Water Quality in the Upper East Branch Penobscot River

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Introduction

Despite the restoration efforts of numerous groups since the 1970s, the population size of Atlantic salmon (*Salmo salar*) has remained low (USASAC 2017). Since 2012, two major dams were removed from the main stem of the Penobscot River and a bypass was constructed around a third dam, improving access to nearly 2000 miles of habitat (PRRT 2018). The Maine Department of Marine Resources has been stocking juvenile salmon in the upper East Branch Penobscot River (hereafter referred to as East Branch) for approximately twenty years but productivity remains lower than expected. Matagamon Dam may have degraded the habitat by reducing the flushing effect from high seasonal flows, however habitat is still considered good for salmon rearing. Smallmouth bass (*Micropterus dolomieu*) are present in the East Branch, but not above Grand Pitch (Fig. 1). Several studies have documented that smallmouth bass prey upon juvenile salmon, in addition to outcompeting salmon for other resources as bass are more tolerant of varied conditions than salmon (Beitinger et al. 2000). This study investigated the hypothesis that water quality in the upper East Branch exceeds stress thresholds for salmon growth and feeding.

Methods

<u>Study Location</u>

The East Branch flows through an undeveloped watershed in northern Maine (Fig. 1), with conserved land for the entire river corridor in the study area, and abutting conservation land to the west, however the area has a history of industrial logging. The bedrock geology in the study area is predominantly marine sandstone and slate with extensive volcanic (rhyolite) and related sedimentary rocks near Bowlin and along the western edge of the drainage (MGS 2017). Surficial geology is primarily till with glaciofluvial deposits (sand, gravel, silt) near Matagamon and eskers and other moraines in the vicinity of the whole reach. In 2017, 507 adults returned to the Penobscot River watershed, 15% of which were of wild or naturally reared origin, resulting in an adult return rate of 1.7% of the conservation limit for spawner requirements (USASAC 2017). The median relative abundance of parr and young-of-year (YOY) in the Penobscot in 2016 was 1.12 and 1.71 CPUE, respectively (USASAC 2017). Two locations in the East Branch were monitored for water quality (Fig. 1), one at the bridge 900 m below Matagamon Dam, and one 15 km downstream, just upstream of the confluence with Bowlin Brook, and below Grand Pitch. Matagamon Dam is a 10-m tall top spill dam constructed in 1941 to replace a timber crib structure built in the 1880s, and it impounds 4,200 acres (Matagamon Lake Assoc. 2018).

<u>Water Chemistry</u>

At each sample location, continuous monitoring devices were deployed May 31, 2017. Sondes were deployed just above the stream bottom in protective PVC casings anchored to two rebar stakes with a wire-coated cable attaching the sonde to a tree on the stream bank. Sondes were oriented parallel with the stream flow, with sensors facing downstream. Hourly measurements of temperature, specific conductance, pH, and dissolved oxygen (DO) were collected using YSI 6000 EDS sondes. Sondes were cleaned and calibrated every three weeks until retrieval on November 8, 2017. Continuous data were corrected as needed based on quality control procedures as described in DEP (2016). Grab samples for calcium, DOC, aluminum species, ANC, closed-cell pH, and air-equilibrated pH were collected at the end of July from each sample location, following the methods in Zimmermann (2018).

