Water Quality During a Small Dam Removal on Temple Stream, Farmington, Maine

April 2023

Contact: Emily Zimmermann, Biologist
Phone: (207) 446-1003

Site of the former Walton's Mill Dam

MAINE DEPARTMENT OF ENVIRONMENTAL PROTECTION
17 State House Station | Augusta, Maine 04333-0017
www.maine.gov/dep

Introduction

Despite the restoration efforts of numerous groups since the 1970s, the population size of Atlantic salmon (*Salmo salar*) in Maine has remained low (USASAC 2020). According to the 2018 recovery plan for Gulf of Maine Atlantic salmon, habitat connectivity is the primary action needed to restore populations (USFWS and NMFS 2018). Although the main stem of the Kennebec River has dams downstream of the Sandy River blocking access for sea-run fish, the Sandy River watershed remains highly productive for salmon, largely due to the trap-and-truck translocation of adults by the Maine Department of Marine Resources (MDMR). In July 2022, the Atlantic Salmon Federation (ASF) removed Walton's Mill Dam (see photo on cover page), the only dam on Temple Stream, a tributary to the Sandy River in Farmington. The 6 m tall dam, originally built in 1820, blocked all fish passage and impounded approximately one mile of stream to create a 19-acre impoundment. Removal of small, surface-spill dams typically results in increased resiliency to the effects of climate change, including improvements in water quality such as decreased temperatures and increased dissolved oxygen concentrations (Abbott et al. 2022; Paukert et al. 2021; Zaidel 2018; Zaidel et al. 2021). Environmental monitoring of the stream before and after dam removal is being conducted as a multi-partner collaboration between the University of Maine at Farmington, US Fish and Wildlife Service, MDMR, ASF, and MDEP. This report characterizes stream water quality before, during, and after dam removal activities.

Methods

Study Location

Temple Stream is a tributary to the Sandy River (originally called Anmessokkanti, UMF 2022), within the homeland of the Nanrantsouak (Norridgewock) Tribe of Wabanaki (Native Land Digital, 2022). The stream and its tributaries are assigned the Statutory Class of B under Maine's Water Classification Program (38 M.R.S.§§ 464). For a description of the watershed and land uses, see Zimmermann 2022. MDMR has been planting salmon eggs upstream of the dam for 13 years and conducting electrofishing surveys to determine average relative abundance of parr (using the catch per unit effort metric of how many parr were captured every minute of fishing). Average relative abundance of salmon in Temple Stream is 0.56 parr/minute (MDMR data from 2012-2022, although in 2022 only two sites were sampled in Temple Stream as part of a generalized random-tessellation stratified sampling design). Three locations in Temple Stream were monitored for water quality (Fig. 1): upstream of the Rt.43 crossing, in a deep section of the former impoundment approximately 380 m above the former dam, and approximately 500 m downstream of the former dam. A biological monitoring site 320 m further downstream was sampled in 2020. The dam gates were opened April 28, 2022, and the dam was fully breached July 21, 2022 (for time lapse photos, see https://www.chronolog.io/site/TOF101). A natural ledge waterfall at the dam site, uncovered following dam removal, creates a bedrock sill that may be maintaining a natural impoundment in the stream within the former impoundment.

Water Quality

All water quality monitoring activities followed the EPA-approved Salmon Habitat Monitoring Program Quality Assurance Project Plan (MDEP 2021). Continuous monitoring devices were deployed to collect water quality data every half hour from April 13 – October 17 (see Zimmermann 2022 for detailed methods), with the addition of a turbidity sensor at the downstream site. Continuous data were corrected as needed based on quality control procedures

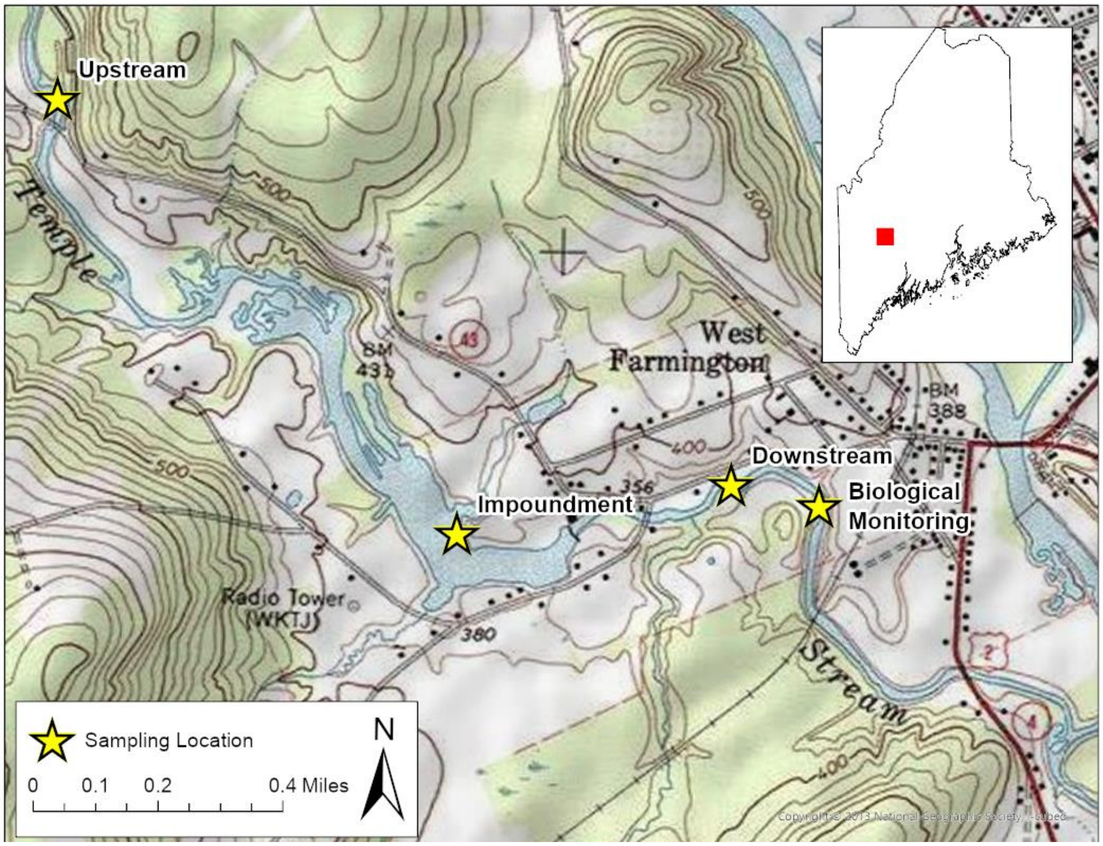

Figure 1. Map of the study sites on Temple Stream. The Biological Monitoring site was only sampled in 2020.

as described in MDEP (2016) and using a sonde as a field meter (Eureka Manta2 Sub2 or Eureka Manta+ 20). Surface grab samples for dissolved organic carbon (DOC), total phosphorus, total Kjeldahl nitrogen (TKN), and nitrate + nitrite as nitrogen were collected in April, August, and October from each sample location, following the methods in Zimmermann (2018).

Water Surface Elevation

Water surface elevation was measured from April 28 – July 19 by ASF (see Zimmermann 2022 for detailed methods).

Data Visualization and Analysis

Water quality data were analyzed using the Water Resources Database (WRDB) 7.0.0.30 (Wilson Engineering 2022) and R 4.2.2 (R Core Team 2022). Figures 5 and 10 were created in WRDB. All other figures were created in R using the *ggplot2* package (Wickham 2009). All data are presented as mean ± standard deviation (SD). Linear mixed models were used to test statistical significance with an α level of 0.05, using the estimated marginal means *emmeans* package with Tukey post-hoc adjustment for multiple comparisons (Lenth 2023). Durations of stressful events, based on thresholds for the protection of salmon and other aquatic life, were calculated based on how many consecutive data points exceeded the water quality threshold before recovery.

