2004 Maine Atlantic Salmon Conservation Fund
Final Report

Are road de-icing salts a factor in the chemistry of salmon rivers?

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Abstract:

This project evaluated the water chemistry of four salmon rivers with study sites upstream and downstream of Route 9 in eastern Maine. The goal was to evaluate whether road de-icing salts are quantitatively influencing the water chemistry of salmon rivers, especially with respect to the potential for increasing the Ca concentrations, a beneficial effect.. The four rivers are the Narraguagus, Mopang, Old Stream, and Machias. These rivers were chosen to represent of the range in size in Downeast salmon rivers, so we can determine if there is a threshold river size or flow above which road salting becomes less quantitatively important. Two questions were addressed: (1) are there conditions for which sodium chloride produces chemical conditions that are beneficial for salmon based on previous studies that suggested that Ca concentrations are increased by road salt-induced soil processes; and, (2) are there conditions under which calcium concentrations could be futher enhanced by application of calcium chloride.

None of the rivers were chemical affected by road salt in the spring of 2005, the project period for this grant. Chloride and sodium concentrations were higher slightly downstream than upstream. Na:Cl ratios were substantially greater than 1.0, indicating that the source of Na was mineral weathering, and that postulated exchange of Na for Ca in soils was not quantitatively measurable. This research occurred in a very wet spring, when high flows could have masked some of the chemical effects of Na for Ca exchange reported in other literature.

At Old Stream, slightly higher calcium downstream than upstream, without a decline in sodium, indicates a source of calcium in road fill rather than an ion exchange effect. This result may support the present effort by project SHARE to use limestone in their water-related BMP restoration work as a means of increasing Ca in salmon rivers during the more sensitive periods.

Introduction

The National Academy of Sciences report (2004) highlighted water chemistry as one of the unknowns for the future of Atlantic Salmon. Acidity was their focus, but it is not the only issue. Lack of calcium (Ca) is another issue receiving attention, especially as proposals for liming continue to be discussed in the U.S. and Canada.

A related issue is the fate of de-icing salts applied to roads in the salmon watersheds. Salts are used to facilitate the removal of snow and ice from roadways throughout much of the United States. In Maine, salt application rates (per event) are in the range of 200 to 300 pounds per mile (60 to 80 kg/km) (Gray, Maine DOT, pers comm), although in areas using a new salt strategy where 100% salt (instead of a sand-salt mix) is applied early in the storm, usage is higher. The range for the United States has been estimated to be 300 to 800 pounds per mile (80 to 230 kg/km) (Paschka *et al.*, 1999).

The effects of salt on soil and water near roadways in Maine have been well documented (Hutchinson, 1966 and 1970; Pugh *et al.*, 1996; Mason *et al.*, 1999, Peckenham, 2002), including seasonal changes in sodium (Na) and chloride (Cl) from a few parts per million to over 200 ppm. This report supplies baseline data on the range of water chemistry that salmon experience in the vicinity of major roads. In particular, we were interested in the possibility that road salting was *improving* the chemical conditions for salmon. One possibility is that the low ionic strength (diluteness) in downeast rivers is being increased to the benefit of salmon that appear to be having difficulty making the transition from freshwater to saltwater. The other possibility is that soil chemical exchange reactions release Ca when subject to high Na loading, hence increasing riverine Ca concentrations to the benefit of salmon.

Mason *et al.* (1999) documented water chemistry anomalies near Route 9 in Eastern Maine, in a small tributary to the Union River (Figure 1). The changes include a significant increase in calcium concentrations below the road, which could be due to road fill, or ion exchange of Na for Ca. Our goal is to determine if similar changes can be documented in salmon rivers of various sizes. We evaluated the pattern of Ca concentrations upstream and downstream of Route 9 on four salmon stream crossings to determine how Ca addition might affect water chemistry. Specifically, the questions relating to Ca for this project were (a) is the 'road effect' quantitatively important to Ca concentrations, (b) does it occur quantitatively everywhere, and (c) will addition of $CaCl_2$ further increase Ca downstream from salted roads?

This project is part of the overall ongoing effort to understand the importance of water chemistry in the recovery of Atlantic salmon. This effort is a collaboration among the UMaine Mitchell Center, NOAA, the Atlantic Salmon Commission, and Plymouth State University. This specific project on road salting is a new initiative to address the possibility that road runoff may be a factor in river chemistry.

