Technical Reports

Massachusetts Division of Marine Fisheries
Technical Report TR-77

River Herring Spawning and Nursery Habitat Assessment

Tom Matthews Pond, Yarmouth, MA, 2012-2013

A.F. Archer and B.C. Chase

Massachusetts Division of Marine Fisheries
Department of Fish and Game
Executive Office of Energy and Environmental Affairs
Commonwealth of Massachusetts

February 2022

Massachusetts Division of Marine Fisheries Technical Report Series

The Massachusetts Division of Marine Fisheries Technical Reports present information and data pertinent to the management, biology and commercial and recreational fisheries of anadromous, estuarine, and marine organisms of the Commonwealth of Massachusetts and adjacent waters. The series presents information in a timely fashion that is of limited scope or is useful to a smaller, specific audience and therefore may not be appropriate for national or international journals. Included in this series are data summaries, reports of monitoring programs, and results of studies that are directed at specific management problems.

All Reports in the series are available for download in PDF format at:
https://www.mass.gov/service-details/marine-fisheries-technical-reports.

Recent Publications in the Technical Series:

TR-73: Chase, B.C. 2020. **Quality Assurance Program Plan (QAPP) for Water Quality Measurements for Diadromous Fish Monitoring.**

TR-72: Livermore, J., B. C. Chase, M. Bednarski, and S. Turner. 2020. **River Herring Spawning and Nursery Habitat Assessment: Mill River Watershed, 2012-2014**.

TR-71: Pugh, T. L., and R. P. Glenn. 2020. **Random Stratified Ventless Trap Survey for American Lobster 2006-2016**.

TR-70: Nelson, G. A. 2019. **Massachusetts striped bass monitoring report for 2018**.

TR-69: Whitmore, K. A., E. M. Moore, and E. J. Brewer. 2019. **Characterization of Fishing Activity and Trap Loss in the Massachusetts Recreational American Lobster Fishery**.

TR-68: Nelson, G. A. 2018. **Massachusetts striped bass monitoring report for 2017.**

TR-67: Chosid, D. M., M. Pol, B. P. Schondelmeier, and M. Griffin. 2019. **Early Opening Experimental Fishery for Silver Hake/ Whiting in Small Mesh Area 1 and the Western Raised Footrope Exemption Area.**.

TR-66: Nelson, G. A., S. H. Wilcox, R. Glenn, and T. L. Pugh. 2018. **A Stock Assessment of Channeled Whelk (*Busycotypus canaliculatus*) in Nantucket Sound, Massachusetts**.

TR-65: Nelson, G. A. 2017. **Massachusetts striped bass monitoring report for 2016**.

TR-64: Nelson, G. A. 2016. **Massachusetts striped bass monitoring report for 2015**.

TR-62 Nelson, G. A. 2015. **Massachusetts striped bass monitoring report for 2014**.

TR-61 Nelson, G. A., J. Boardman, and P. Caruso. 2015. **Massachusetts Striped Bass Tagging Programs 1991–2014**.

TR-60 Nelson, G. A. and J. Stritzel-Thomson. 2015. **Summary of Recreational Fishery Data for Striped Bass Collected by volunteer Anglers in Massachusetts**.

TR-59 Nelson, G. A. 2015. **Massachusetts Striped Bass Monitoring Report for 2013**.

TR-58 Elzey, S. P., K. J. Trull, and K. A. Rogers. 2015. **Massachusetts Division of Marine Fisheries Age and Growth Laboratory: Fish Aging Protocols**.

TR-57 Chase, B.C., K. Ferry, and Carl Pawlowski. 2015. **River herring spawning and nursery habitat assessment: Fore River Watershed 2008-2010.**

TR-56 Sheppard, J.J., S. Block, H.L. Becker, and D. Quinn. 2014. **The Acushnet River restoration project: Restoring diadromous populations to a Superfund site in southeastern Massachusetts**.

TR-55 Nelson, G. 2013. **Massachusetts striped bass monitoring report for 2012**.

TR-54 Chase, B.C., A. Mansfield, and P. duBois. 2013. **River herring spawning and nursery habitat assessment**.

TR-53 Nelson, G.A. 2012. **Massachusetts striped bass monitoring report for 2011**.

TR-52 Camisa, M. and A. Wilbur. 2012. Buzzards Bay Disposal Site Fisheries Trawl Survey Report March 2001-March 2002.

TR-51 Wood, C. H., C. Enterline, K. Mills, B. C. Chase, G. Verreault, J. Fischer, and M. H. Ayer (editors). 2012. **Fourth North American Workshop on Rainbow Smelt: Extended Abstract Proceedings**.

TR-50 Hoffman, W. S., S. J. Correia, and D. E. Pierce. 2012. **Results of an industry-based survey for Gulf of Maine cod, May 2006-December 2007**.

Massachusetts Division of Marine Fisheries
Technical Report TR-77

River Herring Spawning and Nursery Habitat Assessment

Tom Matthews Pond, Yarmouth, MA, 2012-2013

Abigail F. Archer[1] and Bradford C. Chase[2]

[1]Barnstable County
Cape Cod Cooperative Extension Office
3675 Main Street
Barnstable, MA 02630

[2]Massachusetts Division of Marine Fisheries
836 South Rodney French Blvd.
New Bedford, MA 02744

February 2022

Commonwealth of Massachusetts
Charles D. Baker, Governor
Executive Office of Energy and Environmental Affairs
Kathleen Theoharides, Secretary
Department of Fish and Game
Ronald S. Amidon, Commissioner
Massachusetts Division of Marine Fisheries
Daniel J. McKiernan, Director

Members of the Bass River Rod & Gun Club standing on the recently constructed dike that created Tom Matthews Pond. Still frame excerpted from a home movie taken during 1941-1946.

Present view of Tom Matthews Pond.

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 to assist habitat and population restoration efforts and contributes to Massachusetts Department of Environmental Protection (MassDEP) water quality assessments. Tom Matthews Pond in Yarmouth, Massachusetts, was assessed during 2012-2013. Tom Matthews Pond is a 35 acre pond that flows to Cape Cod Bay and was created in the 1940s to provide aquatic habitat for freshwater and migratory fish. The assessment documented a high degree of water quality impairment with *Impaired* classifications assigned for water temperature, water pH, Secchi disc, total phosphorus, and total nitrogen. Cumulative measurements and observations suggest the pond health is degraded by eutrophication. Best Professional Judgment classifications for Fish Passage and Stream Flow were found to be *Impaired*. Favorable conditions identified by the assessment included observations of migrating adult river herring and juvenile American eel during both years, the absence of invasive aquatic plants and summer hypoxia. The fish passage limitations observed during the habitat assessment contributed to the replacement of the pond outlet fish ladder under a cooperative agreement in March 2014.

