Reducing Acidification in Endangered Atlantic Salmon Habitat

Baseline Data

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Executive Summary

Despite restored access to historic Atlantic salmon (*Salmo salar*) habitat in eastern Maine, population sizes have remained low. Most waters in this region are chronically (headwaters) and/or episodically (main stems) acidic, experiencing pH levels below 6.5. Loss of fish populations due to acidification of surface waters (low pH, low calcium and high aluminum ion concentrations) has been well documented in the North Atlantic region, primarily due to acid precipitation. Even episodic acidity can have detrimental impacts when it coincides with key salmon life stages during snow melt and spring runoff. Adding lime to acidic waters, through application of agricultural lime or lime slurry, has increased salmon populations in Scandinavia and Nova Scotia, and has been a recommended restoration action for Maine's acidic rivers and streams. A Project SHARE pilot study investigating the efficacy of using clam shells to lime small streams suggested a trend towards improved habitat quality. To further investigate the efficacy of this mitigation method, a multi-year liming project in the East Machias River watershed will be conducted in collaboration with the Downeast Salmon Federation. Clam shells will be spread along treatment reaches both along the stream bottom and along the banks to capture high flow events (during which episodic acidity events are expected). The project goal is to increase juvenile salmon abundance by application of clam shells to achieve a target pH, and to evaluate changes in the macroinvertebrate community. The first year of the project was used to begin to characterize baseline conditions by monitoring water quality between May and November using continuous monitoring devices and periodic grab samples.

The results of the first year of monitoring indicate that under moderate baseflow conditions, water quality is tolerable but deterioration of water quality during high-discharge, high acidity events could lead to sub-lethal stress or even mortality. Streams experienced stressful conditions for salmon, with pH <6.0 (with the lowest stream mean of 5.4), temperature >22.5°C (with the highest stream mean of 17.6°C), dissolved oxygen <7 mg/L (with the lowest stream mean of 8.2 mg/L), calcium <2.5 mg/L (with the lowest stream mean of 1.6 mg/L), and exchangeable aluminum >27 µg/L (with the highest stream mean of 27.6 µg/L). The dry summer of 2017 resulted in extremely low stream flows, likely causing further stress to salmon in addition to affecting water quality. Samples were collected predominantly during low flow conditions and did not capture high discharge events when stress due to lower pH occurs (in combination with other parameters such as high exchangeable aluminum). Sub-lethal stress, such as from acidic events, has been shown to reduce marine survival by reducing anti-predatory behavior and increasing estuarine residence time, in addition to increasing sensitivity to further stressors. By decreasing exposure to acidity, smolt survival may increase during their seaward migration. As clam shells are added to the target area, monitoring efforts will continue for at least five years to determine the efficacy of using this approach to mitigate acidity.

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Introduction

The only remaining wild Atlantic salmon (*Salmo salar*) populations in the US are in Maine, and the Gulf of Maine distinct population segment (DPS) has been listed as endangered since 2000, with an expanded listing in 2009 due to further population declines (NRC 2004; USFWS-NOAA 2016). The largest threat to Atlantic salmon has been identified as dams, which act as barriers to spawning habitat (USFWS-NOAA 2016). Low marine survival is the second largest threat (Lacroix 2008; USFWS-NOAA 2016). In the Downeast Salmon Habitat Recovery Unit (SHRU), restored access to historic salmon waters has not resulted in expected population increases (USASAC 2017). Reducing stress from low habitat quality and potential stressors such as pH, temperature, and pollutants may help increase productivity by increasing smolt survival at sea (Handeland et al. 1996; Kroglund et al. 2007; Magee et al. 2003).

In Downeast Maine, low habitat quality includes habitat complexity and water quality. Historic timber harvest practices removed large wood and boulders, in addition to straightening stream channels, to aid log drives (Project SHARE-USFWS 2009). Reduced water quality includes increasing temperatures, reduced flow, and episodic acidity (Project SHARE-USFWS 2009; USFWS-NOAA 2016). Acidification of surface waters results in low pH, low calcium, and high aluminum ion concentrations. Acidic depositions have decreased with decreasing emissions since the Clean Air Act, with mean annual pH of precipitation increasing from 4.5 in 1981 to 5.2 in 2017 (NADP 2017). Regional trends show chemical recovery of surface waters has begun (Garmo et al. 2014). Despite these regional trends of decreased sulfate and increased pH and acid neutralization capacity (ANC), detrimental impacts due to acid rain are still predicted to exceed the critical load of surface waters (Miller 2011) due in part to depletion of base cations from the shallow soils, in combination with the impacts of two centuries of intensive forestry (as reviewed in Clair and Hindar 2005; Driscoll et al. 2001; EPA 2008). In addition, the underlying bedrock and surficial geology of the Downeast region is dominated by slow weathering granite with low nutrient concentrations and low buffering capacity, allowing greater impacts from acidification (Potter 1982; Project SHARE-USFWS 2009; Shilts 1981).

Loss of fish populations due to acidification of surface waters has been well documented in the US, Canada, Scotland, and Scandinavia (as reviewed by Clair and Hindar 2005; Dennis and Clair 2012; Driscoll et al. 2001; EPA 2008; Potter 1982; Project SHARE-USFWS 2009). Below a pH of 5.4, acidity negatively impacts all freshwater life stages of salmon due to ion regulatory disturbance (Haines et al. 1990; Hindar 2001; Lacroix and Knox 2005). The impacts of acidity are enhanced in the presence of exchangeable (inorganic monomeric, labile) aluminum (Alx), which impairs respiration by binding to gill epithelia (Farmer 2000; Magee et al. 2003; NRC 2004). Numerous studies have demonstrated that episodic exposure to low pH can have detrimental impacts when coinciding with key salmon life stages during snow melt and rain events in the spring and fall (e.g., Driscoll et al. 2001; Lacroix and Knox 2005; as reviewed by McCormick et al. 1998; NRC 2004; Potter 1982). The most sensitive life stages include eggs, yolk-sac fry, and smolts as they transition to salt water (Rosseland et al. 2001). Episodic events can also have long term, sub-lethal adverse effects on fish populations, including reduced feeding and growth and increased sensitivity to other stressors (Brown et al. 1990 as cited in Magee et al. 2003; Kroglund et al. 2008; Lacroix and Korman 1996; Magee et al. 2003; Potter

1982). At pH values below 5.5, ecosystem-level processes such as nutrient cycling and productivity are impacted (Baker et al. 1990), in addition to fish population size.

Most Downeast waters have been identified as acidic (pH <6.5), with headwaters chronically acidic and main stems episodically acidic (Haines et al. 1990; Whiting and Otto 2008). The buffering capacity of rivers and streams in this area is low, with acid neutralizing capacity (ANC) of many streams sensitive to acidity (<50 μeq/L as defined by Driscoll et al. 2001). In addition, calcium levels in many streams are near or below critical thresholds for the long-term survival of aquatic biota (Whiting 2014). Calcium increases the efficiency of sodium ion regulation and oxygen exchange processes, which are impeded when exchangeable aluminum binds to the gills. Dissolved organic carbon (DOC) can buffer against aluminum toxicity by binding to metals and making them biologically unavailable. Through these chemical interactions, adding lime to acidic waters, via agricultural lime or lime slurry, has increased salmon populations in Scandinavia and Nova Scotia (as reviewed by Clair and Hindar 2005; Halfyard 2007; Hesthagen et al. 2011), and has been a recommended restoration action for Maine’s acidic rivers and streams (NRC 2004). Liming is an attractive strategy because it is amenable to adaptive management and could be a quick and cost-effective remedy to acidification (NRC 2004). It has been predicted that raising the pH by only 0.2-0.4 units could result in a significant increase in smolt production (Lacroix and Korman 1996). Acidity mitigation is necessary because even with a 20% reduction in emissions, it will take 20 years for pH to attain suitable levels for sustainable salmon populations, 10 years for ANC, and more than 100 years for base cations (due to the slow weathering of bedrock), therefore preventing freshwater communities from recovering (Clair et al. 2004).

A 2009 Project SHARE pilot study investigating the efficacy of using clam shells to lime small streams in eastern Maine suggested a trend towards improved habitat quality (Whiting 2014). However, the impact of liming on aquatic biota is unclear due to factors including limited colonization and dispersal and natural background variations in populations of aquatic biota (Bradley and Ormerod 2002). To further investigate the efficacy of liming Downeast Maine streams and in partnership with the Downeast Salmon Federation (DSF), a multi-year liming project will be conducted in the East Machias River watershed. Based on the typical generation span of Gulf of Maine salmon, 3.5 – 5.5 years or more may be required before a salmonid response to liming (increased fry and parr density) may be evident, and it may take up to 20 years before fish populations fully recover, although this time span may be reduced with other mitigation methods including stocking (Hesthagen et al. 2011). The project goal is to increase juvenile salmon abundance by application of clam shells to achieve a target pH, and to evaluate changes in the macroinvertebrate community. The first year of the project was used to begin to characterize baseline conditions of the study area.

Methods

Study Location

The East Machias River watershed is typical of coastal eastern Maine, with extensive wetlands resulting in colored waters high in organic materials and low pH, with high summer temperatures (Project SHARE-USFWS 2009). Streams in this region are characterized by short-term increases of 10-100 times base flow associated with precipitation events (Haines et al. 1990). The East Machias River watershed is vegetated by second-growth mixed hardwoods (white and yellow birch, American beech, red and sugar maple) and softwoods (red spruce, balsam fir, eastern hemlock, northern white cedar, and white pine). Timber harvest has occurred within the last 50 years, including a salvage harvest of softwoods damaged by spruce budworm in the 1980s. The existing salmon population in the East Machias River system is small (median parr density 3 per habitat unit), with an estimated 1223±297 parr exiting the system in 2016, and 12 redds observed (USASAC 2017). In 2017, 9 adults returned, resulting in a smolt to adult return rate of 3.4% (Department of Marine Resources, DMR, and DSF data). Four tributary

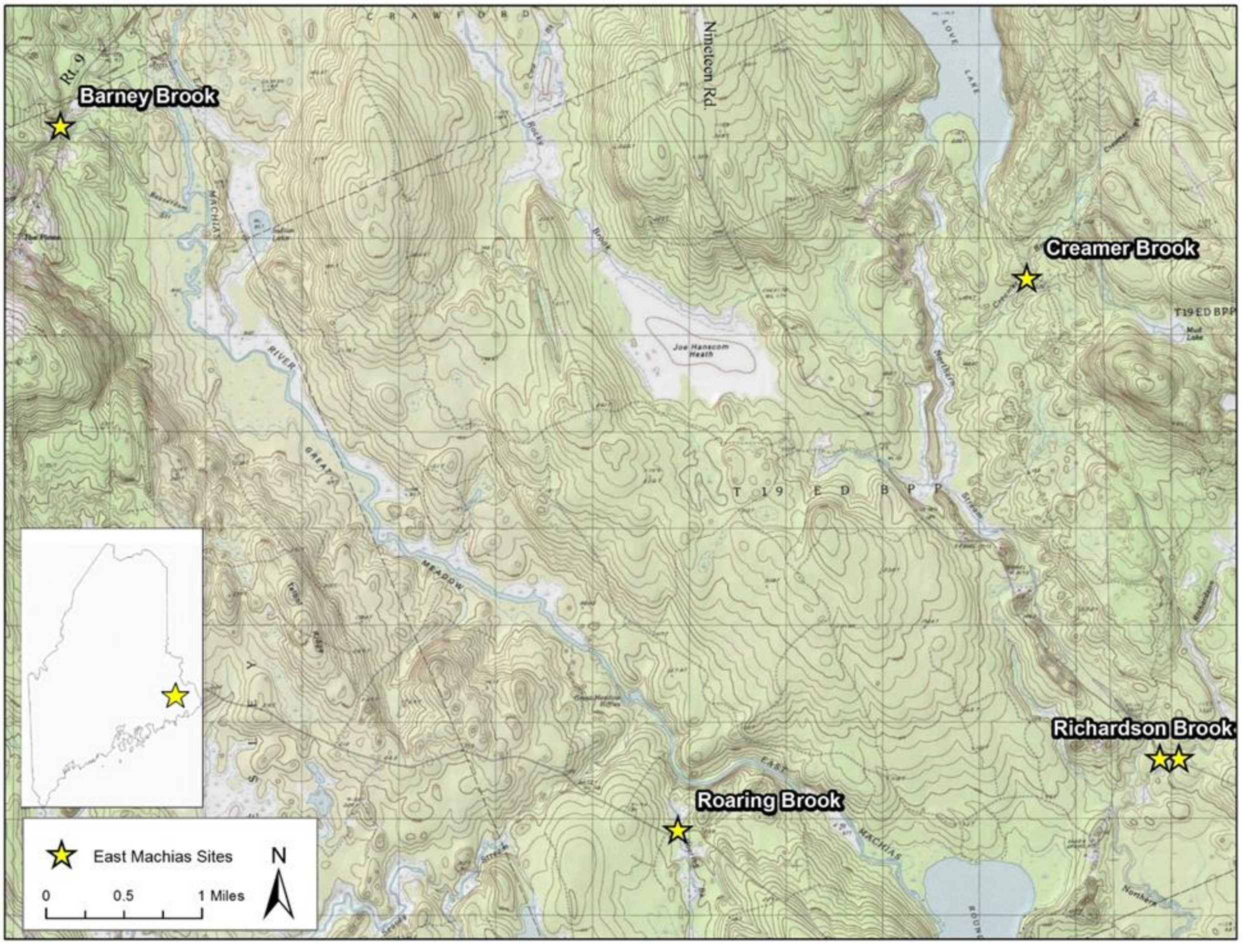

Figure 1. Map of the five study sites on four tributaries to the East Machias River. On Richardson Brook, samples were taken upstream (-A) and downstream (-B) of the road.

Table 1. Study site locations and watershed characteristics. Watershed area and percent wetlands calculated from MEGIS 2017a,b.

Stream Name	Site Code	Town	Latitude	Longitude	Watershed Area (km2)	Percent Wetlands (%)	Percent Wetlands excluding ponds (%)	Mean # of fish species present (DMR data)
Barney Brook	NMCEMBDUB02	Wesley	44.98689397	-67.63584802	3.63	5.8	5.8	unknown
Creamer Brook	NMCEMRLNSCB09	T19 ED BPP	44.97112996	-67.50932403	13.73	7.5	7.2	6
Richardson Brook	NMCEMRLNSRD05-A	T19 ED BPP	44.92615904	-67.49053298	13.47	13.4	8.4	6
	NMCEMRLNSRD05-B	T19 ED BPP	44.92616097	-67.49302299				
Roaring Brook	NMCEMRR04	T19 ED BPP	44.92029699	-67.55642697	4.66	8.4	8.4	unknown

Table 2. Study site physical characteristics. Mean stream depth was measured nine times from May to November.

Stream Name	Bankfull stream width (m)	Mean stream depth (cm)	Substrate (%)				
			Bedrock	Boulder	Cobble	Gravel	Sand/Silt
Barney Brook	2.3	21	-	5	35	45	15
Creamer Brook	6.2	30	-	55	25	18	2
Richardson Brook	6.5	35	-	15	65	15	5
	5.5	29	-	5	75	15	5
Roaring Brook	2.4	21	2	5	65	25	3

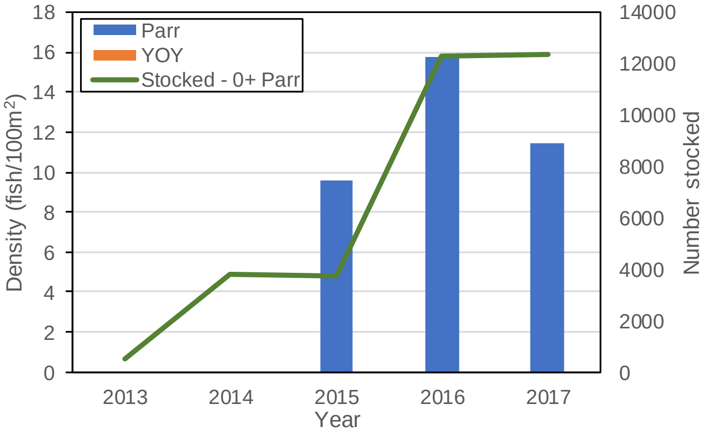

Figure 2. Number of salmon stocked in Richardson Brook per year. Density data from DMR electrofishing surveys. Stocking data from DSF.

streams to the East Machias River (first and second order) were monitored to collect baseline data (Table 1, Fig. 1). All monitored streams are Maine Statutory Class A, except for Creamer Brook which is Class AA. DSF plans to add clam shells to Richardson Stream, so an upstream and a downstream site were monitored. Three other streams, Barney Brook, Creamer Brook, and Roaring Brook, were monitored as unmanipulated controls (Fig. 1), with Barney Brook the only first order stream and the only naturally circumneutral stream (pH between 6.5-7.5). The bedrock geology in the study area is predominantly marine sandstone and slate with some volcanic rocks, especially around Creamer Brook. Surficial geology is glacial till. Study sites were riffles with boulder/cobble substrates (Table 2). DMR currently stocks Richardson Brook with fall parr and Creamer Brook with fry (Fig. 2 and 3, respectively). Anecdotally, Barney Brook contains only brook trout, which are more tolerant of high acidity than salmon, and Roaring Brook has a natural fish barrier at the confluence with the East Machias River. Local weather data were downloaded from Weather Underground's KMEALEXA2 station in Alexander, ME (Weather Underground, 2018).

