Technical Report

Massachusetts Division of Marine Fisheries
Technical Report TR-54

River Herring Spawning and Nursery Habitat Assessment

Silver Lake 2008-2009

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River Herring Spawning and Nursery Habitat Assessment

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Mary B. Griffin, Commissioner
Massachusetts Division of Marine Fisheries
Paul Diodati, Director

Abstract: River herring are native, diadromous fish that make spring spawning runs to coastal rivers in Massachusetts seeking suitable freshwater habitat for egg incubation and juvenile rearing. River herring is the common name for two similar species; the alewife (*Alosa psuedoharengus*) and blueback herring (*Alosa aestivalis*). River herring are important forage for many species of fish and wildlife and formerly supported valuable commercial, recreational, and subsistence fisheries. The Massachusetts Division of Marine Fisheries (*MarineFisheries*) conducts river herring spawning and nursery habitat assessments to assist habitat and population restoration efforts and to contribute to Massachusetts Department of Environmental Protection (*Mass*DEP) Waterbody Assessments. Silver Lake, in the Jones River Watershed, was assessed during 2008-2009 in collaboration with the Jones River Watershed Association. At the time of the assessment, two impassable dams prevented river herring from accessing the 643 acres of potential spawning and nursery habitat in Silver Lake. Project partners initiated the assessment to confirm the status of Silver Lake for supporting the restoration of sea-run fish. A comparison of field data to river herring habitat assessment criteria resulted in the classification of: *Impaired* for dissolved oxygen, pH, total nitrogen, total phosphorus, fish passage, and stream flow; and *Suitable* for water temperature and Secchi disc. Despite the finding of impairment among assessment criteria, several parameters had marginal exceedances or were limited spatially due to seasonal stratification and would not be considered a threat to early life stages of river herring. Overall, much of Silver Lake had water quality conditions that would support river herring spawning and nursery habitat requirements. The most significant impairment for the goal of restoring river herring to Silver Lake was fish passage obstruction at Forge Pond Dam and reduced stream flow that could prevent juvenile herring emigration during summer and early fall.

Introduction

Silver Lake is the primary headwaters of the Jones River watershed and the largest lake in the South Shore Coastal Drainage Area of Massachusetts. Silver Lake is a naturally formed lake of 634 acres that is over 3 km in length with a maximum depth of about 20 m. The Jones River runs for 12 km from Silver Lake to Kingston Bay with a drainage area of 77 km^2. The Jones River is the largest freshwater drainage to Cape Cod Bay. Silver Lake is included in or borders the towns of Pembroke, Kingston, Plympton, and Halifax. Silver Lake receives tributary flow from Tubbs Meadow Brook in Pembroke, Mirage Brook in Kingston, and seasonal water supply diversions; but is mainly recharged from groundwater (WAA 2006). The U.S. Geological Service has maintained a Jones River stream flow gauge at the Elm Street Dam since 1966 (# 01105870, contributing drainage area = 40.7 km^2). The mean monthly discharge at this station for April for 1966-2011 is 57 cfs.

Silver Lake was selected for monitoring following ongoing discussions with the Jones River Watershed Association (JRWA) on restoring diadromous –or sea-run fish that move between salt and fresh water – fish in the watershed. Restoring fish passage to Silver Lake is one of the highest ranking restoration priorities for *MarineFisheries* in the South Shore Coastal Drainage Area. The JRWA has a long history of working to improve water management and restoring natural connectivity in the Jones River watershed. These mutual interests led to a partnership with JRWA to conduct a two-year river herring spawning and nursery habitat assessment starting in 2008.

Diadromous Fisheries. The Jones River estuary historically supported large and diverse runs of diadromous fish that were valued by the Plymouth Colony in the 17th and 18th centuries (Iwanowicz et al. 1974). The Jones River was subject to early fish passage regulations in Massachusetts that required mill owners to provide passage for sea-run fish starting in 1667.

The Belding survey (1921) described two dams that prevented passage to Silver Lake but noted efforts spanning from 1872 to 1913 to maintain an alewife fishery by moving fish from below the first dam to Silver Lake. In 1909, the Town of Kingston closed alewife harvest and in 1913 appropriated funds to construct fishways at the dams (Belding 1921).

The *MarineFisheries* fish passage survey in the late 1960s (Reback and DiCarlo 1972) documented the presence of a concrete fishway at the Elm Street Dam and a run of alewives that were spawning in three ponds in the Furnace Brook sub-watershed. The most recent *MarineFisheries* fish passage survey (Reback et al. 2004) reported the continued presence of a river herring run, the installation of an

Alaskan steeppass fish ladder at Elm Street Dam in 2001, and noted the continued challenges of obstructions at Wapping Road Dam and Forge Pond Dam, and water supply management at Silver Lake. In 2011, the Wapping Road Dam was removed, eliminating a significant barrier to fish passage.

The JRWA leads a counting effort of river herring each year at the Elm Street Dam that produces a statistical run estimate (Nelson 2006). The effort has documented a spawning run of river herring that is likely a small proportion of the run size existing prior to watershed alterations. The run estimates from 2005 to 2012 range from 560 to 4,512.

As with river herring, the presence of other diadromous species has attracted ongoing monitoring efforts in the Jones River. The Jones River rainbow smelt (*Osmerus mordax*) run was considered one of the largest runs in Massachusetts in the 1960s and 1970s (Iwanowicz et al. 1974; Lawton et al. 1990). A more recent survey found the amount of available smelt spawning habitat in the Jones River remained among the largest for Massachusetts rivers, however the run size has declined since the 1970s studies (Chase 2006).

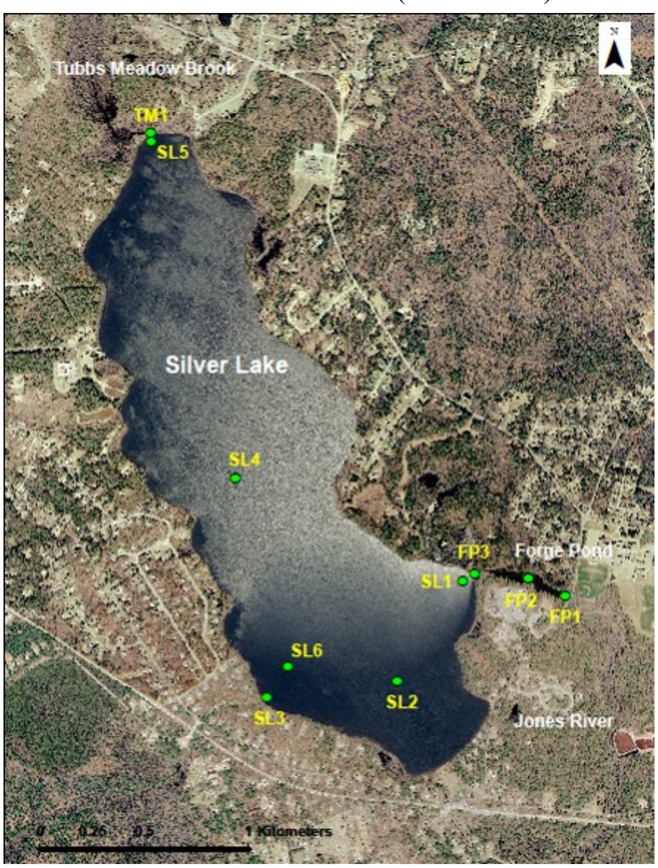

Figure 1. River herring habitat assessment stations at Silver Lake and Forge Pond.

A current *MarineFisheries* smelt fyke net study has confirmed the presence of nine species of diadromous fish in the Jones River (Enterline et al. 2013; Table A.1.). *MarineFisheries* has maintained a young-of-the-year eel monitoring station at the Elm Street since 2001 that serves as a population index of abundance for the Atlantic States Marine Fisheries Commission (ASMFC) American eel stock assessment (ASMFC 2012).

Water Supply Management. Silver Lake is a vital water supply for the City of Brockton and contributes to the Towns of Whitman and Hanson water needs. State legislation in 1899 allowed Brockton to divert water from Silver Lake. Over time, Brockton's water supply grew to involve a network of three reservoirs: Silver Lake in the Jones River watershed, Monponsett Pond in the Taunton River watershed, and Furnace Pond in the North River watershed. Presently, over 90% of Brockton's water for over 150,000 citizens comes from these three reservoirs. Brockton's Water Management Act (WMA) registration allows the withdrawal of 11.11 MGD from the three reservoirs. Since 1967, they have been allowed to divert water from Monponsett Pond and Furnace Pond into Silver Lake between October and May. A water treatment plant on the shore of Silver Lake in Halifax treats the water and sends it over 30 km to the City of Brockton where it is distributed to consumers and ultimately discharged to the Taunton River watershed. Further details on the complex infrastructure and authorizations related to Silver Lake water management are available from several sources (GZA 2003; HMA 2006; City of Brockton 2009; and Gomez and Sullivan 2013).

Assessment QAPP. The assessment of river herring spawning and nursery habitat is a process conducted by *MarineFisheries* to aid in the management and restoration of diadromous fish resources and the evaluation of waterbodies 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 *Mass*DEP-approved Quality Assurance and Program Plan (QAPP) on water quality measurements for diadromous fish monitoring (Chase 2010). *Mass*DEP 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). Waterbodies are assessed as

Figure 2. Forge Pond (taken September 2008).