Introduction

Tom Matthews Pond is located in the Town of Yarmouth on the property of the Bass River Rod & Gun Club. It is a man-made pond created by an earthen dike that was constructed by the Bass River Rod & Gun Club sometime between 1941 and 1946. According to the 2003 Cape Cod Commission Pond and Lake Atlas, it has a surface area of 35.6 acres, a maximum depth of 5 feet, and is located at approximately 7 feet above mean sea level (Eichner 2003). It has a shoreline of 0.95 miles (Horsley & Whitten, 2007). Water from the pond discharges through a culvert and fish ladder into the tidal portion of a stream known as White's Brook. White's Brook drains to Chase Garden Creek which discharges into and receives tidal saltwater from Cape Cod Bay (Figure 1).

The Bass River Rod & Gun Club created the pond by constructing an earthen dike between two higher elevation necks of land that extend into the Chase Garden Creek saltmarsh system. A map of Yarmouth from 1850 shows White's Brook, and the unnamed stream crossing the present Rt 6A that was later dammed to create the pond (Figure 2). Maps from 1880 and 1931 also show the streams and no pond (Swift 1884 and 1936 Zoning Map). White's Brook was named after an English settler named Jonathan White, who was the son of Peregrine White, the child born on the Mayflower in 1620. Jonathan White was granted 7.5 acres in the area and constructed a house next to the stream (Swift 1884). The pond is labelled on current maps as either "Tom Matthews" or just "Matthews" pond and was probably named after the Matthews family – one of the first English families to settle in the area.

According to a Wastewater Plan written for the Town of Yarmouth in 2011, water quality in the pond was sampled in 2007-2009 as part of the citizens science water quality monitoring, "Ponds and Lakes Stewardship" (PALS) program coordinated by the Cape Cod Commission (CDM 2011). The PALS report summarizes the monitoring as finding the pond was "impacted" and eutrophic with exceedances of the MassDEP criterion for dissolved oxygen and very high concentrations of chlorophyll a (CDM 2011).

Water running out of the pond flows through an approximately 45 ft length (L), 23 in diameter (D) metal culvert, and then into a 53 in L x 53 in width (W) x 38 in depth concrete box. During the study period, water flowed from the box into a 24 ft L wooden Denil ladder, constructed by the Rod & Gun Club in the 1990s (Figure 3). In 2014 a new wooden fish ladder and an eel ramp were constructed as part of a cooperative project with the Massachusetts Division of Marine Fisheries (DMF), the Town of Yarmouth and the Rod & Gun Club (Figure 4). The new fish ladder is a 24 ft L wood weir and pool design with 15 baffles of 16 in W. The ladder was designed by the U.S Fish and Wildlife Service with support from this assessment's preliminary results, and fabricated by DMF. A four ft entrance box was added to the fish ladder in 2015 to improve access of river herring during low tides.

DMF is responsible for managing river herring populations in the Commonwealth. This effort includes improving passageways between marine and freshwater areas and evaluating options for restoring degraded populations and habitats. Tom Matthews Pond was prioritized for fish passage improvement by the

Figure 1. Tom Matthews Pond site map (Source: Google Earth).

Figure 2. Map of Yarmouth in 1850 (Source: Swift, 1884, courtesy of the Historical Society of Old Yarmouth).

Barnstable County Coastal Resources Committee and the DMF, and was chosen as one of 23 fish passage projects included in the Cape Cod Water Resources Restoration Project Plan (NRCS 2006), an effort lead by the USDA Natural Resources Conservation Service and its local partner the Cape Cod Conservation District. As part of the efforts to evaluate existing pond and fish passage conditions, staff from the Cape Cod Conservation District and DMF worked together to conduct a two-year river herring spawning and nursery habitat assessment during 2012-2013.

Diadromous Fisheries

Figure 3. Concrete box and Denil fish ladder in 2012. Note the difference in the box water level between July (left) and October (right).

The spring migrations of spawning river herring and juvenile American eel have been regularly observed by Bass River Rod & Gun Club members at the fish ladder. The White's Brook herring run is one of three herring runs in the Town of Yarmouth and is the only Cape Cod Bay run in the Town. This run was not mentioned in Belding's "A report upon the alewife fisheries of Massachusetts" (Belding 1921), and likely did not exist until the pond was created. The DMF anadromous fish survey of 1967 noted the presence of the herring run and that the pond had been recently stocked with alewives (Reback and DiCarlo 1972). The most recent DMF anadromous fish survey in 2001 (Reback et al. 2004) noted the presence of an alewife run but did not document the fish ladder as degraded. By 2006, the fish ladder wood was clearly aging and suffering from ice damage. In 2014 the non-profit environmental group Association to Preserve Cape Cod began working with the Rod & Gun Club to recruit volunteers to participate in a visual count of the run. Using the DMF counting protocols (Nelson 2006) run estimates were generated for 2014 of 70,169 and 52,742 for 2015.

Water Management

Tom Matthews Pond and the surrounding lands are owned by the Rod & Gun Club but the public is allowed to access the waterbody for fishing. The Rod and Gun Club maintains the fish ladder in support of the river herring run, however, the pond has no formal targets for maintaining water surface elevation or outflow. Typically, the outlet pipe regulates pond outflow without the need for active management. In dry years, outflow has been reduced to conserve water for juvenile herring emigration. DMF drafted an Operation and Maintenance for the fish ladder in 2017. The plan provides seasonal guidance for fishway O&M and establishes a staff gauge to record relative pond level data.

Assessment QAPP

The assessment of river herring spawning and nursery habitat, conducted by DMF, aids 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 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 such as Aquatic Life 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 2009). 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.

Figure 4. New Tom Matthews Pond fish ladder constructed in March 2014.

MassDEP Water Quality Status

Chase Garden Creek (MA96-35), which receives water from Tom Matthews Pond via White's Brook, is listed in the Cape Cod Coastal Drainage Areas 2004-2008 Surface Water Quality Assessment Report under "Small Tributaries to Cape Cod Bay". There are three NPDES Discharges into it, Aquaculture Research Corporation (MA005576), and stormwater discharges from the Town of Dennis (MAR041103) and Town of Yarmouth (MAR041176) (MassDEP 2011). It was not assessed for Aquatic Life, Fish Consumption, or Aesthetics but is listed as "Support" for both Primary and Secondary Contact. It is listed as "Impaired" for Shellfish Harvesting with the cause, "Elevated fecal coliform bacteria" and the source stated as, "Waterfowl, upstream source."

