Water Quality Survey of Maine Salmon Rivers: The 2015 Field Season, Downeast, the Union & the Aroostook Rivers

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Executive Summary

Atlantic salmon in Maine are a federally listed Endangered Species. Some of Maine's salmon rivers have become too acidic to support naturally reproducing populations of Atlantic salmon. The most obvious and best documented acid rain problems have been identified in Washington County, but some parts of the Penobscot River watershed and Acadia National Park are also affected. A hatchery stocking program using two federal and two private hatcheries is keeping the river-specific salmon populations alive in Maine. Unfortunately, at this time even the survival of the hatchery fish is poor. The Department of Environmental Protection's contribution to Atlantic salmon conservation is water quality monitoring. For the 2015 field season, the study area was expanded from the Penobscot and Downeast salmon rivers to include some small coastal streams in Hancock and Washington County, the Union River in Hancock County, and the upper Aroostook River in Aroostook County. Previous studies have shown that low calcium and alkalinity are more limiting than low pH or high aluminum (Whiting 2014); therefore the 2015 water quality survey targeted calcium and alkalinity. The results show that of the 29 sites investigated in the Downeast salmon rivers only two had enough calcium (Ca ≥ 4 mg/L) to prevent losses of juvenile salmon due to water quality alone (Lanpher and Thirty-five Brook). These sites are already used for salmon stocking. Adequate calcium concentrations were found at only one of four sites among the coastal brook trout streams (Englishman River), three of five sites on the Union River (West Branch, East Branch and the Middle Branch), and at all four headwaters of the Aroostook River. The 2015 data were combined with previous studies and the implications for salmon and other fisheries are discussed.

Introduction

Acid rain is still a problem in Maine due the decadal lags between the 1990 Clean Air Act Amendments, incremental implementation of emission controls, gradual improvements in air quality, slow recovery of impaired soils, and subsequent recovery of impacted surface waters (Lawrence et al. 2012, Fernandez et al. 2008). Streams recover last because as water flows downhill through soils, soil and forest uptake currently reduces dissolved base cations. At the bottom of the slope, the streams are last in line for nutrients. An additional problem is that forest harvesting impacts soils in the same way that acid rain does, through the loss of calcium and other base cations. Forest harvests can acidify surface waters and delay recovery (Miller 2011, Hornbeck et al. 1990). At the University of Maine experimental watershed on Lead Mountain (in the upper Narraguagus River watershed), the control stream East Bear Brook has continued to acidify through 2009 (Fernandez et al. 2008, Stephen A. Norton personal communication). There appears to have been a minor recovery in calcium concentrations from 2010 through 2014 (the last year with published data).

Not long ago, Maine had a naturally sustained population of sea-run Atlantic salmon. In the early 1980s a small population of wild salmon was reported in Downeast Maine (Haines & Akielaszek 1984). This was lost through gradual population declines in the 1990's (Miller 2006). Acid rain has always been one of the chief suspects in the decline (NAS 2004). The loss of salmon Downeast happened after improvements in the Clean Air Act of 1990 and incremental reductions in acid rain but coincided with recovering soils and new intensive forest cuts. Streams and even the main stems of large rivers became episodically or even chronically acidified. This put acid sensitive species at risk. An experimental liming study by Maine Department of Environmental Protection (DEP) has shown that Atlantic salmon and other aquatic organisms respond well to calcium carbonate additions (Whiting 2014).

Maine Atlantic salmon are currently sustained by a hatchery stocking program involving two federal hatcheries (Craig Brook and Green Lake National Fish Hatcheries) and two private hatcheries owned by the Downeast Salmon Federation (at Columbia Falls and East Machias). These stocking programs are keeping the species alive but have not been successful in restoring self-sustaining salmon runs. For instance, in 2004 almost 4 million fry and smolts were stocked in Maine rivers but the return was only 1000 adults. Most of the returns were in the Penobscot, with an overall return rate of 0.03% (Keliher 2004). For comparison, the smolt-to-adult return conservation goal for the Nova Scotia Southern Upland endangered salmon program is ≥ 5% (Amiro & Gibson 2007). In Maine, the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Office estimates that approximately 1000 returning adults are thought to be the minimum necessary to sustain just the Downeast distinct population segment

(NOAA 2009). In order to meet this goal, salmon must be stocked into the best quality waters; and if there is not enough, then water quality must be modified through liming so that conservation goals can be met.

In order to support the salmon recovery program, Maine DEP has done extensive water quality surveys. A volunteer-based survey of the Downeast area lasted from 1999 through 2004. In 2009-2010, DEP staff sampled some tributaries that were of interest to Maine Department of Marine Resources (DMR) in the upper Penobscot, and to Maine Department of Inland Fisheries and Wildlife (DIFW) and the Eastern Brook Trout Joint Venture (EBTJV) program that were located in the upper Kennebec and Aroostook Rivers watersheds. This historical data will be discussed in the Summary section of this report. In 2015 a water quality survey was designed to fill in some knowledge gaps Downeast, in the Union River watershed, some small coastal streams that support native sea-run brook trout, and some Atlantic salmon sites in the upper Aroostook River. This water quality information is used to evaluate the suitability for stocking historical salmon rivers and for suitability for sea-run brook trout. In addition to the federal Endangered listing for sea-run Atlantic salmon, sea-run brook trout are listed as Threatened by the state of Maine.

Sample sites were selected in consultation with the principal stakeholders, including the US Fish and Wildlife Service (USFWS), DMR, DIFW, the Downeast Salmon Federation (DSF), and Frenchman Bay Partnership.

Methods

Site Selection

Twenty-nine sites were selected from the five Downeast salmon river watersheds (Dennys, East Machias, Machias, Pleasant and Narraguagus Rivers) (Table 1). Most sites were chosen at the request of DMR to fill data gaps. The four small coastal streams were sampled to evaluate suitability for extant sea-run brook trout populations. Flanders Stream was also of interest because of a recent fish passage project at the Thorne Road crossing and an on-going alewife restoration. These coastal streams were requested by DIFW which coordinates the many stakeholders of the Maine EBTJV project. Flanders was also requested by the Frenchman Bay Partnership. The four upper Aroostook River watershed sites were included at the request of DMR. The five Union River sites were chosen by DEP for their significance to the USFWS fish hatchery at Green Lake and for the DSF which is participating in local fishery management decisions and the relicensing of the Union River dams.