Support, Impaired, or *Unassessed* for specific designated uses, such as Aquatic Life, as part of the *Mass*DEP 305(b) reporting requirements. Impaired or threatened waters that require a Total Maximum Daily Load (TMDL) estimate for specified pollutants are placed on the 303(d) list. Starting in 2002, *Mass*DEP combined reporting requirements for the 303(d) list and 305(b) report into an Integrated List of Waters for Massachusetts (*Mass*DEP 2009). The QAPP relates diadromous fish life history requirements to water quality criteria, and provides habitat sampling protocols that contribute data to the 305(b) process for assessing the designated use of Aquatic Life.

***Mass*DEP Water Quality Status.** The *Mass*DEP 2008 Integrated List of Waters records Silver Lake (Segment MA94143) as Category 4 (*Impairment not caused by pollutant*) (*Mass*DEP 2009). This impairment is identified in the 2001 South Shore Coastal Watersheds Water Quality Assessment as flow alteration from water withdrawals for the Brockton water supply (*Mass*DEP 2006). The same assessment also lists two of three Jones River segments downstream of Silver Lake – Wapping Road Dam (removed in 2011) and Forge Pond Dam – as *Impaired* for the designated use of Aquatic Life primarily due to flow alteration but also low dissolved oxygen and fish passage barriers.

Methods

The river herring habitat assessment methodology is fully outlined in *MarineFisheries'* QAPP (Chase 2010). The assessment relates river herring life history requirements to three categories of reference conditions: Massachusetts SWQS (*Mass*DEP 2007), US Environmental Protection Agency (US EPA) nutrient criteria recommendations (US EPA 2001), and the Best Professional Judgment (BPJ) of *MarineFisheries* biologists. Monthly assessment trips were made to Silver Lake and Forge Pond during the May-September period when adult river herring spawning and juvenile occupation of the lake would occur if passage was available. Water quality measurements are made at the surface (0.3 m depth) and bottom (0.5 m from bottom) and at consistent intervals at deeper stations. The following basic water quality parameters were measured with a YSI 6920 sonde: water temperature, dissolved oxygen (DO), pH, specific conductivity, turbidity, and Secchi disc depth. Water temperature, DO, and pH were related to SWQS water quality criteria. Monthly sampling of total phosphorus (TP) and total nitrogen (TN) was conducted by JRWA for their watershed baseline index monitoring. The TP, TN, and Secchi disc data were related to US EPA nutrient criteria recommendations. 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 = <10) for parameter measurements at transect stations are acceptable for a *Suitable* classification. All excursions that exceed the thresholds result in an *Impaired* classification. October sampling was added to this assessment to investigate water quality in relation to water supply operations. However, in accord with the QAPP design, these data were not used to calculate excursion percentages in the classification.

<u>*Assessment Stations*</u>. Stations were selected to provide a transect starting at the lake outlet that contained shallow, medium, and deep depth strata based on lake bathymetry. Secondly, sampling stations were set for primary inlets and outlets to the lake and several off-transect stations were visited periodically to gain information about other locations in the lake. The assessment classification was based on stations SL1, SL2, and SL3 selected along a transect line running from the Silver Lake outlet to the Monponsett Pond diversion outlet and one additional deep station, SL4 (Figure 1; Table A.2). Three stations were routinely sampled in

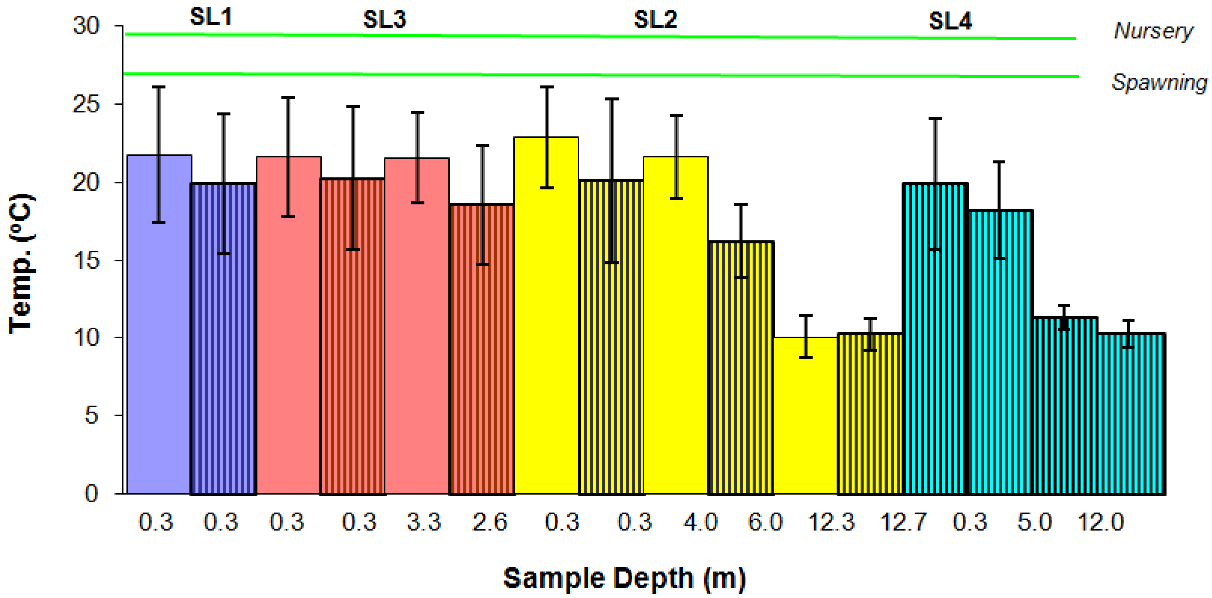

Figure 3. Water temperature measurements taken at Silver Lake, 2008-2009. Stations averages are presented (±2 SE) for 2008 (blank bars) and 2009 (striped bars). The sample size range for the station bars is 3-5.

Forge Pond and three exploratory Silver Lake stations as well as a station at Tubbs Meadow Brook were visited periodically.

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 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 for the Northeast Coastal Zone subecoregion #59 (US EPA 2001). The US EPA nutrient criteria 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 intends to use the US EPA approach to develop TN and TP criteria specific to river herring spawning and nursery habitat in the coastal regions of Massachusetts.

Results

Massachusetts SWQS Criteria.

Water Temperature. The metabolic and reproductive processes of ectothermic fish are directly related to water temperature. Temperature also provides cues for fish migrations and is a vital 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 the *Mass*DEP criterion of ≤28.3 °C for water temperature as *Suitable* to support Aquatic Life for the nursery period of July-September and ≤26.0 °C from the scientific literature for the spawning period of May-June. A single exceedance was recorded with a surface temperature of 28.56 °C at SL1 on July 15, 2008. These data result in a *Suitable* classification for water temperature during 2008-2009. Silver Lake was stratified for the May-September classification period with a thermocline ranging at a depth of 7-10 m and weak stratification in May. Bottom water temperature at deep stations (SL2 and SL4) was consistently near 10 °C during this period (Figure 2). The October samples revealed the seasonal stratification was nearly removed in 2008 and fully dissipated in 2009.

Water pH. The acidification of freshwater is a widely recognized concern regarding fish populations. Low pH can increase metal toxicity and disrupt ionoregulation in gill tissues. The QAPP adopted the *Mass*DEP criterion of ≥6.5 to ≤8.3 for pH as *Suitable* to support Aquatic Life. Water pH outside of this range can be a threat to the development of fish eggs and larvae, and highly acidic and alkaline waters (<4.0 and >9.0 pH) are lethal for some species. Silver Lake was classified

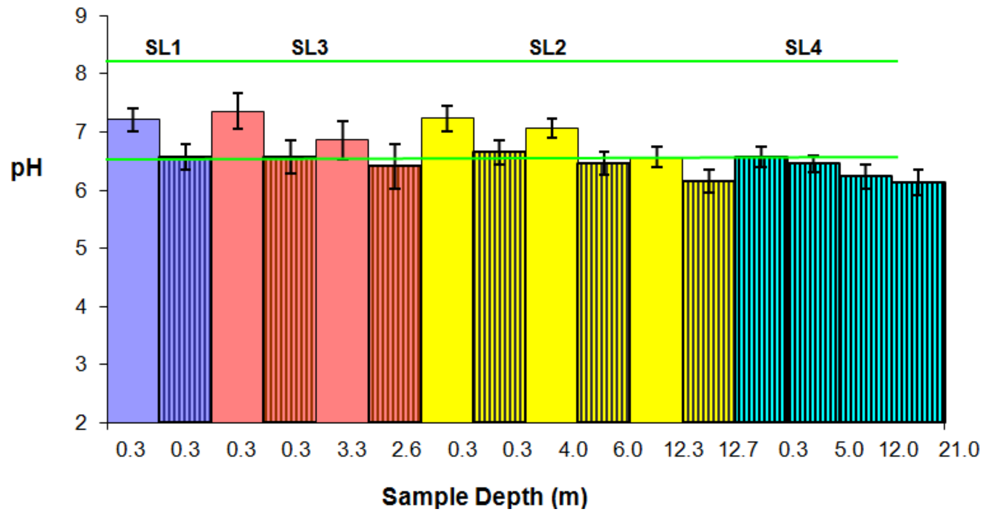

Figure 4. Water pH measurements taken at Silver Lake, 2008-2009. Station averages are presented (±2 SE) for 2008 (blank bars) and 2009 (striped bars). The sample size range for the station bars is 3-5. The green lines mark the *Mass*-DEP SWQS threshold for pH.

as *Impaired* for pH with 38% of transect station measurements below the 6.5 pH threshold. Despite the high excursion percentage, most of the depressed pH measurements were marginally below the threshold and occurred deeper in the water column. Only three of 35 measurements <6.5 pH were surface samples.

