Technical Reports

Massachusetts Division of Marine Fisheries
Technical Report TR-80

River Herring Spawning and Nursery Habitat Assessment

Acushnet River Watershed, 2019-2020

J. J. Sheppard, C. Reusch, C. Rhodes, M. Gendron, and E. Perry

Massachusetts Division of Marine Fisheries
Department of Fish and Game
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Acushnet River Watershed, 2019-2020

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DMF staff collecting biological information from spawning adult river herring prior to releasing them into the New Bedford Reservoir (Credit: DMF).

Abstract

River herring (the collective name for alewife, *Alosa pseudoharengus*, and blueback herring, *A. aestivalis*) are native, anadromous fish that migrate each spring to spawn in coastal watersheds that have suitable freshwater habitat for egg incubation and juvenile rearing. The Massachusetts Division of Marine Fisheries (DMF) conducts river herring spawning and nursery habitat assessments that assist habitat and population restoration efforts and contribute to Massachusetts Department of Environmental Protection (MassDEP) water quality assessments. The Acushnet River watershed has been the focus of much diadromous fish restoration in recent years. The primary spawning habitat for river herring in this system, the lower and upper New Bedford Reservoir in Acushnet, Massachusetts, was assessed in 2019-2020. The habitat assessment identified both water quality and habitat impairments. The lower and upper basins were classified as *Impaired* for exceedances in dissolved oxygen (DO), pH, Secchi disk, total nitrogen (TN) and total phosphorous (TP) based on DMF's habitat assessment criteria. Widespread abundance of invasive fanwort and variable milfoil along with agricultural practices in the surrounding area contribute to the eutrophication and expansive anoxic hypolimnion in both basins. Additionally, classifications for Fish Passage and Stream Flow in the lower reservoir were deemed *Impaired* primarily due to low flow conditions at several locations in the watershed. The impairments identified in this assessment are concerning due to possible limitations on juvenile river herring survival and river herring population recruitment.

Introduction

The Acushnet River Watershed is located in Bristol County, Massachusetts where the river flows through the towns of Acushnet, Fairhaven, and the City of New Bedford (**Figure 1**). It is the largest river basin in Buzzards Bay, encompassing 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; United States Geological Survey [USGS], 2022).

The New Bedford Reservoir (220 acres) functions as the headwaters for the Acushnet River Watershed. There are three tributaries that flow into the New Bedford Reservoir: (1) Roaring Brook, originating in Freetown; (2) Squinn Brook flowing out of Little Quitticas Pond (297 acres) in Lakeville; and (3) Squam Brook which flows out of Long Pond (1,721 acres), in Lakeville. Historically, Long Pond served as the primary headwaters to the Acushnet River. However, in 1869 when the New Bedford Reservoir was created as a water supply source for the City of New Bedford, the connection to Long Pond was severed (Sheppard et al. 2014). Now the main stem of the river flows 13.8 km (8.6 mi) south from the reservoir into the New Bedford Harbor, ultimately emptying into Buzzards Bay. The U.S. Geological Survey (USGS) reports the recent mean annual flow as 0.54 m^3/sec (19.0 ft^3/sec) (USGS 2022).

The Acushnet River, whose name originates from the Wampanoag tribe called "Cushnea" meaning "as far as the waters", was an essential natural resource to native tribes and early European settlers (Howland 1883). It was used as

Figure 1. Map of the Acushnet River watershed with fish passage sampling stations shown (red markers).

an industrial waterway in the early 18th and 19th centuries, in which multiple dams were constructed to support hydropower mills (EA EST 2005). These mills and factories directly contributed to the success of the New Bedford and Fairhaven whaling, textile, and logging industries (Howland 1883). However, heavy industrialization of the area from the 1940's-1970's allowed for decades of contamination. Riverine habitat was altered and polluted, primarily in the lower half of the watershed. In 1982, the Acushnet River Watershed was designated as a Superfund site by the U.S. Environmental Protection Agency (EPA). This was due to sediment hot spots found containing several thousand parts per million PCB concentrations (Sheppard et al. 2014).

Diadromous Fisheries. Historically, the Acushnet River supported several diadromous fish runs including river herring, both alewife (*Alosa pseudoharengus*) and blueback herring (*A. aestivalis*), rainbow smelt (*Osmerus mordax*), white perch (*Morone americanus*), and American eel (*Anguilla rostrata*). Under the control of the City of New Bedford, an alewife fishery was established in 1863 (Belding 1921). Over the centuries, industrial trade waste in the lower portion of the Acushnet River created poor habitat conditions for diadromous species. Pollutants and manufacturing wastes, the creation of dams and other water flow diversions contributed to the collapse of the fishery by the 1920s (Belding 1921; Sheppard et al. 2014). In the 1970's, Reback and DiCarlo (1972) reported that enhancement of this fishery would depend on pollution abatement and fish passage improvements.

Restoration efforts. As part of a cooperative partnership between state and federal agencies, a restoration plan for the Acushnet River was developed in 1991. The National Oceanic and Atmospheric Administration (NOAA) and the New Bedford Harbor Trustees Council (NBHTC) served as the lead agencies responsible for the restoration. In 1997, the NBHTC allocated funds from the New Bedford Harbor Cleanup Fund to help restore diadromous fish passage (Reback et al. 2004; Sheppard et al. 2014). The Massachusetts Division of Marine Fisheries (DMF) was assigned as the project proponent, with assistance from NBHTC, Town of Acushnet, Massachusetts Department of Fish and Game Riverways Program and the Buzzards Bay Coalition (BBC).

The DMF is responsible for managing river herring populations in the Commonwealth of Massachusetts. Management efforts include population monitoring, regulating fish passageways between marine and freshwaters and evaluating options for restoring degraded populations and habitats. DMF facilitated the planning, improvement, and installation of fishways, along with biological enhancement and monitoring.

Restoration activities for the Acushnet River occurred in two phases. The first phase included the design and construction of fishways at the three existing dams to enhance passage. The second phase focused on monitoring diadromous species abundance prior, and in response, to fishway improvements. Fish passage improvements occurred at the Acushnet Sawmill Dam, Hamlin Street Dam, and the New Bedford Reservoir Dam. While each obstruction was passable under average flow conditions, overall passage conditions were considered a limitation on river herring population productivity (Reback et al 2004).

Fishways were designed and constructed for each site. In 2002 the US Fish and Wildlife Service (USFWS), with assistance from DMF, installed a Denil fishway at the New Bedford Reservoir site (**Figure 2**). Nature-like fishways were designed for both the Acushnet Sawmill and Hamlin

Figure 2. The New Bedford Reservoir ladder entrance (left) and exit (right), constructed in 2002.

Street sites, incorporating the existing structures into the fishways. Construction for the Acushnet Sawmill fish ladder began in July 2007 by replacing the existing concrete weir-pool ladder with a flow constrictor-step pool structure (**Figure 3**). A similar design was implemented at the Hamlin Street site with construction of a graduated stone-step weir system (**Figure 4**). In anticipation of fish passage improvements, DMF began stocking alewives in the New Bedford Reservoir starting in 1999. Stocking continued until 2005 to augment the remnant population. Approximately 22,000 adult spawning alewives were transferred to the New Bedford Reservoir during this six-year period (Sheppard et al 2014).

Figure 3. The Acushnet Sawmill Dam and ladder prior to reconstruction in 2004 (left) and post-construction in 2007 (right).

Figure 4. The Hamlin Street fish ladder, reconstructed in 2007.

Phase two involved monitoring of the adult river herring spawning run and was initiated by DMF in 2005. The monitoring was implemented to gather baseline data on the existing population prior to the construction of the Sawmill and Hamlin Street fishways and to evaluate the response of the river herring population to fish passage improvements. Census counts (**Figure 5**) were collected prior to and after fish passage improvements (2005 – 2018) using a combination of census and electronic counting. Pre-construction phase monitoring was conducted between 2005 and 2007, using a locking box trap installed at the New Bedford Reservoir ladder exit. Results indicated that the number of adults returning was generally low (averaging less than 400 fish annually) during this period. Post-construction monitoring commenced in the spring of 2008 using the trap in combination with a Smith-Root 1101 electronic counter in which a total of 977 river herring entered the reservoir. Census monitoring (2009 – 2018) continued to show an overall increasing trend in adult river herring returning to spawn in the reservoir (Sheppard and Block 2013; Sheppard et al. 2014; Sheppard 2018).

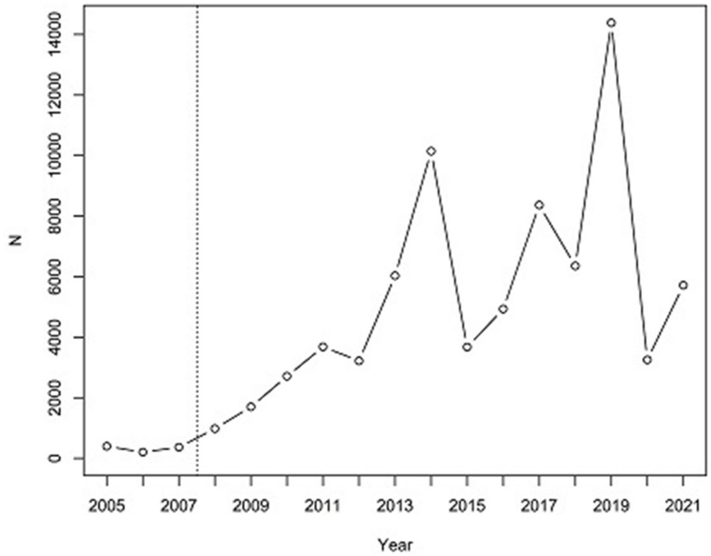

Figure 5. River herring spawning run count for the Acushnet River, 2005 – 2021. The dashed vertical line represents the reconstruction of the Acushnet Sawmill and Hamlin Street fish ladders (summer, 2007). Counts conducted from 2008 – 2021 indicate counts in response to fish passage improvements (counts conducted post-construction).

In 2019, DMF ceased use of the box trap and continued to monitor the Acushnet River river herring population with the electronic counter in partnership with the BBC. The DMF also initiated a two-year river herring spawning and nursery habitat assessment in the Acushnet River watershed during 2019.

Water Supply Management. During the mid-19th century, the Acushnet River Watershed was the water supply for the City of New Bedford. It remained so until 1899 when the city acquired Little Quittacas Pond, part of the Assawompset Pond Complex (Barnes n.d.). Several mills built along the river also used it as a water source, the most prominent being the Acushnet Sawmill, Whelden Cotton Mill, and Whites Factory. During this period, the Town of Acushnet was mostly woodlands and farmland. In 1875, there were 142 farms covering 8,041 acres, most of which were drawing water from the watershed (Howland 1883). Presently, the Acushnet River is primarily used for passive recreation, recreational fishing and agriculture. In 2009, cranberry bogs were reported to use 429.6 acres in the Acushnet River sub watershed (MassDEP 2009). In the northern most part of Acushnet, cranberry bogs abut the North Basin of the New Bedford Reservoir. There are also several farms situated along the river, one of the largest of which is Keith's Farm. Located in the southern end of the New Bedford Reservoir, the farm seasonally draws from the Acushnet River.

