Report to Project SHARE

Third Annual Report on Project SHARE's Acid Mitigation and Fisheries Restoration Project on Dead Stream and Bowles Brook, now Expanded to Honeymoon Brook, Canaan Brook, and First Lake Stream in 2012.

A Progress Report for 2012.

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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. In 2010, 2 metric tons of shells were placed in Dead Stream. In 2011, the treatment was expanded into the southern part of the watershed (Bowles Brook) and increased to 10 tons of shells. In 2012, the project was expanded to other tributaries of the Machias River, namely: Honeymoon Brook, Canaan Brook, and First Lake Stream. In Dead Stream, water chemistry has improved by approximately one pH unit, and total fish abundance has increased 8-fold within the study reach. Leaf packs were used to assess the condition of the detritivore community. In May of 2012, leaf packs were placed into clam shell Treated (Dead Stream site 1) and Untreated (Dead Stream site 2 and Honeymoon Brook) sites and sampled from June – October. Acid-sensitive mayflies and amphipods were abundant at the Treated site while stoneflies, caddisflies and chironomids were abundant at all sites. Leaf processing rates were significantly different ($p = 0.02$) between Untreated sites (weight loss ranged 0.6 - 1.2% per day) and the Treated site (1.7 – 2.0% per day). In Eastern deciduous forests, detritus from the riparian zone represents 99% of the food-carbon that supports aquatic ecosystems in first and second order streams (Fisher & Likens 1972). By adding buffering capacity, a more favorable environment for microbes and macroinvertebrate leaf processers has been created. This boost to the bottom of the food chain has apparently contributed to the greater fish abundance.

I. Project Background:

Project SHARE is a partnership between private landowners, local land trusts and conservation groups, with state and federal environmental and wildlife agencies involved in the restoration of Atlantic salmon in eastern Maine (see Project SHARE website http://salmonhabitat.org/home/). In November of 2009, Project SHARE was granted a Maine Pollutant Discharge Elimination System (MEPDES) permit #ME0002704, Maine Waste Discharge License (MDL) Application #W-009049-5Z-A-N Project SHARE Final Experiment Permit, T37, T31, T30 MD. This permit allowed clam shells to be placed in the Dead Stream- Bowles Lake Stream watershed as a 5-year experiment to mitigate for chronic and episodic acidification of these salmon streams. The permit requires water quality monitoring and an annual report to Maine Department of Environmental Protection (DEP). The first field season was 2010 and began with a single application of 2 metric tons of shell at Dead Stream at the 55-00-0 logging road. The second field season was 2011, included an intensification of the treatment of Dead Stream at three application sites with a total of 10 metric tons of shells applied within the watershed. This report is the third annual report and includes the continuation of the Dead Stream treatment and an expansion of the project to nearby Honeymoon Brook, Canaan Brook and First Lake Stream.

Project Scope:

Wild sea-run Atlantic salmon in Maine are in decline. Both freshwater and marine survival is poor. Maine sea-run Atlantic salmon populations are currently maintained only with a vigorous hatchery stocking program. In order to make salmon populations self-sustaining, both freshwater and marine survival must be improved. In freshwater, there are water quality problems from a combination of related factors, including acid rain and more than two centuries of intensive logging. The effect on soils has been to deplete base cations (calcium, sodium, potassium, and magnesium) from the most susceptible watersheds, resulting in chronic or episodic acidification of streams, low buffering capacity, low calcium concentrations, and high aluminum concentrations. The effects on fish are poor fish condition and low survival. Adding calcium carbonate to chronically or episodically acidified nursery steams is believed to be a short-term remedy. The project plan is to use clam shells as a source of calcium carbonate to improve water quality. The shells are dispersed thinly on the stream bottom, covering about 40% of the bottom, and they dissolved slowly. The stream dose is calculated using the baseflow summer pH and watershed size, and is based on experience with limestone treatments in West Virginia streams (Clayton et al 1998). The dose for a particular stream reach is achieved by adjusting the number of linear meters of stream that is treated. In other words, if the calculated dose is 2 tons, that amount of shell is spread on the stream bottom at a 40% coverage rate over enough linear meters of stream so that all the shells are used. Better water quality should lead to better fish health, growth and survival. The idea is to produce enough young salmon that the river-specific genetic stock can be perpetuated in the wild by natural reproduction. Because salmon restoration is tied to ecosystem health, the project evaluated other fish species, algae, macroinvertebrates, and leaf detritus processing.

To date the shells of, *Mya arenaria*, the common softshell or steamer clam, *Arctica islandica*, the mahogany clam or black quahog, and *Mytilus edulis*, the blue mussel have been used. These shells are a waste product from Maine's seafood industry and have been composted to minimize associated organic material that could cause reductions of oxygen in streams due to decomposition. These shells have the additional benefit of having a large complex shape that does not cause embeddedness of fish and macroinvertebrate habitat (i.e., the filling of interstitial spaces in stream gravel with fine sediments). Stream embeddedness due to limestone sand leads to decreased invertebrate densities (Keener & Sharpe 2005). In contrast, the voids between the shells provide habitat for invertebrates, fish eggs, and fish fry.

Dead Stream was the first study site. It received 2 metric tons of shell in 2010 (Figure 1, Table 1). In the summer of 2011, Dead Stream received another 2 tons and the treatment was expanded within the watershed to include two tributaries, Bowles Brook (called Bowles Lake Stream in last year's report) and an un-named tributary to Bowles Brook. Bowles Brook received 2 tons of shell in 2011 and the un-named tributary (which is smaller, but more acidic) received 6 tons. In 2012, the treatment of the Dead Stream watershed continued at the 10 ton level and the project was expanded to Honeymoon Brook, Canaan Brook and First Lake Stream. These streams are all tributaries to Old Stream, one of the larger sub-watersheds within the Machias River basin. Beaverdam Stream, a project site for next year, is a tributary to the East Machias River. After initial applications, maintenance treatments were used to replace shells lost by dissolution. This was accomplished by maintaining the 40% cover and the linear application area.

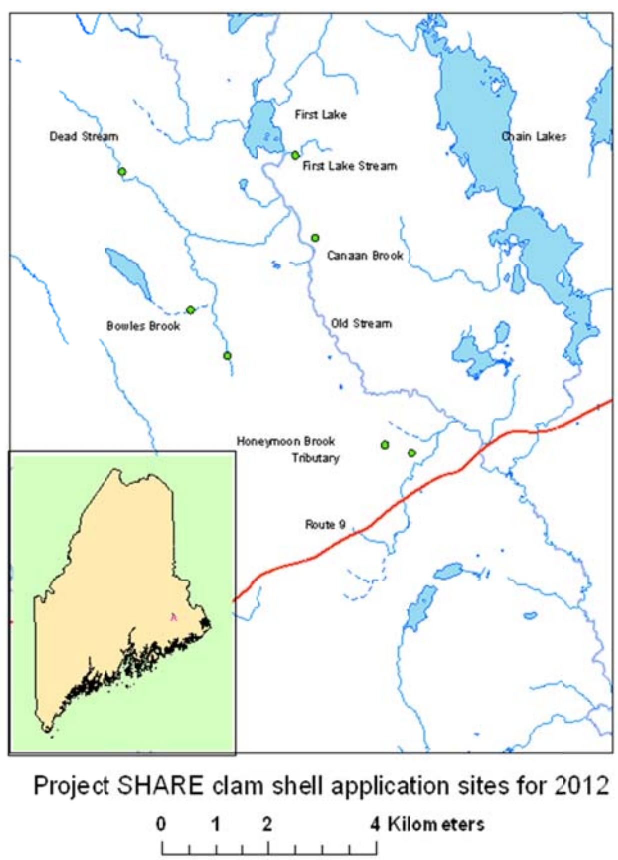

Figure 1. Seven Project SHARE clam shell application sites for 2012. All project streams to date are tributaries to Old Stream, one of the major tributaries to the Machias River. These streams are chronically acidified.

Honeymoon Brook and Canaan Brook do not show on USGS topographic sheets. Water quality sampling sites were in upstream and downstream positions with respect to the shell applications.

Table 1. Present and proposed study sites, with road access points, watershed characteristics (including average summer baseflow pH), shell application rates, and UTM locations. Actual application rates in 2012 for some of the new sites were less than desired due to extreme summer low flows. All UTM coordinate data is Zone 19N NAD83. Beaverdam Stream is a proposed site for 2013.

Study Site	Study Site (Road)	Watershed	Watershed Size	pH	Clam Shells Required Metric Tons [1]	Fish Present	Data Sondes	UTM E	UTM N
Dead Stream	55-00-0	Old Stream	236.1 Ha	5.8	3.5 tons	Yes	2	592,761	4,982,518
Trib to Bowles Br	55-50-0	Old Stream	207.3 Ha	5.1	5.97 tons	No		594,727	4,978,322
Bowles Brook	55-38-0	Old Stream	174 Ha	6.2	2.0 tons	Yes		594,214	4,979,321
Dead Stream[2]	58-00-0	Old Stream	1282 Ha Downstream water quality site		12 tons	Yes	1	594,942	4,980,684
Honeymoon Brook Trib	9-95-0	Old Stream	218 Ha	5.5	5.5 tons	Fish Kills Yes	2	598,359	4,976,870
Canaan Brook	59-00-0	Old Stream	18	5.2	1.1 tons[3]	Yes	2	596,868	4,979,788
First Lake Stream	59-00-0	Old Stream	246 Ha	4.7	11 tons	Yes	2	596,494	4,982,425
Beaverdam Stream	T 26 Road	E Machias	3329 Ha	6.2	33.3 tons	Yes	2	605,074	4,983,506

1. from Clayton et al 1998
2. a non-treatment site, monitoring only
3. a double dose is planned for this stream

The project acidity goal was to increase pH to around 7.0 during summer low flow and to maintain for as long as possible a pH of at least 6.4 during spring high flow (in this case "high flow" was defined as at least two-thirds bank-full). Perennial streams with good habitat and a summer time baseflow pH of 7.0, have abundant fish and no obvious acidity issues (e.g. Lanpher Brook and Harmon Brook). These streams will typically maintain pH values in the 6's even during spring high flows. For instance, Lanpher Brook will have no more than 5 days below pH 6.4 even after large storm events (Whiting 2009). For the Norwegian salmon restoration program (Staurnes et al 1995), rivers are limed in order to maintain a pH of at least 6.4 during the spring, before and during the salmon smolt run (February 1 through July 1). The Norwegian liming program uses computerized mechanical dosers, which provide much better pH-control than with limestone sand or clam shells. However, high-tech dosers are also very expensive and require electric power.

Composted shells were purchased from Maine's seafood industry. In 2012, SHARE purchased softshell calm shells from Albert Carver Inc., of Beals Island, Maine. The shells were delivered by dump trucks to stream-side storage areas on logging roads. The shells were then carried by hand in 5 gallon buckets to application sites and were distributed on the stream bed so as to cover approximately 40% of the stream bottom. Shells were also applied in the flood plain whenever there were clearly defined high flow channels. Terrestrial applications rates were about 80-100% cover, except that mosses and other small living plants were avoided. Because the shells had some remnant organic matter, shell applications with the new shells (purchased in 2012) were restricted to high flows and cold weather in the spring or fall. Shells purchased in previous years have been stored outdoors long enough that they have very little remaining organic matter. These cleaner shells were used for applications at Dead Stream during summer low flows. The summer of 2012 was hot and dry and Canaan Brook, the upper site on the Honeymoon tributary, and the lower site at First Lake Stream went dry in August. Due to low flows, Honeymoon and First Lake Stream did not receive full doses in 2012. Actual applications for 2012 and the estimated achieved doses (new shells plus shells remaining from last year) are provided in Table 2.

