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Upper Narragansett Bay Fish Passage: Case Studies in Connectivity Restoration

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OVERVIEW: Connectivity is an essential consideration and attribute of most aquatic ecosystem restoration projects. Fish passage projects provide one of the most direct demonstrations of the importance of connectivity for imperiled migratory taxa. The U.S. Army Corps of Engineers (USACE) New England District (NAE) completed two efforts in the upper Narragansett Bay, Rhode Island that demonstrate many of the obstacles, or constraints, associated with connectivity restoration of waterways in an urbanized setting. This technical note focuses on two watershed-scale fish passage projects in rivers flowing into the Upper Narragansett Bay and their contribution to the Bay's diadromous fish populations. Together, these projects may provide a substantial increase in the quality and quantity of fish and wildlife resources by reducing the impacts of dams on fish passage connectivity. First is an overview of these ecosystem restoration projects. Then, the key lessons learned are synthesized from these projects which can be transferred to fish passage and connectivity restoration projects nationwide.

NARRAGENSETT BAY CONNECTIVITY RESTORATION: Narragansett Bay, located in Rhode Island and Massachusetts, is one of New England's largest estuaries and the associated watershed drains more than 1,800 square miles from seven major tributaries. The Blackstone and Ten Mile River watersheds comprise approximately 25% of the total bay watershed (475 and 56 square miles, respectively; Figure 1). These rivers have been significantly altered and developed for more than 200 years by navigation structures, channel straightening, and mill and hydropower dams. As a result, habitat for migratory fishes has been significantly fragmented and has become the focal point of a variety of restoration actions. In this section, the assemblage of migratory fishes of the northeastern United States and the project setting for both restoration efforts is described.

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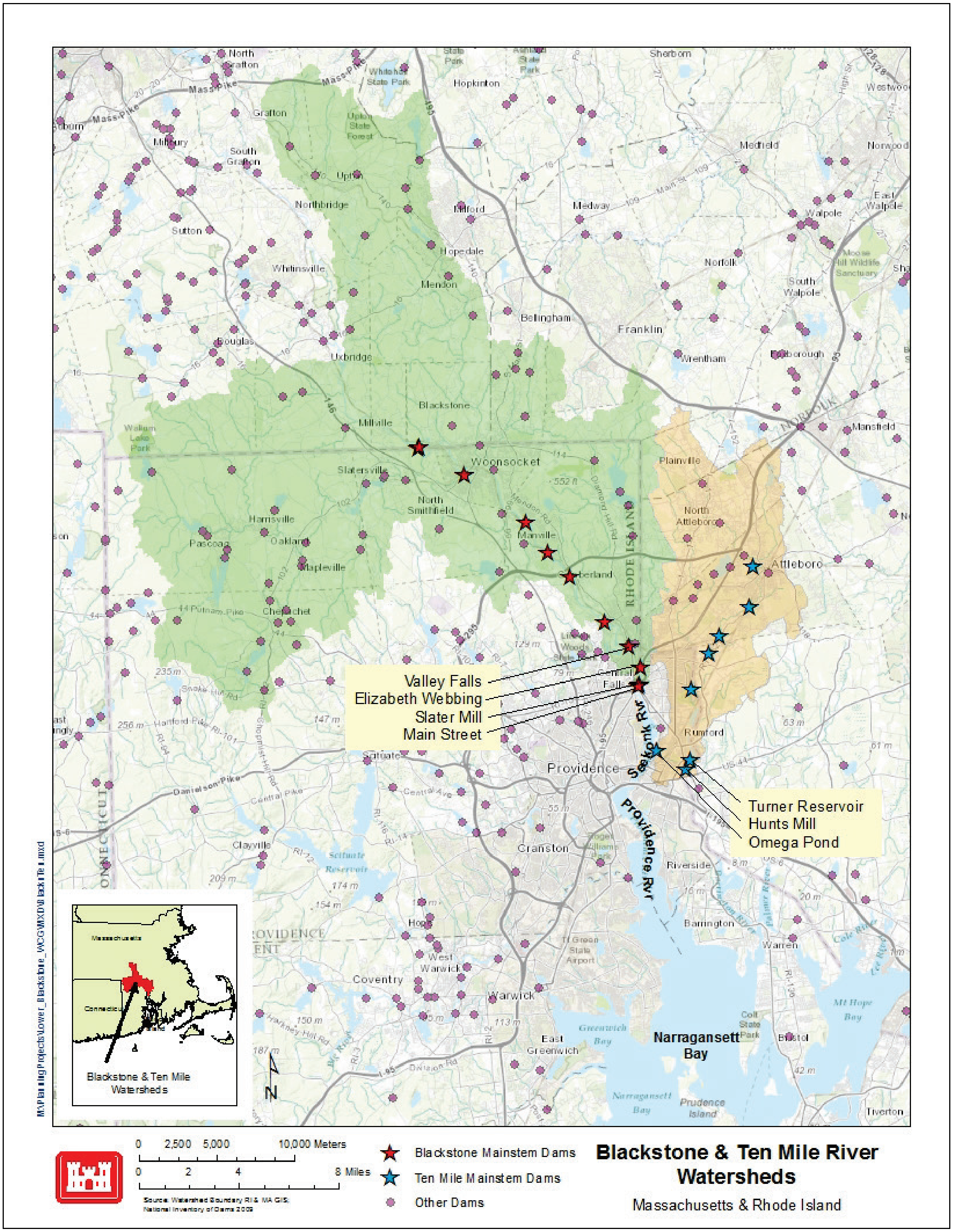