The Acushnet River Watershed is densely populated, and the lower portion of the river is heavily urbanized. In 2010 there were 3,343 households within the watershed on septic systems comprising approximately 19% of properties in the watershed, with an average water use of 142 gallons per day (gpd) and 14,009 properties on sewer (81% of properties) with an average water use of 236 gpd (Costa 2010). There are thirteen active combined sewer overflows (CSOs) in the City of New Bedford that discharge into the New Bedford Harbor. Considerable effort has been made to limit or modify CSO structures, so they are more likely to discharge under higher flow conditions (NBHTC 1998; Costa 2010). The Fairhaven Wastewater Treatment Facility also discharges into the New Bedford Harbor (NPDES permit MA0100765).

According to the Massachusetts Surface Water Quality Standards (SWQS), the New Bedford Reservoir and upper Acushnet River are classified as Class B water bodies. These are waters which are designated for fish, aquatic life and wildlife, primary and secondary recreation, and agricultural uses. Where designated in 314 CMR 4.06(1)(d)6. and (6)(b) this system can also be used as a "Treated Water Supply", waters which are suitable for public supply with appropriate treatment. The lower portion of the Acushnet River along with the New Bedford Harbor are classified as Class SB water bodies where shellfish harvesting may be permitted with depuration (Restricted Shellfishing Areas, MassDEP 2021a).

Assessment QAPP. The assessment of river herring spawning and nursery habitat by DMF aids in the management and restoration of diadromous fish resources and the evaluation of water bodies by the Massachusetts Department of Environmental Protection (MassDEP), as required by Section 305(b) of the Clean Water Act (CWA). The river herring habitat assessment follows a DMF and MassDEP-approved Quality Assurance and Program Plan (QAPP) on water quality measurements for diadromous fish monitoring (Chase et al. 2020). MassDEP will only accept data for 305(b) watershed assessments that were collected under an approved QAPP. The 305(b) process evaluates the capacity of waters to support designated uses as defined by the SWQS. Waterbodies are assessed as *Support*, *Impaired*, or *Unassessed* for specific designated uses as part of the MassDEP 305(b) reporting requirements. Degraded waters that require a total maximum daily load (TMDL) estimate for specified pollutants are placed on the 303(d) Category 5 list. Starting in 2002, MassDEP combined reporting requirements for the 303(d) list and 305(b) report into an Integrated List of Waters for Massachusetts (MassDEP 2021b). The QAPP relates diadromous fish life history to water quality criteria, allowing the contribution of data to the 305(b) process for assessing the designated use of Aquatic Life.

MassDEP Water Quality Status. The Acushnet River Watershed was last assessed by MassDEP in 2020 (MassDEP 2021b). The assessment results are used in the MassDEP Integrated List of Waters (MassDEP 2021b) which lists the Acushnet River as Category 5 Waters (water requiring a TMDL). The river is split in three separate segments. Segment MA95-31 (The New Bedford Reservoir to the Hamlin Street culvert) and MA95-32 (Hamlin Street culvert to Main Street culvert) require TMDLs due to DO impairments, and the presence of Enterococcus, *Escherichia Coli* (*E. coli*), fecal coliforms, and other nutrients. There are significant impairments at Segment MA95-33 (Main Street culvert to Coggeshall Street) such as trash, color, odor, gas and oil, low DO, total nitrogen, eutrophication, and the presence of polychlorinated byphenyls (PCBs), *E. coli*, fecal coliforms, and other nutrients.

Methods

The river herring habitat assessment methodology is fully outlined in DMF's QAPP (Chase et al. 2020). The assessment relates river herring life history characteristics to three categories of reference conditions: Massachusetts SWQS (Chase and Reusch 2022); EPA nutrient criteria recommendations (EPA 2001); and the Best Professional Judgment (BPJ) of DMF biologists (Chase et al. 2020). Monthly assessment trips were made to the New Bedford Reservoir from May to September, targeting the second or third week of each month. This period was used for sampling because it is when (1) water quality can exhibit the most impairment; and (2) adult river herring spawning and juvenile occupation of the water bodies would occur, if passage were available. River herring spawning begins in April, but the month is not sampled by design due to the typical lack of impairment during early spring. The New Bedford Reservoir was sampled in 2019 and 2020. The assessment criteria for all parameters and assessment results for the lower and upper reservoir are summarized in **Table 1** and **Table 2**, respectively. Station specifications are listed in **Table A.1** in the **Appendix**, as are summary statistics for each station.

A HOBO U22 water temperature logger was placed at the exit of the New Bedford Reservoir fish ladder. The logger was set to record temperature continuously for one-hour intervals. The data records water temperature during fish migrations. Mean depths were recorded each month to evaluate fish passage efficiency at the outlet to the river (NBR0). Areas considered potentially problematic for passage were identified and visited weekly during the spawning period (April – June) and monthly during the nursery period (July – September). Water quality measurements were measured at sampling stations with a YSI ProDSS multi-sensor water chemistry sonde at surface (0.3 m depth), at bottom (0.5 m from bottom), and at 1 m intervals at deeper stations. The following basic water quality parameters were measured: water temperature, dissolved oxygen (DO), pH, specific conductivity, turbidity, and Secchi disk depth. Water temperature, DO, and pH were related to SWQS criteria. Monthly total phosphorus (TP) and total nitrogen (TN) samples were collected at each pond and analyzed at a QAPP approved laboratory (Lakes Lay Monitoring Laboratory (TP) and the Water Quality Analysis Laboratory (TN), University of New Hampshire, Durham, NH).

The TP, TN, and Secchi disk data were related to EPA nutrient criteria recommendations. The TP and Secchi disk data were also applied to the Carlson Trophic State Index (TSI) (Carlson 1977), a commonly used classification that relates water chemistry indicators to an expected range of trophic conditions. Finally, QAPP reference conditions for Fish Passage, Stream Flow, and Eutrophication were assigned with each visit based on BPJ. The sampling data were combined for the two seasons to produce a classification (*Suitable* or *Impaired*) for each parameter. Criteria excursions of ≤10% or N = 1 (when N = 5-9) for parameter measurements at transect stations are acceptable for a *Suitable* classification. Criteria excursions >10% of transect samples result in an *Impaired* classification (when N ≥ 10).

Assessment Stations. Transect stations were established from reservoir outlet to reservoir inlet. There are six stations that represent shallow, medium, and deep strata as described above based on lake bathymetry. Additionally, off-transect stations were visited to gain information on (1) other shallow locations that could serve as river herring spawning habitat; and (2) fish passage and flow conditions at potential migration limitations in the watershed. These off-transect stations were not used for water quality classifications but provided supplemental information on the suitability of the watershed to support river herring life history. The New Bedford Reservoir

Table 1. Summary of river herring habitat assessment criteria for the Lower New Bedford Reservoir, 2019-2020.

Parameter	Units	Sample (No.)	Sample (Mean)	Acceptable Criteria	Exceedance (N)	Exceedance (%)	Classification
Temp. (spawning)	°C	43	20.06	≤ 26.0	1	2.3	*Suitable*
Temp. (nursery)	°C	59	23.09	≤ 28.3	1	1.7	*Suitable*
DO	mg/L	92	5.97	≥ 5.0	29	31.5	*Impaired*
pH	SU	102	6.46	≥ 6.5 to ≤ 8.3	57	55.9	*Impaired*
Secchi	m	30	1.18	≥ 2.0	30	100.0	*Impaired*
TN	mg/L	10	0.521	≤ 0.32	9	90.0	*Impaired*
TP	µg/L	9	28.8	≤ 8.0	9	100.0	*Impaired*
Eutrophication	BPJ	10			10	100.0	*Impaired*
Fish Passage	BPJ	30			17	56.7	*Impaired*
Stream Flow	BPJ	30			15	50.0	*Impaired*

Notes: *Impaired* classifications result from exceedances of >10% or >1 (when N<10) for measurements at transect stations (NBR2-4). Fish Passage and Stream Flow classifications are based on stations AR1 through AR6.

Table 2. Summary of river herring habitat assessment criteria for the Upper New Bedford Reservoir, 2019-2020.

Parameter	Units	Sample (No.)	Sample (Mean)	Acceptable Criteria	Exceedance (N)	Exceedance (%)	Classification
Temp. (spawning)	°C	24	18.94	≤ 26.0	0	0.0	*Suitable*
Temp. (nursery)	°C	36	21.21	≤ 28.3	0	0.0	*Suitable*
DO	mg/L	60	3.62	≥ 5.0	39	65.0	*Impaired*
pH		60	6.02	≥ 6.5 to ≤ 8.3	50	83.3	*Impaired*
Secchi	m	28	0.90	≥ 2.0	28	100.0	*Impaired*
TN	mg/L	18	0.549	≤ 0.32	17	94.4	*Impaired*
TP	µg/L	18	30.6	≤ 8.0	18	100.0	*Impaired*
Eutrophication	BPJ	10			10	100.0	*Impaired*
Fish Passage	BPJ	30			0	0.0	*Suitable*
Stream Flow	BPJ	30			0	0.0	*Suitable*

Notes: *Impaired* classifications result from exceedances of >10% or >1 (when N<10) for measurements at transect stations (NBR5, 7-8). Fish Passage and Stream Flow classifications are based on station AR7.

assessment classification was based on stations NBR2-4, 5,7-8 (**Figure 6** and **Figure 7**, respectively).

Nutrient Criteria. The EPA nutrient criteria recommendations are based on the percentile distribution of TN and TP measurements in a designated Ecoregion. The nutrient criteria were derived by calculating a 25th percentile for each of the four seasons with pooled data from all available sampling stations in an Ecoregion. A median is then calculated from the four seasonal 25th percentiles that represents a threshold between minimally impacted and impaired habitats. The QAPP adopts this approach by relating nutrient measurements to the EPA's 25th percentile median for the Northeast Coastal Zone subecoregion #59, resulting in criteria of 8.0 ug/L for TP and 0.32 mg/L for TN. (EPA 2001). The thresholds were accepted in the QAPP, while recognizing they are relatively low for urban watersheds. With additional data collected over time, the QAPP will use the EPA approach to develop TN and TP criteria specific to river herring spawning and nursery habitat for coastal regions of Massachusetts.

Figure 6. The Lower New Bedford Reservoir (south basin) showing locations of the outlet (NBR0, yellow marker), transect (blue markers) and survey (green markers) sampling stations for habitat and water quality monitoring.

Results

Massachusetts SWQS Criteria

Water chemistry monitoring was conducted primarily in the two main basins of the New Bedford Reservoir as well as one station in East Pond (**Figure 7**). Three transect stations and four survey stations were sampled in each basin. Summary statistics for each station are presented in **Table A.2 – 4** in the lower basin and **Table A.5 – 7** in the upper basin.

Water Temperature: The metabolic and reproductive processes of ectothermic fish are directly influenced by water temperature, which is also an important factor for fish migrations and lake stratification and productivity. Temperature thresholds for fish typically target critical warming ranges when acute impacts occur to early life stages. The QAPP adopted the MassDEP water temperature criterion of ≤28.3°C as *Suitable* to support Aquatic Life for the nursery period of July-September and ≤26.0 °C from Greene et al. (2009) for the spawning period of May-June.

Figure 7. The Upper New Bedford Reservoir (north basin) and East Pond (NBR14) showing locations of transect (blue markers) and survey (green markers) sampling stations for habitat and water quality monitoring.