Table 2. Study sites with calculated doses, shells added in 2012, and estimated final dose for 2012. All of the shells still in the stream from last year were mahogany clam shells added last fall.

Study Site	Study Site (Road)	Watershed Size	Ave Summer pH	Clam Shells Required Metric Tons [1]	Clam Shells Actually Applied in 2012	Estimated Total Exsting and New Shells	Linear Meters of Stream Bed Treated
Dead Stream	55-00-0	236.1 Ha	5.8	3.5 tons	2.63 tons	3.5 tons	384 m
Trib to Bowles Br	55-50-0	207.3 Ha	5.1	5.97 tons	0.5 tons	6 tons	45 m
Bowles Brook	55-38-0	174 Ha	6.2	2.0 tons	0.5 tons	2 tons	113 m
Dead Stream	58-00-0	1282 Ha Downstream water quality site		12 tons	NA	10 [2] tons	
Honeymoon Brook Trib	9-95-0	218 Ha	5.5	5.5 tons	1.8 tons	1.8 tons	400 m
Canaan Brook	59-00-0	18	5.22	1.1 tons	1.4 tons	1.4 [3] tons	230 m
First Lake Stream	59-00-0	246 Ha	4.7	11 tons	5.47 tons	5.47 tons	515 m
Beaverdam Stream	T 26 Road	3329 Ha	6.2	33.3 tons	NA	NA	

1. from Clayton et al 1998
2. a non-treatment site, this is a watershed total
3. a little more than a double dose

The shells dissolve slowly, releasing calcium carbonate and thereby driving pH higher (less acidic). Softshell clams and blue mussels dissolve relatively quickly, and were gone in approximately 6 months. Mahogany clams have much heavier shells and take a year or more to dissolve (Scott Craig & Mark Whiting, unpublished data). Adequate calcium nutrition helps fish cope with acidic conditions and the toxic effects of aluminum (Brown, 1983; Danner 2004). Even in hatcheries, where fish are fed nutritionally-balanced foods, fish must have adequate amounts of calcium in their environment to maintain their body calcium (Danner 2004). In addition to the pH goals (a pH of at least 6.4 during high flows), the project tried to maintain dissolved calcium concentrations above 4 mg/L, a critical threshold for brook trout, Atlantic salmon and many other fish (Brockson & Olem 1992).

II. Methods:

In order to determine what dissolving shells add to freshwater, fresh shells were collected from Maine Shellfish, a seafood packing facility in Ellsworth, for laboratory analysis at the Soil Lab at the University of Maine, Department of Plant, Soils and Environmental Science. Approximately a dozen shells were sorted into a relatively clean fraction and a fraction that still had a lot of associated organic matter (especially the remains of mantle and adductor muscle) to provide a range of results. The shells were analyzed for total solids, total volatile solids, calcium carbonate equivalence, nutrients (calcium, total nitrogen, phosphorus), and metals (arsenic, cadmium, chromium, copper, mercury, magnesium, molybdenum, nickel, lead, selenium and zinc).

The effectiveness of the clam shell-based liming program was monitored in several different ways by different agencies (Table 3). For instance, field water quality measurements (water temperature, depth, pH, and conductivity) were monitored by Maine Department of Environmental Protection (DEP) using YSI model 600 XLM data sondes. These automated environmental recorders were programmed to take hourly measurements of water temperature, pH, depth, and conductivity in upstream and downstream locations relative to the shell sites. Sonde performance was checked in the field with an YSI EcoSense 100 pH meter and Oakton dual range EC conductivity pen. Lab chemistry parameters (major cations (calcium, sodium, potassium, magnesium), alkalinity (measured as Acid Neutralizing Capacity or ANC), dissolved organic carbon (DOC), total aluminum, organic aluminum, and exchangeable aluminum (Alx) were analyzed at the University of Maine Sawyer Environmental Chemistry Research Laboratory (SECRL) from water samples collected by DEP.

Table 3. Water quality and biological monitoring plan for 2012, with parties responsible. SHARE partners included the US Fish & Wildlife Service, Maine Department of Environmental Protection, and Maine Department of Marine Resources. The Downeast Salmon Federation and University of Maine at Machias provided labor for spreading shells.

Measurements	Method	Where	Analysis	When	Who
Water chem (pH)	Sonde	9 Sites	before/after up/down stream	hourly, May-Nov	USFWS/DEP
Water chem (pH Ca Al)	Grab	All Sites	before/after up/down stream	quarterly	DEP
Water chem (field pH, cond)	Field meter	All Sites	before/after up/down stream	monthly, May-Nov	DEP
Algae	Grab	All Sites	before/after	yearly	DEP
Leaf packs	Stroud Center[1]	3 Sites	before/after up/down stream	yearly	DEP
Macroinvertebrates	DEP[2]	4 Sites	up/down stream	2012	DEP
Fish abundance	E-fishing	Dead Str	before/after up/down stream	yearly	USFWS/DMR
Fish abundance	E-fishing	First Lake Str	before/after up/down stream	yearly	USFWS
Fish abundance	E-fishing	Canaan Br	before/after up/down stream	yearly	USFWS
Fish abundance	E-fishing	Honeymoon	before/after up/down stream	yearly	USFWS

1. Stroud Water Research Center, Leaf Pack Network Manual
2. DEP Biomonitoring protocol

Biological monitoring included algae, leafpack studies, macroinvertebrates, and fish. Algal blooms are one of the expected consequences of stream acidification, and are mitigated by liming programs (Hendrey 1982, Lampman et al 2008). Visible accumulations of algae, including algal blooms when present, were examined microscopically by DEP. Algal cover was estimated visually. Algal taxa were identified to the genus level for soft-bodied algae in fresh microscope slide mounts. Diatoms were examined at 1250X magnification in permanent mounts, and at least 500 individual frustules (silica shells) were identified to species level.

Leafpacks were used to assess the health of the detrital processing community. Thirty leafpacks were prepared using 20 g dry weight of American beech (*Fagus grandifolia*) leaves and were enclosed in a plastic mesh onion bag. Each leafpack was anchored on the stream bottom by tying it with nylon string to a lobster bait bag filled with approximately 5 kilograms of stone. Ten leafpacks were placed at each of 3 study sites (Dead Stream above the shells, Dead Stream below the shells, and Honeymoon Brook above shells). Two leafpacks were collected from each site at approximately one-month intervals from June through October for processing. Leaves were removed from their bags and placed in trays of tap water. Each leaf was washed free of sediment, macroinvertebrates were picked out, and the leaves were dried for 2 days at 35° C. Prior to weighing, the leaves were brought to room temperature for at least 24 hrs. Dried leaves were weighed to the nearest gram. The macroinvertebrates were sorted and identified into broad categories (such as mayflies, stoneflies, caddisflies, riffle beetle adults, etc.) and enumerated. The weight loss of the leaves was used to assess detritus processing rates (Petersen & Cummins 1974). A negative exponential decay model was used to calculate the slope (k) of the curve (k = decay rate, Petersen & Cummins 1974).

Macroinvertebrate monitoring was used to determine if Dead Stream and Bowles Brook meet their water quality classifications (both streams are Class AA, Maine's highest water quality classification (MRSA Title 38)). The methods followed established DEP protocols (Davies & Tsomides 2002). Rock bags were deployed for one month, from mid-August to mid-September. Rock bags were disassembled and washed in screen buckets in the field. Macroinvertebrates were recovered from the screen bucket and were preserved for additional processing. Species were identified to the species level whenever possible.

Fish populations were assessed by electrofishing standardized study reaches (in the case of Dead Stream a 200 m reach) using a single pass. Fishing was done by the US Fish and Wildlife Service (USFWS).

III. Results & Discussion:

Lab analysis shows that clam shells are primarily calcium carbonate with some phosphorus and trace metals (Table 4). The analysis is also affected by the organic remains from the meat. The first composite (called Clam 1, actually approximately a dozen shells) were the dirty ones while the other composite (Clam 2) were the relatively clean ones. By comparing the two samples, it was possible to make inferences about the contribution the organic fraction makes to the total. For instance, most metals, total nitrogen, and phosphorus were richest in the organic-rich Clam 1 composite. Fresh shells from the packing plant were about 15% water and 4-7% flesh. The shells are around 91.2% calcium carbonate by dry weight, with some phosphorus and magnesium.

Table 4. Summary of an analysis of fresh softshell clams from the Maine Shellfish meat packing plant in Ellsworth. The analysis from the U of Maine, Soils Lab shows total solids (T Solids) as percent wet weight ("as is" from the packing plant but sorted into a "clean" and "dirty" pile). All reported weights are based on dry weights. The organic fraction is what is lost on incineration (TVS= total volatile solids). The carbonate content shows as carbonate equivalence (CaCO3 Eq). TN is total nitrogen.

Parameter	Units	Clam 1	Clam 2
T Solids	%	72.5	85.5
TVS	%	6.88	4.43
CaCO3 Eq	%	87.6	91.2
TN	%	0.74	0.23
Ca	%	39.5	41.3
As	mg/kg	9.73	2.84
Cd	mg/kg	< 0.70	< 0.70
Cr	mg/kg	1.06	0.157
Cu	mg/kg	50.6	16.6
Hg	mg/kg	< 0.08	< 0.08
Mg	mg/kg	743	413
Mo	mg/kg	1.00	1.08
Ni	mg/kg	2.10	< 0.80
P	mg/kg	1254	318
Pb	mg/kg	3.31	3.90
Se	mg/kg	< 0.07	< 0.07
Zn	mg/kg	39.4	11.7

In order to be certain that diseases were not introduced into salmon streams with the shells, all shells used in stream treatments were composted for at least two months and were stored outdoors. Rain washed away the compost on the outer exposed shells, but shells deep in the pile retained organic matter and some associated odor for several months after the initial composting. Presumably, some of the metals associated with the organic fraction remained with the shells even when they were used months or years later.

Arsenic was found in high concentration in clams that were contaminated with clam tissue (9.73 mg/kg in Clam 1) and was much lower in the relatively clean fraction (2.84 mg/kg in Clam 2). Arsenic is a common trace element in the earth's crust (average 2.0 mg/kg), and is found in trace amounts in ocean water (1-2 ug/L), and in unpolluted freshwater (1-10 ug/L) (WHO 2002). Granite and many other volcanic rocks tend to have average concentrations of arsenic (around 2 mg/kg), while some sedimentary and high-sulfur rocks may have very high arsenic (to 900 mg/kg). In an 8-year study of 20 lakes along the Maine – New Brunswick border, arsenic within the Saint Croix watershed ranged from < 1 μg/L to 2.6 μg/L. The non-detects were the most common result, with 170 of 176 arsenic values below 1 μg/L (St Croix IJC 2012). Relatively high arsenic content is typical of seafood and marine shells (range 1< to 100 mg/kg) (WHO 2002). Fortunately, the organic forms of arsenic which are found in seafood are considered safe for human consumption (Wisconsin DHS). Arsenic in shells is incorporated in mineral forms which are potentially harmful. Arsenic salts have a wide range of solubilities in freshwater, depending on the pH and ionic environment, and have variable affinities for adsorbing to clays, iron oxides, aluminum hydroxides, and organic matter (WHO 2002). In well-oxygenated freshwater environments, arsenic-containing minerals generally weather to form the less toxic arsenate (As (V)). The more toxic arsenite (As (III)) dominates in oxygen-poor environments such as lake, river, and marine sediments and in some organic forms. Arsenate and arsenite are inter-convertible by various chemical and biological processes. The Maine drinking water standard for arsenic is 0.01 mg/L (10 μg/L) (Maine Center for Disease Control & Prevention).