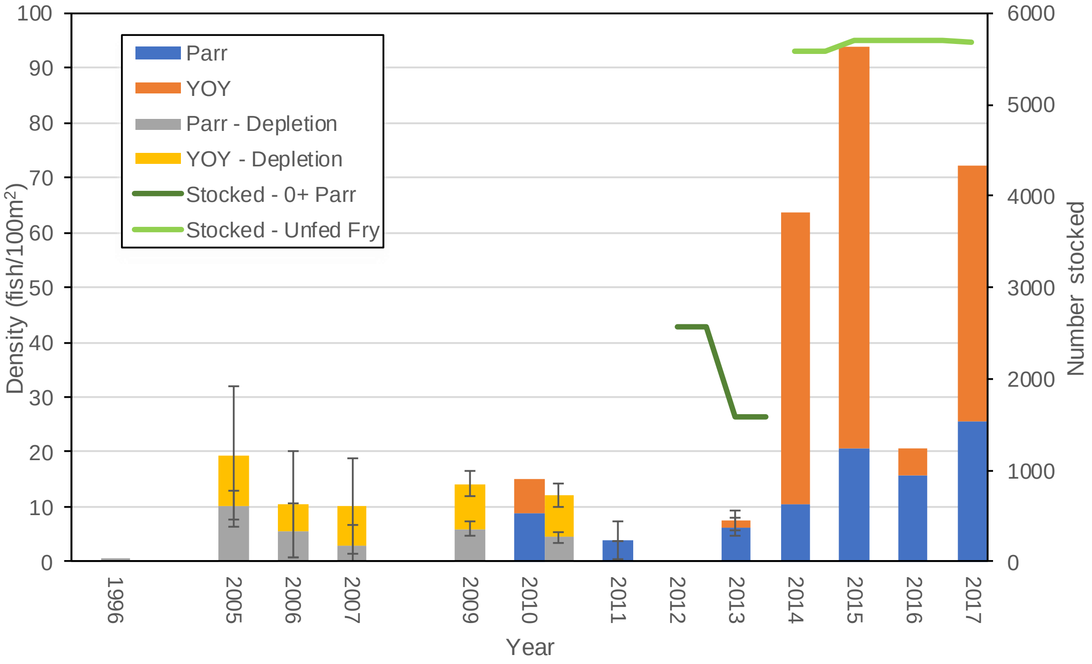

Figure 3. Salmon density in Creamer Brook and the number stocked per year. Density data from DMR electrofishing surveys using two methods: depletion studies and catch per unit effort. Stocking data from DSF.

Water Chemistry

At each sample location, continuous monitoring devices were deployed on May 30, 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, and pH were collected using YSI 600 XLM sondes. In addition, at the two Richardson Brook sites, hourly dissolved oxygen (DO) measurements were collected with Onset Hobo U26 loggers. Sondes and loggers were cleaned and calibrated every three weeks until retrieval on November 20, 2017. Sondes were field checked using a Eureka Manta2 Sub2 sonde, which also measured DO. Minor adjustments to deployment location and depth were made throughout the season to keep the sensors in flowing portions of the streams as much as possible. The sonde in Roaring Brook was retrieved August 1 due to lack of stream flow. The sonde in Creamer Brook was moved on August 28 into a pool approximately 15 meters downstream of the original deployment location due to lack of flow. Continuous data were corrected as needed based on quality control procedures as described in DEP (2016). Onset Hobo Pendant temperature loggers were deployed at all sites except Roaring Brook on October 31, and will remain in-stream until the spring of 2018, collecting hourly temperature data.

Three times throughout the year, in June, August, and October, grab samples were collected from each sample location in moving but not turbulent water (for method, see Goss 2006). Samples were kept cold (0-6°C) until shipping or delivery to the lab. Samples were analyzed by the Katahdin Analytical Services (Scarborough, ME, certified through the State of Maine Laboratory Certification) and the University of Maine's Sawyer Water Research Lab (SWRL, Orono, ME; Table 3). 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). The detection of chemical extremes is dependent on sampling frequency, resulting in these data being an estimate rather than an absolute measure of episodicity.

Table 3. Analytical methods.

Analyte	Method	Analysis Lab	Prep
Calcium	EPA 200.8	Katahdin Analytical	Acidified with nitric acid
DOC	EPA 415.1	Katahdin Analytical	Field filtered, acidified with sulfuric acid
Aluminum species	EPA 200.8 modified	Sawyer Water Research Lab	
ANC	EPA 600/4-87/026*	Sawyer Water Research Lab	
Closed-cell pH	EPA 600/4-87/026*	Sawyer Water Research Lab	
Air-equilibrated pH	EPA 600/4-87/026*	Sawyer Water Research Lab	

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

Macroinvertebrates

Rock bags were deployed in Creamer Brook and at two sites in Richardson Brook in July and retrieved in August, following the sampling and analysis methods in DEP (2014). In addition, triplicate kick net samples were collected at all sample locations in July by DSF staff assisted by volunteers following EPA's Rapid Bioassessment Protocol (Barbour et al. 1999).

Statistical Analysis

Data were analyzed using R 3.2.0 (R Development Core Team 2015). Plots were created using *ggplot2* (Wickham 2009). All data are presented as mean ± standard deviation, unless otherwise stated. Null hypotheses were rejected when $P < 0.05$. Residuals of all models were checked for normality and homogeneity. For continuous data, concentrations were transformed logarithmically to achieve a more normal distribution of residuals. To determine if season or site affected mean concentration of each parameter, a general linear model was run with the response variable of seasonal mean (log) concentration. Fixed effects included season and site. No statistical analyses were performed on grab sample data due to the limited sample size (n=3). Only 5.5% of data were rejected due to environmental conditions (extreme low flow) or data quality issues, with less than one percent of temperature and pH data rejected, 15% of specific conductance data rejected (likely due to switching to a lower calibration standard, 100 µS/cm, from 1417 µS/cm), and 11% of DO data (due to battery failure). These numbers do not include the lack of data from Roaring Brook due to insufficient flow, which represented 64% of the sampling season for that site. See Appendix I for summary data tables.

Results

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). Summer precipitation in the study area was approximately 9 inches lower in 2017 compared with the mean summer precipitation from 2011-2015, and was 3 inches lower than in 2016. In 2017, the largest precipitation events occurred in spring and fall, with the lowest precipitation in the summer. Mean air temperature was 1.4°C higher in 2016 and 2017 than in 2015 and the maximum temperature in 2017 was 2.5°C higher than the other two years. Compared with the mean from 2011-2015, temperatures were 1.1°C higher and 0.5°C higher in 2016 and 2017 respectively, with the largest increase occurring in the fall (1.5°C in 2016 and 2.3°C in 2017).

pH

Air-equilibrated pH was on average 0.29 ± 0.16 pH units higher (with a max of up to 0.5 pH units higher) than closed-cell pH (biologically relevant), indicating that the streams have natural overpressures of carbon dioxide (Fig. 4). pH measured by the sondes was on average 0.12 ± 0.01 lower than lab analyzed closed-cell pH (air equilibrated pH was much more variable), indicating that sonde results can be used as a proxy for closed-cell pH. Hourly pH ranged from 4.48 to 6.88, with the lowest stream mean of 5.4 ± 0.1 at Roaring Brook (Fig. 5; for data table see Appendix I). All sites were significantly different ($p<0.001$) from each other except Creamer Brook and the lower Richardson Brook site ($p=0.794$). Barney Brook is the only circumneutral stream in the study, with a mean pH of 6.5 ± 0.3. At all sites, pH was highest in the summer (mean 6.1 ± 0.4) during low flows. Depressions in pH were rainfall-driven, particularly when 20 mm or more of rain fell within 24 hours (Fig. 5). A significant decline of up to 1.5 pH units occurred after more than 150 mm of rain fell in 48 hours in late October, and low pH values persisted for at least a month following the rain event (Fig. 5). pH was below the Maine Water Quality Standard criterion of 6.0 in all streams (38 MRS Section 464.4.A.5), ranging from only 8.3% of observations at Barney Brook to all observations at Roaring Brook (mean exceedance rate across all sites of 51.5 ± 32.7%; Table 4). pH was below 5.4 (considered a threshold for survival of salmon; Haines et al. 1990; Stanley and Trial 1995) on average 20.2 ± 21.1% of observations, with the most exceedances at Roaring Brook (56.2%).

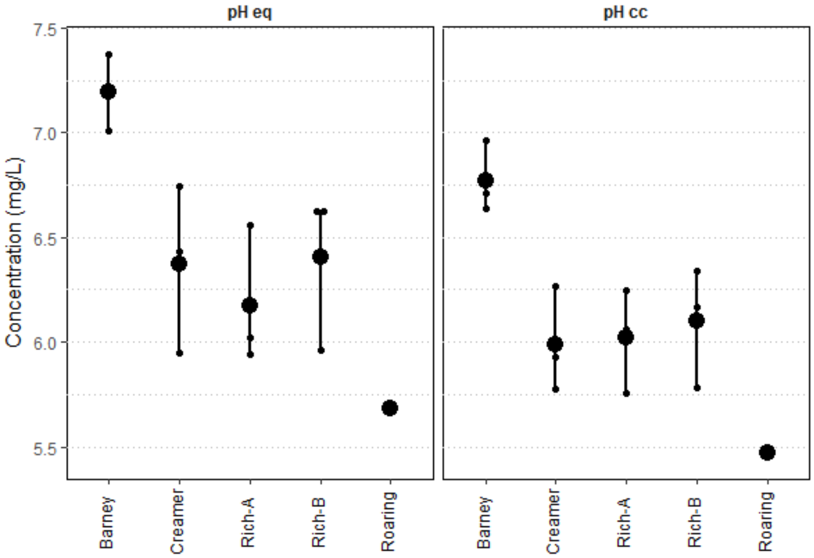

Figure 4. Grab sample data for lab-analyzed pH: air equilibrated (pH eq) and closed-cell (pH cc). n = 3 except for Roaring Brook, n =1 and Barney Brook pH eq, n = 2 (lowest value of 5.0 not included in analyses). Small dots represent data points, large dots represent means.

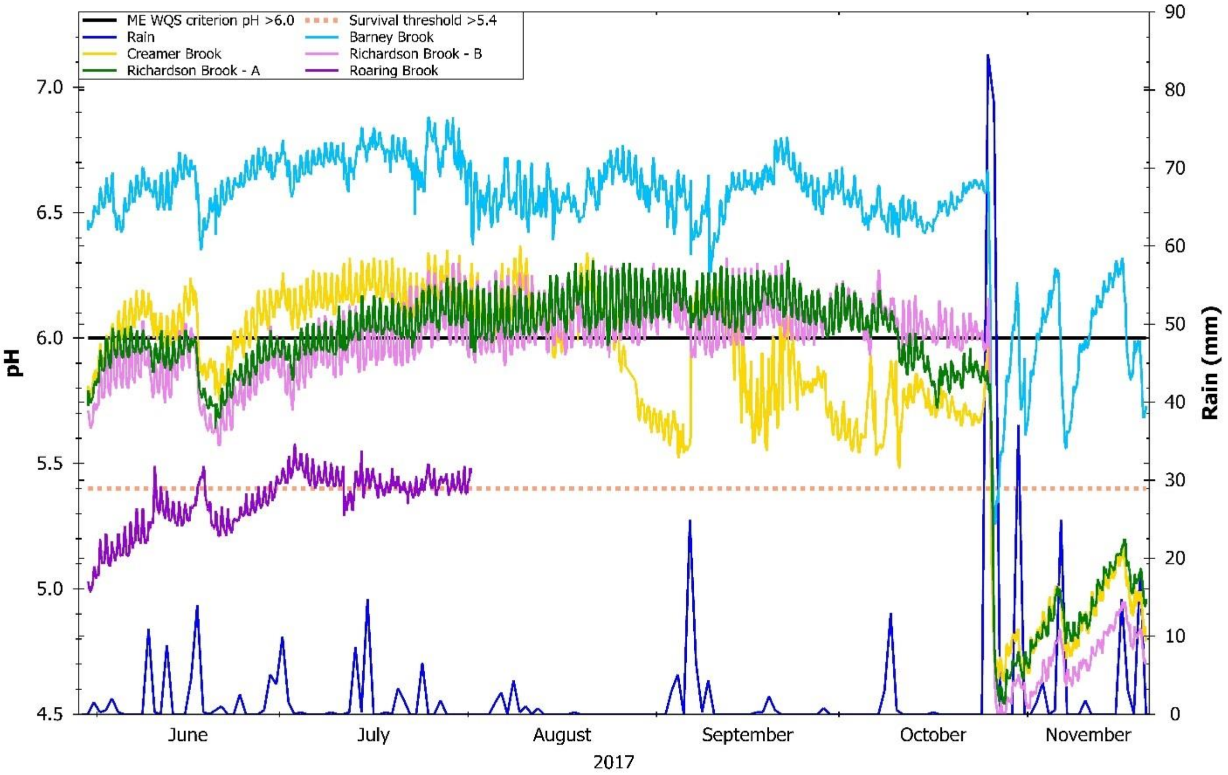

Figure 5. Hourly pH and local rainfall. Roaring Brook had no flow by August 1. Rainfall data from Weather Underground station KMEALEXA2. Survival threshold from Stanley and Trial 1995 and Haines et al. 1990.

Table 4. Percentage of data observation that exceeded stress threshold values.

Stream Name	**Continuous Data**					**Grab Sample Data**		
	pH (n ~ 4,000)		**Temperature (n ~ 4,000)**	**Dissolved Oxygen (n ~ 3,500)**		**Calcium (n = 3)**		**Exchangeable Aluminum (n = 3)**
Thresholds	*<5.4*	*<6.0*	*>20.0 °C*	*<5 mg/L*	*<7 mg/L*	*<2.0 mg/L*	*<4.0 mg/L*	*>15 µg/L*
Barney Brook	0.5	8.3	0.3			0	33.3	33.3
Creamer Brook	15.0	53.1	3.4			33.3	100	66.7
Richardson Brook – A	14.5	44.6	14.8	1.3	9.3	100	100	33.3
Richardson Brook – B	14.6	51.7	15.0	2.4	15.6	66.7	100	66.7
Roaring Brook*	56.2	100	19.1			100	100	100

*Roaring Brook data based on only 1511 sonde data points and one grab sample due to lack of water.

Temperature

Hourly stream temperature ranged from 0.57 to 26.06°C with the highest stream mean of 15.2 ± 5.1°C at Richardson Brook, although variation between sites was minimal (for data table see Appendix I). Data from Roaring Brook were excluded due to the truncated data record. Temperature was above the EPA's recommended ambient water quality criterion (AWQC) for growth of Atlantic salmon of 20°C (weekly mean) in all streams (Fig. 6; EPA 1986), ranging from only 0.3% of hourly observations at Barney Brook to 15.0% of observations at Richardson Brook (mean exceedance rate across all sites of 8.4 ± 7.6°C; Table 4). Only 1.9% of data exceeded the threshold for respiratory and metabolic stress at 22.5°C, when salmon stop feeding (Elliott and Hurley 1997; Stanley and Trial 1995), and only 1.2% exceeded EPA's short-term maxima for survival of 23°C (EPA 1986). These maxima occurred only in June (2.1% of data), July (6.0%) and August (2.3%), and persisted for 6 ± 4 days on average, with a maximum duration of 14 hours. Diel fluctuations were 3.0 ± 1.6°C, with the largest range of 8.3°C at the lower Richardson Brook site.

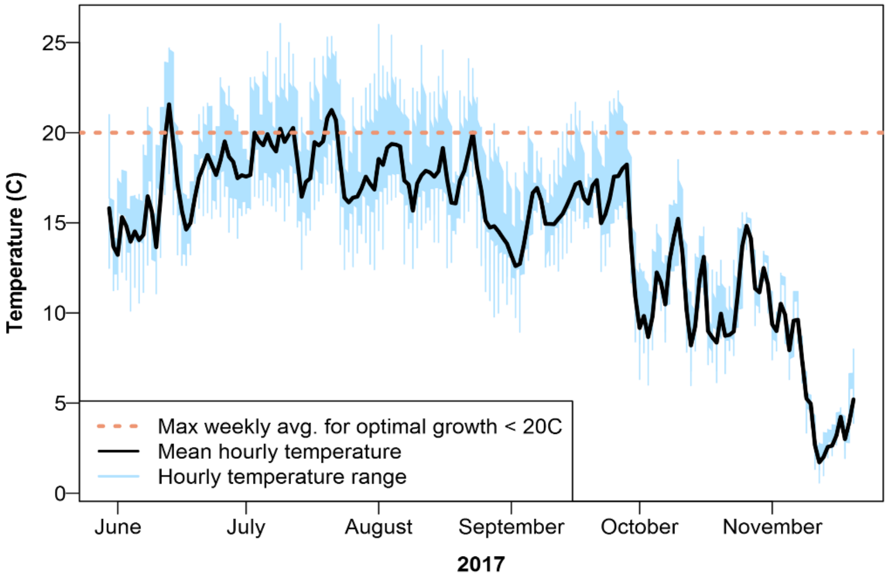

Figure 6. Mean hourly temperature across all study sites.