Objectives

This project supports the overall agency goal of understanding the concentrations and distribution of acidity and Ca in salmon rivers. This goal is related to proposed liming projects in one or more rivers. We are testing the hypothesis that small additions of calcium to rivers, such as from BMP construction, road maintenance, and road de-icing, may be effective in increasing the calcium concentrations in salmon rivers. Such changes may augment the liming project, and longer term, may reduce the need for direct liming. Therefore, our objectives were to:

- Document the seasonal and spatial patterns of major ion chemistry in four salmon rivers (small flows to large flows), in order to understand the influence of the road on the chemistry of Na and Ca, which in turn affect acidity and aluminum.
- Evaluate the potential for road de-icing practices to quantitatively influence calcium, acidity, and/or ionic strength of river chemistry.
- Estimate the cumulative impact of a change in road de-icing practices as one of a set of

land use changes that can be used to improve water chemistry for salmon.

The concept of cumulative impacts is an important consideration in evaluating environmental effects. For example, runoff from one road may be minor, but the impact may be significant when considering runoff from several paved roads that cross a river, plus many gravel roads.

Methods

Site Description

The Narraguagus River is a major drainage river running through Hancock and Washington counties, and eventually emptying into Narraguagus Bay in the Gulf of Maine (Figure 1). Downstream of Route 9, the Narraguagus is crossed by two major highways; State Route 193 in Deblois, and U.S. Route 1 in Cherryfield. There are also several locations where forestry and camp roads run close to or along the river. The Narraguagus watershed is predominantly forested and heavily managed, until it passes through the suburban areas of Cherryfield and Milbridge near its mouth along the coast.

Mopang Stream in Washington County stems from the Mopang Lakes and is a tributary of the Machias River (Figure 1). In addition to Route 9, Mopang Stream is crossed by several small forestry roads. The Mopang Stream watershed is forested, and is located entirely within unorganized territories.

The Machias River in Washington County originates in the Machias Lakes, and empties into Machias Bay in the Gulf of Maine (Figure 1). The river also supports the Atlantic Salmon. The watershed is predominantly forested, but does pass through the suburban areas of Marshfield and Machias along the coast. In addition to Route 9, the Machias River is crossed by numerous forestry roads and several highways; U.S. Route 1, State Route 192, and State Route 92, which all cross far downstream of these sample sites.

Old Stream is a second-order stream that is fed by the outlets of First Lake and Grover Lake in Washington County (Figure 1). Old Stream is a tributary of the Machias River. Route 9 crosses Old Stream in unorganized territory near Wesley, and is crossed by several forestry roads before it meets the Machias. The Old Stream watershed is forested, and the stream supports Atlantic salmon.

Study design

The study design used an upstream-downstream assessment. The upstream site serves as the background reference site against which the downstream sites are compared. The downstream sites included a spatial gradient for evaluation of the change away from the road. In addition, supporting data from small tributaries Rocky, Baker, and Sinclair (Figure 1) far upstream of Route 9 were used to ensure that upstream sites were not affected. Upstream sites were approximately 50 meters upstream of Route 9 (Table 1). Downstream sites were sampled at 50, 100, 300, and 500 meters downstream of Route 9 (Table 1). Mopang Stream was not sampled below the 100 meter site because of difficult access.

Field collection

Field sampling for the project occurred once per month from December through February and twice monthly in March and April during snow melt. Eighty-four samples were collected, not including duplicates and laboratory replicates (Table 2). To eliminate possible error from the influence of immediately-applied road salt, sampling did not occur during or directly after major storms. Sample sites were accessed by snowshoe. Whenever possible, grab samples were obtained from the stream bank. When access to open water was impeded by shelf ice, a throw bottle was used to obtain a grab sample from the stream. When a site was completely iced over or inaccessible, the site was skipped and recorded as such. Field duplicate samples were taken at each outing.

Laboratory Methods

Samples were analyzed for major ion chemistry at the laboratories of the Senator George J. Mitchell Center for Environmental and Watershed Research at the University of Maine, using standard methods (Peck *et al.*, 1993; Norton and Fernandez, 1999) in place for more than a decade as part of several major U.S. Environmental Protection Agency (EPA) projects (Table 3). The laboratory participates in Long Range Transport of Atmospheric Pollutants (LRTAP), Watershed Manipulation Project, EPA Water Pollution and Water Studies, and National Institutes of Water Research, Norway (NIVA) audit programs to ensure data quality (Youden, 1969). Laboratory quality control procedures include field and laboratory blanks, replicates, and standards.