Quality control issues caused rejection of 3% of specific conductance data (11 cumulative days), <1% of pH data (15 cumulative hours) and <1% of DO data (3 cumulative hours). Equipment malfunctions such as dead batteries resulted in rejection or loss of 2% of data from each parameter, plus 3% of DO data from the bottom of the former impoundment, when the logger was not correctly set up to record data for a one-month deployment (May-June). Data flagged due to corrections included 9% of turbidity data (34 days) and 7% of DO data (2.4 months from July through September from the bottom of the former impoundment). For any non-detect data, reporting limits were used in analysis. At the bottom of the impoundment, 8% of DO measurements (13 days) were less than the reporting limit of 0.01 mg/L.

Results and Discussion

Weather

Similar to the prior year, Maine had a warm, dry winter in 2022 followed by a warm spring (NOAA 2022). Approximately 100 mm more rain fell in 2022, however abnormally dry conditions persisted from June through September, escalating to moderate drought for most of July and August (U.S. Drought Monitor 2022). Rain amounts per storm were similar between the two years (9 ± 14 mm), despite two storms greater than 80 mm in July and October 2022. Increased rain may have eased some of the potentially stressful conditions for salmonids and other fishes caused by low flow, such as preventing access to cold water refuges.

Water Surface Elevation

Water surface elevation could not be measured after the dam was breached July 21. Prior to the breach, the average elevation was 110.1 ± 0.6 m, very similar to last year, with a minimum elevation of 109.2 m that occurred July 12.

Stream Temperature

Salmon prefer cold waters (Stanley and Trial 1995). The temperature threshold for optimal growth is less than 20°C (Jonsson et al. 2001; USEPA 1986). Salmon experience physiological stress (e.g., stop feeding) and seek cold water refuge when temperatures are above 22°C (Cunjak et al. 2005; Elliott and Elliott 2010; Lund et al. 2002). Maximum temperature for the survival of adults occurs at 26-27°C (Shepard 1995 as cited in Frechette et al. 2018) and for parr at 28-29°C (Elliott 1991 as cited in Stanley and Trial 1995; Garside 1973 as cited in Lund et al. 2002; Grande and Andersen 1991 as cited in Elliott and Elliott 2010).

Temperatures were slightly cooler in 2022 compared with the previous year (Appendix II Table II-1). The warmest temperatures still occurred at the downstream site, however downstream warming (as compared to the upstream site) was significantly reduced to 0.76 ± 1.31°C. Downstream temperatures cooled sufficiently to place the reach within the transition zone between the coldwater and warmwater classes for fish communities, similar to the upstream site (Beauchene et al. 2014). No changes were observed upstream between the two years. Excluding the cooler bottom waters of the impoundment, temperatures were less than optimal for 35% of the study duration, with the stress threshold of 22°C exceeded 19% of the time (Fig. 2; Appendix II Table II-3). Maximum temperature for survival of adults (26-27°C) was exceeded 0.8% of the time, and for parr (28-29°C) <0.1% of the time, occurring in late July and early August during a period of moderate drought (U.S. Drought Monitor 2022). Although temperatures at the downstream site remained above 22°C for 23.3 hours on average, resiliency

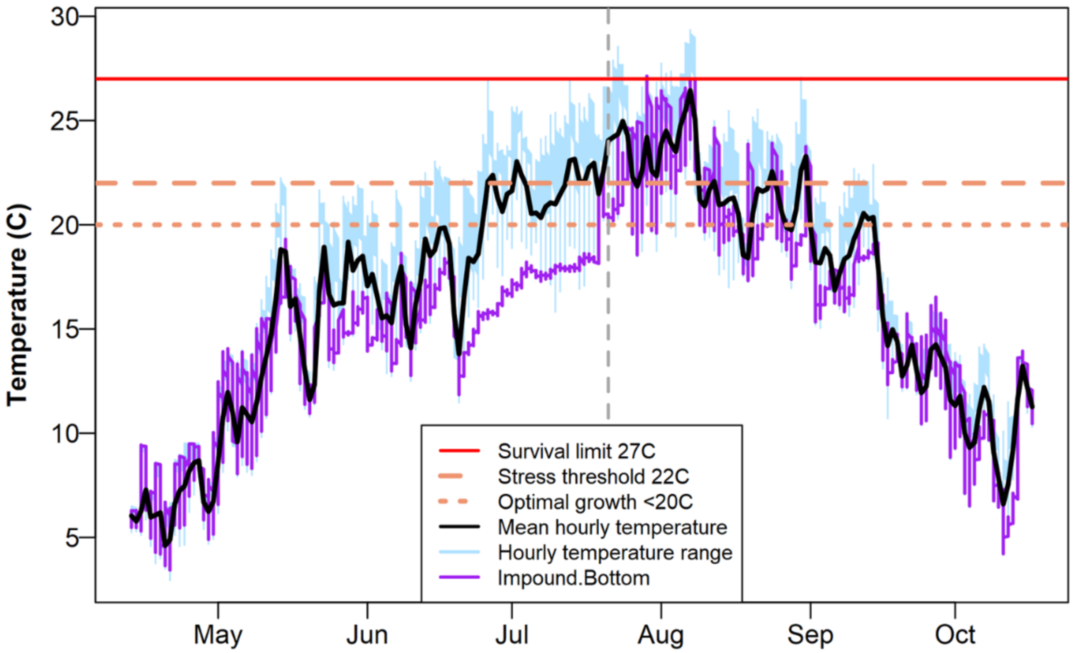

Figure 2. Mean hourly water temperature, May through October. All sites are combined together except for Impound.Bottom (located 1 m above the impoundment bottom). Dam breached July 21, 2022, indicated by the vertical dashed line. Optimal growth limit from Jonsson et al. 2001 and USEPA 1986. Stress threshold from Cunjak et al. 2005; Elliott and Elliott 2010; Lund et al. 2002. Survival limit for adult salmon from Shepard 1995 as cited in Frechette et al. 2018.

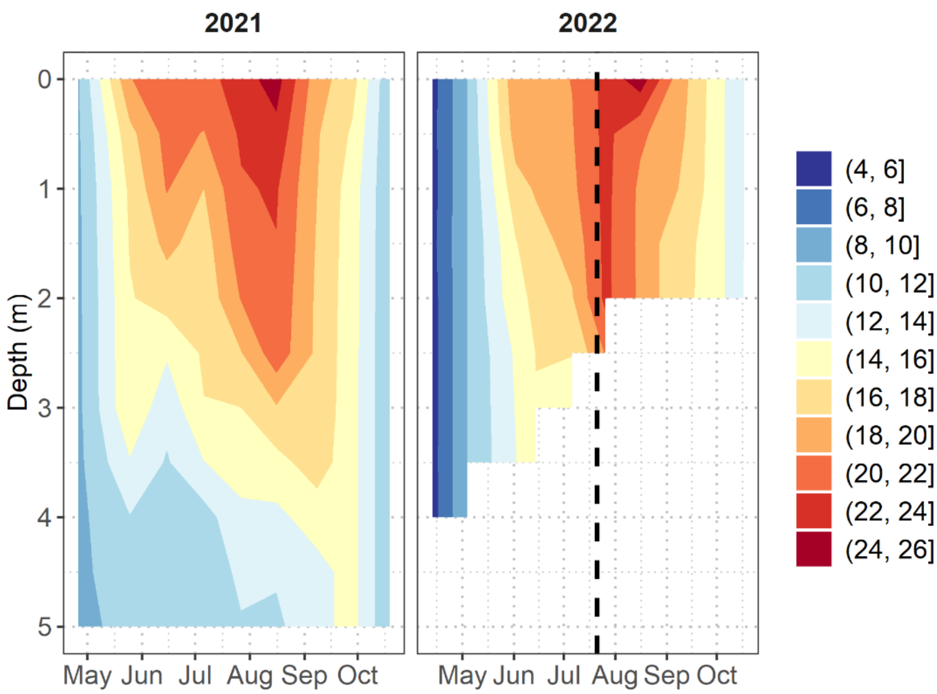

Figure 3. Impoundment temperature-depth profiles collected every three weeks April through October. Blue to yellow represents optimal growth for salmon (<20°C; Jonsson et al. 2001; USEPA 1986). Orange to red represents stressful conditions (>22°C; Cunjak et al. 2005; Elliott and Elliott 2010; Lund et al. 2002). Dam breached July 21, 2022, indicated by the vertical dashed line.