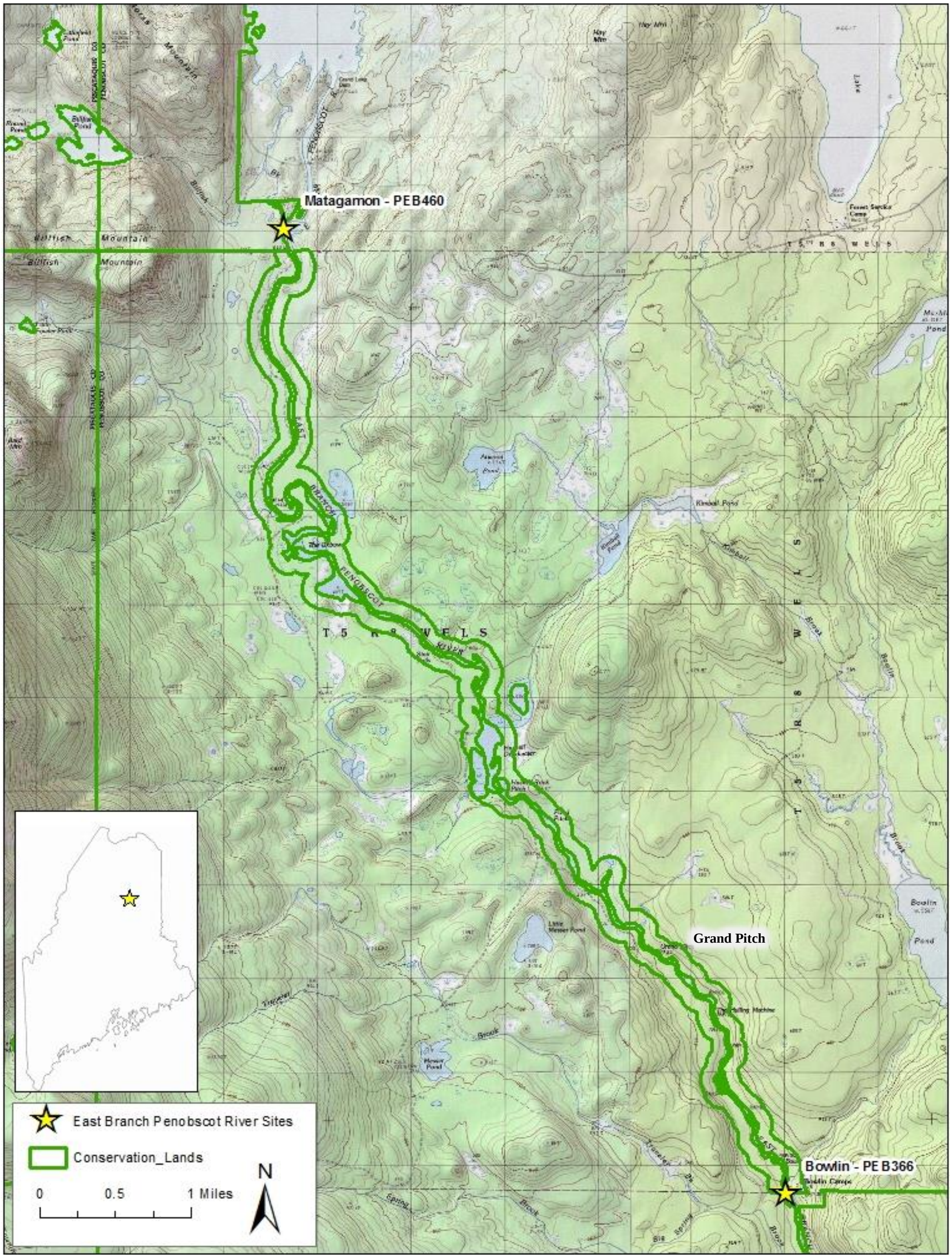

Figure 1. Map of the two study sites on the East Branch Penobscot River. The river corridor as well as the abutting land to the west are all in conservation.

Results and Discussion

Weather

Eastern Maine experienced a moderate drought during summer 2017, with precipitation around 50% of normal levels, following a similar drought in 2016 (NOAA 2017). Drought-induced low flows have significant impacts on stream water quality and aquatic biota. Low flows can reduce fish mobility, potentially trapping them in isolated pools where they could experience higher temperatures and lower dissolved oxygen, and reducing foraging opportunities. The influence of cold groundwater during low flows may reduce stream temperature.

pH

At both sites, pH values remained above the state water quality criterion of 6.0 for the protection of aquatic life, keeping mostly within the circumneutral range (Fig. 2; 38 MRS Section 464.4.A.5). Bowlin was on average 0.5 units higher than the Matagamon site. The mean diel range in pH was 0.36 ± 0.20, with the maximum diel range of 1.03 occurring in August at Matagamon. A decline in pH occurred after more than 160 mm of rain fell in 48 hours in late October (Fig. 2), although the response varied at each site. Bowlin showed a sharp drop of 0.5 units, and after three days increased 0.3 units, where it stayed for at least 10 days. Matagamon showed a gradual decline of 0.2 units, remaining low for 9 days before recovering to pre-rainfall levels. The Matagamon Dam spills surface water, which may have prolonged the impact of the rain event at the upstream site. The minimum pH observed during the episodic depression (6.27) was above the threshold of 6.2, below which harmful impacts to salmon populations have been observed (Monette et al. 2008). Therefore, the episodic depression of pH is not expected to have any adverse impact on salmon in the study area.