Lower New Bedford Reservoir. Water temperature measurements in the Lower New Bedford Reservoir recorded one exceedance for the spawning period (2.3%) and one exceedance for the nursery period (1.7%) resulting in a *Suitable* classification for both periods (**Figure 8A**). The exceedance for the spawning period occurred June 18, 2020, however this was after adult herring were last detected at the counting station on May 28th. The exceedance during the nursery period occurred on August 11, 2020. Bottom temperatures at deep station NBR3 were stable, between 17°C and 19°C at a depth of 4.1 m.

Upper New Bedford Reservoir. No water temperature measurements in the Upper New Bedford Reservoir exceeded the spawning or nursery period thresholds, resulting in a *Suitable* classification (**Figure 9A**). Deep station NBR5 had a maximum depth of 2.7 m with bottom temperatures ranging between 16 and 22°C.

Water pH. The acidification of fresh water is a widely recognized concern for fish populations. Low pH can increase metal toxicity and disrupt ion regulation in gill tissues. The QAPP adopted the MassDEP criterion of ≥6.5 to ≤8.3 for pH as *Suitable* to support Aquatic Life. Water pH outside of this range can threaten the growth and development of fish eggs and larvae, while highly acidic (<5.0 pH) and alkaline waters (>9.0 pH) in some cases can cause lethal effects (NAS 1972; Haines and Johnson 1982). Environmental acidification has been linked to the elimination of anadromous populations and chronic poor recruitment of anadromous fish in North America (Klauda and Palmer 1987; Hesthagen and Hansen 1991).

Lower New Bedford Reservoir. Water pH at the Lower New Bedford Reservoir was relatively stable and slightly acidic with an average pH of 6.46 (**Figure 8B**). There were 102 transect measurements taken, 56% of which were <6.5, resulting in an *Impaired* classification for pH.

Upper New Bedford Reservoir. Water pH at the Upper New Bedford Reservoir was acidic, with 50 of the 60 transect measurements exceeding pH criteria (**Figure 9B**). This resulted in an *Impaired* classification for pH with an exceedance rate of 83%. The average water pH for the upper reservoir was 6.02 for all transect stations during the two-year assessment. The highest pH measurement was 8.56 recorded on June 18, 2020, at NBR14, a non-transect survey station located in the east impoundment. This high pH level can often be a response to elevated photosynthesis due to nutrient enrichment (*see Shallow Off-Transect Stations*).

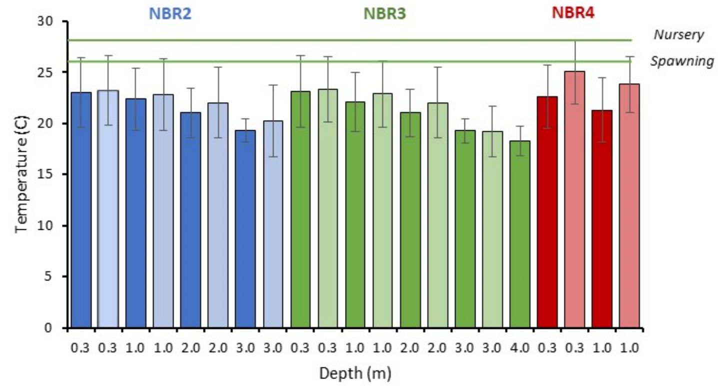

Figure 8A. Water temperature (°C) measurements taken at the Lower New Bedford Reservoir, 2019-2020. Station averages are presented (+/- 2SE) for 2019 (dark bars) and 2020 (light bars). Five samples were made at each depth interval per year.

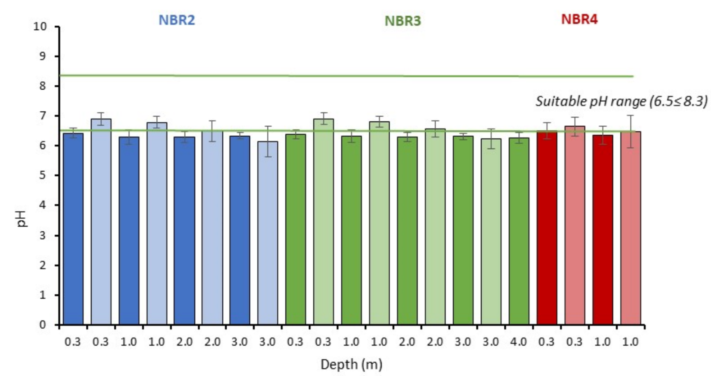

Figure 8B. pH measurements taken at the Lower New Bedford Reservoir, 2019-2020. Station averages are shown (+/- 2 SE) for 2019 (dark bars) and 2020 (light bars). Five samples were made at each depth interval per year.

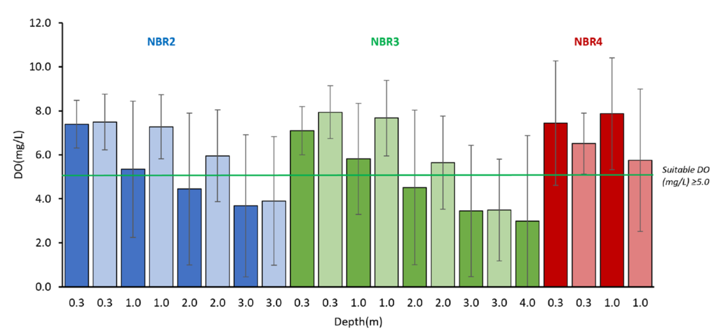

Figure 8C. DO (mg/L) measurements taken at the Lower New Bedford Reservoir, 2019-2020. Station averages are shown (+/- 2 SE) for 2019 (dark bars) and 2020 (light bars). Five samples were made at each depth per year.

Dissolved Oxygen. Adequate DO concentrations are essential for the respiration and metabolism of aquatic life. Water DO is highly influenced by water temperature, as well as chemical and biological processes that influence seasonal and diurnal cycles. The QAPP adopted the MassDEP criterion of ≥5.0 mg/L for DO as *Suitable* to support Aquatic Life.

Lower New Bedford Reservoir. The Lower New Bedford Reservoir was classified as *Impaired* with 32% of the measurements exceeding the DO criterion (**Figure 8C**). Three stations were measured for DO, NBR-2, 3 and 4. At transect station NBR2, a mid-depth stratum, DO exceedances occurred for 20% of 1.0 m depths, and for 50% and 60% at the 2.0 and 3.0 m depths, respectively (**Table A.2**). Station NBR3, a deep strata station, no DO exceedances occurred at the surface interval; however, exceedances increased with increasing depth with 30% at 1.0 m depths, 40% at 2.0 m and 64% at 3.0 m or greater (**Table A.3**). DO Exceedances at station NBR4 (**Table A.4**), a shallow depth stratum, were observed at the surface (40%) and 1 m depths (38%). Almost all exceedances for the three stations were recorded during the summer months. All three transect stations in the lower reservoir failed to meet the DO criterion despite excluding bottom measurements due to a QAPP DO exemption for stratified conditions. Overall, DO sampling during the assessment demonstrates persistent stratification in the lower water column of the lower reservoir for the summer months.

Upper New Bedford Reservoir. Water DO in the Upper New Bedford Reservoir was found to be Impaired, with 65% of the measurements exceeding the DO threshold (**Figure 9C**). Three stations were measured in this basin, NBR-5 7 and 8. Station NBR5, a deep strata station, exceeded 40% of all measurements at the surface and 70% of all measurements at 1.0 and 2.0 m depths (**Table A.5**). At NBR7, DO exceedances occurred in 40% of surface measurements and 70% at 1.0 m depths (**Table A.6**). At NBR8, DO exceeded 60% of the DO threshold in all surface measurements (**Table A.7**). DO measurements at all stations that met the QAPP criterion were recorded in May. Similar to the Lower Reservoir, most DO exceedance measurements were recorded during the summer months, as hypoxia occurred in the lower water column throughout the basin. However, acceptable DO measurements were taken at NBR5 and NBR7 in the month of September in both sampling years. Similar to the lower reservoir, all three transect stations in the upper reservoir failed to meet the DO criterion; however, with higher exceedance rates.

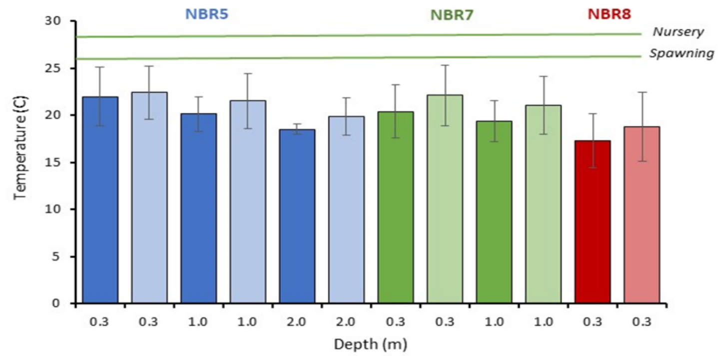

Figure 9A. Water temperature measurements taken at the Upper New Bedford Reservoir, 2019-2020. Station averages are shown (+/- 2 SE) for 2019 (dark bars) and 2020 (light bars). Five samples were made at each depth per year.

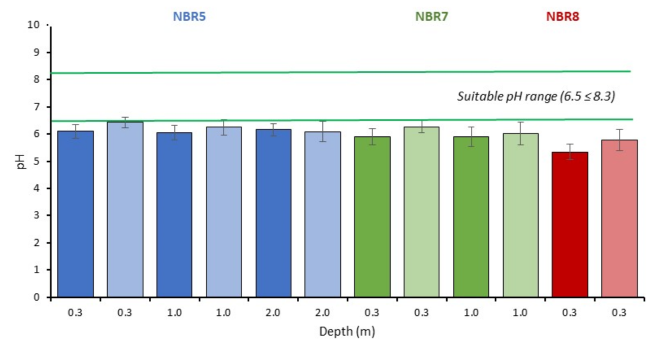

Figure 9B. pH measurements taken at the Upper New Bedford Reservoir, 2019-2020. Station averages are shown (+/- 2 SE) for 2019 (dark bars) and 2020 (light bars). Five samples were made at each depth per year.

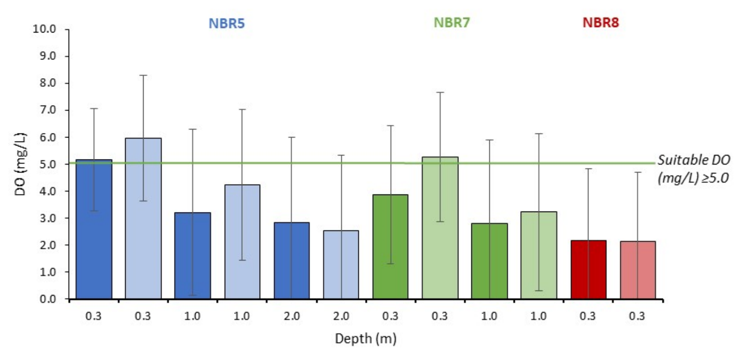

Figure 9C. DO (mg/L) measurements taken at the Upper New Bedford Reservoir, 2019-2020. Station averages are shown (+/- 2 SE) for 2019 (dark bars) and 2020 (light bars). Five samples were made at each depth per year.