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 2007); US Environmental Protection Agency (US EPA) nutrient criteria recommendations (US EPA 2001); and the Best Professional Judgment (BPJ) of DMF biologists (Chase 2010). Monthly assessment trips were made to Tom Matthews Pond from May to September, targeting the second and third week of each month. In 2012, schedule conflicts and weather prevented a trip in September, so the assessment trip was made on October 2. This period was used for sampling because it is when: water quality can exhibit the most impairment; and adult river herring spawning, and juvenile occupation of Tom Matthews Pond would occur. Although river herring spawning does occur in April, the month is not sampled by design due to the typical lack of impairment during early spring. The assessment criteria for all parameters are summarized in Table 1. Station parameter data are summarized in the Appendix.

Table 1. Summary of river herring habitat assessment criteria and classification for Tom Matthews Pond, 2012-2013.

Parameter	Units	Sample Size (No.)	Acceptable Criteria	Exceedance (No.)	Exceedance (%)	Classification
Temp. (nursery)	°C	32	≤28.3	5	16	*Impaired*
Temp. (spawning)	°C	47	≤26.0	8	17	*Impaired*
DO	mg/L	78	≥5.0	5	6	*Suitable*
pH	SU	78	6.5 to ≤8.3	38	49	*Impaired*
Secchi	m	9	≥2.0	9	100	*Impaired*
TN	mg/L	7	≤0.32	7	100	*Impaired*
TP	ug/L	8	≤8.0	8	100	*Impaired*
Eutrophication	NA	9	BPJ	3	33	*Impaired*
Fish Passage	NA	9	BPJ	8	89	*Impaired*
Stream Flow	NA	9	BPJ	2	22	*Impaired*

Note: *Impaired* classifications result from exceedances of >10% or >1 (when N< 10) for transect stations.

Water quality measurements are made at the surface (0.3 m depth) and bottom (0.5 m from bottom) in the water column, and at mid-water column depths at deeper stations. The following basic water quality parameters were measured: water temperature, dissolved oxygen (DO), pH, specific conductivity, turbidity, and Secchi disc depth. Water temperature, DO, and pH were related to SWQS criteria. Total phosphorus (TP) and total nitrogen (TN) samples were collected on 4 dates in 2012 and 5 in 2013. The TP, TN, and Secchi disc data were related to US EPA nutrient criteria recommendations. The TP and Secchi disc 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 Best Professional Judgement. 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 greater than 10% of transect samples result in an Impaired classification (when N ≥ 10).

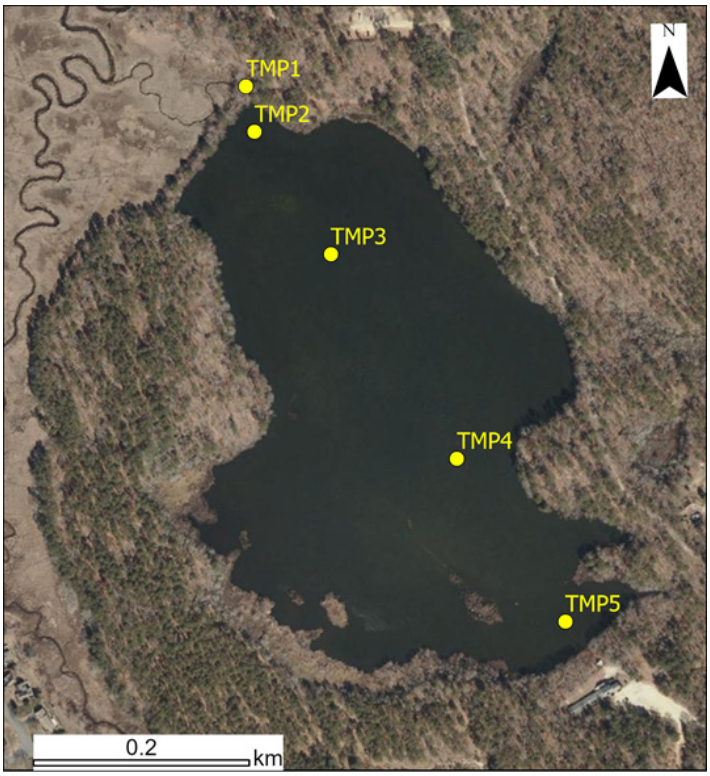

Figure 5. Tom Matthews Pond: river herring spawning and nursery habitat assessment sampling stations.

Assessment Stations

Stations were selected to provide a transect running from the lake outlet to the opposite shore of the pond (Figure 5).These selected stations contained shallow, medium, and deep depth strata based on pond bathymetry. The assessment classification was based on stations TMP2, TMP3, TMP4, and TMP5.

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. A median is then calculated from the four seasonal 25th percentiles that represents a threshold between minimally impacted and impaired habitats. The QAPP adopts this approach by relating nutrient measurements to the EPA's 25th percentile median for the Northeast Coastal Zone subecoregion #59, resulting in criteria of 8.0 ug/L for TP and 0.32 mg/L for TN. (US EPA 2001).

Geographically, Tom Matthews Pond is located in a different subecoregion than the QAPP criteria are based on. It is located in subregion 84, the Atlantic Coastal Pine Barrens which includes most of New Jersey, Long Island in New York, and Cape Cod. However, this subecoregion has far fewer records than subecoregion 59 to base the criteria on – only 317 vs. over 36,000. The nutrient criteria for subregion 84 are 0.41 ug/L for TN and 9.0 ug/L for TP. 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.

Results

Massachusetts SWQS Criteria

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

During the two-year assessment a total of five (16%) measurements at Tom Matthews Pond exceeded the spawning threshold and eight (17%) exceeded the nursery period threshold, resulting in an Impaired classification for water temperature for both periods (Figure 6). All exceedances occurred during either June 2012 or July 2013 sampling. During the 2012 spawning period no exceedances occurred in May; however, in June exceedances occurred at all four stations at the surface, and one subsurface sample at TMP4.

For the nursery period in 2012 no exceedances were measured. In 2013 in July, temperatures were observed above the threshold at every site at every depth measured. The warmest measurement recorded during the two- year assessment was 30.46°C on July 19, 2013 at station TMP4 at the surface depth of 0.3m. Stratification with temperature differences > 2°C between surface (0.3) and mid depth (0.7) measurements was observed at the two deepest stations (TMP3 and TMP4) only in June 2012 and August 2013. There was no significant difference in average temperatures between 2012 and 2013 at the surface depth (T-test, t= -0.07, df=37, p=0.94) or mid depth (T-test, t=0.51, df=27, p=0.61).

