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Massachusetts Division of Marine Fisheries
Technical Report TR-72

River Herring Spawning and Nursery Habitat Assessment: Mill River Watershed, 2012-2014

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River Herring Spawning and Nursery Habitat Assessment: Mill River Watershed, 2012-2014

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Abstract: River herring (the collective name for alewife, *Alosa psuedoharengus*, and blueback herring, *Alosa 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. River herring provide important forage for many species of fish and wildlife and formerly supported valuable commercial, recreational, and subsistence fisheries. 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. Three potential spawning and nursery habitats in the Mill River watershed (Lake Sabbatia, Watson Pond, and Winnecunnet Pond) were assessed in 2012–2014. At the start of the assessment, four impassible dams prevented the passage of migratory fish to Lake Sabbatia. A cooperative restoration effort made significant progress during the study period and by 2014 two dams on the Mill River were removed and the Morey's Bridge Dam at Lake Sabbatia's outlet was reconstructed with a fishway, eel ramp, and low-flow channel for downstream passage. This habitat assessment identified water quality and habitat impairments that should be considered as restoration efforts continue in the watershed. All three water bodies were classified *Impaired* for exceedances of dissolved oxygen (DO), pH, Secchi disk, total nitrogen (TN), and total phosphorus (TP) based on MassDEP's habitat assessment criteria. Watson Pond was additionally classified as *Impaired* for water temperature during the nursery period. Each pond had a high level of TP impairment, as all measurements exceeded the TP criterion. Lake Sabbatia was more impaired than the other ponds by having the highest percentage exceedance for each of the *Impaired* parameters, except DO (higher in Winnecunnet Pond) and TP (all sites exceeded 100%). Additional concerns for Lake Sabbatia are discussed due to the widespread abundance of invasive fanwort (*Cabomba* sp.) and variable milfoil (*Myriophyllum heterophyllum*), and the presence of anoxia or hypoxia for over 60% of the water column at the deep station during summer months.

Introduction

The Mill River is a tributary in the Taunton River Watershed in southeastern Massachusetts. The Taunton River Watershed has a total drainage area of 1456 km^2 and ultimately empties into Mount Hope Bay. The Taunton River arises from the confluence of the Town River and Matfield River in the town of Bridgewater. It flows through the towns of Halifax, Middleborough, and Raynham before it enters Taunton, where it is joined by the Mill River. The Mill River is a moderate sized tributary of the Taunton River that originates in the Canoe River aquifer, an extensive area of wetlands and surface water that was designated as an Area of Critical Environmental Concern (ACEC) by the Commonwealth of Massachusetts in 1991 (DCR 1991). The Canoe River runs for over 23 km before draining into the 61.5 hectare (152 acre) Winnecunnet Pond. Flow exits Winnecunnet Pond as the Snake River, which runs for 6.4 km to connect to northeastern Lake Sabbatia. Lake Sabbatia is a 107 hectare (265 acre) freshwater lake located in Taunton adjacent to Watson Pond State Park. The northwestern corner of Lake Sabbatia joins with the 31.5 hectare (78 acres) Watson Pond. Lake Sabbatia was a natural lake enlarged by damming the Mill River in 1812. The dam was last rebuilt in 2007 to become the Morey's Bridge Dam at Bay Street, which regulates the lake's water levels. The Mill River flows from Lake Sabbatia at the Morey's Bridge Dam for 6.2 km through the center of Taunton to meet the Taunton River. The total drainage area from the outlet of Winnecunnet Pond to the Taunton river is 211 km^2 (Rojko et al. 2005).

Prior to 2012, four dams limited migratory fish access to the Mill River, Lake Sabbatia, Watson Pond, and Lake Winnecunnet. The Massachusetts Division of Ecological Restoration (DER) and partners began a restoration project to remove the dams from the Mill River after one (the Whittenton Dam) came close to failing during a severe flood in 2005. Since the project's initiation, four of the dams have been removed or rebuilt (Figure 1). During 2012-2013, the Hopewell Mills Dam (also known as the State Hospital Dam) was removed and a new dam featuring a fish ladder was built at Morey's Bridge Dam. The Whittenton Dam was removed in 2013 and removal of the West Brittania Dam was completed in early 2018. For the first time in 200 years, migratory fish now have unobstructed access to an added 30 km of riverine habitat, and over 162 hectares (400 acres) of lacustrine habitat. The US Geological Survey has maintained a Mill River stream flow gauge at Spring Street in Taunton since 2006 (No. 01108410, drainage area = 112.7 km^2). The mean monthly discharge for May at this station is 90 cfs during 2006–2014.

DMF is responsible for managing river herring populations in the Commonwealth of Massachusetts. This includes improving fish passageways between marine and freshwater areas and evaluating options for restoring degraded populations and habitats. In 2012, DMF, in conjunction with DER, the National Oceanic and Atmospheric Administration (NOAA), and The Nature

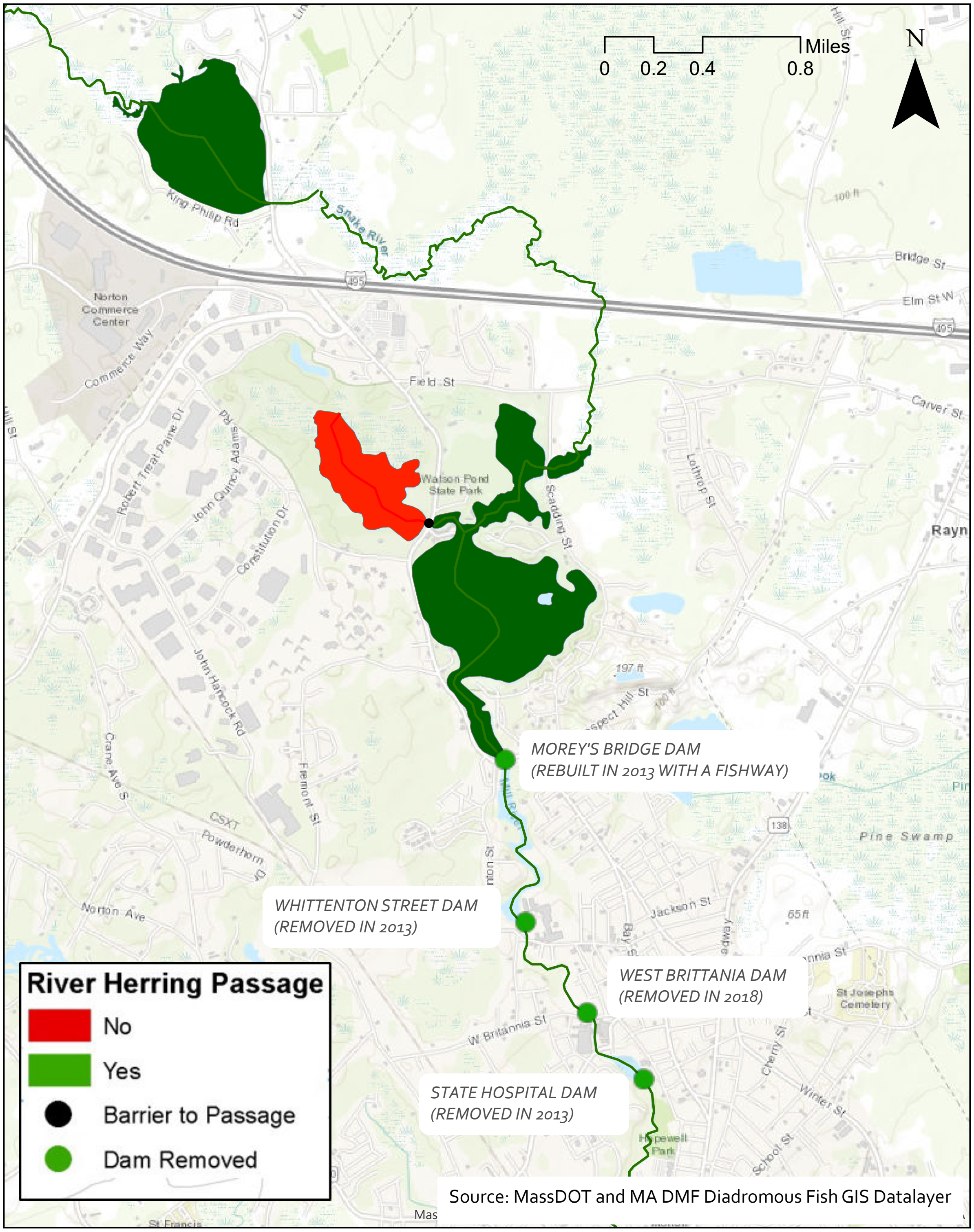

Figure 1. Map of the Mill River Watershed. The West Brittania Dam was removed in 2018, allowing open fish passage to Lake Sabbatia during the spring of 2018 for the first time in over 200 years.

Conservancy (TNC), established a monitoring plan to assess the response of diadromous species in the Mill River to dam removal. One of the goals of this monitoring plan was to assess populations and habitat of river herring (alewife; *Alosa psuedoharengus* and blueback herring; *Alosa aestivalis*) in the Mill River prior to and following the restoration of full passage. To contribute to this goal, a two-year river herring spawning and nursery habitat assessment began in Lake Sabbatia and Watson Pond in 2012, followed by an additional two-year assessment in Winnecunnet Pond, which began in 2013.

Diadromous Fisheries

The Taunton River is one of few free-flowing rivers in New England with no standing main stem dams to obstruct fish passage. The river was historically known for important shad and river herring fisheries, to the extent that the city of Taunton was once referred to as Herring Town. Both Native Americans and colonial settlers built stone and wooden fish weirs along the Mill River and held annual harvests in the 1700s. River herring were mostly dried and preserved as food; however, some fish were used by farmers as fertilizer during spring planting. Iron forges and grist, saw, and fulling mills were built along the Mill River in the early 1800s, limiting access of diadromous fish to the upper river, which led to conflicts with farmers (Calabro 2012). Further development in Taunton and neighboring towns eventually led to vast amounts of industrial pollution and sewage entering the watershed. Coupled with the four dams preventing fish passage, this pollution effectively eliminated the alewife fishery (Belding 1921). River herring presence in Lake Sabbatia or Winnecunnet Pond was not documented in the early 1950s (Stroud 1955), nor was it noted in the Mill River during Belding's surveys (Belding 1921).

By the 1960s, the four dams were still intact and considerable industrial waste was still entering the Mill River; however, a DMF survey noted the presence of alewives reaching the base of the first dam and recognized the potential for Lake Sabbatia to support a large alewife population (Reback and DiCarlo 1972). The removal of the Hopewell Mills Dam in 2012 allowed river herring upstream passage for the first time in 200 years. Presently, fish passage has been provided at all four dams on the Mill River.