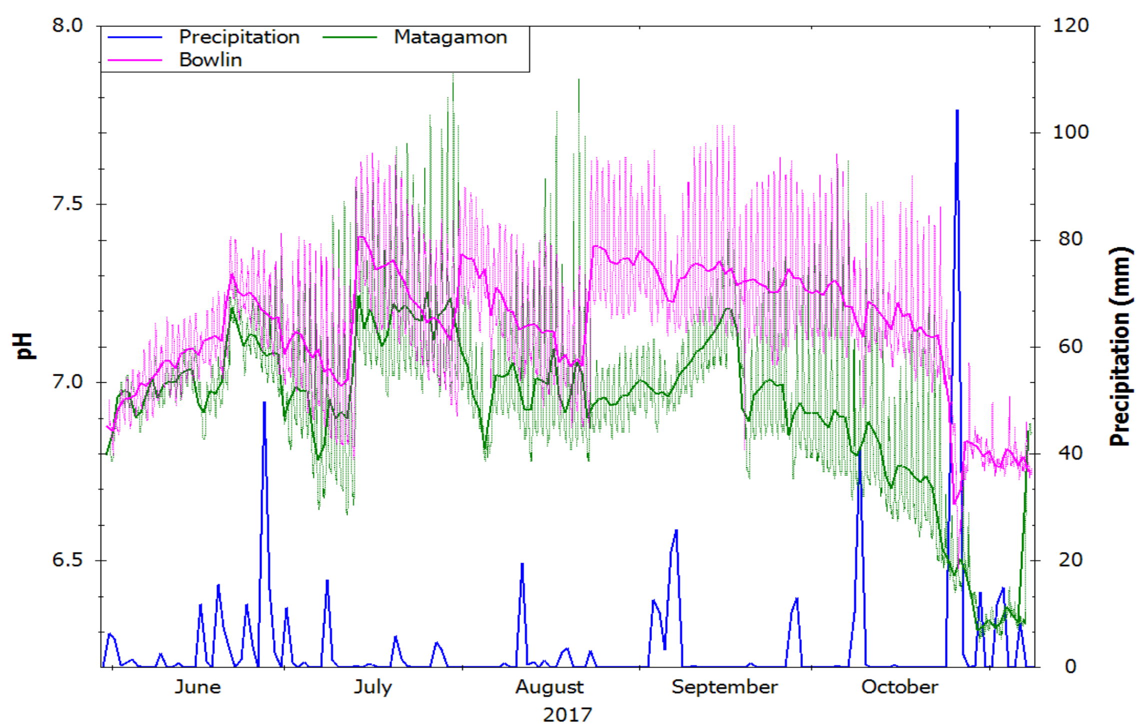

Figure 2. Hourly pH and local rainfall. Rainfall data from Weather Underground station KMESHERM2.

Stream Temperature

Across both sites, temperatures were above the threshold for optimal growth of 20°C for 36% of the study (Fig. 3; EPA 1986). The stress threshold of 22.5°C was exceeded only 6% and 8% of the time, at Bowlin and Matagamon respectively (Elliott and Hurley 1997; Stanley and Trial 1995). The maximum temperature for salmon survival of 27°C was never exceeded, and temperatures remained within or below the 16-19°C preferred temperature range for 52% of the study (Stanley and Trial 1995). Temperature exceedances observed in 2017 are very similar to the mean exceedance at Whetstone Falls (26 km downstream from the Bowlin site) from five previous years (2001-2004 and 2009) for all three thermal thresholds (SHEDS 2018). Thermal stress is likely during the warmest months (July to August), when temperatures remained above 22.5°C for 12 hours on average, with a maximum duration of 1.75-3.5 days, at Bowlin and Matagamon, respectively. Diel fluctuations were smaller at Matagamon (1.3 ± 0.6°C) compared with Bowlin (2.5 ± 1.0°C). Diel fluctuations are not expected to provide thermal refugia for salmon in this reach of the river, however there are some minor tributaries and other potential cold water refugia available for fish. Limited growth is likely for any salmon within the study reach during July and August.