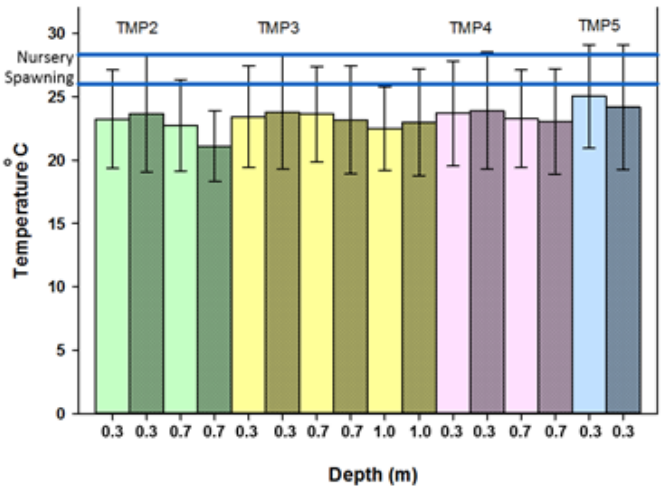

Figure 6. Water temperature measurements taken at Tom Matthews Pond. Station averages (±2 SE) are presented for 2012 (blank bars) and 2013 (shaded bars). Five samples were recorded at each depth per season.

Water pH. The acidification of freshwater 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 wa-ter pH criterion of ≥6.5 to ≤8.3 as *Suitable* to support Aquatic Life. Water pH outside of this range can be a threat to the growth and development of fish eggs and larvae, while highly acidic and alkaline waters (<4.0 and >9.0 pH) in some cases can cause lethal effects (NAS 1972; Haines and Johnson 1982).

Water pH at Tom Matthews Pond ranged from 6.31 to 9.85 for all measurements. Surface pH measurements for the two seasons averaged 8.11. Of the 78 measurements, five were below the criteria of ≥6.5 and thirty-three were above the criteria of ≤8.3 (total 49% exceedance) resulting in an Impaired classification for pH (Figure 7). High pH, which can stress fish respiration, can occur in eutrophic conditions when daytime photosynthesis depletes carbonic acid in the water column.

Exceedances occurred in both years, and at all sites. In 2012, five pH measurements were above 8.3, all occurring in the month of June, and all at surface depths except for one instance at 0.7m at TMP4. In 2013, 28 measurements were above 8.3, and took place at all depths during June-September.

The four measurements below 6.5 were all in 2012 at site TMP2. One occurred in July at the surface depth, and the other four occurred at depth 0.7m in May, July, and August. There was a significant difference (T-test, t =-4.61, df=38, p=0.00) in average pH between the two years: surface measurements (0.3m) from all the sites averaged 7.42 in 2012 and 8.81 in 2013. It has not been common to have pH impairment caused by alkaline water for assessments conducted under the project's QAPP. For the Tom Matthews Pond assessment, the high surface pH, high nutrient concentrations and low visibility all suggest the influence of eutrophication.

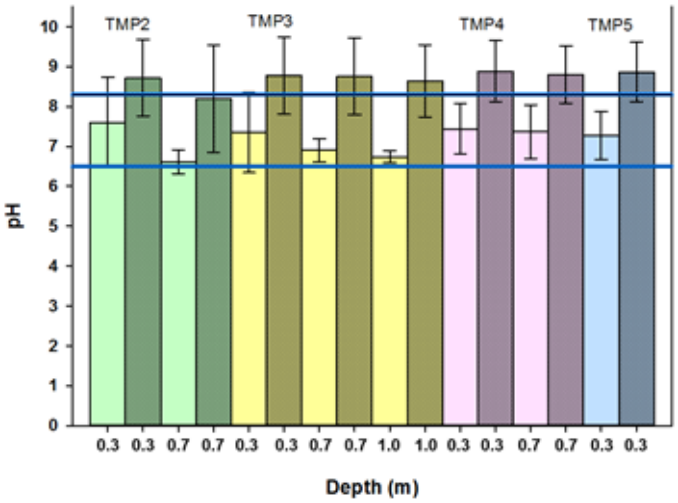

Figure 7. Water pH measurements taken at Tom Matthews Pond. Station averages (±2 SE) are presented for 2012 (blank bars) and 2013 (shaded bars). The sample size is five per season per station. The blue lines mark the MassDEP SWQS thresholds for pH.

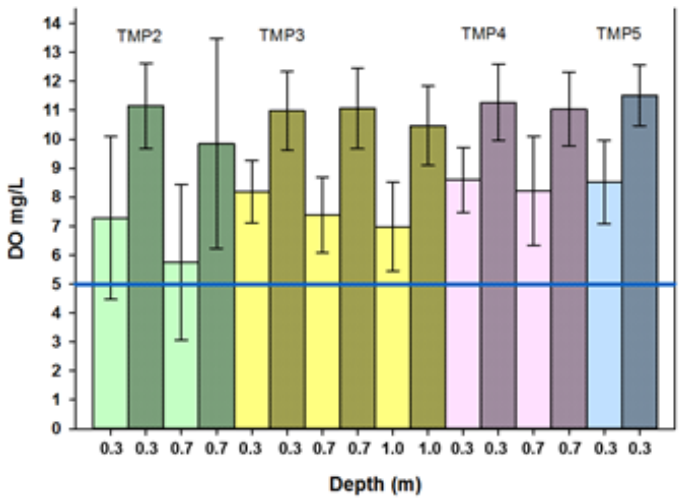

Figure 8. Dissolved oxygen measurements taken at Tom Matthews Pond. Station averages (±2 SE) are presented for 2012 (blank bars) and 2013 (shaded bars). Five samples were recorded at each depth per season. The blue line marks the MassDEP SWQS DO threshold.

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, resulting in seasonal and diurnal cycles. The QAPP adopted the MassDEP DO criterion of ≥5.0 mg/L as *Suitable* to support Aquatic Life.

Tom Matthews Pond was classified as *Suitable* for DO with only five (6%) of the 78 transect station measurements below the 5.0 mg/L DO threshold (Figure 8). Of the five exceedances, only one was at the surface (July 2012 at TMP2). The other four were measured at depth 0.7m and 1.0m. Four of the exceedances took place in 2012 during the months of June and July. The single exceedance in 2013 took place in July at TMP2.

There was a significant difference (T-test, t=-5.95, df=37, p=0.00) in average DO between the two years: surface measurements (0.3m) from the sites averaged 8.12 in 2012 and 11.23 in 2013. Average mid depth measurements at TMP2, TMP3, and TMP4 (0.7m) were also significantly different (T-test, t=-3.89, df=27, p=0.001) between the two years. In 2012 the average was 7.10 and in 2013 it was 10.65.