Water Supply Management

The Snake River, Winnecunnet Pond, Watson Pond, and Lake Sabbatia are entirely within the Canoe River Aquifer ACEC, which encompasses over 6,960 hectares. The aquifer itself is distinguished by an extensive system of surface waters, wetlands, floodplains, and high-yield aquifers. The aquifers are recharged with water percolating through permeable soils and provide "Class B, High Quality" drinking water (pursuant to the Massachusetts Surface Water Quality Standards, 314 CMR 4.00) to over 66,000 people in the area, including the towns of Easton, Foxborough, Mansfield, Norton, and Sharon, as well as the city of Taunton (Tierney 1991).

The Canoe River Aquifer was designated as a Sole Source Aquifer by the US Environmental Protection Agency (US EPA) in 1993, indicating that the quantity of water withdrawn from the aquifer cannot be replaced by another source. There are 11 municipal wells located in the Canoe River segment of the ACEC and many private wells that draw directly from the aquifers (MassDEP MA62-27) and are authorized by Water Management Act (WMA) registrations. A list of municipal WMA registrations can be found in Rojko et al. (2005).

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 MassDEP, as required by Section 305(b) of the Clean Water Act (CWA). The river herring habitat assessment follows a MassDEP-approved Quality Assurance and Program Plan (QAPP) on water quality measurements for diadromous fish monitoring (Chase 2010). 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 Massachusetts Surface Water Quality Standards (SWQS). Water-bodies 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) 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 2013). 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 Taunton River Watershed, including Mill River watershed segments, was last assessed by MassDEP in 2001 (Rojko et al. 2005). The assessment results are used in the MassDEP Integrated List of Waters (MassDEP 2014) which lists the Mill (Segment MA62-29) and Snake (Segment MA62-28) Rivers as Category 3 Waters (*No uses assessed*). Category 3 contains those waters for which insufficient or no information was available to assess any uses. The assessment states that the Canoe River (Segment MA62-27) is Category 2 (*Attaining some uses; other uses not assessed* with listed uses for aesthetic purposes, fish, other aquatic life, and wildlife. Lake Sabbatia (MA62166) and Watson Pond (MA62205) were both described as Category 5 Waters (*Waters Requiring a TMDL*). Lake Sabbatia requires a TMDL due to its low dissolved oxygen levels and presence of non-native aquatic plants. The assessment also lists Watson Pond as having low dissolved oxygen and non-native aquatic plants, in addition to high total phosphorus levels, excess algal growth, and poor Secchi disk transparency. The same assessment signifies Winnecunnet Pond (MA62213) as Category 4c Water (*Impairment not caused by a pollutant – TMDL not required*). The impairment to Winnecunnet Pond is listed as the presence of non-native aquatic plants.

Methods

The river herring habitat assessment methodology is fully outlined in DMF's QAPP (Chase 2010). The assessment relates river herring life history characteristics to three categories of reference conditions: Massachusetts SWQS (MassDEP 2013), US EPA nutrient criteria recommendations (US EPA 2001), and Best Professional Judgment (BPJ) to relate monthly site visit observations for Fish Passage, Streamflow, and Eutrophication to QAPP reference conditions (Chase 2010). Monthly trips were made to Lake Sabbatia, Watson Pond, and Winnecunnet Pond from May to September, targeting the second and 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. Lake Sabbatia and Watson Pond were both sampled in 2012 and 2013, while Winnecunnet Pond was sampled in 2013 and 2014. The assessment criteria for all parameters and assessment results are summarized in Tables 1-3 for the three water bodies. The station specifications are in Table A1 in the Appendix, as are summary statistics for each station (Tables A2-A13).

Water quality measurements were taken with a YSI 6920 multi-sensor water chemistry sonde at the surface (0.3 m depth), at bottom (0.5 m from bottom), and at mid-water column intervals of 1 m at stations 2 m in depth or more. 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 laboratories (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 US 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 monthly 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 lake outlet to the lake inlet in all three waterbodies (Figure 2). These stations contained three or four stations to represent shallow, medium, and deep depth 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. The 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 Lake Sabbatia assessment classification was based on stations LS-2, LS-3, LS-4, and LS-5 selected along a transect line running from the Lake Sabbatia outlet into the Mill River, across to the inflow from the Snake River The Watson Pond assessment classification was based on stations WAP-3, WAP-4, and WAP-5 along a transect from Bay Street to the northwest perimeter. The Winnecunnet Pond assessment was based on stations WIN-2, WIN-3, and WIN-4 along a transect from King Phillip Road at the pond's southwest corner to shallower regions in the north central portion of the lake and directly east of the inflow from the Canoe River.

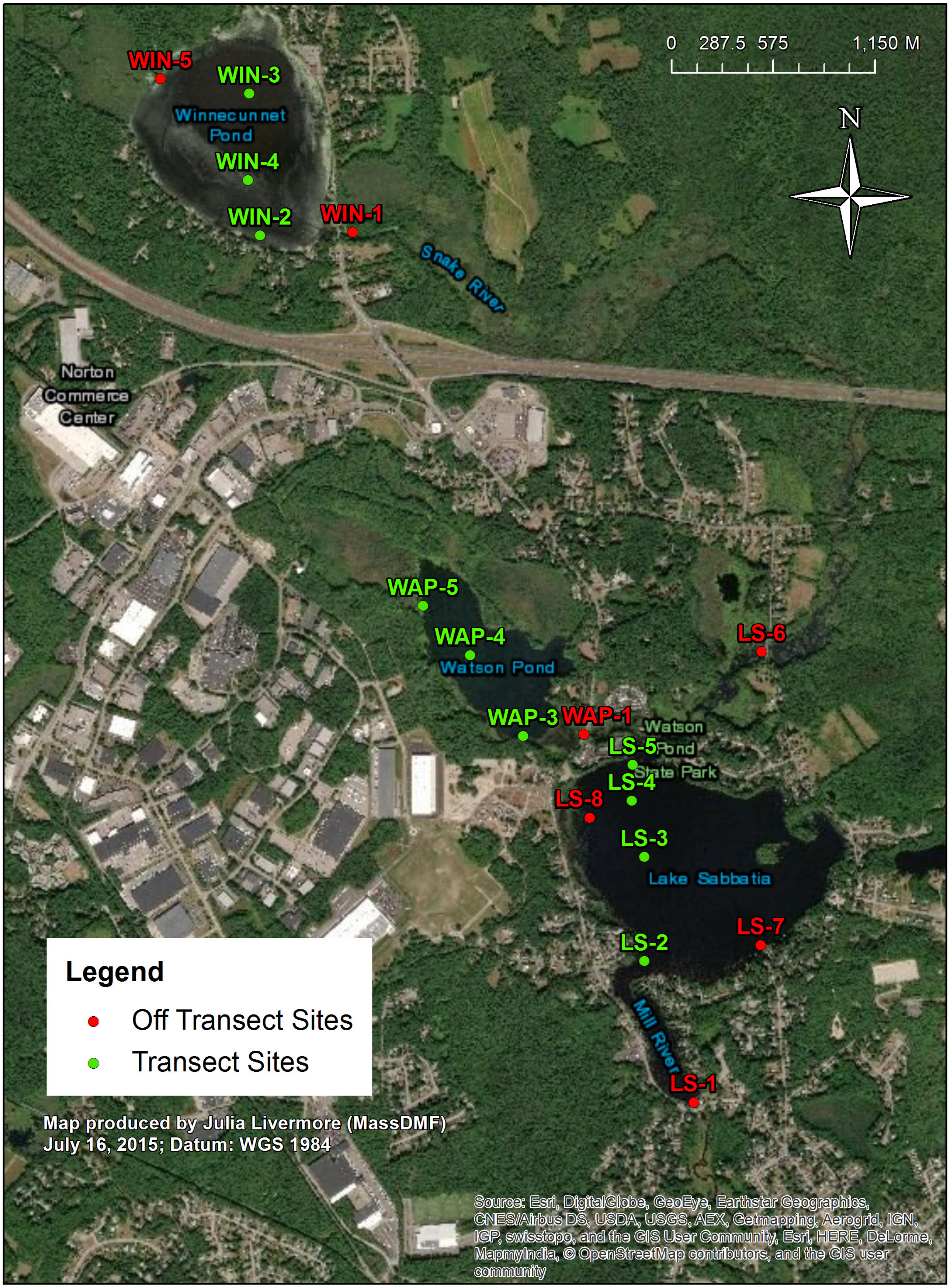

Figure 2. Map of sampling stations at Lake Sabbatia, Watson Pond and Winnecunnet Pond.

Nutrient Criteria

The US 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. The median was calculated from the four seasonal 25th percentiles that represents a threshold between minimally impacted and impaired habitats. The QAPP adopted this approach by relating median nutrient measurements to the EPA's 25th percentile for the Northeast Coastal Zone subecoregion #59 (US EPA 2001). The US EPA nutrient criteria for subecoregion #59 are 8.0 ug/L for TP and 0.32 mg/L for TN. 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 US EPA approach to develop TN and TP criteria specific to river herring spawning and nursery habitat for coastal regions of Massachusetts.

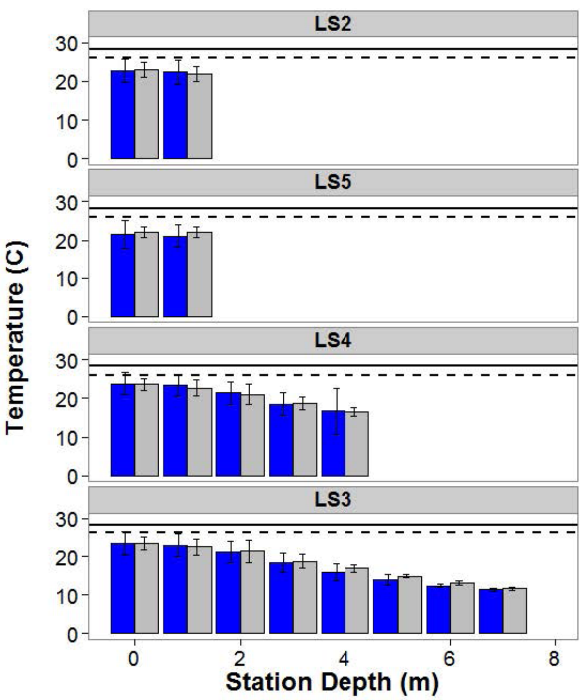

Figure 3. Bar charts of the mean temperatures (°C) ± 2 s.e. observed in Lake Sabbatia. The upper two panels represent the shallow stations, the third panel represents the mid-depth station, and the bottom panel represents the deep station, with observation depth increasing from left to right. Dashed lines indicate the spawning temperature threshold (26.0°C) and solid lines indicate the nursery temperature threshold (28.3°C).

Results and Discussion

Massachusetts SWQS Criteria

Water Temperature

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

No water temperature measurements at Lake Sabbatia exceeded either the spawning or nursery period threshold, resulting in a *Suitable* classification (Figure 3). The lake was thermally stratified each year during summer months. The deep station, LS-3, had a maximum depth of about 8 m, where the bottom temperature range was stable between approximately 11 and 12°C (Figure 3). Winnecunnet Pond is a much shallower body of water, and had only one measurement that exceeded the nursery temperature threshold, resulting in a *Suitable* classification (Figure 7). Watson Pond had temperature exceedances at the surface and for 1 m depth measurements at all stations on July 18, 2013, including a surface temperature of 30.84°C at WAP-3 that was the warmest measurement recorded during the assessment (Figure 7). The six exceedances in July 2013 resulted in an *Impaired* classification for the nursery period in Watson Pond. During the spawning period at Watson Pond, there was one temperature exceedance on May 31, 2012 at the surface for WAP-3; however, a *Suitable* classification was designated given the 6% exceedance rate.