Figure 1. Blackstone and Ten Mile River watersheds and sites considered in this report.

Target Species. USACE guidance lists anadromous fish as nationally significant resources because of their scarcity and importance to aquatic and terrestrial food webs (USACE 2000). Populations of anadromous blueback herring (*Alosa aestivalis*), alewife (*Alosa pseudoharengus*), and American shad (*Alosa sapidissima*) in the northeastern United States are at less than 1, 2, and 3 percent of historic populations, respectively (Limburg and Waldman 2009). Catadromous American eel (*Anguilla rostrata*) are also an important part of coastal watersheds of New England and are at historically low levels; less than 30 percent of their historic population (Limburg and Waldman 2009). Historically, Atlantic salmon (*Salmo salar*) were also present in Narragansett Bay; however, recent attempts to restore salmon to southern New England waters have been unsuccessful and fish passage restoration now focuses almost solely on other species. The NAE has previously completed, and is currently conducting, several projects to restore anadromous fish populations to coastal watersheds, some of which have not supported self-sustaining populations of migratory fish for more than 200 years. By restoring access to historic spawning habitats, these projects reintroduce diadromous fish populations to the river systems and restore connections among marine, estuarine, riverine and terrestrial habitats.

Ten Mile River Project. For over 200 years, dams have blocked migratory fish from their historic spawning grounds in the Ten Mile River. The NAE completed the Ten Mile River Ecosystem Restoration Study in September 2005 under authority contained in a 12 September 1969 resolution by the United States Senate Committee on Public Works to address this problem. The study considered providing fish passage at the three most downstream dams on the river: Omega Pond Dam, Hunts Mill Dam, and Turner Reservoir Dam (Figure 1; Table 1). At each site, the alternatives included; no action, installation of fish passage structures (e.g., technical ladders, lifts), and dam removal.

Table 1. Description of fish passage barriers in the Ten Mile River restoration study.

Dam	Location	Description	Restoration Action
Omega Pond Dam	Mouth of Ten Mile River at tidewater with drainage area of 56 mi^2	Masonry and earth structure with hydraulic height of 15 feet and 106-foot spillway	Denil fish ladder
Hunts Mill Dam	1.9 miles upstream of Omega Pond with drainage area of 53.6 mi^2	Masonry and earth structure with hydraulic height of 8.5 feet and 80-foot spillway	Denil fish ladder
Turner Reservoir Dam	2.3 miles upstream of Omega Pond with drainage area of 48.3 mi^2	Concrete and earth structure with hydraulic height of 22 feet	Denil fish ladder

Although dam removal was the preferred alternative to achieve maximum ecological benefits, planning constraints and public opinion concerning dam removal led to a study recommendation and construction of Denil fishways at all three dams (USACE 2005):

- Omega Pond Dam could not be removed because of concerns about upstream contaminated sediment to include contaminant release to the downstream estuary and the cost of sediment removal, and public opposition to the removal of the impoundment.
- Hunts Mill Dam and associated historic structures, including the Hunt House which serves as a public museum and park, are listed on the National Register of Historic Places eliminating the possibility of removing the dam.