Declining pH with depth is a natural process related to the removal of carbon dioxide by photosynthesis in the daytime. With lower removal rates of carbon dioxide deeper in the water column, the pH remains lower than surface waters (Wetzel 1983). In highly productive ponds, enhanced photosynthesis can increase the daytime pH to alkaline levels above the upper threshold, which can be harmful to fish respiration. This condition was not observed in Silver Lake during 2008-2009.

The water pH in 2008 was consistently and significantly (T-Test, $P<0.001$) higher than measured in 2009. The mean pH of all transect measurements were 7.00 and 6.47 in 2008 and 2009, respectively. Twenty-three percent of the 2008 pH measurements were <6.5 pH compared to 52% in 2009. Despite the high rate of excursions to the QAPP threshold, it is acknowledged that the exceedances were routinely marginal. Only four

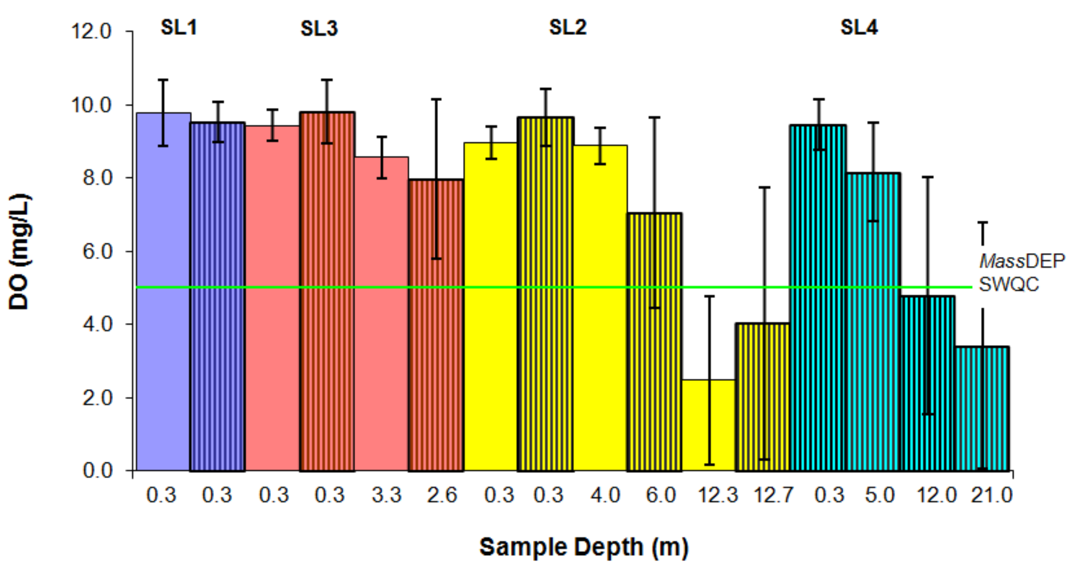

Figure 5. Dissolved oxygen measurements taken at Silver Lake, 2008-2009. Station averages are presented (±2 SE) for 2008 (blank bars) and 2009 (striped bars). The sample size range for the station bars is 3-5.

measurements fell below 6.0 in the range of 5.5-6.0 and were all from the bottom samples at SL4, the deepest station in the assessment.

Dissolved Oxygen. Adequate dissolved oxygen (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 resulting in seasonal and diurnal cycles. The QAPP adopted the *Mass*DEP criterion of ≥5.0 mg/L for DO as *Suitable* to support Aquatic Life. Silver Lake was classified as *Impaired* for DO with 10.7% of transect station measurements below the 5.0 mg/L DO threshold.

The classification for DO is marginal; both numerically given the excursion allowance of 10% and from a practical consideration of the selected transect stations. A second deep station (SL4) was added in October 2008 and sampled each month in 2009. All DO bottom measurements during July-September at the deep stations, SL2 (max. depth = 14 m) and SL4 (max. depth = 22 m), were anoxic. During this period, the anoxia dissipated to hypoxia at a depth range of 8-12 m with a worst-case observation at SL4 in September 2009 when the water column was anoxic from 8 m depth to bottom depths of 20.5 m. Botttom samples are exempt from the DO classification due to natural stratification. The *Impaired* classification resulted largely from the second depth measurement off the bottom for SL2 and SL4 where hypoxia was common. In the absence of sampling at the second deep station SL4, the DO exceedances would have been <10%. Therefore, despite the *Impaired* classification and presence of anoxia at bottom waters, DO was suitable at most depth strata and few DO exceedances were recorded for

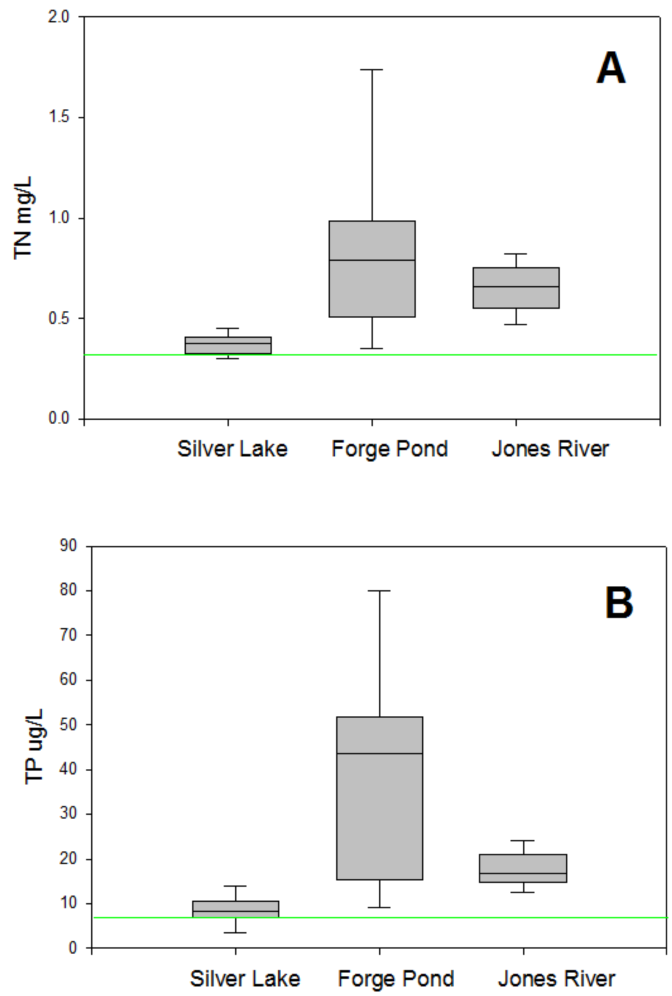

Figure 6. Box plots of total nitrogen (A) and total phosphorus (B) measurements in Silver Lake during 2008-2009. Green lines represent the US EPA nutrient criteria.

Table 1. Summary statistics for total nitrogen and total phosphorus measured during the 2008-2009 river herring habitat assessment.

Station	TN N	TN Mean	TN Median	TN SE	TP N	TP Mean	TP Median	TP SE
SL1	8	0.381	0.390	0.021	8	10.048	8.913	2.190
SL2	7	0.356	0.365	0.013	7	7.365	6.944	0.668
SL3	10	0.418	0.390	0.050	10	8.882	8.758	0.887
FP1	9	0.902	0.810	0.155	9	48.890	46.469	11.613
FP3	8	0.796	0.587	0.187	8	30.337	16.647	8.629
JR 2008	13	0.579	0.569	0.033	13	17.769	16.700	1.064
JR 2009	13	0.731	0.725	0.024	13	17.869	16.700	1.462
JR (all)	26	0.655	0.659	0.025	26	17.819	16.700	0.886

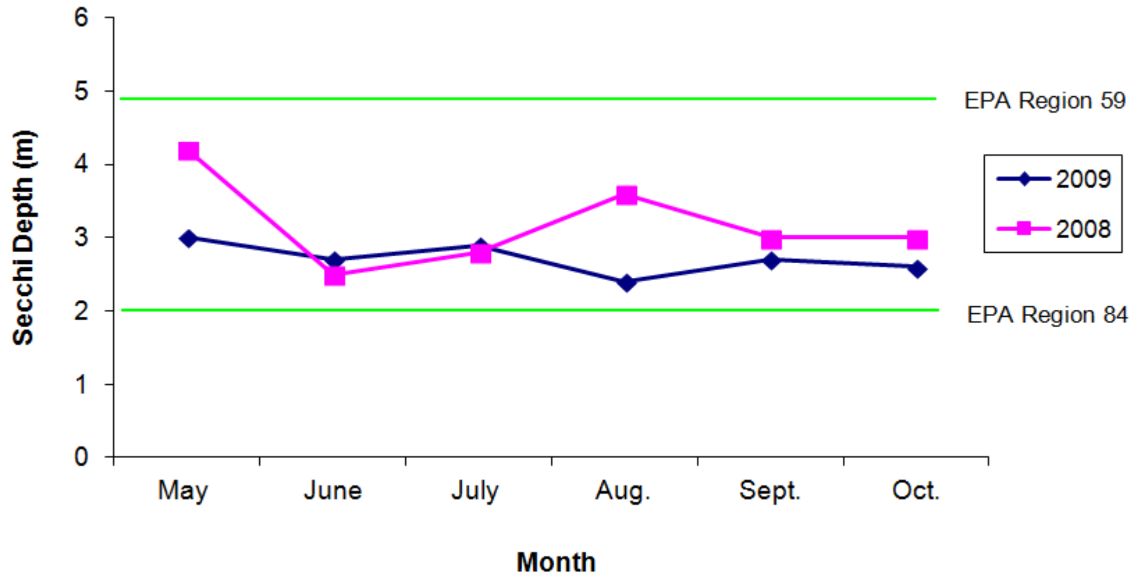

Figure 7. Secchi disc measurements taken at Upper Silver Lake, 2008-2009. The lines plot average Secchi disc depth measured each month at the three transect stations: SL2, SL3, and SL4 (N = 3).

measurements ≤5.0 m depth (4.5%).