Water pH

The acidification of fresh water is a widely recognized concern for fish populations. Low pH can increase metal toxicity and disrupt ionoregulation 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 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 Ameri-

Table 1. Summary of river herring habitat assessment criteria for Lake Sabbatia, 2012-2013.

Parameter	Units	Sample Size (N)	Acceptable Criteria	Exccedance (%)	Classification
Temp (nursery)	°C	95	≤ 28.3	0.00	*Suitable*
Temp (spawning)	°C	69	≤ 26.0	0.00	*Suitable*
DO	mg/L	155	≥ 5.0	51.20	*Impaired*
pH	SU	164	6.5 to ≤ 8.3	60.84	*Impaired*
Secchi disk depth	m	18	≥ 2.0	93.10	*Impaired*
TN	mg/L	31	≤ 0.32	96.77	*Impaired*
TP	ug/L	31	≤ 8.0	100.00	*Impaired*
Eutrophication	N/A	12	BPJ		*Impaired*
Fish Passage	N/A	12	BPJ		*Unsuitable*
Stream Flow	N/A	12	BPJ		*Suitable*

Table 2. Summary of river herring habitat assessment criteria for Watson Pond, 2012-2013.

Parameter	Units	Sample Size (N)	Acceptable Criteria	Exccedance (%)	Classification
Temp (nursery)	°C	47	≤ 28.3	6.45	*Suitable*
Temp (spawning)	°C	29	≤ 26.0	11.32	*Impaired*
DO	mg/L	84	≥ 5.0	10.71	*Impaired*
pH	SU	84	6.5 to ≤ 8.3	14.29	*Impaired*
Secchi disk depth	m	10	≥ 2.0	56.25	*Impaired*
TN	mg/L	17	≤ 0.32	52.94	*Impaired*
TP	ug/L	17	≤ 8.0	100.00	*Impaired*
Eutrophication	N/A	9	BPJ		*Impaired*
Fish Passage	N/A	9	BPJ		*Unsuitable*
Stream Flow	N/A	9	BPJ		*Suitable*

Table 3. Summary of river herring habitat assessment criteria for Winnecunnet Pond, 2013-2014.

Parameter	Units	Sample Size (N)	Acceptable Criteria	Exccedance (%)	Classification
Temp (nursery)	°C	48	≤ 28.3	0.00	*Suitable*
Temp (spawning)	°C	31	≤ 26.0	2.00	*Suitable*
DO	mg/L	80	≥ 5.0	52.22	*Impaired*
pH	SU	80	6.5 to ≤ 8.3	45.56	*Impaired*
Secchi disk depth	m	9	≥ 2.0	89.47	*Impaired*
TN	mg/L	9	≤ 0.32	72.73	*Impaired*
TP	ug/L	9	≤ 8.0	100.00	*Impaired*
Eutrophication	N/A	8	BPJ		*Impaired*
Fish Passage	N/A	8	BPJ		*Suitable*
Stream Flow	N/A	8	BPJ		*Suitable*

Notes: Bottom DO measurements at deep stations in stratified lakes are excluded due to QAPP exemption. *Impaired* classifications result from exceedances of >10% or >1 (when N<10) for transect stations.

ca (Klauda and Palmer 1987; Hesthagen and Hansen 1991).

Water pH at Lake Sabbatia, Watson Pond, and Winnecunnet Pond was stable and slightly acidic during the study period (Figures 4 and 7). Surface pH measurements for the 2012 and 2013 seasons averaged 6.54 at Lake Sabbatia. Of the 166 transect measurements, 98 were <6.5, resulting in an *Impaired* classification for pH at Lake Sabbatia. Both Watson Pond and Winnecunnet Pond were also classified as *Impaired* despite having a mean pH well within the acceptable range and far fewer exceedances than Lake Sabbatia (Tables 1–3). Watson Pond had an average pH of 6.97 with 14.3% of the measurements <6.5; while Winnecunnet Pond averaged 6.44 pH with 45.6% of the measurements <6.5.

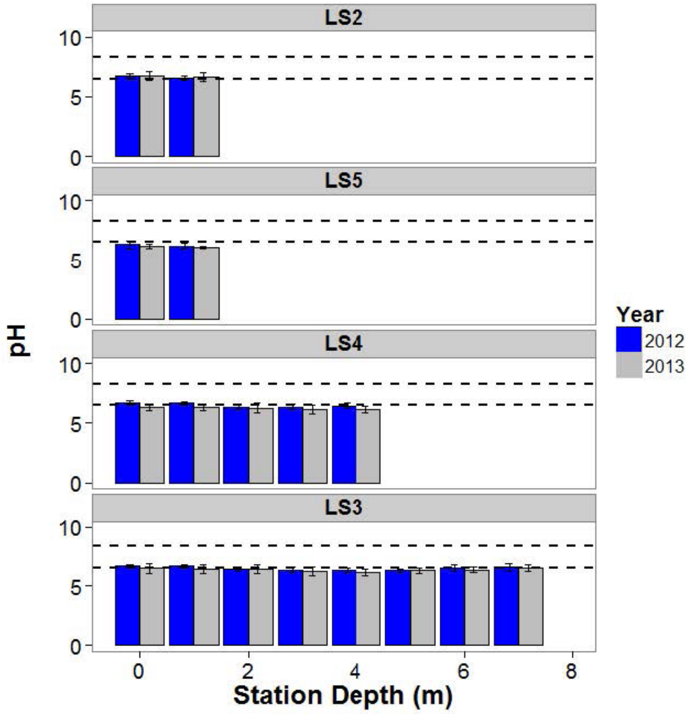

Figure 4. Bar charts of the mean pH ± 2 s.e. observed in Lake Sabbatia. The upper two panels represent the shallow stations, the third panel represents the mid-depth station, and the bottom panel represents the deep station, with observation depth increasing from left to right. Dashed lines indicate the minimum (6.5) and maximum (8.3) acceptable thresholds.

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.

Lake Sabbatia was classified as *Impaired* for DO with 50% of the transect station measurements <5.0 mg/L DO threshold (Figure 5). Bottom samples at the deep transect station (LS-3) are exempt from the DO classification in the QAPP, due to the influence of natural stratification (Figure 6). All measurements at LS-2 were suitable on all visits, but this condition was not found at the other three transect stations. At the surface and 1 m depth intervals at LS-3 90% of measurements were >5.0 mg/L (Figure 6). DO exceedances became more common below 2 m, and 93% of measurements below 5 m were hypoxic or anoxic (Figure 6). Stations LS-4 and LS-5—near the lake inlet—had marginally low surface DO levels with 20% and 60% of measurements falling below 5.0 mg/L. Station LS-4 had low DO in the lower column during the warmest months, with 63% of all measurements below 5.0 mg/L.

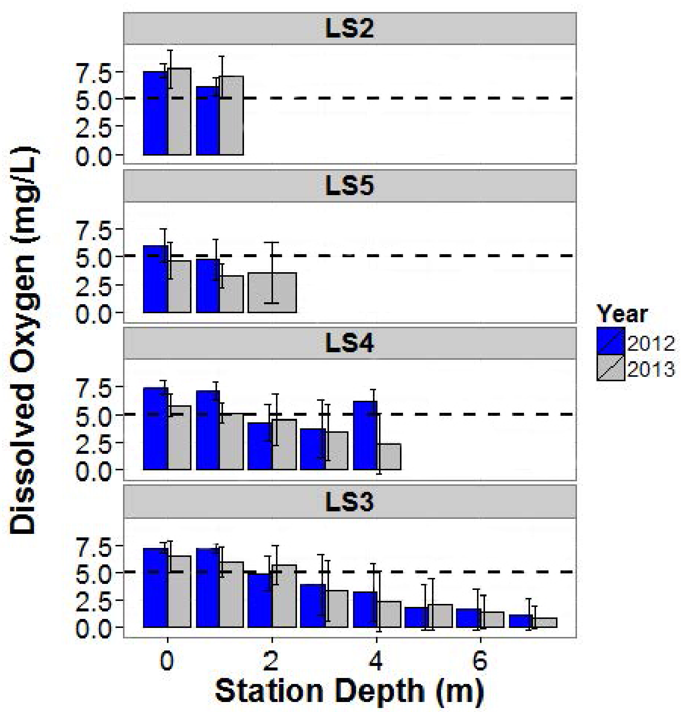

Figure 5. Bar charts of the mean dissolved oxygen (DO, mg/L) ± 2 s.e. observed in Lake Sabbatia. The upper two panels represent the shallow stations, the third panel represents the mid-depth station, and the bottom panel represents the deep station, with observation depth increasing from left to right. Dashed lines indicate the minimum acceptable DO (5 mg/L).

In Watson Pond, only one surface DO measurement was <5.0 mg/L (Figure 7). However, enough threshold exceedances (10.7%) occurred at lower depths across all stations to result in an *Impaired* classification. Winnecunnet Pond also received an Impaired classification, as 52% of DO measurements were <5.0 mg/L over both sampling seasons. Surface measurements were all >5.0 mg/L, but hypoxia or anoxia was found at all other depth intervals revealing stratification high in the water column. The average DO for the all transect

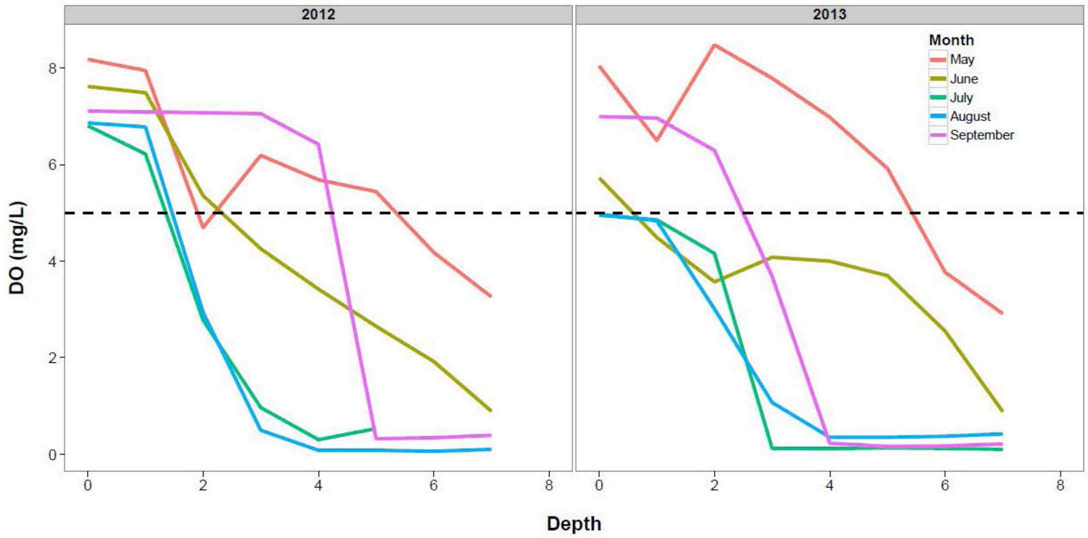

Figure 6. Plots of average monthly dissolved oxygen (DO, mg/L) against measurement depth observed at the deep sampling station in Lake Sabbatia by year. The dashed vertical lines indicate the minimum acceptable DO (5 mg/L).

sites was 4.93 mg/L and 66% of measurements taken below the surface had DO <5.0 mg/L.

