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Monitoring Response of Diadromous Populations to Fish Passage Improvements on a Massachusetts Coastal Stream

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Abstract: One technical fishway and two innovative nature-like fishways were installed at three dams on the Acushnet River in Acushnet, Massachusetts to facilitate migration of river herring and juvenile American eels (elvers). Pre-construction and post-construction monitoring of river herring and elver populations used census counting and abundance estimation, respectively. Numbers of adult river herring returning to the upstream spawning grounds during the pre-construction phase were very low; elver counts declined during the pre-construction period and served as baseline levels to determine the effectiveness of the new fishways. Post-construction monitoring of river herring and elvers indicated an increasing trend of spawning adult river herring returning to the spawning grounds, with the total count in the fourth year of post-construction representing an increase of 1,140% over baseline, pre-construction conditions. Results also show increased elver recruitment into the river as well as increased proportions of elvers accessing habitat in the upper watershed that was mostly inaccessible prior to fishway installation. The new fishways at the three dams on the river have improved diadromous fish passage, thereby increasing the probability of restoring healthy populations of river herring and American eels to the Acushnet River system.

Key words: Nature-like fishways, fish passage improvements, restoration.

1. Introduction

On the Atlantic Coast of the US and Canada, fishways of all types have been used to pass a wide variety of diadromous species. In New England, where river herring [alewife (*Alosa pseudoharengus*) and blueback herring (*A. aestivalis*)] and American eel (*Anguilla rostrata*) are among the most abundant diadromous species, technical fishways such as Denil, weir-pool, and Alaska Steep pass designs have proven effective for passage of large numbers of river herring over small or low head (< 3 m height) dams [1]. Custom-style ramps (such as flumes or pipes roughened to reduce flow velocities) have been designed to take advantage of the swimming and climbing abilities of juvenile eels [2].

In recent years, nature-like fishways, such as roughened ramps and bypass channels, have been developed to improve the passage of a wide variety of diadromous fish species at low-head dams in Europe [3-6]. Studies have shown that fish passage efficiency can be as high as 90%-100% through nature-like fishways [4]. When compared to other technical fishway designs, nature-like fishways allowed the highest fish passage [6]. The natural features of these designs, such as boulder weirs or cobble substrates, dissipate hydraulic kinetic energy and reduce flow velocities to levels that enable migratory species to pass upstream of the obstruction. Fish are believed to find natural substrates more acceptable than concrete channels or channels with baffles in structural fishways [3]. The lower velocities at the boundary layers and flow refugia resulting from

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high roughness of nature-like fishways (generally less than 0.3 m/s) also allow for greater potential passage of very small or weakly swimming species, such as rainbow smelt (*Osmerus mordax*) and juvenile eels [7]. As with technical fishways, nature-like designs need to be constructed to maintain appropriate water depths and velocities over a range of flow regimes and fluctuating headwater levels to facilitate passage. In addition, these fishways need to be designed to prevent the displacement of weirs and substrate during anomalous high flow events or stranding of out-migrating species due to insufficient water depths during low-flow periods.

Few nature-like fishways have been constructed in the northeastern US and limited testing has been conducted to evaluate passage efficiency of these fishways. Results from field studies conducted by Franklin et al. [8] at two New England rivers indicated moderate to good overall passage performance of alewives through nature-like sections of fishways. From an environmental and ecological perspective, dam removal has become an attractive option for river restoration efforts. In cases where dam removal is not an option, installing nature-like fishways may become a more attractive alternative to conventional fishway structures. In some cases, nature-like fishways can serve as alternatives to dam removal in which natural designs can be fitted into existing or partially removed dams. This eliminates the obstruction without completely removing the dam and lowering the impoundment, or incurring costs of remediating potentially contaminated sediments behind the dams. In this paper, the authors describe the successful improvement of diadromous fish passage associated with the use of both technical and nature-like fishways.