When freshwater pH is moderate to alkaline (pH 6-8), arsenate forms harmless co-precipitates with iron, manganese, and aluminum compounds (WHO 2002). Arsenic also forms complexes with dissolved organic matter, such as humic and fulvic acids, found in naturally colored freshwaters (Dutton & Fisher 2012). Even in relatively clean shells from Maine's seafood industry (Clam 2), the 2.84 mg/kg concentration includes both mineral and organic arsenic. The mineral fraction is of most concern (an unknown number less than 2.84 mg/kg), which presumably would still be slightly higher than the average concentration for the earth's crust (2.0 mg/kg) and for average granites. Arsenic is more soluble in acidic or alkaline water than in surface water with pH 6-8. So the shells have a double effect, they add arsenic, but they also produce an environment where arsenic and other heavy metals form harmless precipitates. Biomagnification in freshwater food chains have not been observed, but occurs in some seaweeds and some terrestrial plants (WHO 2002). Since arsenic was not monitored in these streams, the baseline and post-treatment concentrations are unknown. Some follow-up monitoring of arsenic in treated streams is planned for 2013.

a. Water Quality – The Sonde Records

While the spring and fall of 2012 were very wet, the summer was hot and dry. By October 2012, after 16 consecutive months of record high temperatures, the year was on track to become the hottest on record for the lower 48 states (the record began in 1895, NOAA, NCDC). July 2012 was the hottest month on record. In spite of dry weather in July-August, Maine had an overall normal water year (NOAA, NCDC). The smaller streams, such as the upstream site on the tributary to Honeymoon Brook, both upstream and downstream sites on Canaan Brook, and the upstream site on First Lake Stream went dry in August. Since the pH probe can be damaged if it dehydrates, the sondes were retrieved (Canaan and First Lake Stream) or moved to isolated pools (Honeymoon). The un-named tributary to Bowles Brook also went dry, but this was not a sonde site in 2012.

For Dead Stream, this was the second year after the initial clam shell additions in 2010, and the first full year after the intensified watershed-wide treatment in 2011. The 2012 treatment for Dead Stream was essentially identical to last year. The sonde records (Figure 2) showed that the two downstream sites had improved pH that carried over from last year. The increases ranged from around 0.5 pH unit in wet weather to 1.0 pH unit in dry weather. These sites barely reacted to new treatments this year. Some shells were added at the end of July in warm and dry weather. Because these shells were stored outside for two years they had very little odor or organic residue, and were suitable for summer in-stream applications. No loss of dissolved oxygen was observed. As noted last year, the baseflow treatment level achieved the desired pH around 7.0, but the pH continues to fluctuate over 1.5 pH units during some high flows. Unfortunately, these pH extremes often coincide with sensitive life stages for salmon such as spring smolting, annual fry stocking, emergence of fry from natural redds and fall spawning.

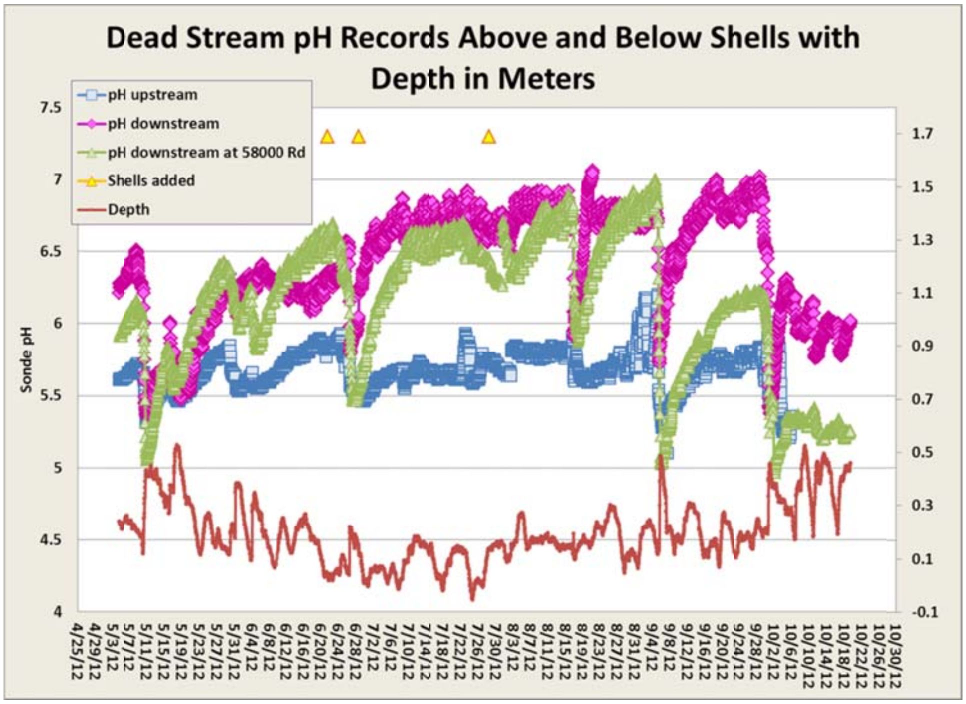

Figure 2. Sonde pH records and stream depth in meters for Dead Stream sites. Upstream (no treatment) sites and downstream (treatment) sites below clam shells were already different due to shell treatments in 2010 and 2011. The 2012 shell application dates are indicated by yellow triangles. The farthest downstream site, at the 58-00-0 logging road, received treatment from both Dead Stream and the Bowles Brook watersheds. The dips in pH correspond to storm events (note stream depth in meters on right axis). The depth record is from the upstream sonde.

For the un-named tributary to Honeymoon Brook, the upstream and downstream pH records were somewhat different even before treatment (Figure 3). The downstream sonde was deployed first in early May. The upstream sonde was deployed in mid-May and the first shells were applied at two access sites in mid-June. Comparing the May records, the downstream site had lower pH during high flows and similar but slightly higher pH during baseflows. After shells were added in June, the difference in the two sites during baseflow was approximately one pH unit. The second shell application was in late June during a rainy period when pH was low. Except for the strongest rain storms, the downstream pH was around 0.5 pH unit higher even during wet spells (note the early October record). The achieved dose for 2012 for the tributary was only about one-third (32.7%) the needed dose. Very high pH observed at the upstream site (values around 6.5) in late July and again in early September was due to extreme low flows and the concentration of groundwater in isolated pools. The remnants of Hurricane Isaac arrived in Maine on September 5th.

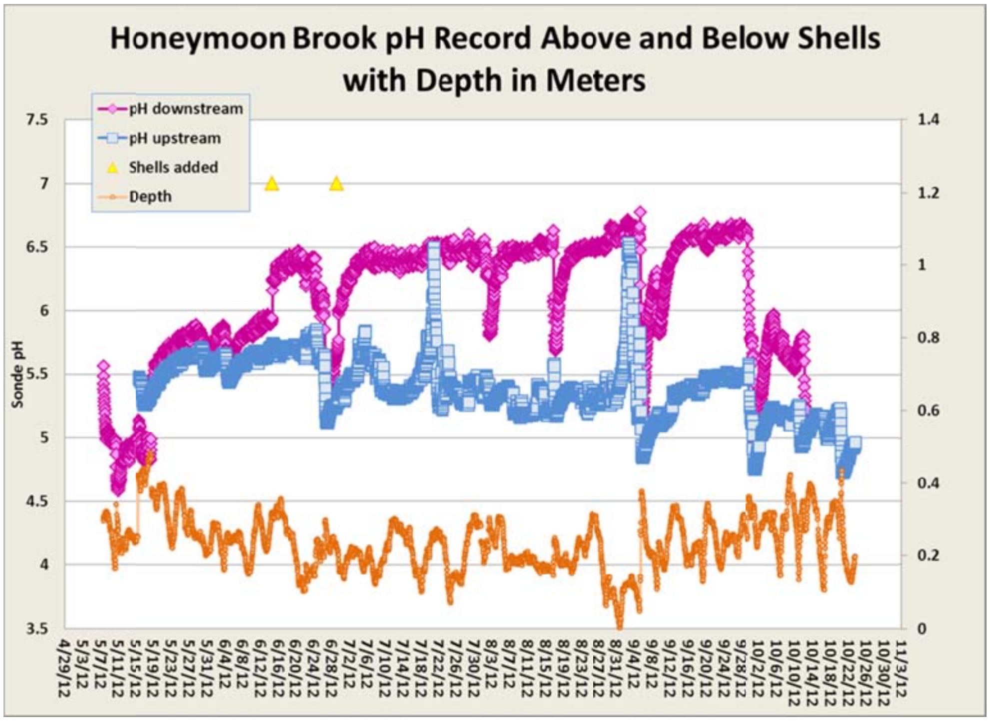

Figure 3. Sonde pH records and stream depth in meters for the Honeymoon Brook tributary sites. Shells were added for the first time on June 14, 2012. The depth record is from the downstream sonde.

The Canaan Brook upstream and downstream sonde records bear little relationship to each other even before clam shells were applied (Figure 4). The headwaters of Canaan Brook are mostly forested wetland with some sedge marsh wetlands, above the 59-00-0 logging road. The downstream record was consistently lower (by as much as 1.25 pH unit) and pH was more variable before shells were added. This was probably due to spring seepage below the 59-00-0 Road, especially where the slope steepens at the lower sonde location. Usually groundwater is colder and better buffered than surface waters, but in this case the temperature was essentially unchanged and the pH was lower. This could be due to a shallow trajectory and extended soil residence time for shallow groundwater (for instance, a shallow impermeable layer could route groundwater in shallow lateral sub-surface flows that increased contact time with organic (and acidic) soil layers, this would also account for the higher DOC downstream, see discussion on lab chemistry below). Even with the shells in place, the downstream site had both the highest and lowest pH recorded in the watershed. The lowest pH values always occurred after rain storms and were in the high 4's. SHARE planned a double dose in this watershed in order to evaluate the potential for additional benefits from larger carbonate doses. The West Virginia liming program typically uses a double dose for the initial dose and then uses either single or double doses thereafter for maintenance (Clayton et al 1998). The calculated dose for 2012 for this stream came from the pH measured at the upstream site. The "double dose" turns out to be close to a single dose value of 1.08 ton when based on a pH of 4.5 for the lower site.