Table 1. *List of 2015 sample sites for the DEP Salmon Rivers program. Samples were taken during summer baseflow to characterize the river during the most stable water chemistry (generally the*

highest pH, alkalinity and calcium values of the year). GPS locations are given in NAD83. The river watershed and town are also indicated. The small coastal streams discharge directly to the ocean, so project names are indicated in the place of a river watershed. The project names are Eastern Brook Trout Joint Venture (EBTJV) and Frenchman Bay Partners (FBP).

Stream Name	Date sampled	Stream conditions	Easting	Northing	River/Project	Town
Preston, Stoddard Rip Rd	07/21/15	low baseflow	634025	4976093	Dennys	Cathance Twp, NO 14 Twp
Curry, Stoddard Rip Rd	07/21/15	low baseflow	633887	4977700	Dennys	Cathance Twp, NO 14 Twp
Dead, above Rt 191	07/21/15	low baseflow	624906	4984747	Dennys	Cooper
Dennys R, above Gilman Falls	07/21/15	low baseflow	630340	4982716	Dennys	Cathance Twp, NO 14 Twp
Venture, Venture Brook Rd	07/21/15	low baseflow	635124	4973667	Dennys	Edmunds Twp
Cathance Str, above Rt 86	07/21/15	low baseflow	632864	4971630	Dennys	Marion
Creamer	07/22/15	low baseflow	618064	4981355	E Machias	T19 ED BPP
Richardson at 19 Rd	07/22/15	low baseflow	618984	4975883	E Machias	T19 ED BPP
Harmon above birch Hill Rd	07/21/15	low baseflow	608961	4984991	E Machias	Crawford
Seavey- Long Lake Str	07/22/15	low baseflow	612816	4975602	E Machias	T19 ED BPP
Barrows, Love Lake Rd	07/22/15	low baseflow	617193	4985591	E Machias	Crawford
Scott Brook, below Rt 192	07/22/15	low baseflow	613218	4963533	E Machias	Northfield
Chase Mill Str, Gardner Lake outlet	08/05/15	low baseflow	629690	4957124	E Machias	East Machias
W Branch, Machias at 39 Rd	08/06/15	low baseflow	574416	4986780	Machias	T 35 MD
Lanpher, 58 Rd	08/06/15	low baseflow	593759	4987231	Machias	T 37 MD BPP
Fletcher	08/06/15	low baseflow	588611	4986680	Machias	T 36 MD BPP
New Stream, Guptil Rd	08/05/15	low baseflow	605077	4972550	Machias	Wesley
Kerwin, 52 Rd	08/06/15	low baseflow	589062	4982868	Machias	T 36 MD BPP
Machias R at Wigwams	08/06/15	low baseflow	598816	4964651	Machias	T 25 MD BPP
Northeast, below Rt 9	09/02/15	low baseflow	581306	4969432	Pleasant	Devereaux Twp
Colonel, at irrigation pond	09/02/15	very low	584929	4957925	Pleasant	T 18 MD BPP
Canoe, W Side Rd	09/02/15	low baseflow	579948	4966822	Pleasant	Beddinton
E Little River, above Cross Rd	08/06/15	low baseflow	600073	4950200	Pleasant	Columbia Falls
Pleasant R Lake outlet	09/15/15	normal baseflow	581994	4965165	Pleasant	Beddington
Great Falls Branch, below Rt 193	09/02/15	normal baseflow	581748	4951832	Narraguagus	Deblois
Thirtyfive Brook, Allen Pond Rd	09/02/15	low baseflow	570939	4978404	Narraguagus	T 34 MD
Rocky, 45 Rd	09/02/15	almost dry	572735	4971811	Narraguagus	Deveraux Twp
Humpback, CCC Rd	09/02/15	low baseflow	571457	4969409	Narraguagus	T 28 MD
Gould, CCC Rd	09/02/15	low baseflow	570515	4973106	Narraguagus	T 28 MD
Card Mill Stream	08/05/15	low baseflow	564111	4935649	EBTJV	Franklin
Flanders Stream, below Thorne Rd	08/05/15	low baseflow	567194	4928322	FBP	Sullivan
Whitten Parritt Str, above Rt 1	08/05/15	low baseflow	580064	4928826	EBTJV	Steuben
Englishman River, Roque Bluffs Rd	08/05/15	normal baseflow	620931	4945241	EBTJV	Roque Bluffs
Big Machias R, Pinkham Rd	09/03/15	normal baseflow	525681	5157047	Aroostook	T 11 R 7 WELS
Munsungan R, Libby Pinnacle	09/03/15	normal baseflow	511815	5133028	Aroostook	T 8 R 9 WELS
Aroostook R, boat landing Oxbow Rd	09/03/15	normal baseflow	534500	5141498	Aroostook	Oxbow Plant.
Mooseleuk R, Pinkham Rd	09/03/15	normal baseflow	515992	5141092	Aroostook	T 9 R 8 WELS
W Branch Union, Tannery Loop Rd	09/15/14	normal baseflow	549651	4965633	Union	Amherst
Middle Branch Union R, above Rt 9	09/15/15	normal baseflow	555679	4967800	Union	Aurora
East Branch Union R, below Rt 179	09/15/15	normal baseflow	553648	4955310	Union	Mariaville
Branch Lake outlet	09/15/15	normal baseflow	539263	4935036	Union	Ellsworth
Green Lake outlet	09/15/15	normal baseflow	544039	4941558	Union	Ellsworth

Water Quality Parameters

Due to the large number of sample sites, water quality samples were taken only once in 2015. Samples were taken during baseflow conditions, which was defined as at or below normal seasonal flow and not within seven days of the last major rain storm of 1.0 inch or more in 48 hours. Summer baseflow water chemistry is not as variable as storm water sampling and generally represents the high values for the year for pH, calcium,

and alkalinity. Water pH and temperature were measured *in situ* with a YSI EcoSense 100 pH meter. The meter calibrations were performed at the beginning of each field trip using pH 4.00 and 7.00 buffers. The pH probe performance was evaluated through calibration slope, efficiency, and response time. The probes were replaced as needed (at least once a year). Grab samples were analyzed for calcium and alkalinity by the Maine Health and Environmental Testing Laboratory (HETL) in Augusta. Aluminum speciation was done in the past and included total Al, total dissolved Al, organic Al and exchangeable (also known as ionic or monomeric) Al (Alx). The presence of ionic aluminum in streams is an indicator of acidification of soils by acid rain (Lawrence et al. 2007). Alx is also one of the key factors in fish toxicity. However, since there is no longer a state-certified laboratory that can do this analysis, aluminum speciation was deleted this year.