2. Study Methods

2.1 Description of Study Area

The Acushnet River (located in Bristol County, Massachusetts) encompasses an area of 48.7 km^2 (18.8 mi^2), with a total stream length (including all tributaries) of 67.9 km (42.2 mi) and a mean annual flow (D50) of 0.54 m^3/s (19.0 ft^3/s) [9]. The mainstem of the river flows approximately 13.8 km (8.6 mi) south from the New Bedford Reservoir into New Bedford Harbor and empties into Buzzards Bay (Fig. 1). This system historically supported several diadromous species including alewife, blueback herring, American eel, smelt, and white perch (*Morone americanus*) [10].

The production of diadromous species in the Acushnet River, in particular river herring (alewife and blueback herring), has been impacted by the presence of three barriers to passage (Acushnet Sawmill Dam, Hamlin Street Dam, and New Bedford Reservoir Dam) located in the upper portion of the watershed (from river 7.1 km - 13.2 km). The first dam, at the Acushnet Sawmill at river 7.1 km (4.4 mi), was 35.9 m (118 ft) in length and approximately 1.4 m (4.6 ft) in height and was equipped with an inefficient and deteriorating weir-pool ladder. At high spring river flows, the ladder configuration minimized and dissipated the attraction flow originating from the

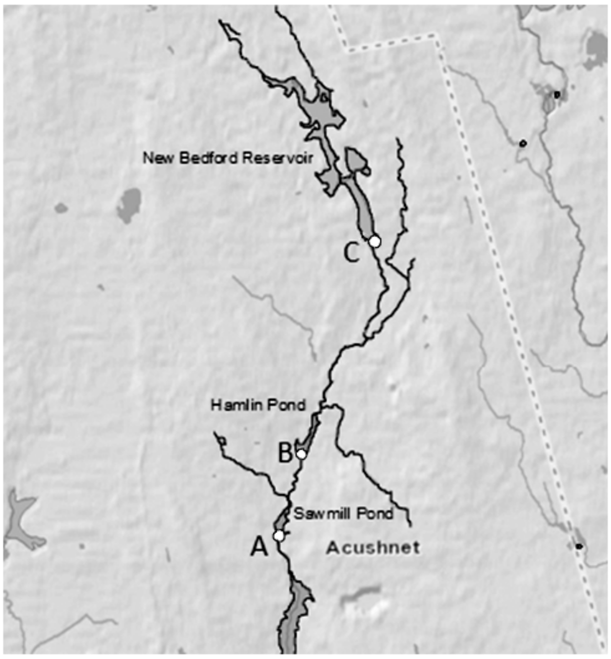

Fig. 1 Map of the Acushnet River watershed showing locations of (A) Acushnet Sawmill Dam; (B) Hamlin Street Dam; and (C) the New Bedford Reservoir Dam.

fishway and served to delay upstream migration. In addition, fish had difficulty in finding the entrance due to heavy vegetation growing in the tailrace area, which eliminated any defined channel [10].

The Hamlin Street Dam at river 8.5 km (5.3 mi), the second obstruction on the river, is a 91.4 m (300 ft) earthen dam that supports an access road (Hamlin Street) over the Acushnet River. The river flows through the dam by way of three culverts, each of which was fitted with slots for flashboards. While herring had been able to pass this obstruction under suitable flow conditions, it was identified as a correctable limiting factor on population recruitment [10].

The third and last obstruction on the system, the New Bedford Reservoir Dam at river 13.2 km (8.1 mi), is a 3.4 m (11 ft) earthen structure that creates a large impoundment providing 89.0 ha (220 ac) of underutilized spawning and nursery habitat for river herring and eels. Although the spillway at this dam has passed fish under ideal flow conditions, this structure hindered upstream migration, as a result, fish passage at this point was extremely inefficient and the structure was the limiting factor in reaching the production potential of the system [10]. The remnant river herring population was sustained by the minimal number of adults ascending into the reservoir.