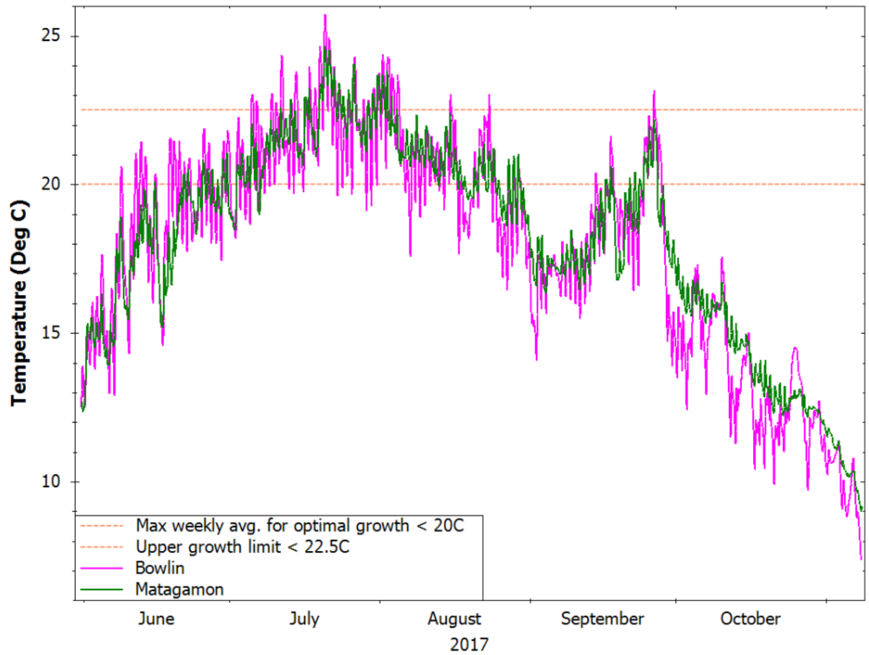

Figure 3. Mean hourly temperature across all study sites.

Dissolved Oxygen (DO)

DO levels were within a healthy range for fish and aquatic life, and remained well above the Maine Water Quality Standard criterion value of 7 mg/L, which is also the

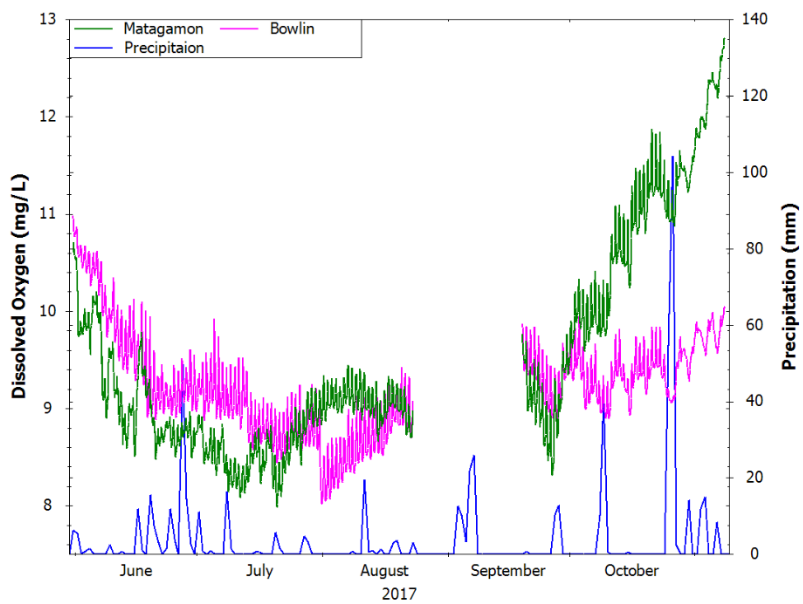

Figure 4. Hourly dissolved oxygen and local rainfall (Weather Underground station KMESHERM2). Gap in data record due to instrument malfunction.

preferred threshold for salmon (Fig. 4; 38 MRS Section 465.2.B Stanley and Trial 1995). Mean DO for the study period was higher at Matagamon (9.5 ± 1.1 mg/L compared with 9.2 ± 0.5 mg/L at Bowlin), however in the early summer DO was higher at Bowlin.