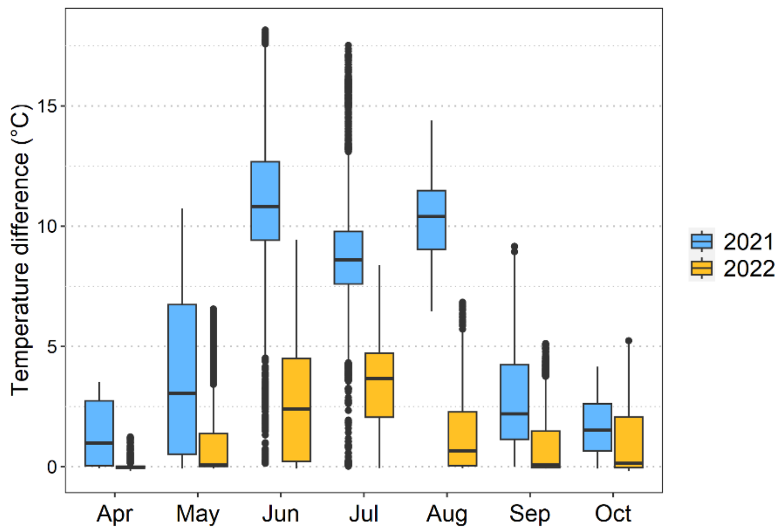

Figure 4. Temperature difference between the surface and bottom of the impoundment, from paired measurements collected every 15 minutes, April through October.

to warm temperatures was improved slightly, with a maximum duration of 8.6 days (2.4 days shorter than in 2021). Similar to 2021, at all sites combined, diel fluctuations were 3.7 ± 1.7°C. In the surface waters of the impoundment, the diel fluctuation doubled (4.28 ± 1.58°C) compared with the prior year (2.1 ± 1.0°C), increasing the possibility of providing nightly thermal refuge for salmon during thermally stressful periods.

The impoundment experienced less thermal stratification in 2022 compared with the prior year, with the thermocline ranging from 0.5-2.5 m June to September (Fig. 3). Reduced stratification caused bottom waters to be significantly warmer (by 2.8°C) and more similar to the surface waters (1.4 ± 1.9°C cooler than the surface compared with 7.0 ± 4.4°C cooler in 2021; Figs. 2 and 4; Appendix II Table II-3). During the strongest stratification (June-July), bottom waters were only 3.9°C cooler than surface waters, as compared with the 10°C difference observed in 2021 (Fig. 4). Increased mixing of the water column in the former impoundment was likely due to the shallower depth (Appendix I, Table I-1) as well as increased flow, influenced by higher rainfall amounts, the opened dam gates, and the dam breach and removal. Some stratification still occurred, possibly due to the abnormally dry summer conditions combined with the low gradient of the stream section and the bathymetry at the study site, including the natural bedrock sill at the former dam site. In addition, the newly exposed, wide, shade-free banks of the former impoundment allow solar radiation to warm the stream.

In the study area, high temperatures likely cause sublethal stress and reduced growth in salmon during the warmest months, however nightly temperature refugia may help mitigate some of those impacts. Although the region experienced cooler temperatures in 2022, dam removal decreased temperature differences between the upstream and downstream sites, potentially increasing the amount of cool-water habitat available for fish in Temple Stream (Beauchene et al. 2014; Zaidel et al. 2021; but see Zwieniecki and Newton 1999). In addition, diel fluctuations were more than 2°C greater at the surface of the former impoundment following dam removal, providing a greater chance for nightly thermal refugia (Dripps and Granger 2013). Maximum temperature reduction may not occur until the former impoundment has revegetated with a resilient riparian zone that provides shade from solar radiation, which may take years despite installation of native stakes of woody vegetation (willow, alder, etc.) in November 2022 (ASF 2023; Lawrence et al. 2014; Velinsky et al. 2006; Zaidel et al. 2021).

Dissolved Oxygen (DO)

Salmon prefer well oxygenated waters with dissolved oxygen concentrations above the Maine Water Quality Standard minimum criterion value of 7 mg/L (38 M.R.S. §§ 465.2.B;

Stanley and Trial 1995). Within riverine impoundments that thermally stratify, such as Temple Stream during the warmest summer months, numeric water quality criteria are not used for compliance purposes (38 M.R.S. §§ 464.13.B), however salmon are likely to avoid areas below 7 mg/L (Stanley and Trial 1995). Salmon experience acute physiological and behavioral stress below 5 mg/L (USEPA 1986).

DO levels at the stream sites were slightly higher than the previous year, remaining within a healthy range for fish (>7 mg/L) for 100% of the study period upstream and 98% downstream (Fig. 5). As in 2021, the upstream site had the highest DO, with concentrations 0.65 ± 0.49 mg/L higher than downstream, and 1.02 ± 0.58 mg/L higher than the surface of the impoundment. Compared with the previous year, surface waters of the former impoundment experienced slightly more time in the optimal range (89% >7 mg/L), but longer durations below this threshold (5 hours on average, with a maximum of 4 days in early August; Fig. 5; Appendix II Table II-3). Similar to 2021, surface waters experienced exceedances in duration, frequency, magnitude, and diurnal swing of MDEP's consolidated assessment and listing methodology associated with the Integrated Water Quality Monitoring and Assessment Report, and the downstream site experienced exceedances in duration and frequency (MDEP 2022, p. 53-55). This assessment methodology is used by MDEP to determine if streams are impaired for aquatic life criteria.

DO concentrations in the bottom waters of the impoundment were higher in 2022, likely as a result of increased flow (increased mixing and reduced residence time) and reduced sediment and nutrient trapping (Fig. 6; Abbott et al. 2022). Bottom waters still experienced the lowest DO concentrations, with 57% of the study period above 7 mg/L (compared with only 25%