Dissolved Oxygen (DO)

Hourly DO ranged from 2.66 to 19.62 mg/L with the lowest stream mean (excluding Roaring Brook) of 8.87 ± 1.99 mg/L at the lower Richardson Brook site (for data table see Appendix I). DO was periodically below the Maine Water Quality Standard criterion of 7.0 mg/L (38 MRS Section 465.2.B) at both Richardson Brook sites, ranging from 9.3% of observations

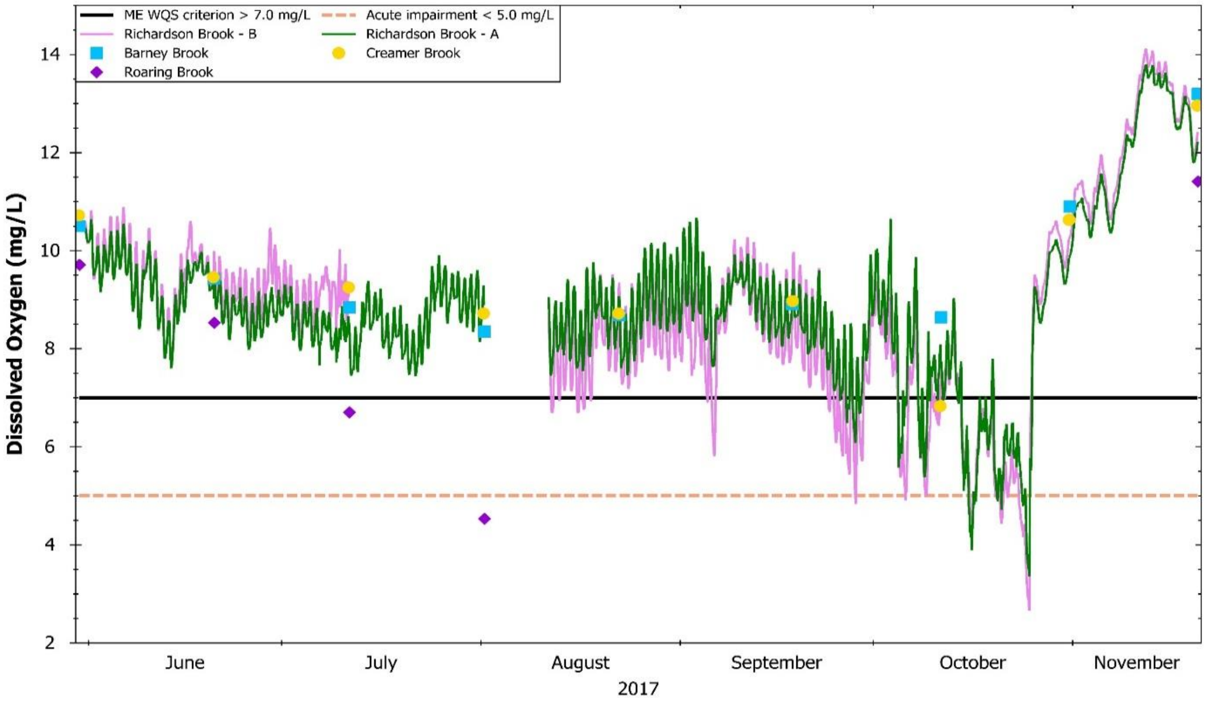

Figure 7. Hourly dissolved oxygen. Data gap due to battery failure. Dots represent discrete data points collected with a handheld sonde.

above the road crossing to 15.6% of observations below the road crossing (Fig. 6, Table 4). DO fell below EPA's threshold for acute impairment of 5.0 mg/L (EPA 1986) at both Richardson Brook sites an average of 1.9% of all observations, corresponding with the lowest flows. These minima persisted for 8.3 ± 10.2 hours, with the longest duration of 40 hours.

Specific Conductance

Hourly specific conductance ranged from 13.2 to 105.1 µS/cm with the highest stream mean of 43.47 ± 11.33 µS/cm at Barney Brook and the lowest stream mean (excluding Roaring Brook) of 24.62 ± 6.45 µS/cm at the upper Richardson Brook site (Fig. 8; for data table see Appendix I). Large rain events resulted in dilution of specific conductance.

Acid Neutralization Capacity (ANC)

ANC ranged from 46.0 to 435.9 µeq/L with the lowest stream mean (excluding Roaring Brook) of 75.8 ± 26.6 µeq/L at the upper Richardson Brook site (Table 4, Fig. 9; for data table see Appendix I). All streams stayed above the 50 µeq/L threshold of acid sensitivity 86% of the time (Driscoll et al. 2001). Barney Brook remained above 50 µeq/L at all three sampling events.

Calcium

Calcium ranged from 1.32 to 5.98 mg/L with the lowest stream mean of 1.44 ± 0.17 mg/L at the upper Richardson Brook site (Fig. 9; for data table see Appendix I). Only Barney Brook had calcium levels above the suggested threshold of 4 mg/L to prevent deformities (M. Whiting pers. comm.). At Richardson and Roaring Brooks, most samples were below the survival threshold of 2 mg/L (Fig. 9; Baker et al. 1990; Baldigo and Murdoch 2007).

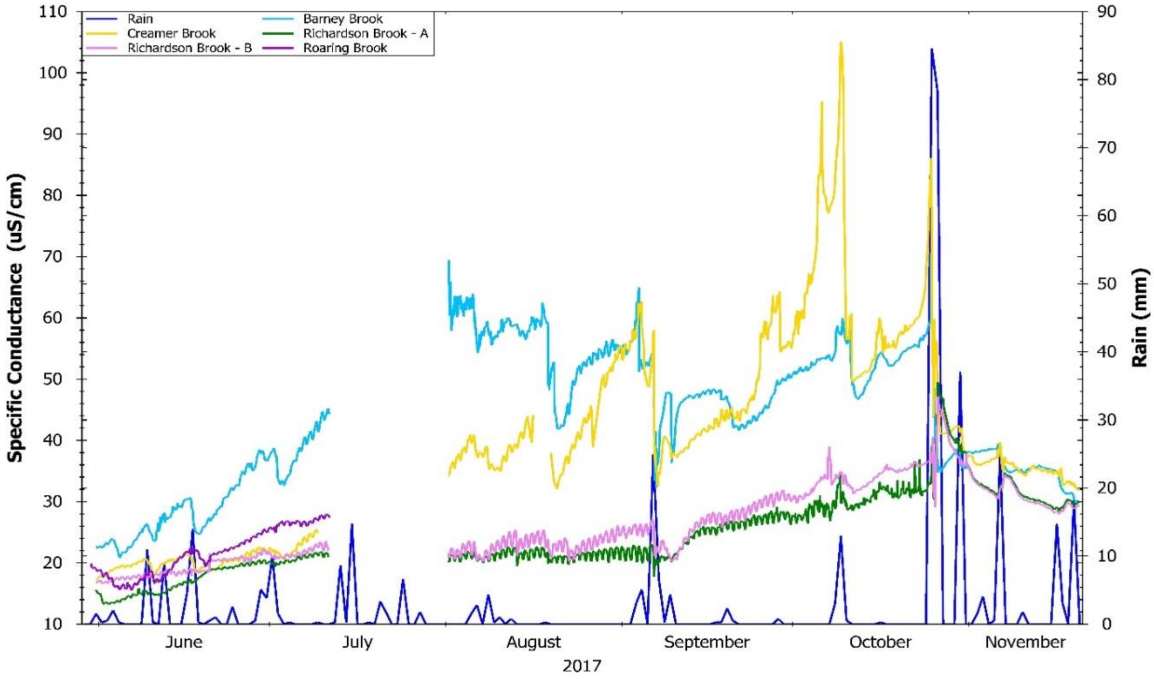

Figure 8. Hourly specific conductance and local rainfall. Data gap due to equipment malfunction.

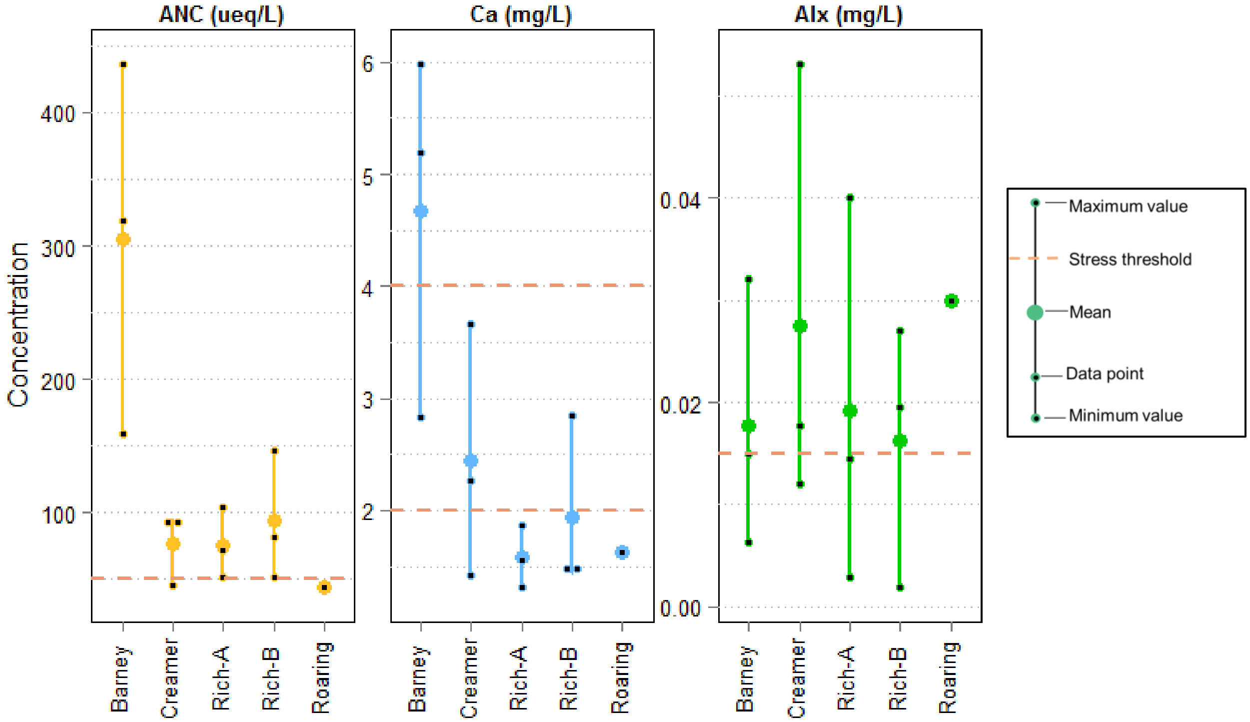

Figure 9. Discrete chemistry data for acid neutralization capacity (ANC), calcium (Ca) and exchangeable aluminum (Alx). n = 3 except for Roaring Brook, n =1. ANC stress threshold of <50 µeq/L from Driscoll et al. 2001. Calcium stress thresholds of <4 mg/L anecdotal from M. Whiting and <2 mg/L from Baker et al. 1990 and Baldigo and Murdoch 2007. Alx stress threshold of >0.015 mg/L from EIFAC as cited in Dennis and Clair 2012. Small dots represent data points, large dots represent means.

Aluminum

Average total aluminum was 179 ± 75 µg/L across all sites (see Appendix I for data table). Alx was on average 121 ± 50 µg/L lower than organic aluminum in all samples, representing 13 ± 6% of aluminum species. The potentially toxic species, Alx (calculated as the dissolved aluminum minus organically complexed aluminum), ranged from 2 to 53 µg/L with the highest stream mean of 28 ± 22 µg/L at Creamer Brook (Fig. 10), and an overall mean across all sites of 21 ± 15 µg/L. Alx was above the stress threshold of 15 µg/L at all sites (from EIFAC as cited in Dennis and Clair 2012).

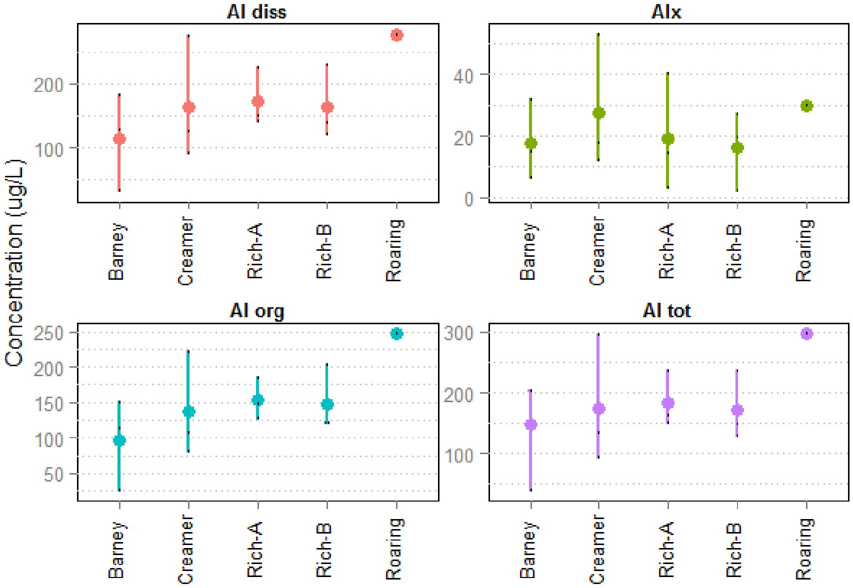

Figure 10. Discrete chemistry data for aluminum species: dissolved aluminum (Al diss), exchangeable aluminum (Alx), Organic aluminum (Al org) and total aluminum (Al tot). n = 3 except for Roaring Brook, n =1. Note different y-axis scales.

Dissolved Organic Carbon (DOC)

DOC is a surrogate for organic acids (Garmo et al. 2014). In non-agricultural waters, the difference between dissolved organic carbon (DOC, filtered) and total organic carbon (TOC, unfiltered) is <5% (Dennis and Clair 2012) and the dissolved fraction in TOC samples is expected to be >90% (Garmo et al. 2014). Therefore, TOC and DOC results are combined in this study. DOC ranged from 3.4 to 14 mg/L with the highest stream mean (excluding Roaring Brook) of 12 ± 2.83 mg/L at the lower Richardson Brook site (Fig. 11; for data table see Appendix I). DOC was lowest during baseflow and increased with precipitation and runoff.

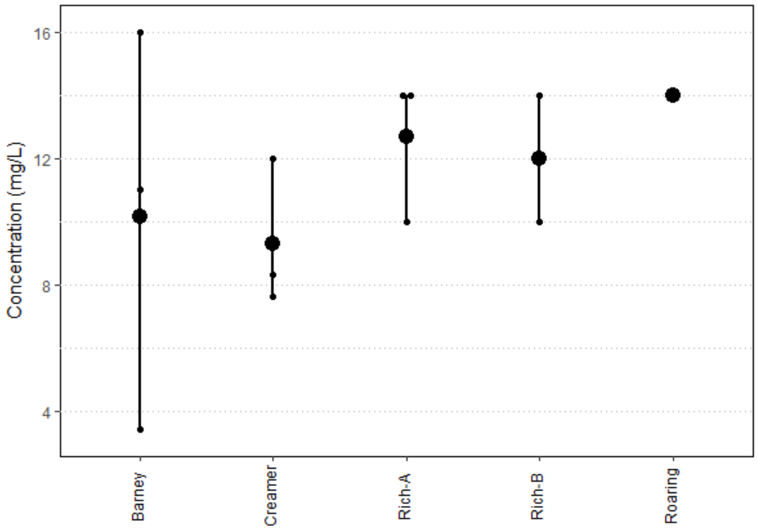

Figure 11. Discrete chemistry data for dissolved organic carbon. n = 3 except for Roaring Brook, n =1.

Trends

Due to small sample sizes (n = 3), statistics were not run on ANC, calcium, aluminum, or DOC, but trends were explored. DOC and aluminum (Alx and total) trended higher at lower pH values. DOC trended higher at higher total aluminum values. The same trend occurred with Alx but with much higher variation. Calcium trended higher at higher pH and at lower aluminum (total and exchangeable) values.

Macroinvertebrates

Macroinvertebrate samples collected by DEP using rock bags in Creamer Brook and Richardson Brook attained Class A aquatic life criteria (Table 5 and Appendix II, Davies et al. 2016). Total mean abundance was twice as high in Creamer Brook compared to the upper Richardson Brook site. Creamer Brook also had the highest generic richness and EPT generic richness, which represented half the total generic richness. Mayflies were the dominant species, and the dominant taxa were similar at all sample locations (Table 5). Abundance in rock bag samples was more than double kick net samples. Kick net samples showed high variability between replicates at each site, however abundance and EPT family richness were greatest at Richardson Brook (for data table see Appendix I). Kick net total family richness was highest at Creamer Brook. A water quality index can be calculated based on occurrence of different taxa groups as defined by the Maine Inland Fish and Wildlife Stream Habitat Survey documentation, with the presence of sensitive taxa increasing the index score. Both sampling methods resulted in the highest water quality index score at Creamer Brook.

Table 5. Summary of macroinvertebrate abundance and richness from rock bag samples. For data, see DEP Biomonitoring reports, Appendix II).

Stream Name	Total Mean Abundance	Generic Richness	EPT Generic Richness	Relative Ephemeroptera Abundance	Dominant Taxa
Creamer Brook	206.67	40	20	28%	*Lepidostoma* (44%) *Paraleptophlebia* (20%) *Plectrocnemia* (12%)
Richardson Brook - A	105.67	37	19	49%	*Paraleptophlebia* (17%) *Lepidostoma* (16%)
Richardson Brook - B	56.33	31	13	31%	*Lepidostoma* (16%) *Paraleptophlebia* (15%)

Discussion

Weather

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. These conditions could be stressful to fish, in addition to limiting foraging opportunities. Low flows also impact stream water quality by concentrating ions (e.g., conductivity) and reducing the influence of surface water. Stream temperatures may be reduced with an increased groundwater influence, which can be beneficial during hot dry years. In Downeast Maine, low precipitation may reduce the rate of acid deposition, resulting in higher stream pH values. Results from this first year of monitoring indicate that depressions in both pH (up to 1.5 units) and specific conductance are driven by rainfall. Increased precipitation or surface water discharge often produces a concurrent elevation of exchangeable aluminum, as suggested by the trends in these data, although the frequency, duration, and magnitude of increases depend on the stream and the season (Baldigo and Murdoch 2007). Therefore, during rainfall-driven episodic acidity events when exchangeable aluminum is also high, fish are likely to be further stressed.

pH

For the majority of the sampling period, the pH values in the study area remained above the state water quality criterion of pH 6.0 and above the threshold of 5.4, where no adverse impacts on salmon are expected (Haines et al. 1990; 38 MRS Section 464.4.A.5; Stanley and Trial 1995). Samples were collected during mostly low flow conditions when pH is expected to be higher (Halfyard 2007). Organic acids from leaf drop may have contributed to the pH depression following the late fall rain event. Precipitation-driven pH depression has been well documented and these rain and rain-on-snow events occur predominantly November to March (Halfyard 2007; Potter 1982). Streams were inaccessible to sampling during this period, but it is expected that during this time stream pH is lower following rain events than levels observed during the study. pH values <5.0 were observed primarily following the fall rain event (8.4% of observations), a concentration considered lethal when exposure lasts from days to weeks (Farmer et al. 1983 as cited in Magee et al. 2003; Lacroix and Knox 2005) and below which juvenile density declines (Watt et al. 1983) and inhibition of hatching enzymes occurs (Stanley and Trial 1995). Roaring Brook remained at pH 5-5.5 for 97.5% of the sampling period, a range considered lethal to a small proportion of salmon on a scale of duration from weeks to months (Lacroix and Knox 2005). The lowest pH observed, 4.48, is considered harmful to all salmonid life stages (Potter 1982), with 72-100% of parr and smolt mortality occurring between pH of 4.6-4.7 pH (Farmer 2000). Goff et al. (1993) observed 1.7-5.3% mortality in smolts over 105 days at pH 5 (as cited in Farmer 2000). The lack of recovery a month after the fall rain event is in contrast with the 10-day recovery time observed in a small New Brunswick stream, however this stream has higher ANC than the study streams (Caissie et al. 1996). The duration of the pH depression could have resulted in fish mortality, and further mortality could occur overwinter in these streams following rain events. In addition, growth may be impaired with episode number (frequency) and exposure (cumulative duration) to stressful conditions (Baker et al. 1996; Haines et al. 1990; Henriksen et al. 1984; Lacroix and Korman 1996; Magee et al. 2003).