Nutrients. Total nitrogen and phosphorus are essential for plant metabolism and indicators of trophic status in water bodies. The QAPP adopted the EPA nutrient criteria of <0.32 mg/L for TN and <8.0 ug/L for TP as *Suitable* to support Aquatic Life.

Lower New Bedford Reservoir. Monthly surface water samples of TN and TP were collected at NBR2 in the lower reservoir. Almost all measurements exceeded the nutrient criteria, resulting in an *Impaired* classification. A total of 10 TN samples and 9 TP samples were collected. For the TN samples (**Figure 10**), 90% exceeded acceptable levels and 100% of the TP samples exceeded the nutrient criteria (**Figure 11**). Average nutrient measurements at NBR2 were 0.521 mg/L TN and 28.8 ug/L TP.

Upper New Bedford Reservoir. Monthly surface samples of TN and TP were collected at NBR7 and NBR8. These samples were pooled for both stations with an exceedance of 94% (TN) and 100% (TP), resulting in an *Impaired* classification for TN and TP (**Figure 10** and **Figure 11**, respectively). At station NBR7, 8 TN and all TP samples exceeded criteria. The average TN was 0.503 mg/L and average TP was 31.5 ug/L (**Table A.6**). At station NBR8, all 8 samples exceeded the nutrient threshold. TN averaged 0.606 mg/L and TP 29.52 ug/L (**Table A.7**).

Secchi Disk. Secchi disk is an easily measured proxy for the transparency of water to light. There is little information that directly links Secchi disk depth to river herring life history, although it is widely accepted as an indicator of water quality. The EPA Secchi disk criterion of ≥4.9 m for subecoregion #59 (Northeast Coastal) is higher than water clarity typically seen in Massachusetts coastal drainages, therefore the criterion for subecoregion #84 (Cape Cod) of ≥2.0 m Secchi disk depth was adopted by the QAPP as *Suitable* to support Aquatic Life.

Lower New Bedford Reservoir. None of the 30 Secchi disk measurements in the Lower New Bedford Reservoir were above the criterion, resulting in an *Impaired* classification (**Figure 12**). Visibility decreased slightly in the summer months but increased later in the month of September each year. The maximum Secchi disk measurement in 2019 was recorded in September at 1.49 m at station NBR3. Maximum Secchi disk depth in 2020 was recorded in May at 1.75 m at station NBR2.

Upper New Bedford Reservoir. Like the Lower Reservoir, all 28 Secchi disk measurements in the Upper Reservoir failed to meet the approved criterion, resulting in an

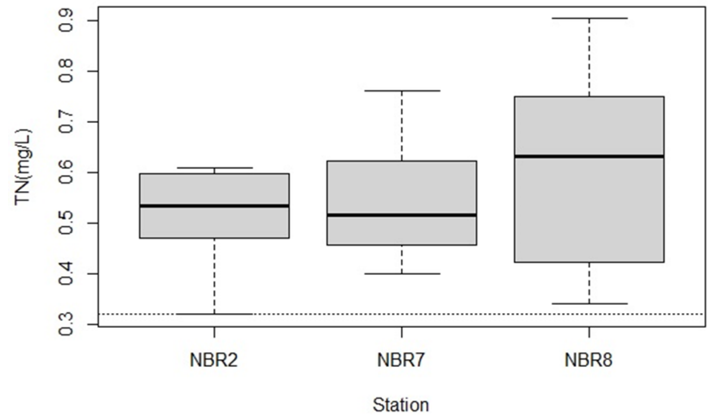

Figure 10. Total nitrogen (TN) measurements taken at the Lower New Bedford Reservoir (NBR2) and Upper New Bedford Reservoir (NBR7, NBR8). The dotted line (0.32 mg/L) represents the US EPA nutrient criteria threshold for subecoregion #59.

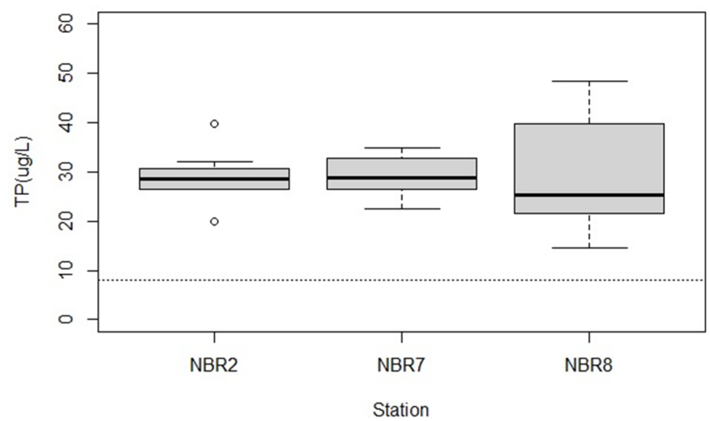

Figure 11. Total phosphorous (TP) measurements taken at the Lower New Bedford Reservoir (NBR2) and Upper New Bedford Reservoir (NBR7, NBR8). The dotted line (8.0 µg/L) represents the US EPA nutrient criteria threshold for subecoregion #59.

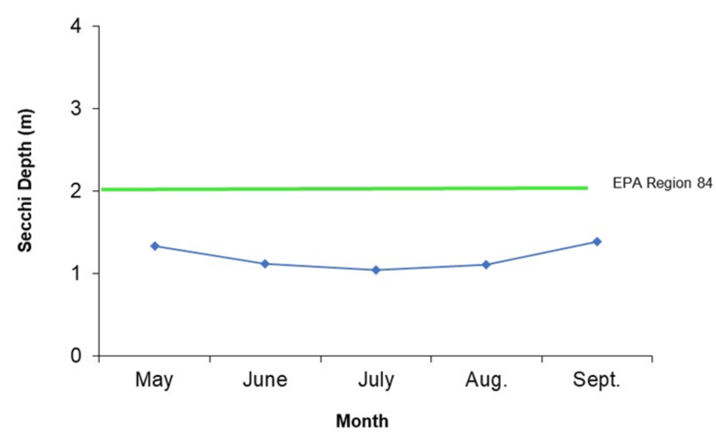

Figure 12. Secchi depth measurements taken at the Lower New Bedford Reservoir, 2019-2020. Average monthly Secchi disk measured at stations NBR2-NBR4. Three samples were targeted each month.

Impaired classification (**Figure 13**). The upper reservoir is the shallower of the two basins, with a maximum depth of 2.7 m. The maximum Secchi disk measurement for 2019 and 2020 was recorded in September at 1.47 m and 1.65 m, respectively.

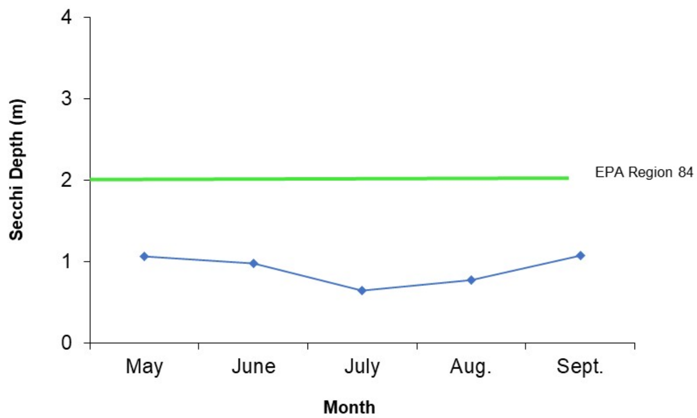

Figure 13. Secchi depth measurements taken at the Upper New Bedford Reservoir, 2019-2020. Average monthly Secchi disk measured at station NBR5, NBR7-NBR8. Three samples were targeted each month.

Best Professional Judgement

Fish Passage. The QAPP provides a process for using Best Professional Judgment (BPJ) to assess the potential of river herring to pass fishways and impediments. With each site visit, the type of impediment is documented and the potential for upstream passage of adult river herring and downstream passage of emigrating adults and juvenile river herring is assessed and classified as *Suitable*, *Impaired*, or *Unsuitable*. Multiple locations were assessed along the Acushnet River for fish passage and each location was classified separately below.

Acushnet River. Fish passage status was assessed at nine stations from the Tarkiln Hill Road bridge to the Lake Street causeway. Locations of the sites are shown in **Figure 1**.

Tarkiln Hill Road crossing (AR1). This station is the outlet to the Upper New Bedford Harbor. It is a bridge crossing that is tidal and deemed *Suitable* for passage, with no limitations identified, even at low tide for all visits throughout the assessment period.

Acushnet Sawmill Park (AR2). This was the site of a former sawmill and degraded weir-pool ladder. A new graduated step-pool ladder was built in 2007 and the surrounding area is now a public park created and owned by the BBC. A total of 24 observations were made during the spawning period and six observations made during the nursery period in the two-year assessment. All classifications for AR2 were *Suitable* except for two *Impaired* in June 2020, and two *Unsuitable* in August/September 2020. This was due to drought conditions, in which low water levels exposed the weirs making the ladder impassable.

Stream crossing under Hamlin Street (AR3). A nature-like fishway constructed in 2007 runs under the Hamlin Street bridge. It was the site of a former sawmill (White's Factory) with ruins still present just downstream of the fishway. Prior to fishway construction, diadromous fish were only able to pass through stone culverts, beneath the road crossing, under certain flow conditions. Twenty-four observations were made during the spawning period of May-June and six observations during the nursery period of July-September. All classifications at AR3 were *Suitable* in 2019, four *Impaired* classifications were assigned in June 2020 as well as in August. Observations in September 2020 were deemed *Unsuitable* as the weirs were dry due to dewatering from drought conditions.

Whelden Cotton Mill Historical Site (WCM). This site wasn't visited until 2020 when the location was encountered during a stream maintenance trip. It is the remains of a historic cotton mill built in 1814. There are three weirs made of stone rubble obstructing passage, two of which are in the main channel and the third in an auxiliary channel. The site was visited once by DMF staff in 2007 to adjust a stone weir to provide passage via a low flow channel. During 2020, the site was observed six times during May-June, and three times during July-September. In May, upstream passage was marginally deemed *Suitable*, as adult river herring could pass but only in the low flow channels on the east and west bank of the first stone weir. In June and July upstream and downstream passage were *Impaired* due to insufficient water depths for upstream and downstream passage. By August and September both weirs were completely dewatered, deeming it *Unsuitable* for passage during juvenile emigration. With 7 of 9 visits classified as *Impaired* or *Unsuitable*, WCM received an overall *Impaired* classification for fish passage.

Pine Hill Farm Dam (AR4). This unlisted low head dam is located on an unnamed dirt road in close proximity to cranberry operations. It was observed 24 times during May-June and six times during July-September. There were 30 observations total; of those 13 were considered *Suitable*, while 13 were *Impaired* and 4 were *Unsuitable*.

This station received an *Impaired* classification due to a 57% exceedance. Of primary concern at this dam is a large stop log board on the upstream face that can present a steep elevation change at lower flows.

Stream crossing under Leonard Street (AR5). Passage consists of a dual box culvert located at Leonard Street. Downstream the channel splits with an auxiliary channel diversion for cranberry bog irrigation. This site was visited 24 times during May-June and six times during July-September. There were 28 classifications of *Suitable* and one each of *Impaired* and *Unsuitable* due to extensive vegetation growth forming an island in the middle of the stream and creating two small narrow channels. Increased vegetation growth constricted channel width during the late spring and summer months, with the channel nearly entirely impassable in August and September of both years. This site was deemed *Impaired* during the nursery period and *Suitable* during the spawning season.