Evaluation of Results

Water quality was evaluated using published threshold values for pH, alkalinity, and calcium (Table 2). The pH value was chosen based on the experience of biologists who were liming Norwegian rivers to restore commercial Atlantic salmon runs (Staurnes et al. 1995). They started with a goal of pH 6.0 but had to increase it to 6.5 to prevent unacceptable losses of young fish. The calcium thresholds were chosen from different sources for different fish species and life stages. In the Adirondack Mountains, NY, lakes with less than 0.6 mg calcium/L are fishless (Driscoll et al. 2003). Fisheries of interest to New York state include bass, walleye, pickerel, perch and other species that are extremely pH tolerant but are considered to be invasive aliens in Maine. For native species, the DEP liming study determined that the fishless sites had less than 1.0 mg calcium/L (below the detection limit) while the brook trout-only sites had more (range ND to 2.1 mg/L, Whiting 2014). For evaluating the suitability of surface waters to support salmonids, calcium should be greater than 2.5 mg/L to avoid sub-lethal pathologies and to support brook trout reproduction (Danner 2004). In order to avoid large losses of fry due to water quality alone, calcium must be at least 4 mg/L (Danner 2004). Some authors insist the value should be closer to 5 mg/L for brook trout and salmon (Sayer et al. 1993, Brockson et al. 1992). The lower value was chosen for Downeast Maine because there were so few sites that met even the lower standard. In addition to the bare minimum, brook trout benefit from calcium concentrations up to 8 mg/L (Gloss et al. 1989). Aluminum must be as low as possible (Staurnes et al. 1995). For Atlantic salmon, Alx must be below 1.0 umol/L (27 ug/L) (Kroglund 2007). However, aluminum was not measured this year. Alkalinity must be 10 mg/L or greater in order for brook trout to have positive recruitment in the wild (Petty et al. 2005). An alkalinity of 20 mg/L is considered to be ideal for fish hatchery production of Atlantic salmon (Haines et al. 2003). Our target fish species for restoration projects are given in Table 3.

Table 2. *Proposed thresholds for pH, calcium, exchangeable aluminum (Alx) and alkalinity needed to support salmonids, are given below with references. Ambient water quality has to meet these thresholds in order to avoid losses of fish due to water quality alone. In general, the other anadromous fish have the same thresholds as the salmonids. Calcium concentrations of at least 1.0 mg/L separate brook trout-only streams from streams that are fishless, at least 2.5 mg/L to avoid sub-lethal pathologies and to support reproduction in brook trout, and at least 4 mg/L to maximize the survival of salmonid fry. An alkalinity of at least 10 mg/L was found to be necessary to have positive recruitment of brook trout in West Virginia streams.*

Analysis	Threshold	Species	Source
pH	≥ 6.5	Atlantic salmon	Staurnes et al 1995
Calcium	> 1.0 mg/L	Native species	This paper
Calcium	> 2.5 mg/L	Brook trout	Danner 2014
Calcium	≥ 4 mg/L	Brook trout	Danner 2014
Alx	< 27 ug/L	All fish species	Kroglund et al 2002
Alkalinity	≥ 10 mg/L	Brook Trout	Petty et al 2005

Table 3. *Species of interest to fisheries managers, such as the US Fish and Wildlife Service (USFWS), Maine Department of Inland Fisheries and Wildlife (DIFW), Maine Department of Marine Resources, Downeast Salmon Federation, and the Frenchman Bay Partners. The state levels of concern range from 1-3, respectively from the most to least. For instance, sea-run brook trout populations are in category 3, the lowest level of concern (they still have healthy populations but are greatly diminished from historical levels). The water quality goals for anadromous fish are the same as for Atlantic salmon (Brocksen et al. 1992)*

	Status - Concern Level (rank 1-3)	
Species	and Listing Agency	
Alewife	2	ME - DIFW
Alewife	Species of Concern	NOAA
Atlantic Salmon	Endangered	USFWS
Blueback Herring	1	ME - DIFW
Blueback Herring	Species of Concern	NOAA
Brook Trout	3	ME - DIFW
Eel	Special Concern	ME - DIFW
Rainbow Smelt	1	ME - DIFW
Rainbow Smelt	Species of Concern	NOAA
Sea-run Brook Trout	Special Concern	ME - DIFW
Shad	1	ME - DIFW

Results and Discussion

1. The Downeast Salmon Rivers

Twenty-nine samples were taken from all five of the official Downeast salmon river watersheds (Table 3). The pH values were good overall, mostly near 6.0 and above. The exceptions were Scott Brook and Northeast Brook with pH in the 5's. Lanpher and East Little River stood out as being slightly alkaline. We used to think of acid rain in terms of pH averages. For episodically acidified streams it is the lowest pH, not the baseflow pH, that is important. The issue is similar to dissolved oxygen (DO) in that we are generally not concerned about the daily high values, and maybe not even the daily means. Low DO is often limiting for aquatic life but the low values are hard to observe. Before the advent of automated loggers, grab samples were a crude estimate of DO problems. So, low pH is generally the limiting factor (no lower than pH 6.5 for Atlantic salmon) but the daily and seasonal variation is generally unknown unless there are good logger records. When sonde records became available for Downeast streams in the early 2000s, they revived interest in acid rain. However, during the DEP liming project (2009-2014), it was determined that calcium concentrations were more limiting than pH, and that calcium was a better indicator of fish diversity and abundance (Whiting 2014). Low pH is probably a useful indicator for fish health, especially of aluminum toxicity when pH is below 6.0 (Muniz & Levistad 1980); but low pH is not an easily obtained field measurement.