The pH ranges observed in these Downeast streams are similar to those observed in other eastern Maine streams (Haines et al. 1990), higher than in Norway and most Nova Scotian streams (Clair et al. 2004; Halfyard 2007; Hesthagen et al. 2011), and lower than in New Brunswick including during stormflows (Caissie et al. 1996). The stream with the lowest pH in this study, Roaring Brook, had higher pH than 43% of Nova Scotian sites (Clair et al. 2004), and was similar to the mean pH (4.3-5.5) of Nova Scotian waters considered for a liming study (Halfyard 2007), suggesting that the streams in this study are not chronically acidified as are streams in Nova Scotia. Following the addition of lime, Nova Scotia streams achieved pH values of 4.8-7.5, comparable to the ones studied here (Halfyard 2007), whereas Norwegian and Welsh streams were 0.4 units higher (Bradley and Ormerod 2002; Hesthagen et al. 2011). In comparison with streams in maritime Canada, the pH values of eastern Maine streams are most similar to Nova Scotia and Newfoundland and least similar to New Brunswick (Dennis and Clair 2012). These comparisons suggest that the impact of acidification has been less significant in Maine, and this is further supported by the underlying bedrock of the regions. Southwestern Nova Scotia is primarily granitic and slate bedrock with thin, poorly drained podzolic soil (Dennis and Clair 2012), whereas the study area is primarily underlain by marine volcanics, which have a variable buffering capacity (MGS 2017). Barney Brook, which had the highest pH in this study, overlays a limey protolith, giving it a higher buffering capacity than the marine volcanics in the rest of the study area (MGS 2017). Although eastern Maine streams are not chronically acidic, as in Norway and Nova Scotia, episodic acidification following rain events in the fall and spring can be just as harmful to salmon populations.

It is possible that episodic acidification is due to the salt effect, when cations from marine salts (usually sodium and magnesium) displace hydrogen ions in soil (Heath et al. 1992; Monteith et al. 2007). A previous study of high-order streams in Maine found acidification due to the salt effect up to 40 km from the ocean (Kahl et al. 1992 as cited in Heath et al. 1992). The study area is approximately 55 km from the coast. Short term declines of up to 2 pH units and 130 µeq/L ANC have been observed in Acadia National Park, due in part to the salt effect (Heath et al. 1992). However, in low ionic strength water pH trends can be difficult to detect due to measurement uncertainty (Hovind 2010 as cited in Garmo et al. 2014). To determine if the study sites are impacted by the salt effect, concentrations of sodium and chloride would need to be measured over time to detect depressions in the Na:Cl ratio during precipitation events.

Temperature

Temperatures remained below the threshold for optimal growth of 20°C for the majority of the study (EPA 1986). The stress threshold of 22.5°C was exceeded 6.0% of the time in July and 2.3% of the time in August, with small diel fluctuations (7.2 ± 1.8 °C). At two nearby locations, at the mouth of Roaring Brook and just below the confluence of Richardson Brook and Northern Stream, temperature loggers deployed year-round by the USFWS recorded comparable results, with temperatures exceeding 22.5°C only 2.7-4.3% of the observation period, with the highest exceedance rate occurring in July (11.5-26.3%; SHEDS 2018). In contrast, Nova Scotian streams exceeded this threshold 29.1% of the time in July and 8.6% of the time in August, with diel fluctuations as large as 9.5°C (range 6-7°C common), likely due to wide shallow sections of river and low albedo due to the high organic content (Elliott and Hurley 1997; Halfyard 2007; Stanley and Trial 1995). Despite being a hot, dry year, stream temperatures never exceeded the maximum temperature for salmon survival of 27°C (Stanley and Trial 1995), and remained within the 16-19°C preferred temperature range, or lower, for 70% of the spring and summer. Salmon are likely able to recover from thermal stress experienced in the study streams due to the relatively short duration of stressful temperatures, and the diel fluctuations may provide a nightly temperature refuge. Increased temperature can increase the toxicity of exchangeable aluminum (Poléo and Muniz 1993 as cited in Kroglund et al. 2008), however temperatures were lower during observed pH depressions. Thermal stress is not expected to play a significant role during episodic acidity events in the study area.

Dissolved Oxygen (DO) and Specific Conductance

DO levels were within a healthy range for fish and aquatic life, in addition to the preferred range for salmon of >6-7 mg/L for the majority of the study period (Stanley and Trial 1995). However, during extreme low flows DO decreased below both the Maine Water Quality Standard of 7 mg/L as well as EPA's threshold for acute impairment of 5 mg/L (38 MRS Section 465.2.B; EPA 1986). DO minima coincided with the warmest temperatures as well as with low flows, increasing stress and possibly preventing fish movement to oxygen and temperature refugia, if any existed nearby. Specific conductance in the study streams was very low, following the typical dilution response with increased discharge due to precipitation. Low conductivity waters may decrease tolerance to low pH (Potter 1982), in addition to decreasing the efficacy of electrofishing, resulting in an underestimate of the number of fish present. In addition, in low ionic strength water, pH trends can be difficult to detect due to measurement uncertainty (Hovind 2010 as cited in Garmo et al. 2014). The patterns of DO and specific conductance were typical for small streams.

Acid Neutralizing Capacity (ANC)

ANC remained above the threshold of acid sensitivity of 50 μeq/L in all but two samples (Driscoll et al. 2001), and above both the 20 μeq/L (Baker et al. 1990; Lien et al. 1996) and 30 μeq/L critical limits for salmon in Norway in all samples (Kroglund et al. 2002). Despite this, the study streams are low (especially Barney Brook) to intermediate in terms of acid sensitivity as defined by MacAvoy and Bulger (1995). Higher ANC gives greater buffering capacity and correlates with higher pH (lower acidity), as seen in this study, particularly at Barney Brook. Waterbodies are considered chronically acidic when ANC is less than zero (Driscoll et al. 2001). No values were recorded that low, however no samples were taken during the high flow, acidic rain event in late October, when ANC would be expected to be lower. In low DOC waters, ANC is an approximate surrogate for alkalinity (Garmo et al. 2014). When calculated from ANC, alkalinity values in this study ranged from 2.2 to 15, all significantly lower than EPA's recommended AWQC of 20 mg/L (EPA 1986). EPA notes this threshold does not apply where values are naturally lower (EPA 1986). No historic ANC data are known for these study sites, so it is unknown if ANC values are low naturally or due to anthropogenic influence (acid rain). In comparison with streams in maritime Canada, ANC in eastern Maine streams are most similar to Nova Scotia streams although ANC values are often higher in Maine (Clair et al. 2004; Dennis and Clair 2012; Halfyard 2007). Roaring Brook had the lowest ANC of all streams studied, yet it was higher than at 47% of sites in Nova Scotia (Clair et al. 2004), indicating that the streams studied have a greater buffering capacity than those in Nova Scotia. Relatively low ANC values in the study streams indicate a deficit of buffering materials in the watershed, due to thin soils (Potter 1982), allowing volatile swings in pH after rain inputs and increasing the potential for salmon mortality (MacAvoy and Bulger 1995). Due to the low buffering capacity, if liming mitigation is pursued, it is expected that the system would revert to the pre-treatment acidified state relatively quickly if mitigation ceased (Halfyard 2007).

Calcium

Calcium was lower than the survival threshold of 2 mg/L at all sites except for Barney Brook (Baker et al. 1990; Baldigo and Murdoch 2007). Low calcium coincided with low pH and high aluminum. Calcium, at any concentration, can buffer the detrimental impacts of exchangeable aluminum by increasing the efficiency of ion regulation (Baldigo and Murdoch 2007, McDonald et al. 1980), however this buffering capacity decreases below 1 mg/L Ca when pH is 6.5, and around 2 mg/L Ca when pH is lower (Wood et al. 1990). Based on observed pH, the buffering capacity of calcium is expected to be low in the study streams. Brook trout mortality has been observed when calcium is 2 mg/L in waters with pH <5-5.4 (Baldigo and Murdoch 2007), especially when DOC is <2, and Alx is >200 (Baker et al. 1990). Brook trout are more tolerant than salmon (Rosseland and Skogheim 1984), so salmon are expected to experience more severe stress in these conditions. During baseflows, only Roaring Brook had pH low enough to potentially see detrimental impacts due to low calcium, however the rain event in late October pushed all streams except Barney Brook into the lower pH range. DOC, Alx, and calcium were not measured during this high flow event, so the risk of mortality is unknown, however it is expected that DOC and Alx would be higher and calcium 2-5 times lower during high discharge (Haines et al. 1990). Compared with rivers in Nova Scotia, including the West River (which has been limed), calcium was higher in eastern Maine (Clair et al. 2004; Halfyard 2007), lower than in Catamaran Stream in New Brunswick (Caissie et al. 1996) and similar to acid reference sites in Wales (Bradley and Ormerod 2002). Only Barney Brook had calcium levels comparable with circumneutral reference streams (Bradley and Ormerod 2002). Despite the low calcium levels, some buffering is likely occurring (Baker et al. 1990; Wood et al. 1990), depending on the relative levels of the other water quality parameters.

<u>Aluminum</u>

Total aluminum was well below the Maine AWQC maximum of 750 μg/L at all sites, however all samples were higher than the chronic criterion of 87 μg/L, except for one sample at Barney Brook (DEP CMR Chapter 584). These criteria are based on a pH of 6.5-9.0 and DOC <5 mg/L, significantly higher than the pH observed in the study streams. The toxicity of aluminum increases as pH becomes more acidic or basic (EPA 2017), and it depends on the relative dominance of exchangeable aluminum (Lacroix and Kan 1986). Exchangeable aluminum represented 10-15% of the aluminum species in the study streams, which is similar to Nova Scotian streams, although this fraction is expected to increase with high flows and low pH, possibly becoming dominant during hydrologic events (Lacroix and Kan 1986). Dominance of the organic fraction of aluminum is likely due to the relatively high DOC values observed (>10 mg/L), which also prevents major changes in aluminum speciation due to the excess of organics (Lacroix and Kan 1986). Therefore, the effects of aluminum toxicity are most severe in the spring when the capacity of DOC to complex metals is reduced due to dilution in spring runoff (Dennis and Clair 2012). The range of Alx in this study is similar to data from other cool ecosystems underlain by a range of geological types, however values were lower than in Nova Scotian and Norwegian streams (Dennis and Clair 2012; Hesthagen et al. 2011). Post-liming, Norwegian streams attained Alx values similar to the minima observed in this study. Total aluminum in the study streams was similar to Welsh streams pre-liming (150-190 μg/L), with the minimum values at Barney Brook most closely matching post-liming values (60-100 μg/L) (Bradley and Ormerod 2002). Within eastern Maine, average exchangeable aluminum was similar to observations in tributaries to the Narraguagus and Union Rivers, but total aluminum was slightly higher in this study (Haines et al. 1990).

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 (Howells et al. 1990 as cited in Dennis and Clair 2012; Kroglund and Staurnes 1999). All streams except for Barney Brook exceeded the EIFAC criteria but only in the June sampling event, when flows were high and pH was approximately 5.8. Above pH 6.0, aluminum solubility is reduced and is likely not toxic (Dennis and Clair 2012; Driscoll et al. 2001), however all streams fell below a pH of 6 periodically, for a total of about half the study period, especially following the late October rain event. Aluminum samples were not collected during this event, but it is expected that Alx would be increased as pH and calcium decreased, therefore increasing the risk of stress during high flows (Clair and Hindar 2005; Haines et al. 1990). The abundance of acid-sensitive species (such as brook trout) decreases when Alx is >72 μg/L and pH is ≤5 (Driscoll et al. 2001), conditions that may occur in the study streams during rainfall driven episodic events. Based on previous studies, the risk of salmon mortality in the study streams due to high Alx concentrations is unlikely except during high discharge events (Baldigo and Murdoch 2007; Haines et al. 1990). However, smolt development and tolerance to saltwater are compromised by short-term exposure to aluminum at concentrations as low as 15 µg/L, which can reduce survival and therefore reduce adult returns (Dennis and Clair 2012; Kroglund and Staurnes 1999; Kroglund et al. 2008; McCormick et al. 2009; Monette et al. 2008; Staurnes et al. 1995, 1996). Recovery from low pH/high Alx events can take up to 3 days in neutral waters (Kroglund and Staurnes 1999) and up to 3 weeks for early life stages (Wood et al. 1990). Compared with Alx and pH in Norwegian rivers, reduced salmon populations are expected at all streams except for Barney Brook (Kroglund et al. 2002).

Dissolved Organic Carbon (DOC)

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). Downeast streams, including those studied here, are highly colored, with relatively high organic content due to wetlands and coniferous forests, potentially providing a buffer system to counter low pH and aluminum toxicity (Haines et al. 1990). DOC concentrations greater than 2.0-5.0 mg/L help buffer against the toxic impacts of exchangeable aluminum, by binding the aluminum into inert organic inert complexes, at pH <5.5 (Baldigo and Murdoch 2007; Lacroix et al. 1990 as cited in Farmer 2000; Tipping et al. 1991). However, at the lowest observed pH of 4.99, any protective effects of high DOC may be negated. DOC values in Maine are lower than most streams in Nova Scotia (Clair et al. 2004; Dennis and Clair 2012), possibly due to differences in the underlying bedrock (as discussed above), however, values were similar to those observed in the West River (Halfyard 2007). More data are needed to determine the relative impact of anthropogenic acidification versus organic acidity from wetlands. To determine the actual concentration range of DOC in these streams, measurements should be taken weekly or monthly (Caissie et al. 1996).

Macroinvertebrates

The water quality of the streams sampled with rock bags support robust macroinvertebrate communities that attain Maine’s highest aquatic life water quality classification (Class A), despite drought conditions. The high relative abundance of mayflies, considered to be the most sensitive group of aquatic insects to acidity (Weiderholm 1984), suggest good water quality at all sites. Macroinvertebrate abundance was slightly lower at the downstream Richardson Brook site, possibly due to higher temperatures at the open road crossing (no canopy cover) or because the rock bags were placed in a deep pool with very low flow. At all sites, the dominant taxa were mayflies and caddisflies that most often occur in cool springs and streams, usually in areas of little current, including temporary pools, such as were found in the low flow conditions this year. The macroinvertebrate rock bag results compare well with other first and second order reference systems (L. Tsomides pers. comm.). The low abundances and high variability between kick net samples may be due to the challenges of sampling streams with boulder substrates at extremely low flows. The rainfall driven decrease in acidity below pH 5 may have had a detrimental impact on any acid-sensitive macroinvertebrates present in the streams (Weiderholm 1984). Both severity and duration of episodic acidity affect these taxa, however multiple years of data are required to come to any concrete conclusions (Bradley and Ormerod 2002). Downeast streams may contain a macroinvertebrate assemblage tolerant to episodic acidity, as these events have been occurring for decades. It is thought that the most critical period for macroinvertebrates is emergence, so it is expected that species that reproduce in the spring would be most affected due to low pH (Weiderholm 1984). As a food source, changes to the macroinvertebrate assemblage composition may not have an impact on salmon, as salmon are thought to be opportunistic feeders, changing their diet to the most abundant prey available, which often includes the larvae of mayflies, chironomids, caddisflies, blackflies, stoneflies, annelids, and mollusks (Scott and Crossman 1973 as cited in Stanley and Trial 1995). However, a decrease in abundance, as may occur following episodic acidity events, may reduce the available prey.

Conclusion

The results of the first year of monitoring indicate that under moderate baseflow conditions, water quality is decent for salmon but deterioration of water quality during high-discharge, high acidity events could lead to sub-lethal stress or even mortality. Samples were collected predominantly during low flow conditions and did not capture high discharge events when stress due to lower pH occurs (in combination with other parameters). More stormflow and winter samples are needed to better predict fish community status (Baker et al. 1996). Richardson Brook, the potential site of future lime treatments, has similar water quality characteristics to Creamer Brook, in a neighboring watershed. Barney Brook has the coldest water of the four streams and is predominantly circumneutral, which is not surprising based on the underlying limey geology (MGS 2017). The only chronically acidic stream was Roaring Brook, but the other study streams were episodically acidified due to precipitation events.

Although these streams were above the pH threshold of 5.4 during baseflows, sub-lethal stress is likely still causing detrimental impacts to salmon due to the combined impact of low pH and aluminum toxicity. The use of only one indicator, such as pH, to predict adverse effects of acidity can be misleading, due to the relationship between pH, ANC, and aluminum, in addition to the cumulative effects of acid events (Baker et al. 1996, Haines et al. 1990). Exposure to physiological stressors, such as changes in salinity and acidity, has been shown to reduce anti-predatory behavior in smolts (Handeland et al. 1996), in addition to increasing residence time in estuaries, an area of high smolt predation. Salmon are more susceptible to these negative impacts if further stress events occur during the recovery period (more than three days) following acidic events (Magee et al. 2003). The most sensitive life stages to acidity are alevins (from hatch to swim up) which are present in the study area from March through June, and smolts (especially as they out migrate), which are present from April through June. This time range also coincides with snow melt conditions, when streams become episodically acidic, increasing the severity of detrimental impacts to salmon. By decreasing exposure to acidity, smolt survival may increase during their seaward migration. As clam shells are added to the target area, monitoring efforts will continue for at least five years to determine the efficacy of using this approach to mitigate acidity.