River herring population estimates are largely unavailable for this system. A one-year pilot study conducted in 2008 (post-construction) by Haro et al. [11] estimated total population size of river herring in the Acushnet River using a video counter system installed above the head of tide and downstream of the first weir of the Acushnet Sawmill fishway. Counts were conducted by passively monitoring their entry into the system using underwater video recording at a diversion weir. Using both video counts and the reservoir fish trap census counts, Haro et al. [11] conservatively estimated the run size between 1,000 and 1,500 river herring.

2.2 Project Purpose

The project purpose was to increase the size of the existing diadromous fish populations in the Acushnet River by improving fish passage at three obstructions and allow access to the spawning and nursery habitat in the headwater impoundment. The short-term objective was to improve existing upstream passage of adult river herring at the New Bedford Reservoir by 1,000% by 2011 over baseline conditions established during the pre-construction phase (2005 through 2007). To document the success of these improvements, the populations of river herring and American eel were monitored over an extended temporal frame including both pre-construction and post-construction phases of the fish passage improvement projects. Monitoring commenced in 2005 and continued for seven years, terminating in 2011.

2.3 Fish Passage Improvements

Restoration efforts began in 2002 with the construction of an 80.8 m (265 ft) state-of-the-art Denil fishway at the New Bedford Reservoir Dam. Restoration efforts continued in the autumn of 2007 with replacement of the fishway at the Acushnet Sawmill Dam and installation of a new passageway at the Hamlin Street Dam. Due to the need to maintain water levels in the headponds, these latter two sites were fitted with innovative nature-like fishways, including a stone flow-constrictor, step-pool system at the former, and a stone step-weir system at the latter. Fishway replacement at the Acushnet Sawmill site involved partially breaching the dam, reducing the length of the dam, and re-defining the stream channel. Large boulders were placed side-by-side forming 11 weirs (and 10 pools) at different elevations, thereby allowing fish to navigate at most water flow levels predicted by hydrologic models. A similar stone structure overcoming a smaller elevation differential (five rock weirs and no pools) was fabricated in the river channel at Hamlin Street to facilitate fish passage.

2.4 Diadromous Species Monitoring and Data Analysis

To census the river herring population, a locking box trap (2.4 m × 25.4 cm *L* with mount; 1.5 m × 15.2 cm *L* holding area, 0.9 m *W* × 0.6 m *H*) was constructed and installed at the exit of the fishway at the New Bedford Reservoir. The trap was constructed with 5.1 cm^2 wire mesh to capture all fish using the fishway. The trap was tended daily and all individuals were recorded, identified to species, removed from the trap using a dip net and released alive immediately upstream.

Two American eel traps, built following a *Marine Fisheries* modified Sheldon design [12] were placed at appropriate locations in the Acushnet River. One was placed at the head of tide in the lower river below the Acushnet Sawmill Dam and the other was placed in the upper river just downstream to the ladder entrance of the New Bedford Reservoir Dam. The traps were set and tended daily at both sites and the times the traps were hauled and set were recorded. All trapped elvers were separated by developmental stage (un-pigmented young-of-the-year and larger pigmented age-1 +) and counted. Daily catches were released alive in the New Bedford Reservoir.

Each spring (between 2005 and 2011), the traps were set on April 1 and tended seven days a week for a minimum of 10 weeks in order to encompass the entire spawning run for river herring as well as the majority of the elver migration. Monitoring in nearby rivers identified an approximate four week period (encompassing the last two weeks of April and the first two weeks of May) as the peak migration period for river herring. To determine the effectiveness of the fishways installed downstream, total counts of river herring were recorded each year and an average total count of the pre-construction years (2005 through 2007) was used as baseline conditions in order to establish the 1,000% enumeration target level for 2011.