- Turner Reservoir Dam also impounds contaminated sediment, serves as a significant recreational resource and provides a backup water supply for the city of East Providence and therefore, could not be removed.

Blackstone River Project. The Lower Blackstone River Fish Passage Study is being conducted under the Section 206 Aquatic Ecosystem Restoration Program. A series of dams have blocked fish passage in the Blackstone River for over 200 years. This study is considering measures to provide diadromous fish passage at the three most downstream dams; Main Street Dam, Slater Mill Dam, and Elizabeth Webbing Dam (Figure 1; Table 2). A fourth dam, Valley Falls, also blocks passage to substantial spawning and rearing habitats; however, passage at this site is being evaluated by other studies. At each site, the alternatives being evaluated included: no action, installation of fish passage structures (e.g., technical ladders, lifts), trap and truck, nature-like fishways (e.g., bypasses, ramps), and dam removal.

Table 2. Description of fish passage barriers in the Blackstone River study.

Dam	Location	Description	Restoration Action
Main Street Dam	Mouth of Blackstone at tidewater with drainage area of 640 mi^2	Constructed in 1718 “Furnace Dam” (16.5 feet high). Used historically to power mills. Currently used for hydropower	Trap and truck
Slater Mill Dam	400 feet upstream of Main Street Dam	Historic textile mill dam constructed in 1891 (15 feet high). The mill and dam are part of the Blackstone River Valley National Park	Trap and truck
Elizabeth Webbing Dam	Less than 5,000 feet upstream of Slater Mill Dam	Historic textile mill dam constructed in 1891 (11 feet high). Repurposed for hydropower (in operation from 1981–2001). Mill was converted into a condominium development constraining actions; has deed restriction limiting lowering of crest height	Trap and truck
Valley Falls	1.2 miles upstream of Elizabeth Webbing Mill Dam	Historic textile mill dam currently used for hydropower	Trap and truck

As with the Ten Mile River project, planning constraints and public opinion are significant drivers of study alternatives.

- Main Street Dam is a historic structure tightly confined by local development in the center of downtown Pawtucket with a natural barrier (waterfall) underlying the dam. The river was historically relocated, shortening its course and complicating the potential options for dam removal. The NAE, the Rhode Island Department of Environmental Management (RIDEM), the National Oceanic and Atmospheric Administration (NOAA) Restoration Center, and the U.S. Fish and Wildlife Service (USFWS) developed a viable plan to partially remove the dam and create step pools to meet passage criteria (NOAA, undated). The dam is a Federal Energy Regulatory Commission (FERC) licensed dam, and is therefore not eligible for cost sharing under USACE restoration programs. The study considered relocation of the FERC license to the Slater Mill Dam (next upstream dam) as part of the partial removal alternative. However, eventual loss of interest by the dam owner and license holder led to the abandonment of this option, leaving a technical fishway as the only viable option.

- The Slater Mill Dam is a historic textile mill on the National Register of Historic Places and was recently designated as part of the Blackstone River Valley National Historic Park. The dam's historic significance and limited available space make the construction of a technical fishway the only viable fish passage alternative at this site.
- The textile mill at Elizabeth Webbing Dam was redeveloped as a condominium and the dam is bound by a deed restriction that prohibits complete dam removal. A technical fishway or rock ramp with partial dam removal are the only viable alternatives for this site.

The Rhode Island Department of Environmental Management (RIDEM) in cooperation with the Natural Resources Conservation Service (NRCS) completed design and issued a request for proposal to construct Denil fish ladders at Main Street Dam and Slater Mill Dam. However, the single bid received far exceeded the available funds precluding construction of the fish ladders. The RIDEM subsequently requested assistance from NAE to explore other fish passage options. Due to the complexity of these sites and associated costs of restoration measures, the non-Federal sponsor is currently considering a trapping and trucking alternative, where migratory fishes would be manually caught at the Main Street Dam and transported upstream beyond the fourth dam, Valley Falls. This is not a preferable alternative as it requires substantial operation and maintenance over the life of the project, funding is uncertain and it is not self-sustaining or as efficient as the other options. In addition, this alternative would exclude access to habitat in a substantial tributary (Abbot Run) that enters the Blackstone River between Elizabeth Webbing and Valley Falls dams, the fourth dam on the river where fish would be released (Figure 1). Given the site constraints and funding, trap and truck appears to be the only viable option at this time.