Samples were analyzed for major anions (Cl^-, NO_3^-, SO_4^{2-}), cations (Ca^{2+}, Mg^{2+}, K^+, Na^+, NH_4^+), DOC (dissolved organic carbon), air-equilibrated pH, total dissolved Aluminum (Al), and acid neutralizing capacity (ANC). Data were re-evaluated and/or samples re-analyzed for samples with charge balance discrepancies greater than 15%, consistent with EPA QC protocols (Peck, 1992). For the final data set (Table 2), ion balances were calculated for each sample, and ranged from 1.00 to 1.11 with an average of 1.05, within US EPA's acceptable limits of 15% anion or cation deficit. We assumed a DOC charge density of 6 μeq/mg to estimate the contribution of DOC to anion charge balance. Mason *et al.* (1999) used a DOC charge of 6-8 for ion balances for sites in this area.

Background

Overview of Chloride (Cl)

Chlorine is the most abundant halogen in the environment. Its atmospheric sources are the ocean, methyl chloride emissions from biological processes, volcanic emissions, and industrial emissions of chloride (Cl) and chlorofluorocarbons (Turco, 2002). The main source of chlorine to forested catchments is the ocean, in the form of marine aerosols, where an aerosol is a small particle suspended in the atmosphere. These marine aerosols, formed when bubbles burst or wind blows over waves at the ocean's surface, act as cloud or fog condensation nuclei (Turco, 2002). National Atmospheric Deposition Program data for the U.S. clearly shows a pattern of greatest Cl wet deposition in coastal areas (Figure 2). Evidence from Scandinavia indicates this same pattern of greatest deposition on the coast (Beier *et al.*, 1992; Johansson *et al.*, 2003). Seasonal patterns play a role in supplying Cl to the atmosphere. Higher winter deposition of Cl was found in Hiroshima, Japan, where winter storms originated from marine sources (Seto *et al.*, 2000).

Cl has long been considered to be conservative with respect to soils and biological processes in watersheds (Likens and Bormann, 1995; Oberg, 2002), although it is increasingly being documented that there is uptake by vegetation and retention in soils. (Mason *et al.*, 1999; Oberg, 2002; Johansson *et al.*, 2003, Rodstedth *et al.*, 2003, Lovett *et al.*, in press). At the Hubbard Brook Experimental Forest in New Hampshire (HBEF), Cl may be accumulating in the terrestrial system (net gain of 2.02 ± 1.10 kg/ha/yr), with notable losses occurring after a deforestation treatment (Likens and Bormann, 1995).

Overview of Sodium (Na)

In coastal areas, as with Cl, the main source of Na in atmospheric deposition is the ocean, and it is primarily deposited in particulate form (Beier *et al.*, 1992; Harkel, 1997). In the context of a watershed, Na is derived from chemical weathering, indicated by greater Na:Cl ratios in streamwater as compared to Na:Cl ratios in the ocean or atmospheric deposition (Heath *et al.*, 1992). At HBEF, long-term Na budgets indicated a net loss from the watershed of 5.64 ± 0.5 kg/ha/yr; root exudates of Na balanced uptake of Na by roots, but Na from weathering (5.8 kg/ha/yr) was on the same order of magnitude as Na in streamwater (7.2 kg/ha/yr), and approximately balances the budget (Likens and Bormann, 1995).

Salt-induced acidic episodes in streamwater can result from deposition of sea salts that displace hydrogen ion from soil exchange sites by simple mass action of high loading of Na. (Heath *et al.*, 1992; 1993; Kahl *et al.*, 1992). Evidence for episodic acidification through sea salt exchange at Acadia National Park comes from prior work at the Hadlock Pond Watershed (Heath *et al.*, 1993). We did not expect to see this salt-effect acidification rom road salting.

Road salt application

The Maine Department of Transportation (MDOT) distributes salt and sand on Route 9 to improve traction and melting in inclement weather. Currently, MDOT orders a winter allotment of 14 tons of NaCl per lane mile on Route 9. The mined NaCl is purchased by the Department and generally distributed in its granular form. To increase adhesion, the salt may be mixed with a 23% NaCl brine solution before applied to the roads. In very cold conditions (20 degrees Fahrenheit or less), the NaCl is mixed with a 32% solution of $CaCl_2$, to further enhance adhesion (Gray, Maine DOT pers. comm., 2005). Information regarding actual application on NaCl and $CaCl_2$ for the winter of 2004/5 was not available at the time of this report.