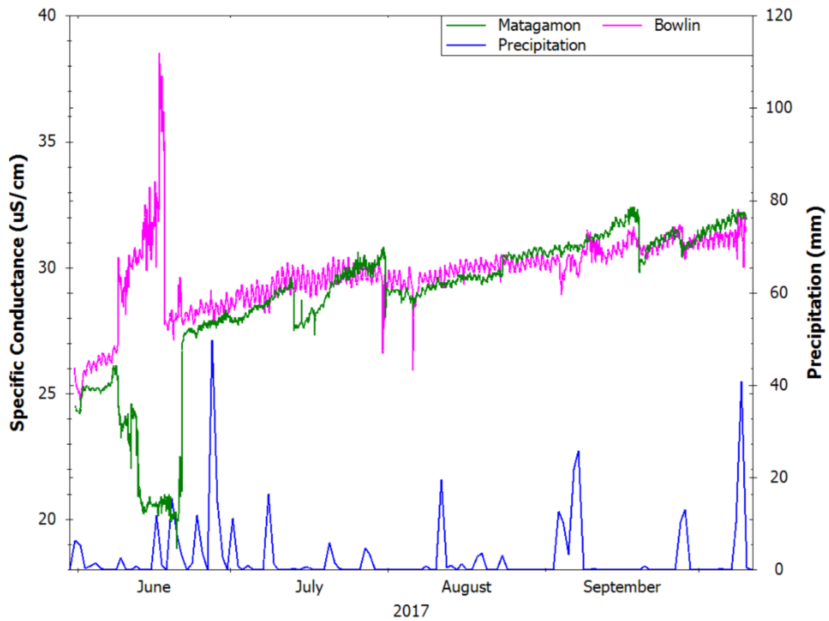

Figure 5. Hourly specific conductance and local rainfall (Weather Underground station KMESHERM2).

<u>Specific Conductance</u>

Hourly specific conductance was very similar at the two sites, with an overall mean of 29.0 ± 2.5 µS/cm (Fig. 5), and similar to Matagamon Lake (data from DEP Lake Assessment Section). Rain events did not have a significant impact on specific conductance. The large spikes in June occur in both deployed sondes (increased specific conductance at Bowlin, and decreased at Matagamon), ruling out the possibility the signal was due to equipment malfunction. The spikes do not correlate with a significant precipitation event. A discharge from Matagamon Dam could possibly have resulted in a decrease in specific conductance at the upstream site, however this does not explain the corresponding increase at the downstream site. In addition, flows through the dam were reduced in late May-early June to assist with DMR's salmon restoration work, which does not support the decrease in specific conductance at Matagamon (P. Ruksznis, pers. comm.).

<u>Acid Neutralization Capacity (ANC)</u>

ANC was slightly higher at Bowlin (230.0 µeq/L, 11.5 mg/L alkalinity) than at Matagamon (221.7 µeq/L, 11.1 mg/L alkalinity). Values at both sites were well above the threshold of acid sensitivity of 50 µeq/L (Driscoll et al. 2001), and the Norwegian 20-30 µeq/L critical limits for salmon (Baker et al. 1990; Lien et al. 1996; Kroglund et al. 2002). Higher ANC gives greater buffering capacity and correlates with higher pH (lower acidity), as seen at the study sites. It is expected that ANC would be lower during high flow events as a result of acidic rain. Alkalinity values (calculated from ANC) were similar to Matagamon Lake (data from DEP Lake Assessment Section). Alkalinity values were below EPA's recommended ambient water quality criteria (AWQC) of 20 mg/L, however this threshold does not apply where values are naturally lower (EPA 1986). Given the relatively undeveloped and protected nature of the watershed, low ANC is likely of natural and not anthropogenic origin.