CPUE (catch-per-unit-effort) scores (N_{elvers}/h/d) from elver catches at both stations were generated as daily catch rates. Peak migration periods occurred in April (both April and May in some years), therefore, catch data during these months were used to generate mean CPUE indices. Annual mean CPUE scores were generated as indices of juvenile abundance and yearly comparisons were made. To determine if annual differences in CPUE exist, a generalized linear model was used where CPUE was the dependent variable and year was the categorical predictor. To select the appropriate distributional error form, annual mean CPUE scores and variances (σ) were calculated and the following equations were fitted:

The formula shown in Eq. (1) was used for Poisson, Gamma and Inverse Gaussian error distributions:

$$\sigma = b(\mu)^c \qquad (1)$$

The formula shown in Eq. (2) was used for the Negative Binomial error distribution:

$$\sigma = \mu + b(\mu)^c \qquad (2)$$

If c = 1, a Poisson error distribution was used; if c = 2, a Gamma or Negative Binomial distribution was suggested; if c = 3, then an Inverse Gaussian distribution was suggested. The c coefficient estimates were 2.1 (Acushnet Sawmill station) and 1.7 (Reservoir station) for both models, which suggested either the Gamma or Negative Binomial error distributions were most appropriate. Given that CPUE is a continuous variable, the Gamma distribution was used. Because the Gamma distribution assumes non-zero observations, 0.01 was added to each CPUE score before the model was fitted and a log link function was used. Deviance residuals were used to assess model fit. Annual mean CPUE values were plotted and examined using an analysis of deviance for any trends in catch rates at both stations on the river. If applicable, mean catch rates at the Reservoir station were grouped by monitoring period (pre-construction and post-construction) and tested again using an analysis of deviance to determine if catch rates differ by period. Catch rates by period and catch compositions at the reservoir station were examined to determine the effectiveness of the fishways to facilitate access for elvers into the upper watershed.

3. Results

Monitoring results of total counts of river herring, including peak observation periods and the percent change in total counts per year are summarized in Table 1. A total of 10,035 river herring (9,951 alewives; 84 blueback herring) were captured and released into the New Bedford Reservoir throughout the entire monitoring period. Based on peak observations recorded in Table 1, it is assumed that we were able to capture the entire run each year. The data are grouped into two phases (the pre-construction phase period: 2005 through 2007; and post-construction phase period: 2008 through 2011).

Total counts of alewives observed during pre-construction phase monitoring were low (less than 400 per year). No blueback herring were observed in the trap during this period. Peak migrations occurred within a short temporal scale during this period. Each year during the pre-construction period, the peak of the run was observed to occur within less than one week. The average total count for this period (N_{PRE} = 323) served as a baseline level to establish the 1,000% enumeration target in 2011 ($N_{1,000\%}$ = 3,230).

During the 2008 sampling season (the first year of post-construction phase monitoring), the total count of river herring (N_{2008} = 978) represented an increase of 264% over the total count in 2007. Total counts for both species increased each year of post-construction monitoring at an average rate of 183% per year. Peak observation periods increased during the post-construction phase from a two week migration period in 2009 to four weeks periods in 2010 and 2011. A second peak migration occurred in 2011 (between May 14 and May 16) during which the majority of blueback herring were observed. The total number of river herring captured and released into the reservoir in 2011 (N_{2011} = 3,679) represents an increase of 1,140% over baseline conditions established during the pre-construction period.

Results of elver catch rates for both sampling sites are shown in Fig. 2. Each year, the elver traps were deployed and removed at the same time as the fish trap. Based on peak observations, it is assumed that the monitoring periods encompassed the majority of the elver migration periods. Log-transformed annual mean CPUE scores of elver catches at the Acushnet Sawmill station are shown in Fig. 2a. Distribution of deviance residuals versus predictor (on link scale)

Table 1 Summary results of census counts, means, and percent changes of river herring sampled from the New Bedford Reservoir fish trap throughout the monitoring period (2005-2011).