Nutrient Criteria.

Nutrients. The JRWA conducted monthly sampling of TN and TP at Silver Lake and Jones River stations as part of their watershed baseline index. The nutrient samples at transect stations SL1, SL2, and SL3 were adopted for TN and TP classification for this assessment. The JRWA nutrient samples were processed by the Provincetown Center for Coastal Studies under a *Mass*DEP approved QAPP for their laboratory (PCCS 2008).

The pooled nutrient samples for the transect stations routinely exceeded the US EPA nutrient criteria of 8.0 ug/L for TP and 0.32 mg/L for TN, leading to an *Impaired* classification for both parameters. Nineteen of 25 TN measurements were below the criterion, resulting in an exceedance rate of 76%. Station SL3, next to the Monponsett Pond diversion outlet, had the highest mean TN at 0.418 mg/L (Table 1). Fourteen of 25 TP measurements were above the criterion resulting in an exceedance rate of 56%. Despite the high proportion of Silver Lake TP samples exceeding the criterion, the margin of exceedance was slim (Figure 6). Station SL2 had the lowest nutrient concentrations, with median values for the two seasons slightly less than the TP criterion and slightly higher than the TN criterion.

Nutrients were also measured at the FP1 and FP2 stations in Forge Pond during the assessment. These measurements were typically much higher than those found in Silver Lake with all TN and all but one TP measurements exceeding the criteria. The Forge Pond measurements are indicative of water quality impairment, but data are not comparable to Silver Lake due to the lack of flow in the shallow mill pond for most of the study period.

During the study period, TN and TP were measured in the main stem Jones River as part of a separate study assessing rainbow smelt spawning habitat (Enterline et al. 2013). The main stem nutrient data provide a useful comparison to the Silver Lake nutrient data.

Weekly TN and TP measurements were made during the smelt spawning period (early March to mid-May) using the same QAPP as this study (Chase 2010). The measurements were taken below the Elm Street Dam approximately 8 km downstream of Forge Pond. The TN and TP concentrations routinely exceeded the Silver Lake samples and all TN and TP measurements exceeded the US EPA Lake criteria; however, different criteria apply to rivers (TN = 0.57 mg/L and TP = 23.75 ug/L). When compared to the river criteria, the Elm Street Dam station data was *Impaired* for TN (73% exceedance) and TP was classified as *Minimally Impacted* for TP (8% exceedance). Despite the *Impaired* classification for TN and TP in Silver Lake, the nutrient measurements were not

Figure 8. Views of Silver Lake (left, taken August 2008) and Silver Lake outlet (right, taken September 2008).

associated with indicators of eutrophication and were relatively low for habitat assessments conducted under the QAPP to date. It should be noted that the assessment design would not provide information on the relative contributions of nutrients via water supply diversions from Monponsett Pond, which is known to exhibit impairment from nutrient loading (*Mass*DEP 2006; WAA 2006).

Secchi Disc. Secchi disc is an easily measured proxy for the transparency of water to light. There is little information that directly links Secchi disc depth to river herring life history, although it is widely accepted as an indicator of water quality. The US EPA Secchi disc 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 disc depth was adopted by the QAPP as *Suitable* to support Aquatic Life. No exceedances to the criterion were measured at the transect stations (SL2, SL3, and SL4, N = 23) during 2008-2009, resulting in a *Suitable* classification (Figure 7). The highest monthly average Secchi disc depth of 3.5 m occurred in May. Water clarity in Silver Lake was consistently good relative to other QAPP assessments conducted to date where mid-summer plankton blooms cause common excursions <2.0 m.

<u>Best Professional Judgment</u>.

Fish Passage. The QAPP provides a process for using Best Professional Judgment to assess the capability of river herring to pass barriers as spawning adults and emigrating juveniles. This classification results in the assignment of *Suitable*, *Impaired*, or *Unsuitable* for each barrier or outlet.

During the study period, three dams impeded the passage of diadromous fish from marine waters into Silver Lake. The lowermost dam, the Elm Street Dam (2.7 rm), has a fishway that was rebuilt with an Alaskan Steeppass ladder in 2001. This fishway has been the site of a JRWA herring count since 2005. The next dam upstream was the Wapping Road Dam (3.7 rm). This site was under design for dam removal during the study period and the dam was removed in 2011. Because of the known passage condition during the study period, sites visits were not made to the Elm Street (*Suitable*) and Wapping Road (*Unsuitable*) dams. Fish passage observations were therefore focused on the Forge Pond Dam (FP1, 7.4 rm) and Silver Lake outlet (FP3, 7.7 rm) to Forge Pond.

The Forge Pond Dam had no fishway or provisions for fish passage, resulting in a classification of *Unsuitable* for fish passage during May-October, 2008-2009. Forge Pond Dam is a concrete dam with a 48 ft total length and 5.5 ft spillway height. The dam includes a 38 ft spillway next to three bays with adjustable wood stoplogs. Flow was only observed to pass over the dam crest during the two May visits when 2-3 cm of water depth was measured at a mid-crest reference station. The water height over the western bay stoplog was 8 cm during May each year. The Forge Pond water level was much lower in 2008 than 2009. On average the pond level at the reference station was 25 cm below the dam crest in 2008 and 8 cm in 2009. For both years, the conditions for June to October were stable at FP1: flow was not observed exiting Forge Pond except for minor leakage through stoplog slots and surrounding cracks in the dam concrete.

The outlet of Silver Lake (FP3) to Forge Pond has the appearance of a natural channel and was the likely natural outlet to the Jones River prior to the construction of Forge Pond Dam. A transect was established here to measure water chemistry and depth. A berm of sand slightly upstream of the transect has accumulated as a result of low outflow and the Forge Pond impoundment. The berm is at a higher elevation than the transect and is the control for water exiting the Lake most of the year. The fish passage assessment at this site considered the ability of fish to pass the entire section from the transect through the natural outlet. The **fish passage** classification at FP3 was classified as *Impaired* due to an *Impaired* or *Unsuitable* assessment for 4 of the 12 (33%) site visits during May-October 2008-2009. All four assessments that were not *Suitable* came during July-October, 2008. The Lake was lower in 2008 with much less outflow than seen in 2009. The classification for each site visit in 2009 was *Suitable* and the average transect depth at mid-transect was 57 cm. The average transect depth in 2008 at mid-transect was 39 cm.

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 in the absence of an existing obstruction. In this example, the station would be classified as *Impaired* for **fish passage** and *Suitable* for **stream flow**. In the case of Forge Pond Dam (FP1), stream flow was not *Suitable* during any observation to support adult herring passage, resulting in an *Impaired* classification. The stream flow during both May sites visits was potentially sufficient to allow juvenile eel passage into Forge Pond and juvenile herring emigration downstream. Forge Pond itself would have been poor migratory habitat for most of 2008 and the summer of 2009. In 2008, stream flow exiting Silver Lake declined sharply from May to June. Forge Pond became choked with surface plant growth by June and was estimated to have a 95% surface coverage of lily pads in July.

The **stream flow** classification at FP3 mirrored the **fish passage** classification of *Impaired* due to an *Impaired* or *Unsuitable* assessment for 4 of the 12 site visits during May-October 2008-2009. This location showed potential for fish passage in 2009 as water flow and depth were *Suitable* for movements into and out of Silver Lake at each site visit. Migratory habitat conditions were poor in 2008 as evident by the exposure of about 30 m of lake perimeter from May to August and the observation of reverse flow from Forge Pond into Silver Lake. Conditions in September 2008 were the driest observed, with about 50 m of dry lake perimeter and thick grass growing in the natural outlet. In contrast, the lake level remained high and stable in 2009, supporting suitable stream flow and fish passage during each month at FP3.

Flow records for the Jones River from the USGS stream flow station at the Elm Street Dam

Table 2. Substrate composition at shoal stations in Silver Lake during 2008-2009. The table proportions are the average of qualitative estimates to the nearest 10% during each site visit to SL1 (N = 12), SL3 (N = 10), and SL5 (N = 2).

