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Fourth Annual Report on Project SHARE's Acid Mitigation and Fisheries Restoration Project

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Report to Project SHARE

Fourth Annual Report on Project SHARE's Acid Mitigation and Fisheries Restoration Project.

The Clam Shell Liming Project, A Progress Report for 2013.

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Executive Summary

Project SHARE is using clam shells as a calcium carbonate supplement to mitigate stream acidity and to help restore Atlantic salmon. Beginning in 2010, 2 metric tons of shells were placed in Dead Stream, a tributary to Old Stream and the Machias River, located in T 37 MD BPP and Day Block Township. The following year (2011), the treatment was expanded into the southern part of the watershed (known as Bowles Brook) and treatment was increased to 10 tons of shells. In the third year (2012), the project was expanded to other tributaries of the Machias River: an un-named tributary to Honeymoon Brook, Canaan Brook, and First Lake Stream. In 2013, the project was expanded to the main stem of Honeymoon Brook and to Beaverdam Stream.

In Dead Stream, water chemistry has improved by approximately 1.0 pH unit, and total fish densities increased two-fold. In Canaan Brook water chemistry has improved by 1.0 pH unit and First Lake Stream improved by 0.71 pH unit, while fish densities have increased 2- and 6- times, respectively. Macroinvertebrate communities have improved somewhat, especially among mayflies and stoneflies, while amphipods and snails have appeared for the first time. However, even at treated sites, macroinvertebrate communities continue to have low diversity and may not achieve Class A water quality. Overall, by adding buffering capacity, there has been a boost to the bottom of the food chain which has contributed to improved fish abundance. In the fourth year of a 5-year project, biological communities are still adapting to the new conditions.

I. Introduction

Project SHARE (an acronym for Salmon Habitat and River Enhancement) is a non-profit organization that is comprised of the principal eastern Maine landowners (primarily forest management and blueberry growers), with state and federal fishery agencies (Maine Department of Marine Resources, Maine Inland Fisheries and Wildlife, US Fisheries and Wildlife Service, and NOAA Fisheries Service), environmental agencies (Maine Forest Service and Maine Department of Environmental Protection), and NGOs (Downeast Salmon Federation and Downeast Coastal Conservancy) which are involved in Atlantic salmon recovery projects. SHARE's role is to be a facilitator and manager of projects that benefit salmon, especially improving fish passage, restoring fish habitat, and preventing non-point source pollution. This document is a report to Project SHARE, our stakeholders, and this fulfills a reporting requirement for our NPDES discharge permit.

Unfortunately, Atlantic salmon in Maine are not doing well. Of 32 Maine rivers that used to have self-sustaining salmon populations, there are currently none. Even in the largest rivers like the Penobscot and Kennebec Rivers, salmon are maintained by stocking from federal and private hatcheries. Of fourteen diadromous fish species in the Penobscot River, thirteen have been able to sustain themselves naturally. Although these populations are much reduced, they are still present in the river. However, due to the complicated life history of salmon, and the need for access to habitat in the upper river, salmon have not been able to survive on their own. The central and southern Maine salmon rivers suffer from multiple dams and human development, including urban areas and heavy industry (mainly paper mills). Most of Maine's human population is found along the coast from southern to central Maine. Fortunately, there are restoration projects in the Penobscot and Kennebec Rivers which are removing the lower dams and are restoring fish passage (see Natural Resources Council of Maine website for a bulletin on Kennebec restoration, and Penobscot River Restoration Trust website). These large watersheds will be critical for salmon recovery in Maine.

In eastern coastal Maine, there are 5 smaller rivers mostly without dams in the main stems and with minimal development within the watersheds. These rivers are the Narraguagus, Pleasant, Machias, East Machias and Dennys Rivers. These watersheds have large commercial forests and some blueberry agriculture, but have nearly 100 % forest and other plant cover. Small towns dominate, with the larger population centers generally located on river banks near the heads-of-tide. By all appearances, these rivers have good water quality. However, these rivers do have problems. In particular, they have very soft water, often thin and vulnerable soils, and the main stems experience episodic acidification even in the summer (Figure 1). Headwater streams in these watersheds are generally worse off and many are chronically acidic.

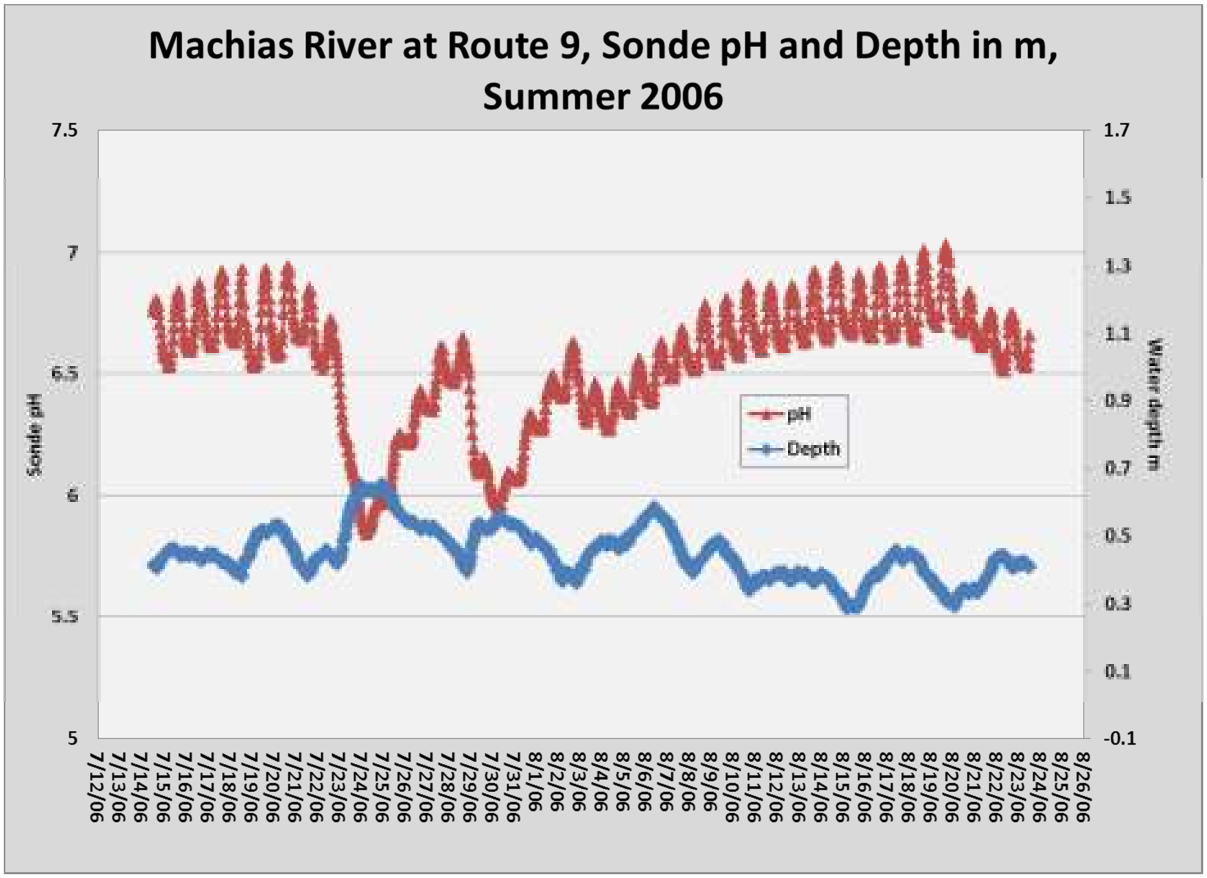


Figure 1. Machias River pH and water depth in meters as measured by a water quality sonde (automated environmental recorder) located in the mid-watershed. The daily pH cycle is driven by biological processes, photosynthesis and respiration, and their effect on dissolved carbon dioxide. Large drops in pH usually occur during rain storms (notice depth changes in blue). These high flows last for several days are episodic acidification events, and are especially intense in the spring and fall. These acidic episodes are challenging for anadromous fish and for many other species.

Atlantic salmon, *Salmo salar* , thrive in waters that range in pH from 6.5 to around 8.2 (Staurnes et al 1995), except apparently in Nova Scotia where salmon may thrive at pH 5.5 and above (Halfyard 2008, 2013). The acidic conditions in Downeast Maine, even if only episodic, can be fatal for young salmon. This explains (in part) why salmon have to be sustained by hatcheries even in Washington County. For instance, the East Machias River (a small river with 6,000 salmon habitat units, almost one-third of the total for all five Downeast rivers), in spite of being intensively stocked, it produced only 582 smolts in 2013. One habitat unit is 100 m² of rocky riffle habitat that is suitable as a salmon nursery area. Under better circumstances, this river should be producing tens of thousands of smolts each year and should be hosting hundreds of returning adults.