Weather and climate

Maine has a mean annual temperature of 5° C and mean annual precipitation of 108 cm (http://www.ncdc.noaa.gov/oa/climate/research/cag3/me.html). Annually, downeast Maine gets 28-36 snowfalls in excess of 0.25 cm. There are approximately 20 snowfall events of 2.5 cm inch or more, 5-6 events of 12 cm or more, and 1-2 events resulting in 25 cm or more (Zielinski, pers. comm., 2005). Mean annual water content of the snow pack in Downeast areas of Maine is 10.2-12.7 cm (http://me.water.usgs.gov/WRIR01-4258.pdf). The National Climatic Data Center (NCDC) records precipitation – including snowfall – at a site in Wesley, Maine, just east of the Old Stream site (Table 4). Winter 2004/5 was relatively snowy, with several significant events occurring in January, February, and March.

Results and discussion

This research project addressed three main questions:
1) Is water chemistry at these sites on four Downeast rivers quantitatively affected by road salt?
2) Is the change, if any, beneficial or detrimental to salmon?
3) Do the results provide information that can be used by managers to improve biologically-relevant chemistry for salmon?

These questions are answered below.

1) Road salt had minimal affect on water chemistry

To evaluate whether road salt affected water chemistry, we assessed the sample data for December 2004 – April 2005 (Table 2). This period encompassed all the major snowfall in the relatively snowy winter 2004/5 and ended after spring melt. Mopang Stream had the least variable Ca, Cl, and Na concentrations, and the Narraguagus River had the most variable Ca, Cl, and Na concentrations (Table 5). All sites had air-equilibrated pH values between 5.95 and 7.15. Mean chemistry for these streams for the analytes of interest (Table 5) was similar to mean chemistry for Rocky, Baker, and Sinclair Brooks during the same time period (air-equilibrated ph: 6.50, Cl: 46.8 μeq/L, Na: 72.6 μeq/L; Ca: 107 μeq/L). These small tributaries of the Narraguagus River are located ~2 km upstream from the nearest salted road (Figure 1).

Time-series evaluation of Cl and Na data for these sites indicates that there is very little change in Cl or Na concentration between the upstream and downstream sites for Machias, Mopang, and Old Stream, and little change with increasing distance from Route 9 for all four rivers (Figure 3, Figure 4). However, the Narraguagus River had higher Cl and Na at the site 50 m downstream of Route 9 as compared to the upstream site on all sample dates except December 30, 2004 (Figure 3, Figure 4). On December 30, the upstream and downstream sites had similarly elevated concentrations of Na and Cl, declining and stabilizing after the 50 m downstream site. A possible explanation may be transport of aerosol NaCl upstream by wind or mechanical means. Since the upstream site later returned to relatively low Cl and Na concentrations, the data do not support moving the upstream site farther upstream.

We plotted Na:Cl for all four streams, for the March 30 collection, a representative chemical event for all sites and with all stations sampled (Figure 5). The ratios is most variable in the Narraguagus (Figure 5). Na:Cl for the Narraguagus River was lower at downstream sites as compared to the upstream site for every sample date except December 30, 2004 (Figure 6a). By comparison, Na:Cl was virtually the same at all sites on the Machias River for all sample dates (Figure 6b; note exception on December 30 at site D). These results suggest that (1) road salt did not affect the chemistry of the Machias, Mopang, or Old Stream; (2) road salt did affect the chemistry of the Narraguagus within 50 to 100 feet downstream of the road; and, (3) distance from the road did not affect stream chemistry, except for the near-road Narraguagus sites as noted above.

There are spatial patterns in the chemistry among rivers (Figures 6a and 6b), and temporal patterns determined by precipitation chemistry. We used a general linear model, essentially an ANOVA with these data (SYSTAT version 11.1, 2005), to determine which factors may affect differences in stream chemistry. Distance from Route 9 did not significantly affect Cl, Ca, or Na concentrations ($P>0.6$; $F<0.7$). However, there were significant differences between rivers for Cl ($P<0.01$, $F=7.5$), Ca ($P<0.01$, $F=65.7$), and Na ($P<0.14$, $F=3.8$) concentrations. Finally, the strongest influence on chemistry appears to be the temporal pattern. Results indicated a significant effect of sample date for Cl ($P<0.01$, $F=7.78$), Ca ($P<0.01$, $F=101.4$), and Na ($P<0.01$, $F=10.9$) concentrations. These data corroborate precipitation information from Acadia National Park, where the chemistry of snowfall appears to be most strongly affected by temporal patterns, especially individual storm tracks and snow amount, as well (Nelson, unpubl.).