	SL1	**SL3**	**SL5**
Gravel	12%	3%	10%
Sand	24%	25%	40%
Silt	15%	15%	7%
Periphyton	13%	14%	10%
Vascular Plant	36%	43%	33%
Total	100%	100%	100%

revealed that 2008 discharge was below average while 2009 flows were well above average. The average daily flow in 2008 at the Elm Street gauge during the May site visit was 28 cfs, and the daily flow ranged from 8-16 cfs June-October. The average daily flow in 2009 at the Elm Street gauge during the May site visit was 36 cfs, and the flow and daily ranged from 20-92 cfs June-October.

Additionally, the monthly mean discharge for May-October in 2008 was 13% below the time series (1966-2011) means for those months, while 2009 was 93% above the mean discharge. These data should be considered with caution due to the water supply manipulations at Silver Lake and unknown influence of downstream tributaries. However, it can be inferred from the stream flow data that the 2008 flow conditions may have been closer to the time series average than conditions in 2009.

Eutrophication. The QAPP provides a process for using BPJ observations to assess if shoal transect stations are impacted by eutrophication. The indicators used are nutrients, DO, pH, turbidity, Secchi disc, and plant growth in the water column and substrate. When nitrogen and phosphorus data are available, as was the case for this assessment, the QAPP classification for **eutrophication** is based on US EPA criteria and not BPJ. Measured nutrient concentrations during the Silver Lake habitat assessment resulted in an *Impaired* classification for **eutrophication**. However, it should be noted that the BPJ designation for each site visit to SL1, SL3 and SL5 was *Suitable*. No combination of eutrophication indicators resulted in an *Impaired* designation at any site. Water clarity was adequate during for all site visits with a minor reduction during a suspected cyanobacteria bloom during June-August 2009. Water column plant growth did not exceed 25% for any sites visited. The substrata at SL1, SL3, and SL5 did not experience significant increases in periphyton or vascular plant growth. For most observations, substrate plant growth was estimated at 25-50%, with occasional exceedances to >50% during the summer of 2009.

Dissolved oxygen was suitable at all site visits with only occasional supersaturation during summer daytime measurements when higher DO is normally expected. Overall, the shoal stations in Silver Lake exhibited relatively clean substrate and a naturally diverse plant community that did not suggest impairments that would be expected from eutrophication.

Spawning Substrate. River herring deposit dermersal eggs that stick to whatever surface they encounter. After one day, the eggs become non-adhesive, but remain on the bottom until hatching in typically 2-5 days (Greene et al. 2009). No spawning substrate classification was provided in the QAPP because of 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 may be a better surface for egg survival than fine silt or dense periphyton growth. The observations recorded on substrate conditions at the three shoal stations complimented the BPJ observations on eutrophication: the station substrate featured a diversity of native vascular plants with no evidence of nuisance growth and a range of larger sediment sizes that would be expected to provide suitable habitat for river herring spawning and egg incubation.

The average percent composition of major substrate types are reported in Table 2. The conditions at SL1 (closest to Silver Lake outlet) may have been most favorable; this station is located in a large shoal with substrate containing a diversity of aquatic plants, coarse sand, gravel, and abundant freshwater mussels. Observations for SL3 were made about 50 m north of the Monponsett Diversion outlet to avoid the scour pool and finer sediments directly at the SL3 coordinates. This shoal was an extensive shallow region that had less gravel than SL1 but would likely provide very suitable spawning habitat. The shoal station off Tubb Meadow Brook (SL5) was visited twice. SL5 had the highest presence of sand, but still had heterogeneous plant and sediment cover that would be expected to be suitable for river herring.

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 *Mass*DEP 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

Figure 9. Jones River downstream from Lake Street Culvert (taken May 2009).

condition for rivers in sub-ecoregion #59 is ≤1.7 NTU (US EPA 2001). Similar to the Secchi disc measurements, the turbidity data reflect consistently high water clarity at all transect stations. The average turbidity for all four transect stations with bottom samples removed was 1.3 NTU (N = 74) and 1.1 NTU (N = 41) for surface samples only.

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 *Mass*DEP or US EPA reference conditions are provided for conductivity, therefore the QAPP does not have a conductivity criterion. High conductance in freshwater can indicate watershed contributions of natural alkaline compounds or ionic contributions from pollution sources. Specific conductivity at Silver Lake was consistently low with little variability among stations and depth strata. The average for all transect measurements was 0.163 mS/cm (N =112, SD = 0.011). Although the QAPP provides no guidance on conductivity, this finding is favorable for water quality considerations. The low conductivity found at Silver Lake would not be expected if high ionic contributions were present in surface inflow or from historic pollution sources.

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 disc depth with a range of scores from 0 to 100. Scores near zero would indicate uncommon nutrient poor and low productivity conditions, and scores near 100 would indicate extremely degraded, 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. The mean Secchi disc depths for SL2, SL3, and SL4 during May-September measurements resulted in TSI scores of 43.9 - 45.2 which are near the middle of the mesotrophic range, a trophic class supportive of swimming and aesthetic uses but having the potential for hypolimnetic anoxia during summer. The mean TP for SL1, SL2, and SL3 during May-September measurements resulted in TSI scores of 32.9 - 37.4 which are near the middle of the oligotrohic range, a trophic class of lower primary productivity that prompts little concern over eutrophication.

The Carlson Index scores for Silver Lake are generally supportive of the assessment's nutrient data that were classified as *Impaired*, but not associated with obvious indicators of eutrophication and were relatively low compared to other recent assessments in Massachusetts. However, the results along with the TN concentrations suggest a slim margin may be present between suitable water quality and eutrophic symptoms. These data represent useful baseline data for future monitoring.

Forge Pond Water Quality

Forge Pond is a shallow, narrow impoundment (max. depth = 0.5 m; <0.5 km length) created by the Forge Pond Dam that connects to Silver Lake via a natural outlet with no water control structures. Water quality sampling was conducted at Forge Pond at three stations FP1 (pond side of dam crest), FP2 (mid-pond), and FP3 (outlet of Silver Lake). The sampling results and data classification will be only briefly summarized as follows. Forge Pond is an artificial pond that suffers from water quality degradation and is not a target habitat for restoration of river herring spawning and nursery habitat in the Jones River watershed. Under future restoration options, it would be an essential migratory pathway that requires improvements.

Only four measurements were made at FP2 because the site could not be accessed during most months. The pond became too shallow each summer to reach FP2 by canoe, resulting in no samples during July-September. The substrate was dense silt and the water surface was fully covered with lily pads during each month July-September. The other two Forge Pond sites displayed significant water quality impairment as a result of chronic low flow and the declining trophic status of an artificial mill pond. During the study period, all samples (N = 8) exceeded thresholds for pH, TN, and TP and all but one exceeded the DO threshold.

The Silver Lake outlet (FP3) had similar results, but benefitted slightly from periodic outflow from Silver Lake. During the study period, all samples (N = 9) exceeded the TN threshold, 78% exceeded the pH threshold, 67% exceeded the DO threshold, and 88% exceeded the TP threshold. The only Forge Pond temperature exceedance was recorded at FP3 on June 17, 2008 at 26.32 ºC. The resulting classification for Forge Pond Dam is *Impaired* for pH, DO, TN and TP, fish passage, and stream flow and *Suitable* for water temperature. Overall, water and habitat conditions in Forge Pond were found to be highly degraded during 2008-2009, reducing the consideration of this site for spawning and nursery habitat restoration, while highlighting the need for migratory habitat restoration to meet the goal of fish passage improvement to Silver Lake.

Off-Transect Stations

Tubbs Meadow Brook. Two visits were made to the inlet of Tubbs Meadow Brook on the north side of Silver Lake. The brook receives flows from surrounding wetlands and Furnace Pond in Pembroke. A small volume of freshwater flow was coming from Tubbs Meadow Brook on the sampling dates (<0.5 cfs) and was characterized as cooler, more acidic and more turbid than the receiving waters of Silver Lake. Water quality samples were measured at TM1 in the brook channel a few meters upstream of the confluence with the lake and at SL5 a shallow (1.0 m) station located about 20 m off the brook confluence. During both the August 2008 and July 2009 samples, the brook flows at TM1 were 4-5 ºC cooler and about three times more turbid than at SL5. The pH at TM1 averaged 6.09 for the two dates compared to 6.63 at SL5. The TM1 DO averaged 2.56 mg/L for the two dates compared to 9.28 at SL5. Although evidence was found of impaired water quality coming out of Tubbs Meadow Brook, the substrate at SL5 represented a large shoal area that appeared favorable for river herring spawning habitat with patches of clean gravel, sand and aquatic plants.

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 2010) that relies on parameter-based precision and accuracy indicators. Data become 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 in 2008 were acceptable. Despite high accuracy and precision, the turbidity data in 2008 were found to be consistently low relative to the 0.0 NTU standard. Through troubleshooting and discussions with the manufacturer (Yellow Springs Inc., YSI), a calibration method error was identified for a new model of turbidity sensors. These data were adjusted using an YSI-approved correction and classified as *Conditional*. Suitable data quality was also achieved in 2009 with minor exceedances of DO and pH accuracy on two occasions that were accepted as *Conditional* data. A temperature sensor error was identified by reoccurring calibration exceedances over four months in 2009. The temperature data for these months were adjusted by the average deviation from the calibration value and classified as *Conditional.*

Natural Resource Observations

American Eel. Young-of-the-year (YOY) American eel are known to undergo an annual migration each spring in the Jones River. A *MarineFisheries* monitoring station at the Elm Street Dam provides an annual population index of abundance (Chase 2011). In addition, eels were observed during the study period at the spillway of Forge Pond Dam and were captured in Silver Lake while eel potting. Baited pots were set in 2009 to confirm the presence of larger yellow eels and to gauge the potential of developing a yellow eel index of abundance for Silver Lake. Low numbers of yellow eels were caught in Silver Lake in August and September 2009. Also, juvenile age-1+ eels were observed in the Forge Pond Dam spillway in 2009: hundreds were observed in June below the dam and several individuals were seen in August.