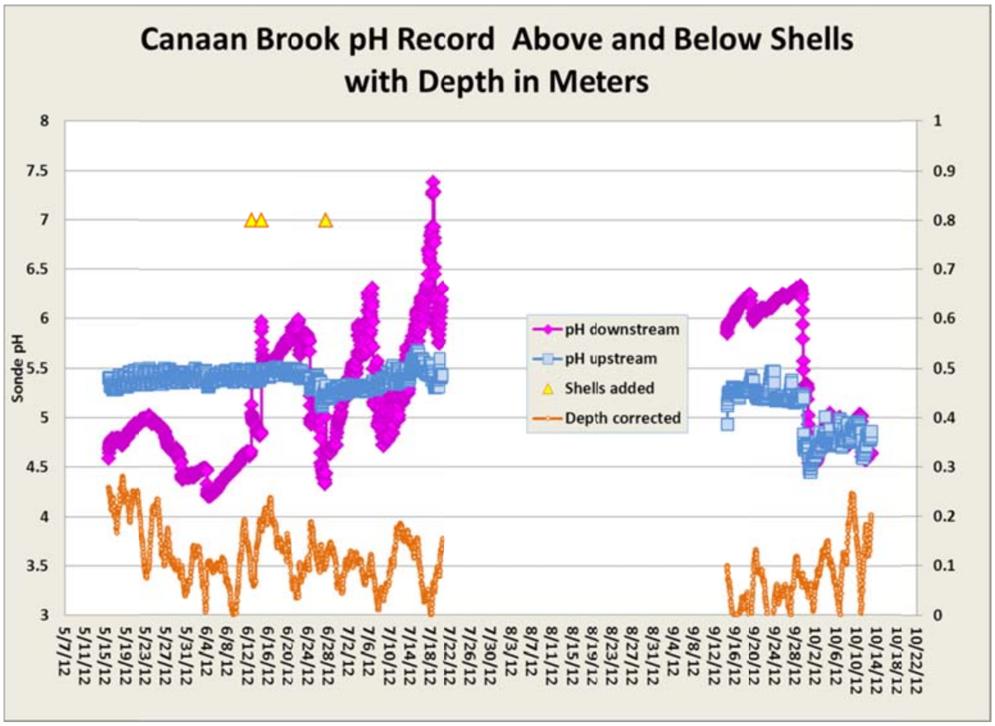

Figure 4. Sonde pH records and stream depth in meters for Canaan Brook. The gap in the record for mid-summer is due to the stream drying up. The depth record is from the downstream sonde.

Canaan Brook was the smallest of the study sites (a watershed of only 18 hectares) and it dried up completely in July. The remnants of Hurricane Isaac replenished the eastern Maine salmon streams on September 5 with up to 3 inches of rain in some watersheds. However, the sondes were redeployed the following week.

Before shells were added to First Lake Stream, the upstream and downstream pH records were very similar. However, the downstream pH was approximately 0.1 pH unit higher during both baseflow and storm flows (Figure 5). There were three shell applications, with the last one in July. The July application was limited to dry high flow channels. The two initial applications resulted in very high pH, as high as pH 7.0, and then quickly settled to approximately a 0.75 pH unit improvement. Softshell clam shells are thin and fragile, and shoveling shells into buckets results in some breakage. The initial pH spikes are due to the rapid dissolution of shell fragments associated with handling.

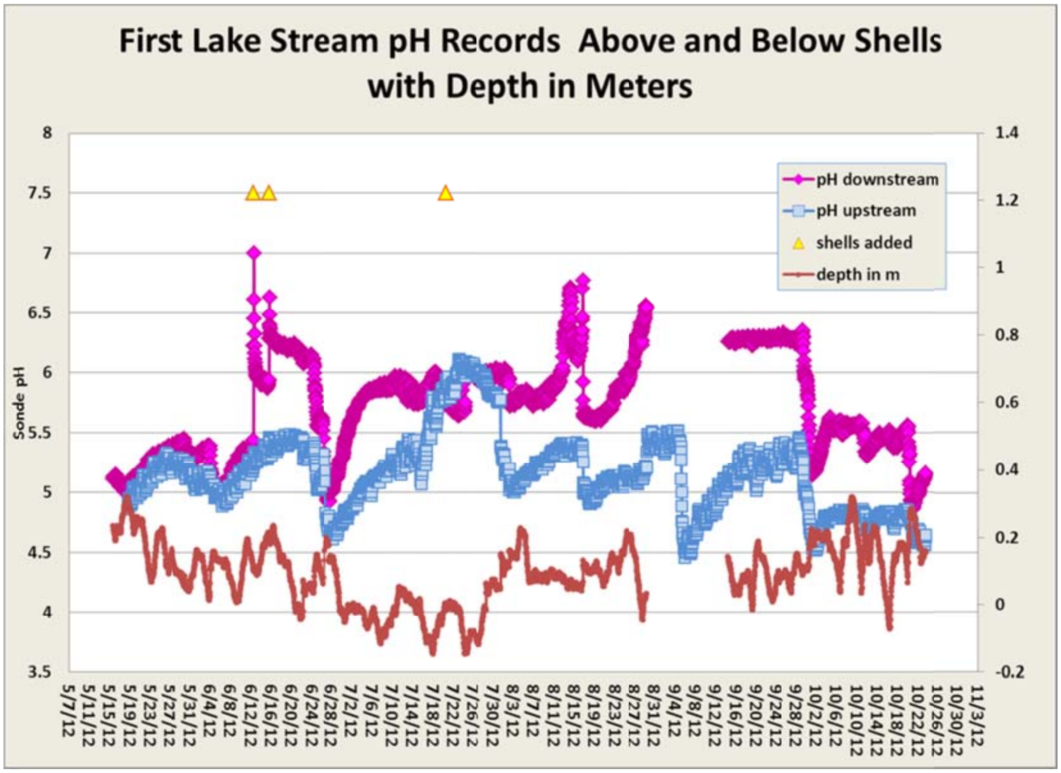

Figure 5. Sonde pH records and stream depth in meters for First Lake Stream. The downstream sonde was removed in late August due to low flows. The depth record is from the downstream sonde.

Due to summer heat and low flows, the downstream sonde was recovered at the end of August. This sonde was restored to the downstream location after Hurricane Izaac on September 5. The improved pH of about 0.75 pH unit persisted during high flows. However, the treatment pH remained well below the project targets of 6.4 and 7.0 for high flow and baseflow, respectively. First Lake received only 50% of the planned shell dose for 2012.

b. Water Quality – The Lab Chemistry

Water quality has improved at all downstream sites. Alkalinity has doubled in most cases, and was sometimes as high as 6-times the upstream values during low baseflows at the Honeymoon tributary (Table 5). Lab pH has improved. In Dead Stream, the pH was near 7.0 during high flows, and not quite as good at the lowest Dead Stream site. Only Dead Stream, Bowles Brook and Canaan Brook have received the full single doses this year. First Lake Stream and the tributary to Honeymoon Brook needed 2-3 times as much shell, respectively. Calcium levels were higher at all treatment sites, but even at Dead Stream and Canaan Brook which received the highest doses, the levels are often critically low.

Table 5. Lab analysis of water samples from above and below shell application sites for 2012. Samples from the same date are alternately shaded or not, to help the reader locate upstream – downstream comparisons. Restoration goals were a baseflow pH of 7, high flow pH ≥ 6.4, calcium ≥ 4mg/L, and Alx ≤ 24 µg/L. Lab analysis was provided by the University of Maine, Sawyer Environmental Chemistry and Research Lab (SECRL).

	Date	Flow Type	Relative Depth	ANC ueq/L	pH	Ca mg/L	Al x ug/L	DOC mg/L	Total P ug/L
Dead Stream Upstream	6/19/12	Baseflow	Low	119	5.99	1.99	20	16	28
Dead Stream Downstream	6/19/12	Baseflow	Low	277	7.02	3.06	9	9	21
Dead Stream Farther Downstream	6/19/12	Baseflow	Low	162	6.71	2.13	21	10	16
Dead Stream Upstream	8/27/12	Baseflow	Low	161	6.03	3.14	36	28	--
Dead Stream Downstream	8/27/12	Baseflow	Low	306	7.07	5.46	12	18	--
Dead Stream Farther Downstream	8/27/12	Baseflow	Low	299	6.99	3.81	9	15	--
Dead Stream Upstream	10/11/12	Storm flow	High	84	5.55	2.67	31	27	17
Dead Stream Downstream	10/11/12	Storm flow	High	120	6.02	3.26	39	26	18
Dead Stream Farther Downstream	10/11/12	Storm flow	High	72	5.55	2.47	26	26	--
Honeymoon Upstream	6/19/12	Baseflow	Low	42	5.84	1.02	29	8	--
Honeymoon Downstream	6/19/12	Baseflow	Low	100	6.56	2.09	18	5	--
Honeymoon Upstream	8/27/12	Baseflow	Very Low	66	5.67	1.37	67	10	9
Honeymoon Downstream	8/27/12	Baseflow	Very Low	470	6.8	8.51	7	3	16
Honeymoon Upstream	10/11/12	Storm flow	High	24	5.07	1.9	83	24	--
Honeymoon Downstream	10/11/12	Storm flow	High	31	5.26	2.67	76	21	--
Canaan Brook Upstream	6/19/12	Baseflow	Low	33	5.56	0.82	25	7	--
Canaan Brook Downstream	6/19/12	Baseflow	Low	107	6.28	2.43	13	9	--
Canaan Brook Upstream	8/27/12		Dry						
Canaan Brook Downstream	8/27/12		Dry						
Canaan Brook Upstream	10/11/12	Storm flow	High	32	5.14	1.99	35	21	--
Canaan Brook Downstream	10/11/12	Storm flow	High	-2	4.62	2.57	34	34	--
First Lake Stream Upstream	6/19/12	Baseflow	Low	50	5.59	1.08	28	17	--
First Lake Stream Downstream	6/19/12	Baseflow	Low	142	6.34	2.92	41	16	--
First Lake Stream Upstream	8/27/12	Baseflow	Very Low	77	5.61	1.91	43	29	--
First Lake Stream Downstream	8/27/12	Baseflow	Very Low	158	6.13	2.85	56	20	--
First Lake Stream Upstream	10/11/12	Storm flow	High	22	4.85	2.33	62	33	--
First Lake Stream Downstream	10/11/12	Storm flow	High	40	5.1	2.56	49	32	--

Toxic exchangeable aluminum (Alx) was generally lower, except at First Lake Stream where Alx increased. This might be due to the poor levels of treatment achieved this year at this site. Increases in Alx can occur in "mixing zones." A mixing zone occurs when an alkaline material is added to acidified streams or lakes. As the pH changes, the equilibrium between the different forms of aluminum also changes (the forms of aluminum are organic-bound dissolved Al, particulate Al, and the free ionic form Alx). As a new equilibrium is being formed, the actively changing aluminum is available to interact with fish gills causing gill damage (Rosseland & Hindar 1991). Mixing zones can result in higher levels of Alx (Kroglund et al 2001; Poleo et al 1993). These changes take place quickly and so are limited in time and space, but this is one of the few negative but unavoidable effects of liming. Fish avoid these mixing zones. The final result of this change is that calcium carbonate reduces aluminum and heavy metals by precipitating them in harmless mineral forms (Flick et al 1982). SHARE made a decision to initiate treatment in the upper part of watersheds in order to isolate the mixing zones above the best salmon habitat.

Whenever the pH is below 6.0, depending on how long the exposure is, any concentration of exchangeable aluminum above 20 μg/L will damage fish gills and can be fatal for Atlantic salmon smolts (McCormick & Monettte 2007). Last year the maximum Alx in treated parts of Dead Stream was 88 μg/L (at the Dead Stream crossing on the 58-00-0 Road during high flow, Whiting 2011). This year the Alx levels in Dead Stream were lower, with a maximum observed value of 39 μg/L. This coincided with a pH of 6.02, which is also a mitigating factor. Honeymoon and First Lake Stream had maximum values of 76 and 56 μg/L, respectively. But these streams are yet to receive the full dose of shells. Canaan Brook had fairly low Alx in spite of having high DOC and low pH.