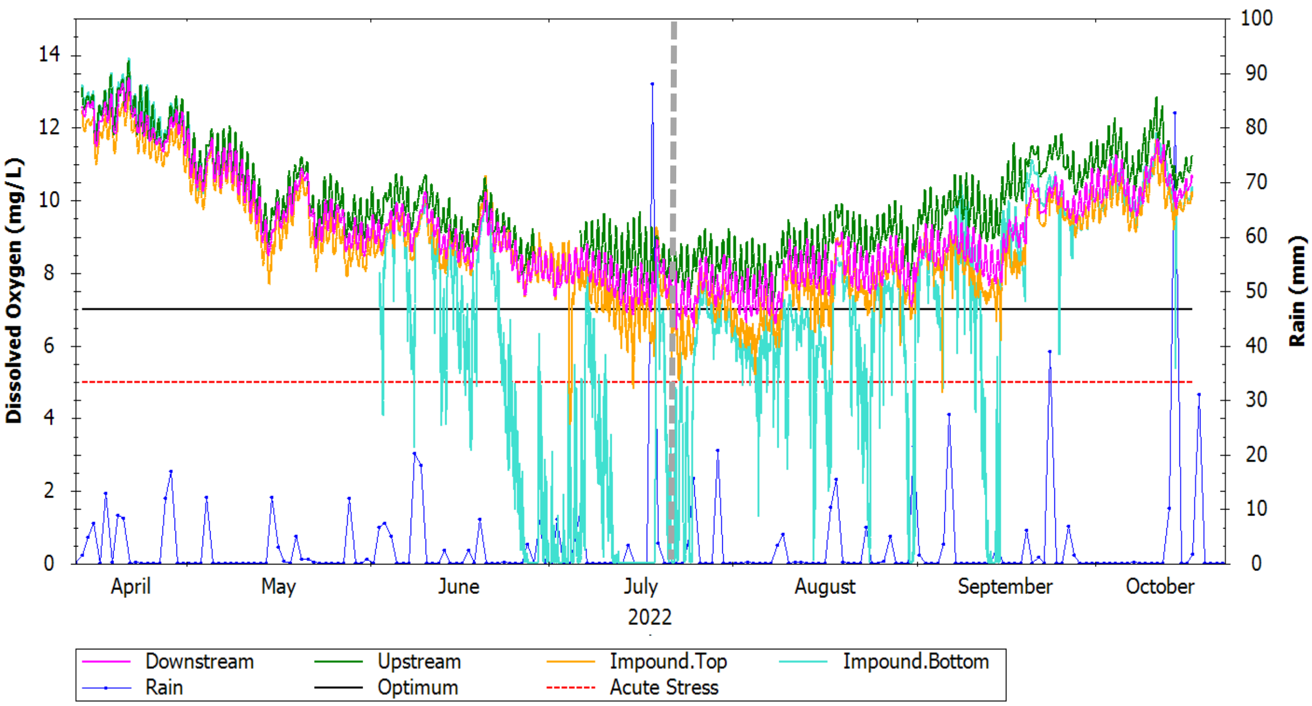

Figure 5. Dissolved oxygen and local rainfall May through October. The logger at Impound.Surface was 0.5 m from the surface of the impoundment; the logger at Impound.Bottom was 1 m above the impoundment bottom. Dam breached July 21, 2022, indicated by the vertical dashed line. Optimum threshold from Stanley and Trail 1995 and for surface waters, 38 M.R.S. §§ 465.2.B. Stress threshold from USEPA 1986. Rainfall data from Weather Underground station KMEFARMI35.

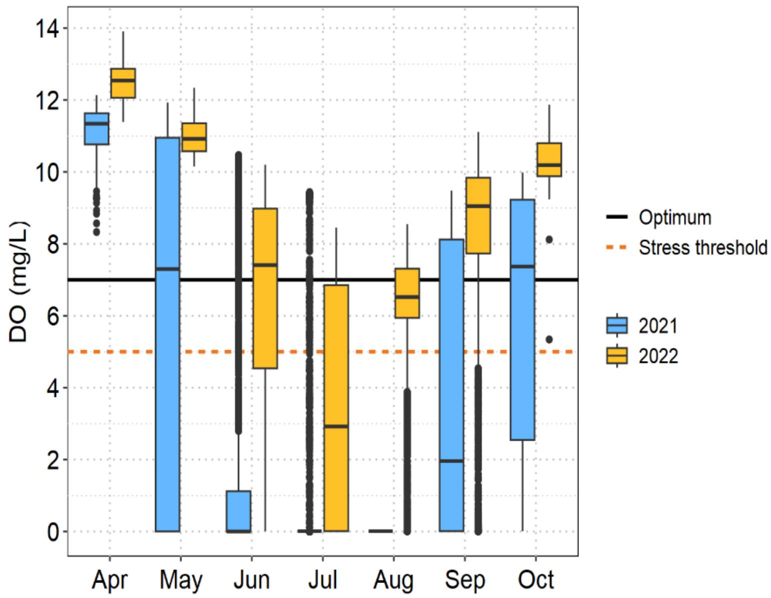

Figure 6. Dissolved oxygen concentration in the bottom of the impoundment, collected every 15 minutes April through October. Optimum threshold from Stanley and Trial 1995. Stress threshold from USEPA 1986.

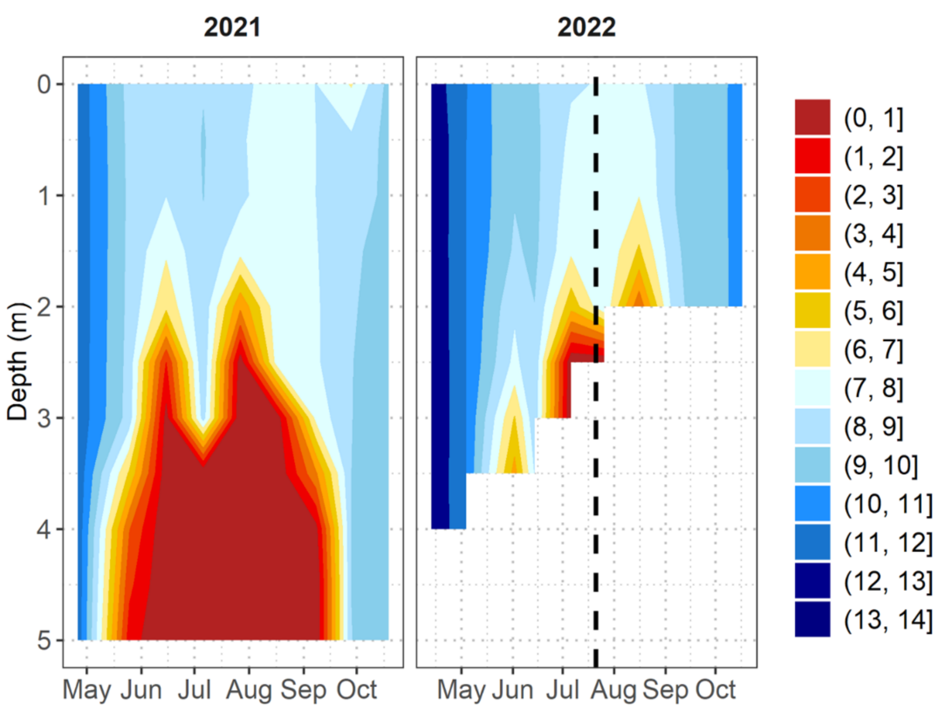

Figure 7. Impoundment dissolved oxygen-depth profiles collected every three weeks April through October. Red represents hypoxic conditions (<2 mg/L; Rounds et al. 2013); orange represents acute stressful conditions (<5 mg/L; USEPA 1986); yellow suboptimal conditions (<7 mg/L); and blue represents optimal conditions (>7 mg/L; 38 M.R.S. §§ 465.2.B; Stanley and Trial 1995). Dam breached July 21, 2022, indicated by the vertical dashed line.

in 2021; Fig. 5; Appendix II Table II-3). Acute stress (<5 mg/L) only occurred for 24% of the study period (vs. 71% in 2021), with much shorter durations (8 hours on average, with a maximum duration of 8 days, vs. an average of 48 hours and maximum of two months in 2021). Hypoxic conditions (<2 mg/L, Rounds et al. 2013) occurred for only 16% of the study period and lasted on average 7 hours (vs. 65% and lasting 2.2 days in 2021). As in 2021, DO stratification occurred primarily in conjunction with thermal stratification June-August, with DO concentrations decreasing dramatically in the bottom meter, however stratification events were shorter and less frequent (Figs. 5 and 7).

Periods of low DO in the surface waters of the former impoundment coupled with warm temperatures likely cause stress to salmon and other aquatic life (Maxted et al. 2005; Remen et al. 2012). Opening the dam gates followed by dam removal resulted in more stream-like conditions with well-mixed water, reducing the frequency of stratification and decreasing the occurrence of summer hypoxia in the bottom waters (Abbott et al. 2022; Zaidel 2018). The bottom meter of the former impoundment likely still does not support aquatic life during the summer, possibly due to the maintenance of a natural, smaller impoundment by the bedrock sill at the former dam site. As seen in prior studies, the downstream site was not significantly impacted by the low DO from the impoundment, suggesting the water becomes reaerated during its passage downstream, regardless of dam presence (Abbott et al. 2022; Lessard and Hayes 2003; Velinsky et al. 2006; Zaidel 2018). Within a year of dam removal, as the former impoundment becomes more stream-like, DO concentrations in the surface waters are expected to improve to levels similar to upstream (Abbott et al. 2022).

pH

Salmon prefer pH values that are circumneutral (6.5-7.5), rather than acidic (<6.5; Kroglund and Staurnes 1999; Kroglund et al. 2008). The impacts of acidity depend on 1.) duration, magnitude, and frequency of the episode, 2.) the ability of the fish to avoid adverse water quality conditions, 3.) the concentration of exchangeable aluminum (Al_x), and 4.) the buffering capacity of the water (i.e., ANC and calcium; see [Zimmermann 2018] for overview). pH thresholds used in this analysis are estimates of anticipated impacts to salmon populations and do not include a detailed analysis of the impact of other factors.

