: 1521 – 1537.