Dissolved organic carbon (DOC) has also declined below treatment areas (except at Canaan Brook where low initial downstream pH may have been due to extended contact with the soil organic horizon). Stream chemistry and soil solution chemistry are closely linked (McDowell & Likens 1988). DOC enters streams with rain water falling through the forest canopy, and then picks up additional DOC when percolating through forest soils (McDowell & Likens 1988). High concentrations of DOC give many Maine streams their typical tea color. This is not harmful. DOC actually helps to bind metals such as arsenic and aluminum in complexes that are not taken up by fish. Conversely, with episodic swings to lower pH, the metals can desorb from the DOC and revert to toxic forms. Since a large fraction of DOC are organic acids (such as humic and fulvic acids) an increase in pH will tend to neutralize them. When not in ionic form, the organic acids are less soluble in water and may polymerize, aggregate and precipitate.

Total phosphorus was not one of the regular analytes. Because phosphorus is one of the components of clam shells, some spot checks were done in 2012. Post-treatment, Honeymoon Brook might have increased total phosphorus while Dead Stream probably did not; but no conclusions can be made given the limited data set. Phosphorus is often considered to be the limiting nutrient in freshwater lakes and streams where it can govern primary productivity (i.e., productivity due to photosynthesis). The observed levels are considered normal - high for Class AA salmon streams. However, for small forested streams, primary productivity is typically more limited by shade due to forest cover than by nutrients (Fisher & Likens 1972).

c. Algae

Before Dead Stream was limed, algal blooms were observed in sunny exposures above and below Dead Stream at the 55-00-0 Rd culvert and at the un-named tributary to Bowles Brook on the 55-50-0 Road. The reason why weedy algae species can bloom in acidic environments is not known, but probably has to do with release from competition with acid-sensitive species. Blooms have not occurred after liming (Whiting 2011).

The only noticeable algal concentrations found in the streams new to the 2012 field season, were found in the sunny marshes above First Lake Stream (Figure 6) and Canaan Brook. The algae observed at First Lake Stream were a mix of Green algae *Tetraspora, Spirogyra, and Mougeotia* and diatoms. These species are also common in roadside ditches in Maine. These blooms occurred above the 2012 shell application sites and so are not expected to change. The treatment areas were all deeply shaded, except for sunny exposures at road crossings. Plant life in treated areas included some moss, at times forming dense cushions on rocks, and only a few aquatic vascular plants (such as burr reed, *Sparganium* spp and water crowfoot, *Ranunculus aquaticus*). Diatom films were observed on rocks, but rarely formed visible accumulations in 2012.

Figure 6. Photo of algae at First Lake Stream in the beaver dam meadow above the 59-10-0 logging road. This algal bloom covered over 80% of the stream bottom at this non-treatment site. High algal cover was restricted to sunny marsh areas and was not observed in the forested parts of the watershed.

There are no TP data from First Lake Stream at this time. However, pH was chronically around pH 5.5. Summer pH can reach pH 6.0 or more during extreme low flow conditions. There was a good brook trout population, but no Atlantic salmon are stocked here and none have been observed here.

d. Leafpacks

Detritus from the terrestrial environment is extremely important to the carbon budget of small forested streams. For instance, in Bear Brook, New Hampshire (Hubbard Brook Experimental Forest) organic carbon primarily from the stream-side riparian zone, constituted 99% of the carbon budget (Fisher & Likens 1972). Photosynthesis within the stream (mostly from mosses) constituted about 1%. Thus, leafpack studies are thought to accurately reflect the overall energetics and food web health of small streams in forested temperate watersheds (Petersen & Cummins 1974).

The leafpack study occurred at three sites, upstream and downstream of the shell application site on Dead Stream, and an upstream site on the Honeymoon tributary. The Honeymoon site will become a treatment site in 2013 as the clam shell applications within the tributary stream are expanded upstream to improve pH results. The decomposition patterns for six pairs of leafpacks are given in Figure 7.

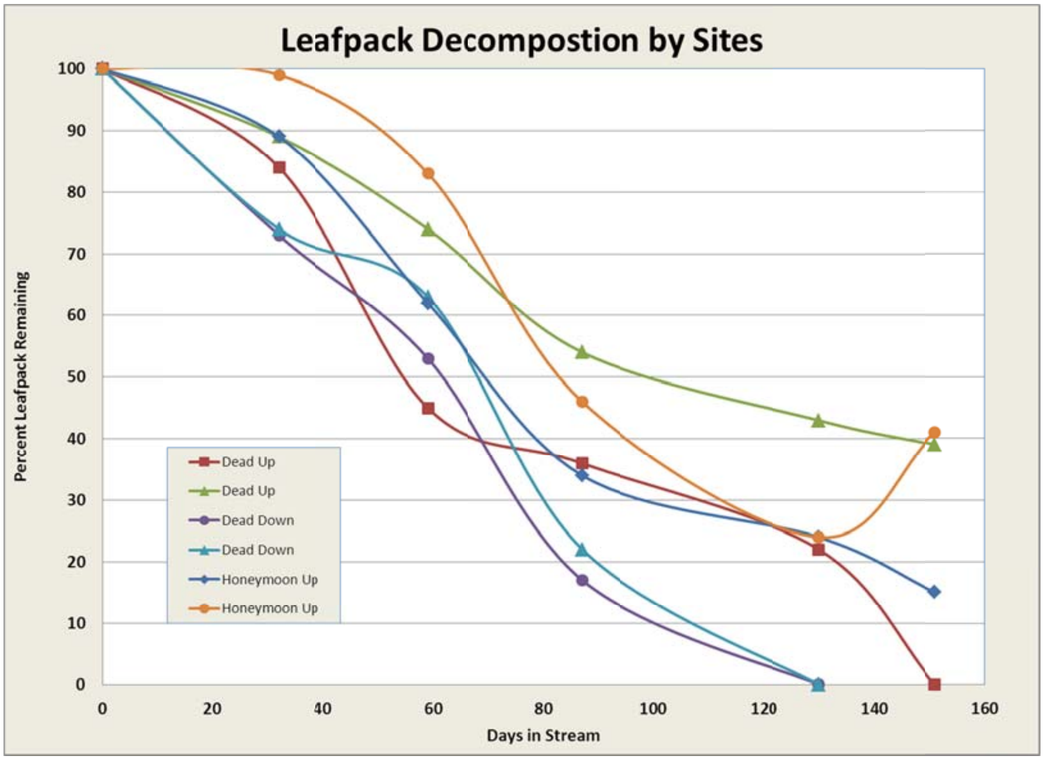

Figure 7. Leafpack decomposition as a percentage of the weight of leaves remaining on a given sample date. The leafpacks were deployed in early May at upstream (2 sites) or downstream (one site) locations relative to clam shell treatments. Two leaf packs were sampled each month from June – October. The leaf weights were sorted into the "fast" and "slow" values so as to provide a range of decay rates for each site and sample date. The curved lines only connect the dots, and do not represent a particular model.

Traditionally for leafpack studies, the leaf processing rate is calculated as the slope (k) of an exponential decay curve (Petersen & Cummins, 1974), although linear and multivariate models have also sometimes been used (Webster & Benfield 1986). The average processing rate for the upstream leafpacks was k = 0.0102 (S.D. = 0.0029, n = 4) with a range of 0.0062 to 0.0120 (around 1% per day or less by dry weight). While the average rate for downstream leafpacks was k = 0.0185 (S.D. = 0.0020, n = 2), and the range was 0.0170 to 0.0200 (almost 2% per day). The two non-treatment sites had a significantly lower leaf processing rate ($p = 0.02$, $df = 4$) in an un-paired t-test compared to the treatment site. In other words, the treatment leafpacks were processed at 1.7 to 2.7 times the rate of non-treated leafpacks.

Most leafpack studies begin in the fall and end in the winter or spring. In these studies, processing rates of 2% per day are considered "fast" (such as for soft leaves like maple or poplar) and 1% to 0.5 % per day are considered "medium." Rates below 0.05% for winter decomposition are considered "slow" (and are expected for tough leaves such as oak and beech, Webster & Benfield 1986). But leafpacks are year-around features of streams. Spring freshets often pick up a new load of leaves as streams overflow their banks into the floodplain. Also some trees like oak and beech hold on to some of their leaves through the winter and release them in the spring with the sprouting of new leaves. Unfortunately, summer studies of leafpack decomposition are uncommon, so a good comparison with other Eastern US deciduous forests was not available. One year-around leafpack study found that box elder (*Acer negundo*, a type of maple) in Utah alpine streams had summer leaf processing rates of 2-4% per day (McArthur et al 1988) with a maximum in July. But Maine streams are warmer than alpine streams (Utah summer averages ranged 7-9 ° C for different elevations, the Dead Stream July average was 23°C in 2012), and beech leaves are tougher than maple.

With respect to the macroinvertebrates, only the mayflies, stoneflies, caddisflies, chironomids (midges) and amphipods were abundant enough in most samples to be graphed with respect to their abundance and distribution. The results for mayflies are given in Figure 8. Mayflies were found in all samples. However, most mayflies were found at the treatment site (59% of all mayfly occurrences, even though there were two upstream sites). In September, even though only some entangled twigs, moss and fine peat-like detritus were found in the downstream leafpacks, macroinvertebrates were present and were enumerated. In October, the empty leafpacks had been removed, so there were no downstream samples. The downstream leafpacks had most of the mayflies but represented only 4 of 15 potential samples, or 27%.

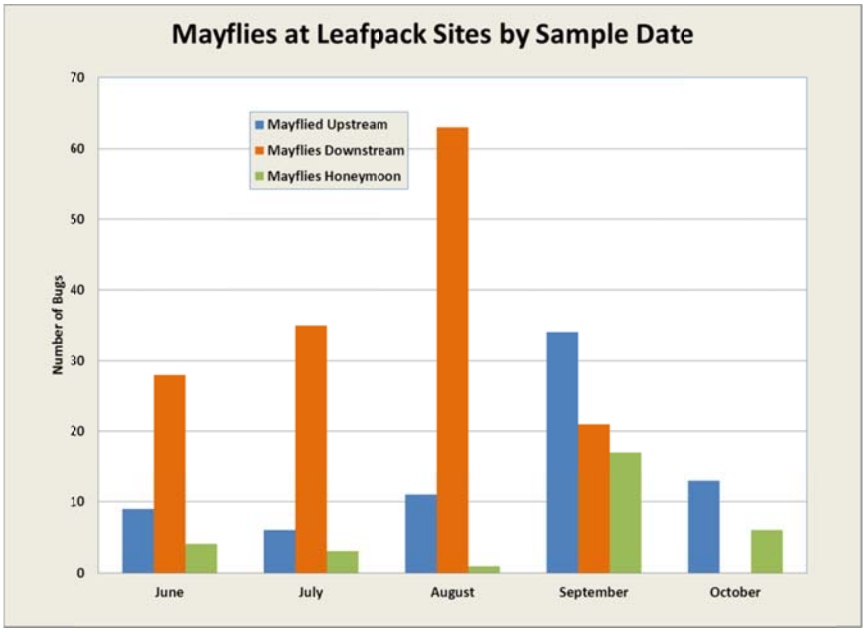

Figure 8. Abundance of Mayflies found in leafpacks in Dead Stream upstream and downstream (treatment) sites, and at the Honeymoon tributary also an upstream site. The graphed macroinvertebrate numbers represent the total for two leafpacks. There were no actual leaves remaining in the downstream bags in September, but macroinvertebrates were present.