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Appendix I – Summary Data Tables

Continuous Data Summary. Summary statistics (mean, standard deviation (SD), minimum and maximum) of hourly measurements from YSI 600 XLM sondes, May-Nov. 2017 (n ~ 4,000*). Dissolved oxygen data are from hourly Onset Hobo U26 loggers for Richardson Brook and discrete measurements for all other streams from a Eureka Manta2 Sub2 sonde (n = 9*).

Stream Name	**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**
Barney Brook	6.51	0.27	5.26	6.88	13.33	3.98	0.57	20.9	43.47	11.33	20.9	70.6	9.72	1.57	8.35	13.2
Creamer Brook	5.81	0.44	4.63	6.37	13.88	4.31	1.00	22.76	39.72	16.16	13.6	105.1	9.58	1.71	6.83	19.62
Richardson Brook - A	5.87	0.43	4.54	6.31	15.15	5.05	1.16	25.46	24.62	6.45	13.2	49.5	8.91	1.65	3.36	13.8
Richardson Brook - B	5.82	0.48	4.48	6.32	15.18	5.03	1.09	26.06	26.16	6.16	16.6	47.2	8.87	1.99	2.66	14.12
Roaring Brook*	5.35	0.11	4.99	5.58	17.57	2.57	11.38	24.48	21.73	3.73	15.5	27.9	8.18	2.67	4.53	11.41

*Roaring Brook n ~ 1,500 for hourly data and n = 5 for discrete data (DO).

Discrete Data Summary. Summary statistics (mean, SD, minimum and maximum) from grab samples collected June 20, Aug. 1, and Oct. 11, 2017 (n = 3). Roaring Brook only had one grab sample collected because the stream dried up in July.

Stream Name	**Calcium (mg/L)**				**Organic Carbon (mg/L)**				**ANC (µeq/L)**				**pH (air-equilibrated)**				**pH (closed-cell)**			
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Barney Brook	4.40	2.23	2.83	5.98	7.2	5.37	3.4	11	304.5	139.2	158.6	435.9	6.46	1.28	5.00	7.37	6.77	0.17	6.64	6.96
Creamer Brook	1.85	0.60	1.42	2.27	9.8	3.11	7.6	12	80.8	23.3	46.0	94.9	6.37	0.40	5.95	6.74	5.97	0.21	5.78	6.26
Richardson Brook - A	1.44	0.17	1.32	1.56	11.33	2.31	10	14	75.8	26.6	51.3	104	6.12	0.29	5.94	6.56	6.02	0.25	5.75	6.25
Richardson Brook - B	1.46	0.06	1.41	1.53	12	2.83	10	14	90.5	40.1	52.4	147	6.47	0.34	5.96	6.66	6.15	0.26	5.78	6.34
Roaring Brook	-	-	1.63	-	-	-	14	-	-	-	44.8	-	-	-	5.69	-	-	-	5.47	-

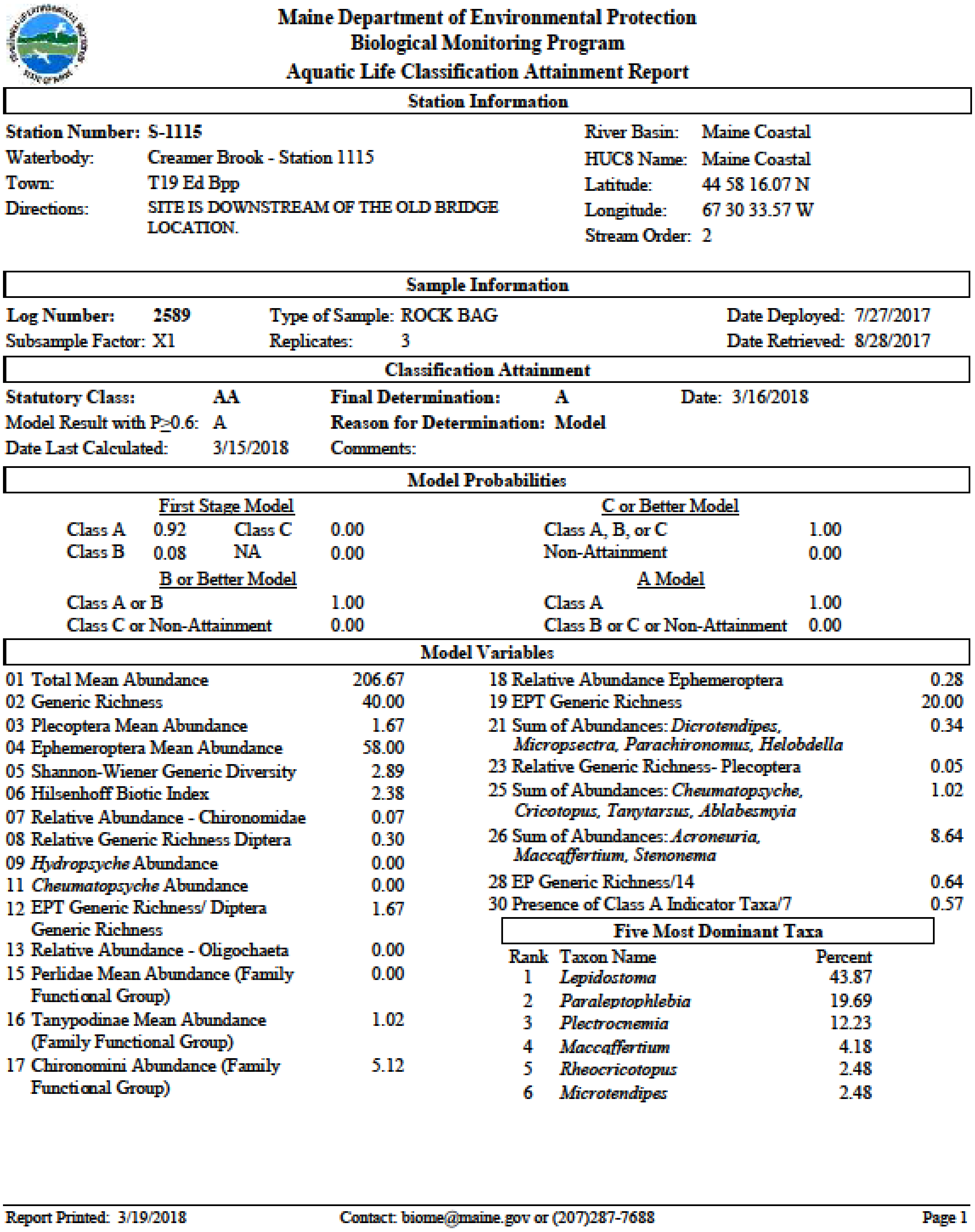
Aluminum Species Data Summary. Summary statistics (mean, SD, minimum and maximum) from grab samples collected June 20, Aug. 1, and Oct. 11, 2017 (n = 3). Roaring Brook only had one grab sample collected because the stream dried up in July.

Stream Name	Total Aluminum (µg/L)				Dissolved Aluminum (µg/L)				Exchangeable Aluminum (µg/L)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Barney Brook	163.8	82.6	40	209	128.8	60.0	32.1	182	17.8	13.1	6.3	32
Creamer Brook	174.2	105.7	94	294	163.7	96.9	92	274	27.6	22.2	12	53
Richardson Brook - A	182.7	46.5	150	236	172.0	46.1	141.1	225	19.1	18.9	3	40
Richardson Brook - B	165.8	47.8	129	236	157.1	48.6	122	229	16.0	10.5	2	27
Roaring Brook	-	-	297	-	-	-	277	-	-	-	30	-

Macroinvertebrate Kick Net Summary. Macroinvertebrates were identified to the family in the field. Barney Brook only had EPT richness recorded for two kick net samples so both values are reported as a range. The water quality index values are based on the occurrence of different taxa groups as defined by the Maine Inland Fish and Wildlife Stream Habitat Survey protocol.

Stream Name	Mean Abundance	Mean Family Richness	EPT Family Richness	Water Quality Index
Barney Brook	14 ± 11	5 ± 4	1 to 17	10.3 ± 5.5
Creamer Brook	20 ± 4	7 ± 1	5 ± 3	16 ± 2.6
Richardson Brook - B	42 ± 27	6 ± 0	8 ± 3	14.3 ± 1.2

Appendix II – Biomonitoring Key Reports



Maine Department of Environmental Protection
Biological Monitoring Program
Aquatic Life Classification Attainment Report

Station Information

Station Number:	**S-1115**	River Basin:	Maine Coastal
Waterbody:	Creamer Brook - Station 1115	HUC8 Name:	Maine Coastal
Town:	T19 Ed Bpp	Latitude:	44 58 16.07 N
Directions:	SITE IS DOWNSTREAM OF THE OLD BRIDGE LOCATION.	Longitude:	67 30 33.57 W
		Stream Order:	2

Sample Information

Log Number:	**2589**	Type of Sample:	ROCK BAG	Date Deployed:	7/27/2017
Subsample Factor:	X1	Replicates:	3	Date Retrieved:	8/28/2017

Classification Attainment

Statutory Class:	**AA**	**Final Determination:**	**A**	Date:	3/16/2018
Model Result with P≥0.6:	A	**Reason for Determination:**	**Model**		
Date Last Calculated:	3/15/2018	Comments:			

Model Probabilities

First Stage Model

Class A	0.92	Class C	0.00
Class B	0.08	NA	0.00

C or Better Model

Class A, B, or C	1.00
Non-Attainment	0.00

B or Better Model

Class A or B	1.00
Class C or Non-Attainment	0.00

A Model

Class A	1.00
Class B or C or Non-Attainment	0.00

Model Variables

01 Total Mean Abundance	206.67
02 Generic Richness	40.00
03 Plecoptera Mean Abundance	1.67
04 Ephemeroptera Mean Abundance	58.00
05 Shannon-Wiener Generic Diversity	2.89
06 Hilsenhoff Biotic Index	2.38
07 Relative Abundance - Chironomidae	0.07
08 Relative Generic Richness Diptera	0.30
09 *Hydropsyche* Abundance	0.00
11 *Cheumatopsyche* Abundance	0.00
12 EPT Generic Richness/ Diptera Generic Richness	1.67
13 Relative Abundance - Oligochaeta	0.00
15 Perlidae Mean Abundance (Family Functional Group)	0.00
16 Tanypodinae Mean Abundance (Family Functional Group)	1.02
17 Chironomini Abundance (Family Functional Group)	5.12
18 Relative Abundance Ephemeroptera	0.28
19 EPT Generic Richness	20.00
21 Sum of Abundances: *Dicrotendipes, Micropsectra, Parachironomus, Helobdella*	0.34
23 Relative Generic Richness- Plecoptera	0.05
25 Sum of Abundances: *Cheumatopsyche, Cricotopus, Tanytarsus, Ablabesmyia*	1.02
26 Sum of Abundances: *Acroneuria, Maccaffertium, Stenonema*	8.64
28 EP Generic Richness/14	0.64
30 Presence of Class A Indicator Taxa/7	0.57

Five Most Dominant Taxa

Rank	Taxon Name	Percent
1	*Lepidostoma*	43.87
2	*Paraleptophlebia*	19.69
3	*Plectrocnemia*	12.23
4	*Maccaffertium*	4.18
5	*Rheocricotopus*	2.48
6	*Microtendipes*	2.48

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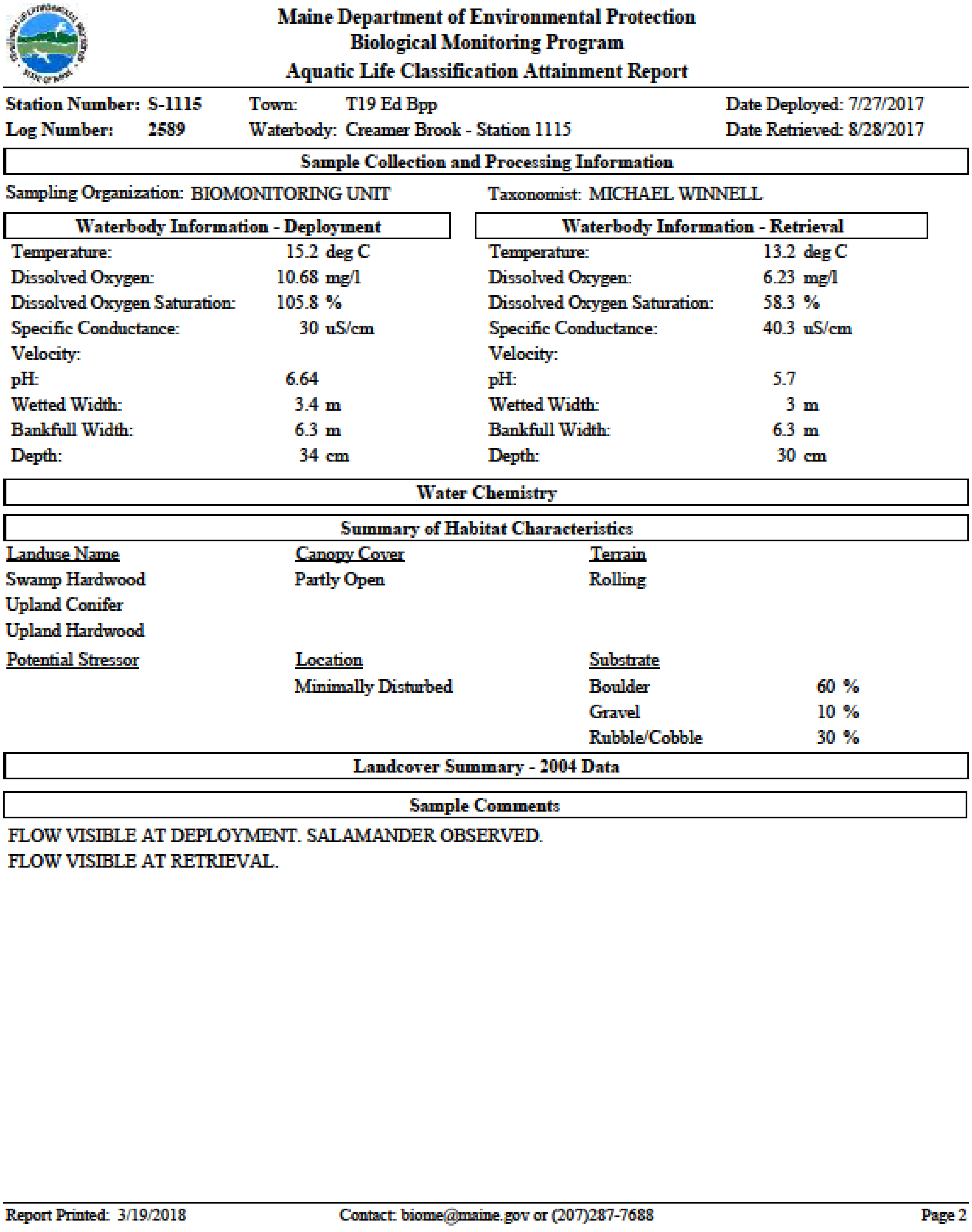

Maine Department of Environmental Protection
Biological Monitoring Program
Aquatic Life Classification Attainment Report

Station Number: S-1115	Town: T19 Ed Bpp		Date Deployed: 7/27/2017
Log Number: 2589	Waterbody: Creamer Brook - Station 1115		Date Retrieved: 8/28/2017

Sample Collection and Processing Information

Sampling Organization: BIOMONITORING UNIT

Taxonomist: MICHAEL WINNELL

Waterbody Information - Deployment		Waterbody Information - Retrieval	
Temperature:	15.2 deg C	Temperature:	13.2 deg C
Dissolved Oxygen:	10.68 mg/l	Dissolved Oxygen:	6.23 mg/l
Dissolved Oxygen Saturation:	105.8 %	Dissolved Oxygen Saturation:	58.3 %
Specific Conductance:	30 uS/cm	Specific Conductance:	40.3 uS/cm
Velocity:		Velocity:	
pH:	6.64	pH:	5.7
Wetted Width:	3.4 m	Wetted Width:	3 m
Bankfull Width:	6.3 m	Bankfull Width:	6.3 m
Depth:	34 cm	Depth:	30 cm

Water Chemistry

Summary of Habitat Characteristics

Landuse Name	Canopy Cover	Terrain	
Swamp Hardwood	Partly Open	Rolling	
Upland Conifer			
Upland Hardwood			

Potential Stressor	Location	Substrate	
	Minimally Disturbed	Boulder	60 %
		Gravel	10 %
		Rubble/Cobble	30 %

Landcover Summary - 2004 Data

Sample Comments

FLOW VISIBLE AT DEPLOYMENT. SALAMANDER OBSERVED.
FLOW VISIBLE AT RETRIEVAL.

