Water Quality in Togus Stream, Chelsea, Maine

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Maine Department of Marine Resources fry trap in Togus Stream

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Introduction

Togus Stream, a tributary to the Kennebec River, contains approximately 3.1 miles of spawning and rearing habitat for endangered Atlantic salmon (*Salmo salar;* Maine Department of Marine Resources, MDMR). Beginning in 2018, MDMR conducted an ecosystem-scale restoration project in Togus Stream, including planting eyed salmon eggs in the gravel, assessing survival of the eggs to the parr stage, installing fish passage at Lower Togus Pond Dam in 2019, and removal of two small stone dams further downstream (Ledwin et al. 2021). The project was anticipated to increase the abundance and distribution of Atlantic salmon and river herring due to increased access to habitat. In addition, the improved river herring runs were anticipated to reduce the chance of predation on Atlantic salmon due to prey buffering (Saunders et al. 2006). To assess the potential of reintroducing salmon to this historic habitat, eyed eggs were planted in the stream gravel in 2019, but emergence rates were extremely low (1.7%; Ledwin et al. 2021). MDMR repeated the experiment in 2020 and saw fry begin to emerge in early May with large yolk sacs, indicating early emergence from eggs, with an average emergence rate of 5.7% (Ledwin et al. 2021; Malcolm et al. 2003). Previous studies have found that low dissolved oxygen results in low emergence rates of salmonids (Ingendahl 2001; Rubin and Glimsäter 1996; Youngson et al. 2004). To investigate the hypothesis that water quality, either surface or interstitial pore water, is inhibiting survival to the fry stage, water quality monitoring was conducted in 2020 and 2021 by the Maine Department of Environmental Protection (MDEP).

Methods

Study Location

Togus Stream flows through the towns of Randolph, Pittston, Chelsea, and Augusta, 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). The 105km^2 watershed is predominantly forested (75%), with 6% agricultural use, 4.5% developed, and several large ponds (13%; MEGIS 2006). Conservation lands represent 16% of the total watershed (MEGIS 2017). Relative abundance of young-of-year salmon following the egg planting was a maximum of 2.8 fish per minute (a catch per unit effort metric of how many salmon were captured every minute while electrofishing; Ledwin et al. 2021). Four locations were monitored for water quality (Fig. 1; Appendix I Table I-1): the outlet of Togus Pond (TPO1), downstream of Rt. 17 and below the outlet of Lower Togus Pond (KTG70), downstream of Windsor Rd. (KTG41), and downstream of Barber/Pinkham Rd. (KTG21).

Water Quality

A calibrated Eureka Manta2 Sub2 was used to collect discrete water quality measurements of temperature, dissolved oxygen (DO), specific conductance, and pH from the water column. Readings were collected 8 times (every 1-2 weeks February-May 2020 and on May 3, 2021) at sites KTG70, KTG41, and KTG21 and once (May 3, 2021) at TPO1. Interstitial pore water samples were collected twice (May 12, 2020 and May 26, 2020) at sites KTG70, KTG41, and KTG21. A 2-inch PVC pipe with narrow slits cut in the bottom 10 cm of the pipe, to allow water but no sediment into the tube, was driven into the stream bottom 20-30 cm, to cover all the slits. A peristaltic pump with 10 ft. of tubing was used to pump water out of the pipe. After pumping for 5 minutes to clear the pipe, water quality probes were inserted into the