Nutrient Criteria. Nutrient samples were collected in 2012 & 2013 and processed according to the project QAPP. Surface samples of TN and TP were collected at TMP3 for the 2012 July-October site visits, and in 2013 for the May-September site visits (Table A3). There were 8 samples for TP and 7 for TN. One duplicate sample for TN and TP was collected on September 2013. The samples met the QAPP thresholds for QA/QC.

The average TN at Tom Matthews Pond was 1.04 mg/L and the average TP was 73.79 ug/L. All measurements exceeded the QAPP recommended limits (based on EPA's 25th percentile for the Northeast Coastal Zone subecoregion #59) of 0.32 mg/L TN and 8.0 ug/L TP resulting in an Impaired classification. Overall, the Tom Matthews Pond TN and TP concentrations were relatively high among DMF river herring habitat assessments published to date (Chase et al., 2010, 2013, and 2015). Additional assessments have been completed, but not yet published for six other river herring spawning ponds on Cape Cod. Among these seven ponds, only Red Lily Pond in Barnstable had a higher average TN value (1.83 mg/L) than Tom Matthews Pond, and Tom Matthews Pond had the highest total phosphorus (Pers. comm., Brad Chase).

Based on a sampling of 175 Cape Cod ponds in August & September 2001, the average TP concentration in surface samples was 27.2ug/L (Eichner et al. 2003). According to the authors of the Cape Cod Pond

and Lake Atlas, without human influence, Cape Cod lakes would have low phosphorus concentrations because of a lack of phosphorus in the glacially derived sands (Eichner et al. 2003). Based on sampling from 184 Cape Cod ponds in August & September 2001, the average TN concentration in surface samples was 0.58mg/l (Eichner et al. 2003).

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, there-fore 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.

Because of the shallow water depth at Tom Matthews Pond (measured station depth range of 0.6 to 1.8 m), some Secchi disc measurements resulted in the disc visible and resting on the bottom. These observations were excluded from further analysis. The deepest station TMP3 (average depth = 1.3 m) had nine Secchi disc measurements that were all valid with an average of 0.8 m and range of 0.4 to 1.4 m (Figure 9). Given these results of no suitable measurements above the Secchi disc criterion (≥2.0 m), the Secchi disc parameter was classified as *Impaired.*

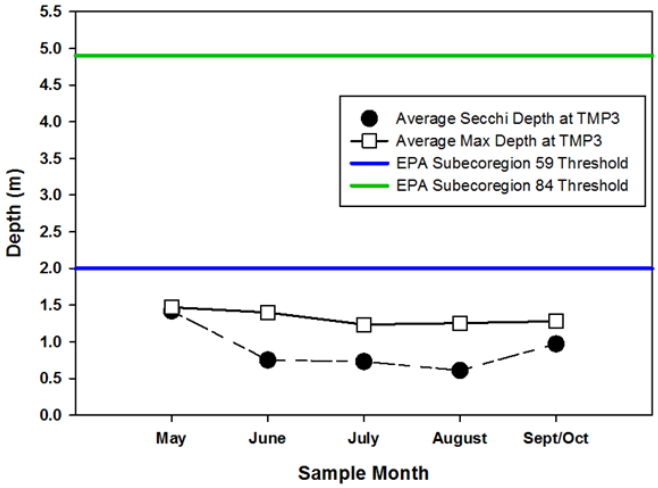

Figure 9. Average Secchi disc measurements and maximum depths taken at TMP3 at Tom Matthews Pond in 2012 and 2013.

Best Professional Judgement

Fish Passage. The QAPP provides a process for using Best Professional Judgment (BPJ) to assess the capability 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*. Monthly inspections were made at the outlet of the pond and at the fish lad-der. The depth of water was observed and measured in the culvert on the pond side, in the concrete box located on the salt marsh side, and when it was safe to do so, at the entrance to the fish ladder in the salt marsh creek. Presence or absence of migrating fish was also noted.

During the two-year assessment, nine Fish Passage observations were made, with *Unsuitable* or *Impaired* fish passage conditions found on eight dates (89%), resulting in an *Impaired* classification. For the spawn-ing period (May and June) this was due primarily to the entrance of the fish ladder, which rested on concrete blocks set directly in the tidal saltmarsh channel. The depth of water at the entrance to the fish ladder fluctu-ated with the tidal cycle. On the days and times the site was visited the tide was low and the water downstream of the ladder was not at a depth that would allow adult upstream migrating herring to access it, leading to the QAPP fish passage designation #1 “Excess vertical rise at outlet”. In addition, as the fish ladder degrad-ed, it slipped off the concrete blocks and the wood frame warped so badly that the entrance to the lad-der was no longer parallel to the surface of the water.

For the nursery period (July-September), fish passage for downstream migrating adults and juveniles was *Unsuitable* in 2012 because of QAPP designation #4, “No flow at outlet”. In July no flowing water was present in the ladder (Figure 6) and in August water was present, but it was not high enough in the fish ladder to allow juvenile fish to swim over the baffles. In 2013, variable conditions of fish passage were ob-served. In July water was observed exiting the side of the fish ladder which could potentially have impinged downstream migrating juveniles – although none were observed on that sampling date. In August, adequate flow was available in the fish ladder for downstream migrating juveniles and the tide was high, which left no gap between the ladder entrance and the surface of the creek water. Fish Passage was determined to be *Impaired* in September due to a 25cm gap

between the entrance of the ladder and the surface of the water in the tidal creek. Average pond depth was higher overall in 2013 than in 2012 (Figure 10).

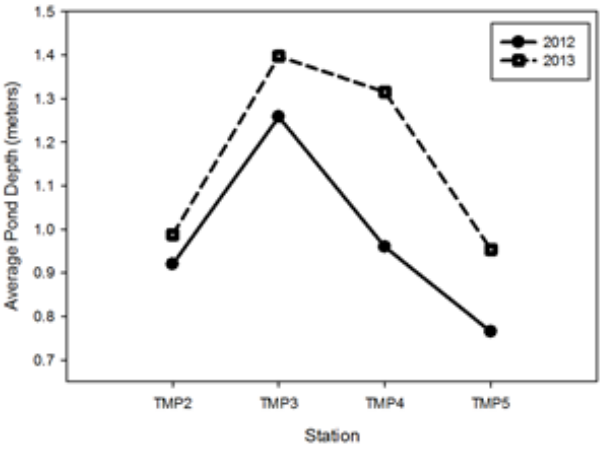

Figure 10. Tom Matthews Pond level measurements.

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.