Calcium ranged from below detection limit at Colonel Brook (< 1.0 mg/L) to 5.4 mg/L at Lanpher Brook. Only Colonel Brook failed to meet the 1.0 mg/L threshold. Of 29 streams, only two, Lanpher and Thirty-five Brook stand out as having 4 mg calcium/L or better. East Little River is close at 3.8 mg calcium/L. All streams with less than this are vulnerable to losing young fish due to inadequate calcium nutrition. Only seven sites have calcium that exceeds 2.5 mg/L. That means that almost 76% of the Downeast salmon watershed samples have inadequate calcium to maintain brook trout (our most acid tolerant native stream species) in a hatchery and fed with nutritionally-balanced feed (Danner 2004). The Phillips Hatchery successfully mitigated their acidity – low calcium problem by putting calcium chloride flakes in the bottom of their raceways. Other Maine hatcheries with the same problem were successfully treated with limestone sand. Hatchery calcium was maintained at 30 mg/L (Danner 2004) until the Phillips Hatchery was closed due to state budget cuts. Streams with calcium less than 2.5 mg/L might be able to sustain low populations of wild fish in spite of sub-lethal pathologies and catastrophic losses of egg viability (Danner un-published ms.) as long as some fish and eggs survive. The long-term prospects for population viability, however, are poor.

The alkalinity data generally reflects the calcium results. Alkalinity and calcium are linearly related (r-square = 0.82). An alkalinity of 10 mg/L (about 3 mg calcium/L) is a threshold given for sustaining brook trout in the wild. The ideal alkalinity for a salmon hatchery is 20 mg/L, which is about 5.5 mg calcium/L.

Table 3. *Water quality results for 2015 field season. The pH and water temperature were measured in the field. The Alkalinity and Calcium lab results were provided by HETL. Water temperatures are given in degrees C. The official Downeast salmon rivers are the Dennys, East Machias, Machias, Pleasant, and Narraguagus Rivers.*

Stream Name	Date sampled	Stream conditions	River/Project	field pH	Summer Temp	Alkalinity mg/L	Calcium mg/L
Preston, Stoddard Rip Rd	07/21/15	low baseflow	Dennys	6.18	20.3	6	1.9
Curry, Stoddard Rip Rd	07/21/15	low baseflow	Dennys	6.28	19.1	6	2
Dead, above Rt 191	07/21/15	low baseflow	Dennys	6.53	20.4	6	2.3
Dennys R, above Gilman Falls	07/21/15	low baseflow	Dennys	6.72	21.5	5	2
Venture, Venture Brook Rd	07/21/15	low baseflow	Dennys	5.95	18	4	1.5
Cathance Str, above Rt 86	07/21/15	low baseflow	Dennys	6.56	19.9	5	1.3
Creamer	07/22/15	low baseflow	E Machias	5.99	20.4	4	1.5
Richardson at 19 Rd	07/22/15	low baseflow	E Machias	6.58	18.7	3	1.2
Harmon above birch Hill Rd	07/21/15	low baseflow	E Machias	6.38	17.6	9	2.7
Seavey- Long Lake Str	07/22/15	low baseflow	E Machias	6.62	23.1	3	1.3
Barrows, Love Lake Rd	07/22/15	low baseflow	E Machias	6.63	18.9	8	2.4
Scott Brook, below Rt 192	07/22/15	low baseflow	E Machias	5.44	24.3	4	2
Chase Mill Str, Gardner Lake outlet	08/05/15	low baseflow	E Machias	6.83	23.6	5	1.5
W Branch, Machias at 39 Rd	08/06/15	low baseflow	Machias	6.95	23.9	6	1.6
Lanpher, 58 Rd	08/06/15	low baseflow	Machias	7.14	23.5	18	5.4
Fletcher	08/06/15	low baseflow	Machias	6.8	21.3	11	2.6
New Stream, Guptil Rd	08/05/15	low baseflow	Machias	6.67	21.9	6	2.5
Kerwin, 52 Rd	08/06/15	low baseflow	Machias	6.58	20.4	7	1.5
Machias R at Wigwams	08/06/15	low baseflow	Machias	6.76	21.9	7	1.9
Northeast, below Rt 9	09/02/15	low baseflow	Pleasant	5.12	18	2	1.7
Colonel, at irrigation pond	09/02/15	very low	Pleasant	6.14	18	3	<1
Canoe, W Side Rd	09/02/15	low baseflow	Pleasant	6.32	18.9	4	1.6
E Little River, above Cross Rd	08/06/15	low baseflow	Pleasant	7.25	18	20	3.8
Pleasant R Lake outlet	09/15/15	normal baseflow	Pleasant	6.33	19.3	3	1.2
Great Falls Branch, below Rt 193	09/02/15	normal baseflow	Narraguagus	6.31	17.6	9	2.2
Thirtyfive Brook, Allen Pond Rd	09/02/15	low baseflow	Narraguagus	6.58	20.7	12	4.2
Rocky, 45 Rd	09/02/15	almost dry	Narraguagus	6.14	15.5	6	1.4
Humpback, CCC Rd	09/02/15	low baseflow	Narraguagus	5.99	21.6	10	2.7
Gould, CCC Rd	09/02/15	low baseflow	Narraguagus	6.84	19.1	20	2.8
Card Mill Stream	08/05/15	low baseflow	EBTJV	6.55	21.9	6	1.5
Flanders Stream, below Thorne Rd	08/05/15	low baseflow	FBP	6.55	21.4	7	1.9
Whitten Parritt Str, above Rt 1	08/05/15	low baseflow	EBTJV	6.23	20.6	6	1.8
Englishman River, Roque Bluffs Rd	08/05/15	normal baseflow	EBTJV	7.04	20.6	27	6.4
Big Machias R, Pinkham Rd	09/03/15	normal baseflow	Aroostook	7.54	22	23	6.2
Munsungan R, Libby Pinnacle	09/03/15	normal baseflow	Aroostook	7.62	22.4	22	6.9
Aroostook R, boat landing Oxbow Rd	09/03/15	normal baseflow	Aroostook	7.65	23.9	23	6.5
Mooseleuk R, Pinkham Rd	09/03/15	normal baseflow	Aroostook	7.79	22.5	23	7.2
W Branch Union, Tannery Loop Rd	09/15/14	normal baseflow	Union	7.08	17.6	10	3.8
Middle Branch Union R, above Rt 9	09/15/15	normal baseflow	Union	6.47	17.1	11	4
East Branch Union R, below Rt 179	09/15/15	normal baseflow	Union	6.45	19.6	10	3.4
Branch Lake outlet	09/15/15	normal baseflow	Union	6.64	22.2	4	1.6
Green Lake outlet	09/15/15	normal baseflow	Union	6.93	22.7	5	1.6