Approach channel to Lower New Bedford Reservoir (AR6). The entrance to the New Bedford Reservoir fish ladder begins at this site. The site was observed 24 times during May-June, and six times during July-September. There were 30 visits, 28 deemed *Suitable* and 2 were *Unsuitable*, in the months of August and September 2020. The impairments were mainly due to a drought which led the farm to board up the ladder exit to maintain surface water levels in the reservoir for irrigation. During this period, downstream passage was not possible through the ladder. This in conjunction with the lack of flow through the main channel prevented downstream passage due to dewatered sections in the channel leading to the fish ladder entrance. Overall, with a 7% exceedance rate, this site was deemed *Suitable* for fish passage.

Lake Street causeway (AR7). This station is a road crossing with a culvert that connects the Lower and Upper Reservoirs. The site was visited 26 times during May-June, and 6 times July-September. All assessments were *Suitable* for passage and no obstructions were observed.

In summary, passage into the Lower New Bedford Reservoir (stations AR1 – AR6 and WCM) was deemed *Impaired* with 57% of all observations classified as *Impaired* or *Unsuitable*. Conditions at Stations AR4 and WCM contributed largely to this classification as they were both deemed *Impaired* due to low flow conditions and nearly impassable obstructions. Passage into the Upper New Bedford Reservoir was classified as *Suitable*, with the only obstruction, AR7, receiving a *Suitable* classification for all assessments.

Stream Flow. Stream flow is a separate classification from fish passage because in some cases, stream flow can influence passage and habitat quality independent of a structural impediment. A common example is a situation where stream flow would be adequate to provide upstream passage for spawning adult river herring or downstream passage of juveniles if an obstruction was not present. In that example, the station would be classified as *Impaired* or *Unsuitable* for fish passage and *Suitable* for stream flow. In other cases, stream flow can be too low to support river herring passage regardless of channel dimensions or the presence of obstructions.

The Acushnet River stream flow was monitored throughout the river herring spawning and juvenile emigration periods. A flow gauge maintained by the MA Division of Ecological Restoration (DER) River Instream Flow Stewards (RIFLS) Program is located at the entrance to the Acushnet Sawmill fish ladder (RIFLS_ID89). Discharge measurements from this site (**Figure 14**) indicate the highest monthly mean flows occurred in March 2019 (76.5 cfs) and April 2020 (60.7 cfs). Low flows also commonly occurred in August and September of both years, ranging from 0 – 10 cfs. There were no major trends in 2019, with most months having a mean discharge near the 10-year time series monthly mean discharge (TSM_{10}). The only exceptions were June and October, during which discharge was 2 times higher (June) and 3 times lower (October) than the TSM_{10}. In summer of 2020, an extensive drought across the region led to impassable conditions at the Acushnet Sawmill ladder. This caused the summer 2020 discharge measurements to be well below the TSM_{10}, ranging from 0-64% of the TSM_{10}.

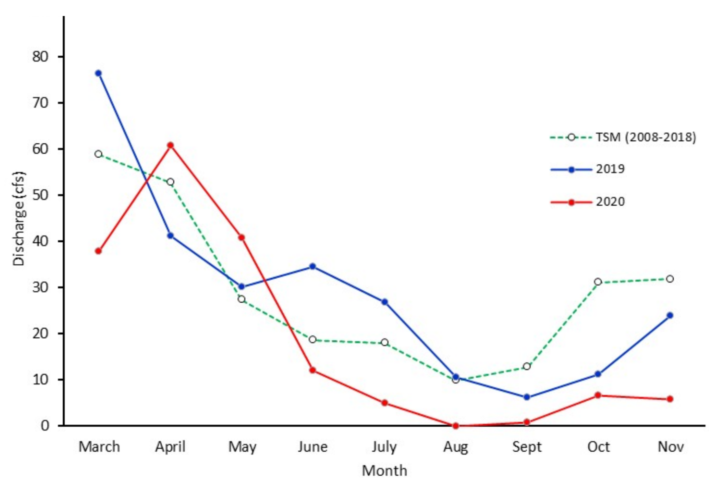

Figure 14. Mean monthly flow readings (cfs) recorded at the Acushnet Sawmill fishway entrance (station AR2; RIFLS_ID89, Mill Road), 2019-2020 and 10-year time series mean (TSM 2008-2018). Source: Massachusetts Division of Ecological Restoration River Instream Flow Stewards Program (RIFLS).

Acushnet Sawmill Park (AR2). Stream flow conditions were deemed *Suitable* for river herring passage at this site. All site visits during the 2019 season were *Suitable*. The 2020 assessment year was similar with the exceptions of June with two *Impaired* classifications and August and September with two *Unsuitable* classifications. Water depth below the fish ladder during the spawning season of May-June ranged from 3 to 18 inches and <1 to 7 inches during the nursery period of July-September.

Stream crossing under Hamlin Street (AR3). This site received a *Suitable* classification for stream passage. Like AR2, all site visits in 2019 were deemed *Suitable* along with most site visits in 2020. Four visits made in June 2020 were classified as *Impaired*, while August and September of 2020 were deemed *Unsuitable*. Water depth measurements were made below the fish ladder ranging from 6 - 18 inches during the spring and <1 - 6 inches in the summer.

Whelden Cotton Mill Historical Site (WCM). This site was not in the 2019 assessment year, yet low flow conditions during the 2020 season were enough to deem this site *Impaired*. Only during the spring spawning season (May) is stream flow high enough, with a maximum depth of 8.5 inches. June and July were both classified as *Impaired*, while August and September were *Unsuitable* with a minimum water depth <1 inch. Flow during this period was running through, and not over, the irregular cobble of this remnant dam. This raised significant concerns for the potential for juvenile river herring to be impinged as they passively move downstream during their summer emigration.

Pine Hill Farm Dam (AR4). Low stream flow was a significant concern for the Pine Hill Farm Dam as documented by 11 site visits classified as *Impaired*, and four visits classified as *Unsuitable*. Late May into June assessments were deemed *Impaired*, and July-September was classified as *Unsuitable*. Water depth ranged from a maximum of 16 inches in the spring to a minimum of <1 inch in late summer.

Stream crossing under Leonard Street (AR5). This site earned a *Suitable* classification for stream flow at each site visit during the monitoring period. Water depth measurements were recorded from a gauge located at the downstream entrance to the culverts. Gauge data at this site (**Figure 15**) shows an average mean depth of 1.38 ft from April-September in 2019 and 1.20 ft in 2020, with a depth range of 0.66 - 1.26 ft. Water depth downstream of the culvert ranged from 11.6 - 20.4 inches during the spawning period and 7.2 - 18 inches during the nursery period.

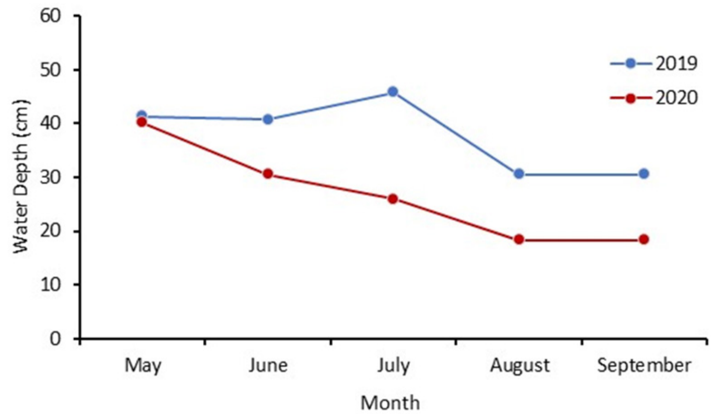

Figure 15. Pond level staff gauge at station AR5, Acushnet River, Acushnet, 2019-2020. The data indicated decreasing stream water surface elevation throughout the assessment period.

Approach channel to the New Bedford Reservoir (AR6). This site was classified as *Suitable*. All visits made in 2019 were deemed *Suitable*, and only two visits in August and September 2020 were deemed *Unsuitable*. Water depth was measured at the entrance to the fish ladder. Depth ranged from 8.5 - 15 inches during the spawning period, and <1 - 13.5 inches during juvenile emigration. Minimal flows in August and September 2020 were due to boarding the ladder exit to retain water in the reservoir for irrigation.

Southern outlet of New Bedford Reservoir (NBR0). Downstream of the lower New Bedford Reservoir outlet is the exit of the Denil fish ladder. Mean water depth at this site indicated a decreasing water depth during juvenile emigration period of the two-year study (**Figure 16**). Despite this, upstream and downstream passage were still deemed *Suitable* for observed stream flow during all assessment trips.

Lake Street causeway (AR7). The culvert at Lake Street conveys flow between the lower and upper basins of the New Bedford Reservoir. This site was visited 26 times during May-June, and 6 times during July-September. Surface water elevations at this site (**Figure 17**) indicated a decreasing water depth during the juvenile emigration period. Despite this, all visits were recorded as *Suitable* for stream flow as the water depth was too deep to measure.

In summary, stream flow for the Acushnet River (from the outlet to the Lower New Bedford Reservoir, stations AR1 – AR6, NR0) was classified as *Impaired*, with 50% of all observations classified as *Impaired* or *Unsuitable*. As with fish passage conditions, stream flow in this system is most affected by two sites: the Whelden Cotton Mill and the Pine Hill Farm Dam. The Upper New Bedford Reservoir (AR7) had a 0% exceedance, classifying it as *Suitable* for stream flow.

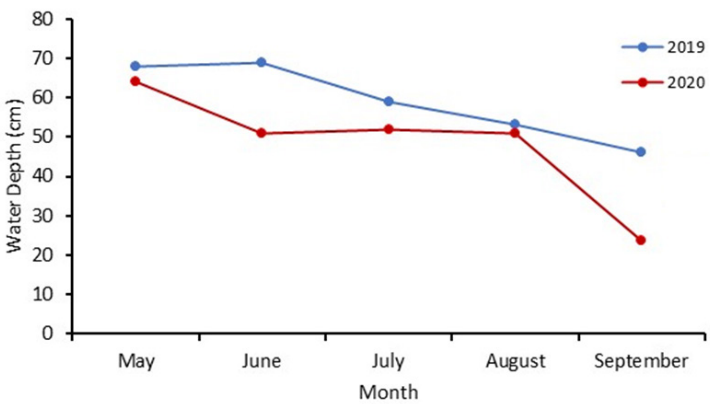

Figure 16. Surface water elevations recorded at the outlet of the Lower New Bedford Reservoir (NBR0), 2019-2020. The data indicated decreasing reservoir water surface elevation throughout the assessment period.