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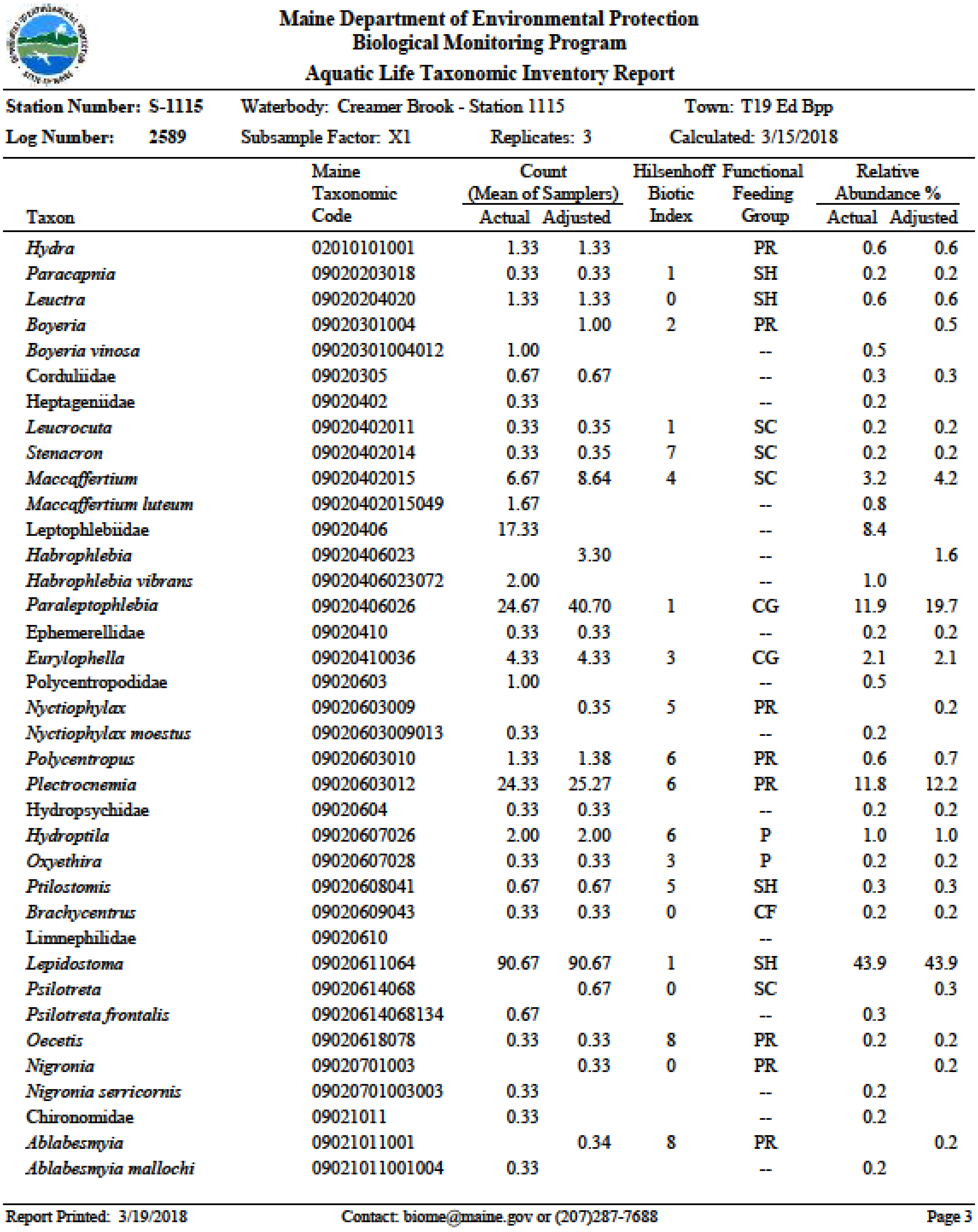

Maine Department of Environmental Protection
Biological Monitoring Program
Aquatic Life Taxonomic Inventory Report

Station Number: S-1115 Waterbody: Creamer Brook - Station 1115 Town: T19 Ed Bpp

Log Number: 2589 Subsample Factor: X1 Replicates: 3 Calculated: 3/15/2018

Taxon	Maine Taxonomic Code	Count (Mean of Samplers)		Hilsenhoff Biotic Index	Functional Feeding Group	Relative Abundance %	
		Actual	Adjusted			Actual	Adjusted
Hydra	02010101001	1.33	1.33		PR	0.6	0.6
Paracapnia	09020203018	0.33	0.33	1	SH	0.2	0.2
Leuctra	09020204020	1.33	1.33	0	SH	0.6	0.6
Boyeria	09020301004		1.00	2	PR		0.5
Boyeria vinosa	09020301004012	1.00			--	0.5	
Corduliidae	09020305	0.67	0.67		--	0.3	0.3
Heptageniidae	09020402	0.33			--	0.2	
Leucrocuta	09020402011	0.33	0.35	1	SC	0.2	0.2
Stenacron	09020402014	0.33	0.35	7	SC	0.2	0.2
Maccaffertium	09020402015	6.67	8.64	4	SC	3.2	4.2
Maccaffertium luteum	09020402015049	1.67			--	0.8	
Leptophlebiidae	09020406	17.33			--	8.4	
Habrophlebia	09020406023		3.30		--		1.6
Habrophlebia vibrans	09020406023072	2.00			--	1.0	
Paraleptophlebia	09020406026	24.67	40.70	1	CG	11.9	19.7
Ephemerellidae	09020410	0.33	0.33		--	0.2	0.2
Eurylophella	09020410036	4.33	4.33	3	CG	2.1	2.1
Polycentropodidae	09020603	1.00			--	0.5	
Nyctiophylax	09020603009		0.35	5	PR		0.2
Nyctiophylax moestus	09020603009013	0.33			--	0.2	
Polycentropus	09020603010	1.33	1.38	6	PR	0.6	0.7
Plectrocnemia	09020603012	24.33	25.27	6	PR	11.8	12.2
Hydropsychidae	09020604	0.33	0.33		--	0.2	0.2
Hydroptila	09020607026	2.00	2.00	6	P	1.0	1.0
Oxyethira	09020607028	0.33	0.33	3	P	0.2	0.2
Ptilostomis	09020608041	0.67	0.67	5	SH	0.3	0.3
Brachycentrus	09020609043	0.33	0.33	0	CF	0.2	0.2
Limnephilidae	09020610				--		
Lepidostoma	09020611064	90.67	90.67	1	SH	43.9	43.9
Psilotreta	09020614068		0.67	0	SC		0.3
Psilotreta frontalis	09020614068134	0.67			--	0.3	
Oecetis	09020618078	0.33	0.33	8	PR	0.2	0.2
Nigronia	09020701003		0.33	0	PR		0.2
Nigronia serricornis	09020701003003	0.33			--	0.2	
Chironomidae	09021011	0.33			--	0.2	
Ablabesmyia	09021011001		0.34	8	PR		0.2
Ablabesmyia mallochi	09021011001004	0.33			--	0.2	

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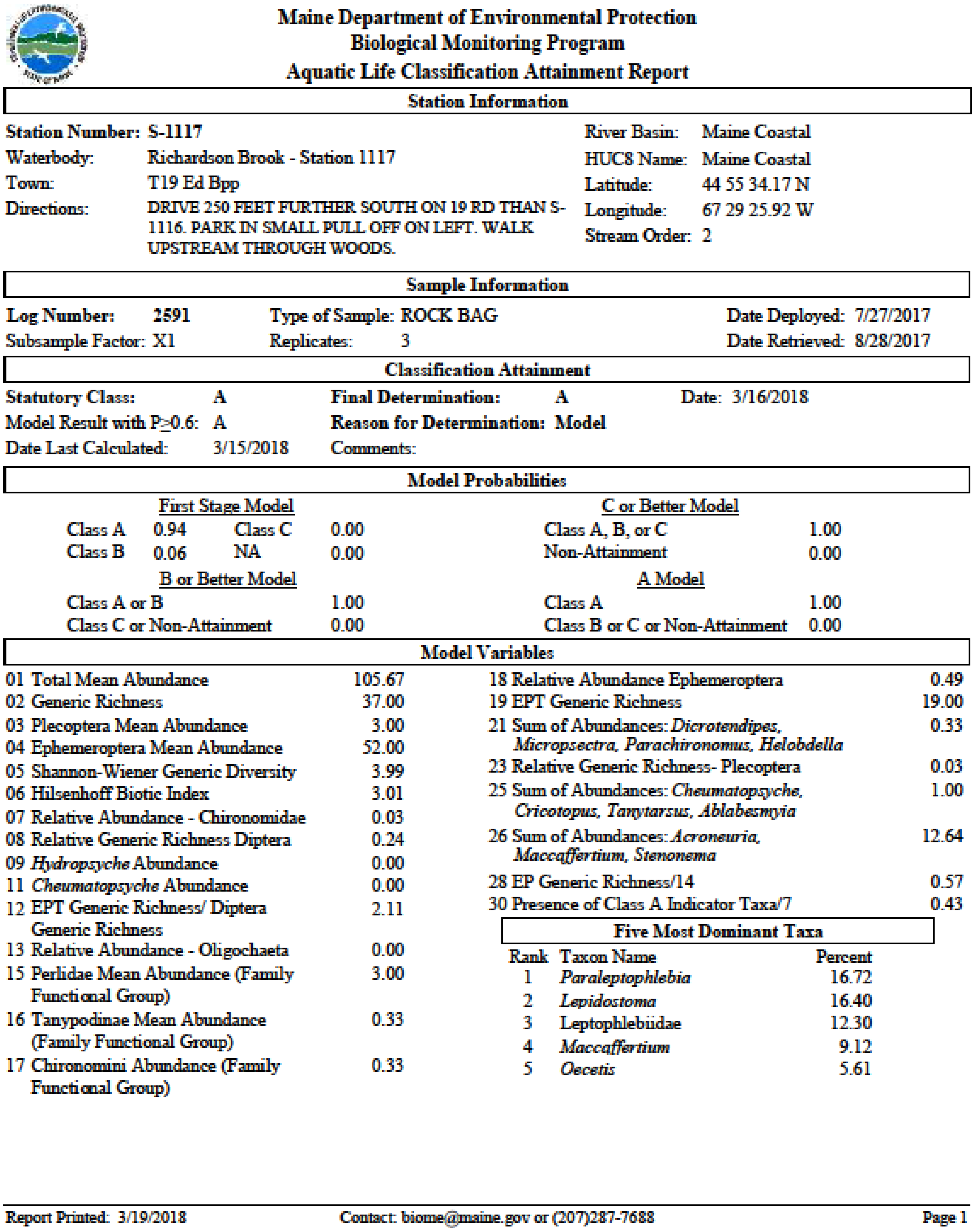
Maine Department of Environmental Protection
Biological Monitoring Program
Aquatic Life Taxonomic Inventory Report

Station Number: S-1115 Waterbody: Creamer Brook - Station 1115 Town: T19 Ed Bpp

Log Number: 2589 Subsample Factor: X1 Replicates: 3 Calculated: 3/15/2018

Taxon	Maine Taxonomic Code	Count (Mean of Samplers) Actual	Count (Mean of Samplers) Adjusted	Hilsenhoff Biotic Index	Functional Feeding Group	Relative Abundance % Actual	Relative Abundance % Adjusted
Conchapelopia	09021011004	0.33	0.34	6	PR	0.2	0.2
Meropelopia	09021011010	0.33	0.34		--	0.2	0.2
Cricotopus	09021011037		0.34	7	SH		0.2
Cricotopus bicinctus	09021011037057	0.33			--	0.2	
Orthocladius	09021011050		1.02	6	CG		0.5
Orthocladius annectens	09021011050092	1.00			--	0.5	
Psectrocladius	09021011056		0.34	8	CG		0.2
Psectrocladius simulans	09021011056110	0.33			--	0.2	
Rheocricotopus	09021011057		5.12	6	CG		2.5
Rheocricotopus pauciseta	09021011057111	5.00			--	2.4	
Micropsectra	09021011070	0.33	0.34	7	CG	0.2	0.2
Stempellinella	09021011074		0.34	2	--		0.2
Stempellinella fimbriata	09021011074002	0.33			--	0.2	
Tanytarsus	09021011076	0.33	0.34	6	CF	0.2	0.2
Microtendipes	09021011094	0.67	5.12	6	CF	0.3	2.5
Microtendipes pedellus group	09021011094166	4.00			--	1.9	
Microtendipes rydalensis group	09021011094168	0.33			--	0.2	
Atherix	09021015055	0.33	0.33	2	PR	0.2	0.2
Dubiraphia	09021113064		3.33	6	--		1.6
Dubiraphia quadrinotata	09021113064037	3.33			--	1.6	
Optioservus	09021113067	0.33	0.33	3	SC	0.2	0.2
Promoresia	09021113069		3.00		--		1.5
Promoresia tardella	09021113069052	3.00			--	1.5	
Sperchonopsis	09030107002	0.33	0.33		--	0.2	0.2



Maine Department of Environmental Protection
Biological Monitoring Program
Aquatic Life Classification Attainment Report

Station Information

Station Number:	**S-1117**	River Basin:	Maine Coastal
Waterbody:	Richardson Brook - Station 1117	HUC8 Name:	Maine Coastal
Town:	T19 Ed Bpp	Latitude:	44 55 34.17 N
Directions:	DRIVE 250 FEET FURTHER SOUTH ON 19 RD THAN S-1116. PARK IN SMALL PULL OFF ON LEFT. WALK UPSTREAM THROUGH WOODS.	Longitude:	67 29 25.92 W
		Stream Order:	2

Sample Information

Log Number:	**2591**	Type of Sample:	ROCK BAG	Date Deployed:	7/27/2017
Subsample Factor:	X1	Replicates:	3	Date Retrieved:	8/28/2017

Classification Attainment

Statutory Class:	**A**	**Final Determination:**	**A**	Date:	3/16/2018
Model Result with P≥0.6:	A	**Reason for Determination:**	**Model**		
Date Last Calculated:	3/15/2018	Comments:			

Model Probabilities

First Stage Model

Class A	0.94	Class C	0.00
Class B	0.06	NA	0.00

C or Better Model

Class A, B, or C	1.00
Non-Attainment	0.00

B or Better Model

Class A or B	1.00
Class C or Non-Attainment	0.00

A Model

Class A	1.00
Class B or C or Non-Attainment	0.00

Model Variables

01 Total Mean Abundance	105.67
02 Generic Richness	37.00
03 Plecoptera Mean Abundance	3.00
04 Ephemeroptera Mean Abundance	52.00
05 Shannon-Wiener Generic Diversity	3.99
06 Hilsenhoff Biotic Index	3.01
07 Relative Abundance - Chironomidae	0.03
08 Relative Generic Richness Diptera	0.24
09 *Hydropsyche* Abundance	0.00
11 *Cheumatopsyche* Abundance	0.00
12 EPT Generic Richness/ Diptera Generic Richness	2.11
13 Relative Abundance - Oligochaeta	0.00
15 Perlidae Mean Abundance (Family Functional Group)	3.00
16 Tanypodinae Mean Abundance (Family Functional Group)	0.33
17 Chironomini Abundance (Family Functional Group)	0.33
18 Relative Abundance Ephemeroptera	0.49
19 EPT Generic Richness	19.00
21 Sum of Abundances: *Dicrotendipes, Micropsectra, Parachironomus, Helobdella*	0.33
23 Relative Generic Richness- Plecoptera	0.03
25 Sum of Abundances: *Cheumatopsyche, Cricotopus, Tanytarsus, Ablabesmyia*	1.00
26 Sum of Abundances: *Acroneuria, Maccaffertium, Stenonema*	12.64
28 EP Generic Richness/14	0.57
30 Presence of Class A Indicator Taxa/7	0.43

Five Most Dominant Taxa

Rank	Taxon Name	Percent
1	*Paraleptophlebia*	16.72
2	*Lepidostoma*	16.40
3	Leptophlebiidae	12.30
4	*Maccaffertium*	9.12
5	*Oecetis*	5.61

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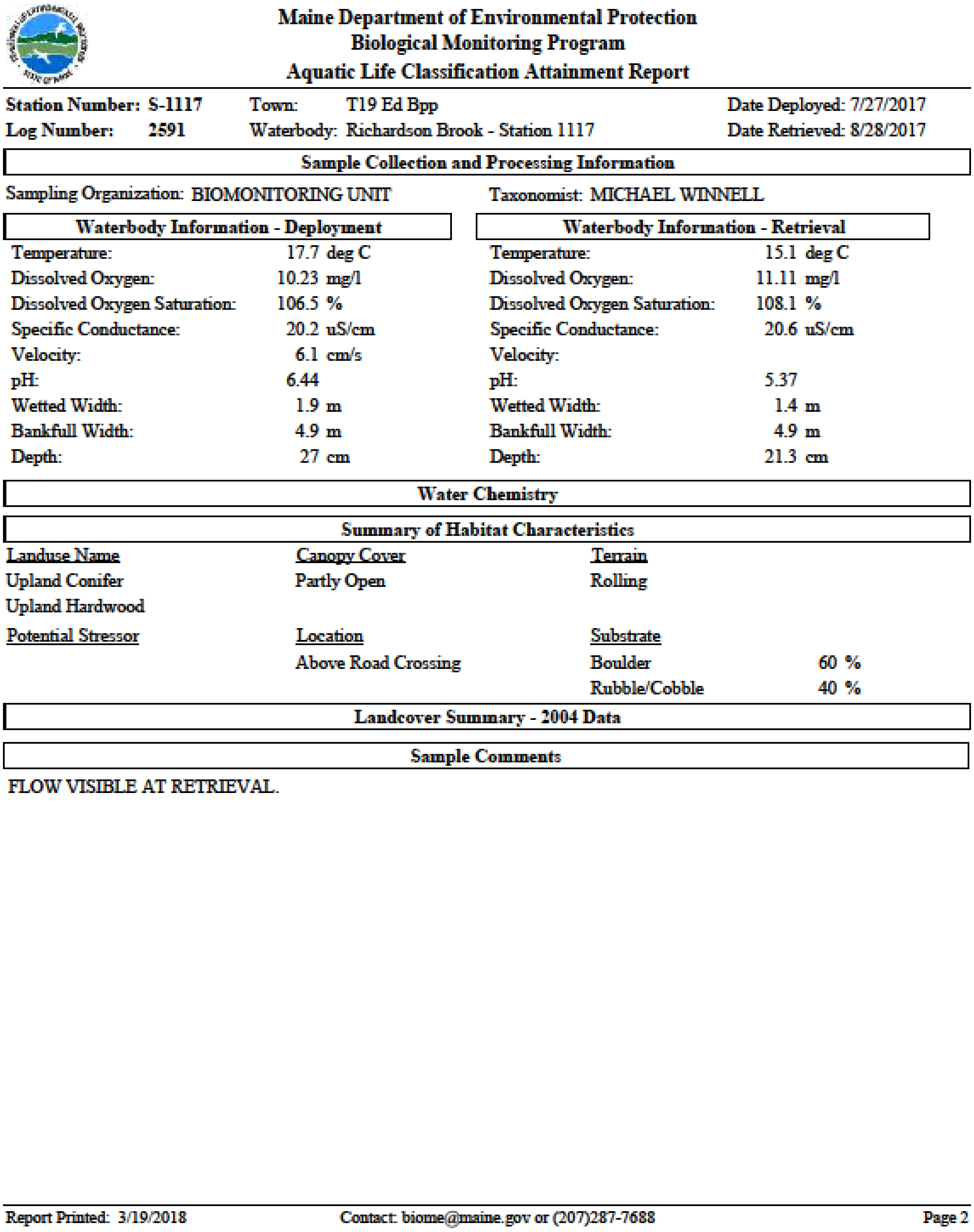

Maine Department of Environmental Protection
Biological Monitoring Program
Aquatic Life Classification Attainment Report

Station Number: S-1117	Town: T19 Ed Bpp		Date Deployed: 7/27/2017
Log Number: 2591	Waterbody: Richardson Brook - Station 1117		Date Retrieved: 8/28/2017

Sample Collection and Processing Information

Sampling Organization: BIOMONITORING UNIT

Taxonomist: MICHAEL WINNELL

Waterbody Information - Deployment		Waterbody Information - Retrieval	
Temperature:	17.7 deg C	Temperature:	15.1 deg C
Dissolved Oxygen:	10.23 mg/l	Dissolved Oxygen:	11.11 mg/l
Dissolved Oxygen Saturation:	106.5 %	Dissolved Oxygen Saturation:	108.1 %
Specific Conductance:	20.2 uS/cm	Specific Conductance:	20.6 uS/cm
Velocity:	6.1 cm/s	Velocity:	
pH:	6.44	pH:	5.37
Wetted Width:	1.9 m	Wetted Width:	1.4 m
Bankfull Width:	4.9 m	Bankfull Width:	4.9 m
Depth:	27 cm	Depth:	21.3 cm

Water Chemistry

Summary of Habitat Characteristics

Landuse Name	Canopy Cover	Terrain	
Upland Conifer	Partly Open	Rolling	
Upland Hardwood			

Potential Stressor	Location	Substrate	
	Above Road Crossing	Boulder	60 %
		Rubble/Cobble	40 %

Landcover Summary - 2004 Data

Sample Comments

FLOW VISIBLE AT RETRIEVAL.