Year	Date deployed	Date removed	Run start	Alewife	Blueback herring	Combined	Peak observation	Annual difference (%)
2005	4/1/05	6/10/05	4/25	395	0	395	5/3-5/6	
2006	3/29/06	6/6/06	4/11	202	0	202	4/25-4/28	-48.9
2007	3/28/07	6/15/07	4/23	371	0	371	4/23-4/27	183.7
2008	4/1/08	6/6/08	4/3	977	1	978	4/10-5/1	263.6
2009	3/30/09	6/5/09	3/31	1,695	5	1,700	4/19-5/2	204.3
2010	3/29/10	6/10/10	3/30	2,703	7	2,710	4/6-5/4	159.4
2011	3/28/11	6/3/11	3/30	3,608	71	3,679	4/8-5/2 *5/14-5/16	135.8
Totals				9,951	84	10,035		**1,140
Pre-construction means (2005-2007)				323	0	323 (baseline)		67.4
Post-construction means (2008-2011)				2,246	21	2,267		183.2

* Peak observation period for blueback herring in 2011.

** Percent change in 2011 over baseline conditions (mean observations during the pre-construction phase).

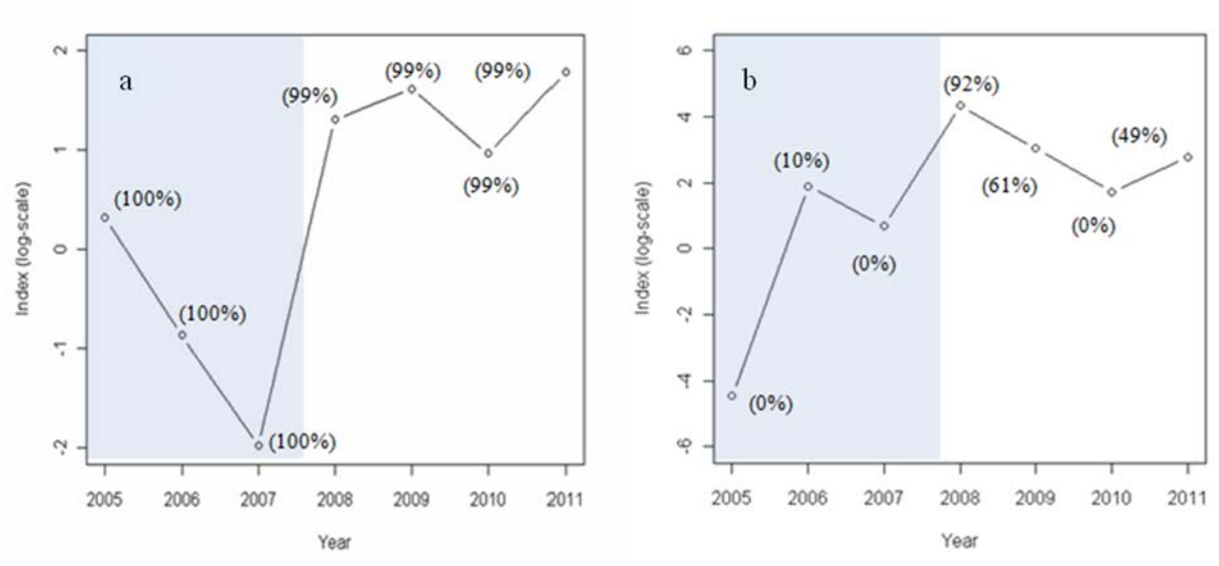

Fig. 2 Log-transformed annual mean CPUE of elver catches at (a) the Acushnet Sawmill station and (b) the Reservoir station. Percent indicates proportion of young-of-the-year within yearly sample. Results are grouped by pre-construction (shaded) and post-construction phase monitoring.

showed no pattern of residuals indicating that the model fits the data well. Analysis of deviance (F = 11.7, p < 0.01, df = 6) showed that year was a significant factor, indicating annual differences in CPUE among years.