The Downeast coastal watersheds have other problems. Over 200 years of land management has led to a network of state, town and private roads that often have poorly constructed stream crossings. Improper sizing and installation of culverts are the most common problems. Some 90% of stream crossings present some barriers to fish passage and 40% are impassible or represent severe barriers to fish (Maine's Fish Smart Program, see Maine Audubon website). This leads to fragmentation of fish habitat and to greatly reduced fish populations. Project SHARE works with Washington County landowners to remove old stream crossings and replace them with fish-friendly alternatives (primarily arch culverts). SHARE also restores fish habitat by removing old lumber drive remnants (often these are dam remnants or piers made of log cribbing filled with stone). SHARE has also been adding coarse woody debris (logs and root wads) to increase habitat complexity. In 2009 SHARE got state permits to do an experimental liming project with clam shells as the calcium carbonate source. The clam shell project was developed to improve water quality by reducing acidity, provide better calcium nutrition for fish, and to neutralize aluminum and other toxic metals.

Historically, each of the Downeast rivers supported commercial and recreational salmon fisheries. Due to declines in salmon populations, commercial net harvests were banned in 1947 (Haines 1987). Some of the people that benefitted from that fishery were alive only a decade ago, and have contributed to the oral history of their communities. In contrast, historical records on the water quality of these rivers only go back to the 1969 and 1970. Follow up studies in 1981-1982 reported that pH was approximately the same as in 1970, sulfate was the dominant anion (an indicator of acid rain), episodic acidification was reported in headwater streams, and there was an increasing trend for toxic aluminum (Haines & Akielaszek 1984). At the time, with relatively good pH in the river main stems this was thought to have not greatly affected salmon abundance (Haines 1992). In 1984, all of the Downeast salmon rivers still had remnant self-sustaining salmon populations. Acid rain reached its peak in the 1980s and then declined due to the Clean Air Act amendments of 1990. In spite of improvements in air quality and rain chemistry, self-sustaining salmon populations were lost and salmon have had to be sustained by hatcheries since the 1990's. In terms of baseline water chemistry, there are no reliable records of what the water quality was like before acid rain was an issue.

A number of factors led to the collapse of the Downeast salmon fishery. Overfishing and hydroelectric development were big factors (Haines 1992). Small hydroelectric dams were built at the mouth of the Pleasant and East Machias River (these were removed in 1988 and 2000 respectively). Acid rain became a factor during the intensive industrialization of the United States in the early to mid-20th century. For instance, acid rain was already a problem in the 1940's in Norway when it was noticed that some lakes were losing salmon and brown trout populations (Muniz & Leivestad 1980). The fishery losses accelerated after 1960 and peaked in the 1980's. In Maine salmon rivers, only the Downeast rivers suffered from acid rain (because of the thin soils and granitic bedrock). These issues (low pH, low calcium, and high dissolved aluminum) were probably intensified by intensive forestry (i.e., the removal of tree biomass exports calcium, potassium and other base cations and impoverishes soils, just like acid rain does, Federer et al 1989). Maine forests and soils began a partial recovery after the Clean Air Act improvements of 1990, which capped nitrogen emissions and reduced national sulfur emissions by one-half. This resulted in soils rebuilding cation exchange capacity (i.e., soils accumulate calcium, potassium, sodium and magnesium). Ironically, the partial recovery of soils can be problematic for surface waters. As soils sequester cations and other nutrients, there may be less alkalinity available in runoff and groundwater discharges to streams (Lawrence et al 2012). Streams may fail to recover right away with improvements in rain chemistry or may even become more acidic. Eventually, soils and streams will both be in recovery phase. Because acid rain continues (at lower levels) recovery will be partial and will take decades. Atlantic salmon are in trouble right now.

For the most part, Atlantic salmon are adapted to circumneutral-to-alkaline water, but tolerate mildly acidic conditions to pH 6.5 (Staurnes, et al 1995). Salmon parr and adults may survive for a time in strongly acidic water, but cannot reproduce or persist in the long run. The liming of lakes or streams is generally recognized as the only short-term solution (Brockson et al 1992). In the long term, air pollution has to be reduced to address both acid rain and global climatic change. In the United States, liming of streams and lakes has been done in Massachusetts, Michigan, Minnesota, New Hampshire, New York, Pennsylvania, Tennessee, Virginia and West Virginia. There are a number of ways that calcium carbonate can be distributed in lakes, ponds or flowing water; but generally it has involved limestone sand applications in streams or fine powder for lakes. In lakes, the fine powder dissolves quickly in water and is eventually mixed throughout the lake by wind, waves and currents. The treatments generally last from 1-6 years depending on the hydraulic residence times of the lakes. In streams, limestone sand or limestone gravel forms bars that migrate downstream in the current and dissolve gradually. These treatments generally last for 1-3 years. Unfortunately, in addition to the positive effect on water chemistry, the limestone sand fills voids within gravel and cobble substrates. This substrate "embeddedness" smothers the benthic in-fauna, including macroinvertebrates, fish eggs and even larval fishes. Limestone gravel is added with heavy machinery that also forms the initial bars. The machinery causes a severe but relatively short-term disruption of benthic communities.

SHARE decided to try a different approach. Instead of burying the benthic habitat, clam shells have enough surface area to dissolve quickly and deliver enough calcium carbonate to improve water quality. At the same time, shells have a size and shape that creates voids and allows access to bottom habitat. Shells develop a biofilm after just a few days in a stream and quickly become habitat. For instance, small fish, amphibians, and invertebrates are known to use native freshwater mussel shells for cover (Grabarkiewicz & Davis 2008, note photo of brindled madtom under a mussel shell).

In 2009, Maine Department of Environmental Protection's Salmon Program took the lead and developed a shell-based liming project for SHARE. Later that same year, Project SHARE received a Maine NPDES permit for a 5-year demonstration liming project. The first shell applications began in 2010 when softshell clams shells (*Mya arenaria*) were scattered on the bottom of Dead Stream, a tributary to Old Stream. Old Stream is one of the principal tributaries to the Machias River. In subsequent years, the project has been expanded to Bowles Brook, Honeymoon Brook, Canaan Brook, and First Lake Stream, all headwater tributaries to Old Stream. In 2013, Beaverdam Stream was treated for the first time, thereby expanding the project into the East Machias River watershed.

II. Methods

Study Sites

All of the experimental treatment sites are in eastern Maine in Washington County. Dead Stream and Bowles Brook are part of the same watershed, with Bowles being a tributary in the southern part of the Dead Stream watershed. Honeymoon Brook also has a tributary almost as large as the Honeymoon main stem, which has no name (and does not show on maps). Dead Stream, Honeymoon, Canaan, and First Lake Stream are all headwater tributaries to Old Stream, one of the principal tributaries to the Machias River. Beaverdam Stream is a tributary to the East Machias River (Table 1).

Table 1. Summary of study sites, watershed sizes, and original pH. Also shown is a summary of clam shell applications, including the calculated "required" dose and the actual total, "existing and new" applications (shaded columns). The dose is achieved by spreading the shell over approximately

40% of the stream bottom over as much linear meters of stream as is needed to use up the calculated dose.

Study Site	Study Site (Road)	Watershed	Watershed Size	First Treatment	Original pH	Clam Shells Required Metric Tons	Clam Shells Actually Applied in 2013	Estimated Total Exsting and New Shells	Linear Meters of Stream Bed Treated
Dead Stream upper site	55-00-0	Old Stream	236 Ha	2010	5.80	2 tons	2 tons	3.5 tons	240
Trib to Bowles Br	55-50-0	Old Stream	207 Ha	2011	5.10	6 tons	0	3 tons	60
Bowles Brook	55-38-0	Old Stream	174 Ha	2011	6.20	2 tons	1 ton	2 tons	200
Dead Stream lower site	58-00-0	Old Stream	1282 Ha	2013	5.80	2 tons (12 total)	0.5 tons	0.5 tons (9 total)	50 550 total
Honeymoon Brook Trib	9-95-0	Old Stream	218 Ha	2012	5.50	5.5 tons	3 tons	3.5 tons	375
Honeymoon Brook	9-95-0	Old Stream	368 Ha	2013	5.70	7.5 tons	3 tons	3 tons	342
Canaan Brook	59-00-0	Old Stream	18 Ha	2012	5.22	1 ton	1 tons	1 tons	170
First Lake Stream	59-00-0	Old Stream	246 Ha	2012	4.70	11 tons	2.5 tons	3.5 tons	350
Beaverdam Stream	ME Route 9	E Machias	3329 Ha	2013	6.20	33 tons	10.5 tons	10.5 tons	275

Clam Shell Applications

The dose is calculated using models from West Virginia where the calcium carbonate is supplied from limestone sand (Clayton et al, 1998). A dose factor is calculated from the average summer baseflow pH. The dose factor is multiplied by the size of the watershed to get the dose in metric tons. This calculation appears to work reasonably well for shells as a carbonate source. So far, shells from *Mya arenaria* (softshell clam), *Arctica islandica* (mahogany or black quahog) and *Mytilus edulis* (blue mussel) have been used. The softshell clams last approximately 6 months, mahogany clam shells last almost 2 years, and blue mussels last approximately 8 months. The useful life of a clam shell depends on the exposure to *in-situ* pH, temperature, and current in each treatment location as well as the robustness of the shell. The mahogany clam shell is by far the largest and heaviest.