With each monitoring trip during 2012-2013 stream flow at the outlet was classified as either *Suitable* or *Impaired*. In 2012, flow was adequate for upstream migrating adults in May and June, but not enough water was present for juveniles to migrate downstream through the ladder in July and August. In 2013, flow was again adequate in May and June to support upstream passage. Unlike 2012, stream flow during July-September was adequate for downstream passage. The depth of water in the pond side of the outlet pipe was higher in 2013 than 2012 in all months except for September/October (Figure 11). The overall classification for stream flow is *Impaired* due to the two observations (22%) of impaired flow during the summer of 2012.

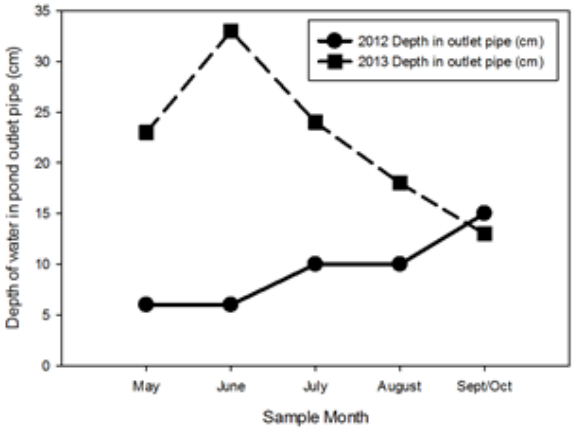

Figure 11. Depth of water (substrate to water surface) at Tom Matthews Pond outlet pipe, station TM1.

Eutrophication. The QAPP provides a process for using BPJ observations to assess if shoal transect stations are impact¬ed 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, the QAPP classification for eutrophication is based on US EPA criteria and not BPJ.

The reference condition of eutrophication was classified as *Impaired* for Total Nitrogen (TN) and Total Phosphorus (TP), as all TN and TP measurements were above the QAPP adopted thresholds. There was visual evidence of eutrophication as well – in July of 2012 and June and September of 2013 a high density of green colored algae was present in the water column, and in August of 2013 the water color was described as, “murky, green-brown”. These conditions were also reflected in the low Secchi disc measurements. In July of 2012, dense mats of waterweed (Genus *Elodea*) were as observed across the pond, and this was the same date that the only surface water DO exceedance was recorded.

Spawning Substrate. River herring deposit demersal eggs that stick to whatever surface they encounter. After one day, the eggs become non-adhesive and will hatch in 3 to 4 days. 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 mon¬itoring during QAPP assessments supports the view that clean gravel is a better surface for egg survival than fine silt or dense periphyton growth.

Observations of the substrate were made when possible and substrate composition was observed when taking up the 5-pound mushroom anchor after sampling was complete at each station. Visual estimates of percentage of gravel, sand, silt, periphyton, and vascular plants were made and recorded. The following average substrate proportions were estimated during 10 sampling dates: gravel (0%), sand (0%), silt (51%), periphyton (<1.0%), and vascular plants (49%). No invasive aquatic plants were observed in Tom Matthews Pond during the assessment. The waterweed (Genus Elodea) was the dominant vascular plant. However, a more thorough survey would be needed to confirm the absence of invasive plants.

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 sub-ecoregion #59 is ≤1.7 NTU (US EPA 2001).

Relatively high turbidity measurements were made at Tom Matthews Pond during both years of the habitat assessment. The average turbidity for all samples at the four transect stations was 30.0 NTU (N = 77, SD = 58.3, range = 1.3 to 236.5. NTU). Four high measurements of turbidity were censored because they exceeded 3 standard deviations of the average. The average turbidity in 2012 (45.9 NTU, 82.3 SD) was much higher than 2013 (16.1 NTU, 10.8 SD). These are the highest average turbidity values measured among QAPP habitat assessments to date. The QAQC review did not reveal concerns over data quality. In both years the highest values occurred in June when high phytoplankton growth was apparent.

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 freshwater can indicate watershed contributions of natural alkaline compounds or ionic contributions from pollution sources.

The average specific conductivity for all transect measurements at Tom Matthews Pond was 0.243 mS/cm (N=89, SD=0.027). Looking at other published river herring spawning and nursery habitat assessments, this value is lower than the averages observed at the more urban Mystic Lakes, and the Fore River spawning ponds Great Pond and Sunset Lake. It is higher than that observed at Silver Lake (Chase et al. 2010, 2013, and 2015).

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 score ranging 0-100. Scores near zero would indicate uncommonly nutrient poor and low productivity conditions, while scores near 100 indicate extremely degraded and highly productive conditions. The TSI for each of these parameters relates to a numeric scale of trophic conditions based on the premise that increasing nutrients elevate plant productivity and result in reduced water clarity.

The mean Secchi disc depths for measurements made at TMP3 resulted in a TSI score of 62.5. The mean TP measurements for TMP3 resulted in a TSI score of 66.2. These scores are in the upper end of the Eutrophic range, which according to the 2003 Cape Cod Pond and Lake Atlas, 26% of ponds on Cape Cod fall into. Only 3% across the Cape are in the range of 70-80 (Eichner, 2003). These scores are also the highest to date among river herring habitat assessment reported under the DMF QAPP.

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), which relies on parameter-based precision and accuracy indicators. Data were classified as Final, Conditional, or Censored based on the agreement of precision and accuracy checks to QAPP criteria. All laboratory calibrations and precision checks in 2012 and 2013 were acceptable to classify all field data as Final with no adjustments. All field precision checks in 2012 and 2013 were acceptable.

Diadromous Fish Observations

Adult river herring were observed in the pond, in the concrete box, swimming upstream through the pipe into the pond, and in the salt marsh creek below the fish ladder in May of both 2012 and 2013, and in June of 2012. The largest school observed was in May 2013 when 50-70 river herring were seen schooling in the pond near the outlet pipe. In May of 2012 while kayaking around the pond, adult herring were observed in the shallows of the pond just below the Bass River Rod & Gun clubhouse. Juvenile river herring were not observed during assessment trips. In May 2012, two glass eels were observed in water underneath the fish ladder.

Wildlife Observations

Tom Matthews Pond and the surrounding area had a high diversity of bird activity. Fourteen species were both seen and heard on or near the pond over the course of the 10 sampling days including two species that might have an effect on the water quality. Adult and juvenile mute swans (*Cygnus solor*) and Double crested cormorants (*Phalacrocorax auritus*) were observed during every sampling day. In June of 2012 there were two families of swans observed, by July there was only one swan family with six cignets. This family was observed feeding on the pond vegetation through October. In 2013 the pond supported one swan family with six cignets that were observed feeding on the pond vegetation May-September. On most sampling days cormorants could be seen roosting in the trees on the west side of the pond, and the leaves below were white with guano. During the August 2013 sampling trip a flock of 50 cormorants landed on the pond.