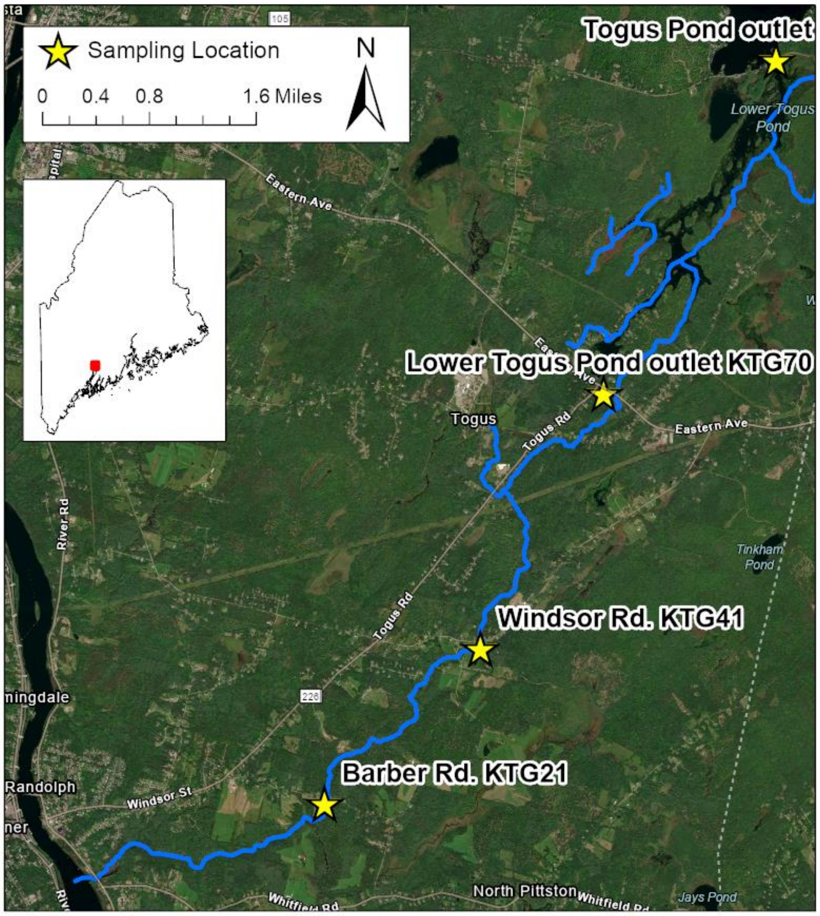

Figure 1. Map of the study sites on Togus Stream.

pipe (Eureka Manta2 Sub2 on May 11, 2020, and a YSI DO Pro on May 26, 2020). The pump remained running to allow fresh interstitial pore water to constantly enter the pipe. Discrete water quality measurements were recorded after values stabilized.

Grab samples for acid neutralization capacity (ANC), calcium, magnesium, aluminum species, dissolved organic carbon (DOC), total Kjeldahl nitrogen (TKN), nitrate + nitrite as nitrogen, and total phosphorus were collected on May 12, 2020, at KTG21 and KTG70. Additional grab samples for DOC, aluminum species and dissolved iron were collected on May 3, 2021 at all four sample locations. Grab samples were collected from each sample location in moving but not turbulent water and kept cold (0-6°C) until shipping or delivery to the analytical lab (Appendix I table I-2). Exchangeable aluminum (Alx), defined as all dissolved species of aluminum that do not pass through the ion exchange column (including all –(OH), -(SO_4), -(F) and –(Cl) complexes and Al^{+3}), was not measured directly but estimated as the difference between dissolved aluminum and organically complexed aluminum. The presence of suspended aluminum could cause an overestimation of the exchangeable aluminum in the sample (Dennis and Clair 2012).

Data Visualization

All data are presented as mean ± standard deviation, unless otherwise stated.

Results and Discussion

Surface Water

During both years of springtime monitoring, the influence of Lower Togus Pond on water temperature, DO, and pH was apparent within 200 m of the outlet, at site KTG70. Water temperatures at KTG70 were 1-1.5°C warmer (9.3 ± 6.0°C) than at the sites further downstream (8.5 ± 7.0°C at KTG41 and 8.1 ± 7.4°C at KTG21; Appendix II Table II-1). Salmon prefer cold waters, below 20°C, for optimal growth (Jonsson et al. 2001; USEPA 1986). Warmer waters near the outlet of Lower Togus Pond may cause stress to salmon during the warmest months of the year. Dissolved oxygen (DO) concentrations were 2-3 mg/L lower at KTG70 (11.0 ± 1.2

mg/L; 94.7 ± 6.1% saturation) than at the downstream sites (12.1 ± 2.0 mg/L, 100.1 ± 2.2% saturation at KTG41; 12.5 ± 2.3 mg/L, 102.4 ± 1.4% saturation at KTG21; Appendix II Table II-1). Salmon prefer well oxygenated water, requiring more than 8 mg/L for early life stage development (USEPA 1986). DO remained above this threshold for all samples. However, data were collected in the middle of day when photosynthesis contributes to maximum DO concentrations and therefore DO minima may not have been captured in the dataset.

Specific conductance, a measure of the concentration of ions in the water, or the ability of the water to conduct electricity, was lowest at KTG70 (38 ± 17 µS/cm), with increasing concentrations downstream (53 ± 23 µS/cm at KTG41 and 54 ± 21 µS/cm at KTG21; Appendix II Table II-1). pH was close to neutral at all sites, with pH 0.5-0.9 units lower at KTG70 (6.52 ± 0.17) as compared with the downstream sites (6.82 ± 0.11 at KTG41; 6.99 ± 0.13 at KTG21). The outlet of Lower Togus Pond (KTG70) was the only site that fell below the threshold of 6.5, an optimal minimum pH for the protection of the most sensitive salmon life stages (alevins and smolts; Kroglund and Staurnes 1999; Kroglund et al. 2008). pH remained less than optimal at this site for all three sample days in March 2020, potentially causing stress to salmon.