Nutrients
Monthly surface samples of TN and TP were collected at LS-1, LS-3, and LS6 in Lake Sabbatia; at WAP-1, WAP-3, and WAP-4 in Watson Pond; and WIN-3 in Winnecunnet Pond. The samples were collected and processed according to the project QAPP. All three water bodies were classified as *Impaired* for both TN and TP, with few measurements below TN criterion and no measurements below TP criterion (Figures 8 and 9). Lake Sabbatia averaged 0.505 mg/L TN and 26.9 µg/L TP for all station measurements combined, with only one TN measurement below the criterion. The sample station near the Snake River inlet (LS-6) had the highest concentrations for TN and TP among all stations and much higher concentrations than the lower two stations (LS-1 and LS-2)—differences of approximately 39% for both TN and TP. Winnecunnet Pond averaged 0.399 mg/L TN and 27.7 µg/L TP for all station measurements, with three TN measurements below the criterion. Watson Pond averaged 0.383 mg/L TN and 43.7 µg/L TP for all station measurements combined, with eight TN measurements below the criterion.

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 US 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. Only two of 20 Lake Sabbatia Secchi disk measurements at stations LS-3 and LS-4 were above the criterion resulting in an *Impaired* classification. Combined Secchi disk measurements at Lake Sabbatia averaged 1.66 m for 2012 and 2013 (Figure 10). Watson Pond and Winnecunnet Pond were also classified as *Impaired* for Secchi disk with combined averages of 1.97 m and 1.77 m, respectively.

Best Professional Judgment

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*. The BPJ assessment for passage to Lake Sabbatia and further upstream as *Unsuitable* was readily made with little uncertainty, as the impassible West Brittania Dam was not removed during the assessment period, preventing upstream passage to the newly constructed fish ladder (2013) at Morey's Bridge Dam.

Hopewell Mills Dam
The Hopewell Mills Dam (State Hospital Dam) was

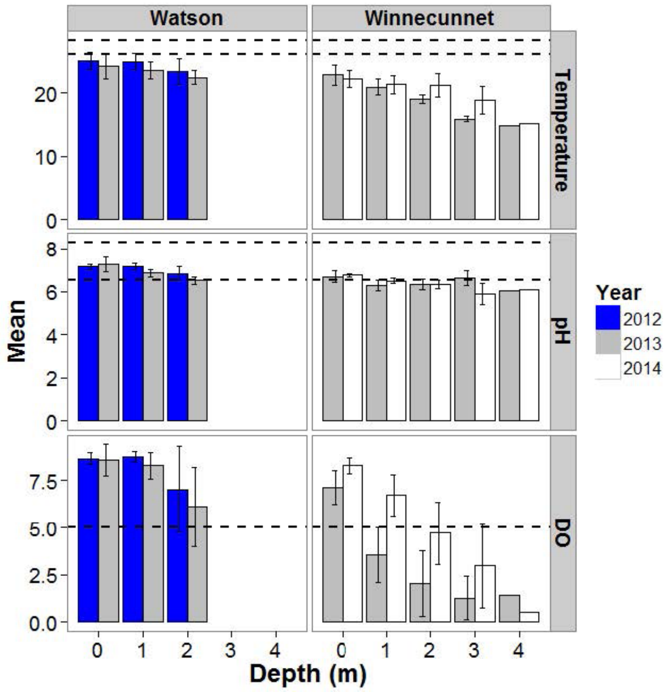

Figure 7. Bar charts of the mean temperature (upper panels) ± 2 s.e., pH (middle panels) ± 2 s.e., and dissolved oxygen (DO, mg/L; lower panels) ± 2 s.e. for Watson Pond (left) and Winnecunnet Pond (right) by year, with observation depth increasing from left to right. The dashed lines indicate threshold criteria.

constructed in 1818 to provide hydropower and served a variety of mills that no longer exist. The dam was constructed with a concrete spillway (10.7 m wide by 1.7m high), incurred over three small vertical drops (Reback et al. 2004). This dam location was visited a total of eight times during the sampling season in 2012 and 2013. For the first three visits, the dam's vertical elevation prevented fish passage upstream, resulting in an *Unsuitable* classification. It was noted that flow over the dam did not obstruct downstream passage and that juvenile American eel (*Anguilla rostrata*) were probably able to ascend the dam spillway and crest. Following removal in August 2012, the site received a *Suitable* classification for all subsequent visits. During 2013, the former impoundment and channel upstream of the former dam were observed to have quickly established natural river features such as meanders and pool and riffle transitions. During the assessment in the spring of 2014, sea lamprey (*Petromyzon marinus*) were observed building spawning redds in the upstream restored river habitat.

West Brittania Dam

The West Brittania Dam was built in the early 1800s by the silversmith manufacturer Reed & Barton to run a mill within the factory. The dam creates two separate impoundments with a bifurcated channel of the Mill River. The northern channel has a concrete spillway with wooden boards used to control the water level. The spillway is about 9 m wide with a vertical drop of about 1 m, creating a barrier to upstream passage for river herring. The southern channel runs directly beneath the Reed & Barton factory and served as a mill race. The mill raceway leads to a spillway that is also about 1 m in height and prevents upstream passage. Removal of the northern spillway, or main stem dam occurred January 2018.

The dam at the northern channel was visited eight times from May 2012 to June 2013 on a monthly basis. On all eight occasions, there was no barrier to downstream migration, but the vertical drop at the spillways prevented upstream passage, resulting in an *Unsuitable* classification for fish passage.

Whittenton Street Dam

The Whittenton Dam was built in 1832 out of wood, concrete, asphalt, and stone to power another mill (Reback et al. 2004). It was owned by L & O Realty Trust until its removal in 2013. Prior to removal, the impoundment was retained by a spillway 3.7 m high and 36 m wide. Eight monthly visits were made to the dam site, all prior to the initiation of its removal. During each visit in 2012, the dam was present and prevented upstream passage and limited downstream passage for all months except May and June. This resulted in an *Unsuitable* classification for 2012. The classification in 2013 for May–July was reduced to *Impaired* as the greater volume of water passing over the dam had decreased the elevation drop, possibly allowing limited upstream passage. Site assessments ceased after July because the site was fully mobilized for dam removal. By May 2014, the dam was removed and the site was classified as *Suitable* for river herring passage.

Morey's Bridge Dam

Morey's Bridge Dam (LS-1) was visited seven times in 2012 and 5 times in 2013 during the sampling season on a monthly or bimonthly basis. The dam was constructed in 1832 entirely of wood. The spillway was 8.5 m wide and 3 m high. While the dam would not have allowed river herring passage, the wooden configuration provided leaks and crevices that likely allowed some level of eel passage, in the case that eels were able to pass the three downstream impediments prior to 2012. The removal of the existing Morey's Bridge Dam and reconstruction of the new dam was ongoing during the entire study period in 2012 and 2013. The construction was a cooperative effort led by the Massachusetts Department of Conservation and Recreation (DCR) and Massachusetts Department of Transportation (Mass-

DOT), with DCR assuming the dam ownership upon completion.

Two cofferdams were constructed prior to May 2012, one upstream and the other downstream of the dam, to allow for dam reconstruction. During times of moderate flow, such as May and June 2012, fish passage actually would have been possible given the removed former dam and consolidation of flow by the cofferdams. The summary of all site visits during 2012 and 2013 resulted in an *Unsuitable* classification for this site. However, construction was completed in September 2013, with a new Denil fish ladder and a low-flow channel to support downstream passage. Therefore, visits after September 2013 found fish passage into Lake Sabbatia possible. In addition to the fish ladder and low-flow channel installed in 2013, a custom, aluminum eel ramp was designed and installed next to the fish ladder by DMF in 2014.

Watson Pond

Watson Pond connects to Lake Sabbatia through a culvert that crosses under Bay Road. This culvert (WAP-1) was visited four times during the 2012 assessment and several other times during 2013 and 2014. The outlet consists of a culvert with wooden boards installed to control the water level in the pond. Water flows over the boards and makes an approximately 0.6 m vertical drop into the culvert to Lake Sabbatia. All visits to WAP-1 indicated that there was no downstream impediment, but the vertical elevation of the boards created an obstruction to upstream river herring passage, classifying the site as *Unsuitable* for fish passage. Observations at WAP-1 identified the potential to modify the outlet boards with notching or additional weirs to enable fish passage into Watson Pond.

Lake Winnecunnet

The outlet at Lake Winnecunnet (WIN-1) was assessed on a monthly basis from May through September 2013 and 2014, with the exceptions of June and July 2014. On all eight occasions, the outlet (approximately 14 m wide and 1 m deep) into the Snake River had no physical upstream or downstream impediments, leading to a classification of *Suitable* for fish passage. However, we noted that the August 2012 survey of the Snake River indicated the presence of excessive vegetation growth near the outlet that could hinder river herring passage. The inlet to Lake Winnecunnet was not easily accessible and was visited only twice, in August and September 2014. On both occasions, there was significant vegetation growth in the channel limiting upstream and downstream passage, although no classification was made given the few visits.

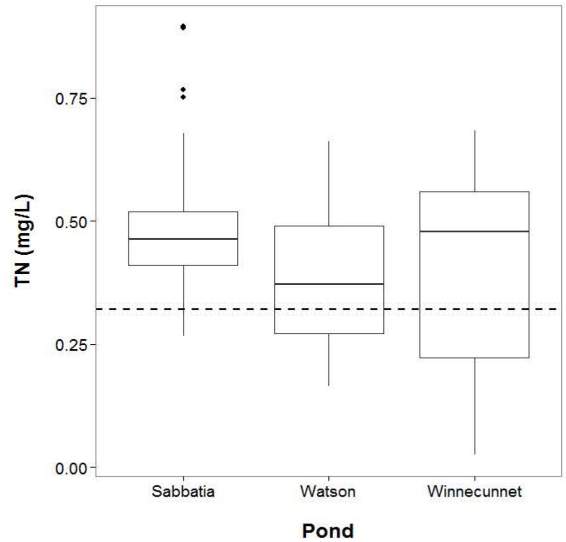

Figure 8. Boxplots of the total nitrogen (TN, mg/L) observed in the three sampling locations. Upper and lower hinges correspond to the first and third quartiles, and whiskers extend the observed values closest to ± 1.5 * IQR (interquartile range); data beyond the whiskers are outliers and plotted as points.