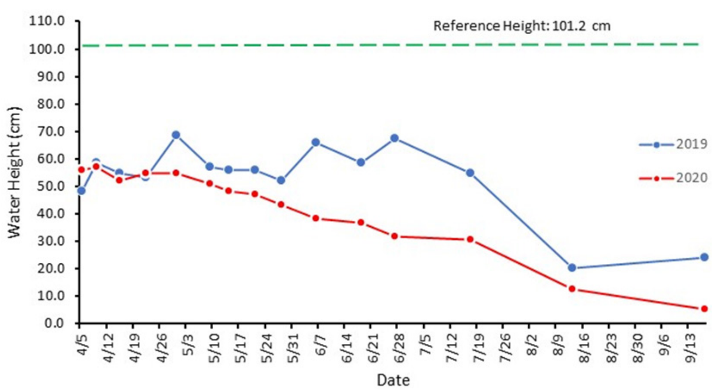

Figure 17. Surface water elevations recorded at the outlet of the Upper New Bedford Reservoir (Lake Street causeway, station AR7), 2019-2020. The data indicated decreasing reservoir water surface elevation throughout the assessment period.

Eutrophication. The QAPP provides a process for using BPJ observations to assess if shallow transect stations are impacted by eutrophication. The indicators used are nutrients, DO, pH, turbidity, Secchi disk, and plant growth in the water column and substrate. When nitrogen and phosphorus data are available, the QAPP classification for eutrophication is based on EPA criteria and not Best Professional Judgment.

The reference conditions for TN and TP were classified as *Impaired*, as almost all TN and TP measurements exceeded the QAPP criteria. Visual evidence of eutrophication was present with low Secchi disk measurements along with a high density of invasive aquatic plants such as Fanwort (*Cabomba caroliniana*) and variable milfoil (*Myriophyllum heterophyllum*; see Aquatic Vegetation). Supersaturated DO readings were recorded infrequently at one off-transect station, NBR14.

Spawning Substrate. River herring deposit demersal, adhesive eggs. After one day, the eggs become non-adhesive and hatch in an additional 3 to 4 days. No spawning substrate classification was provided in the QAPP due to the wide variety of substrate used by river herring and the lack of consensus in the scientific literature on optimal or preferred substrate. Instead, the QAPP provides a qualitative protocol for assessing the percent composition of major substrate cover. To date, habitat monitoring during QAPP assessments supports the view that clean gravel is a better surface for egg survival than fine silt or dense periphyton growth.

Lower New Bedford Reservoir. The observations recorded on substrate conditions in the Lower New Bedford Reservoir were collected at station NBR4. Substrate is comprised primarily of sand (50%) and silt (50%) with low to moderate volumes of detritus in the spring and moderate to heavy volumes of detritus in the summer.

Upper New Bedford Reservoir. Substrate sampling for the Upper New Bedford Reservoir was conducted at station NBR8. Silt (75%) was the primary substrate with sand (25%) making up a smaller portion. Heavy amounts of detritus covering the substrate along with high turbidity levels throughout the assessment period made it difficult to determine plant growth on the substrate and in the water column.

Additional Water Quality Data

Additional water chemistry parameters (turbidity, specific conductivity, and Carlson Trophic State Indices) were collected from transect stations in the two basins of the New Bedford Reservoir. Summary statistics for each parameter are presented in **Table A.2 – 4** in the lower basin and **Table A.5 – 7** in the upper basin.

Turbidity. Turbidity in water is caused by suspended inorganic and organic matter. Concentrations of organic material can be related to productivity and high levels of inorganic particulates that can threaten aquatic life, especially filter feeders. No MassDEP or EPA reference conditions are provided for turbidity in lakes and ponds, therefore the QAPP does not have a turbidity criterion. The EPA does have a turbidity reference condition of ≤1.7 NTU for rivers in subecoregion #59 (EPA 2001).

Lower New Bedford Reservoir. The average turbidity for the lower reservoir for all transect stations was 1.90 NTU (SE = 0.16, N = 100); a level that suggests moderate reduction in water clarity.

Upper New Bedford Reservoir. The average turbidity in the upper reservoir for all transect stations was 1.79 NTU (SE = 0.23, N = 56); a level that suggests moderate reduction in water clarity. Measurements were variable by station, depth, and sampling intervals with higher turbidity observations recorded during the summer months.

Specific Conductivity. Conductivity is proportional to the concentration of major ions in solution. Specific conductivity is a measure of the resistance in a solution to electrical current that has been corrected to the international standard of 25°C. The ionic composition of fresh water is usually dominated by dilute solutions of natural compounds of bicarbonates, carbonates, sulfates, and chlorides. No MassDEP or EPA reference conditions are provided for conductivity, therefore the QAPP does not have a conductivity criterion. High conductance in fresh water can indicate watershed contributions of natural alkaline compounds or ionic contributions from pollution sources.

Lower New Bedford Reservoir. Specific conductivity in the lower reservoir was low with little variance among stations and depth strata. The mean for all transect measurements was 0.151 mS/cm (SE = 0.003, N = 102).

Upper New Bedford Reservoir. Specific conductivity for the upper reservoir was relatively low with little variance among stations and depth strata. The average for all transect measurements was 0.135 mS/cm (SE = 0.004, N = 60).

Carlson Trophic State Index. The Carlson Trophic State Index (TSI) (Carlson 1977) is a commonly used classification that relates water chemistry indicators to an expected range of trophic conditions. The TSI established relationships for TP, chlorophyll *a*, and Secchi disk depth with a score ranging from 0-100. Scores near zero indicate uncommonly nutrient poor and low productivity conditions, while scores near 100 indicate extremely degraded and highly productive conditions. The TSI for each of these parameters relates to a numeric scale of trophic conditions based on the premise that increasing nutrients elevate plant productivity and result in reduced water clarity.

Lower New Bedford Reservoir. The mean Secchi disk measurements for all transect measurements in the lower reservoir resulted in a TSI score of 55.4. The mean TP measurements recorded at NBR2 resulted in a TSI score of 52.1.

Upper New Bedford Reservoir. The mean Secchi disk measurements for all transect measurements in the upper reservoir resulted in a TSI score of 63.6. The mean TP measurements recorded at stations NRB-7 and 8 resulted in a TSI score of 57.2.

These scores are within the index range for eutrophic conditions which include anoxic hypolimnia, macrophyte problems and low water clarity. All these conditions were observed in the lower reservoir during various times throughout the monitoring period. These conditions were also observed in the upper reservoir during the months of June-September.

Shallow Off-Transect Stations. Several shallow off-transect stations were visited to gain information on spawning and nursery habitat conditions at both the Lower and Upper New Bedford Reservoirs.

Lower New Bedford Reservoir. Four shallow off-transect stations were visited in the lower basin: NBR-1, 9, and 11 were sampled once in 2019 and NBR15 was sampled once in 2020. All stations were <2 m in depth and had similar substrate characteristics comprised mostly of sand and silt, with low to moderate densities of vascular plants. There were no exceedances in water temperature or DO at any stations, however a few exceedances in pH were recorded.

Upper New Bedford Reservoir. There were five shallow off-transect stations visited in the upper basin: NBR-6, 10, 12, 13 and 14. Station NBR14 is located in a separate impoundment called East Pond (**Figure 7**). Stations NBR-6 and 14 were sampled twice during the assessment, while the other three stations were sampled once. Maximum depth at stations NBR-6, 12 and 13 was ≤1 m, while stations 10 and 14 had a maximum depth of <2 m. Transect stations exhibited similar substrate characteristics which were mainly comprised of sand and silt along with heavy volumes of detritus. Variable milfoil along with other vascular plants were observed in moderate to heavy concentrations at each station. Water quality exceedances were recorded for pH and DO at all off-transect sites except NBR13. All other stations were sampled when plant growth began to increase. Station NBR14, East Pond, recorded high DO readings (>125% saturation) on June 18th, 2020. DO supersaturation along with elevated pH readings (>8.3) and moderate (>25%) aquatic macrophyte coverage are indicators of nutrient enrichment. Water chemistry at NBR14 was within acceptable QAPP parameters again when sampled on September 15, 2020.

QA/QC Summary. Field and laboratory measurements conducted for the habitat assessment were guided by sampling protocols and data quality objectives from the project's QAPP (Chase et al. 2020), which relies on parameter-based precision and accuracy indicators. Data was classified as *Final*, *Conditional*, or *Censored* based on the agreement of precision and accuracy checks to QAPP criteria. All laboratory calibration and laboratory and field precision checks for 2019-2020 were acceptable, with the exception of several turbidity and DO measurements that exceeded warning limits due to low-values. One TN and TP sample collected at NBR8 on August 11, 2020, and two TP samples (sample and replicate) from September 15, 2020, were *Censored* for exceeding the mean of all TN and TP samples by 3 SD and for sample location concerns. These samples were collected at the outlet of a cranberry farm at the northern end of the upper reservoir east of the Keene River outlet due to heavy plant densities on the surface and water column which prevented access to NBR8. A total of six turbidity measurements were determined to be outliers and *Censored* for exceeding the mean of all turbidity measurements by 3 SD. A common cause of such outliers is debris obstruction of the turbidity optical sensor.

Diadromous Fish Observations

Funding by the NOAA Office of Habitat Restoration and the New Bedford Harbor Trustees Council and in collaboration with the BBC allowed for continued census monitoring of adult river herring entering the New Bedford Reservoir to spawn during the two-year assessment. In 2019, a total of 14,385 river herring were estimated to pass through the counter, entering the Lower New Bedford Reservoir (Sheppard 2019; **Figure 5**). The overall count is an increase from 2018 and a time series high since monitoring began in 2005. During the spring of 2019, the run's peak was observed between April 1 and April 25.

During the 2020 season, the run count decreased sharply, with an estimated total of 3,254 river herring entering the New Bedford Reservoir (Sheppard 2020). The peak of the run was observed from April 8-17, with a second smaller peak between May 3-6.

River herring observations were also made during fish passage evaluations. Approximately 6 adult herring were observed at AR3 in April 2020. In April 2019, high flow at AR4 was observed to impede adult herring attempting to pass upstream above the weir. Similar impedance to herring passage at AR4 was observed in May 2019 and 2020; however, in these cases it was due to steep water elevation change and air pockets at the weir. Fish passage assessment at the Whelden Cotton Mill site in June 2020 observed roughly 50 juvenile herring successfully passing downstream. However later visits in July-September determined passage was *Unsuitable* due to low water levels resulting in dewatering.

Although no eels were observed during the assessment period, monitoring conducted by DMF between 2005 – 2013 (with funding provided by the NBHTC) examined changes in juvenile eel (elver) abundance prior to and after fish passage improvements at the Sawmill and Hamlin Street dams in 2007. Monitoring was conducted using Sheldon box traps located at the entrance to the Sawmill fish ladder (AR2) and at the entrance to the New Bedford Reservoir fish ladder (AR6). Prior to the fish passage improvements (2005 – 2007), elver abundance declined, then increased after the improvements were made (Sheppard and Block 2013). In addition, post-construction monitoring indicated higher proportions of young-of-the-year (YOY) to age-1+ elvers were present at the New Bedford Reservoir fish ladder (Sheppard et al. 2014). The results indicate that the fish passage improvements also improved access for elvers into the upper watershed. Elver monitoring was discontinued in 2014 when the BBC purchased and restored the Sawmill property including re-channeling the stream downstream of the fish ladder which prevented installing the elver trap.