The outlet of Togus Pond (TPO1) was only sampled in 2021, and it had the most suitable water quality for salmon, in terms of coolest temperature (13.69°C) and highest dissolved oxygen (10.66 mg/L; Appendix II Table II-1). Specific conductivity was 84 µS/cm, most similar to the furthest downstream site (KTG21). pH was 6.66, most similar to the upper stream site, KTG70.

Interstitial Water

Variability was high between measurements taken by the two water quality meters used on the two sampling dates, indicating the importance of using similar equipment for comparability of measurements. In addition, the interstitial measurements collected on May 12, 2020, may have been influenced by some surface water intrusion due to a crack in the PVC sampling pipe.

Compared to surface water, interstitial water at all sites was 0.04°C warmer than surface water and had 0.42 mg/L (3.8% saturation) less DO, but similar pH (0.05 units lower; Appendix II Table II-2). Dissolved oxygen is usually lower in groundwater than in surface water due to chemical and biological reduction during passage through soils. The upper site, KTG70, had the biggest difference in DO, with interstitial water containing up to 1.11 mg/L (9.9% saturation) less DO than the surface water. Although oxygen concentrations in the interstitial water at the time of sampling (early afternoon) remained above the threshold of 8 mg/L (USEPA 1986), measurements may have missed early morning DO minimum concentrations, as mentioned above. As has been demonstrated in previous studies, low dissolved oxygen results in low emergence rates of salmonids (Ingendahl 2001; Rubin and Glimsäter 1996; Youngson et al. 2004). It is possible that interstitial DO at the upper site dropped below levels required for optimal early life stage development.

Grab Samples

Discharge of water from Togus and Lower Togus Ponds dilutes the stream water immediately below the outlets, resulting in increasing concentrations downstream. Acid neutralization capacity (ANC, the capacity to buffer against changes in acidity), calcium (a required mineral for faster growth and higher survival in fish), magnesium and dissolved iron were all twice as high downstream (209 µEq ANC/L; 4.1 mg Ca/L; 1.0 mg Mg/L) as compared to below the outlet of Lower Togus Pond (KTG70; 101 µEq ANC/L; 2.4 mg Ca/L; 0.5 mg Mg/L; Appendix II Table II-3). Calcium at KTG70 was above the survival threshold of 2 mg/L (Baker et al. 1990; Baldigo and Murdoch 2007), but significantly lower than the threshold of 4 mg/L suggested to prevent deformities and other stresses in developing fish (Marcus et al. 1986, as cited in Brocksen et al. 1992).

Total aluminum increased progressively downstream, from 15.2 µg/L at the outlet of Togus Pond to 212 ± 11 µg/L at the furthest downstream site, well below the acute Maine Ambient Water Quality Criteria maximum (Criteria Maximum Concentration, CMC) of 750 µg/L at all sites (based on a pH of 6.5-9 and dissolved organic carbon (DOC) <5 mg/L, which is low compared to data collected in this study; MDEP CMR Chapter 584; Appendix II Table II-4). The chronic Maine Ambient Water Quality Criteria (Criterion Continuous Concentration, CCC) of 87 µg/L was exceeded at the two most downstream sites (KTG41 and KTG21). Neither USEPA's site-specific acute maximum criterion (CMC; ranging from 330-1,400 µg/L) nor the chronic criterion (CCC; ranging from 190-530 µg/L) was ever exceeded (these criteria depend on DOC, total hardness, and pH at each sample site; USEPA 2018). Organic aluminum was the dominant species of aluminum at the outlet of Togus Pond (77%), and lower at the other sites (38 ± 5%).