Conclusion

Adult river herring migrated to Tom Matthews Pond each year of the habitat assessment. No juvenile herring were observed during this assessment; however, Bass River Rod & Gun Club members observed juveniles in the fall. These collective observations provide evidence that the pond continues to support spawning and nursery habitat for river herring. However, water quality impairments in Tom Matthews Pond were documented during the habitat assessment. Of the six water quality parameters assessed, only dissolved oxygen met the criteria for a *Suitable* classification. Fish Passage and Stream Flow were also classified as *Impaired* due to the degraded condition of the fish ladder and low outflow during summer and early fall.

The cumulative results of assessment data portray degraded water quality at Tom Matthews Pond with significant symptoms of eutrophication. The turbidity, TN, TP and Carlson Trophic Index values were among the highest measured in the other published and unpublished QAPP habitat assessments. The alkaline pH measurements in surface waters and high plant growth provide further evidence of eutrophication. To the contrary, DO was the one parameter that was found *Suitable*: the shallow pond did not have conditions of surface DO supersaturation or stratification at depth. Also positive was the lack of observations of invasive aquatic plants and the appar-ently robust resident populations of freshwater fish.

The cause of degraded water quality is uncertain, but past and present land use is a probable influence, as is the maturation process of an artificial pond. Pri-or to the building of the dike, the area received tidal flow and was probably dominated by the high eleva-tion salt marsh (*Spartina patens*). Spartina species create layers of peat as the plants grow, die, and col-lect suspended sediment over successive years. The dike prevented tidal flow from entering the area, and allowed it to flood with freshwater from groundwater springs. A large body of literature exists on the water quality effects of altering salt marsh habitat, but the mechanisms are diverse. Salt marsh peat contains both phosphorus and nitrogen in organic and inorgan-ic forms (Pomeroy et al, 1965, Valiela & Teal 1979). One possible source of the phosphorous could be phosphate bound to iron in the peat layers. When the pH of overlaying water is <7.0 the phosphorous can be released (Reimold and Daiber 1970). At Tom Mat-thews Pond, 30 of the 78 pH measurements were <7.0. Recent and present watershed influences include a farm, cranberry bogs, and homes with septic systems.

A difference in rainfall amounts and patterns in 2012 and 2013 could have influenced the statistically significant differences observed between the two years in pH and dissolved oxygen. The depth at Tom Mat-thews Pond sampling stations was higher in 2013 than 2012. Further, the 2013 water chemistry had higher pH, more oxygenated, and higher conductivity at both surface and mid depths. Based on the closest Nation-al Weather Service rain gauge (Hyannis, HYANWS), during the five assessment months the area received 1.97 in more rain in 2013 than 2012 with starker dif-ferences seen with other comparisons. For example, in June 2012 the area received 1.95 in, and June 2013 received 9.05 in. Further, Tom Matthews Pond is fed by groundwater springs so rainfall leading up the assessment period is also an important factor: rainfall at the Hyannis gauge during January to April in 2013 exceeded this period in 2012 by 7.12 inches.

The presence of invasive mute swans (*Cynus olor*) could be negatively affecting physical spawning habitat for river herring. River herring are known to deposit eggs on submerged vegetation. Swans eat submerged aquatic vegetation (SAV) and exclosure studies have documented the negative effects large numbers of swans can have on SAV in coastal ponds and marshes (Allin & Husband, 2003, Ketan et al 2007). According to a Maryland Department of Natural Resources Wildlife and Heritage Service report, in coastal wetlands a single swan can eat an average of 8 lbs of SAV a day (MDNR, 2011). However, no studies have examined the effect a single pair of adult swans and their cignets can have on SAV, nutrient dynamics and the water quality in a single freshwater pond. One favorable outcome of the two-year habitat assessment was the contribution that assessment observations on fish passage made towards the local interest of improving the fish ladder status at Tom Matthews Pond. A cooperative partnership of the Town of Yarmouth, the Bass River Rod & Gun Club, and DMF formed in 2014 and acted proactively to replace the degraded Denil ladder with a new, custom, wood pool and weir ladder in March 2014.

Recommendations

To maintain and improve the river herring spawning and nursery habitat and aquatic health of Tom Matthews Pond the following actions are recommended:

1. Operate and maintain the new fish ladder according to the DMF approved Operations & Maintenance Plan (June 2017). This includes annual attention to the tidal channel below the fish ladder where accumulated debris can impede fish passage.

2. The river herring spawning and nursery habitat assessment data should be provided to MassDEP to support 305(b) reporting and to assist local water quality protection. Significant concerns were identified over the potential for slumping salt marsh peat and accumulated thatch to impede the emigration of juvenile river herring.

3. Conduct a thorough survey of aquatic plant species and document the presence or absence of invasive species.

4. Monitor the condition of the outlet pipe and assess outflow volume related to its effectiveness for juvenile herring emigration. Seek opportunities to redesign the outlet pipe and outlet box for more efficient fish passage.

5. Investigate the potential source(s) of nitrogen and phosphorus impacting the pond and develop remediation options.

6. The Town of Yarmouth and Bass River River Rod and Gun club should consider alternative management strategies for improving the water quality of Tom Matthews Pond. The habitat assessment does not provide clear guidance on management practices such as pond dredging, winter drawdowns and the control of invasive mute swans; however, the present health of the pond should prompt conceptual discussions on strategies for improvement.

Acknowledgements

Thank you to Mark Galkowski and the members of the Bass River Rod & Gun Club for their dedication to maintaining this herring run, and to the volunteers who continue to spend their time counting herring at the fish ladder. Thank you to field assistants Lindsay Cook, Richard Archer, and Kate O'Hora for their time spent kayaking the pond and help with collecting samples. Thank you to the Town of Yarmouth Department of Natural Resources Director Karl von Hone for providing early input on this project, and for providing information on the history of the run. The staff of the Historical Society of Old Yarmouth assisted with finding early maps of the area, and information about the early settlers along White's Brook - thank you in particular to Duncan Oliver and Amy Heller. The Cape Cod Conservation District and the Barnstable County Cape Cod Cooperative Extension supported the staff time required to complete this project. This assessment is the fifth published habitat assessment report to follow the QAPP for water quality measurements conducted for diadromous fish habitat monitoring (Chase 2010) approved by MassDEP in November 2009. The field and laboratory efforts of DMF are supported by the Sportfish Restoration Act.