Because almost all of these sites have fish, it is clear that adult wild fish can survive at low calcium concentrations between 2-2.5 mg/L. Wild fish can move around and exploit different parts of the watershed even if conditions there are stressful in the long term. Hatchery fish and captive fish in an experimental tank do not have the option of moving to better conditions. Each of the Downeast salmon rivers has some relatively

high calcium refugia. It is always difficult to specify meaningful thresholds especially where pH, calcium, aluminum, and alkalinity are highly variable, interrelated, and interact (Brown 1982). Fish species that are currently found in Downeast watersheds include Atlantic salmon, alewife, blacknose dace, blueback herring, brook trout, brown bullhead, creek chub, common shiner, American eel, fallfish, chain pickerel, largemouth bass, pumpkinseed sunfish, sea lamprey, smallmouth bass, and white sucker. Atlantic salmon and slimy sculpin are especially sensitive to acid rain issues and are among the first species to be lost (Jenkins et al. 2005, Lien et al. 1996). Fish that used to be seen that are now rare or not seen at all are threespine and ninespine stickleback and slimy sculpin (DMR unpublished e-fishing data). Atlantic salmon would not be present in these streams if they were not stocked. Crayfish are almost never found in e-fishing results from Downeast Maine but are common in Hancock County (DMR unpublished e-fishing data). Crayfish, snails, and clams have especially high calcium requirements (Økland & Økland 1986) and Hancock County generally has slightly better water chemistry.

No new potential salmon stocking areas were identified in 2015 in the official five rivers. Because most of these sites have good habitat and cold water, and the pH remains moderate, the main limiting factor appears to be calcium. Those sites with otherwise good water quality could be limed. Our experience with liming was positive. In Dead Stream, we began with 0.0 salmon per habitat unit (100 m^2 of rocky riffles) and saw it increased to 18 parr per unit in three years when stocked and limed (Whiting 2014). In 1982, at a time when all the fish were wild, this stream had 45 salmon fry and 21 parr per habitat unit (Trial & Stanley 1984). So the liming project restored natural productivity in only three years.

According to the Maine DMR website only three returning adult salmon and 59 American shad were counted in 2015 in the Narraguagus River trap. Because of the ice dam in Cherryfield, the Narraguagus is the only Downeast river with yearly fish counts. Alewife were observed but were not counted, since they are small enough to escape the trap. Given that 1000 returning Atlantic salmon are needed to sustain the Downeast distinct population segment, the fact that the river with the best water quality had only 3 returning adults shows how badly the current restoration efforts are failing.

2. The small Coastal Streams

Englishman River stands out among the Brook Trout Joint Venture and Frenchman Bay Partnership sites, with alkaline pH and high alkalinity and high calcium. The water chemistry of Card Mill, Flanders, and Whitten Parritt Stream were similar to the official salmon watersheds. Brook trout and other native fish species might be expected to be struggling in these three streams. Further studies of small coastal streams are warranted.

3. Aroostook River

The Aroostook River sites have alkaline pH, an ideal alkalinity for salmonids, and high calcium. These values are high enough that these streams are unlikely to be vulnerable to acid rain issues. All of the sites sampled in 2015 were warm, 22-23° C in early September. Atlantic salmon parr stop feeding when temperature are above 22.5° C (Elliott 1991) and seek out thermal refugia if they have to (Corey et al. 2013). All of these sites are currently used by the salmon stocking program for the St. John River watershed.

4. The Union River

The three main stems of the Union River have good water quality, including calcium values that equal or are close to the minimum. The West Branch has the best salmon habitat and cold water. Several sites could be used for Atlantic salmon stocking, and have been used in the past. Unfortunately, the Leonard and Graham Lake dams represent a serious obstacle for both upstream and downstream passage. When there were still salmon in the river, they were trapped at the Leonard's Lake dam and were trucked to the Tannery Loop Road in Amherst where they were released. A private hatchery operated by the Union River Salmon Club was abandoned due to high iron in its water supply, production difficulties, and poor adult returns. The lower watershed sites, Green Lake and Branch Lake, are on silica-rich and calcium-poor (Ca < 1.5%) granite bedrock. They are consequently similar to the Washington County streams in chemistry. Low calcium in Green Lake may be a problem for the USFWS Green Lake Hatchery.

Summary

By combining the 2015 water quality study with the results of previous years, especially the 1999-2004 surveys, a better overall picture of the watersheds can be constructed to identify good water quality, look for missed opportunities for stocking, and to start identifying priorities for liming projects. The combined data are summarized in Table 4. The best water quality is generally associated with carbonate-rich sedimentary bedrock or cation-rich mafic volcanic bedrock. Sometimes sites with favorable water chemistry are found on calcium poor bedrock. This might be due to a "signal lag," in that stream chemistry reflects the inputs of upstream soils and bedrock, not those of the sample site itself. Another issue is that the surficial geology sometimes will be more informative than the bedrock geology. For instance, some Downeast sites occur on deep glacial till or are associated with sand and gravel aquifers. These sites might benefit from groundwater inputs and might have rock debris carried from calcium-rich sources.

Table 4. A summary of all samples from a given watershed, including 2015 and historical data, compared to proposed calcium concentration thresholds. Most values are from baseflow conditions, and so represent the most favorable end of the seasonal range. Warm water fish can tolerate the lower threshold, while adult salmonids and fry need the higher concentrations. The values in the table are the percentage of sample sites meeting the thresholds.