Exchangeable aluminum (Alx, also referred to as inorganic monomeric aluminum or labile aluminum) can cause respiratory distress when it binds to the gills of fish (e.g., Magee et al. 2003). Alx represented a fairly high fraction of aluminum species (17 ± 8 %), with highest concentrations downstream (42 µg/L at KTG41 and 34 µg/L at KTG21), well above the threshold for the protection of aquatic life of 15 µg/L (Appendix II Table II-4; Howells et al. 1990 as cited in Dennis and Clair 2012; Kroglund and Staurnes 1999; McCormick et al. 2009). The lowest concentration of Alx (3.7 µg/L), representing a higher fraction of aluminum species (24%), was at the outlet of Togus Pond (Appendix II Table II-4). Alx may represent a higher percentage of aluminum species near the pond outlets because solar gain heats brown colored water, as in Togus and Lower Togus Ponds, breaking down organic complexes and freeing ionic metals such as Alx, iron, and mercury. In addition, aluminum is more soluble in acidic waters, such as at the outlet of Lower Togus Pond. Ionic metals will eventually bind to new complexes and may precipitate out, however the increase of Alx and iron concentrations downstream indicates these metals are remaining in ionic form. At the downstream sites, Alx concentrations may decrease smolt tolerance to saltwater as the fish migrate out of freshwater (Kroglund and Staurnes 1999; McCormick et al. 2009; Monette et al. 2008; Staurnes et al. 1995).

Dissolved organic carbon (DOC) can help buffer against the toxic impacts of Alx by binding aluminum into inert organic complexes in acidic waters (Baldigo and Murdoch 2007; Kroglund et al. 2008; Tipping et al. 1991). DOC concentrations at the outlet of the ponds are strongly influenced by concentrations within the ponds. DOC at the sites downstream of Lower Togus Pond (7.5 ± 1.2 mg/L; Appendix II Table II-4) were similar to the average concentration within the pond (8.1 ± 0.9 mg/L; MDEP data 1998-2011, n = 5). Lower Togus Pond contains an extensive wetland complex, contributing to higher levels of DOC relative to other Maine ponds (MDEP data). DOC was lowest at the outlet of Togus Pond (3.5 mg/L), similar to the average concentration within the pond (3.1 ± 0.7 mg/L; MDEP data 2019-2022, n =3). Although pH was close to neutral at all the stream sites, DOC may be providing some buffering of Alx, in combination with the buffering capacity provided by higher concentrations of ANC and calcium, particularly at the furthest downstream site.

Biologically available nitrogen (nitrate + nitrite as nitrogen) was low downstream (0.0175 mg/L at KTG21), and just above the detectable limit at the outlet of Lower Togus Pond (0.0021 mg/L at KTG70; Appendix II Table II-3). Total Kjeldahl nitrogen (TKN) was higher at the outlet of Lower Togus Pond (0.38 mg/L at KTG70 compared to 0.31 mg/L at KTG21), likely due to the tannins in the colored pond water, as mentioned above. Total phosphorus was lower downstream (13 µg/L at KTG21 compared to 21 µg/L at KTG70). Nutrients were typical of moderately developed Class B streams in Maine, with the exception of very low biologically available nitrogen, which may limit growth of aquatic life near the outlet of Lower Togus Pond.

Conclusion

Within 200 m of the outlet of Lower Togus Pond, habitat suitability is reduced for salmon, with warmer, more acidic water containing less dissolved oxygen. In addition, interstitial water contained less dissolved oxygen within this upper section of Togus Stream. As has been seen in prior studies (e.g., Youngson et al. 2004), lower dissolved oxygen may have reduced the survival of Atlantic salmon eggs in the upper section of Togus Stream. The increase in ionic metals, including calcium, magnesium, and iron at the downstream sites may be beneficial for fish growth after emergence from eggs. However, the increase in exchangeable aluminum may decrease smolt tolerance to saltwater unless there is sufficient buffering capacity in the stream due to DOC, ANC, and calcium. Combined with the observed higher fry emergence rates downstream, data collected in this study support the hypothesis that water quality is inhibiting survival to the fry stage at the upstream site.

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Appendix I – Stream Characteristics

Table I-1. Study site physical characteristics, measured May 12, 2020.

Site Name	Site Code	Latitude	Longitude	Bankfull stream width (m)	Stream depth (cm)	Substrate (%)				
						Bedrock	Boulder	Cobble	Gravel	Sand/Silt
Togus Pond Outlet	TPO1	44.313545	-69.657762	15	43	-	-	-	-	-
Lower Togus Pond Outlet	KTG70	44.27728	-69.68341	6.5	40	-	10	70	5	15
Windsor Rd.	KTG41	44.24946	-69.70170	15	24	-	5	75	15	5
Barber Rd.	KTG21	44.95932	-67.72502	15	43	-	5	65	20	10

Table I-2. Analytical methods.