Individual mayflies that could be tentatively identified to family level were Heptageniidae, Baetidae, and Leptophlebiidae. Mayflies as a group are very acid-sensitive and are useful indicators of the severity of acidity problems (Simpson et al 1983). For instance, of 77 mayflies with known environmental tolerances, only 4 species are acidophils (prefer pH under 6.0) (Hubbard & Peters 1978). Mayflies are usually grazers and scrapers, feeding on algae and surface films. Hyphomycete fungi typically invade the leaf tissues with their own hyphae. Invertebrate scrapers typically consume the microbes and leaf tissue together in the same bite. Scrapers typically leave behind skeletonized leaves, with only the larger leaf veins left. The Heptageniidae are often predators.

Stoneflies were also found at all sites, but did especially well at the Honeymoon Brook tributary, the most acidic site (Figure 9). While stoneflies are very sensitive to pollution, they are among the most tolerant of acidic or acidified waters (Tixier & Guerold 2005). All of the leafpack stoneflies were Capnidae, or other small fine-bodied stoneflies. The small stoneflies are usually detritivores. Most individuals were found in June samples and they became less abundant through the summer, and were virtually gone in October even though some leafpacks still had lots of detritus left.

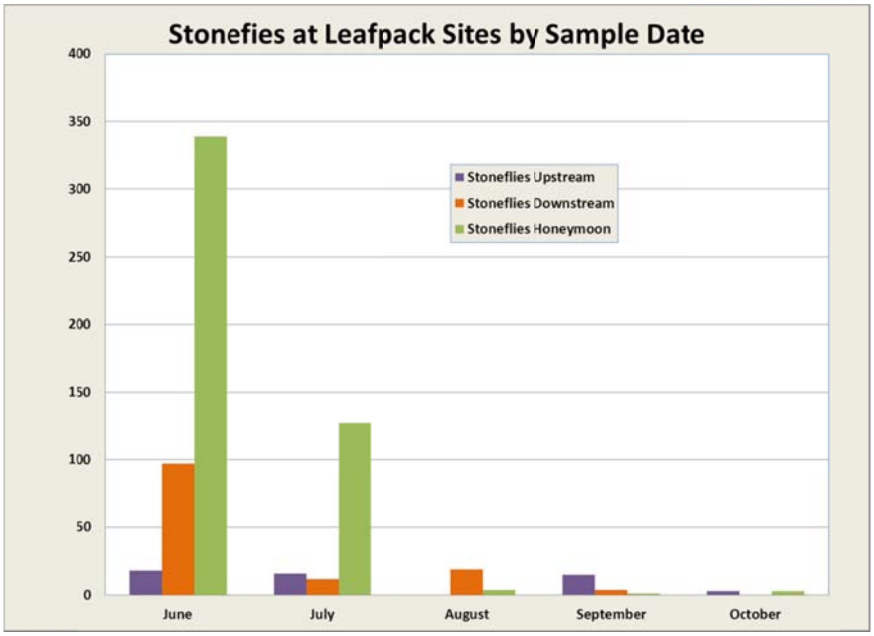

Figure 9. Abundance of Stoneflies found in leafpacks in Dead Stream upstream and downstream sites, and at the Honeymoon tributary also an upstream site. The numbers of macroinvertebrates represent the total for two leafpacks.

Caddisflies were abundant at all sites and all months. Almost all caddisflies were case builders with the families Brachycentridae, Lepidostomatidae, Limnephilidae, and Phyrandeidae represented. Overall, they did best in July, and were abundant in all months. Of the macroinvertebrates that were present in October, caddisflies were the second most abundant group (after mayflies). Caddisflies are a large and diverse group with predators, grazers, shredders, and collectors. Large detritivores like some case-making caddisflies are typically powerful shredders, and rapidly convert large organic matter (like leaves) into small fragments (fine particles packed together in insect feces). A leaf exposed to shredders has large sections missing. The onion bag mesh is 6 by 10 mm, and is large enough for all but the largest case-building caddisflies to pass through. Some of these larger caddisflies might have been trapped in the onion bags near the end of the experiment.

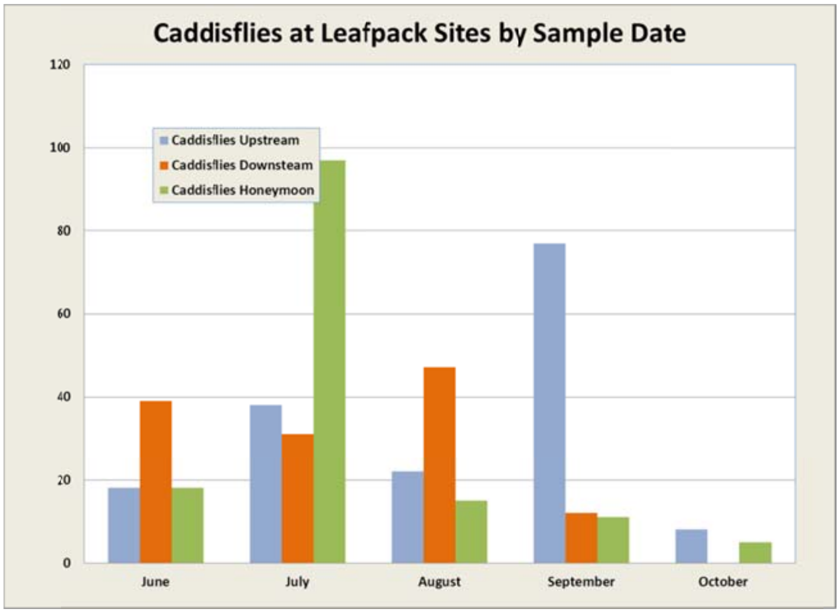

Figure 10. Abundance of Caddisflies found in leafpacks in Dead Stream at upstream and downstream sites, and at the Honeymoon tributary also an upstream site. The numbers of macroinvertebrates represent the total for two leafpacks.

Chironomids were abundant at all sites, especially in summer and less so in September and October. They are widely represented in freshwater environments, from the most pristine waters to sewage lagoons. Chironomids are deposit feeders. Chironomids and blackflies (both true flies) taken as a whole will do well in acidic waters (Brezonic et al 1993). Most species feed on algae and fine detritus. Blackflies are seasonally abundant in Maine streams but were not observed in the leafpacks except in small numbers, primarily in June. Blackflies were abundant in Dead Stream on the outside of rock bags in November (Whiting, unpublished data). Since they are filter-feeder and deposit feeders, they live where they are exposed to the current. They probably are not common in leafpacks (but might occur clinging to the outside).

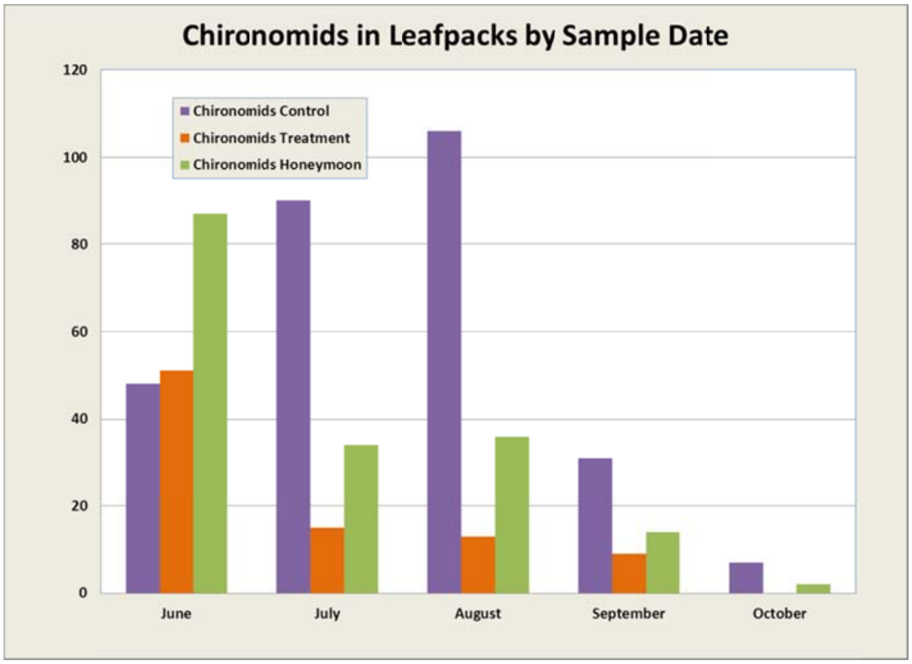

Figure 11. Abundance of Chironomids found in leafpacks in Dead Stream Upstream and Downstream sites, and at the Honeymoon tributary also an Upstream site. The numbers of macroinvertebrates represent the total for two leafpacks.

Amphipods are freshwater crustaceans and were present at both Dead Stream sites, but especially the treatment site. They were not found at Honeymoon Brook, the most acidic site. Amphipods are so important to brown trout conservation that when acidic lakes are restored in Norway, brown trout are stocked along with their favorite invertebrate food species, *Gammarus lacustris*, an amphipod, *Lepidurus arcticus*, a tadpole shrimp, and a snail *Lymnaea peregra* (Fjellheim et al 2001). Even when *Gammarus lacustris* does not do well in a lake, based on fish stomach analysis, brown trout apparently seek them out in tributary streams or within microhabitats in the lake. The genus *Gammarus* is common and is widely distributed, but is not found in acidified waters (Fjellheim et al 2001). *Hyalella* is a smaller and more acid-tolerant genus that is more common in Maine. There are many species and *Hyalella* is probably the amphipod found in Dead Stream. Amphipods are generally detritivores and scavengers, although some are grazers, and a few are predators. Of all amphipods observed, 63% were found at the downstream site. They were abundant in September at the downstream site even though there were no leaves left.

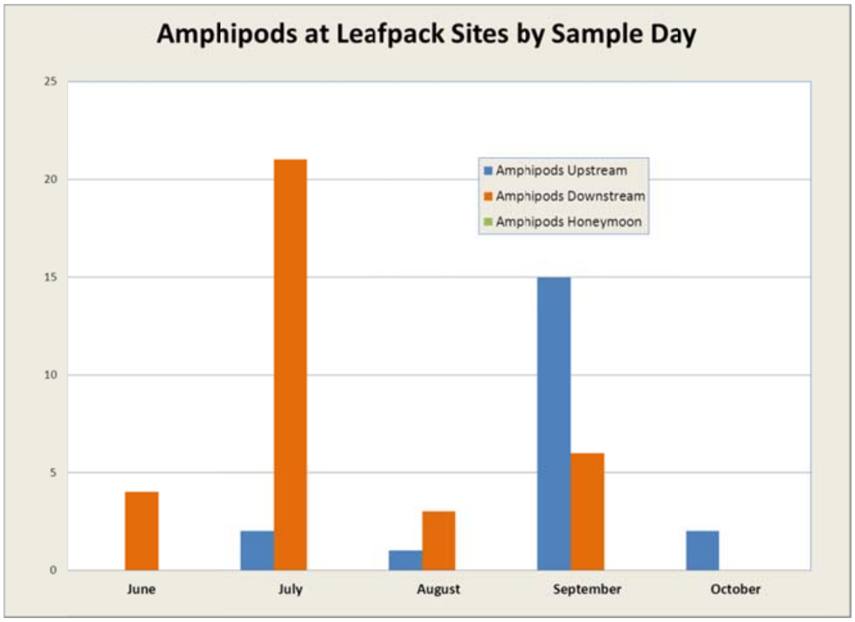

Figure 12. Abundance of Amphipods found in leafpacks in Dead Stream upstream and downstream sites, and at the Honeymoon tributary also an upstream site. The numbers of macroinvertebrates represents the total for two leafpacks.