Literature Cited

Allin, Charles C. and Thomas P. Husband. 2003. Mute Swan (Cygnus olor) impact on submerged aquatic vegetation and macroinvertebrates in a Rhode Island coastal pond. Northeastern Naturalist 10(3):305-318

Belding, D.L. 1921. A report upon the alewife fisheries of Massachusetts. Massachusetts Division of Fisheries and Game, Department of Natural Resources. Wright and Potter Printing Company, Boston. http://capecodhistory.us/books/Belding-herring-1920.htm

Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography 22 (2): 361-369. CDM, July 2011. Single Environmental Impact Report and Comprehensive Wastewater Management Plan. Prepared for Town of Yarmouth. 1125-75359-03-CWMP.

Chase, B. C., T. Callaghan, M. B. Dechant, and P. Patel. 2010. River herring spawning and nursery habitat assessment: Upper Mystic Lake, 2007–2008. TR-44

Chase, B.C., A. Mansfield, and P. duBois. 2013. River herring spawning and nursery habitat assessment: Silver Lake 2008–2009. Massachusetts Division of Marine Fisheries Technical Report Series. T4-54. http://www.mass.gov/eea/docs/dfg/dmf/publications/tr-54.pdf

Chase, B. C., K. Ferry, and C. Pawlowski. 2015. River herring spawning and nursery habitat assessment: Fore River Watershed 2008–2010. Massachusetts Division of Marine Fisheries Technical Report Series. TR-57.http://www.mass.gov/eea/docs/dfg/dmf/publications/tr-57-full4final.pdf

Chase, B. C. 2010. Quality assurance program plan (QAPP) for water quality measurements for diadromous fish monitoring 2008–2012, version 1.0. Massachusetts Division of Marine Fisheries Technical Report Series.TR-42. http://www.mass.gov/eea/docs/dfg/dmf/publications/tr-42.pdf

Commonwealth of Massachusetts Executive Office of Energy and Environmental Affairs Department of Conservation and Recreation Office of Water Resources. (2017). Precipitation Database Data 2015 0323 (Data file). Retrieved from http://www.mass.gov/eea/agencies/dcr/water-res-protection/water-data-tracking/rainfall-program.html

Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas. Cape Cod Commission, Barnstable MA.

Gamble, Adam, editor Cape Cod's Earliest Atlas. 1998. 1880 Atlas of Barnstable County. On Cape Publications.

Greene, K.E., J.L. Zimmerman, R.W. Laney, and J.C. Thom¬as-Blate. 2009. Atlantic coast diadromous fish habitat: a review of utilization, threats, recommendations for conservation, and research needs. Atlantic States Marine Fisheries Commission Habitat Management Series No. 9, Washington, D.C. https://www.asmfc.org/files/Habitat/HMS9_Diadromous_Habitat_2009.pdf

Haines, T., and R. Johnson, eds. 1982. Acid rain/Fisheries. Proceedings of an international symposium on acidic precipitation and fishery impacts in Northeastern North Ameri¬ca. American Fisheries Society, Bethesda, Maryland.

Horsely and Whitten Group, December 2007, Town of Yarmouth Open Space and Recreation Plan, Prepared for the Town of Yarmouth Open Space Committee and Recreation Division. http://www.yarmouth.ma.us/DocumentCenter/View/664

Ketan S. Tatu, James T. Anderson, Larry J. Hindman, and George Seidel. 2007. Mute Swans' Impact on Submerged Aquatic Vegetation in Chesapeake Bay. Journal of Wildlife Management 71:5, 1431-1439.

Maryland Department of Natural Resources Wildlife and Heritage Service. 2011. Mute Swan Management Plan for Maryland. http://dnr.maryland.gov/wildlife/Documents/2011_MUSW_MDMgtPlan.pdf

MassDEP. 2013. Massachusetts surface water quality standards. Massachusetts Department of Environmental Pro¬tection, Division of Water Pollution Control, Technical Ser¬vices Branch, Westborough, Massachusetts. (Revision of 314 CMR 4.00, December 2013). http://www.mass.gov/eea/docs/dep/service/regulations/314cmr04.pdf

MassDEP. 2012. Massachusetts year 2012 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. Massachusetts Department of Environmental Protection, Division of Watershed Management, CN 400.1 http://www.mass.gov/eea/docs/dep/water/resources/07v5/12list2.pdf

MassDEP 2011. Cape Cod Coastal Drainage Areas 2004-2008 Surface Water Quality Assessment Report. Prepared by: MassDEP Division of Watershed Management Report Number: 96-AC-2 DWM Control Number: CN 171.0 Massachusetts Department of Environmental Protection Division of Watershed Management Worcester, Massachusetts. http://www.mass.gov/eea/docs/dep/water/resources/71wqar09/96wqar12.pdf

NAS (National Academy of Sciences). 1972. Water quality criteria 1972. A report of the Committee on Water Quality Criteria. National Academy of Sciences and National Acade¬my of Engineering. Washington, D.C.

Nelson, Gary, A. 2006. A Guide to Statistical Sampling for the Estimation of River Herring Run Size Using Visual Counts. Massachusetts Division of Marine Fisheries Technical Report Series,TR-25. http://www.mass.gov/eea/docs/dfg/dmf/publications/tr-25.pdf

NRCS, 2006. Final Watershed Plan and Areawide Environmental Impact Statement for the Cape Cod Water Resources Restoration Project. U.S. Dept. of Agriculture, Nat. Res. Conservation Services, Nov. 2006.

Pomeroy, Lawrence R., Smith, E E., Grant, Carol M., 1965.The Exchange of Phosphate between estuarine water and sediments. Limnology and Oceanography, 10:2, 167-172.

Reback, K.E., P.D. Brady, K.D. McLauglin, and C.G. Milliken. 2005. A survey of anadromous fish passage in coastal Massachusetts: Part 3. Cape Cod. Massachusetts Division of Marine Fisheries, Massachusetts Division of Marine Fisheries Technical Report Series. TR-17. http://www.mass.gov/dfwele/dmf/publica- tions/technical.htm. 361-371

Swift, Charles, F. 1884 Edited by Charles A. Holbrook “History of Old Yarmouth Comprising the Present Towns of Yarmouth and Dennis From the Settlement to the Division in 1794 With the History of Both Towns to 1876” The Historical Society of Old Yarmouth. 1975

US EPA. 2001. Ambient water quality criteria recommendations: information supporting the development of state and tribal nutrient criteria for lakes and reservoirs in Nutrient Ecoregion XIV. Office of Water, US Environmental Protection Agency, Washington, D.C. EPA 822-B-01-011. https://www.epa.gov/sites/production/files/documents/lakes14.pdf

Valiela, Ivan and John M. Teal. 1979. The nitrogen budget of a salt marsh ecosystem. Nature 280:23, 652-656

Tom Matthews Pond fish ladder installation, March 2014.