Analysis Lab	Lab Location	Analyte	Method	Sample Preparation
ALS Environmental	Rochester, NY	Nitrate + Nitrite as Nitrogen	EPA 353.2	Sulfuric acid
		Nitrogen, total Kjeldahl	EPA 351.2	Sulfuric acid
UMO Sawyer Water Research Laboratory	Orono, ME	Acid neutralization capacity (ANC)	EPA 600/4-87/26 5.53*	
		Aluminum (speciation)	SW6010B	
Maine Environmental Laboratory	Yarmouth, ME	Calcium and Magnesium	EPA 200.7	Nitric acid
		Dissolved organic carbon (DOC)	SM5310B	Field filtration and sulfuric acid
		Iron, dissolved	EPA 200.7	Field filtration and nitric acid
		Phosphorus, total	EPA 365.3	Sulfuric acid

*EPA method 600/4-87/026 refers to the Handbook of Methods for Acid Deposition Studies; EPA 1987

Appendix II – Summary Data Tables

Table II-1. Discrete Surface Water Data Summary. Summary statistics (mean, standard deviation (SD), minimum and maximum) of measurements from a Eureka Manta2 Sub2 collected February – May 2020 and May 3, 2021 (n = 8 except TPO1, n =1).

Site Code	Temperature (°C)				Dissolved Oxygen (mg/L)				Specific Conductance (µS/cm)				pH			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
TPO1	-	-	-	13.69	-	-	-	10.66	-	-	-	84	-	-	-	6.66
KTG70	9.31	6.02	2.74	19.26	11.05	1.21	8.66	12.39	38	17	13	60	6.52	0.17	6.24	6.75
KTG41	8.46	7.02	1.43	20.53	12.14	1.95	9.08	14.45	53	23	27	91	6.82	0.11	6.75	7.08
KTG21	8.07	7.43	-0.01	20.68	12.48	2.27	9.05	15.00	54	21	28	82	6.99	0.13	6.87	7.30

Table II-2. Comparison of Discrete Interstitial Pore Water and Surface Water Data. Summary statistics (mean, standard deviation (SD)) of measurements from a Eureka Manta2 Sub2 collected May 12, 2020, and from a YSI DO Pro May 26, 2020 (n = 2). Specific conductance and pH were only measured on May 12, 2020 (n = 1). Interstitial measurements collected May 12, 2020, may have been influenced by some surface water intrusion due to a crack in the PVC sampling pipe.

Site Code	Sample Type	Temperature (°C)				Dissolved Oxygen (mg/L)				Specific Conductance (µS/cm)	pH
		Mean	SD	May 12	May 26	Mean	SD	May 12	May 26	May 12	May 12
KTG70	Surface	16.43	6.19	12.05	19.26	10.06	0.81	10.63	9.49	44	6.71
	Interstitial	16.46	6.00	12.22	20.70	9.37	0.22	9.21	9.52	44	6.64
KTG41	Surface	16.06	6.43	11.51	20.60	10.15	0.90	10.78	9.51	56	6.79
	Interstitial	16.10	6.37	11.59	20.60	9.76	0.34	10.00	9.52	57	6.73
KTG21	Surface	15.56	5.30	11.81	19.3	10.07	1.36	11.03	9.11	62	7.07
	Interstitial	15.61	5.08	12.02	19.2	9.90	1.20	10.74	9.05	60	7.05

Table II-3. Grab Sample Data Summary. Summary statistics (mean, standard deviation (SD)) from samples collected May 12, 2020. Iron samples were collected May 3, 2021. n = 1.

Site Code	ANC (µeq/L)	Calcium (mg/L)	Magnesium (mg/L)	Iron (mg/L)	Nitrate + Nitrite as N (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Phosphorus (µg/L)
TPO1	-	-	-	0.026	-	-	-
KTG70	101.39	2.4	0.53	0.083	0.0021	0.38	13
KTG41	-	-	-	0.19	-	-	-
KTG21	208.55	4.1	1.0	0.19	0.0175	0.31	21

Table II-4. Aluminum Species and Dissolved Organic Carbon Data Summary. Summary statistics (mean, standard deviation (SD)) from grab samples collected May 12, 2020 (KTG21 and KTG70) and May 3, 2021 (all sites). n = 2 for KTG21 and KTG70; n = 1 for TPO1 and KTG41.

Site Code	Total Aluminum (µg/L)				Organic Aluminum (µg/L)				Alx (µg/L)				DOC (mg/L)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
TPO1	-	-	15.2	-	-	-	4.9	-	-	-	4	-	-	-	3.5	-
KTG70	68.5	12.8	59.4	77.5	52.9	10.0	45.8	59.9	13	4	10	16	6.6	0.8	6.0	7.2
KTG41	-	-	178	-	-	-	65.7	-	-	-	42	-	-	-	8.7	-
KTG21	212	11.3	204	220	87.0	3.2	84.7	89.2	20	21	5	34	7.7	1.4	6.7	8.7