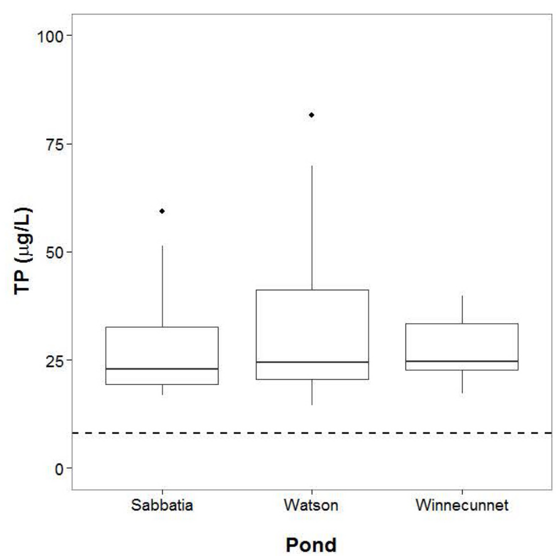

Figure 9. Boxplots Boxplots of the total phosphorus (TP, µg/L) observed in the three sampling locations. Upper and lower hinges correspond to the first and third quartiles, and whiskers extend the observed values closest to ± 1.5 * IQR (interquartile range); data beyond the whiskers are outliers and plotted as points.

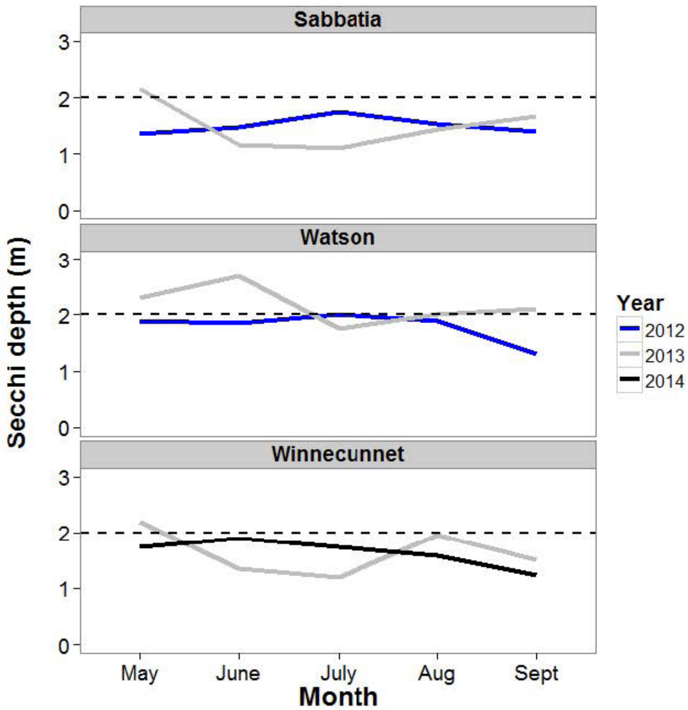

Figure 10. Line charts showing the mean monthly Secchi disk depth (m) observed in Lake Sabbatia (upper panel), Watson Pond (middle panel), and Winnecunnet Pond (lower panel) for each month and year. The dashed line indicates the US EPA Secchi disk criterion for subecoregion #84 (Cape Cod) of ≥ 2.0 m.

Stream Flow

Stream flow is a separate classification from fish passage because in some cases, stream flow can influence passage and habitat quality independently 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.

Stream flow records from the US Geological Survey gage at Spring Street on the Mill River (No. 01108410) documented the flow conditions present during the study period. There were no major trends or aberrations in stream flow for the study years, with most months having mean discharge near the time series monthly mean discharge. The exceptions were June 2013, with flows that were 2.5 times higher than the gage series mean for June; and June–September in 2014, when low precipitation resulted in flows that ranged from 8%–43% of the time series means for those months.

Hopewell Mills Dam

During May–September 2012, the Hopewell Mills site had consistent stream flow. No habitat dewatering was recorded during any visit and the downstream reach type was riffle with approximately 15 to 45 cm of depth. These conditions would not prevent passage in either direction and enabled a *Suitable* classification for stream flow. The dam removal construction began in August 2012, but did not influence flow conditions for the remainder of the monitoring period. Construction related site work in 2013 did reduce downstream flow, preventing both upstream and downstream passage. This condition was a temporary response to the dam removal and was relieved with the completion of the project late in 2013.

West Brittania Dam

While the West Brittania Dam presented a physical barrier to fish passage, the stream flow conditions were *Suitable* for river herring passage at all site visits during 2012 and 2013. Steady flow over the main stem dam crest was found with each site visit and the water depth in the channels below the dam ranged from 15 cm to 30 cm for both seasons.

Whittenton Street Dam

The Whittenton Dam also presented a physical barrier to passage while stream flow conditions were *Suitable* for river herring passage at all site visits during 2012 and 2013. The water depth in the downstream channel remained from 15 cm to 30 cm for both seasons. The start of the dam removal construction in July 2013 did not inhibit downstream flow enough to alter the classification from *Suitable* for the remainder of the monitoring period.

Morey's Bridge Dam

Morey's Bridge Dam earned a *Suitable* classification for flow for each site visit during the monitoring period. The water depth along the dam spillway was approximately 15 cm in May 2012 and was approximately 30 cm during all other months. Dam reconstruction began in July 2012. A cofferdam was installed to allow work on half of the new spillway and dam while maintaining flow in the other half. This approach kept suitable downstream flow that was supportive of river herring passage. The new Morey's Bridge Dam was completed by the final site visit in September 2013 with a new fish ladder and low flow channel to accommodate downstream passage (Figure 11). The fishway and low flow channel were designed to provide at least 30 cm of water depth at all times when operated in concert with the adjustable gates at the dam.

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 US EPA criteria and not Best Professional Judgment. Total nitrogen and TP were the reference conditions for eutrophication for this assessment with all water bodies classified as *Impaired* for 2012–2014 nutrient measurements. Other assessment observations that may also reflect symptoms of eutrophication include the low water clarity demonstrated through Secchi disk measurements and the high density of invasive variable milfoil and fanwort found throughout the shallow fringe of Lake Sabbatia.

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.

The observations recorded on substrate conditions at Lake Sabbatia were collected at LS-2. Vascular plants comprised roughly 30% of the substrate in May, and dominated the substrate from June through September (80%–100%). Beneath the vascular plants, silt was dominant, with some sand and gravel noted below the silt. Only three species of vascular plant were noted at LS-2: the invasive variable milfoil and fanwort, and the native bladderwort. The two invasive plants were highly abundant at LS-2 and throughout most of the Lake's shallow fringe. Water lily was present at various locations away from sampling stations. Other native plant species may also have been present in Lake Sabbatia but were not observed.

Substrate sampling for Watson Pond was conducted at WAP-3 and WAP-5. Vascular plants dominated the substrate later in the season. A silt layer occurred beneath the vascular plants, with the presence of some gravel. The Winnecunnet Pond substrate had similar composition as Watson Pond. Both ponds shared the presence of invasive vascular plants including variable milfoil and fanwort (Figure 12), in addition to native water lily and yellow pond lily (also called spadderdock).

Additional Water Quality Data

Turbidity

Turbidity in water is caused by suspended inorganic and organic matter. Concentrations of organic material can relate to productivity and high levels of inorganic particulates can threaten aquatic life, especially filter feeders. No MassDEP or US EPA reference conditions are provided for turbidity in lakes and ponds, therefore the QAPP does not have a turbidity criterion. The US EPA turbidity reference condition for rivers in subecoregion #59 is ≤ 1.7 NTU (US EPA 2001). Similar to the Secchi disk measurements, the turbidity observations in Lake Sabbatia reflected consistently low water clarity. The average turbidity for all samples at the transect stations was 2.02 NTU (N = 155, SE = 0.218). Watson Pond was similarly turbid to Lake Sabbatia. The average turbidity for all samples at the three Watson Pond transect stations was 2.10 NTU (N = 82, SE = 0.254). Winnecunnet Pond had higher turbidity than the other two water bodies, with an average of 3.53 NTU (N = 90, SE = 0.416) at the three transect stations.

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 US 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. of natural alkaline compounds or ionic contributions from pollution sources.

Specific conductivity at Lake Sabbatia was relatively low with little variability among stations and depth strata. The average for all transect measurements was 0.181 mS/cm (N = 166, SE = 0.002). Watson Pond's specific conductivity had similar stability and a higher average of 0.223 mS/cm (N = 84, SE = 0.001). Winnecunnet Pond had a similar average specific conductivity to Watson Pond of 0.236 (N = 90, SE = 0.006); however, with unexplained annual differences (2013: mean = 0.198, N = 44, SE = 0.007; 2014: mean = 0.273, N = 46, SE = 0.004).

Figure 11. The newly installed eel ramp at Morey's Bridge Dam in 2014

Figure 12. The invasive fanwort plant in Lake Sabbatia.

Carlson Trophic State Index
The Carlson Trophic State Index (TSI) (Carlson 1977) is a commonly used classification that relates water chemistry indicators associated with algal biomass to an expected range of trophic conditions. The TSI established relationships for TP, chlorophyll a, and Secchi disk depth with a score ranging 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 TSIs for these parameters relates to a numeric scale of trophic state where the expected changes in trophic status are connected by the concept that increasing nutrients elevate plant productivity and result in reduced water clarity.

The mean Secchi disk measurements for all transect measurements at Lake Sabbatia, Watson Pond, and Winnecunnet Pond resulted in TSI scores of 53.7, 50.2, and 51.8, respectively. The mean TP measurements for all transect measurements at Lake Sabbatia, Watson Pond, and Winnecunnet Pond resulted in TSI scores of 51.6, 55.8, and 52.0. All these scores are in the index range for eutrophy (Carlson 1977). The index attributes for scores in the 50s include anoxic hypolimnia, macrophyte problems, and reduced water clarity: all conditions observed during the assessment. These symptoms of eutrophy appeared most obvious at Lake Sabbatia among the three water bodies; however, the separation in index scores was minor and Lake Sabbatia had the lowest average TP TSI. These TSI values are higher than found for the two previously reported habitat assessments that were both conducted at municipal water supply reservoirs. Silver Lake in Kingston had TSI scores of 35.6 for TP and 44.6 for Secchi disk (Chase et al. 2013), and Great Pond Reservoir in Braintree had TSI scores of 31.6 for TP and 41.8 for Secchi disk (Chase et al. 2015); all scores below the eutrophic range.

Shallow Off-Transect Stations
Two shallow off-transect stations were visited to investigate potential spawning and nursery habitat at other locations in Lake Sabbatia. Station LS-7 (shallow area at southeast edge) was sampled four times in 2012 and two times in 2013. Station LS-8 (shallow area near the boat ramp off Bay Street) was sampled with the same frequency as the transect stations. Both stations had a maximum depth of approximately 2.5 m, dense growth of invasive plants, and silt dominated substrate. Water quality conditions were generally consistent with the shallow transect stations. Neither station had temperature exceedances, but both had a few exceedances each for DO and pH.