<u>Calcium</u>

Calcium was above the survival threshold for salmon of 2 mg/L (Baker et al. 1990; Baldigo and Murdoch 2007), and close to the suggested threshold of 4 mg/L to prevent deformities (M. Whiting pers. comm.). Summer base flow calcium was higher at Bowlin (3.78 mg/L) compared with Matagamon (3.57 mg/L). Calcium values were similar to those from circumneutral reference streams in Wales (Bradley and Ormerod 2002). Calcium buffers the detrimental impacts of exchangeable aluminum (Alx) by increasing the efficiency of ion regulation (Baldigo and Murdoch 2007; MacDonald et al. 1980). Some level of buffering of Alx is likely occurring in the study streams (Baker et al. 1990; Wood et al. 1990).

<u>Aluminum</u>

Total aluminum was 40 µg/L at both sites, well below the Maine AWQC maximum of 750 µg/L and below the chronic criterion of 87 µg/L (DEP CMR Chapter 584). The solubility (and therefore toxicity) of aluminum increases as pH becomes more acidic or basic (EPA 2017), and toxicity also depends on the relative dominance of exchangeable aluminum (Lacroix and Kan 1986). Exchangeable aluminum (Alx, calculated as dissolved aluminum minus organically complexed aluminum) was very low at both sites during summer base flow (10.6 and 10.9 ug/L at Bowlin and Matagamon, respectively), representing approximately 26% of the aluminum species present, however values are expected to be higher during high flow events. These aluminum values are similar to data from other cool ecosystems underlain by a range of geological types (Haines et al. 1990), although the Alx percentage in Nova Scotian streams impacted by acid rain was much lower than the East Branch (Lacroix and Kan 1986). The dominant fraction was organic aluminum, as in Nova Scotian and Eastern Maine streams, which helps prevent major changes in aluminum speciation (Lacroix and Kan 1986, Zimmermann 2018). For protection of aquatic life, including macroinvertebrates, the European Inland Fisheries Advisory Commission (EIFAC) recommends that exchangeable aluminum should not exceed 0.015 mg/L at pH 5.0-6.0, even for short durations (Howells et al. 1990 as cited in Dennis and Clair 2012; Kroglund and Staurnes 1999; McCormick et al. 2009). The risk of sub-lethal stress in the study area due to high Alx is therefore unlikely.

<u>Dissolved Organic Carbon (DOC)</u>

DOC was 6.35 mg/L at both sites. DOC has been shown to be a strong determinant of fish mortality (for brook trout, Baldigo and Murdoch 2007) and can be used as an indicator of organic acidity to determine the role of anthropogenic activity in acidic streams. DOC is strongly correlated with trends in deposition chemistry (precipitation) and catchment acid sensitivity (Monteith et al. 2007; Schiff et al. 1998 as cited in Clair and Hindar 2005). Where pH is low due to organic acids, the effects of mineral acidity and metal toxicity may be reduced (Garmo et al. 2014; Kroglund et al. 2008). The East Branch is a very clear river, with relatively low organic content and high pH, indicating a well-buffered system. Above pH 5.5, and at DOC concentrations greater than 2.0-5.0 mg/L, as measured in the East Branch, DOC can buffer against the toxic impacts of exchangeable aluminum, by binding the aluminum into inert organic complexes (Baldigo and Murdoch 2007; Kroglund et al. 2008; Tipping et al. 1991).

Conclusion

The upper East Branch of the Penobscot River has good water quality for salmon growth and development, with values of pH, ANC, calcium, and Alx similar to those observed in the well-buffered tributary to the East Machias River, Barney Brook (Zimmermann 2018). Water quality at the two East Branch study sites were very similar to each other, although they exhibited varied responses to in-stream changes, such as rainfall, possibly due to the influence of

Matagamon Dam upstream. Warm water temperatures throughout most of the summer could lead to sub-lethal stress or avoidance behavior in salmon. The most sensitive life stages of salmon (from hatch to swim up and smolts) are not present in this reach during most of the temperature maxima. However, sub-lethal stresses, such as thermal stress, are additive and can cause detrimental impacts to growth and survival.

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