Clam shells are scattered lightly on the stream bottom by hand from 5-gallon buckets. The goal is to cover approximately 40% of the stream bottom while not completely covering natural habitat or burying native species (such as freshwater mussels or aquatic plants). The dose is adjusted by spreading the treatment over more linear meters of stream. For instance, if the calculated dose is 2 metric tons, this amount of shell is distributed over enough linear meters of stream bottom to use up that amount of shell.

SHARE has tried to avoid covering trout spawning areas and freshwater mussel beds. The clam shells are much larger than typical substrates for brook trout spawning (i.e., sand to fine gravel) and the shells would probably interfere with spawning. Also, freshwater mussels have a limited ability to relocate themselves if they were accidently buried under shell applications. However, crushed shell has been used in Norway to improve salmon spawning gravels (Hindar 2007). It is likely that native mussels would also benefit from higher pH and calcium. Treating salmon spawning areas or the use of crushed shell for freshwater mussel conservation could be topics of future experimentation. The use of limestone sand on sandy bottom streams or sandy reaches might also be worth trying in the future.

Water Quality Monitoring

Water quality was monitored with both data sondes and grab samples of stream water which were collected for lab analysis. The sondes are automated environmental recorders which were programmed to take water temperature, pH, specific conductance, and water depth measurements every hour. There were 9 YSI model 600 XLM sondes that were deployed to gather "before and after" data for new shell additions, and "upstream and downstream" data for on-going treatments. Due to a limited number of sondes, only downstream sondes were used for some streams where there were certain preconditions, namely: (1.) where sites were treated in previous years, and where there are (2.) good existing pre-deployment records (i.e., Dead Stream, First Lake Stream and Canaan Brook), and where this year's treatment was (3.) only a maintenance dose.

Grab samples for lab analysis were taken to the University of Maine Sawyer Environmental Chemistry and Research Lab (SECRL). Water samples were analyzed for alkalinity (measured as acid neutralizing capacity, or ANC), calcium, dissolved organic carbon (DOC), aluminum species (total Al, dissolved Al, organically bound Al and free ionic Al (here called "exchangeable Al" or Alx)), and total phosphorus (TP). Since the shells have arsenic from their former marine environment, this year water samples were also analyzed for total As.

Fish Sampling

Fish communities were electrofished by US Fish and Wildlife Services staff from the Maine Fisheries Research Office (MFRO) at the Craig Brook Fish Hatchery. Study reaches were generally 100 m above and below access roads and were single passes. To compensate for annual variation in stream width and where some of the early baseline studies were less than 100 m, the e-fishing data was converted to catch per 100 m^2 (the standard habitat unit for Atlantic salmon). All fish were recorded by species, along with fish lengths and weights. Fulton's K was used as an index of fish condition (Anderson & Gutreuter 1983).

Macroinvertebrates

Macroinvertebrates are an important link the aquatic community and provide another gauge of habitat and water quality. In 2012, macroinvertebrate samples were collected using rock bags above and below application sites on Dead Stream and Bowles Brook. These samples were delivered to Lotic, Inc. for professional evaluations. Maine Department of Environmental Protection (DEP) uses the taxa identifications and abundances in a computer model to assess compliance with state water quality standards (both sites are expected to have macroinvertebrates assemblages that are "as naturally occurs" for these Class AA streams). The results will be reported this year. In addition, some rapid assessments using rock bags have been done each year using Izaac Walton League protocols. These simple in-the-field assessments give instant feedback and cover more sites.

Leafpacks

Leafpacks are a small collection of fallen leaves, taken in the autumn, that are bundled into mesh bags and are placed in streams to evaluate trophic dynamics (following the Stroud Center leafpack protocol, see Stroud Center in references section). In this study, 8 grams of dried American beech leaves were placed in small onion bags. The leafpacks were tied to anchors made of lobster bait bags filled with about 3.5 kg of rocks. A single fist-sized rock was placed downstream of the leafpack to keep the lobster bait bag from rolling downstream. The leafpack was positioned facing upstream (just like a natural leafpack). Ten leafpacks were deployed at each of three study sites (all in the un-named tributary to Honeymoon Brook, above, in the middle of, and below the shell applications). The leafpacks were sampled monthly by taking two bags from each site. Leaves were cleaned, separated from macroinvertebrates, and were dried and weighed to the nearest 0.1 g. Macroinvertebrate identification followed the same Stroud Center protocols (picture keys of major groups).

III. Results and Discussion

Water Quality

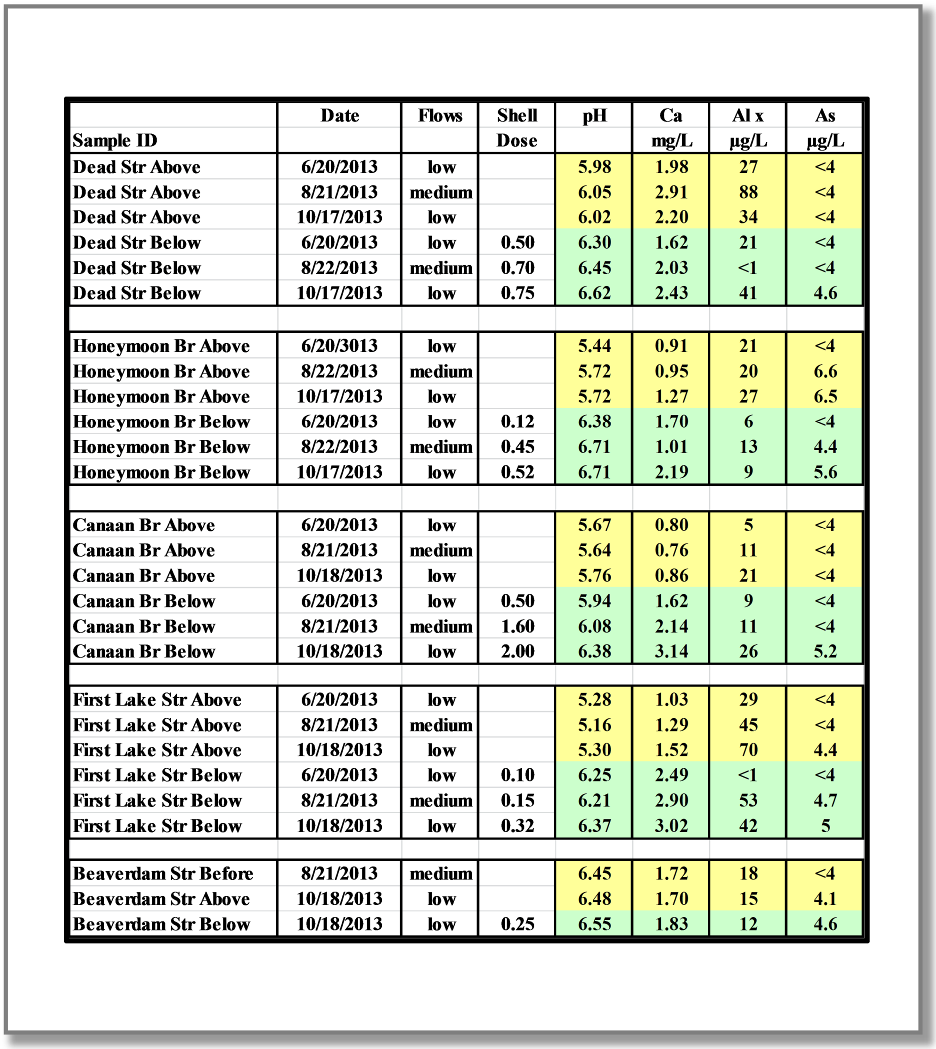
The sonde records show improvement at all sites (Table 2). Treatment levels achieved in 2013 were mostly less than planned due to a lack of manpower (the pH goal was 6.4 or above). Only Canaan Brook received the planned dose. This was a double dose based on the original sonde record (an upstream site). Now that we have a downstream sonde record at Canaan, the double dose turns out to be a single dose based on the downstream (more acidic) record. Upper Dead Stream was also adequately treated, but the watershed overall was a little short (only 75% of the planned dose for the lower watershed). Honeymoon Brook and Beaverdam Streams were treated for the first time this year. Shells have been stockpiled in advance of the 2014 season to facilitate an early start. In spite of low doses in some cases, sonde results show improvements at all sites with final pH around 6.0 or above. No sites achieved the goal of pH 6.4 as a minimum. During high flows, pH can still drop into the 5's (or even 4's for the Honeymoon tributary). Without a mechanical doser, there is currently no way to deliver more calcium carbonate during high flows when it is needed the most. Notice that the standard deviation (SD) is generally smaller after treatment even though the range is often about the same. This reduction in variation is due to faster recovery after storms (i.e., fewer hours at low pH) for treated sites. In order to get the desired effect, the full dose and probably more must be applied (maybe 1.5 X or 2 X doses).