No amphipods were observed in Dead Stream in 2009 during baseline studies using both kick net and rock bag sampling methods at three sites (Dead Stream at the 55-00-0 Rd, Dead Stream at the 58-00-0 Rd, and the un-named Bowles tributary at the 55-50-0 Rd). Three of each sample type was taken at each site. Nor have amphipods been seen in rock bag collections at the same sites in 2010 and 2011 (all after treatment and within the treatment area) (Whiting unpublished data). So the amphipods were something new observed in 2012. This may be due to a preference for leafpacks, or it may be due to improvements in pH, or both. Crustaceans in general, and amphipods and Daphnids in particular, are sensitive to acidity (Walseng & Shartau 2001, Waervagen et al 2002). It is interesting that amphipods were found above the treatment. However, it may be important to know that amphipods are good swimmers and the upstream sample site is only 10 m above the upper limit of the clam shells. In 2012, the summer baseflow pH above the shells in Dead Stream can approach pH was 5.9.

Mayflies and amphipods are useful indicators, or "sentinel species," for streams that are effected by acid rain. In a restored stream, there should be more mayflies and amphipods. But there should also be mollusks and other crustaceans. For instance, crayfish are widely distributed in Maine, including urban and agriculturally-impacted streams, but are not common in eastern Maine. Crayfish (*Procambarus acutus*, the white river crayfish) are found in the Union and Pleasant Rivers (see Gulf of Maine Knowledgebase database) and has been observed in the Narraguagus River (author's experience). However, this state-wide database does not have crayfish records from the Machias, East Machias or Dennys Rivers. No crayfish have ever been observed by the author in the project streams. While some crayfish are very sensitive to acidic waters (*Procambarus* species are generally found in water with pH 6.5-8.5 and more than 50 ppm CaCO3 total alkalinity, McClain & Romaire 2007), other species can be very acid tolerant (*Cambarus bartonii*, the stream crayfish, Seiler & Turner 2004, a species that occurs in northern Maine, Reid 1971). Other sentinel species that are missing or underrepresented in project streams are snails, fingernail clams and Unionoid mussels. Two fingernail clams and two "snails" were observed in 2011 in rock bag collections from Dead Stream treatment areas. The snails were small, and since there are caddisflies with coiled cases that look like snails, positive identification in the field was not possible. Unionoid mussels occur in eastern Maine in the river mainstems and major tributaries, but have not been observed in the project streams. Snails and fingernail clams should be common in natural or restored streams, and maybe Unionoid mussels should be there too.

In order to investigate how the density of macroinvertebrates changed over time, the data was normalized for the remaining weight of the leafpack (Figure 13). For the first two months, the average number of macroinvertebrates per gram of leaves ranged from 3 to 8.8 per gram of dry weight of leaves. The peaks for the different sites occurred at different times. Honeymoon Brook peaked early at 8.8 individuals per gram, due to stoneflies, caddisflies and chironomids. The Dead Stream non-treatment site peaked late in mid-September at 16.5 individuals per gram, due to mayflies and caddisflies. The treatment site at Dead Stream peaked at 22.4 per gram in August, just as the leaves were getting soft and ragged. August was the same time that mayflies and caddisflies peaked at this site. For Dead Stream above and below the clam shells, the macroinvertebrate density peaked at about the same time that leaf material was being depleted. There is probably a cause and effect relationship between high invertebrate numbers and low leaf biomass on these dates. Honeymoon, the most acidic site, maintained the lowest macroinvertebrate densities late in the season.

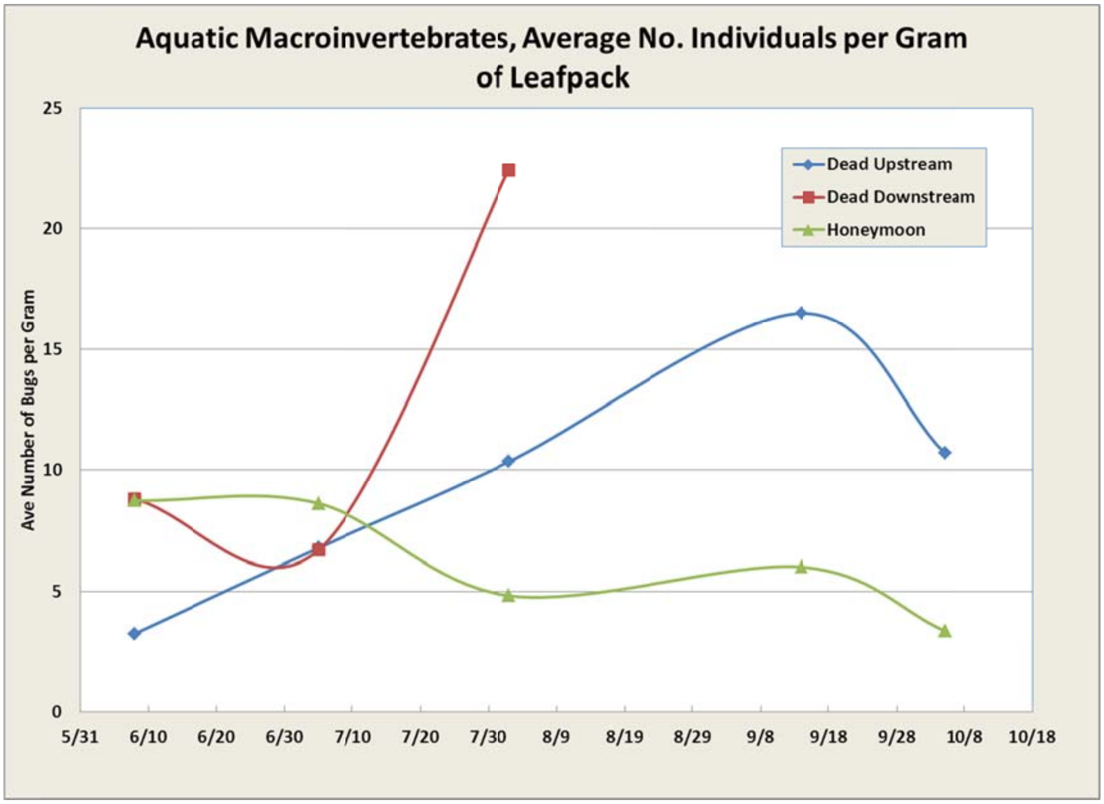

Figure 13. The average density of macroinvertebrates per remaining gram dry weight of leaves in leafpacks by sample date. Leafpacks were deployed in early May and were sampled in early June, July, August, mid-September, and early October. The curved lines only connect the dots, and do not represent a particular model.

When acidity is not the issue, leaf processing rates in streams are generally limited by nutrients, especially by nitrogen (Ostrofsky 2012, Meyer & Johnson 1983). In autumn, deciduous plants salvage nutrients from leaves before they drop. Fallen leaves are primarily cellulose and are nitrogen-poor. When leaves fall or are washed into streams, they are colonized first by hyphomycete fungi (the "water molds") and later by bacteria (Cummins & Klug 1979). These microorganisms have the enzymes needed to digest cellulose. Macroinvertebrates take advantage of the situation, since they lack cellulase and hemicallulase enzymes, and the microbial biomass is rich in protein. So if the system were nitrogen-limited, the addition of calcium carbonate (and some phosphorus) from shells would not be helpful. Processing rates of leaves should not change from calcium additions alone. However, if streams were limited by pH then increasing buffering capacity would allow more micro-organisms to thrive, especially acid-sensitive bacteria. Better pH should improve macroinvertebrate diversity, especially mayflies (scrapers) and amphipods (a shredder). Scrapers and shredders are essential to leaf processing, since they break up the leaf structure into fine particulate organic matter (FPOM). This increases the surface area of leaf fragments and allows re-colonization with more microbes. The fine particles are eaten by other invertebrate functional groups such as the collectors (worms and midges) and filter feeders (blackflies and fingernail clams). Reduced detritus decomposition rates are reported in other acid rain studies and can result in abnormal accumulations of leaf litter (see reviews by Webster & Benfield 1986, and Hendry 1982). When the bottom of the food chain is impaired, the whole food chain fails to function properly. For as long as we have data for eastern Maine salmon rivers, they have always appeared to be ultra-oligotrophic. However, they are not short of nutrients in the classic sense. They have total nitrogen, total phosphorus can even be excessive, and they have leaves and other terrestrial detritus. Instead of lacking nutrients, these streams appear to have an impaired ability to assimilate carbon and food energy from detritus.

Last year's report (Whiting 2011) provided a literature review of acid rain issues and streams. It predicted that acid rain would not only prove to be a problem for fishes and mayflies, but that there would be ecosystem level problems. The 2012 leafpack study strongly suggests that ecosystem level problems are occurring.

d. Macroinvertebrates

The macroinvertebrates from rock bag samples have been shipped off to a private contractor for analysis. The results for this analysis are not yet available.

e. Fish

Dead Stream was electrofished by USFWS staff on August 30, 2012. While mid-August was hot and dry, Old Stream had returned to normal flows by the end of the month (USGS gauge) and remained average or higher for the rest of the year. Figure 13 presents the number of fish by species in the Dead Stream study reach (100 m above and 100 m below the 55-00-0 Rd, all within the shell application site, not exactly a "below" site). The true below - treatment site was never electrofished, because the 2009 study was done for the culvert replacement. Thus, 2007, 2009 and 2010 are baseline studies (the shells were first applied in 2010 after the e-fishing was completed). Over the next two years, the total number of fish within the reach has improved from 36 and 20 in 2007 and 2009 respectively, to 100 in 2010 after the culvert replacement, to 142 and 294 in 2011 and 2012 one year and two years after the first shell applications. Similar to last year, this summer there were a lot of second year (age 1+) and older fish. This year, two more species were observed (white sucker and blacknose dace) that were not seen last year.