Aquatic Vegetation

Native and non-native plant species were identified and documented in both basins of the New Bedford Reservoir throughout the assessment period. In the lower reservoir, vascular plants comprised 10-20% of the substrate during May-June. Plant coverage increased significantly at NBR4 during the months of August and September

(80-100%). Variable milfoil was present and increased in volume throughout the summer, with the die off from milfoil contributing to increasing substrate coverage of detritus in September. Fanwort was present at the outlet (NBR0) in June increasing in density throughout the summer; however, it was determined to not disrupt downstream passage. Native whitewater lilies (*Nymhaea odorata*), yellow water lilies (*Nuphar variegatum*), common bladderwort (*Utricularia vulgaris*), Richardson's pondweed (*Potamogeton richardsonii*) and Robbins pondweed (*P. robbinsii*) were also observed during the two-year assessment.

In the upper reservoir, vascular plant coverage was high in May-June (70-80%) and increased to 90-100% in the summer months. Vascular plants were comprised primarily of white and yellow water lilies. Low densities of purple pickerel weed (*Pontederia sp.*) and moderate densities of variable milfoil and watermeal (*Wolffia sp.*) were observed in the spring and increased to high concentrations in the summer months. Common bladderwort, water shield (*Brasenia schreberi*), and smartweed (*Polygonum sp.*) were also observed during the two-year assessment.

Wildlife Observations

The New Bedford Reservoir is a highly active area for waterfowl. Mute swans (*Cygnus olor*) were observed throughout the assessment in the lower and upper basins and East Pond. Canada geese (*Branta canadensis*) were present in the lower reservoir and the adjacent farm during the summer months. Up to 4 great blue herons (*Ardea herodias*) were observed during the assessment, often at the fishway entrance to prey on migrating adult river herring. Osprey (*Pandion haliaetus*) were observed during the spawning migration preying upon aggregating adults. A pair of redtail hawks (*Buteo jamaicensis*) were observed intermittently during the assessment.

Conclusion

The Acushnet River habitat assessment evaluated the quality of available habitat for river herring spawning and juvenile rearing as well as the passage conditions for the spring adult migration and later juvenile emigration. With 220 acres of available spawning habitat at the New Bedford Reservoir and improvements to the Sawmill and Hamlin Street dams, an increase in the river herring population was anticipated. However, abundance monitoring since 2008 has indicated only modest increases post-restoration. This assessment has identified several factors that could be limiting production, such as low dissolved oxygen and extensive hypoxia in the New Bedford Reservoir, the high abundance of aquatic vegetation (particularly invasive plants), anthropogenic manipulations of flow as well as impaired passage conditions for juvenile river herring emigration during the summer months. The interaction of low flow and physical limitations of debris accumulation and vegetation overgrowth in the river channel between the reservoir (AR6) and Hamlin Street (AR3) was identified as a significant concern for young-of-year river herring recruitment. The sites of the Pine Hill Farm Dam (AR4) and the Whelden Cotton Mill (WCM) were also identified as specific physical barriers for juvenile emigration at low flows. All the low flow concerns were amplified by the drought that occurred in this region in 2020.

Run count monitoring during this assessment and in prior years suggests that river herring spawning occurs earlier, March-May, when conditions are more favorable. Spawning conditions appear to be favorable in early spring but degrade in the latter part of spring and summer. Exceedances in pH and dissolved oxygen were observed at most sampling locations throughout the assessment. In the lower New Bedford Reservoir, surface pH and DO readings were generally within acceptable ranges. DO levels degraded from June into August, and generally recovered in September. Exceedances in pH were recorded in late spring and summer of 2019, improving in 2020 at most sampling locations. In the upper New Bedford Reservoir DO measurements exceeded acceptable limits from June through September. DO data collected during this assessment indicates that an expansive hypolimnion contributes to low DO concentrations throughout the reservoir. The TN, TP, and TSI data also support the collective observations of eutrophic impacts in both reservoir basins. The proliferation and life cycle of the abundant invasive variable milfoil and fanwort, along with possible nutrient inputs and water manipulations from the surrounding agriculture and golf course may be contributing factors to these eutrophic conditions.

Overall, significant limitations were recorded and observed that may reduce the natural carrying capacity of the Acushnet River watershed to support river herring spawning, nursery and migratory habitat. The actual role of these limitations in the modest response of river herring population dynamics to large-scale habitat restoration is uncertain because of the undefined influences of ocean and climatic processes on river herring growth and survival.

Figure 18. Low flow channels created (above) to improve passage at the upper weir (left) and lower weir (right) at the Whelden Cotton Mill (WCM) by DMF staff (August 31, 2022).

Recommendations

Based on the results of this assessment, DMF offers the following recommendations for future restoration actions:

1. *Development of an Operation and Management Plan (O&M) for the New Bedford Reservoir Fish Ladder*. The New Bedford Reservoir Ladder was designed to maintain adequate flows for passage through the ladder with excess flows directed through the upper spillway and main channel during spring (Kleinschmidt 2001; Quinn 1995). In the summer months, water would be directed primarily through the fish ladder due to reduced flows. Drought conditions in the summer and fall of 2020 prompted the farm to install wooden boards to shut off flow through the ladder to retain water in the reservoir for irrigation. Restricting flow through the ladder created *Unsuitable* conditions for downstream passage preventing juvenile river herring from emigrating. It is **recommended** that an O&M Plan be drafted for the operation of the New Bedford Reservoir fish ladder to maintain adequate flows to ensure safe and timely passage for river herring throughout the migratory season.

2. *Improvements to passage at Whelden Cotton Mill*. The Whelden Cotton Mill Dam site was classified as *Impaired* for fish passage with *Unsuitable* conditions recorded at lower flows. It was **recommended** in draft assessment reports to improve fish passage at the stone weirs. Drought conditions during 2022 caused DMF staff to visit the Whelden Cotton Mill Dam to evaluate current conditions. On August 30, 2022, the status at the rubble weirs had degraded to the point where all downstream flow was seeping through the weir stones. Under this condition, all young-of-year river herring moving downstream would be entrained into the weir stones and suffer high or full mortality. Six DMF Diadromous Project staff manually moved stones from the two rubble dams to create passage channels free of interstitial spaces that could trap fish (**Figure 18**). It is **recommended** that DMF staff return to this site annually to confirm suitable passage is supported and make adjustments to the stone weirs as needed.

3. *Improvements to passage at Pine Hill Farm Dam*. The Pine Hill Farm Dam was classified as *Impaired* for fish passage with *Unsuitable* conditions recorded at lower flows. On August 30, 2022, the DMF Diadromous Fish Project personnel visited the Pine Hill Farm to evaluate current conditions and install headpond and tailwater depth loggers to support decisions on how to best improve fish passage at the site. DMF staff discussed options with the property owners. It is **recommended** that the depth logger data is used to design a structural improvement or operational change to the weir board at the dam to improve fish passage.

4. *Development of a Stream Maintenance Plan*. Prior to and during this assessment, DMF have identified areas within the watershed where passage is *Impaired* or *Unsuitable* due to obstructions and channel braiding created by tree falls, vegetation overgrowth and debris buildup. DMF personnel have invested considerable efforts to improve fish passage by removing these obstructions. Surveys to maintain fish passage throughout the watershed will need to be conducted periodically, and should be a cooperative effort between DMF, the Town of Acushnet and the BBC which have been active participants in efforts to restore this watershed. It is **recommended** that a DMF-approved Stream Maintenance Plan be drafted and implemented to maintain passage conditions for the Acushnet River watershed.

5. *Invasive plant management*. Little is known about the long-term effects invasive aquatic plants have on an ecosystem. However, there is concern that annual plant decomposition near the shallow fringes of the reservoir could alter substrate, from a coarse sand to a fine silt, impacting river herring spawning. Herbicides are being used as a tool to treat invasive plants in other watershed systems, unfortunately information is lacking concerning acute and long-term effects of herbicides on the early life stages of river herring (egg, larval and juvenile phases). It is **recommended** that an evaluation is made on options to remediate invasive plant impacts in the reservoir. Consideration of herbicide treatments in the reservoir should include a staged approach with adequate monitoring to track both improvements and impacts to aquatic life.

6. *Best Management Practices for water withdrawals for flow management*. Belding (1921) lists the New Bedford Reservoir and Acushnet River as one of several systems whose spawning grounds have been severely degraded by water supply development. A golf course, and several farms and cranberry bogs are located near the New Bedford Reservoir and along the Acushnet River. Below average flows are creating difficult conditions for young-of-year river herring to emigrate to marine waters. It is possible

that contemporary average river flows are deficient to support river herring emigration. A multi-agency, cooperative review is **recommended** to determine what impact is occurring to the river from all sources of water withdrawals and what measures can be enacted to mitigate surface flow reductions. For example, Best Management Practices (BMP) for cranberry growers are designed to maximize efficiency while modifying water use management during periods of high demand (Lampinen et el. 2000). Cooperation with cranberry bog owners and farmers is needed for flow management to ensure safe passage during critical migratory periods.

7. *Nutrient Management*. The elevated TN and TP measured during the assessment may be influenced by landscape contributions from the cranberry bogs, farms and golf course with water use authorizations in the watershed. A multi-jurisdictional effort is **recommended** to identify point sources and stormwater sources of nutrient loading and to develop management plans for remediation.

8. *Run Size Monitoring*. DMF has been conducting pre- and post-restoration monitoring of the river herring population to evaluate the population's response to fish passage improvements at the former Acushnet Sawmill and Hamlin Street dams. With improvements to fish passage made at the Whelden Cotton Mill and impending improvements to be made at the Pine Hill Farm Dam, it is **recommended** that run size monitoring continue to further document the success of the fish passage improvements.

9. *MassDEP Assessments*. The river herring spawning, and nursery habitat assessment data should be provided to MassDEP to support 305(b) reporting, their ongoing watershed assessments, and to assist local water quality remediation.

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Appendix Tables (A.1 - A.7)

Table A.1. Station locations sampled during the Acushnet River watershed habitat assessment, 2019-2020.

No.	Latitude	Longitude	Station Type	Depth Strata	Max. Depth (m)	Average Depth (m)	Sample (No.)	Location
NBR0	41° 43.786	70° 53.930	Outlet	Shallow	0.69	0.5	10	Lower New Bedford Reservoir outlet
NBR1	41° 43.800	70° 53.948	Survey	Shallow	0.74	0.7	2	Southern shore of lower reservoir near outlet
NBR2	41° 43.783	70° 53.996	Transect	Mid	3.66	3.2	40	Near southern shore of lower reservoir
NBR3	41° 43.853	70° 54.031	Transect	Deep	4.1	3.8	44	Along transect near mid-reservoir
NBR4	41° 44.355	70° 54.193	Transect	Shallow	1.48	1.3	27	Along transect at north end
NBR5	41° 44.300	70° 54.392	Transect	Deep	2.71	2.5	30	Southern shore of upper reservoir near AR7
NBR6	41° 44.501	70° 54.416	Survey	Shallow	0.69	0.5	3	Cove located on eastern shore near mid-reservoir
NBR7	41° 44.809	70° 54.595	Transect	Mid	1.75	1.6	20	Entrance to northern basin
NBR8	41° 45.164	70° 55.006	Transect	Shallow	0.79	0.6	20	Northern basin, entrance to Keene River
NBR9	41° 43.965	70° 54.006	Survey	Shallow	1.08	1.1	2	Eastern shore at mid-reservoir
NBR10	41° 44.192	70° 54.475	Survey	Mid	1.76	1.8	2	West cove in southern basin
NBR11	41° 44.242	70° 54.257	Survey	Shallow	0.98	1.0	2	Western shore in northern section
NBR12	41° 44.323	70° 54.559	Survey	Shallow	0.65	0.7	2	Southern cove, north of island
NBR13	41° 44.347	70° 54.371	Survey	Shallow	1.1	1.1	2	Southeast nearshore station by boat launch
NBR14	41° 44.442	70° 54.189	Survey	Mid	1.65	1.6	5	East impoundment; north of Lake Street causeway
NBR15	41° 43.753	70° 54.072	Survey	Shallow	1.19	1.2	2	Southwest corner of reservoir, by control structure

Table A.2. Summary water chemistry data collected at station NBR2 in the Lower New Bedford Reservoir, 2019 and 2020. The maximum sample size at each depth level was ten.