Watershed	Calcium Concentration		
	% sites > 1.0 mg/L	% sites ≥ 2.5 mg/L	% sites ≥ 4mg/L
Dennys	100.00	40.00	0.00
E Machias	100.00	61.54	0.08
Machias	100.00	24.13	0.03
Pleasant	100.00	0.09	0.00
Narraguagus	100.00	43.48	13.04
Tunk	80.00	0.00	0.00
Coastal streams	100.00	25.00	25.00
Aroostook	100.00	100.00	100.00
Penobscot	100.00	66.67	54.16
Saco	100.00	100.00	63.64
Union	100.00	60.00	20.00

The reason why Atlantic salmon cannot be restored in Downeast Maine is that there is too little suitable habitat with suitable water quality to produce the amount of fish needed to overcome substantial survival problems at sea. Instead of a single problem, good habitat has to coincide with several important factors. These are: connectivity, suitable water temperature, and water quality. Connectivity is about fish passage, the ability for fish to get past potential obstacles to access desirable habitat. The temperature optima for Atlantic salmon range from 16-19° C, with oxygen saturation levels above 60% (Stanley & Trial 1995). However, almost every site in Downeast Maine misses the mark for pH, calcium and alkalinity. While state and federal agencies and NGOs are working on habitat and connectivity, water quality restoration must be part of the mix. Whole watersheds must be limed to meet conservation goals.

Macroinvertebrates have similar sensitivities to pH and calcium. Almost all organisms are stressed below 2.5 mg calcium/L (Danner 2004). Poor productivity at the bottom of the food chain affects predators at the top. The cumulative impact of sub-lethal pathologies, widespread poor water quality, poor reproductive success and poor survival of fry causes gradual declines and losses of fish populations. It is rare to see dead adults, and is more typical that local extinction is caused by incremental losses of young (Haines 1981, Muniz 1980)

There are some differences from river to river. The Dennys River Watershed is the eastern-most of the Downeast salmon rivers. It had 40% of study sites with calcium greater than 2.5 mg/L but no sites that were greater than 4 mg/L. The best water quality was in the river's main stem in the lower part of the watershed, especially from

Stoddard Rips to the estuary. The lower river was influenced by the Quoddy and Edmunds Formations, both mafic to felsic volcanic rock. The mafic members are good sources of base cations. Tributaries typically have the coldest water, best gravel habitat, and refuge from smallmouth bass. However in this case, Dead, Curry, Preston, and Cathance Stream had poor calcium concentrations. Based on the historical mean, Venture Brook had better than average calcium. The single low value for Venture (1.5 mg/L) was from this year. The previous six values were from 2001. The mix of 14-year old calcium values with data from 2015 may be a problem. Venture Brook in the past had the lowest pH in the watershed and may have lost calcium in the last 14 years. If the findings at East Bear Brook (Fernandez et al. 2008) can be generalized broadly to the Downeast area, then declining trends in calcium could be widespread. There should be follow-up work on some the DEP historical sites to evaluate trends.

The East Machias Watershed is one of the smaller rivers but it has one of the largest amounts of salmon habitat. In terms of calcium, the best sites were in the upper watershed, especially Beaverdam, Harmon, and Northern Stream. These were influenced by the Digdeguash Formation, a lime-rich siltstone and shale, the Cookson Formation a sulfidic (acidic) but sometimes lime-rich mudstone, and mixed gabbro-diorite (mafic) volcanic bedrock. The East Machias had the highest number of sites with at least 2.5 mg calcium/L (61%) but had a low percentage of sites with values greater than 4 mg/L. Harmon and Northern Stream have good fish production but they also have smallmouth bass. Scott Brook had low pH, low calcium, high water temperature (above 24° C) and was dominated by ponded marsh habitat.

The Machias Watershed had a low number of sites with at least 2.5 mg calcium/L (24%). This does not favor native species. The Machias does offer some high calcium refugia, such as Lanpher Brook, Old Stream and New Stream. Lanpher had good water quality but was warm, nearly 24° C in August. Lanpher and Old Stream benefited from lime in the Flume Ridge and Digdeguash Formations, while New Stream benefited from the Cookson Formation. Fletcher Brook and the Machias mainstem above Route 9 are located on calcium-poor granite but benefit from groundwater input from a fluvial sand and gravel deposit. Water quality data is still needed for Libby and Denning. Honeymoon Brook has been described as a "factory" for brook trout but has not been stocked with salmon since 2010 due to poor survival. This stream is located on the Cookson Formation but the calcium concentration was around 2.1 mg/L. Perhaps the brook trout are actually being produced in nearby Old Stream and then are attracted to Honeymoon by the cooler temperatures.

The Pleasant River Watershed had almost no sites meeting the 2.5mg/L and 4 mg/L thresholds. The Pleasant had the worst water quality of the official Downeast salmon rivers and the worst fish production. Little River had the best water quality, probably derived from gabbro (10-12% CaO) and diorite (c. 5% CaO) in its headwaters. Pleasant

River Lake (at 1.2 mg calcium/L) currently has stocked landlocked salmon and splake, with naturally sustaining brook trout, alewife, and introduced smallmouth bass and white perch. Northeast Brook used to be a nursery for landlocked rainbow smelt in Pleasant River Lake. Smelt eggs were collected here and stocked in other lakes to support sport fisheries in other lakes. It now had calcium concentrations below 2 mg/L and a summer baseflow pH of 5.12. It is likely that this stream is no longer suitable for smelt. DIFW reports that rainbow smelt are successfully reproducing in Canoe Brook (1.6 mg calcium/L but favorable pH of 6.32) and some smaller tributaries. A fish survey by DIFW (1995) mentions that the white perch in Pleasant River Lake are stunted.

The Narraguagus Watershed had the best water quality and has the best salmon production in eastern Maine. The most favorable water quality was found in the middle of the watershed, above and below Route 9. Unfortunately, the main stem is very warm in the summer and it supports smallmouth bass. The best salmonid nurseries (i.e., good habitat, cold water, good water chemistry, and no bass) are limited to small tributaries, especially Baker and Shorey. These two tributaries have always been heavily stocked with salmon. Good water quality comes from an association with the Bucksport Formation, a lime-rich siltstone. Water quality data is still needed for the Little Narraguagus River and West Branch tributaries Pork, Mahanon, Colson and Spring River.