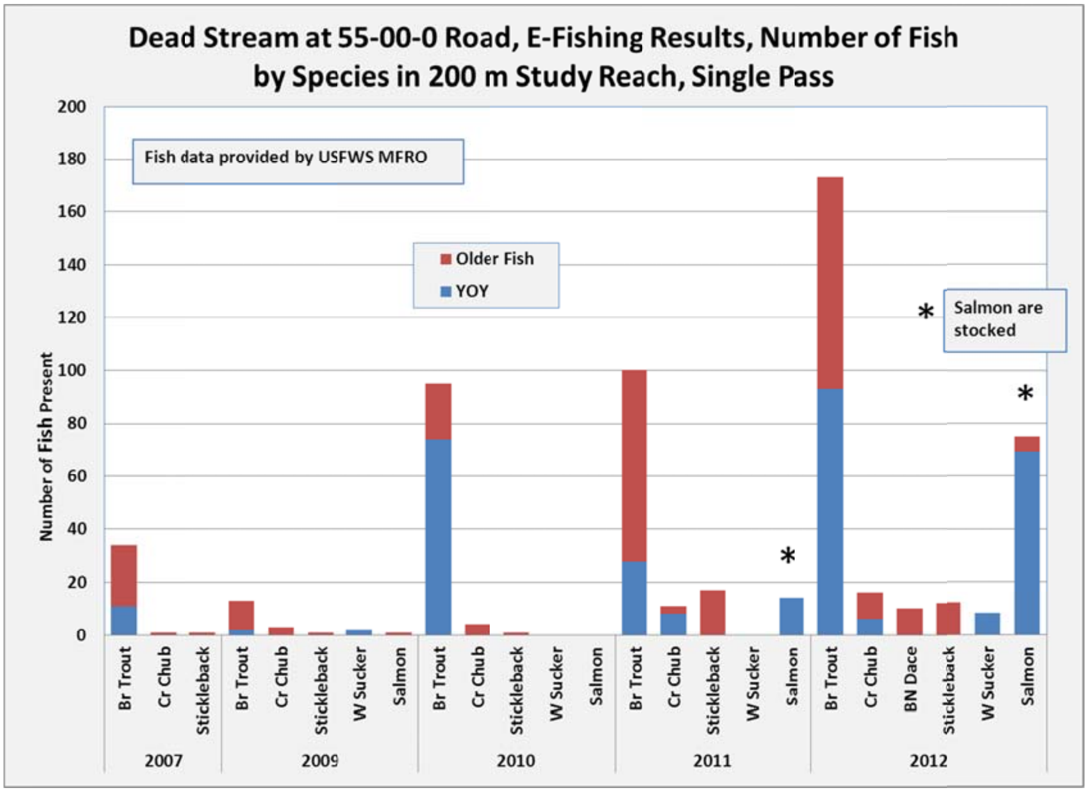

Figure 13. Dead Stream electrofishing results for the 55-00-0 Road, a clam shell application site. The 2007, 2009 and 2010 fish results are baseline conditions, and the summer of 2011 was the first full year after shell applications. The fish species are brook trout, creek chub, blacknose dace, ninespine stickleback, white sucker and Atlantic salmon. YOY are young-of-the-year fish. Salmon fry were stocked at the 55-00-0 Rd in the spring of 2011 and 2012. Data are from USFWS, Maine Fishery Resources Office, Craig Brook National Fish Hatchery.

This treatment reach was stocked with Atlantic salmon fry in the spring of 2011 and again in 2012. The stocking rate was 100 fry per habitat unit for all 33 habitat units above the 58-00-0 Road (each unit is 100 m²) and was the same for both years (3,300 fish). The SHARE study area represents approximately 5 habitat units (6.6 % of the upper watershed mapped habitat units). The salmon fry survival appears to have been better at this site in 2012 (14 young-of-the-year, or YOY, last year and 40 this year). This comes to a density of 8 salmon YOY per habitat unit in 2012. Although this summer was drier than last year, there were more frequent rains. Year-to-year variations in fish numbers are expected due to weather and habitat issues (e.g., poor summer baseflow has a strongly negative effect on habitat quality for salmonids (Raleigh 1982)). But it looks like salmon YOY recruitment has improved, even though the presence of more older and larger fish also means there is some predation on salmon fry.

Brook trout recruitment was also good in 2012. Looking at the number of brook trout YOY in Dead Stream, there were 93 YOY brook trout present, thereby representing 54% of the population. In a survey of eastern Maine streams from the Union River to the Saint Croix, the USFWS found that YOY were 42% of all brook trout observed, and brook trout were 30% of all fish sampled (Craig & McKerley 2012). In Dead Stream brook trout were 59-95% of all fish caught from 2007 to 2012. Brook trout are especially acid tolerant, and are often the only fish species present in acidic lakes and streams (Jenkins et al 2005).

Larger fish are also doing well. There were a large number of older brook trout (80 fish, mostly 1+ age class, representing 46% of all trout), so there was also good recruitment into older age classes. The Atlantic salmon numbers are affected by stocking as well as local conditions. Only three 1+ year salmon might seem disappointing, but older salmon and brook trout are more mobile and they may have moved to more suitable habitat. Salmon move into deeper riffles as they get older while older brook trout move widely within the watershed.

Water quality restoration has both similarities and some differences with other types of habitat restoration projects. For instance, logs are sometimes dropped into streams to form weirs and increase habitat diversity. These weirs or "log-vanes" are used to concentrate flows in over-widened streams. They accumulate fine sediments in dammed pools upstream, create small cascades, and scour plunge pools downstream. These log weir structures are also generally successful in increasing fish densities. For instance, in a 21-year study of 53 log weirs in five Colorado Rocky Mountain streams, increases in trout densities were almost immediate (White et al 2011). Most of the increase was due to immigration into the treatment areas rather than recruitment of young fish. The species concerned were mixes of brook trout, brown trout, and/or rainbow trout depending on the stream. Pool abundance in the treatment areas increased by 520%, and pool volume increased by 229%, while wetted area remained the same. Adult trout (age 1+ and older) increased 53% in the treatment areas and was sustained throughout the study period. However, no difference was found in YOY density. After 21 years, only one weir was no longer functioning as designed. In contrast, by liming an acidified stream total fish abundance was increased by 6.7 to 8.7 times in treatment areas, but the water quality improvements are expected to last a year or less without new shell applications (i.e., annually for mahogany shells or twice a year for softshell clams).

Project SHARE replaced the culverts at the 58-00-0 and 55-00-0 logging roads in 2009. Within two weeks, one Atlantic salmon was observed at the 55-00-0 road during electrofishing. The similarity in fish numbers in 2007 and 2009, and then a large increase in fish in 2010, suggest that culvert replacement was important in restoring fish passage within the Dead Stream drainage. This connected 33 Atlantic salmon habitat units with the lower part of the watershed. The first shells were added in the summer of 2010. Increases in fish densities in 2011 and 2012 suggest that both fish passage and better water quality were responsible. Comparing 2007 and 2012, there has been an 8-fold improvement in fish abundance within the study reach. There is probably a cause-and-effect chain reaction between improved water chemistry and increased efficiency of detrital food processing by almost 2-3 times, increased macroinvertebrate densities and diversity, especially for mayflies and amphipods, and increased fish density. There is also a possibility that there is improved fish diversity (six total species and improved representation of rarer species). An ecosystem level boost in productivity and species diversity is expected when there is a release from a toxic limiting factor (e.g., Flick et al 1982, and Hendry 1982, acid rain; McCall & Pennings 2012, oil spill; Argent & Kimmel 2012, acid mine drainage).

Returning to the concept of sentinel species, the appearance of ten blacknose dace for the first time in Dead Stream may be important. In a review of 23 years of acid rain studies in the Adirondack Mountains of New York, Jenkins et al (2005) concluded that slimy sculpin and blacknose dace are among the most sensitive of fish species to acidification. While blacknose dace are sometimes thought of as being "ubiquitous" in clear running waters (Trial et al 1983) and are found in some urban streams (e.g., Birch and Penjajawoc Streams in Bangor), they are not commonly seen in eastern coastal Maine (see DIFW lake surveys in Gulf of Maine KnowledgeBase website). But blacknose dace do appear in DIFW surveys in Black Brook in the Machias watershed. The author has seen schools of blacknose dace in Lanpher Brook (a tributary to Old Stream), which has limestone bedrock in its watershed and has a circumneutral baseflow pH.

The known distribution of Slimy sculpin (*Cottus cognatus*) may also be significant. Slimy sculpin is found in many northern and western Maine locations in both streams and lakes. However, in eastern Maine this species is found in just a few widely scattered locations (Gulf of Maine KnowledgeBase). It is found in Mopang Lake, in the Machias River watershed, in West Grand Lake and Musquash Lake in the Saint Criox watershed, and in Phillips Lake in the Union River watershed, but nowhere else within these watersheds or in watersheds in between. These sightings could be recent introductions, but are more likely isolated relict populations. Presumably, slimy sculpin was once more widely distributed in Eastern Maine but its range is now more restricted. If these watersheds were once more circumneutral, then sculpins could have been found in streams and in many lakes. In eastern Maine today, slimy sculpin may find refuge in the stable water chemistry on the bottom of large deep lakes. Unlike streams, lakes have long water residence times that integrate the impact of many months or even years of inputs. The extreme pH characteristic of small streams is reduced in rivers, and is greatly reduced in lakes. Perhaps slimy sculpin will be the next species to show up at Dead Stream.

IV. Discussion & Summary:

SHARE believes that the clam shell liming project has improved water quality, and that it is a useful model for helping to manage Atlantic salmon recovery in eastern Maine. Other recovery tools such as fish stocking strategies, the replacement of failed culverts with fish-friendly stream crossings, drop log weirs, and potentially marine-derived nutrient additions also could play a role the short-range recovery plan. Of course, in the long-run, salmon are expected to be self-sustaining in fully functioning natural or restored stream ecosystems.

V. Plans for Next Year:

Clam shells from marine sources introduce some arsenic into freshwater streams. Fresh clams right out of a meat packing plant have a lot more arsenic. For biosecurity reasons (clam tissue can be a source of neoplasia infections in shellfish (DMR 2012 fact sheet)), fresh clam shells are not used for acidity treatments. Some arsenic is lost as the shells are composted and as rains wash away remaining organic material in outdoor shell storage areas. Even so, future water quality evaluations will include some upstream/downstream comparisons of arsenic.

In 2012, Project SHARE's clam shell additions have improved pH, calcium concentrations, and reduced Alx at all project sites. The dose for Dead Stream is good for the upper watershed, but Dead Stream at the 58-00-0 Road still has large swings in pH with every storm. Calcium levels are still often critically low. An additional treatment in the lower watershed would improve Atlantic salmon health and survival. A single dose calculation allows 2 metric tons of shells below the 58-00-0 Road. SHARE initially avoided treating reaches of stream where salmon are stocked to avoid altering habitat in a detrimental way. However, with the observed swings in pH it might be worth the risk to put shells directly in this lower salmon stocking area. The habitat alterations might be positive. For instance, the fish may be able to nestle down among the shells during high flows and benefit from microhabitats with higher pH and calcium compared to the ambient stream flow. With the initial shell applications in the upper watershed, there should not be mixing zone problems in the lower watershed

Another lesson from this year is that treating salmon habitat alone, without treating upstream reaches, is not a good idea. Based on the high Alx found at the poorly treated First Lake Stream site, mixing zone problems must be considered. There should be at least one shell application site upstream from the best salmon nursery sites.

The treatments on the Honeymoon tributary and First Lake Stream have just begun. SHARE did not meet treatment goals this year at these sites. In 2013, treatments will have to be increased to reach single dose goals. An expansion of treatments within Honeymoon Brook is scheduled for 2013, with new treatments to the mainstem planned on the Bear Brook Road, old Route 9 and the 9-95-0 logging road. The treatment at Canaan will be doubled to see if a much larger dose can reduce the pH swings. SHARE's current permit allows the dose to be adjusted as needed to meet pH or calcium goals.

Beaverdam Stream is a tributary to the East Machias River. The East Machias hatchery at EMARC stocks fall parr in this stream. The Downeast Salmon Federation (DSF), owner of the EMARC hatchery, is currently stocking fall parr into Beaverdam. DSF wants to have a shell treatment site to evaluate the benefits to parr survival. With that in mind, treatments are planned for Beaverdam Stream in 2013. As usual, the treatments would be incremental and will be accompanied with water quality assessments.

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