American Shad. The historical presence of an American shad (*Alosa sapidissima*) run in the Jones River has been noted (Iwanowicz et al. 1974). A photograph was received from a river abutter of two dead adult shad taken downstream of the Elm Street `Dam on May 23, 2009. The following season, a juvenile American shad was captured near the tidal interface in the Jones River during smelt fyke net monitoring on March 9, 2010. These recent observations and sporadic reports of sportfishing catches of shad confirm the presence of a persisting shad run, although our expectations are that few shad are participating in the Jones River run.

Invasive Plants. The QAPP followed during the study period did not provide guidance for routine sampling of invasive plants. Despite the lack of a routine process during site visits, no observations were made of an identified invasive plant in Silver Lake. Likewise, previous studies in the watershed did not identify Silver Lake as being impaired by invasive plants (*Mass*DEP 2006; WAA 2006). The plant communities at all shoal stations were composed of diverse and apparently healthy native vascular plants that were not burdened with heavy periphyton growth. This was not the case at the smelt spawning habitat station below Elm Street

Table 3. Summary of river herring habitat assessment criteria for Silver Lake, 2008-2009. A classification of *Impaired* for each water quality parameter results from exceedances of >10% or >1 (when N < 10) for transect station samples during the two-season assessment.

Parameter	Units	Sample Size (No.)	Acceptable Criteria	Exceedance (%)	Classification
Temp. (nursery)	°C	53	≤28.3	2%	*Suitable*
Temp. (spawning)	°C	37	≤26.0	0	*Suitable*
DO	mg/L	75	≥5.0	11%	*Impaired*
pH	SU	90	6.5 to ≤8.3	38%	*Impaired*
Secchi	m	23	≥2.0	0	*Suitable*
TN	mg/L	25	≤0.32	76%	*Impaired*
TP	ug/L	25	≤8.0	56%	*Impaired*
Eutrophication	NA	12	BPJ	0	
Fish Passage	NA	12	BPJ	100%	*Impaired*
Stream Flow	NA	12	BPJ	83%	*Impaired*

Notes:

1. Bottom measurements at the deep stations (SL2 and SL4) were excluded from DO classification due to QAPP hypolimnion exemption. See tables A.4 and A.6 for bottom DO data.
2. Classification Rules (Chase 2010, QAPP page 57): transect station samples for May-September during both seasons are pooled. Criteria exceedances for temperature, pH, DO, and Secchi disc ≤10% of the sample size for each parameter result in a *Support* classification.

Dam, where large growths of invasive variable milfoil and filamentous green algae were observed during late-spring in both years. The presence of milfoil at this location had not been observed by the lead author prior to 2008.

Downstream Survey. The co-authors conducted a survey of the Jones River from Forge Pond Dam to the Wapping Road Dam during May 2009 to confirm no passage impediments were present in the form of transportation infrastructure or natural debris. The survey observations confirmed that fish passage was possible for this segment of the Jones River. The Lake Street culvert was identified as a location that may need attention under future restoration options. The culvert appeared passable for river herring under most expected flow levels, but may have high entrance velocity at higher discharges. Further downstream, a few jams of logs and sticks occurred that, if left to accumulate more debris, could become an impediment. This segment will need periodic maintenance as part of future efforts to restore fish passage to Silver Lake.

Conclusion

Six out of nine criteria used to classify river herring spawning and nursery habitat were found to be *Impaired* at Silver Lake during 2008-2009. This resulted because reference conditions were routinely exceeded for four measured water quality parameters, **fish passage** and **stream flow** (Table 3). Water quality impairment was classified for field measurements of DO, pH, TN, and TP. Of the *Impaired* classifications, all but TN were either marginal (DO and TP) or influenced by seasonal stratification (pH and DO).

Despite the classification of four parameters as *Impaired,* the assessment documented a range of conditions that should be considered suitable for river herring spawning and nursery habitat. The **eutrophication** and Substrate BPJ observations provided no indication that eutrophication had degraded spawning substrate or surface waters. Water temperature and Secchi disc depth were classified as *Suitable.* These observations support the Carlson Trophic State indices that indicated the lake was between an oligotrophic and mesotrophic state, which would be supportive of early life stages of river herring. The primary concern identified in the assessment was the low flow exiting Silver Lake during the period needed for juvenile emigration and the obvious obstruction to adult migration presented by Forge Pond Dam. A secondary concern that should be considered for future monitoring is over the presence of hypolimnetic anoxia. This phenomenon was spatially limited during 2008-2009 but could become a threat to nursery habitat with increasing lake productivity.

Recommendations

The water quality impairment documented in Silver Lake was mainly limited to TN and the effects of seasonal stratification and would not prevent a large proportion of Silver Lake from providing a significant contribution to river herring spawning and nursery habitat in the South Shore Coastal Drainage Area. Therefore, we recommend that restoring a native river herring run to Silver Lake should be a high priority for the region. The impairments with the highest consequence are the fish passage obstruction at Forge Pond Dam and the water supply operations in Silver Lake that reduce outflow to the Jones River. The concept of restoring sea run fish to Silver Lake received an essential contribution when the next dam downstream, the Wapping Road Dam, was removed during the summer of 2011 through a proactive restoration project led by JRWA. Given this momentum and the large amount of suitable spawning and nursery habitat available in Silver Lake we recommend that the City of Brockton should be engaged to determine feasible options for improving fish passage to Silver Lake and stream flow exiting the lake.

1. A feasibility study should be conducted in cooperation with the City of Brockton to determine options for providing migratory habitat and sustainable stream flow to pass sea-run fish and other aquatic life from the Jones River into Silver Lake (Gomez and Sullivan *in Preparation*).

2. Additional information is needed on the tributaries leading into Silver Lake and the main stem Jones River in terms of water quality, water quantity, stormwater influences, and potential fish habitat.

3. Silver Lake demonstrated trophic conditions that are expected to support early life stages of diadromous fish. However, signs hypolimnetic anoxia were present in the summer. If these conditions degraded further it could become limiting for nursery habitat and negatively affect

other aquatic life. It is recommended that further evaluations are conducted on the source and status of nutrient loading in the watershed and that comparable monitoring is repeated at regular intervals.

4. The river herring spawning and nursery habitat assessment data should be provided to *Mass*DEP to support 305(b) reporting and to assist local water quality remediation.

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Literature Cited

ASMFC. 2012. American eel benchmark stack assessment. Atlantic States Marine Fisheries Commission, Stock Assessment Rep. No. 12-01.

Belding, D.L. 1921. A report upon the alewife fisheries of Massachusetts. Mass. Div. of Fish. and Game, Dept. of Natural Resources, 135 pp.

Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography 22: 361-369.

Chase, B.C., M.H. Ayer, K.J. MacGowan, and K. Taylor. 2006. Population Indices of Rainbow Smelt Spawning Runs in Massachusetts. Mass. Div. of Mar. Fisheries, Completion Report for NMFS Project No: O-2003-NER4, Gloucester, MA.

Chase, B.C. 2010. Quality Assurance Program Plan (QAPP) for Water Quality Measurements Conducted for Diadromous Fish Habitat Monitoring. Version 1.0, 2008-2012. Mass. Div. of Mar. Fisheries, Tech. Report No. TR-42.

Chase, B.C. 2011. American eel compliance report for 2010 to the Atlantic States Marine Fisheries Commission. Mass. Div. of Mar. Fisheries, New Bedford, MA.

City of Brockton. 2009. Comprehensive water management plan. *Prepared by* CDM, for City of Brockton Public Works Dept. and Brockton Water Commission, Brockton, MA.

Enterline, C.L, G. Wipplehauser, J.M. Carloni, B.C. Chase. 2013. A Multi-State Collaborative to Develop & Implement a Conservation Program for Three Anadromous Finfish Species of Concern in the Gulf of Maine. Final Report *submitted for* NOAA Species of Concern Grant Program Award #NA06NMF4720249A.

Gomez and Sullivan Engineers. In Preparation. Forge Pond Dam Fish Passage Improvement Feasibility Study and Preliminary Design. For Mass. Div. of Mar. Fisheries.

Greene, K.E., J.L. Zimmerman, R.W. Laney, and J.C. Thomas-Blate. 2009. Atlantic coast diadromous fish habitat: a review of utilization, threats, recommendations for conservation, and research needs. Atlantic States Marine Fisheries Commission Habitat Mgt. Series No. 9, Washington, D.C.

GZA. 2003. Jones River watershed study: Final Report. *Prepared by* GZA GeoEnvironmental, Inc., Norwood, MA, for Mass. Dept. of Environ. Protection.