Log-transformed annual mean CPUE scores of elver catches at the Reservoir station are shown in Fig. 2b. Distribution of deviance residuals versus predictor (on link scale) showed no pattern of residuals indicating that the model fits the data well. Analysis of deviance (F = 23.1, p < 0.01, df = 6) showed that year was a significant factor, indicating annual differences in CPUE among years. Catch rates were grouped by monitoring period (pre-construction: 2005-2007; post-construction: 2008-2011) and tested to determine if catch rates differ between periods. Results (F = 2.0, p = 0.2, df = 1) indicated that variability in catch rates was too great to detect differences between the two periods.

Results from pre-construction phase monitoring indicated declines in catch rates at the Acushnet Sawmill station (Fig. 2a). Catches at the Acushnet Sawmill station were comprised only of young-of-the-year elvers. Peak observations occurred within 10 day periods (starting the last week of April) in 2005 and 2006, respectively. No discreet peak observation period could be identified in 2007 due to low catch levels. Low catch numbers were observed at the Reservoir station (Fig. 2b) during this period in which age-1 + elvers constituted the majority of elvers captured. Young-of-the-year were observed at the Reservoir station in 2006 (comprising 10% of the total catch) and were absent in catches in 2005 and 2007, respectively.

Results from post-construction phase monitoring indicated increased catch numbers and catch rates at the Acushnet Sawmill station (Fig. 2a) in which young-of-the-year comprised 99% of the catches each year. Migrations occurred over longer temporal scales with two discreet periods (occurring in April and May) in 2008, 2009 and 2010 and one period (lasting four weeks in April) in 2011. Although catch rates were not significantly different from the pre-construction monitoring period, increased elver catches were observed at the Reservoir station (Fig. 2b) during the post-construction period. Higher proportions of young-of-the-year were observed in the catches in comparison to pre-construction phase monitoring comprising 92%, 61% and 49% of the catches in 2008, 2009 and 2011, respectively (young-of-the-year were not present in the catches in 2010).

4. Discussion

Census results indicate increasing numbers of river herring entering the New Bedford Reservoir throughout the course of post-construction phase monitoring. The rate of increase (% annual difference, Table 1) was highest in 2008 and 2009 where total counts were doubling in size during the first two years of post-construction monitoring. The rate of increase declined toward the end of the monitoring period, however, total counts maintained a positive trend in which the total count in 2011 exceeded the 1,000% enumeration target level established using baseline conditions during pre-construction phase monitoring. Given the iteroparous life history of river herring in which maturation occurs at sea and adults return to freshwater to spawn for the first time in three to four years, there is a delay in observing increased numbers associated with improvements to passage. Calles and Greenberg [4] indicated that nature-like fishways are effective for re-establishing stream connectivity and increased passage efficiency for salmonids albeit at a re-colonization rate that is slower than expected. The rate of re-colonization for this system is unknown at this time, however, the short-term results are encouraging and it is anticipated that numbers should continue to increase in future years.

Results from monitoring suggest that the fish passage improvements to the three dams have significantly improved access to the primary spawning habitat in the New Bedford Reservoir. In addition, peak observation periods have increased, possibly as a result of the design characteristics of the nature-like fishways, which enable herring to pass upstream at various flow levels without significant delay. These results are consistent with those of Franklin et al. [8], which indicated overall passage performance of alewives through nature-like sections of fishways was modest (40.6%; East River, Guilford, CT) to good (94%; Town Brook, Plymouth, MA), with relatively rapid transit times through the fishways. These results also support those of Calles and Greenberg [4] who evaluated the function of two nature-like fishways and estimated between 90% and 100% passage efficiency for anadromous salmonids in the River Emån, Sweden. Bunt et al. [6] evaluated the attraction performance and passage efficiency of various fishway designs for a variety of anadromous and potadromous species. They found that mean passage efficiency was inversely related to mean attraction efficiency by fishway structure type, with highest passage observed for nature-like fishways (range = 0-100%, mean = 70%, median = 86%), when compared to other technical fishway designs.