Table 2. Summary of pH before and after shell additions for each watershed, including the minimum, maximum, mean and standard deviation taken from sonde records. The before and after means are shaded to facilitate comparisons. The results from Dead Stream include the treatments to the tributary Bowles Brook. The planned dose for Canaan Brook was twice the original calculated dose based on an upstream site as baseline (the downstream site is naturally more acidic).

Study Site	Study Site (Road)	2013 Dose	pH Before Shells				pH After Shells				pH Improvement
		as fraction	min	max	mean	SD	min	max	mean	SD	mean
Dead Stream lower site	58-00-0	0.75	4.79	6.56	5.94	0.38	5.18	6.60	6.41	0.13	0.47
Honeymoon Trib	9-95-0	0.64	4.58	5.56	4.92	0.14	4.87	6.23	5.98	0.15	1.06
Honeymoon Brook	9-95-0	0.40	5.38	6.41	5.99	0.24	5.91	6.55	6.39	0.08	0.40
Canaan Brook	59-00-0	2.00	4.52	5.34	4.98	0.24	5.18	6.09	5.90	0.15	0.92
First Lake Stream	59-00-0	0.32	4.99	5.45	5.24	0.30	5.51	6.27	5.95	0.19	0.71
Beaverdam Stream	ME Route 9	0.32	5.43	6.51	6.04	0.29	6.15	6.51	6.29	0.07	0.25

Compared with historical measurements, the Dead Stream appears to have recovered somewhat since 1980-1982, when Haines & Akielaszek (1984) reported the mean pH (the authors called this Bowles Brook and the pH was reported as 5.37, while the summer baseline pH for the current study was 5.94). However, the naturally self-sustaining populations of Atlantic salmon reported in the 1980's have been lost due to the cumulative effects of years of poor water quality.

Lab chemistry also shows improvement (Table 3). Compared to the goal of pH 6.4, he pH levels for Dead and Honeymoon are pretty good. Canaan Brook and First Lake Stream still have low pH, but the achieved dose for 2013 was low and most stream applications were made late in the year. The calcium goals (must be above 2.5 mg/L, a critical low level for salmon survival, and should be at or above 4 mg/L to avoid some loss of fry, Brocksen et al 1992), have always been harder to achieve than pH goals. This year is no exception. Again, the calculated treatment levels should be adjusted higher than the West Virginia models suggest. Aluminum levels are mostly good, except that the low shell dose at First Lake Stream in August resulted in unacceptably high Alx on that date.



Sample ID	Date	Flows	Shell Dose	pH	Ca mg/L	Al x µg/L	As µg/L
Dead Str Above	6/20/2013	low		5.98	1.98	27	<4
Dead Str Above	8/21/2013	medium		6.05	2.91	88	<4
Dead Str Above	10/17/2013	low		6.02	2.20	34	<4
Dead Str Below	6/20/2013	low	0.50	6.30	1.62	21	<4
Dead Str Below	8/22/2013	medium	0.70	6.45	2.03	<1	<4
Dead Str Below	10/17/2013	low	0.75	6.62	2.43	41	4.6
Honeymoon Br Above	6/20/3013	low		5.44	0.91	21	<4
Honeymoon Br Above	8/22/2013	medium		5.72	0.95	20	6.6
Honeymoon Br Above	10/17/2013	low		5.72	1.27	27	6.5
Honeymoon Br Below	6/20/2013	low	0.12	6.38	1.70	6	<4
Honeymoon Br Below	8/22/2013	medium	0.45	6.71	1.01	13	4.4
Honeymoon Br Below	10/17/2013	low	0.52	6.71	2.19	9	5.6
Canaan Br Above	6/20/2013	low		5.67	0.80	5	<4
Canaan Br Above	8/21/2013	medium		5.64	0.76	11	<4
Canaan Br Above	10/18/2013	low		5.76	0.86	21	<4
Canaan Br Below	6/20/2013	low	0.50	5.94	1.62	9	<4
Canaan Br Below	8/21/2013	medium	1.60	6.08	2.14	11	<4
Canaan Br Below	10/18/2013	low	2.00	6.38	3.14	26	5.2
First Lake Str Above	6/20/2013	low		5.28	1.03	29	<4
First Lake Str Above	8/21/2013	medium		5.16	1.29	45	<4
First Lake Str Above	10/18/2013	low		5.30	1.52	70	4.4
First Lake Str Below	6/20/2013	low	0.10	6.25	2.49	<1	<4
First Lake Str Below	8/21/2013	medium	0.15	6.21	2.90	53	4.7
First Lake Str Below	10/18/2013	low	0.32	6.37	3.02	42	5
Beaverdam Str Before	8/21/2013	medium		6.45	1.72	18	<4
Beaverdam Str Above	10/18/2013	low		6.48	1.70	15	4.1
Beaverdam Str Below	10/18/2013	low	0.25	6.55	1.83	12	4.6

Table 3. Summary of lab chemistry results, above and below shell application sites for 2013. Above (yellow) and below (green) sites have different shading to facilitate comparisons. This year's achieved shell dose is given as a fraction. The desired pH is 6.5 or greater, calcium is 4 mg/L or greater, exchangeable aluminum (Alx) is 24 µg/L or less, and the Maine drinking water standard for arsenic (As) is 10 µg/L or less. Note that most As values are below detection limits. All cations (Ca, Alx and As) are given as total dissolved values.

Arsenic was measured as total dissolved As. Arsenic in baseline samples was below detection limit or only a few ppb. Samples downstream from shell applications are within the same ranges and well below the Maine drinking water threshold of 10 ppb (µg/L). Arsenic only shows up Honeymoon Brook and First Lake Stream, and only occasionally. There appears to be no relationship between arsenic detections and shell applications.

Not shown are the DOC and TP measurements. DOC ranged from 4.74 mg/L at Canaan Brook to 23.5 mg/L at Dead Stream. Total P ranged from 5.5 µg/L at Canaan Brook to 39 µg/L at Dead Stream. There is a good correlation between DOC and TP ($r^2 = 0.75$). In these watersheds, most DOC comes from soils, from which phosphorus is also mobilized. DOC and TP have the same sources and both are mobilized by groundwater.

Fish

In spite of treated areas still having some water quality problems, fish communities have improved. While species diversity has stayed about the same (3-7 species/year for Dead Stream), the total number of fish has increased by approximately 2- times (in Dead Stream and Canaan Brook) to 6- times (First Lake Stream) (Figures 2-4). All the fish observed at Canaan and First Lake Stream so far are brook trout. There are also the most acidic streams. Brook trout dominate in Dead Stream, but white sucker, creek chub, blacknose dace, ninespine stickleback, and American eel have also been observed in low abundances. Atlantic salmon are stocked in Dead Stream and Honeymoon Brook and are the second most abundant fish species at Dead Stream. There are still no fish data available from Honeymoon Brook or Beaverdam Stream.

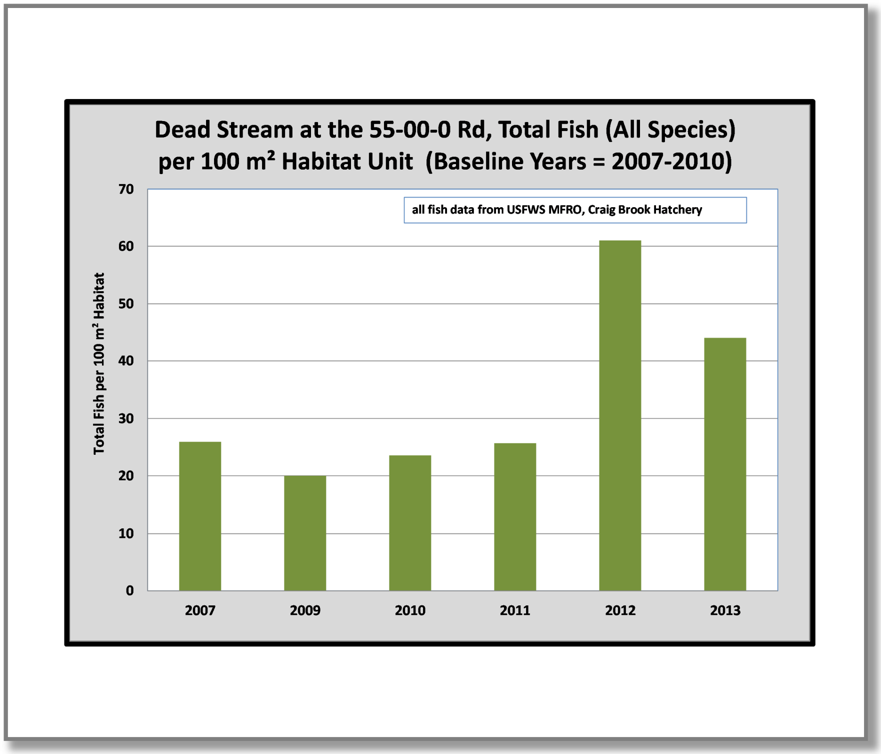


Figure 2. Summary of electrofishing results with total number of fish per 100 m²habitat unit. Baseline years are 2007 through 2010. Shells were added at the 55000 Road for the first time in 2010, just after the electrofishing was finished. The fish response was delayed one year, with the first clear difference from the baseline in 2012. Salmon fry were stocked for the first time in the spring of 2011 and stocking has continued at the same rate (3,300 fish) each year since.