HMA. 2006. Silver Lake water supply system overview report. *Prepared by* Hanson, Murphy & Associates (HMA) *for* Brockton Water Commission, Brockton, MA.

Iwanowicz, H.R., R.D. Anderson, and B.A. Ketschke. 1974. A study of the marine resources of Plymouth, Kingston, and Duxbury Bay. Mass. Div. of Mar. Fisheries, Monograph Series No. 17.

Lawton, R., P. Brady, C. Sheehan, S. Correia, and M. Borgatti. 1990. Final report on spawning sea-run rainbow melt (*Osmerus mordax*) in the Jones River and impact assessment of Pilgrim Station on the population, 1979-1981. Boston Edison, Pilgrim Nuclear Power Station Marine Environmental Monitoring Program Report Series.

*Mass*DEP. 2006. South Shore Coastal Watersheds 2001 Water Quality Assessment Report. Dept. of Environ. Protection, Mass. Division of Watershed Mgt. Report No. 94-AC-2.

*Mass*DEP. 2007. Massachusetts Surface Water Quality Standards. Massachusetts Department of Environmental Protection, Division of Water Pollution Control, Technical Services Branch, Westborough, MA (Revision of 314 CMR 4.00, January 2007).

*Mass*DEP. 2009. Massachusetts Year 2008 Integrated List of Waters. Final Listing of the Conditions of Massachusetts' Water Pursuant to Sections 303(d) and 305 (b) of the Clean Water Act. Dept. of Environ. Protection, Mass. Division of Watershed Mgt., CN: 281.1

Nelson, G.A. 2006. A guide to statistical sampling for the estimation of river herring run size using visual counts. Mass. Div. of Mar. Fisheries, Tech. Report No. TR-25.

PCCS. 2008. General Quality Assurance Project Plan. Water Quality Monitoring of Cape Cod Bay, 2008-2009. Provincetown Center for Coastal Studies, Provincetown, MA.

Reback, K.E. and J.S. DiCarlo. 1972. Completion report on the anadromous fish project. Mass. Div. Mar. Fisheries, Publication No. 6496, 113 pp.

Reback, K.E., P.D. Brady, K.D. McLauglin, and C.G. Milliken. 2004. A survey of anadromous fish passage in coastal Massachusetts: Part 3. South Shore. Mass. Div. of Mar. Fisheries, Tech. Report No. TR-17.

US EPA. 2001. Ambient Water Quality Cireteria Recommendations. Lakes and Reservoirs in Nutrient Ecoregion XIV. Office of Water, US Environ. Protection Agency, Washinggton, DC, Document EPA 822-B-01-011.

Wetzel, R.G. 1983. Limnology. 2nd Edition, Saunders College Publishing, Philadelphia. US EPA. 2001. Ambient Water Quality Criteria Recommendations. Lakes and Reservoirs in Nutrient Ecoregion XIV. Office of Water, US Environ. Protection Agency, Washington, DC, Document EPA 822-B-01-011.

WAA. 2006. South Coastal Watershed Action Plan. *Prepared by* Watershed Action Alliance of Southeastern, MA. Marshfield, MA, *for* Mass. Ex. Office. of Environ. Affairs.

Appendix

Table A1. Rainbow melt fyke net catch summary in the Jones River.

Species Name	Scientific Name	Type	2008 Catch (No.)	2009 Catch (No.)	2010 Catch (No.)	2011 Catch (No.)	2012 Catch (No.)	Total (No.)	FOC (No.)	FOC (%)	CPUE
rainbow smelt	*Osmerus mordax*	Diadromous	395	326	859	242	1785	3607	128	79.0	22.27
white perch	*Morone americanus*	Diadromous	19	41	185	34	22	301	66	40.7	1.86
American eel	*Anguilla rostrata*	Diadromous	17	21	20	7	16	81	49	30.2	0.50
sea lamprey	*Petromyzon marinus*	Diadromous	1	2		1	1	5	5	3.1	0.03
alewife	*Alosa pseudoharengus*	Diadromous	7			3	48	58	28	17.3	0.36
blueback herring	*Alosa aestivalis*	Diadromous			1		16	17	9	5.6	0.10
Atlantic tomcod	*Microgadus tomcod*	Diadromous	3	6	6	2	30	47	25	15.4	0.29
American shad	*Alosa sapidissima*	Diadromous			1			1	1	0.6	0.01
striped bass	*Morone saxatilis*	Diadromous					1	1	1	0.6	0.01
mummichog	*Fundulus heteroclitus*	Estuarine	14	15		69	137	235	61	37.7	1.45
threespine stickleback	*Gasterosteus aculeatus*	Estuarine	4	39	2	14	79	138	37	22.8	0.85
fourspine stickleback	*Apeltes quadracus*	Estuarine	9	59	10	22	20	120	68	42.0	0.74
Atlantic silverside	*Menidia menidia*	Estuarine	2	1	2	1	14	20	13	8.0	0.12
Atlantic herring	*Clupea harengus*	Estuarine	5			9	147	161	10	6.2	0.99
winter flounder	*Pseudopleuronectes americanus*	Estuarine		1	2	5	2	10	8	4.9	0.06
summer flounder	*Paralichthys dentatus*	Estuarine					1	1	1	0.6	0.01
golden shiner	*Notemigonus crysoleucas*	Freshwater				1		1	1	0.6	0.01
bluegill	*Lepomis macrochirus*	Freshwater	2	1	12	1		16	13	8.0	0.10
pumpkinseed	*Lepomis gibbosus*	Freshwater				1		1	1	0.6	0.01
white sucker	*Catostomus commersoni*	Freshwater			1			1	1	0.6	0.01
yellow perch	*Perca flavens*	Freshwater	2	898	5	1		906	20	12.3	5.59
brown bullhead	*Ameiurus nebulosus*	Freshwater					1	1	1	0.6	0.01
redfin pickerel	*Esox americanus*	Freshwater					1	1	1	0.6	0.01
brook trout	*Salvelinus fontinalis*	Freshwater			2		3	5	3	1.9	0.03
brown trout	*Salmo trutta*	Freshwater					1	1	1	0.6	0.01
white-tip mud crab	*Rhithropanopeus harrisii*	Invertebrate	1			2		3	2	1.2	0.02
Atlantic mud crab	*Panopeus herbstii*	Invertebrate		7	5	5	1	18	10	6.2	0.11
grass shrimp	*Palaemonetes sp.*	Invertebrate	7	8	1	9	13	38	18	11.1	0.23
sand shrimp	*Crangon septemspinosa*	Invertebrate	17	227	1	36	153	434	48	29.6	2.68
green crab	*Carcinus maenas*	Invertebrate			1		2	3	2	1.2	0.02
Total Catch			505	1652	1116	465	2494	6232			
Total Hauls			33	32	33	31	33				

Data Status: 2008-2011 *Final* (audited); 2012 *Preliminary* (not audited)
FOC: Frequency of Occurrence (number of haul when species were present)
CPUE: Catch per unit effort (total number caught/total hauls, N=162)

Table A2. Station locations sampled in Silver Lake and Forge Pond during 2008-2009.

No.	Latitude	Longitude	Station Type	Depth Strata	Max. Depth (m)	Sample (No.)	Location
SL1	42° 00.826	70° 47.645	transect	shallow	1.0	11	shallow cove off Lake outlet
SL2	42° 00.568	70° 47.876	transect	deep	13.8	12	mid-depth transect station
SL3	42° 00.528	70° 48.328	transect	shallow	5.4	12	off Monponsett Pond diversion
SL4	42° 01.097	70° 48.431	transect	deep	21.6	8	mid-Lake deep hole
SL5	42° 01.969	70° 48.714	survey	shallow	0.9	2	off Tubbs Meadow Brook oulet
SL6	42° 00.606	70° 48.254	survey	mid	7.5	1	exploratory station
SL1-A	42° 00.797	70° 47.715	transect	shallow	0.5	1	substitute for SL1 when dry
FP1	42° 00.786	70° 47.288	outlet	shallow	0.3	10	Forge Pond dam
FP2	42° 00.831	70° 47.416	transect	shallow	0.4	4	mid-Forge Pond location
FP3	42° 00.845	70° 47.602	outlet	shallow	0.4	11	Silver Lake outlet to Forge Pond
TM1	42° 01.994	70° 48.715	outlet	outlet	0.2	2	Tubbs Meadow Brook outlet

Table A3. Summary of the water chemistry data collected at station SL1 in Silver Lake 2008-2009.

Surface (0.3 m depth)

Parameter	Units	N	Mean	SE	Median	WQ Criteria	Meeting Criteria (%)
Temp.	(°C)	10	22.37	1.289	22.74	≤28.3	90
pH	(SU)	10	6.97	0.118	6.99	≥6.5, ≤8.3	90
DO	(mg/L)	10	9.44	0.210	9.46	≥5.0	100
DO sat.	%	10	108.2	2.997	106.9	NA	
Turbidity	(NTU)	10	1.0	0.142	1.0	NA	
Sp. Cond.	(mS/cm)	10	0.160	0.002	0.160	NA	
TN	(mg/L)	8	0.381	0.021	0.390	0.320	25
TP	(ug/L)	8	10.048	2.190	8.913	8.000	50
Secchi	(m)	0				≥2.0	

Bottom-water (0.6 m ave. depth)

Parameter	Units	N	Mean	SE	Median	WQ Criteria	Meeting Criteria (%)
Temp.	(°C)	6	21.04	1.585	20.72	≤28.3	100
pH	(SU)	6	6.74	0.123	6.70	≥6.5, ≤8.3	67
DO	(mg/L)	6	9.64	0.315	9.51	≥5.0	100
DO sat.	%	6	107.2	3.768	106.7	NA	
Turbidity	(NTU)	6	2.0	0.571	1.7	NA	
Sp. Cond.	(mS/cm)	6	0.161	0.003	0.161	NA	

Table A4. Summary of the water chemistry data collected at station SL2 in Silver Lake, 2008-2009.