Tunk Stream used to be an Atlantic salmon river with an important sports fishery; but it lost its salmon before 1982. It also had the lowest mean calcium concentrations, around 1 mg/L with ranges that go as high as 2.5 mg/L. Within this watershed, which has more than six lakes, the headwater inlet to Mud Pond is in the late phase of acidification from acid rain (Goss & Norton 2008). Tunk Stream has an alewife run, and supports some brook trout. The low means suggests that this stream may be in danger of losing all of its native species.

All streams tested this year from the Aroostook River watershed had very good calcium concentrations. The pH was good, many fish and different species were present. Water temperatures were above 22° C in September.

Of the four coastal streams, only Englishman River had good calcium concentrations. The other streams are much like the Downeast salmon rivers. These coastal streams are very important for rainbow smelt and river herring conservation. Flanders Stream is a current river herring restoration project. The culvert at the Thorne Road has been replaced and stone terraces added that allow fish passage. Because of their importance, more water quality information should be collected from coastal streams in Hancock and Washington Counties.

The Penobscot River watershed has not generally been on anyone's list as threatened by acid rain, or partial recovery from acid rain. Still, recent studies show that 100% of

river herring and rainbow smelt that were surveyed in 2015 had hyperplasia and various degrees of other gill damage (Meseck et al. 2016). Gill damage of this sort used to be commonly reported from the Penobscot and Downeast rivers (Kocik 2003). The origin of the gill damage recently reported in the Penobscot is not clear but this kind of gill damage is unique to acid rain, heavy metals, ammonia toxicity, or toxic algal blooms. These fish appear to be originating in streams with water quality problems.

The Saco River and its sampled tributaries had circumneutral to alkaline pH and were all greater than 2.5 mg calcium/L. Only 63% attain the ideal. Like the Union River, fish conservation and recovery are hampered by large dams on the main stem. Also like the Downeast river watersheds, these streams occur on calcium-poor bedrock.

The three Union River main stems, the West, Middle and East Branches had relatively good calcium concentrations, around 4 mg/L. The upper Union River watershed was strongly influenced by lime-bearing bedrock in its headwater (Vassalboro and Bucksport Formations). The Bucksport Formation is the same bedrock that provides good water quality to the middle reaches of the Narraguagus River. Green Lake and Branch Lake occur on different bedrock, the Lucerne Granite, and had very different chemistry. Both of these lakes have renowned sport fisheries. Green Lake is the home to one of the original land-locked salmon populations, while Branch Lake is known for its large togue. The calcium means were both at 1.6 mg/L which are very low. Green Lake provides water for the Green Lake National Fish Hatchery that provides Atlantic salmon parr and fry for stocking within the Penobscot River watershed. In spite of the limits, this large watershed may be important to the conservation goals of the Downeast salmon population segment.

So, how important is marginal water quality? For one, marginal water quality does not kill instantly. Fish typically die off gradually due to not being able to replace themselves over a period of years (Jackson & Harvey 1995, Haines 1981). Furthermore, within interconnected waterways, local extinctions can be replaced by migrating fish from areas that still support them. Stocked fish or fish that migrate from the ocean have part of their life cycle that is sheltered from fresh water quality. Fish also are migratory within the watershed and will seek out and use different waters at different times. Brook trout are more likely to do this than the territorial salmon parr. However, even salmon parr will move if they have, into network refugia (Corey et al. 2013). Another problem is that pH, calcium, alkalinity, and aluminum all interact in complicated ways, so that observations are site specific. Very little published data on fish tolerances are from Maine. What we do know is that we have important stressors and that many of our streams have tipped beyond important thresholds. These streams were not always this way. They used to provide important sports and commercial fisheries for Maine's coastal communities. These fisheries are well documented in oral history, state archives, and by historical

photographs. The big issue is that we are stocking healthy fish into unhealthy water and we are running out of time to get this right.

References and Resources

Amiro, P & AJ Gibson. 2007. Status of wild Atlantic salmon, in general and on the Southern Upland of Nova Scotia to 2006 with options for population persistence. In: Brylinsky, M & L Hinks, eds. *Proceedings of the Acid Rain Mitigation Workshop*, Bedford Institute of Oceanography, May 26-27 2006, Sponsored and published by the American Salmon Federation and Nova Scotia Salmon Association.

Brocksen, RW, MD Marcus & H Olem. 1992. *Practical Guide to Managing Acidic Surface Waters and their Fisheries*, Lewis Publishers Inc., Chelsea MI, 190 pp.

Brown, DJA. 1982. Influence of calcium on the survival of eggs and fry of brown trout (*Salmo trutta*) at pH 4.5. Bulletin of Environmental Contamination and Toxicology 28: 664-668.

Corey, E, S Dugdale, C Breau, T Linnansaari, R Cunjak & N Bergeron. 2013. Movement and distribution of Atlantic salmon (*Salmo salar*) during periods of thermal stress in two Eastern Canadian rivers. In: Carr, J (ed.) *What Works? A Workshop on Wild Atlantic Salmon Recovery Programs*, Proceedings of a Conference by the Atlantic Salmon Federation, September 18-19, 2013, St. Andrews, New Brunswick.

Danner, GR. 2004. Improving brook trout egg quality in Maine: adding calcium overcomes the effects of acidic environment. Hatchery International, Nov-Dec: 33-34.

DIFW. 1995. Pleasant River Lake, fish and bathymetry. Survey report by Maine Department of Inland Fisheries and Wildlife, available at http://maine.gov/ifw/fishing/lakesurvey_maps/washington/pleasant_river_lake.pdf

DMR. Sea-run Atlantic salmon trap counts are available at http://www.maine.gov/dmr/searunfish/trapcounts.shtml

Elliott, JM. 1991. Tolerance and resistance to thermal stress in juvenile Atlantic salmon, *Salmo salar*. Freshwater Biology 25: 61-70.

Fernandez, IJ, SA Norton, GB Wiersma, LE Rustad & KS Simon. 2008. New challenges for the third decade of whole ecosystem experimental manipulations at the Bear Brook Watershed in Maine (BBWM). A poster is available on-line from the University of Maine http://umaine.edu/bbwm/findings/posters/

Gloss, SP, CL Schofield & MD Marcus. 1989. *Liming and Fisheries Management Guidelines for Acidified Lakes in the Adirondack Region.* US Department of the Interior, US Fish and Wildlife Service, Air Pollution and Acid Rain Report No. 27, Washington DC 20240.