QA/QC Summary

Field and laboratory measurements conducted for the habitat assessment are guided by sampling protocols and data quality objectives from the project's QAPP (Chase 2010) that rely on parameter-based precision and accuracy indicators. Data are classified as *Final*, *Conditional*, or *Censored* based on calibration performance, agreement of precision and accuracy checks to QAPP criteria, and the relation of outliers to data distributions. All laboratory calibration and laboratory and field precision checks for 2012–2014 were acceptable. Several potential nutrient outliers required further review. A high TP sample at WAP-4 on Sept. 20, 2012 was *Censored* for exceeding the mean of all TP samples by 3 SD.

Diadromous Fish Observations

As part of a cooperative effort to monitor the response of river herring to Mill River restoration, a video monitoring station was placed upstream of the recently removed Hopewell Mills Dam in 2013. During the spring of 2013, the first year of possible passage above the removed dam, an estimated 900 river herring were recorded moving upstream of the video station. River herring were documented at the video station from April 1 through May 14, 2013. In addition to river herring, 12 other species were observed at the video monitoring site, including the diadromous white perch (*Morone americana*), American eel, and sea lamprey. The most common freshwater fish species were yellow perch (*Perca flavescens*) and white sucker (*Catostomus commersonii*).

The next obstruction upstream of the video station is the West Brittania Dam, which was not removed at the time of the habitat assessment, but since removal, river herring have been observed entering Lake Sabbatia via the Morey's Bridge Dam fish ladder.

In addition to river herring monitoring, American eel monitoring commenced in 2014 and was carried out at the eel ramp installed at the new Morey's Bridge Dam. In 2014, 428 young-of-the-year and 2,943 age-1 eels passed through the ramp. Also included in the cooperative restoration monitoring was a 2014 lamprey redd survey upstream of the Hopewell Mills Dam removal site. This effort documented the presence of 33 lamprey redds in the newly restored and accessible channel substrate along a 400 meter river length upstream of the dam site (Livermore et al. 2017).

Conclusion

The Mill River watershed river herring habitat assessment occurred during a period of exceptional progress towards the goal of restoring migratory fish passage and natural functions to the Mill River. Two of four main stem dams were removed during the study period and the Morey's Bridge Dam was fully reconstructed with a fish ladder, eel ramp, and low-flow channel for juvenile river herring emigration. This is only the second coastal dam in Massachusetts; the Mystic Lakes Dam in Medford was the first in 2011, constructed with these three fish passage facilities integrated into the design and construction. With the removal of the West Brittania Dam, the Mill River restoration project has achieved unprecedented success in coastal Massachusetts with three dam removals and restoring access to 30 km of riverine habitat and over 400 acres of spawning and nursery habitat.

The habitat assessment identifies water quality and aquatic habitat impairment requiring attention to ensure that populations of diadromous fish can successfully use the upstream habitat. Lake Sabbatia, Watson Pond, and Winnecunnet Pond were all classified as *Impaired* for DO, pH, Secchi disk, TN, and TP. Watson Pond was additionally classified as *Impaired* for water temperature during the nursery period. Each pond was found to have a high level of TP impairment as all measurements exceeded the TP criterion.

Lake Sabbatia was more impaired than the other ponds, as evident by having the highest percentage exceedance for each of the *Impaired* parameters, except DO (Winnecunnet Pond) and TP (all were 100%). Furthermore, concerns are raised for Lake Sabbatia due to the widespread high abundance of invasive fanwort and variable milfoil and the presence of anoxia or hypoxia for over 60% of the water column at the deep station during the summer months.

Despite the high level of impairment classified for Watson Pond, there was clearly a gradient of water quality between Lake Sabbatia and Watson Pond. The *Impaired* classifications for temperature, DO, and pH at Watson Pond marginally exceeded the thresholds. The spawning substrate of the shallow fringe in Watson Pond is far less impacted than at Lake Sabbatia. This finding suggests that extending river herring passage from Lake Sabbatia to Watson Pond should be considered. Further attention is needed to address concern over the compatibility of dense growth of invasive plants to the spawning substrate and juvenile rearing habitat for river herring and over the elevated nutrient concentrations in each water body.

Recommendations

1. Watson Pond Control Boards
The culvert under Bay Street that allows flow from Watson Pond to Lake Sabbatia has wood control boards maintained to meet desired pond levels by DCR. Removal of some boards may allow seasonal passage of river herring into Watson Pond, but could lead to a reduction in the pond level. It is recommended that DMF and DCR staff explore the potential to combine seasonal flow management with the installation of a custom, low volume, weir and pool fish ladder at the control structure at Watson Pond to allow river herring to access this habitat.

2. Invasive Plant Management
The proliferation of variable milfoil and fanwort has reduced recreational opportunities—such as boating and swimming—in Lake Sabbatia and could be having adverse impacts on native species of plants and animals; however, little is known on long-term human and ecological effects of invasive plants in the watershed. Related to river herring, there is concern that the shallow fringes typically used for river herring spawning may be negatively altered as coarse substrate is buried by the silt produced during annual decomposition of the dense plant beds. Investigations that contribute to management actions on the causes and effects of invasive plants on the health of Lake Sabbatia and river herring spawning and nursery habitat are needed.

3. Nutrient Management
Elevated concentrations of TN and TP were documented in the habitat assessment. These nutrient levels may be contributing to the high growth of invasive plants in each waterbody. A multi-jurisdictional effort should be initiated to identify point sources and stormwater sources of nutrient loading and to develop management plans for remediation.

4. 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

Table A.1 Station locations

Table A.2 Lake Sabbatia water chemistry LS2

Table A.3 Lake Sabbatia water chemistry LS3

Table A.4 Lake Sabbatia water chemistry LS4

Table A.5 Lake Sabbatia water chemistry LS5

Table A.6 Watson Pond water chemistry WAP-3

Table A.7 Watson Pond water chemistry WAP-4

Table A.8 Watson Pond water chemistry WAP-5

Table A.9 Winnecunnet Pond water chemistry WIN-2

Table A.10 Winnecunnet Pond water chemistry WIN-3

Table A.11 Winnecunnet Pond water chemistry WIN-4

Table A.1. Station locations sampled during the Lake Sabbatia habitat assessment, 2012-2014.

No.	Latitude	Longitude	Station Type	Depth Strata	Max. Depth (m)	Sample (No.)	Location
LS-1	41.93427	-71.10815	outlet	dam	2.5	12	Morey's Bridge Dam
LS-2	41.93962	-71.11066	transect	shallow	1.6	12	Lake Sabbatia
LS-3	41.94355	-71.11067	transect	deep	8.0	12	Lake Sabbatia
LS-4	41.94568	-71.11131	transect	mid	4.7	12	Lake Sabbatia
LS-5	41.94703	-71.11126	transect	shallow	2.4	12	Lake Sabbatia
LS-6	41.95130	-71.10470	inlet	shallow	2.6	10	Snake River
LS-7	41.94021	-71.10476	off-transect	shallow	2.8	7	Lake Sabbatia
LS-8	41.94503	-71.11345	off-transect	shallow	2.0	6	Lake Sabbatia
WAP-1	41.94818	-71.11374	outlet	culvert	2.2	11	Watson Pond
WAP-3	41.94811	-71.11683	transect	mid	3.5	13	Watson Pond
WAP-4	41.95117	-71.11951	transect	shallow	2.8	13	Watson Pond
WAP-5	41.95303	-71.12192	transect	shallow	2.0	13	Watson Pond
WIN-1	41.96715	-71.12548	outlet	shallow	1.7	9	Snake River
WIN-2	41.96703	-71.13018	transect	shallow	3.9	7	Winnicunnet Pond
WIN-3	41.97240	-71.13073	transect	mid	4.3	10	Winnicunnet Pond
WIN-4	41.96912	-71.13080	transect	shallow	3.0	9	Winnicunnet Pond
WIN-5	41.97295	-71.13525	inlet	shallow	2.5	8	Winnicunnet Pond

Table A.2. Summary water chemistry data collected at station LS2 at Lake Sabbatia, 2012 and 2013. The maximum sample size at each depth level was eight.

Surface (0.3 m depth)

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	8	23.22	0.96	23.60	≤26.0 / ≤28.3	100
pH	(SU)	8	6.78	0.10	6.67	≥6.5, ≤8.3	100
DO	(mg/L)	8	7.78	0.42	7.54	≥5.0	100
DO sat.	%	8	90.8	4.9	89.9	NA	NA
Turbidity	(NTU)	7	2.4	0.8	2.0	NA	NA
Sp. Cond.	(mS/cm)	8	0.181	0.007	0.182	NA	NA
TN	(mg/L)	NA	NA	NA	NA	0.320	NA
TP	(ug/L)	NA	NA	NA	NA	8.000	NA
Secchi	(m)	2	1.5	0.0	1.5	≥2.0	0

Bottom-water (1.0 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	7	22.45	1.12	22.12	≤26.0 / ≤28.3	100
pH	(SU)	7	6.61	0.09	6.54	≥6.5, ≤8.3	100
DO	(mg/L)	7	6.58	0.47	6.16	≥5.0	100
DO sat.	%	7	75.7	5.4	70.9	NA	NA
Turbidity	(NTU)	7	3.4	1.3	2.1	NA	NA
Sp. Cond.	(mS/cm)	7	0.180	0.008	0.179	NA	NA

Table A.3. Summary water chemistry data collected at station LS3 at Lake Sabbatia, 2012 and 2013. The maximum sample size at each depth level was twelve.