No significant changes were observed between the two years of sampling nor following the dam breach at either the upstream or downstream site. pH was generally neutral (grand mean 6.78 ± 0.20), staying above the threshold of 6.5, an optimal minimum pH for the protection of the most sensitive salmon life stages (alevins and smolts), for the majority of the study duration (93%; Fig. 8; Appendix II Table II-1; Kroglund and Staurnes 1999; Kroglund et al. 2008). The abnormally high spike in pH to 8.02 at the downstream site in July is discussed in the turbidity section, below. Despite similarities in rainfall amounts per storm, rain-driven depressions between May and October lasted almost twice as long as in 2021, lasting on average 4 hours downstream (maximum duration 20 hours) and 7.5 hours upstream (maximum duration 2.9 days, in October). As in 2021, larger diel fluctuations occurred upstream (0.5 ± 0.3, compared to 0.2 ± 0.1 downstream), possibly driven by increased productivity (Nimick et al. 2011).

When the impoundment stratified (June-September), low pH occurred below 2 m, as in 2021, with a minimum pH of 6.1 observed at 3-3.5 m (Fig. 9). While lower than the optimal pH for salmon, the minima was well above the critical stress threshold of 5.5, above which no adverse impacts to salmon populations are expected (Haines et al. 1990; Stanley and Trial 1995). Carbon dioxide produced as a result of anaerobic respiration at the bottom of the stratified impoundment waters may be causing the low pH at depth. After the dam was breached, pH at the former impoundment remained above 6.5 for 93% of the time, compared with 68% before the breach. Increased mixing following dam removal increased the minimum pH from 6.1 to 6.4. While pH in the study area is not expected to have negative impacts to salmon at the population level, dam removal has decreased the occurrence of suboptimal conditions at depth in the former impoundment by reducing stratification.

Specific Conductance

Specific conductance (SPC) is a measure of the concentration of ions in the water, or the ability of water to conduct electricity. SPC was similar at all sites, with a grand mean of 61 ± 14 µS/cm, similar to 2021 (Fig. 10; Appendix II Table II-1). As seen in 2021, slightly higher SPC downstream may be due to the influence of winter de-icing salts washed off roads. No adverse

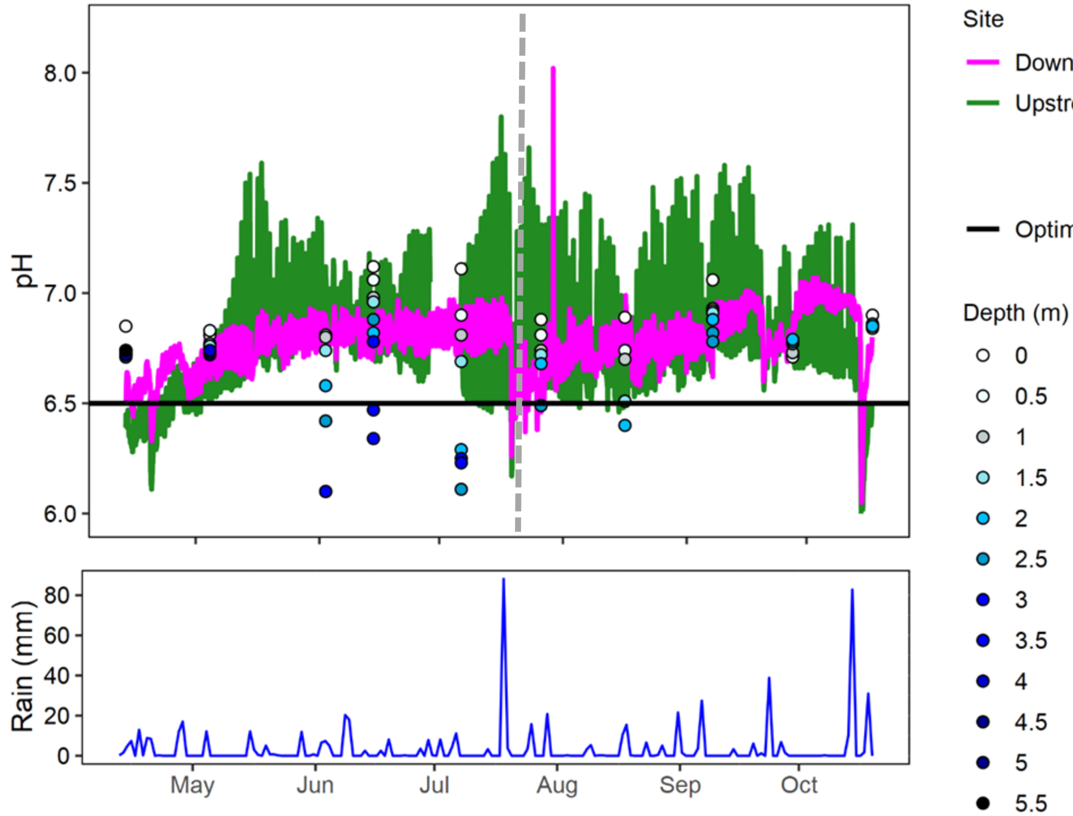

Figure 8. Continuous and discrete pH and local rainfall. Optimum pH from Kroglund and Staurnes 1999 and Kroglund et al. 2008. Rainfall data from Weather Underground station KMEFARMI35. Dam breached July 21, 2022, indicated by the vertical dashed line.

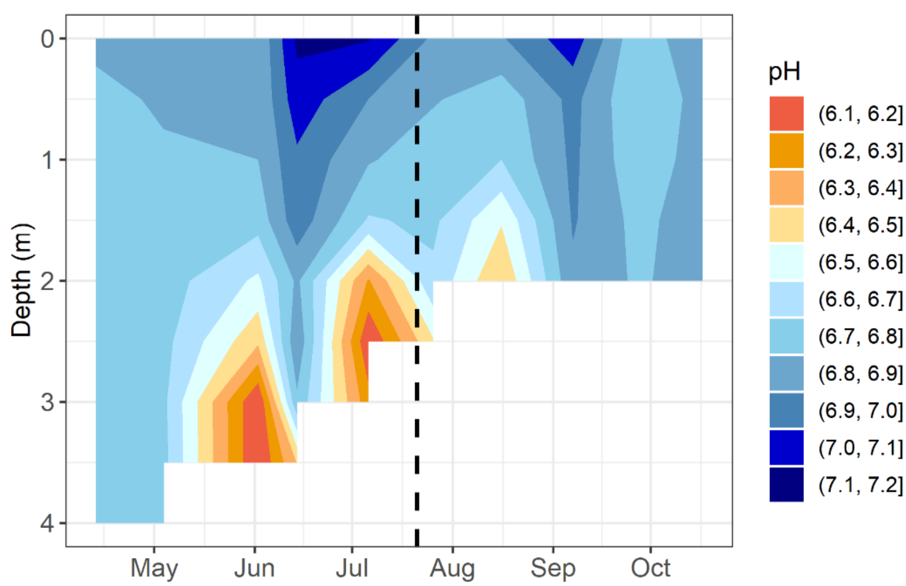

Figure 9. Impoundment pH-depth profiles collected every three weeks April through October at the former impoundment. Dam breached July 21, 2022 (dashed line). Red to yellow represents potentially stressful pH (<6.5). Blue represents optimal pH (>6.5, from Kroglund and Staurnes 1999; Kroglund et al. 2008).

impacts due to specific conductance are expected at any of the study sites.