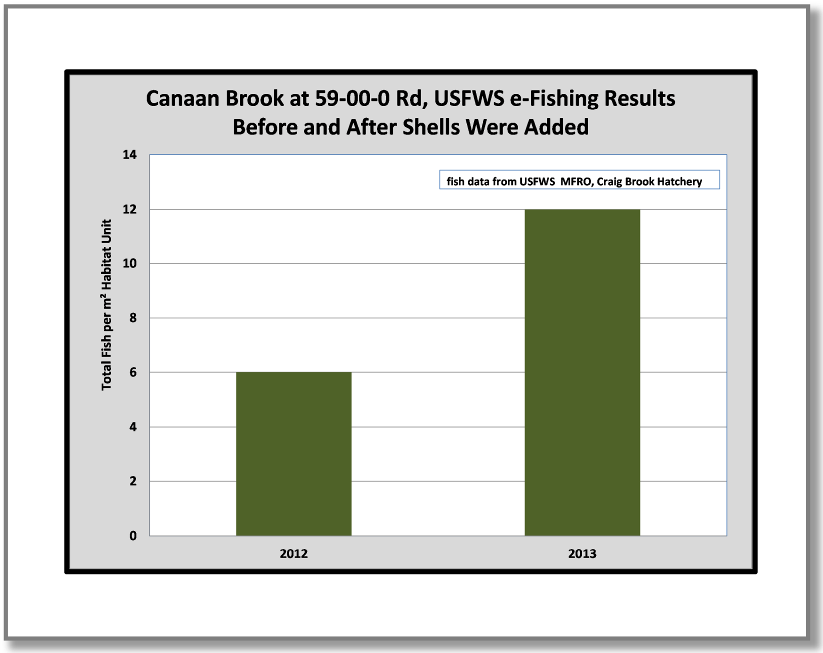


Figure 3. Summary of electrofishing results from Canaan Brook. All of these fish are brook trout and are presented as total number of fish per habitat unit. Shells were added for the first time in 2012, the baseline year.

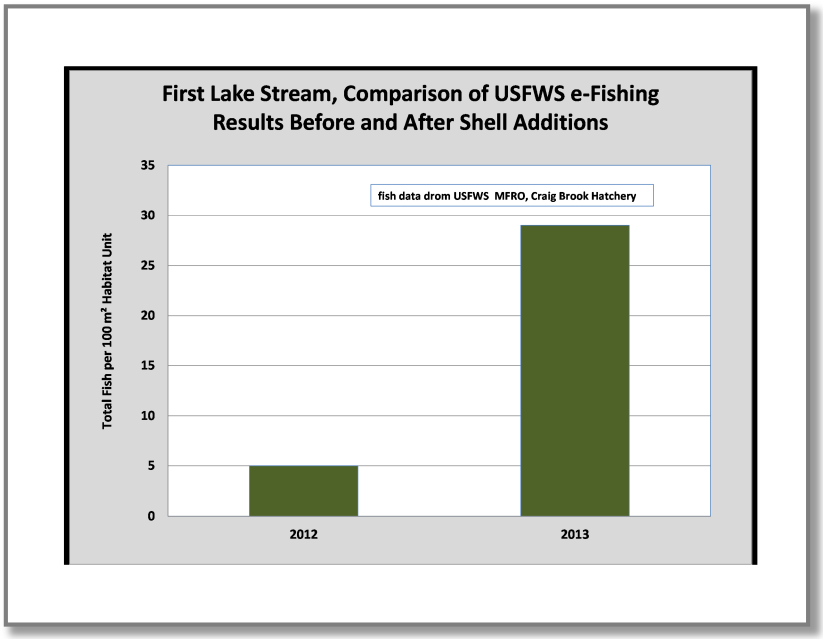


Figure 4. Summary of electrofishing results from First Lake Stream. Shells were added for the first time in 2012 the baseline year. All of these fish were brook trout and are presented as total number of fish per habitat unit.

The 2013 field season was not as good for brook trout, and the total fish abundance is lower than last year (down from a high of 61 fish per habitat unit). This may have been due to normal year-to-year variation, the lower shell doses, the high flow conditions in 2013 and thus the lower pH. However, salmon young-of-the-year (YOY) were doing slightly better in 2013 (Figure 5). Almost 20 salmon YOY per habitat unit is still low compared to that reported by Trial and Stanley (1984) for the lower part of the same watershed (45.5 YOY/unit, where the habitat quality is better). In treated Norwegian rivers, it took about 3 years of treatment to achieve approximately 20 YOY per habitat unit when native salmon populations were extirpated; and it was at 55 YOY/unit after 10 years (Hesthagen et al 2011). The authors also reported that the estimated natural capacity for these rivers, a parr densities of 30 parr /unit, took 20 years to achieve. The average pH achieved mainly by lime dosers was 6.33 ±0.14 SD with Alx 7 ug/L ±4.0.

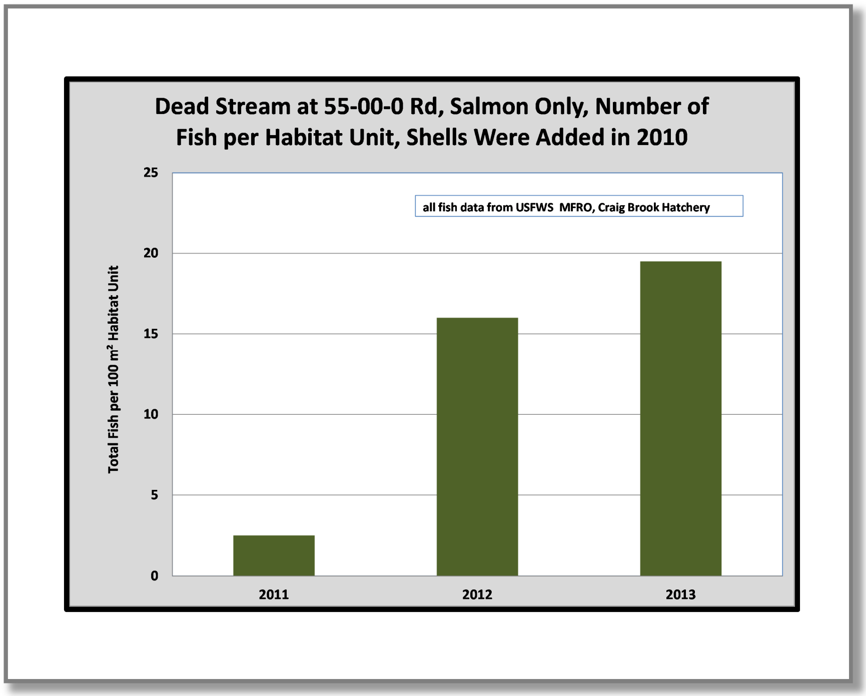


Figure 5. Summary of salmon found during electrofishing at Dead Stream at the 55000 Road. The summer of 2011 was one year after shells were first applied. Almost all fish are young-of-the-year (YOY), four older fish were seen in 2012 and five in 2013.

Generally an increase in fish density comes at the expense of fish condition due to crowding and an increased competition for limited resources. However, in the case where water quality improvements result in increased carrying capacity, perhaps due to increases in food or decreases in environmental stress, then fish condition might remain good in spite of increased densities. This is the case in Dead Stream (Whiting 2012) and in Canaan Brook (Figure 6). The abundance and condition of the young-of-the-year brook trout is a good indicator of recruitment. YOY are usually not far from their nest site, while older fish are more mobile and may have migrated from other parts of the Old Stream watershed.