Surface (0.3 m depth)

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	23.37	0.81	23.02	≤26.0 / ≤28.3	100
pH	(SU)	10	6.59	0.11	6.66	≥6.5, ≤8.3	70
DO	(mg/L)	10	6.82	0.38	6.99	≥5.0	100
DO sat.	%	10	79.9	4.3	79.6	NA	NA
Turbidity	(NTU)	10	1.1	0.2	0.8	NA	NA
Sp. Cond.	(mS/cm)	10	0.177	0.009	0.182	NA	NA
TN	(mg/L)	11	0.432	0.021	0.445	0.320	9
TP	(ug/L)	11	22.473	1.601	19.500	8.000	0
Secchi	(m)	11	1.6	0.1	1.6	≥2.0	20

Mid-water (1.0 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	22.69	0.85	21.74	≤26.0 / ≤28.3	100
pH	(SU)	10	6.57	0.10	6.67	≥6.5, ≤8.3	70
DO	(mg/L)	10	6.53	0.39	6.94	≥5.0	80
DO sat.	%	10	74.7	4.1	79.1	NA	NA
Turbidity	(NTU)	10	1.1	0.2	1.0	NA	NA
Sp. Cond.	(mS/cm)	10	0.177	0.008	0.182	NA	NA

Mid-water (2.0 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	21.23	0.96	20.47	≤26.0 / ≤28.3	100
pH	(SU)	10	6.38	0.10	6.40	≥6.5, ≤8.3	30
DO	(mg/L)	10	5.26	0.58	5.37	≥5.0	60
DO sat.	%	10	58.7	6.0	57.7	NA	NA
Turbidity	(NTU)	10	1.3	0.2	1.1	NA	NA
Sp. Cond.	(mS/cm)	10	0.352	0.178	0.181	NA	NA

Mid-water (3.0 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	18.57	0.74	18.18	≤26.0 / ≤28.3	100
pH	(SU)	10	6.27	0.10	6.26	≥6.5, ≤8.3	20
DO	(mg/L)	10	3.60	0.92	3.94	≥5.0	30
DO sat.	%	10	37.9	9.6	42.2	NA	NA
Turbidity	(NTU)	10	1.1	0.2	0.8	NA	NA
Sp. Cond.	(mS/cm)	10	0.170	0.009	0.174	NA	NA

Table A.3. Continued

Mid-water (4.0 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	16.41	0.59	16.34	≤26.0 / ≤28.3	100
pH	(SU)	10	6.23	0.09	6.23	≥6.5, ≤8.3	20
DO	(mg/L)	10	2.72	0.91	1.88	≥5.0	30
DO sat.	%	10	27.9	9.3	18.4	NA	NA
Turbidity	(NTU)	10	2.1	0.7	1.0	NA	NA
Sp. Cond.	(mS/cm)	10	0.169	0.086	0.170	NA	NA

Mid-water (5.0 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	14.42	0.41	14.44	≤26.0 / ≤28.3	100
pH	(SU)	10	6.28	0.06	6.31	≥6.5, ≤8.3	10
DO	(mg/L)	10	1.93	0.74	0.44	≥5.0	20
DO sat.	%	10	18.6	7.1	4.3	NA	NA
Turbidity	(NTU)	10	3.8	1.7	1.2	NA	NA
Sp. Cond.	(mS/cm)	10	0.184	0.065	0.184	NA	NA

Mid-water (6.0 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	9	12.73	0.21	12.90	≤26.0 / ≤28.3	100
pH	(SU)	9	6.42	0.09	6.31	≥6.5, ≤8.3	33
DO	(mg/L)	9	1.50	0.55	0.37	≥5.0	0
DO sat.	%	9	14.0	5.1	3.5	NA	NA
Turbidity	(NTU)	9	3.7	2.2	1.3	NA	NA
Sp. Cond.	(mS/cm)	9	0.206	0.090	0.211	NA	NA

Bottom-water (7.0 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	9	11.52	0.15	11.60	≤26.0 / ≤28.3	100
pH	(SU)	9	6.50	0.10	6.36	≥6.5, ≤8.3	44
DO	(mg/L)	9	1.02	0.40	0.42	≥5.0	0
DO sat.	%	9	9.2	3.6	3.9	NA	NA
Turbidity	(NTU)	9	4.1	1.5	1.9	NA	NA
Sp. Cond.	(mS/cm)	9	0.223	0.102	0.225	NA	NA

Note: Temperature criterion is ≤ 26.0 °C for May/June and ≤ 28.3 °C for July-September.

Table A.4. Summary water chemistry data collected at station LS4 at Lake Sabbatia, 2012 and 2013. The maximum sample size at each depth level was ten.

Surface (0.3 m depth)

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	23.66	0.78	23.33	≤26.0 / ≤28.3	100
pH	(SU)	10	6.55	0.09	6.61	≥6.5, ≤8.3	70
DO	(mg/L)	10	6.63	0.39	6.92	≥5.0	70
DO sat.	%	10	70.7	8.5	80.3	NA	NA
Turbidity	(NTU)	10	1.2	0.2	1.1	NA	NA
Sp. Cond.	(mS/cm)	10	0.176	0.008	0.183	NA	NA
TN	(mg/L)	NA	NA	NA	NA	0.320	NA
TP	(ug/L)	NA	NA	NA	NA	8.000	NA
Secchi	(m)	10	1.6	0.1	1.6	≥2.0	0

Mid-water (1.0 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	22.99	0.81	22.54	≤26.0 / ≤28.3	100
pH	(SU)	10	6.50	0.09	6.57	≥6.5, ≤8.3	70
DO	(mg/L)	10	6.11	0.44	6.24	≥5.0	60
DO sat.	%	10	64.2	8.1	64.6	NA	NA
Turbidity	(NTU)	10	1.2	0.2	1.2	NA	NA
Sp. Cond.	(mS/cm)	10	0.176	0.008	0.182	NA	NA

Mid-water (2.0 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	21.23	0.94	20.45	≤26.0 / ≤28.3	100
pH	(SU)	10	6.33	0.11	6.33	≥6.5, ≤8.3	30
DO	(mg/L)	10	4.41	0.67	3.69	≥5.0	40
DO sat.	%	10	43.3	7.9	36.8	NA	NA
Turbidity	(NTU)	10	1.3	0.1	1.3	NA	NA
Sp. Cond.	(mS/cm)	10	0.177	0.009	0.183	NA	NA

Mid-water (3.0 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	10	18.63	0.80	18.21	≤26.0 / ≤28.3	100
pH	(SU)	10	6.27	0.10	6.29	≥6.5, ≤8.3	20
DO	(mg/L)	10	3.54	0.87	3.83	≥5.0	30
DO sat.	%	10	33.6	9.6	27.7	NA	NA
Turbidity	(NTU)	10	1.2	0.2	1.3	NA	NA
Sp. Cond.	(mS/cm)	8	0.173	0.010	0.181	NA	NA

Table A.4. Continued.

Bottom-water (4.0 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting Criterion (%)
Temp.	(°C)	7	16.58	1.97	0.75	≤26.0 / ≤28.3	100
pH	(SU)	7	6.23	0.31	0.12	≥6.5, ≤8.3	29
DO	(mg/L)	7	3.43	3.11	1.18	≥5.0	43
DO sat.	%	7	34.9	32.6	12.3	NA	NA
Turbidity	(NTU)	7	2.9	2.3	0.9	NA	NA
Sp. Cond.	(mS/cm)	6	0.170	0.030	0.011	NA	NA

Note: Temperature criterion is ≤ 26.0 °C for May/June and ≤ 28.3 °C for July-September.

Table A.5. Summary water chemistry data collected at station LS5 at Lake Sabbatia, 2012 and 2013. The maximum sample size at each depth level was ten.

Surface (0.3 m depth)

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting
Temp.	(°C)	10	21.83	0.92	21.38	≤26.0 / ≤28.3	100
pH	(SU)	10	6.24	0.10	6.19	≥6.5, ≤8.3	10
DO	(mg/L)	10	5.29	0.57	5.07	≥5.0	50
DO sat.	%	10	60.3	6.8	54.3	NA	NA
Turbidity	(NTU)	9	1.5	0.3	1.4	NA	NA
Sp. Cond.	(mS/cm)	10	0.178	0.009	0.186	NA	NA
TN	(mg/L)	NA	NA	NA	NA	0.320	NA
TP	(ug/L)	NA	NA	NA	NA	8.000	NA
Secchi	(m)	7	1.2	0.1	1.3	≥2.0	0

Mid-water (1.0 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting
Temp.	(°C)	10	21.41	0.81	21.36	≤26.0 / ≤28.3	100
pH	(SU)	10	6.14	0.07	6.10	≥6.5, ≤8.3	0
DO	(mg/L)	10	4.12	0.57	4.13	≥5.0	30
DO sat.	%	10	45.6	6.1	46.7	NA	NA
Turbidity	(NTU)	9	2.5	0.3	2.4	NA	NA
Sp. Cond.	(mS/cm)	10	0.181	0.009	0.193	NA	NA

Bottom-water (1.5 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	WQ Criterion	Meeting
Temp.	(°C)	4	21.65	1.13	21.16	≤26.0 / ≤28.3	100
pH	(SU)	4	6.02	0.07	6.06	≥6.5, ≤8.3	0
DO	(mg/L)	4	3.09	0.74	2.88	≥5.0	0
DO sat.	%	4	34.9	8.2	32.1	NA	NA
Turbidity	(NTU)	2	2.0	0.8	2.0	NA	NA
Sp. Cond.	(mS/cm)	4	0.187	0.021	0.204	NA	NA

Note: Temperature criterion is ≤ 26.0 °C for May/June and ≤ 28.3 °C for July-September.

Table A.6. Summary water chemistry data collected at station WAP-3 at Watson Pond, 2012 and 2013. The maximum sample size at the 0.3 m depth was nine.

Surface (0.3 m depth)

Parameter	Unit	N	Mean	SE	Median	WQ	Meeting
Temp.	(°C)	9	24.68	1.15	23.83	≤26.0 / ≤28.3	78
pH	(SU)	9	7.14	0.10	7.07	≥6.5, ≤8.3	89
DO	(mg/L)	9	8.52	0.24	8.71	≥5.0	100
DO sat.	%	9	100.6	3.2	101.0	NA	NA
Turbidity	(NTU)	9	2.0	0.7	1.2	NA	NA
Sp. Cond.	(mS/cm)	9	0.221	0.003	0.220	NA	NA
TN	(mg/L)	4	0.260	0.047	0.245	0.320	75
TP	(*u*g/L)	4	23.875	4.947	21.650	8.000	0
Secchi	(m)	3	1.6	0.1	1.6	≥2.0	0

Mid-water (1.0 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	Criterion	Criterion (%)
Temp.	(°C)	9	24.36	1.03	23.40	≤26.0 / ≤28.3	78
pH	(SU)	9	7.09	0.09	7.00	≥6.5, ≤8.3	100
DO	(mg/L)	9	8.56	0.20	8.69	≥5.0	100
DO sat.	%	9	100.59	2.80	101.50	NA	NA
Turbidity	(NTU)	9	1.93	0.87	1.00	NA	NA
Sp. Cond.	(mS/cm)	9	0.22	0.00	0.22	NA	NA

Bottom-water (1.5 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	Criterion	Criterion (%)
Temp.	(°C)	6	23.47	1.28	22.21	≤26.0 / ≤28.3	100
pH	(SU)	6	6.84	0.07	6.88	≥6.5, ≤8.3	100
DO	(mg/L)	6	7.89	0.49	8.47	≥5.0	100
DO sat.	%	5	95.00	3.31	97.40	NA	NA
Turbidity	(NTU)	5	3.80	2.06	2.10	NA	NA
Sp. Cond.	(mS/cm)	6	0.22	0.00	0.22	NA	NA

Table A.7. Summary water chemistry data collected at station WAP-4 at Watson Pond, 2012 and 2013. The maximum sample size at the 0.3 m depth was ten.