LESSONS LEARNED: The Ten Mile and Blackstone River projects provide an opportunity to demonstrate the benefits and challenges of planning and executing multiple fish passage restoration projects within an urbanized watershed. From a restoration standpoint, the most effective mechanism for improving access for migratory fishes is full removal of the barriers. However, each of the six sites (seven including Valley Falls) in these watersheds required site-specific decision making to address the distinct technical and social challenges associated with dam removal (i.e., contaminated sediment, exceptional historical value, water supply, aesthetics concerns, FERC licensing, and engineering constraints). Four transferrable lessons from these case studies are highlighted relative to: (1) the cumulative effects of multiple projects in spatial sequence, (2) constrained fish passage improvement for historical preservation, (3) other physical and logistical constraints of restoration in developed areas, and (4) other factors identified during project implementation.

Dam removal vs. fish passage improvement. Dam removal provides the greatest benefits for fish passage improvement (Kraft 2013) and other ecosystem processes by restoring the full range of river functions (e.g., upstream and downstream benthic organism passage, hydrologic and sediment continuity, and woody debris transport) (Poff and Hart 2002). Where possible, dam removal should be recommended in restoration efforts due to ecological efficacy. However, as in the case of these projects in the upper Narragansett Bay watershed, other environmental and social factors often preclude dam removal. A central consideration in assessing dam removal relative to other forms of fish passage restoration should be the cumulative effects of many barriers in series and the consequences of imperfect passage at a watershed scale.

For example, the Ten Mile River restoration project installed three fish ladders at sequential structures. The cumulative effects of suboptimal passage could reduce overall project success. Based on projections by RIDEM using a method developed by Gibson (1984), the Ten Mile River projects will provide access to habitats that could support a fish run of over 200,000 river herring; however, the actual number of fish accessing the habitat may be affected by the effectiveness of fish passage through the series of fish ladders. In a recent review of fish passage structures, Noonan et al. (2011) determined the average upstream passage efficiency through fish ladders for non-salmonids was only 41.7%. Studies have suggested that the cause for the low passage percentage are most commonly associated with attraction efficiencies (ability to attract fish into the structure entrance), design limits for specific fish species (size, swimming ability etc.), and energy expenditure searching for entrances and ascending a structure. Applying the average reduction in fish passage efficiency reported by Noonan to each fish ladder on the Ten Mile River, and assuming the river herring would fully utilize the habitat in each successive river segment, the series of fish ladders could theoretically reduce the number of river herring making it beyond Turner Reservoir dam to only about 5,500 compared to a carrying capacity of 211,000 fish (Table 3, Figure 2). Table 3 provides a simple, theoretical estimate of the effects of reduced fish passage effectiveness (e.g., it assumes full utilization of each downstream habitat segment) and most likely, a significant overestimate of the reduction caused by the series of ladders on the Ten Mile River. Table 3 also highlights the need for careful design of fish ladders, the necessity for considering effectiveness in calculating the benefits of various fish passage and river restoration options, and desirability of opting for dam removal over fish ladders. Although fish passage structures provide an alternative for addressing historical or social constraints, the cumulative effects of imperfect passage can be dramatic at a watershed scale where many barriers operate in series.

Table 3. Theoretical reduction in the estimated population of river herring considering fish passage efficiency.

Location	**Total**	**Omega Pond Dam**	**Hunts Mill Dam**	**Turner Reservoir**
Carrying capacity from Gibson (1984)				
Upstream Pond Habitat (ac)	340	33	10	297
Upstream River Habitat (ac)	9	9	0	0
Theoretical Population Based on Habitat Area	267,000	39,000	17,000	211,000
Reduction in fish due to passage efficiency				
Passage Rate (0 = no passage, 1 = perfect passage) (Noonan et al. 2011)		0.417	0.417	0.417
Number Approaching Structure		267,000	72,339	13,165
Number Accessing Habitat		111,339	30,165	5,490
Number Remaining in Habitat		39,000	17,000	5,490
Number Proceeding Upstream		72,339	13,165	0