<u>Turbidity</u>

Turbidity is a measure of the relative cloudiness of the water based on the amount of light scattered by suspended or dissolved material including clay, silt, and organic materials. When turbidity increases above ambient background levels by more than even 10 NTU, potential negative impacts include decreasing primary production (e.g., siltation, scouring), increasing stress (e.g., in fish, physiologically such as gill trauma, behaviorally such as reduced foraging effectiveness), and altering habitat (e.g., siltation and embeddedness; Bash et al. 2001). Chronically high turbidity has stronger negative impacts to aquatic life than short high pulses (Stanley and Trial 1995). At the downstream site, turbidity was low (6.0 ± 18.9 NTU) with occasional spikes above the background level that lasted 4.4 hours on average (Figure 10). The highest turbidity concentrations occurred following the dam breach while deconstruction activities were occurring at the dam site, despite the maintenance of turbidity curtains, and did not coincide with rain events or elevated specific conductance (ASF 2023). The high pH spike (8.02) that occurred downstream on July 29 corresponds with spikes in specific conductance (91 µS/cm) and turbidity (33 NTU) as well as a rain event of 20.8 mm (Figs. 2 and 10). Rain events typically decrease the specific conductance of streams, however dam removal exposed fine sediments through the drawdown of the former impoundment and through construction activities within the stream channel, along the bank, and in the upland area of the town park. The substrate in the former impoundment is glaciomarine silt and clay, which is easily suspended in the water column (MGS 2003). On July 29, the former tail race was being filled with boulders and fill materials, including washing smaller materials to create a cohesive layer, and dam material was being removed from the former dam footprint (ASF communication). Powdered concrete from the dam removal could have contributed to the spike in pH. Pulses of increased turbidity may have had short-term negative impacts on downstream habitat and aquatic life, however turbidity remained low for most of the study period, indicating clear water.

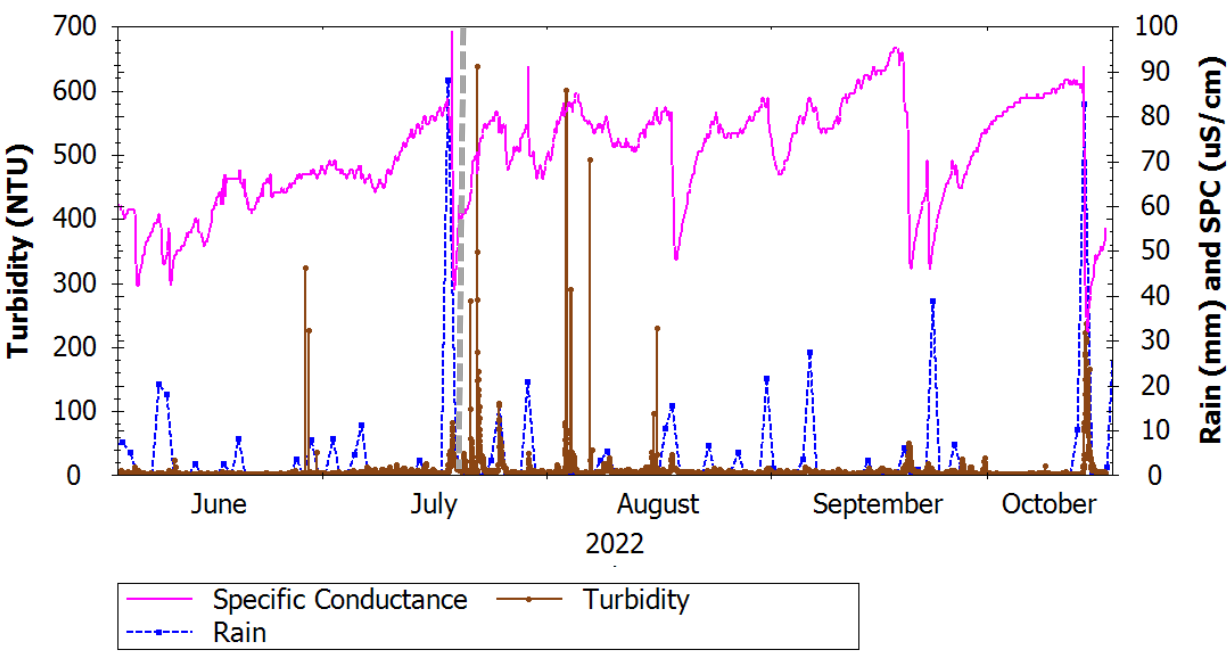

Figure 10. Specific conductance, turbidity and local rainfall at the downstream sampling site. Dam breached July 21, 2022, indicated by the vertical dashed line. Rainfall data from Weather Underground station KMEFARMI35.

Nutrients

Biologically available nitrogen (nitrate + nitrite as nitrogen) levels were low (grand mean 0.025 ± 0.013 mg/L), slightly higher than in 2021 but comparable to other tributaries to the Sandy River (Appendix II Table II-2; Zimmermann 2021). Lowest concentrations were in the former impoundment (0.019 ± 0.006 mg/L), however levels were twice as high as the previous year. Increased flows following the breach and removal of the dam likely reduced the potential for denitrification at the sediment-water interface as oxygen concentrations in the bottom waters increased and as retention time in the former impoundment decreased (Fairchild and Velinsky 2006; Saunders and Kalff 2001; Stanley and Doyle 2002). Total Kjeldahl nitrogen (TKN) was higher at all sites in 2022 (grand mean 0.41 ± 0.25 mg/L), almost doubling at the downstream site compared with 2021 (Appendix II Table II-2). Highest values were observed during summer baseflow, possibly due to erosion of organic deposits from the banks of the former mill pond, however levels were high at both the upstream and downstream sites. Total phosphorus was slightly lower in 2022, with a grand mean of 10.7 ± 6.0 μg/L and a summer baseflow average of 13.3 ± 7.0 μg/L, similar to values observed at other Sandy River tributaries (Appendix II Table II-2; Zimmermann 2021). Concentrations were lowest upstream (10.7 ± 6.7 μg/L) and highest in the former impoundment (12.0 ± 6.2 μg/L). The downstream concentrations decreased significantly between the two years, possibly due to the increased retention of phosphorus in the shifting sediments of the free-flowing former impoundment (Fairchild and Velinksy 2006; Stanley and Doyle 2002). Nutrient levels were typical of natural, minimally disturbed streams in Maine, except for organic nitrogen (TKN), which was slightly higher during baseflow at the two stream sites.

Biological Data

Biological data were sampled in 2020 approximately 320 m further downstream from the lowest water quality site (Fig. 1), but delays in processing meant algae results only became available in 2023. While the water quality of Temple Stream supports a robust macroinvertebrate community that attains Maine’s highest aquatic life water quality classification (38 M.R.S.§§ 465; Davies et al. 2016; Zimmermann 2022), algae only attained class C. Nutrient enrichment may encourage the growth of pollution-tolerant algae species. Typical sources of nutrient enrichment are not widely represented in Temple Stream’s watershed, with only 2.9% land cover in agriculture, 7.1% in logging activities, and 0.8% in developed land use (MEGIS 2006). However, the sub-watershed containing the biological sampling location, representing 3% of the Temple Stream watershed, contains 38% of the developed land use, where stormwater runoff may increase stream nutrients and sedimentation. Streams with a lot of fine silt and clay sometimes have a large proportion of diatoms that are motile and nutrient tolerant despite low concentrations of nutrients in the water. Some motile diatoms extract nutrients from organic matter mixed with the clay and sediment during the night and migrate to the surface of the sediment layer during the day to photosynthesize. It is possible that the abundance of fine silt and clay in this river segment contributed more to the Class C bioassessment model result than the amount of nutrients in the water. Biological samples will be collected in 2023 further upstream, at the downstream water quality site, which has less silt and clay.