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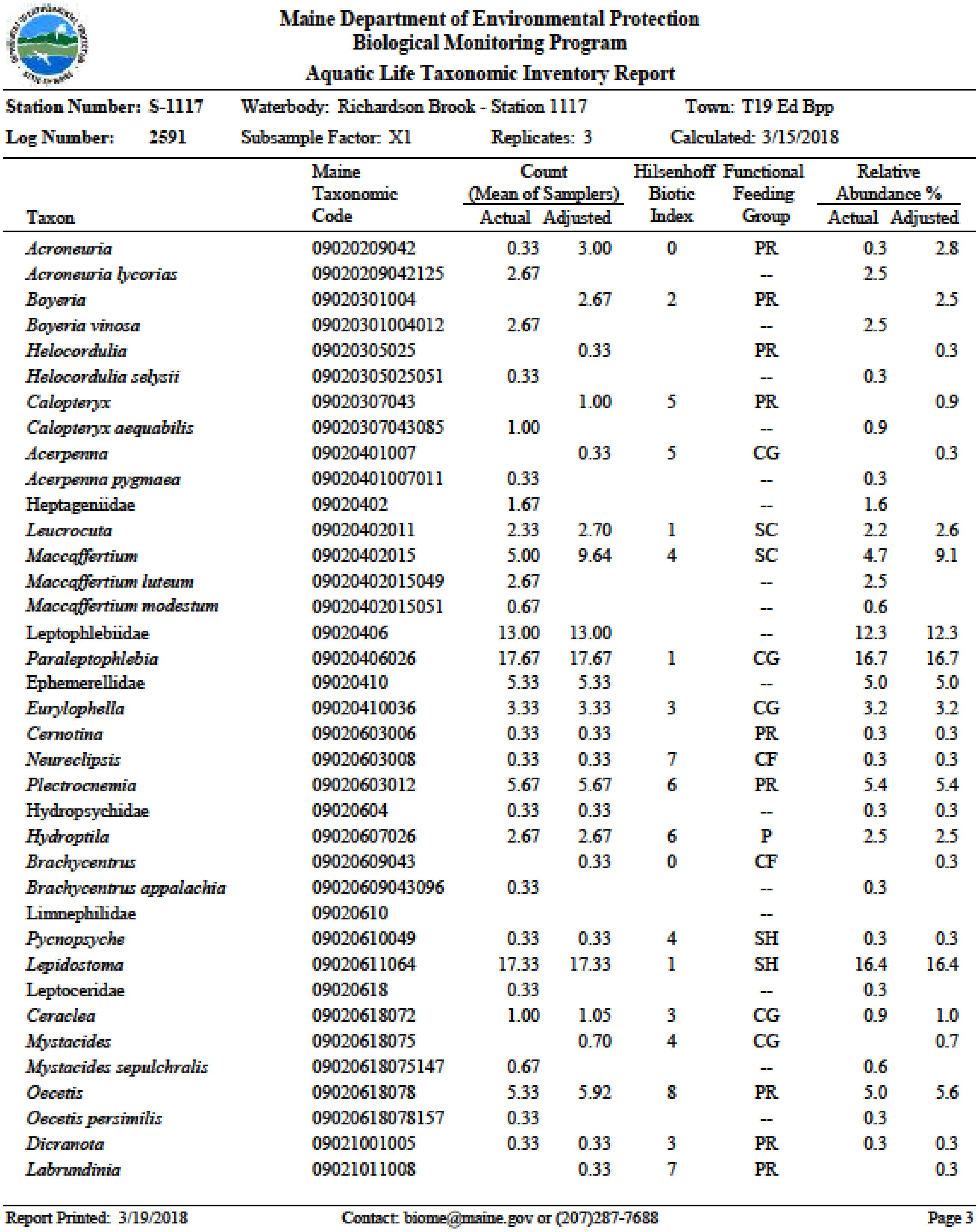

Maine Department of Environmental Protection
Biological Monitoring Program
Aquatic Life Taxonomic Inventory Report

Station Number: S-1117 Waterbody: Richardson Brook - Station 1117 Town: T19 Ed Bpp
Log Number: 2591 Subsample Factor: X1 Replicates: 3 Calculated: 3/15/2018

Taxon	Maine Taxonomic Code	Count (Mean of Samplers)		Hilsenhoff Biotic Index	Functional Feeding Group	Relative Abundance %	
		Actual	Adjusted			Actual	Adjusted
Acroneuria	09020209042	0.33	3.00	0	PR	0.3	2.8
Acroneuria lycorias	09020209042125	2.67			--	2.5	
Boyeria	09020301004		2.67	2	PR		2.5
Boyeria vinosa	09020301004012	2.67			--	2.5	
Helocordulia	09020305025		0.33		PR		0.3
Helocordulia selysii	09020305025051	0.33			--	0.3	
Calopteryx	09020307043		1.00	5	PR		0.9
Calopteryx aequabilis	09020307043085	1.00			--	0.9	
Acerpenna	09020401007		0.33	5	CG		0.3
Acerpenna pygmaea	09020401007011	0.33			--	0.3	
Heptageniidae	09020402	1.67			--	1.6	
Leucrocuta	09020402011	2.33	2.70	1	SC	2.2	2.6
Maccaffertium	09020402015	5.00	9.64	4	SC	4.7	9.1
Maccaffertium luteum	09020402015049	2.67			--	2.5	
Maccaffertium modestum	09020402015051	0.67			--	0.6	
Leptophlebiidae	09020406	13.00	13.00		--	12.3	12.3
Paraleptophlebia	09020406026	17.67	17.67	1	CG	16.7	16.7
Ephemerellidae	09020410	5.33	5.33		--	5.0	5.0
Eurylophella	09020410036	3.33	3.33	3	CG	3.2	3.2
Cernotina	09020603006	0.33	0.33		PR	0.3	0.3
Neureclipsis	09020603008	0.33	0.33	7	CF	0.3	0.3
Plectrocnemia	09020603012	5.67	5.67	6	PR	5.4	5.4
Hydropsychidae	09020604	0.33	0.33		--	0.3	0.3
Hydroptila	09020607026	2.67	2.67	6	P	2.5	2.5
Brachycentrus	09020609043		0.33	0	CF		0.3
Brachycentrus appalachia	09020609043096	0.33			--	0.3	
Limnephilidae	09020610				--		
Pycnopsyche	09020610049	0.33	0.33	4	SH	0.3	0.3
Lepidostoma	09020611064	17.33	17.33	1	SH	16.4	16.4
Leptoceridae	09020618	0.33			--	0.3	
Ceraclea	09020618072	1.00	1.05	3	CG	0.9	1.0
Mystacides	09020618075		0.70	4	CG		0.7
Mystacides sepulchralis	09020618075147	0.67			--	0.6	
Oecetis	09020618078	5.33	5.92	8	PR	5.0	5.6
Oecetis persimilis	09020618078157	0.33			--	0.3	
Dicranota	09021001005	0.33	0.33	3	PR	0.3	0.3
Labrundinia	09021011008		0.33	7	PR		0.3

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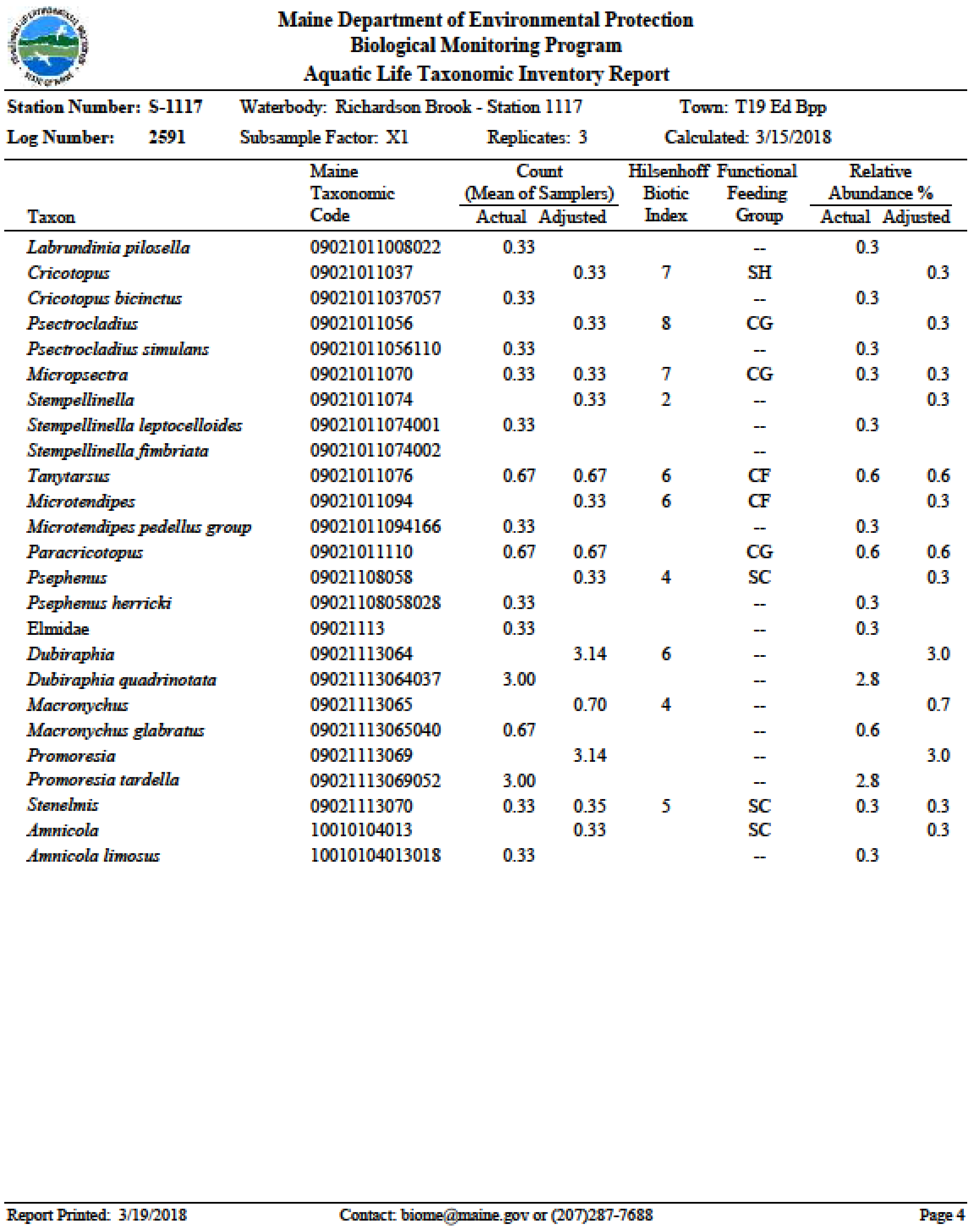

Maine Department of Environmental Protection
Biological Monitoring Program
Aquatic Life Taxonomic Inventory Report

Station Number: S-1117 Waterbody: Richardson Brook - Station 1117 Town: T19 Ed Bpp

Log Number: 2591 Subsample Factor: X1 Replicates: 3 Calculated: 3/15/2018

Taxon	Maine Taxonomic Code	Count (Mean of Samplers) Actual	Count (Mean of Samplers) Adjusted	Hilsenhoff Biotic Index	Functional Feeding Group	Relative Abundance % Actual	Relative Abundance % Adjusted
Labrundinia pilosella	09021011008022	0.33			--	0.3	
Cricotopus	09021011037		0.33	7	SH		0.3
Cricotopus bicinctus	09021011037057	0.33			--	0.3	
Psectrocladius	09021011056		0.33	8	CG		0.3
Psectrocladius simulans	09021011056110	0.33			--	0.3	
Micropsectra	09021011070	0.33	0.33	7	CG	0.3	0.3
Stempellinella	09021011074		0.33	2	--		0.3
Stempellinella leptocelloides	09021011074001	0.33			--	0.3	
Stempellinella fimbriata	09021011074002				--		
Tanytarsus	09021011076	0.67	0.67	6	CF	0.6	0.6
Microtendipes	09021011094		0.33	6	CF		0.3
Microtendipes pedellus group	09021011094166	0.33			--	0.3	
Paracricotopus	09021011110	0.67	0.67		CG	0.6	0.6
Psephenus	09021108058		0.33	4	SC		0.3
Psephenus herricki	09021108058028	0.33			--	0.3	
Elmidae	09021113	0.33			--	0.3	
Dubiraphia	09021113064		3.14	6	--		3.0
Dubiraphia quadrinotata	09021113064037	3.00			--	2.8	
Macronychus	09021113065		0.70	4	--		0.7
Macronychus glabratus	09021113065040	0.67			--	0.6	
Promoresia	09021113069		3.14		--		3.0
Promoresia tardella	09021113069052	3.00			--	2.8	
Stenelmis	09021113070	0.33	0.35	5	SC	0.3	0.3
Amnicola	10010104013		0.33		SC		0.3
Amnicola limosus	10010104013018	0.33			--	0.3	

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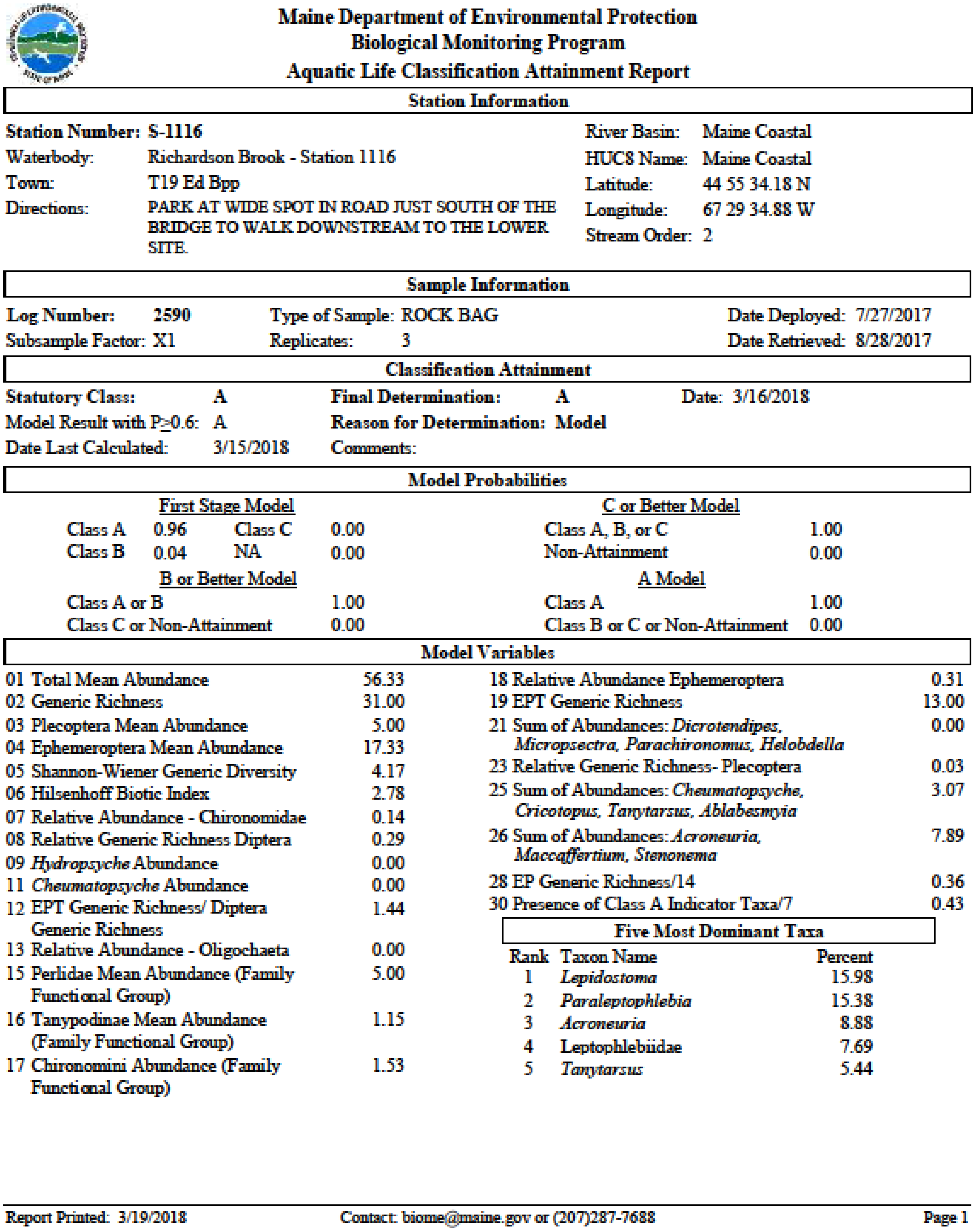