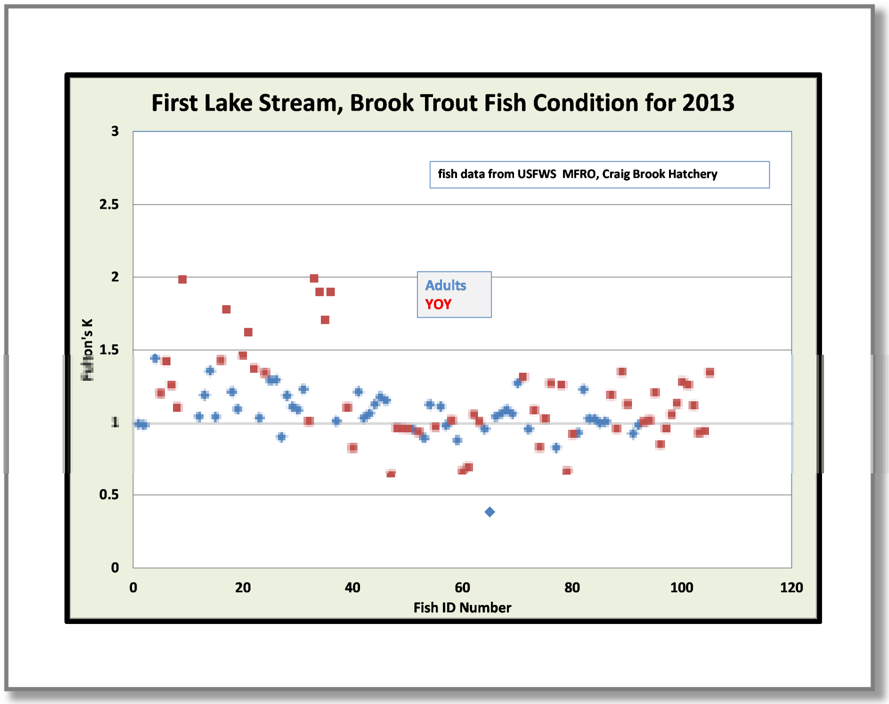


Figure 6. Summary of fish condition for adult and young-of-the-year (YOY) brook trout found during electrofishing at First Lake Stream in 2013. Fulton's K is an index of fish condition that is based on length and weight data. Only brook trout are shown since expectations are different for different species and ages of fish. Values around 1.0 are considered normal and values above 1.0 are especially good.

River herring (alewife, shad, and blueback herring) and striped bass are also sensitive to pH, and will suffer catastrophic reproductive failure if pH is less than 6.3 (Hendry 1987). The adults of these species are quite tolerant of pH fluctuations, but the fry and juveniles are sensitive. This is exactly the same issue that salmon have with pH.

Macroinvertebrates

Macroinvertebrate communities have been assessed with two methods, a rapid assessment using simple field-oriented visual assessments and professional identifications and counts. Both methods used rock bags. The informal assessments varied in sample dates from late September in 2012 to early November in 2009 (Table 4). The different dates represent an attempt to solve some sampling problems. For instance, the original sample date was early November and was thought to represent the time of year when species which are adapted to a leaf-litter dominated food chain would be abundant. However, a combination of cold air and cold water temperatures and an abundance of leaf detritus made field processing difficult. The samples were dominated by hundreds of chironomids and black flies. Samples taken in October, just a couple of weeks earlier the following year, were easier to process. However, black flies still dominated some samples. In 2011, samples were taken in late September to avoid overwhelming dominance by black flies, and to see if small early instars of mayflies and "winter stoneflies" would continue to be the dominant EPT taxa. In 2013 mild weather extended into October and made for ideal stream side sampling, and the date was more consistent with the earlier years. For all four years, early instars of mayflies and stoneflies dominated those groups.

Table 4. Summary of mean macroinvertebrate individuals or "taxa" per rock bag using Izaac Walton protocols for Dead Stream sites. Dead Stream at the 55000 Rd is in the middle of a treatment area and the 58000 Rd site is below all treatments. High numbers of total individuals (N) on November 9, 2009 (a baseline sample) and on October 28, 2010 (two months after the first shell application) reflect large numbers of chironomids and black flies which dominate the counts. The EPT taxa are the Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies), which are commonly used as clean water and/or disturbance indicators.

Dead below 55000 Rd, mean EPT individuals or taxa per rock bag

Sample Date	Mayflies	Stoneflies	Caddisflies	N	EPT taxa
Nov. 9, 2009	5	16	4	250	3
Oct. 28, 2010	14	9	11	57	5
Sept. 27, 2011	25	25	15	76	8
Oct. 28, 2013	46	48	46	158	15

Dead below 58000 Rd, mean EPT individuals or taxa per rock bag

Sample Date	Mayflies	Stoneflies	Caddisflies	N	EPT taxa
Nov. 9, 2009	4	16	22	272	5
Oct. 26, 2010	6	16	58	219	7
Sept. 27, 2011	45	15	34	106	8
Oct. 28, 2013	22	41	101	207	11

In all cases, at treated and non-treated sites the counts are dominated by EPT taxa (unless there were black flies present). Other clean water indicators are very rare. Clean water indicators include hellgrammites, gilled snails, riffle beetles, water pennies and limpets. Only the occasional hellgrammites or riffle beetles show up in the counts. Water pennies have not been observed in any samples at any locations in a four year period and snails appeared for the first time last year. Only a couple of limpets have been seen in 25 collections (1 or 3 bags per collection). Of the somewhat sensitive species, namely: beetle larvae, clams, craneflies, crayfish, dragonflies, damselflies, amphipods, sowbugs, fishflies, alderflies, watersnipe and planaria, only craneflies and planaria are often found and only in low numbers. Some of the sites with better natural or treated water have dragonflies, damselflies, fingernail clams, or amphipods. Crayfish, sowbugs, alderflies, fishflies and watersnipe have not been observed at all. The pollution tolerant group includes the chironomids, blackflies, aquatic worms, leaches, mosquito larvae and lunged snails. Except for snails, all of these occur occasionally. In other words, there are many groups of organisms that are generally abundant in streams with good water quality that appear to be absent or very rare in these collections. Often these are known to be acid sensitive (especially the mollusks and crustaceans).

For the treated sites, the trends over time appear to be gradual increases in EPT taxa. All three groups increased in the number of recognizable "taxa." For our level of experience, "taxa" are roughly equivalent to family level identification. Any potential increase in total number of individuals (N) is hidden by different sample dates and seasonal trends, especially with black flies being so abundant in late season collections.

The professional assessments of last year's samples show generally indeterminate (I) or poor quality macroinvertebrate communities (Class C, the state's poorest water quality class). Only Bowles Brook, the site above the shells, had a community that was consistent with a Class AA salmon or brook trout stream. This stream has the best initial water quality of any of the study sites, with an initial baseline pH around 6.0. Bowles Brook has abundant rocky riffles with clear, almost colorless water. The water quality classification model requires a minimum number of individuals to make a determination. Since this minimum number was not achieved at Bowles below the treatment, the outcome is indeterminate (I). The two Dead Stream sites, above and below the shells did not attain their Class AA rating for aquatic life, both attained only Class C, indicating poor quality communities (in this case with low mayfly and stonefly richness). Streams that do not meet water quality classification are generally classified as "Impaired," and impaired streams are supposed to have an abatement plan. The SHARE liming program is the abatement plan.

Table 5. Professional assessment of rock bag macroinvertebrate assemblages at Dead Stream and Bowles Brook above and below shell applications. Macroinvertebrate identification and enumeration was provided by Lotic Inc. and water quality modelling results are from Maine DEP Biomonitoring Program. Class A is the best water quality (or Class AA for Maine's best salmon and trout streams) and C is the worst, I is "indeterminate" due to a lack of enough individuals to make a determination.

Study Site	Maine Water Classification	Assignment based on Macroinvertebrates
Dead Str Above Shells	A	C
Dead Str Below Shells	A	C
Bowles Br Above Shells	A	A
Bowles Br Below Shells	A	I

Leafpacks

Leaf processing rates are used as indicators of the health of the detritus processing community (microbes and various invertebrate detritivore functional groups, like the leaf shredders, scrapers, and the fine particle collectors) (Petersen & Cummins 1974). Ordinarily, primary producers are considered to be the bottom of the food chain; but in eastern North America small streams are heavily shaded and the most important primary producers are the surrounding forest. Energy and carbon inputs to the steam are provided as a rain of coarse and fine plant material (and some animal material) from the forest canopy. In the spring, there is a rain of pollen, buds and spent flowers. In summer there is a rain of seeds and fruit, small organisms that have fallen, and frass (invertebrate fecal pellets). In the fall within the north-temperate zone, there is a large leaf drop in all hardwood and mixed forests. In winter there is a loss of evergreen needles (these are actually dropping year-around, but needles are conspicuous on new fallen snow), fragments of evergreen cones (as squirrels hunt for seeds), and twigs and branches (also a year around event, but accelerated by the weight of ice and snow during storms).

Grazers occur in streams, but algae in shaded reaches are usually limited to a fine biofilm that coats rocks and other solid objects. This biofilm also includes bacteria and fungi that feed on dissolved and fine particulate organic matter available in the water. So grazers in streams are really "scrapers" that eat algae, fine detritus, and microbes, essentially consuming the entire biofilm. In general, these aquatic grazers are generalists that also scrape leaf surfaces and consume the leaf surface biofilm (the leaf surface and the protein-rich microbes associated with it) (Hall et al 2001). Because scrapers eat so much leaf material, they are generally included in the detritivore community.