Although access to the upper watershed has improved, it is possible that river herring may also be utilizing habitats downstream of the reservoir for spawning. Based on census counts in 2008 (N = 978) and results from Haro et al. [11], it is assumed that between 65% and 98% of the run entered the New Bedford Reservoir in 2008, and the remaining proportion of the run utilized downstream habitats. In particular, alewives can utilize spawning habitat in the shallow impoundments created upstream of the Acushnet Sawmill and Hamlin Street dams [Sawmill Pond, 3.8 ha. (9.5 acres); Hamlins Pond, 5.1 ha. (12.5 acres)]. The design specifications of the nature-like fishways at the Acushnet Sawmill and Hamlin Street dams involved only a partial removal of the spillways in order to minimize impacts to surface-water levels of the impoundments. Complete removal of the dams at these sites would have resulted in a decrease in impoundment water levels and potentially eliminated these spawning habitats. The overall objective to improve passage to the New Bedford Reservoir has been met, and increasing the proportion of the run accessing the primary spawning habitat will maximize reproductive success.

The presence of blueback herring in the reservoir trap during post-construction phase monitoring was an unexpected result. The fish ladder installed at the New

Bedford Reservoir Dam was designed primarily to facilitate access for alewives to the reservoir. While both species are capable of spawning in riverine or lacustrine environments [13], alewives prefer spawning in lentic habitats such as ponds and lakes [13, 14], while blueback herring prefer spawning in lotic environments [15]. The increases in blueback herring in the trap catches suggest that fish passage improvements in the lower obstructions (the Acushnet Sawmill Dam and Hamlin Street Dams) may facilitate access for blueback herring to spawning habitat available in the upper watershed (including the New Bedford Reservoir) and is an additional benefit to this population and to this restoration effort.

Results of elver catches from the Acushnet Sawmill station during post-construction phase monitoring indicated increased catch rates of elvers in the lower river. Given the location of the Acushnet Sawmill elver trap (at the head of tide), it serves as an indicator of the abundance of elvers entering the system. Increasing catch-per-unit effort scores may suggest a possible increase in recruitment into the system. However, the mechanism behind this trend is currently unknown.

Catch data from pre-construction phase monitoring indicated that few elvers (comprised mainly of age-1 +) were reaching the ladder entrance to the reservoir. Elver catches increased moderately during post-construction phase monitoring and suggest that eels have improved access to the upper reaches of the river due to improvements at the downstream obstructions. In particular, greater proportions of young-of-the-year were present at the Reservoir station in comparison to pre-construction years. However, the increase in catch rates did not exhibit the same trend as river herring. Results indicated that young-of-the-year were not present in the catches every year of post-construction phase monitoring (young-of-the-year were not observed at the Reservoir station during the 2010 monitoring season), which suggests that elvers may be residing in the impoundments downstream, prior to migrating to the reservoir. Residence time in downstream impoundments is unknown at this time. It is possible that young-of-the-year may be migrating upstream outside of the monitoring period as suggested by the counts at the reservoir station observed toward the latter part of the monitoring periods (late May and into June). Maximizing the proportion of young-of-the-year that can access their primary nursery habitat in the upper watershed provides a good standard to measure the level of success in the effort to improve passage. Based on these results, with increased recruitment into the system, it is anticipated that greater proportions of young-of-the-year will utilize nursery habitat in sections of the upper watershed including the reservoir.