Goss, HV & SA Norton. 2008. Contrasting chemical response to artificial acidification of three acid-sensitive streams in Maine. The Science of the Total Environment 404 (2-3): 245-252.

Haines, TA. 1981. Acidic precipitation and its consequences for aquatic ecosystems: A review. Transactions of the American Fisheries Society 110 (6): 669-707.

Haines, TA & JJ Akielaszek. 1984. Effects of acid precipitation on Atlantic salmon in New England. USFWS, US Department of the Interior, publication number FS/OBS – 80/40.18

Haines, TA, B Spaulding, K Beland & B Watten. 2003. Evaluation of water alkalinity enhancement at the Craig Brook National Fish Hatchery on Atlantic salmon growth and survival. In: B Arter (ed.*) Status and Trends of Water Chemistry in Maine Atlantic Salmon Watersheds*, proceedings of a conference by Project SHARE, at the Black Bear Inn, Orono, ME (abstracts only).

Hornbeck, JW, CT Smith, QW Martin, LM Tritton, & RS Pierce. 1990. Effects of intensive harvesting on nutrient capitals of three forest types in New England. Forest Ecology and Management 30:55-64.

Jackson, DA & HH Harvey. 1995. Gradual reduction and extinction of fish populations in acid lakes. Water Air & Soil Pollution 85: 389-394.

Jenkins, J, K Roy, C Driscoll & C Buerkett. 2005. *Acid Rain and the Adirondacks: A Research Summary*, published by the Adirondack Lakes Survey Corporation, Ray Brook NY, 258 pp.

Keliher, P. (editor). 2004. Annual Report to the Maine Atlantic Salmon Commission, (now Maine Department of Marine Resources), Augusta, Maine.

Kocik, J. 2003. Effects of episodic acidification on Atlantic salmon (*Salmo salar*) smolts. In: Arter, B (ed), *Status and Trends of Water Chemistry in Maine Atlantic salmon watersheds,* proceedings of a conference by Project SHARE, March 26, 2003, Black Bear Inn, Orono, ME.

Kroglund, F, B Finstad, SO Stefansson, TO Nilsen, T Kristensen, BO Rossland, HC Tien & B Salbu. 2007. Exposure to moderate acid water and aluminum reduces Atlantic salmon post-smolt survival. Aquaculture 273: 360373.

Lawrence, GB, JW Sutherland, CW Boylen, SW Nierzeweicki-Bauer, B Momen, BP Baldigo & HA Simonen. 2007. Acid rain effects on aluminum mobilization clarified by inclusion of strong organic acids. Environmental Science and Technology 47: 93-98.

Lien, L, GG Raddum, A Fjellheim & A Henricksen. 1996. A critical limit for acid neutralizing capacity in Norwegian surface waters, based on a new analysis of fish and invertebrate responses. The Science of the Total Environment 177: 173-193.

Meseck, S, JYL May, M Dixon, I Sunila, C Lipsky, J Stevens & G Wikfors. 2016. Characterizing chemical and biological parameters in Penobscot Bay before, during and after the release of Atlantic salmon (*Salmo salar*). In the proceedings of The 2016 Atlantic Salmon Ecosystems Forum, Jan 6-7, 2016, Wells Conference Center, University of Maine, Orono, ME (abstracts only).

Miller, K. 2006. Life support for salmon; restoration program yielding slow, but encouraging results. Bangor Daily News, September 15 (available on-line at archive.bangordailynews.com/2006/09/15).

Miller, E. 2011. *Steady-state Critical Loads and Exceedance for Terrestrial and Aquatic Ecosystems in the Northeastern United States.* National Park Service, US Department of the Interior, NPS/Multi-agency Northeast Critical Loads Project – Technical Report – 2.

Muniz, I & H Leivestad. 1980. Acidification – effects on freshwater fish. In: D Drablos & A Tollan (eds), *Ecological Impact of Acid Precipitation*, Proceedings of an international conference on the impacts of acid precipitation, Aas, Norway.

NAS. 2004. *Atlantic Salmon in Maine*. National Academy of Sciences, National Research Council, National Academies Press, Washington DC. (available at www.nap.edu)

NOAA. 2009. *Biological Valuation of Atlantic Salmon Habitat Within the Gulf of Maine Distinct Population Segment*. NOAA, National Marine Fishery Service, Northeast Regional Office, Gloucester, Massachusetts.

Økland, J & KA Økland. 1986. The effects of acid deposition on benthic animals in lakes and streams. Experimentia 42: 471-486.

Petty, JT, PJ LaMothe & PM Mazik. 2005. Spatial and seasonal dynamics of brook trout populations inhabiting a central Appalachian watershed. Transactions of the American Fisheries Society 134: 572-587.

Sayer, MDJ, JP Reader & TRK Dalziel. 1993. Freshwater acidification: effects of early life stages of fish. Reviews in Fish Biology and Fisheries 3: 95-132.

Stanley, JG & JG Trial. 1995. Habitat Suitability Index Models: Nonmigratory Freshwater Life Stages of Atlantic Salmon, US Department of the Interior, US Fish & Wildlife Service, Biological Sciences Report 3, Information Transfer Center, Ft Collins, CO.

Staurnes, M, F Kroglund & BO Rosseland. 1995. Water quality requirement of Atlantic salmon *(Salmo salar)* in water undergoing acidification or liming in Norway. Water Air and Soil Pollution 85: 347-352.

Trial, JG & JG Stanley. 1984. *Calibrating Effects of Acidity on Atlantic Salmon for Use in Habitat Suitability Models.* Maine Cooperative Fisheries Unit, Land and Water Resources Center, University of Maine at Orono, Completion Report Project A-054-ME.

Weatherley, NS, AP Rogers, X Goenaga & SJ Ormerod. 1990. The survival of early life stages of brown trout (*Salmo trutta L.*) in relation to aluminum speciation in upland Welch streams. Aquatic Toxicology 17 (3): 213-230.

Whiting, M. 2014. *Final Report for Project SHARE's Clam Shell Pilot Project. An Experimental Acid Rain Mitigation Plan for the Downeast Salmon Rivers*. Maine Department of Environmental Protection.