Conclusion

With the removal of the Walton’s Mill dam, the water quality in Temple Stream has become more suitable for salmon and other aquatic life, particularly within the former impoundment. Downstream warming was reduced from 1.5°C to 0.8°C as has been observed at other small dams (Zaidel et al. 2021). At all study sites, high summer water temperatures, likely exacerbated by summer drought conditions, could lead to sub-lethal stress or avoidance behavior in salmon, however the most sensitive life stages of salmon (from hatch to swim up and smolts) are not present during the summer when most temperature maxima occur. Stratification in the former impoundment was significantly reduced, resulting in greater diel temperature fluctuations and higher dissolved oxygen. No significant changes were observed in DO downstream, likely due to the reaeration of water in its passage downstream, over the surface spill dam prior to removal and over the natural waterfall uncovered following the removal of the dam (Abbott et al. 2022; ASF 2023; Lessard and Hayes 2003; Zaidel 2018). The abundance of fine silt and clay may be encouraging the growth of tolerant algae species, indicative of a lower water quality classification. With the predicted 2°C increase in air temperatures in Maine by 2040 (Fernandez et al. 2020), protecting and enhancing cool water habitat, such as limiting the influence of dammed impoundments, is essential for the protection of aquatic life (Paukert et al. 2021). Removal of small dams, such as Walton's Mill dam, helps buffer the negative effects of climate change on streams, such as warming temperatures, by increasing flow through the former impounded area, narrowing the channel, and increasing shade from restored riparian vegetation (Lawrence et al. 2014; Zaidel et al. 2021). As conditions in the former impoundment return to stream-like conditions, and the riparian zone revegetates, water quality is expected to continue to improve due to decreased water temperatures and reduced stratification of hypoxic waters of the impoundment, creating more resilient aquatic habitat for Atlantic salmon.

Works Cited

Abbott, K.A., Zaidel, P.A., Roy, A.H., Houle, K.M., and Nislow, K.H. 2002. Investigating impacts of small dams and dam removal on dissolved oxygen in streams. PLoS One. 17(11). 23 p.

Atlantic Salmon Federation (ASF). 2023. Walton's Mill dam removal: 2022 MNCRCP work completion report and wetland monitoring report. 46 p.

Bash, J., Berman, C., and Bolton, S. 2001. Effects of turbidity and suspended solids on salmonids. Center for Streamside Studies, University of Washington. 80 p.

Beauchene, M., Becker, M., Bellucci, C.J., Hagstrom, N., and Kanno, Y. 2014. Summer thermal thresholds of fish community transitions in Connecticut streams. North American Journal of Fisheries Management. 34, 119-131.

Cunjak, R.A., Roussel, J.-M., Gray, M.A., Dietrich, J.P., Cartwright, D.F., Munkittrick, K.R., and Jardine, T.D. 2005. Using stable isotope analysis with telemetry or mark-recapture data to identify fish movement and foraging. Oecologia. 144: 1-11.

Davies, S.P., Drummond, F., Courtemanch, D.L., Tsomides, L., and Danielson, T.J. 2016. Biological water quality standards to achieve biological condition goals in Maine rivers and streams: Science and policy. Maine Agricultural and Forest Experiment Station. Technical Bulletin 208. URL https://digitalcommons.library.umaine.edu/cgi/viewcontent.cgi?article=1205&context=aes_techbulletin.

Dripps, W. and Granger, S.R. 2013. The impact of artificially impounded, residential headwater lakes on downstream water temperature. Environmental Earth Sciences. 68: 2399-2407.

Elliott, J.M., and Elliott, J.A. 2010. Temperature requirements of Atlantic salmon *Salmo salar*, brown trout *Salmo trutta* and Arctic charr *Salvelinus alpinus*: predicting the effects of climate change. Journal of Fish Biology. 77: 1793-1817.

Fairchild, G.W. and Velinksy, D.J. 2006. Effects of small ponds on stream water chemistry. Lake and Reservoir Management. 22(4): 321-330.

Fernandez, I., Birkel, S., Schmitt, C., Simonson, J., Lyon, B., Pershing, A., Stancioff, E., Jacobson, G., and Mayewski, P. 2020. Maine's climate future 2020 update. Orono, ME: University of Maine. URL: climatechange.umaine.edu/climate-matters/maines-climate-future/.

Frechette, D.M., Dugdale, S.J., Dodson, J.J., and Bergeron, N.E. 2018. Understanding summertime thermal refuge use by adult Atlantic salmon using remote sensing, river temperature monitoring, and acoustic telemetry. Canadian Journal of Fisheries and Aquatic Sciences. 75: 1999-2010.

Haines, T.A., Norton, S.A., Kahl, J.S., Fay, C.W., Pauwels, S.J., and Jagoe, C.H. 1990. Intensive studies of stream fish populations in Maine. EPA/600/3-90/043.

Jonsson, B., Forseth, T., Jensen, A.J., and Næsje, T.F. 2001. Thermal performance of juvenile Atlantic Salmon, *Salmo salar*. Functional Ecology. 15: 701-711.

Kroglund, F., and Staurnes, M. 1999. Water quality requirements of smolting Atlantic salmon (*Salmo salar*) in limed acid rivers. Canadian Journal of Fisheries and Aquatic Sciences. 56: 2078-2086.

Kroglund, F., Rosseland, B.O., Teien, H.-C., Salbu, B., Kristensen, T., and Finstad, B. 2008. Water quality limits for Atlantic salmon (*Salmo salar*) exposed to short term reductions in pH and increased aluminum simulating episodes. Hydrology and Earth Systems Sciences. 12: 491-507.

Lawrence, D.J., Stewart-Koster, B., Olden, J.D., Ruesch, A.S., Torgersen, C.E., Lawler, J.J., Butcher, D.P., and Crown, J.K. 2014. The interactive effects of climate change, riparian management, and a nonnative predator on stream-rearing salmon. Ecological Applications. 24(4): 895-912.

Lenth, R.V. (2023). emmeans: Estimated marginal means, aka least-squares means. R package version 1.8.5. URL: https://CRAN.R-project.org/package=emmeans

Lessard, J.L. and Hayes, D.B. 2003. Effects of elevated water temperature on fish and macroinvertebrate communities below small dams. River Research and Applications. 19: 721-723.

Lund, S.G., Caissie, D., Cunjak, R.A., Vijayan, M.M., and Tufts, B.L. 2002. The effects of environmental heat stress on heat-shock mRNA and protein expression in Miramichi Atlantic salmon (*Salmo salar*) parr. Canadian Journal of Fisheries and Aquatic Sciences. 59: 1553-1562.

Maine Department of Environmental Protection. 2016. Continuous Monitoring of Water Quality SOP, revision No. 1, effective date 6/7/2016.

Maine Department of Environmental Protection. 2021. QAPP for the Salmon Habitat Monitoring Program. Revision No. 1. Effective date Feb. 22, 2021.

Maine Department of Environmental Protection. 2022. 2018/2020/2022 Integrated water quality monitoring and assessment report. Chapter 4: Surface water monitoring and assessments. Pages 53-55 for dissolved oxygen assessment criteria. 3/20/2022.

Maine Geological Survey (MGS). 2003. Surficial Geology, Farmington Quadrangle, Maine. Augusta, ME, Maine Geological Survey. URL https://digitalmaine.com/cgi/viewcontent.cgi?article=2071&context=mgs_maps.

Maine Office of Geographic Information System (MEGIS). 2006. MELCD 2004 Landcover – wetland enhanced. Augusta, ME. Using: Using: ArcGIS. Version 10.3.1. Redlands, CA: Environmental Systems Research Institute, Inc., 2010. Date accessed 3/20/2023.

Maine Revised Statutes (M.R.S.). Title 38: Waters and navigation. Chapter 3: Protection and improvement of waters. Article 4-A: Water Classification Program. Section 464. URL http://www.mainelegislature.org/legis/statutes/38/title38sec464.html.

Maine Revised Statutes (M.R.S.). Title 38: Waters and navigation. Chapter 3: Protection and improvement of waters. Article 4-A: Water Classification Program. Section 465. URL http://www.mainelegislature.org/legis/statutes/38/title38sec465.html.

Maxted, J.R., McCready, C.H., and Scrasbrook, M.R. 2005. Effects of small ponds on stream water quality and macroinvertebrate communities. New Zealand Journal of Marine and Freshwater Research. 39:1069-1084.

National Oceanic and Atmospheric Administration (NOAA). 2022. Gulf of Maine region quarterly climate impacts and outlook. March, June, and September 2022. URL https://gulfofmaine.org/public/climate-network/climate-outlook/.

Native Land Digital. 2022. URL native-land.ca

Nimick, D.A., Gammons, C.H., and Parker, S.R. 2011. Diel biogeochemical processes and their effect on the aqueous chemistry of streams: a review. Chemical geology. 283: 3-17.