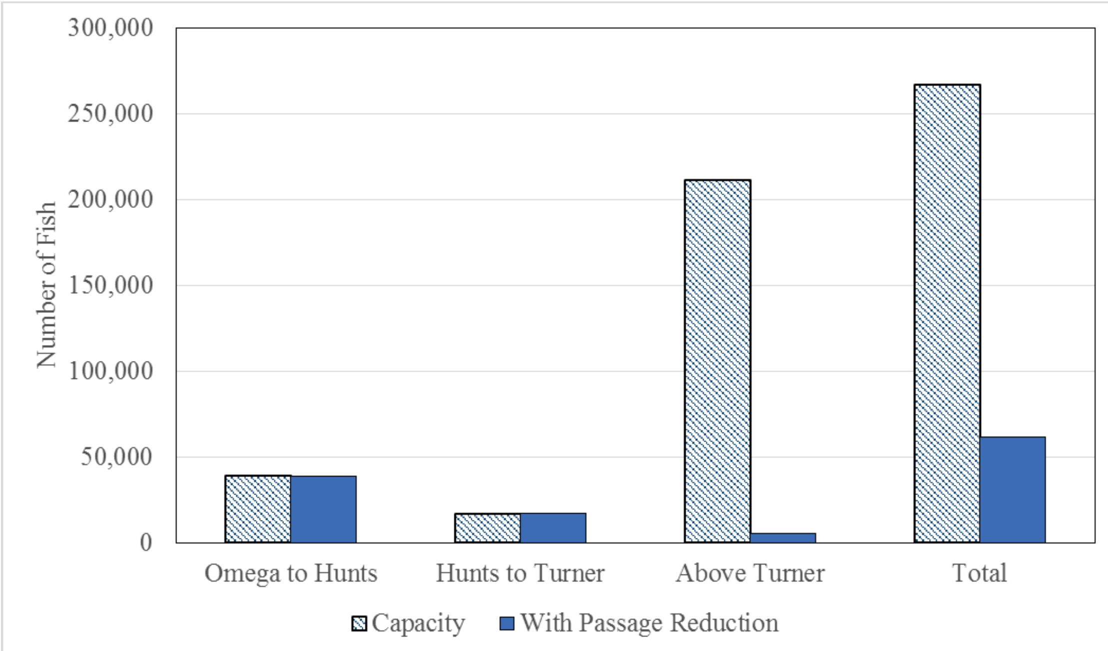

Figure 2. Theoretical reduction in the estimated population of river herring by reach considering fish passage efficiency.

Historical preservation. Both the Ten Mile and Blackstone Rivers have sites on the National Register of Historic Places (Hunts Mill Dam on the Ten Mile River and Slater Mill Dam on the Blackstone River) that absolutely precluded removal of the dams. In many cases mitigation can be used to lessen the effects of projects on historic resources. For instance, mitigation at the Hunts Mill Dam consisted of photo-documentation, fitting the fish passage structure within existing historic structures to maintain the preexisting character as much as possible (Figure 3), and adding simulated stone facing to the exposed wall of the fish ladder. Although, this mitigation allowed sufficient modifications to construct Denil fish ladders, the limitations in fish passage effectiveness of Denil fish ladders puts more pressure on the need to maximize fish passage efficiency at other impediments. At the Ten Mile River, additional dams upstream of the Turner Reservoir will need to be addressed in future projects. If further research substantiates the reductions in fish passage with fish ladders in sequence, dam removal will become ever more imperative to realize further gains in anadromous fish populations.

Constrained environments. Site constraints can have a very substantial impact on the feasibility of fish passage and river restoration alternatives, particularly in heavily developed urban environments like the upper Narragansett Bay. The constraints on the lower Ten Mile and Blackstone rivers drove alternative selection toward the more technical options; Denil fish ladders for the Ten Mile River and trap and truck for the Blackstone River, and away from the preferred alternative of dam removal.

(A)

(B)

Figure 3. Example of the historical constraints and opportunities offered in a confined social setting. (A) Replication and preservation of historic structure at Hunts Mill Dam (B) Main Street Dam constrained by local bridge and natural waterfall (Slater Mill dam is visible in background).

Fish passage and river restoration projects, in general, are affected by a variety of constraints:

- Uses of the river, dams, and impoundments (e.g., cultural and historic resources, water supply, recreation, aesthetics, hydropower, flood risk reduction, and real estate value).
- Biological challenges (e.g., presence and limits of target species, limits on fish passage efficiency, the potential spread of nuisance species).