Surface (0.3 m depth)

Parameter	Units	N	Mean	SE	Median	WQ Criteria	Meeting Criteria (%)
Temp.	(°C)	9	22.48	1.322	23.56	≤28.3	100
pH	(SU)	9	7.05	0.113	7.07	≥6.5, ≤8.3	100
DO	(mg/L)	9	9.12	0.256	8.75	≥5.0	100
DO sat.	%	9	104.5	2.223	104.0	NA	
Turbidity	(NTU)	9	0.9	0.174	0.9	NA	
Sp. Cond.	(mS/cm)	9	0.161	0.002	0.160	NA	
TN	(mg/L)	7	0.356	0.013	0.365	0.320	29
TP	(*u* g/L)	7	7.365	0.668	6.944	8.000	74
Secchi	(m)	9	2.9	0.128	3.0	≥2.0	100

Mid-water (4.0 m ave. depth) Sampled in 2008 only

Parameter	Units	N	Mean	SE	Median	WQ Criteria	Meeting Criteria (%)
Temp.	(°C)	5	21.60	1.438	20.78	≤28.3	100
pH	(SU)	5	7.11	0.076	7.18	≥6.5, ≤8.3	100
DO	(mg/L)	5	8.86	0.294	8.50	≥5.0	100
DO sat.	%	5	100.2	1.784	102.0	NA	
Turbidity	(NTU)	5	1.1	0.133	1.1	NA	
Sp. Cond.	(mS/cm)	5	0.157	0.001	0.159	NA	

Mid-water (7.3 m ave. depth)

Parameter	Units	N	Mean	SE	Median	WQ Criteria	Meeting Criteria (%)
Temp.	(°C)	9	15.74	0.715	15.41	≤28.3	100
pH	(SU)	9	6.48	0.092	6.41	≥6.5, ≤8.3	44
DO	(mg/L)	9	4.87	1.088	5.44	≥5.0	56
DO sat.	%	9	49.1	10.841	52.0	NA	
Turbidity	(NTU)	9	1.5	0.434	0.9	NA	
Sp. Cond.	(mS/cm)	9	0.160	0.003	0.159	NA	

Bottom (12.5 m ave. depth)

Parameter	Units	N	Mean	SE	Median	WQ Criteria	Meeting Criteria (%)
Temp.	(°C)	9	9.58	0.143	9.46	≤28.3	100
pH	(SU)	9	6.37	0.105	6.34	≥6.5, ≤8.3	33
DO	(mg/L)	9	2.06	0.805	0.35	≥5.0	22
DO sat.	%	9	18.0	7.025	3.0	NA	
Turbidity	(NTU)	9	7.9	5.374	7.9	NA	
Sp. Cond.	(mS/cm)	9	0.175	0.024	0.173	NA	

Table A5. Summary of the water chemistry data collected at station SL3 in Silver Lake, 2008-2009.

Surface (0.3 m depth)

Parameter	Units	N	Mean	SE	Median	WQ Criteria	Meeting Criteria (%)
Temp.	(°C)	10	22.45	1.188	22.49	≤28.3	100
pH	(SU)	10	7.05	0.169	7.08	≥6.5, ≤8.3	90
DO	(mg/L)	10	9.58	0.275	9.35	≥5.0	100
DO sat.	%	10	109.8	2.604	108.90	NA	
Turbidity	(NTU)	10	1.1	0.385	0.9	NA	
Sp. Cond.	(mS/cm)	10	0.161	0.002	0.160	NA	
TN	(mg/L)	10	0.418	0.050	0.390	0.320	20
TP	(ug/L)	10	8.882	0.887	8.758	8.000	20
Secchi	(m)	9	3.0	0.274	2.9	≥2.0	100

Bottom (3.0 m ave. depth)

Parameter	Units	N	Mean	SE	Median	WQ Criteria	Meeting Criteria (%)
Temp.	(°C)	10	20.67	1.142	20.19	≤28.3	100
pH	(SU)	10	6.68	0.162	6.86	≥6.5, ≤8.3	60
DO	(mg/L)	10	8.06	0.634	8.52	≥5.0	90
DO sat.	%	10	89.0	7.033	98.3	NA	
Turbidity	(NTU)	10	7.5	5.163	2.0	NA	
Sp. Cond.	(mS/cm)	10	0.157	0.004	0.160	NA	

Table A6. Summary of the water chemistry data collected at station SL4 in Silver Lake, 2008-2009.

Surface (0.3 m depth)

Parameter	Units	N	Mean	SE	Median	WQ Criteria	Meeting Criteria (%)
Temp.	(°C)	6	22.33	1.728	21.87	≤28.3	100
pH	(SU)	6	6.80	0.209	6.74	≥6.5, ≤8.3	83
DO	(mg/L)	6	9.26	0.361	8.86	≥5.0	100
DO sat.	%	6	105.5	3.668	105.8	NA	
Turbidity	(NTU)	6	0.8	0.221	0.9	NA	
Sp. Cond.	(mS/cm)	6	0.166	0.004	0.167	NA	
Secchi	(m)	5	2.8	0.153	2.8	≥2.0	100

Mid-water (5.0 m ave. depth)

Parameter	Units	N	Mean	SE	Median	WQ Criteria	Meeting Criteria (%)
Temp.	(°C)	5	19.37	1.223	19.46	≤28.3	100
pH	(SU)	5	6.47	0.082	6.48	≥6.5, ≤8.3	40
DO	(mg/L)	5	7.83	0.716	8.61	≥5.0	100
DO sat.	%	5	83.6	6.366	92.5	NA	
Turbidity	(NTU)	5	0.5	0.149	0.5	NA	
Sp. Cond.	(mS/cm)	5	0.167	0.005	0.173	NA	

Lower-water column (12.0 m ave. depth)

Parameter	Units	N	Mean	SE	Median	WQ Criteria	Meeting Criteria (%)
Temp.	(°C)	5	11.16	0.436	11.28	≤28.3	100
pH	(SU)	5	6.22	0.098	6.28	≥6.5, ≤8.3	0
DO	(mg/L)	5	3.79	1.547	2.58	≥5.0	40
DO sat.	%	5	33.9	13.756	23.1	NA	
Turbidity	(NTU)	5	2.7	1.061	2.5	NA	
Sp. Cond.	(mS/cm)	5	0.170	0.005	0.172	NA	

Bottom-water measurement (20.9 m ave. depth)

Parameter	Units	N	Mean	SE	Median	WQ Criteria	Meeting Criteria (%)
Temp.	(°C)	6	9.80	0.223	9.85	≤28.3	100
pH	(SU)	6	6.14	0.119	6.26	≥6.5, ≤8.3	0
DO	(mg/L)	6	1.83	1.135	0.37	≥5.0	17
DO sat.	%	6	16.0	9.968	3.1	NA	
Turbidity	(NTU)	6	13.9	3.506	13.2	NA	
Sp. Cond.	(mS/cm)	6	0.173	0.005	0.176	NA	

Table A7. Summary of the water chemistry data collected at stations FP1 and FP3 at Forge Pond, 2008-2009.

FP1 (0.2 m average depth)

Parameter	Units	N	Mean	SE	Median	WQ Criteria	Meeting Criteria (%)
Temp.	(°C)	8	17.40	1.043	16.73	≤28.3	100
pH	(SU)	8	5.95	0.067	5.98	≥6.5, ≤8.3	0
DO	(mg/L)	8	1.59	0.785	0.77	≥5.0	13
DO sat.	%	8	16.0	7.822	7.7	NA	
Turbidity	(NTU)	8	2.1	0.495	1.8	NA	
Sp. Cond.	(mS/cm)	8	0.278	0.020	0.300	NA	
TN	(mg/L)	9	0.902	0.155	0.810	0.320	0
TP	(*u*g/L)	9	48.890	11.613	46.469	8.000	0
Secchi	(m)	0				≥2.0	

FP3 (0.2 m average depth)

Parameter	Units	N	Mean	SE	Median	WQ Criteria	Meeting Criteria (%)
Temp.	(°C)	9	19.91	1.541	19.11	≤28.3	89
pH	(SU)	9	6.25	0.086	6.18	≥6.5, ≤8.3	22
DO	(mg/L)	9	4.44	1.029	3.36	≥5.0	33
DO sat.	%	9	49.2	11.740	36.3	NA	
Turbidity	(NTU)	9	2.7	0.562	2.5	NA	
Sp. Cond.	(mS/cm)	9	0.215	0.022	0.181	NA	
TN	(mg/L)	8	0.796	0.187	0.587	0.320	0
TP	(*u*g/L)	8	30.337	8.629	16.647	8.000	13
Secchi	(m)	0				≥2.0	