Maine Department of Environmental Protection
Biological Monitoring Program
Aquatic Life Classification Attainment Report

Station Information

Station Number:	**S-1116**	River Basin:	Maine Coastal
Waterbody:	Richardson Brook - Station 1116	HUC8 Name:	Maine Coastal
Town:	T19 Ed Bpp	Latitude:	44 55 34.18 N
Directions:	PARK AT WIDE SPOT IN ROAD JUST SOUTH OF THE BRIDGE TO WALK DOWNSTREAM TO THE LOWER SITE.	Longitude:	67 29 34.88 W
		Stream Order:	2

Sample Information

Log Number:	**2590**	Type of Sample:	ROCK BAG	Date Deployed:	7/27/2017
Subsample Factor:	X1	Replicates:	3	Date Retrieved:	8/28/2017

Classification Attainment

Statutory Class:	**A**	**Final Determination:**	**A**	Date:	3/16/2018
Model Result with $P\geq0.6$:	A	**Reason for Determination:**	**Model**		
Date Last Calculated:	3/15/2018	Comments:			

Model Probabilities

<u>First Stage Model</u>

Class A	0.96	Class C	0.00
Class B	0.04	NA	0.00

<u>C or Better Model</u>

Class A, B, or C	1.00
Non-Attainment	0.00

<u>B or Better Model</u>

Class A or B	1.00
Class C or Non-Attainment	0.00

<u>A Model</u>

Class A	1.00
Class B or C or Non-Attainment	0.00

Model Variables

01 Total Mean Abundance	56.33
02 Generic Richness	31.00
03 Plecoptera Mean Abundance	5.00
04 Ephemeroptera Mean Abundance	17.33
05 Shannon-Wiener Generic Diversity	4.17
06 Hilsenhoff Biotic Index	2.78
07 Relative Abundance - Chironomidae	0.14
08 Relative Generic Richness Diptera	0.29
09 *Hydropsyche* Abundance	0.00
11 *Cheumatopsyche* Abundance	0.00
12 EPT Generic Richness/ Diptera Generic Richness	1.44
13 Relative Abundance - Oligochaeta	0.00
15 Perlidae Mean Abundance (Family Functional Group)	5.00
16 Tanypodinae Mean Abundance (Family Functional Group)	1.15
17 Chironomini Abundance (Family Functional Group)	1.53
18 Relative Abundance Ephemeroptera	0.31
19 EPT Generic Richness	13.00
21 Sum of Abundances: *Dicrotendipes, Micropsectra, Parachironomus, Helobdella*	0.00
23 Relative Generic Richness- Plecoptera	0.03
25 Sum of Abundances: *Cheumatopsyche, Cricotopus, Tanytarsus, Ablabesmyia*	3.07
26 Sum of Abundances: *Acroneuria, Maccaffertium, Stenonema*	7.89
28 EP Generic Richness/14	0.36
30 Presence of Class A Indicator Taxa/7	0.43

Five Most Dominant Taxa

Rank	Taxon Name	Percent
1	*Lepidostoma*	15.98
2	*Paraleptophlebia*	15.38
3	*Acroneuria*	8.88
4	Leptophlebiidae	7.69
5	*Tanytarsus*	5.44

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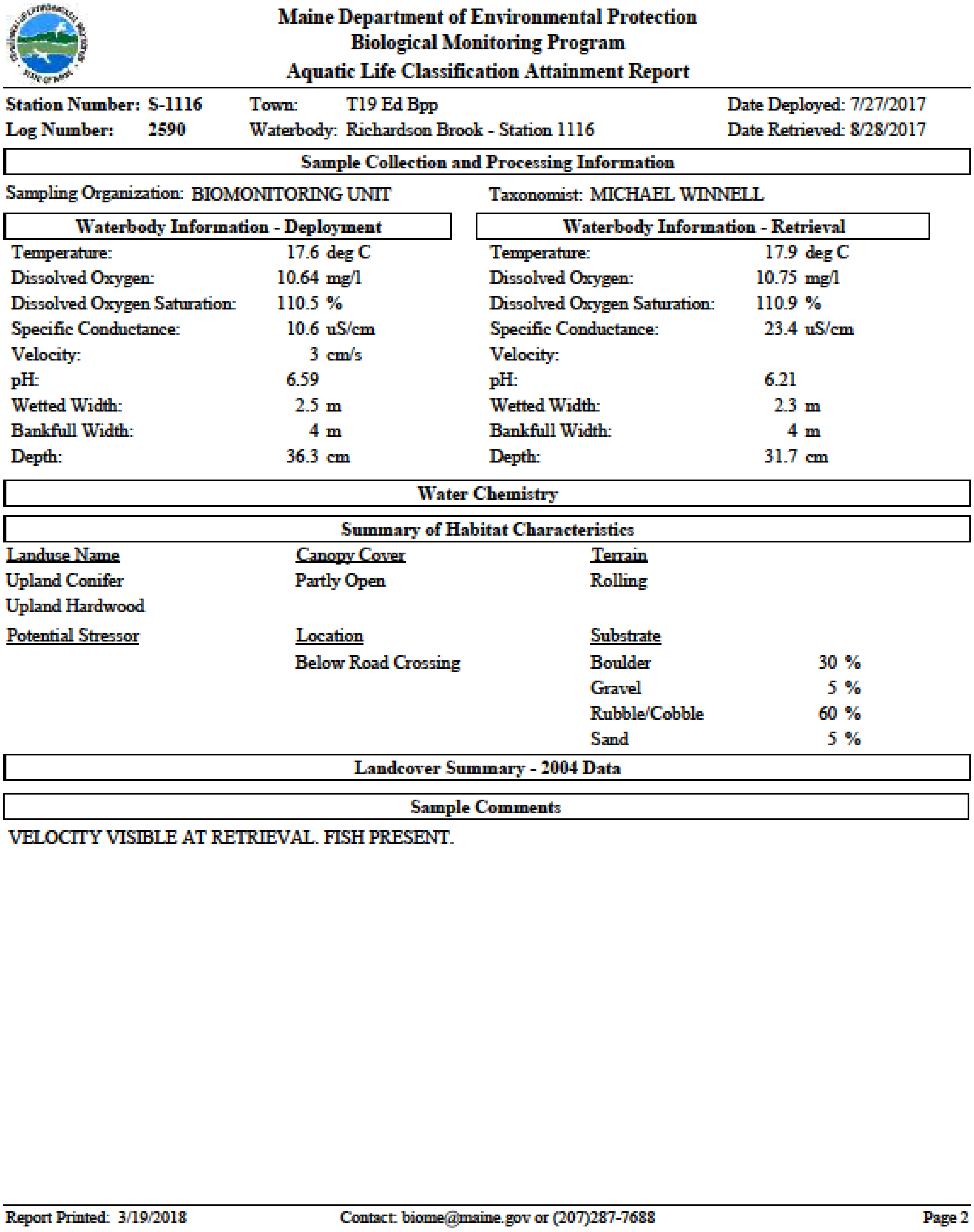

Maine Department of Environmental Protection
Biological Monitoring Program
Aquatic Life Classification Attainment Report

Station Number: S-1116	Town:	T19 Ed Bpp		Date Deployed: 7/27/2017
Log Number: 2590	Waterbody:	Richardson Brook - Station 1116		Date Retrieved: 8/28/2017

Sample Collection and Processing Information

Sampling Organization: BIOMONITORING UNIT Taxonomist: MICHAEL WINNELL

Waterbody Information - Deployment		Waterbody Information - Retrieval	
Temperature:	17.6 deg C	Temperature:	17.9 deg C
Dissolved Oxygen:	10.64 mg/l	Dissolved Oxygen:	10.75 mg/l
Dissolved Oxygen Saturation:	110.5 %	Dissolved Oxygen Saturation:	110.9 %
Specific Conductance:	10.6 uS/cm	Specific Conductance:	23.4 uS/cm
Velocity:	3 cm/s	Velocity:	
pH:	6.59	pH:	6.21
Wetted Width:	2.5 m	Wetted Width:	2.3 m
Bankfull Width:	4 m	Bankfull Width:	4 m
Depth:	36.3 cm	Depth:	31.7 cm

Water Chemistry

Summary of Habitat Characteristics

Landuse Name	Canopy Cover	Terrain
Upland Conifer	Partly Open	Rolling
Upland Hardwood		

Potential Stressor	Location	Substrate	
	Below Road Crossing	Boulder	30 %
		Gravel	5 %
		Rubble/Cobble	60 %
		Sand	5 %

Landcover Summary - 2004 Data

Sample Comments

VELOCITY VISIBLE AT RETRIEVAL. FISH PRESENT.

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Maine Department of Environmental Protection
Biological Monitoring Program
Aquatic Life Taxonomic Inventory Report

Station Number: S-1116 Waterbody: Richardson Brook - Station 1116 Town: T19 Ed Bpp

Log Number: 2590 Subsample Factor: X1 Replicates: 3 Calculated: 3/15/2018

Taxon	Maine Taxonomic Code	Count (Mean of Samplers) Actual	Count (Mean of Samplers) Adjusted	Hilsenhoff Biotic Index	Functional Feeding Group	Relative Abundance % Actual	Relative Abundance % Adjusted
Acroneuria	09020209042	0.33	5.00	0	PR	0.6	8.9
Acroneuria lycorias	09020209042125	4.67			--	8.3	
Aeshnidae	09020301	0.33	0.33		--	0.6	0.6
Boyeria	09020301004	0.33	1.33	2	PR	0.6	2.4
Boyeria vinosa	09020301004012	1.00			--	1.8	
Corduliidae	09020305	0.67	0.67		--	1.2	1.2
Helocordulia	09020305025		0.33		PR		0.6
Helocordulia selysii	09020305025051	0.33			--	0.6	
Calopteryx	09020307043		2.33	5	PR		4.1
Calopteryx aequabilis	09020307043085	1.00			--	1.8	
Calopteryx maculata	09020307043088	1.33			--	2.4	
Heptageniidae	09020402	0.33			--	0.6	
Leucrocuta	09020402011	1.33	1.44	1	SC	2.4	2.6
Maccaffertium	09020402015	2.00	2.89	4	SC	3.6	5.1
Maccaffertium luteum	09020402015049	0.67			--	1.2	
Leptophlebiidae	09020406	4.33	4.33		--	7.7	7.7
Paraleptophlebia	09020406026	8.67	8.67	1	CG	15.4	15.4
Plectrocnemia	09020603012	2.67	2.67	6	PR	4.7	4.7
Brachycentrus	09020609043		0.67	0	CF		1.2
Brachycentrus appalachia	09020609043096	0.67			--	1.2	
Limnephilidae	09020610				--		
Lepidostoma	09020611064	9.00	9.00	1	SH	16.0	16.0
Psilotreta	09020614068	0.67	0.67	0	SC	1.2	1.2
Helicopsyche	09020616070		0.33	3	SC		0.6
Helicopsyche borealis	09020616070137	0.33			--	0.6	
Ceraclea	09020618072	1.00	1.00	3	CG	1.8	1.8
Mystacides	09020618075		1.67	4	CG		3.0
Mystacides sepulchralis	09020618075147	1.67			--	3.0	
Oecetis	09020618078	2.67	3.00	8	PR	4.7	5.3
Oecetis persimilis	09020618078157	0.33			--	0.6	
Chironomidae	09021011	1.00			--	1.8	
Meropelopia	09021011010	0.67	0.77		--	1.2	1.4
Paramerina	09021011013	0.33	0.38		--	0.6	0.7
Tvetenia	09021011065		0.38	5	CG		0.7
Tvetenia paucunca	09021011065114	0.33			--	0.6	
Stempellinella	09021011074		1.53	2	--		2.7
Stempellinella leptocelloides	09021011074001	0.33			--	0.6	

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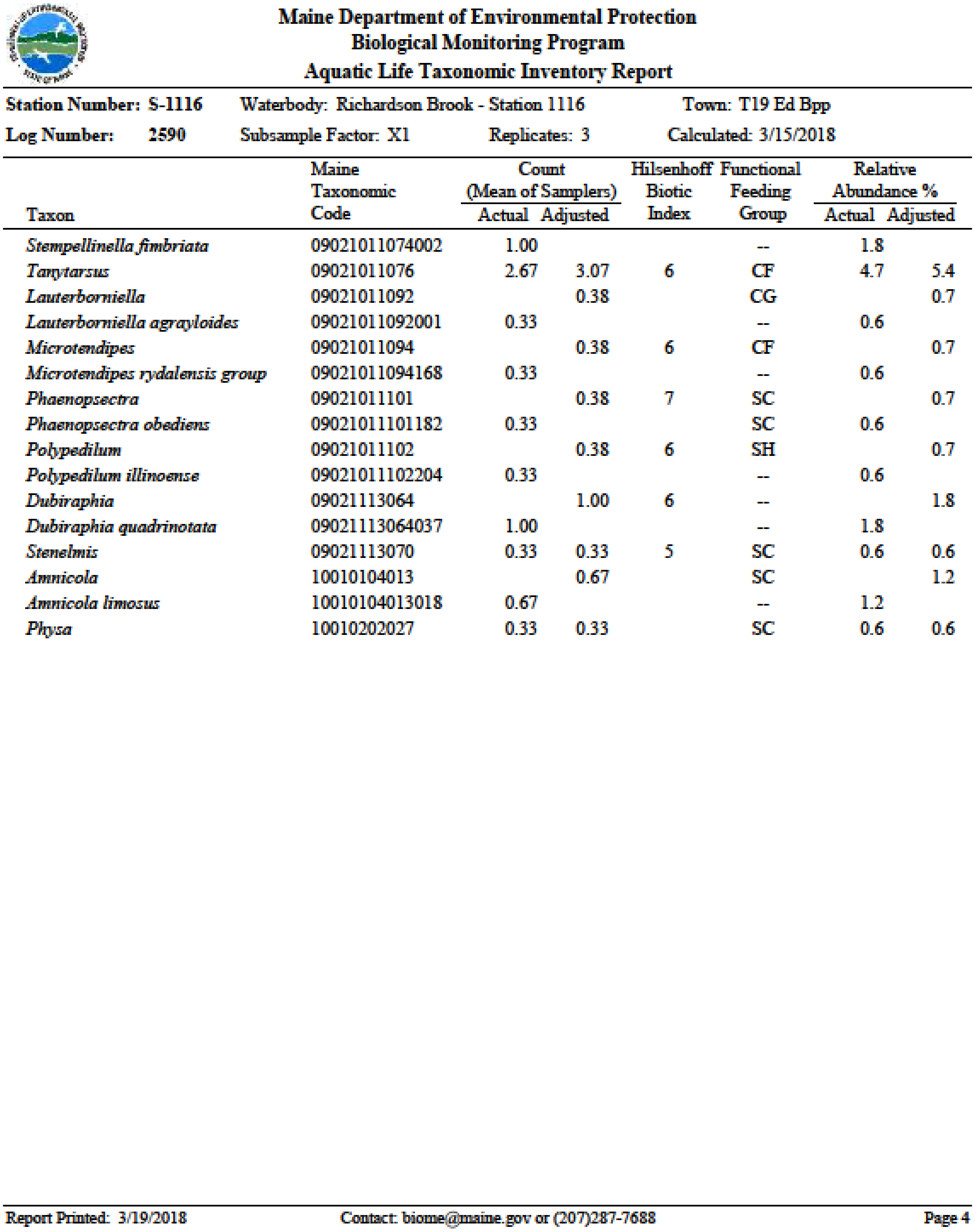

Maine Department of Environmental Protection
Biological Monitoring Program
Aquatic Life Taxonomic Inventory Report

Station Number: S-1116 Waterbody: Richardson Brook - Station 1116 Town: T19 Ed Bpp

Log Number: 2590 Subsample Factor: X1 Replicates: 3 Calculated: 3/15/2018

Taxon	Maine Taxonomic Code	Count (Mean of Samplers)		Hilsenhoff Biotic Index	Functional Feeding Group	Relative Abundance %	
		Actual	Adjusted			Actual	Adjusted
Stempellinella fimbriata	09021011074002	1.00			--	1.8	
Tanytarsus	09021011076	2.67	3.07	6	CF	4.7	5.4
Lauterborniella	09021011092		0.38		CG		0.7
Lauterborniella agrayloides	09021011092001	0.33			--	0.6	
Microtendipes	09021011094		0.38	6	CF		0.7
Microtendipes rydalensis group	09021011094168	0.33			--	0.6	
Phaenopsectra	09021011101		0.38	7	SC		0.7
Phaenopsectra obediens	09021011101182	0.33			SC	0.6	
Polypedilum	09021011102		0.38	6	SH		0.7
Polypedilum illinoense	09021011102204	0.33			--	0.6	
Dubiraphia	09021113064		1.00	6	--		1.8
Dubiraphia quadrinotata	09021113064037	1.00			--	1.8	
Stenelmis	09021113070	0.33	0.33	5	SC	0.6	0.6
Amnicola	10010104013		0.67		SC		1.2
Amnicola limosus	10010104013018	0.67			--	1.2	
Physa	10010202027	0.33	0.33		SC	0.6	0.6

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