Paukert, C., Olden, J.D., Lynch, A.J., Breshears, D.D., Chambers, R.C., Chu, C., Daly, M., Dibble, K.L., Falke, J., Issak, D., Jacobson, P., Jensen, O.P., and Munroe, D. 2021. Climate change effects on North American fish and fisheries to inform adaptation strategies. Fisheries. 46(9): 449-464.

R Core Team. 2022. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Remen, M., Oppdeal, F., Torgersen, T., Imsland, A.K., and Olsen, R.E. 2012. Effects of cyclic environmental hypoxia on physiology and feed intake of post-smolt Atlantic salmon: initial responses and acclimation. Aquaculture. 326-329.

Rounds, S.A., Wilde, F.D., and Ritz, G.F. 2013. Dissolved oxygen. U.S. Geological Survey Techniques of Water-Resources Investigations. Book 9, chapter A6, section 6.2. URL http://water.usgs.gov/owq/FieldManual/Chapter6/6.2_v3.0.pdf.

Saunders, D.L., and Kalff, J. 2001. Nitrogen retention in wetlands, lakes and rivers. Hydrobiologia. 443: 205-212.

Stanley, J.G., and Trial, J.G. 1995. Habitat suitability index models: nonmigratory freshwater life stages of Atlantic salmon. U.S. Department of the Interior. Biological Science Report 3.

Stanley, E.H. and Doyle, M.W. 2002. A geomorphic perspective on nutrient retention following dam removal. BioScience. 52(8): 693-701.

United States Atlantic Salmon Assessment Committee (USASAC). 2020. Annual Report, no. 32 – 2019 activities.

United State Drought Monitor. 2022. National Drought Mitigation Center, Lincoln, NE. URL https://droughtmonitor.unl.edu/Maps/MapArchive.aspx.

United States Environmental Protection Agency (USEPA). 1986. Quality Criteria for Water. EPA 440/5-86-001. URL https://www.epa.gov/sites/default/files/2018-10/documents/quality-criteria-water-1986.pdf.

U.S. Fish and Wildlife Service (USFWS) and NMFS. 2018. Recovery plan for the Gulf of Maine Distinct Population Segment of Atlantic salmon (Salmo salar). 74 pp. URL https://media.fisheries.noaa.gov/dam-migration/final_recovery_plan2.pdf.

University of Maine at Farmington (UMF). 2022. Indigenous Land and Water Acknowledgement. URL umf.maine.edu/about/indigenous.

Velinsky, D.J, Bushaw-Newton, K.L., Kreeger, D.A. and Johnson, T.E. 2006. Effects of small dam removal on stream chemistry in southeastern Pennsylvania. Journal of the North American Benthological Society. 25(3): 569-582.

Wickham, H. 2009. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.

Wilson Engineering, LLC. 2022. Water Resources Database (WRDB). St. Louis, Missouri. URL wrdb.com.

Weather Underground. 2022. WKTJ-Voter Hill KMEFARMI35. URL https://www.wunderground.com/

Zaidel, P.A. 2018. Impacts of small, surface-release dams on stream temperature and dissolved oxygen in Massachusetts. University of Massachusetts Amherst. Masters Theses. 680. 283 pp.

Zaidel, P.A., Roy, A.H., Houle, K.M., Lambert, B., Letcher, B.H., Nislow, K.H., and Smith, C. 2021. Impacts of small dams on stream temperature. Ecological Indicators. 120: 1-13.

Zimmermann, E. 2018. Reducing acidification in endangered Atlantic salmon habitat: baseline data. Maine Department of Environmental Protection: Augusta, ME. URL https://www.maine.gov/dep/water/monitoring/rivers_and_streams/salmon/2017-downeast-baseline-report.pdf.

Zimmermann, E. 2021. Water quality in Orbeton Stream, Madrid, Maine. Maine Department of Environmental Protection: Augusta, ME. URL https://www.maine.gov/dep/water/monitoring/rivers_and_streams/salmon/Orbeton%20Stream%202020%20report.pdf.

Zimmermann, E. 2022. Water quality in Temple Stream, Farmington, Maine. Maine Department of Environmental Protection: Augusta, ME. URL https://www.maine.gov/dep/water/monitoring/rivers_and_streams/salmon/Temple%20Stream%20Report.pdf.

Zwieniecki, M.A. and Newton, M. 1999. Influence of streamside cover and stream features on temperature trends in forested streams of Western Oregon. Western Journal of Applied Forestry. 14(2): 106-113.

Appendix I – Stream Characteristics

Table I-1. Study site locations and watershed characteristics. Wetted stream width measured for channel sampled, with full multichannel width in parentheses. Mean stream depth was measured every three weeks while sondes were deployed in 2022. For watershed and substrate characteristics, see Appendix I Table I-1 in Zimmermann 2022.

Site	Site Code	Latitude	Longitude	Wetted stream width (m)	Mean stream depth (cm)
Upstream	KSDTE29	44.67001	-70.18253	5.8 (17.6)	31
Impoundment	KSDTE17	44.66005	-70.16934	15.4 (113)	314
Downstream	KSDTE12	44.66127	-70.16044	11.7 (25)	44
Biological monitoring	S-1183	44.66046	-70.15982	13.6	32

Appendix II – Summary Data Tables

Table II-1. Continuous Data Summary. Summary statistics (mean, standard deviation (SD), minimum and maximum) of measurements from YSI 6000 EDS sondes and Onset Hobo U26 dissolved oxygen loggers (KSDTE17), May to October 2022 (n ~ 8,600, except for KSDTE17 where n ~ 17,900 due to 15 minutes sampling interval). pH and specific conductance at KSDTE17 from Eureka Manta+ 20 field meter (n = 10).

Site	Site Code	pH				Temperature (°C)				Specific Conductance (µS/cm)				Dissolved Oxygen (mg/L)			
		Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Upstream	KSDTE29	6.76	0.25	5.82	7.8	16.28	5.55	2.94	29.35	57	12	27	82	9.92	1.37	7.13	13.83
Impoundment	KSDTE17 - TOP	6.84	0.10	6.71	7.06	16.82	5.53	3.36	28.62	59	12	39	75	8.83	1.56	3.80	13.13
	KSDTE17 - BOTTOM	6.70	0.20	6.29	6.91	15.39	4.87	3.38	27.16	60	12	39	76	7.14	3.79	0	13.91
Downstream	KSDTE12	6.78	0.13	6.05	8.02	17.28	5.76	3.64	29.29	65	15	28	99	9.21	1.47	6.43	13.38

Table II-2. Discrete Data Summary. Summary statistics (mean, SD, minimum and maximum) from grab samples collected April 14, Aug. 16, and Oct. 18. n = 3 except for DOC where n =1. Samples in the impoundment (KSDTE17) were collected from surface waters.

Site Code	Dissolved Organic Carbon (mg/L)	Nitrate + Nitrite as Nitrogen (N+N; mg/L)				Total Kjeldahl Nitrogen (TKN; mg/L)				Total Phosphorus (µg/L)			
		Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
KSDTE29	1.9	0.023	0.008	0.013	0.029	0.36	0.31	0.16	0.72	11	7	5	18
KSDTE17	2.2	0.019	0.006	0.013	0.024	0.35	0.11	0.25	0.47	12	6	5	17
KSDTE12	2.7	0.032	0.022	0.014	0.057	0.50	0.36	0.25	0.91	9	8	5	18

Table II-3. Exceedances Pre- and Post-dam Removal. 2021 data from April 26 – Oct. 19. 2022 data from April 13 – July 21 (pre) and July 27 – Oct. 19 (post).

Year	Impoundment Location	Dam removal status	% >22 deg C	% <7 mg/L
2022	**TOP**	PRE	<0.1	5.8
		POST	24.1	16.4
	BOTTOM	PRE	0.3	46.5
		POST	17.1	40.9
2021	**TOP**	PRE	27.5	14.0
	BOTTOM	PRE	0	75.2