So the bottom of the food chain in a deciduous or mixed forest is the detritivore community. The diversity of these organisms and the efficiency with which they consume their food sources are reflections of ecosystem health, and a representation of the amount of carbon/energy available for higher trophic levels (like fish). Last year, leafpacks in treated areas had almost twice the decomposition rates of un-treated areas (Whiting 2012). Invertebrate species diversity was greatest for the treated leafpacks. Acid sensitive detritivores like amphipods and mayflies were especially abundant. However, this year was dominated by high flows in the spring and early summer, and leafpack weight loss appeared to be dominated by leaf fragmentation. The stream flows where so strong that some sondes (including the downstream one in the un-named tributary) were lifted from the stream bed by the current and were deposited in the floodplain. Thus stream turbulence rather than biological processes appeared to govern the leaf pack weight losses. There was no statistical difference in the treated, partially treated and non-treated leafpack loss rates (Kruskal Wallis test, H = 0.857, df = 2, p = 0.651) (Figure 7).

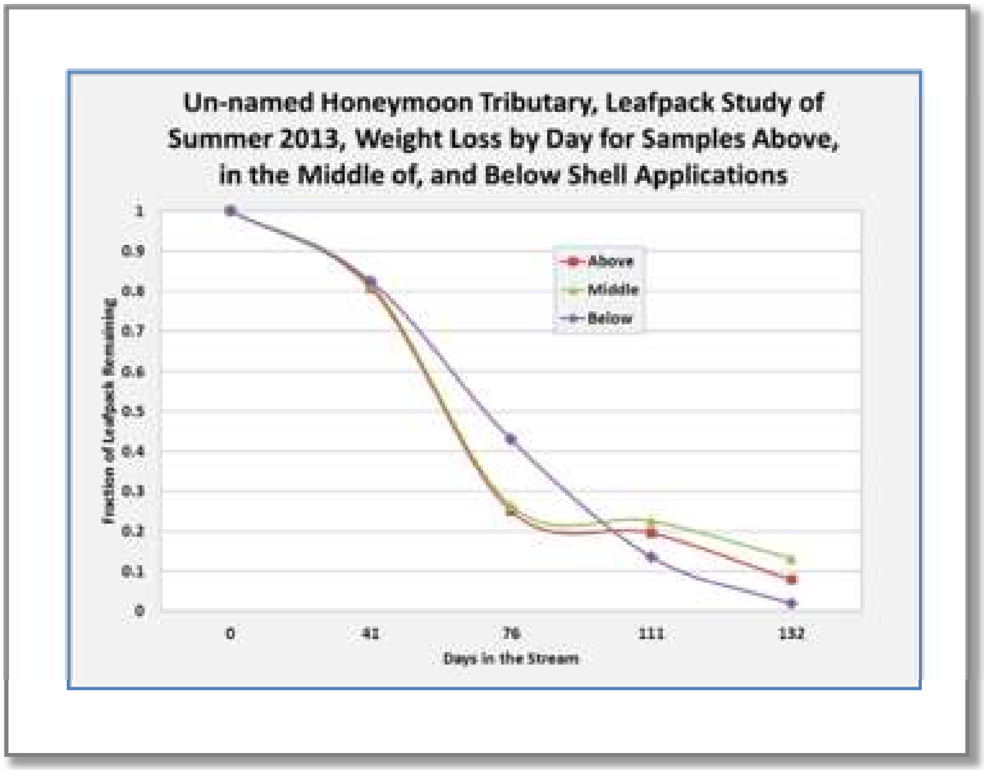


Figure 7. Summary of leafpack decomposition study, weight loss by day, for samples above, in the middle of, and below shell applications. The differences in the rate of weight loss among the difference pH conditions (no treatment, partial treatment, and full treatment) was not statistically significant in a Kruskal – Wallace test (p = 0.651).

As was the case with rock bags, the leafpacks were dominated by the EPT taxa. The dominant macroinvertebrate groups had some patterns, with mayflies appearing in July only at the treatment site, but later were found everywhere (Figure 8). Stoneflies preferred the middle and lower site (Figure 8), while caddisflies preferred the above and middle sites. Chironomids were found everywhere. Mayfly diversity was low (only 2 "species," Ephemerellidae and Leptophlebiidae). Last year in Dead Stream there were 3 mayfly taxa in leaf packs and in rock bags, the already mentioned families plus Hepatageniidae. Dead Stream had a higher initial pH and benefitted from an additional year of shell treatments. It clearly takes some time for macroinvertebrate assemblages to recover. In treated streams in Norway, Raddum & Fjellheim (2003) report that insect recovery was largely complete after 5 years, while the less mobile species (snails) took 10 years. Our leafpacks from 2013 had no mollusks, crustaceans (such as amphipods or crayfish) or Odonates (dragonflies and damselflies). This tributary to Honeymoon Brook was a very acidic site before liming, and this year was the second year of treatment. The mean pH is still only around 6.0 and acidic episodes still drop into the 4's. Acidic episodes, even if they only last a day or two, are known to have strong impacts on sensitive populations (Bernard et al 1990, Kowalik et al 2007). So, full recovery will be dependent on achieving better treatment.

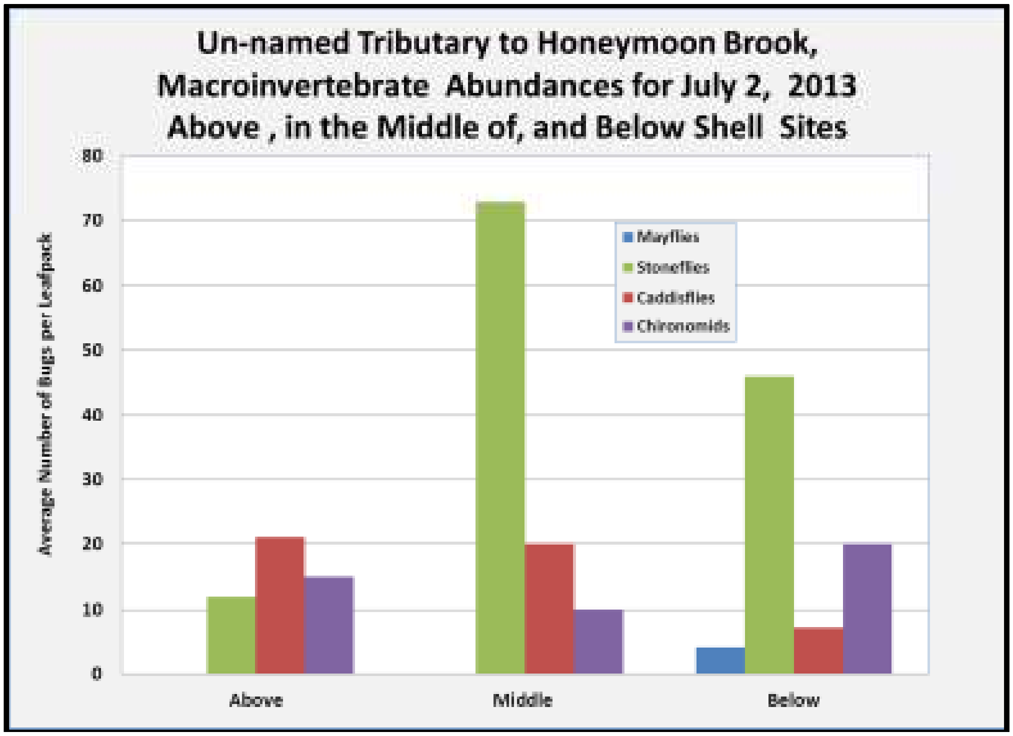


Figure 8. Summary of macroinvertebrates in leafpacks for July 2 showing the mean abundances for the most common groups.

IV. Conclusions

Given that the treatment levels are still below the ideal, SHARE's plans for 2014 are to complete the planned treatments and gradually to increase them. The goal is to keep pH above 6.4 even during high flow situations and to have calcium levels above 4 mg/L. In Norway, fishery scientists find that even if streams are not chronically acidic, i.e. have only mildly acidic episodes of short duration, there are losses of salmon smolts when pH falls below 6.5 (Staurnes et al 1995). Likewise, to avoid calcium-related mortalities of juvenile fish and to provide adequate nutrition to spawning fish, stream water calcium levels must be above 2 mg/L and should be above 4 mg/L (Danner 2004; Brockson, et al 1992; Sayer et al 1993). In southern Norway, where acid rain is a problem for forests and freshwater lakes and streams, the health of fish populations are thought to be more closely related to calcium levels than pH *per se* (Brown 1982).

It should be possible to approach these calcium and pH goals by increasing the dose beyond the single dose calculation. The West Virginia biologists typically apply a double dose to their streams because the treatment level is better for fish and endangered mussels (Clayton et al 1998). This is what SHARE is finding too. One issue is that there are a limited number of easily accessible stream crossings, and that additional stream bottom that has not already been treated is increasingly remote.