Surface - 0.3 m average sample depth

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	23.13	1.14	24.06	≤26.0 / ≤28.3	100
pH	(SU)	10	6.66	0.10	6.68	≥6.5, ≤8.3	70
DO	(mg/L)	10	7.44	0.39	7.48	≥5.0	100
DO sat.	(%)	10	86.4	7.44	88.9	NA	
Turbidity	(NTU)	10	2.0	3.43	1.4	NA	
Sp. Cond.	(mS/cm)	10	0.138	0.04	0.140	NA	
TN	(mg/L)	10	0.52	0.03	0.54	0.32	10
TP	(ug/L)	9	28.8	1.77	28.6	8.00	0
Secchi	(m)	10	1.4	0.07	1.4	≥2.0	0

Mid-Depth - 1.0 m average sample depth

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	22.60	1.09	23.25	≤26.0 / ≤28.3	100
pH	(SU)	10	6.54	0.11	6.60	≥6.5, ≤8.3	70
DO	(mg/L)	10	6.31	0.87	7.02	≥5.0	80
DO sat.	(%)	10	72.0	9.21	86.1	NA	
Turbidity	(NTU)	10	1.8	0.40	2.0	NA	
Sp. Cond.	(mS/cm)	10	0.137	0.00	0.140	NA	

Mid-Depth - 2.0 m average sample depth

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	21.50	1.01	21.20	≤26.0 / ≤28.3	100
pH	(SU)	10	6.39	0.10	6.31	≥6.5, ≤8.3	30
DO	(mg/L)	10	5.20	0.98	6.29	≥5.0	50
DO sat.	(%)	10	57.8	10.59	73.7	NA	
Turbidity	(NTU)	10	2.0	0.42	2.0	NA	
Sp. Cond.	(mS/cm)	10	0.140	0.00	0.150	NA	

Bottom - 3.0 m average sample depth

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	19.80	0.89	20.03	≤26.0 / ≤28.3	100
pH	(SU)	10	6.23	0.13	6.22	≥6.5, ≤8.3	10
DO	(mg/L)	10	3.79	1.03	3.15	≥5.0	40
DO sat.	(%)	10	40.5	10.86	33.8	NA	
Turbidity	(NTU)	10	3.1	0.89	2.1	NA	
Sp. Cond.	(mS/cm)	10	0.153	0.01	0.151	NA	

Table A.3. Summary water chemistry data collected at station NBR3 in the Lower New Bedford Reservoir, 2019 and 2020. The maximum sample size at each depth level was eleven.

Surface - 0.3 m average sample depth

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	23.24	1.12	3.54	≤26.0 / ≤28.3	100
pH	(SU)	10	6.65	0.10	6.65	≥6.5, ≤8.3	70
DO	(mg/L)	10	7.51	0.41	7.33	≥5.0	0
DO sat.	(%)	10	87.6	3.57	87.8	NA	
Turbidity	(NTU)	10	1.4	0.25	1.6	NA	
Sp. Cond.	(mS/cm)	10	0.138	0.00	0.142	NA	
Secchi	(m)	10	1.4	0.07	1.2	≥2.0	0

Mid-depth - 1.0 m average sample depth

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	22.50	1.04	23.00	≤26.0 / ≤28.3	100
pH	(SU)	10	6.56	0.10	6.57	≥6.5, ≤8.3	70
DO	(mg/L)	10	6.75	0.78	7.23	≥5.0	70
DO sat.	(%)	10	76.5	8.40	86.5	NA	
Turbidity	(NTU)	10	1.6	0.30	2.0	NA	
Sp. Cond.	(mS/cm)	10	0.137	0.00	0.142	NA	

Mid-depth - 2.0 m average sample depth

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	21.53	1.00	21.30	≤26.0 / ≤28.3	100
pH	(SU)	10	6.42	0.09	6.40	≥6.5, ≤8.3	20
DO	(mg/L)	10	5.08	0.99	6.37	≥5.0	60
DO sat.	(%)	10	56.4	10.57	72.9	NA	
Turbidity	(NTU)	10	2.1	0.43	2.0	NA	
Sp. Cond.	(mS/cm)	10	0.141	0.00	0.142	NA	

Mid-depth - 3.0 m average sample depth

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	11	19.24	0.70	19.82	≤26.0 / ≤28.3	100
pH	(SU)	11	6.27	0.09	6.23	≥6.5, ≤8.3	91
DO	(mg/L)	11	3.47	0.88	3.16	≥5.0	36
DO sat.	(%)	11	36.9	9.30	33.9	NA	
Turbidity	(NTU)	11	3.7	1.46	1.8	NA	
Sp. Cond.	(mS/cm)	11	0.155	0.01	0.151	NA	

Bottom - 4.0 m average sample depth

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	3	18.29	0.71	18.55	≤26.0 / ≤28.3	100
pH	(SU)	3	6.27	0.09	6.22	≥6.5, ≤8.3	0
DO	(mg/L)	3	2.98	1.95	1.78	≥5.0	67
DO sat.	(%)	3	31.1	19.99	19.2	NA	
Turbidity	(NTU)	3	3.8	2.13	2.0	NA	
Sp. Cond.	(mS/cm)	3	0.170	0.01	0.162	NA	

Table A.4. Summary water chemistry data collected at station NBR4 in the Lower New Bedford Reservoir, 2019 and 2020. The maximum sample size at each depth level was ten.

Surface - 0.3 m average sample depth

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	23.72	1.25	24.22	≤26.0 / ≤28.3	90
pH	(SU)	10	6.56	0.10	6.63	≥6.5, ≤8.3	60
DO	(mg/L)	10	7.07	1.04	7.44	≥5.0	60
DO sat.	(%)	10	83.7	12.72	86.5	NA	
Turbidity	(NTU)	10	1.4	0.29	1.5	NA	
Sp. Cond.	(mS/cm)	10	0.179	0.01	0.166	NA	
Secchi	(m)	10	1.0	0.08	0.9	≥2.0	0

Surface - 1.0 m average sample depth

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	8	22.26	1.14	22.81	≤26.0 / ≤28.3	87.5
pH	(SU)	8	6.39	0.13	6.42	≥6.5, ≤8.3	37.5
DO	(mg/L)	8	5.50	1.26	5.75	≥5.0	37.5
DO sat.	(%)	8	62.5	14.06	70.1	NA	
Turbidity	(NTU)	8	1.8	0.45	1.6	NA	
Sp. Cond.	(mS/cm)	8	0.194	0.01	0.200	NA	

Table A.5. Summary water chemistry data collected at station NBR5 in the Lower New Bedford Reservoir, 2019 and 2020. The maximum sample size at each depth level was ten.

Surface - 0.3 m average sample depth

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	22.22	1.00	23.10	≤26.0 / ≤28.3	100
pH	(SU)	10	6.27	0.09	6.24	≥6.5, ≤8.3	30
DO	(mg/L)	10	5.57	0.72	5.26	≥5.0	60
DO sat.	(%)	10	54.7	10.86	55.8	NA	
Turbidity	(NTU)	10	1.3	0.28	1.0	NA	
Sp. Cond.	(mS/cm)	10	0.132	0.00	0.129	NA	
Secchi	(m)	10	1.1	0.09	1.0	≥2.0	0

Mid-depth - 1.0 m average sample depth

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	20.84	0.84	20.85	≤26.0 / ≤28.3	100
pH	(SU)	10	6.15	0.09	6.08	≥6.5, ≤8.3	20
DO	(mg/L)	10	3.73	1.00	3.30	≥5.0	30
DO sat.	(%)	10	40.6	10.53	38.2	NA	
Turbidity	(NTU)	10	1.6	0.45	1.1	NA	
Sp. Cond.	(mS/cm)	10	0.134	0.00	0.130	NA	

Bottom - 2.0 m average sample depth

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	19.19	0.54	19.15	≤26.0 / ≤28.3	100
pH	(SU)	10	6.13	0.10	6.02	≥6.5, ≤8.3	20
DO	(mg/L)	10	2.69	1.00	0.60	≥5.0	30
DO sat.	(%)	10	28.5	10.54	6.5	NA	
Turbidity	(NTU)	9	3.8	1.13	1.7	NA	
Sp. Cond.	(mS/cm)	10	0.173	0.01	0.164	NA	

Table A.6. Summary water chemistry data collected at station NBR7 in the Lower New Bedford Reservoir, 2019 and 2020. The maximum sample size at each depth level was ten.

Surface - 0.3 m average sample depth

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	21.28	1.04	21.93	≤26.0 / ≤28.3	100
pH	(SU)	10	6.09	0.11	6.09	≥6.5, ≤8.3	10
DO	(mg/L)	10	4.57	0.86	4.42	≥5.0	60
DO sat.	(%)	10	50.6	9.10	50.4	NA	
Turbidity	(NTU)	10	1.2	0.41	0.9	NA	
Sp. Cond.	(mS/cm)	10	0.131	0.00	0.129	NA	
TN	(mg/L)	9	0.50	0.05	0.50	0.32	11
TP	(ug/L)	9	31.5	2.59	29.8	8.00	0
Secchi	(m)	10	1.1	0.13	1.1	≥2.0	0

Bottom - 1.0 m average sample depth

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	20.25	0.93	19.53	≤26.0 / ≤28.3	100
pH	(SU)	10	5.96	0.13	5.90	≥6.5, ≤8.3	20
DO	(mg/L)	10	3.02	1.00	1.23	≥5.0	30
DO sat.	(%)	10	32.1	10.42	14.6	NA	
Turbidity	(NTU)	10	1.6	0.48	1.2	NA	
Sp. Cond.	(mS/cm)	10	0.136	0.01	0.134	NA	

Table A.7. Summary water chemistry data collected at station NBR8 in the Lower New Bedford Reservoir, 2019 and 2020. The maximum sample size at each depth level was eight.

Surface - 0.3 m average sample depth

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	8	17.69	1.10	18.44	≤26.0 / ≤28.3	100
pH	(SU)	8	5.39	0.09	5.42	≥6.5, ≤8.3	20
DO	(mg/L)	8	2.36	1.09	0.71	≥5.0	40
DO sat.	(%)	8	23.9	10.91	7.3	NA	
Turbidity	(NTU)	8	2.4	0.61	1.9	NA	
Sp. Cond.	(mS/cm)	8	0.091	0.00	0.092	NA	
TN	(mg/L)	8	0.61	0.07	0.63	0.32	0
TP	(ug/L)	8	29.5	4.46	25.2	8.00	0
Secchi	(m)	8	0.5	0.05	0.5	≥2.0	0