Surface (0.3 m depth)

Parameter	Unit	N	Mean	SE	Median	WQ	Meeting
Temp.	(°C)	10	24.56	1.02	23.64	≤26.0 / ≤28.3	90
pH	(SU)	10	7.12	0.11	7.02	≥6.5, ≤8.3	100
DO	(mg/L)	10	8.70	0.30	8.64	≥5.0	100
DO sat.	%	10	103.3	3.8	103.3	NA	NA
Turbidity	(NTU)	10	1.8	0.9	1.1	NA	NA
Sp. Cond.	(mS/cm)	10	0.221	0.002	0.220	NA	NA
TN	(mg/L)	6	0.350	0.350	0.314	0.320	50
TP	(u g/L)	6	35.960	10.523	20.700	8.000	0
Secchi	(m)	6	2.0	0.4	2.1	≥2.0	83.33

Mid-water (1.0 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	Criterion	Criterion (%)
Temp.	(°C)	10	24.24	0.90	23.35	≤26.0 / ≤28.3	90
pH	(SU)	10	7.03	0.09	7.06	≥6.5, ≤8.3	100
DO	(mg/L)	10	8.23	0.65	8.65	≥5.0	100
DO sat.	%	10	102.7	3.6	103.0	NA	NA
Turbidity	(NTU)	10	1.5	0.5	1.1	NA	NA
Sp. Cond.	(mS/cm)	10	0.221	0.002	0.220	NA	NA

Bottom-water (2.0 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	Criterion	Criterion (%)
Temp.	(°C)	10	23.01	0.67	22.45	≤26.0 / ≤28.3	100
pH	(SU)	10	6.51	0.11	6.36	≥6.5, ≤8.3	40
DO	(mg/L)	10	5.46	1.32	5.27	≥5.0	40
DO sat.	%	10	69.2	15.1	80.9	NA	NA
Turbidity	(NTU)	10	4.0	1.1	3.1	NA	NA
Sp. Cond.	(mS/cm)	10	0.229	0.005	0.226	NA	NA

Table A.8. Summary water chemistry data collected at station WAP-5 at Watson Pond, 2012 and 2013. The maximum sample size at the 0.3 m depth was ten.

Surface (0.3 m depth)

Parameter	Unit	N	Mean	SE	Median	WQ	Meeting
Temp.	(°C)	10	24.75	0.97	24.18	≤26.0 / ≤28.3	90
pH	(SU)	10	7.35	0.21	7.17	≥6.5, ≤8.3	100
DO	(mg/L)	10	8.65	0.53	8.83	≥5.0	90
DO sat.	%	9	108.8	3.5	106.0	NA	NA
Turbidity	(NTU)	10	1.2	0.4	0.6	NA	NA
Sp. Cond.	(mS/cm)	10	0.222	0.003	0.221	NA	NA
TN	(mg/L)	NA	NA	NA	NA	0.320	NA
TP	(*u*g/L)	NA	NA	NA	NA	8.000	NA
Secchi	(m)	2	1.6	0.0	1.6	≥2.0	0

Mid-water (1.0 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	Criterion	Criterion (%)
Temp.	(°C)	10	24.11	0.86	23.28	≤26.0 / ≤28.3	90
pH	(SU)	10	6.98	0.13	6.88	≥6.5, ≤8.3	90
DO	(mg/L)	10	8.61	0.33	8.79	≥5.0	100
DO sat.	%	9	105.1	3.1	104.3	NA	NA
Turbidity	(NTU)	10	1.5	0.4	1.3	NA	NA
Sp. Cond.	(mS/cm)	10	0.221	0.003	0.220	NA	NA

Bottom-water (1.5 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	Criterion	Criterion (%)
Temp.	(°C)	7	23.10	0.91	22.44	≤26.0 / ≤28.3	100
pH	(SU)	7	6.73	0.20	6.69	≥6.5, ≤8.3	71
DO	(mg/L)	7	6.86	1.27	8.15	≥5.0	71
DO sat.	%	7	91.9	9.0	101.3	NA	NA
Turbidity	(NTU)	7	2.5	1.2	1.6	NA	NA
Sp. Cond.	(mS/cm)	7	0.222	0.004	0.218	NA	NA

Table A.9. Summary water chemistry data collected at station WIN-2 at Winnecunnet Pond, 2013 and 2014. The maximum sample size at the 0.3 m depth was seven.

Surface (0.3 m depth)

Parameter	Unit	N	Mean	SE	Median	WQ	Meeting
Temp.	(°C)	7	22.12	0.85	22.62	≤26.0 / ≤28.3	100
pH	(SU)	7	6.84	0.19	6.71	≥6.5, ≤8.3	86
DO	(mg/L)	7	8.29	0.39	8.62	≥5.0	100
DO sat.	%	7	95.9	5.2	96.0	NA	NA
Turbidity	(NTU)	7	3.2	1.2	1.8	NA	NA
Sp. Cond.	(mS/cm)	7	0.240	0.023	0.256	NA	NA
TN	(mg/L)	NA	NA	NA	NA	0.320	NA
TP	(ug/L)	NA	NA	NA	NA	8.000	NA
Secchi	(m)	3	1.0	0.2	0.9	≥2.0	0

Bottom-water (0.8 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	Criterion	Criterion (%)
Temp.	(°C)	5	21.30	1.05	22.00	≤26.0 / ≤28.3	100
pH	(SU)	5	6.35	0.18	6.44	≥6.5, ≤8.3	40
DO	(mg/L)	5	4.51	0.95	4.37	≥5.0	40
DO sat.	%	5	49.2	9.3	52.3	NA	NA
Turbidity	(NTU)	5	3.7	1.1	2.2	NA	NA
Sp. Cond.	(mS/cm)	5	0.253	0.028	0.265	NA	NA

Note: Temperature criterion is ≤ 26.0 ˚C for May/June and ≤ 28.3 ˚C for July-September.

Table A.10. Summary water chemistry data collected at station WIN-3 at Winnecunnet Pond, 2013 and 2014. The maximum sample size at the 0.3 m depth was nine.

Surface (0.3 m depth)

Parameter	Unit	N	Mean	SE	Median	WQ	Meeting
Temp.	(°C)	9	23.15	1.03	23.03	≤26.0 / ≤28.3	100
pH	(SU)	9	6.63	0.11	6.64	≥6.5, ≤8.3	67
DO	(mg/L)	9	7.06	0.41	6.48	≥5.0	100
DO sat.	%	9	82.3	4.4	76.8	NA	NA
Turbidity	(NTU)	9	1.6	0.4	1.5	NA	NA
Sp. Cond.	(mS/cm)	9	0.227	0.020	0.227	NA	NA
TN	(mg/L)	9	0.475	0.057	0.518	0.320	11
TP	(ug/L)	9	27.656	2.546	24.600	8.000	0
Secchi	(m)	9	1.7	0.1	1.7	≥2.0	0

Mid-water (1.1 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	Criterion	Criterion (%)
Temp.	(°C)	9	21.85	0.81	21.16	≤26.0 / ≤28.3	100
pH	(SU)	9	6.49	0.13	6.36	≥6.5, ≤8.3	44
DO	(mg/L)	9	5.51	1.00	6.14	≥5.0	56
DO sat.	%	9	62.7	11.5	71.6	NA	NA
Turbidity	(NTU)	9	2.5	0.8	1.2	NA	NA
Sp. Cond.	(mS/cm)	9	0.235	0.019	0.243	NA	NA

Mid-water (2.1 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	Criterion	Criterion (%)
Temp.	(°C)	9	20.51	0.80	20.14	≤26.0 / ≤28.3	100
pH	(SU)	9	6.44	0.13	6.50	≥6.5, ≤8.3	56
DO	(mg/L)	9	3.88	1.21	1.71	≥5.0	44
DO sat.	%	9	44.0	13.8	19.0	NA	NA
Turbidity	(NTU)	9	3.4	0.8	2.9	NA	NA
Sp. Cond.	(mS/cm)	9	0.237	0.018	0.227	NA	NA

Mid-water (3.0 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	Criterion	Criterion (%)
Temp.	(°C)	9	17.69	0.86	16.75	≤26.0 / ≤28.3	100
pH	(SU)	9	6.37	0.18	6.47	≥6.5, ≤8.3	33
DO	(mg/L)	9	2.46	0.96	0.49	≥5.0	22
DO sat.	%	9	26.5	10.6	5.4	NA	NA
Turbidity	(NTU)	9	5.7	1.4	3.5	NA	NA
Sp. Cond.	(mS/cm)	9	0.247	0.020	0.273	NA	NA

Table A.10. Continued.

Bottom-water (3.4 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	Criterion	Criterion (%)
Temp.	(°C)	6	15.60	0.47	15.24	≤26.0 / ≤28.3	100
pH	(SU)	6	6.10	0.41	6.25	≥6.5, ≤8.3	56
DO	(mg/L)	6	1.02	0.54	0.43	≥5.0	33
DO sat.	%	6	10.2	5.4	4.3	NA	NA
Turbidity	(NTU)	6	10.7	3.6	7.7	NA	NA
Sp. Cond.	(mS/cm)	6	0.237	0.025	0.255	NA	NA

Note: Temperature criterion is ≤ 26.0 ˚C for May/June and ≤ 28.3 ˚C for July-September.

Table A.11. Summary water chemistry data collected at station WIN-4 at Winnecunnet Pond, 2013 and 2014. The maximum sample size at the 0.3 m depth was nine.

Surface (0.3 m depth)

Parameter	Unit	N	Mean	SE	Median	WQ	Meeting
Temp.	(°C)	8	23.50	0.87	23.45	≤26.0 / ≤28.3	100
pH	(SU)	8	6.69	0.11	6.72	≥6.5, ≤8.3	75
DO	(mg/L)	8	8.06	0.51	7.58	≥5.0	100
DO sat.	%	8	94.3	5.7	86.9	NA	NA
Turbidity	(NTU)	8	5.8	0.6	1.9	NA	NA
Sp. Cond.	(mS/cm)	8	0.284	0.018	0.220	NA	NA
TN	(mg/L)	NA	NA	NA	NA	0.320	NA
TP	(ug/L)	NA	NA	NA	NA	8.000	NA
Secchi	(m)	7	1.6	0.1	1.7	≥2.0	0

Mid-water (1.1 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	Criterion	Criterion (%)
Temp.	(°C)	8	21.37	0.80	20.90	≤26.0 / ≤28.3	100
pH	(SU)	8	6.29	0.07	6.30	≥6.5, ≤8.3	13
DO	(mg/L)	8	4.70	0.95	4.03	≥5.0	38
DO sat.	%	8	52.9	11.1	44.1	NA	NA
Turbidity	(NTU)	8	2.6	0.7	2.1	NA	NA
Sp. Cond.	(mS/cm)	8	0.234	0.025	0.229	NA	NA

Bottom-water (1.9 m ave. depth)

Parameter	Unit	N	Mean	SE	Median	Criterion	Criterion (%)
Temp.	(°C)	9	19.64	0.78	19.56	≤26.0 / ≤28.3	100
pH	(SU)	9	6.18	0.10	6.19	≥6.5, ≤8.3	22
DO	(mg/L)	9	2.16	0.74	1.05	≥5.0	22
DO sat.	%	9	24.0	8.3	11.0	NA	NA
Turbidity	(NTU)	9	3.3	0.4	3.0	NA	NA
Sp. Cond.	(mS/cm)	9	0.225	0.017	0.243	NA	NA