Many of these environmental, economic, and social constraints influenced decisions and outcomes in the Ten Mile River and the Blackstone River projects. As discussed previously, historic resource value dictated alternative selection at Hunts Mill and Slater Mill dams. At

Omega Pond and Turner Reservoir, the combined constraints related to contaminated sediments and aesthetics drove the selection of Denil fish ladders. The value of Turner Reservoir as a backup water supply also led to the selection of a Denil fish ladder. Concerns about the release of contaminated sediments during dam removal result from perceived risk and uncertainty regarding the spread and effects of contaminated sediments on the ecosystem. Additional research and tools are needed to more clearly define the nature and severity of contaminated sediment releases and their significance.

Other engineering and institutional factors affected project alterative selection at the lower Blackstone River sites. The Blackstone River has been called "*America's Hardest Working River*" (NHCC 2003) It was significantly modified during the Industrial Revolution leaving a limited ability to make major modifications. Braids in the river were filled, portions of the river were diverted to canals, the mainstem was channelized, locks and dams were constructed to harvest the power of water and the remaining floodplain was developed. These modifications are part of this country's heritage and are often considered significant resources that warrant protection. However, the majority of this infrastructure is no longer active and the environmental impacts remain.

In the case of the Main Street Dam, a technically viable solution of constructing Denil fish ladders was too expensive for the project partners to implement. Additionally, the effectiveness of the ladder was debated. The fishway entrance is located over 300 feet upstream of the hydropower tailrace. The flow from the hydropower facility would likely cause false attraction and the number of fish successfully finding the Denil entrance is unknown. Therefore, the risk of project failure was higher than most. The success of subsequent structures depends on ample passage at this first impediment. At the request of the RIDEM, the project development team, including representatives of several Federal and State agencies, developed an alternative to the Denil (a combination of weir-pool and rock ramp); however, the institutional constraints related to the ownership and operation of the FERC licensed dam led to abandonment of this solution. Given these factors, the stakeholders have recommended implementation of a trap and truck facility to restore as much fish passage as available within the heavily constrained site. Although not ideal, this alterative will restore at least a portion of the anadromous fish populations to the lower Blackstone River and upper Narragansett Bay.

Other factors to consider. Two factors came to light following completion of construction of the fish ladders on the Ten Mile River. After construction of the fish ladder at Hunts Mill Dam, local watershed members noticed that fish were having difficulty passing during low flows because of natural rock obstructions to fish passage. These obstructions are being addressed by the project team. This highlights the need to visually survey the entire stretch of river to which fish passage will be restored under various flow conditions to ensure that the project addresses all potential obstructions across a range of discharge. The second factor identified following construction was the potential implications of sea level rise. The entrance to fish ladders are designed to attract fish under flow conditions at the site under existing sea levels. A substantial increase in the rate of sea level rise would eventually reduce and possibly eliminate the effectiveness of the entrance to attract fish. This is yet another reason to prefer dam removal over fish ladder construction.

SUMMARY: The combined Ten Mile River and Blackstone River restoration projects have the capacity to contribute as many as 400,000 river herring and as many as 35,000 American shad to

Narragansett Bay and the Atlantic Ocean. This subsequently would provide important ecological benefits and ecosystem services to the rivers as well as the Narragansett Bay and the Atlantic Ocean ecosystems. Multiple restoration actions and the associated return of an ecologically important group of species can have far reaching effects on a variety of ecosystem process (e.g., coastal food web support) (Hall et al. 2012).

The effectiveness of fish ladders and other technical fishways depends on proper siting and design. However, they will always limit the number of species of fish and the number of individuals within a species that can pass and the other ecosystem functions that are provided by dam removal. Trap and truck operations are labor intensive and have similar problems of efficiency. These limitations are important considerations when restoring rivers with a number of dams in sequence. If each dam and associated fish passage structure reduces passage efficiency by a certain factor (e.g., 41% in this example), reduced numbers of fish will arrive at dams further upstream. Research and monitoring on the Ten Mile River project will help to define the effects on fish passage efficiency of multiple fish ladders on a river segment.

In some cases, technical and nature-like fishways may be appropriate where ecological and social constraints are insurmountable (e.g., historic sites, contaminated sediment and water supply). Fish passage improvement may not restore riverine characteristics to upstream impoundments (e.g., sediment delivery), but it can partially restore the connections among ecosystems and restore a portion of ecological function via the fish community with its concomitant contribution to productivity, biodiversity, and trophic functioning. This Technical Note has used case studies on the Ten Mile and Blackstone rivers to demonstrate some of the challenges associated with connectivity restoration to aid other project planning teams in the planning and design of restoration in constrained environments.

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