SHARE's NPDES permit allows treatment levels to be adjusted to achieve pH and calcium goals. However, the permit does not currently allow the use of limestone products. If a permit modification is accepted, SHARE proposes to use agricultural lime to experiment with some terrestrial applications. Floodplain wetlands adjacent to salmon nursery habitat will absorb the limestone and will leach excess calcium into groundwater over a period of several years (usually 3-5). The suggested dose is 10-15 tons/ha for riparian zones (Brockson et al 1992). This kind of application should reduce the need for shells and supplement the existing shell treatments. The limestone could be carried in 5-gallon buckets and be applied by hand. This approach, the use of terrestrial riparian limestone applications to treat acidic streams, was successfully tried in Nova Scotia on Maria Brook (west of Halifax, Biagi et al 2012).

Nova Scotia salmon have been recognized as being especially tolerant of humic-rich low pH water (Rossland et al 2001). This was originally attributed to the neutralizing effect of humic materials on aluminum, i.e., forming organic complexes that prevented damage to fish gills. That turned out to not be the case (Dennis & Clair 2012). The current thinking is that DOC is only partially successful in protecting fish from aluminum toxicity and only if streams are naturally acidic. Artificial acidification converts more aluminum to the toxic Alx form and this is an important problem in Nova Scotia. So Nova Scotia salmon may actually have a special acid adaptation after all.

Gjedrem and Rosseland 2012 concluded in their review of the literature that acid rain probably occurred too quickly for natural selection to produce fish that are adapted to more acidic conditions. No such genetic adaptation could be found in Europe. The authors concluded that salmon restoration should concentrate on the reduction of acid deposition and on river and lake liming to restore lost fisheries and to protect existing ones. However, in Nova Scotia where present day salmon streams have pH in the 4's and 5's and where the liming target is pH 5.5 or better (Halfyard 2008), there are still self-sustaining populations of salmon. It is clear that those rivers have become acidified in the 20th Century. But they also must have been acidic to begin with. If acid rain dropped river pH by about 1-1.4 pH unit (as it did in Norway, Anderson & Renberg 1992 and in Massachusetts, Halliwell 1989) then the original pH of Nova Scotia streams would be in the 5's and 6's. The fish in those rivers would have had about 10,000 years to evolved acid tolerances. This could explain why a liming goal of pH 5.5 is functional in Nova Scotia, but nowhere else. For all other populations of Atlantic salmon, the liming goal was originally at 6.0 or better (Degerman & Appleberg 1992), then was adjusted above 6.3 (Brockman et al 1992) and most recently set at 6.5 or above (Staurnes et al 1995). SHARE picked our pH goal of 6.4 from somewhat dated literature. The extinction of self-sustaining populations of Maine fish in our modestly acidic streams, and the poor performance of hatchery fish in eastern Maine, shows that our fish are not acid-adapted.

This suggests there could be alternative plans for salmon restoration in Maine. SHARE might (1.) use various liming techniques to bring the pH of our rivers up to a level that our fish will tolerate, or (2.) federal and state fishery agencies could experimentally begin to incorporate genetic material with acid tolerances in our hatchery program (possibly creating a Nova Scotia – Downeast Maine hybrid). This second suggestion is not realistic under the current understanding of the Endangered Species Act (ESA). The ESA is designed to protect and perpetuate the existing distinct genetic stocks. These are the endangered species. But what happens if the current genetic stock is adapted to an environment that no longer exists? Maybe there should be some changes in the law or in its interpretation. In the meantime, SHARE will have to do what others have done, and that is to modify the current chemistry of our streams to something that is more like the probable historical norm.

V. Plans for Next Year

The Downeast salmon rivers have systematic problems and SHARE is addressing them one by one. The habitat restorations will improve access to, and quality of salmon habitat. The liming project will restore water quality to the known tolerances of Atlantic salmon (which also happen to be protective for blacknose dace, alewife and many other species). There is good reason to be hopeful, since liming projects have worked well elsewhere. In West River, Sheet Harbor, Nova Scotia which is the size of the Pleasant (but has more salmon habitat as all the Downeast rivers combined, i.e., West River has 20,000 units, five Downeast rivers have 18,200 units) with only one-tenth of the river limed, it was able to produce 20,000 smolts in 2012. The Machias, the largest Downeast river with 7,000 habitat units, in the fall of 2013 had one redd (so maybe two returning adults). We need to restore entire rivers, not just isolated headwaters.

There are three kinds of liming projects, namely: (1) Protective Liming of a body of water to protect an existing resource (such as a fishery or endangered species), (2) Restorative Liming to bring back a resource that has been lost, and (3) Refuge Liming, treating a body of water (such as a cove, spawning habitat, or an upwelling cold spring) to make sure species under duress have a safe place to go (Gloss et al 1989). All of these are appropriate strategies for the Downeast Maine salmon rivers. Fortunately, there are good reference manuals with decision trees for different liming techniques (Gloss et al 1989, Olem et al 1991 and Brockson et al 1992).

Based on the experience of others, treating an entire river should lead to large improvements in populations. Sometimes these increases are 10-times, but also 30-times or more. This is what has happened in Nova Scotia, where the West River was limed using a mechanical lime doser beginning in 2009. The single doser was located far upstream on the main stem where there was a falls that prevented any additional migration for salmon. The liming goal was a pH of 6.5 or better at the doser, and pH 5.5 or better downstream where there are untreated tributaries that mix with the main stem. Post-liming the calcium levels are still low 0.56-1.8 mg/L in West River. In spite of the fact that headwaters and two major tributaries were not treated at all, the annual smolt run has gone from 1-3,500 per year to 15-20,000 in 5 years. All of this is natural reproduction, since the Canadian government shut down all the federal Atlantic salmon hatcheries in a cost-saving measure. West River is now producing about one smolt per habitat unit. The estimated smolt production rate for the Narraguagus River, the best of the Downeast rivers, is about 0.3-0.4 smolt per habitat unit.

Project SHARE needs to graduate from treating a few headwater streams and begin to develop the tools and experience needed to treat entire rivers. Brocksen et al (1992) established a decision tree for lake and stream liming. With respect to stream liming, they recommend treating headwater lakes as the first choice (the simplest and cheapest option), treating watersheds or water "discharge areas" (floodplains and wetlands) as the second choice, and treating streams directly as the least desirable option. According to the authors, watershed liming costs about 5 times that of direct lake liming, but it lasts longer. There are no established dose calculations for terrestrial liming, but a rule of thumb is 5-10 metric tons /ha for soils and 15-25 tons /ha for floodplain and wetlands (a metric ton is 1000 kg and is 2205 pounds) (Brocksen et al 1992). The Maria Brook riparian liming project used 5 tons/hectare (but then did another liming the following year).

Terrestrial liming is expected to stimulate forest production (i.e., faster tree growth, accelerated photosynthesis and transpiration, increased water use, increased mycorrhizal biomass, and more leaf biomass) (Green et al 2013). Terrestrial liming is also expected to favor some plants over others, for instance, broad leaf deciduous trees would be favored over conifers (Green et al 2013) and favor *Trillium* (Thompson & Sharpe 2005) and wood sorrel (*Oxalis*) possibly at the expense of some other species (e.g. some species of *Sphagnum* moss) (Degerman & Appleberg 1992). Increased forest growth might lead to less water runoff (by as much as 25% for whole watershed additions) due to evapotranspiration loss. Water yields from a whole watershed liming project resulted in a 10-25% reduction in stream flow at Hubbard Brook, New Hampshire (Green et al 2013). Forests with treated soils might begin a transition from softwoods to hardwoods, and there would be a gradual transition to less acidic leaf litter and soils, and less acidic runoff (Ivan Fernandez, University of Maine, personal communication). This transition might be beneficial for fish because of the decreased soil acidity, increased amount and quality of leaf litter, and better spread of the forest canopy (and summer shade) provided by hardwoods.

In order to treat whole rivers, SHARE will need to gain experience with the use of limestone. It is not realistic to suppose that entire rivers can be treated with 5-gallon buckets of shells. A watershed scale project will have to be mechanized, for example, using snowmobiles or farm tractors to spread agricultural lime on winter ice on lakes (Olem et al 1991). For the 2014 field season, SHARE proposes some small-scale experimental terrestrial limestone applications to gain experience with this technique. Applications will still be made by hand at existing project sites. SHARE plans to use agricultural or pelletized limestone.

Specifically for 2014, SHARE proposes to continue shell applications on the existing 5 project streams and use terrestrial liming to supplement or replace some of the shell dose. The proposed terrestrial dose is 5 tons/Ha per year (the lowest recommended rate) applied to forested floodplain wetland. The pelletized lime applications will avoid concentrations of *Sphagnum* moss. No beaver meadows (sedge – fen wetlands) are proposed at this time for limestone treatments. If successful, then shell treatments would be scaled back. As usual, the applications would be incremental and would be adjusted to achieve the pH, calcium and Alx goals.

VI. Acknowledgements:

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