5. Conclusions

Results suggest that the fish passage improvements to the three dams on the Acushnet River have successfully improved passage for river herring and juvenile American eel. Alterations to the lower two obstructions (Acushnet Sawmill Dam and Hamlin Street Dam) using nature-like fishway designs has facilitated access to the upper watershed for elvers and river herring and installation of a technical (Denil) fishway has enabled passage for river herring into the primary spawning habitat in the New Bedford Reservoir. Increasing numbers of river herring entering the reservoir were observed each year of post-construction monitoring. The highest rate of increase was observed in 2008, the first year after installation of the new fishways downstream and the total count in 2011 (the final year of post-construction monitoring) surpassed the short-term restoration target level. Although elver counts have not exhibited the same incremental increase as river herring, catches have increased at both sampling locations during the post-construction period. It is anticipated that the numbers of spawning adult river herring and elvers reaching the New Bedford Reservoir will continue to increase and monitoring should continue in successive years to examine changes in these populations and further document the success of the fish passage improvements.

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References

[1] C. Katopodis, N. Rajaratnam, A Review and Lab Study of Hydraulics of Denil Fishways, Canadian technical report fisheries aquatic sciences 1145, Winnipeg, Manitoba, Jan. 1983.

[2] C.H. Clay, Design of Fishways and Other Fish Facilities, 2nd ed., CRC Press, Inc., 1995.

[3] Deutscher Verband für Wasserwirtschaft und Kulturban e.V. (FAO/DVWK.), Fish Passes—Design, Dimensions, and Monitoring, FAO Food and Agriculture Organization, Rome, 2002.

[4] E.O. Calles, L.A. Greenberg, Evaluation of nature-like fishways for re-establishing connectivity in fragmented salmonid populations in the River Emån, River Research and Applications 21 (9) (2005) 951-960.

[5] E.O. Calles, L.A. Greenberg, The use of two nature-like fishways by some fish species in the Swedish River Emån, Ecology of Freshwater Fish 16 (2) (2007) 183-190.

[6] C.M. Bunt, T. Castro-Santos, A. Haro, Performance of fish passage structures at upstream barriers to migration, River Research and Applications 28 (2012) 457-478.

[7] A. Haro, A. Franklin, T. Castro-Santos, J. Noreika, Design and Evaluation of Nature-Like Fishways for Passage of Northeastern Diadromous Fishes, Final report submitted to NOAA National Marine Fisheries Service Office of Habitat Conservation, 2008.

[8] A. Franklin, A. Haro, T. Castro-Santos, J. Noreika, Evaluation of nature-like and technical fishways for the passage of alewives at two coastal streams in New England, Transactions of the American Fisheries Society 141 (2012) 624-637.

[9] United States Geological Survey (USGS), StreamStats [Online], http://streamstatsags.cr.usgs.gov/ma_ss/default.aspx?stabbr=ma&dt=1316199203967 (accessed Sept. 16, 2011).

[10] K.E. Reback, P.D. Brady, K.D. McLaughlin, C.G. Milliken, A Survey of Anadromous Fish Passage in Coastal Massachusetts: Part 1, Southeastern Massachusetts, *Marine Fisheries* technical report 15, 2004.

[11] A. Haro, A. Franklin, T. Williams, Evaluation of Fish Migration in the Acushnet River, Final report submitted to NOAA National Marine Fisheries Service Office of Habitat Conservation, 2008.

[12] ASMFC (Atlantic States Marine Fisheries Commission), Interstate Fishery Management Plan for American Eel, ASMFC fisheries management report, Apr. 2000.

[13] J.G. Loesch, Overview of life history aspects of anadromous alewife and blueback herring in freshwater habitats, in: Common Strategies of Anadromous and Catadromous Fishes, American Fisheries Society Symposium, 1987.

[14] J.G. Loesch, W.A. Lund, A contribution to the life history of the blueback herring, *Alosa aestivalis*, Transactions of the American Fisheries Society 106 (1977) 583-589.

[15] B.C. Marcy, Planktonic fish eggs and larvae of the lower Connecticut River and effects of the Connecticut Yankee plant including entrainment, in: D. Merriman, L.M. Thorpe (Eds.), The Connecticut River Ecological Study: The Impact of a Nuclear Power Plant, American Fisheries Society Monographs 1, 1976.