2. The seasonal changes and spatial patterns are probably irrelevant for salmon.

We evaluated air-equilibrated pH for all sample dates and streams (Figure 7). The pH of each stream varied by sample date, but not by distance from Route 9. Any differences between sample dates or sites were only one- or two-tenths of a pH unit, supporting the assertion that acidification did not occur. ANC values for these streams averaged 50-80 ueq/L (Table 5). In Penobscot Brook at Acadia National Park where episodic acidification was first identified by Kahl *et al.* (1985), mean winter pH was 6.03 and mean winter ANC was 14.2 ueq/L; pH declines were up to 2 pH units and ANC declines were 130 ueq/L during acidification events (Heath *et al.*, 1993). Higher ANC in these Downeast streams may be buffering salt inputs and mitigating any effects of salt application.

The streamwater chemistry indicates no consistent difference in Ca between upstream and downstream sites on the Machias, Mopang, or Narraguagus rivers (Figure 8). At Old Stream, Ca was slightly higher at downstream sites than the upstream site (Figure 8). As reported above, there was no upstream-downstream difference in Na for Old Stream, so an ion exchange explanation seems unlikely. A more likely explanation is that there is leachable Ca in road fill used in the construction of Route 9.

Summary and Implications

How can managers use this information?

The data indicate that Narraguagus River chemistry in the vicinity of Route 9 is somewhat affected by road salt, resulting in increases in Na and Cl downstream of the road, and a decline in the Na:Cl ratio at downstream sites. However, the change is small, and distance from the road did not appear to matter, with the salt signal continuing as far as our 500 m downstream site. Future research should evaluate sites even farther up- and down- stream to evaluate the geographical extent of changes in Na and Cl chemistry. The Machias River, Mopang Stream, and Old Stream sites near Route 9 did not show road salt effects. The Na and Cl data suggest that the timing of snowfall or road salt application are probably important in controlling chemistry. The temporal patterns in the data were stronger than spatial patterns.

Should calcium chloride be substituted for sodium chloride?

There was little change in Ca downstream of Route 9. While we do not yet have access to the information about use of $CaCl_2$ this past winter, it does not appear that Ca in rivers was significantly affected. With these data, we cannot evaluate whether the permanent and exclusive use of $CaCl_2$ near river crossings would have a beneficial effect on river chemistry.

Broader impacts of dataset

These data are in preparation for posting on PEARL, Maine's environmental information resource on the Web (pearl.maine.edu). Although developed for lakes, PEARL has recently been expanded to include data on streams and terrestrial systems. Including this data set on PEARL allows open access to the data by agencies, university researchers, students, and the public. PEARL-style metadata are in preparation, and data will be transferred to the PEARL administrator in early September, 2005.

This data set also includes a GIS layer with all of the points sampled for this research, taken using a GPS receiver and hand-digitized using topographic maps where GPS points were not available. The spatial data set will accompany the chemical data set to ensure that sites are plotted correctly on PEARL. PEARL's spatial component ensures that these data are grouped with other data available for geographically nearby studies, and helps agency staff and researchers place projects in a regional context.

This project is part of a integrated spatial and chemical baseline data effort for Maine salmon rivers. In concert with other agency and university projects, baseline chemical data now exist for most major rivers in the area, and survey data exist for all rivers that have supported Atlantic Salmon. The project has benefited from atmospheric deposition data and research at the Bear Brook Watershed in Maine and paired calibrated watersheds at Acadia National Park. In turn, the project provides data that support seemingly unrelated graduate theses and research projects on atmospheric deposition and long term chemical budgets. The integrated evaluation is a unique and valuable resource for parties interested in salmon habitat and the chemical condition of Downeast rivers.

Acknowledgements

Tanya Hyssong, Catherine Schmitt, and Paul Dumond assisted with field work for this project. The Mitchell Center Laboratory provided aboratory data and QC/QA support. GIS layers used for figures in this report were available from the Maine Office of GIS; base data were attributed to the Maine DEP and Maine DOT. Randy Gray of the Maine DOT provided information regarding road salting practices in the study area. Wet deposition data from Bear Brook Watershed in Maine (BBWM) have been collected since 1986 with support from the U.S. Environmental Protection Agency, U.S. National Science Foundation, U.S. Geological Survey, U.S.D.A. Forest Service, The Maine Agricultural and Forest Experiment Station, the Senator George Mitchell Center for Environmental and Watershed Research, and the University of

Maine. Project principal investigators are I.J. Fernandez, J.S. Kahl, S.A. Norton, L.E. Rustad, and G.B. Wiersma.

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Table 1. Site names and characteristics for this research. Site abbreviations are used for display purposes on some graphics. Distances from Route 9 are approximate, determined by field measurement. Distances were measured along the stream channel, and are not straight-line distances. Elevations determined by cross-referencing topographic maps.

Site Name	Site abbreviation	Distance from Route 9 (meters)*	Easting (UTM)	Northing (UTM)	Elevation (meters a.s.l.)
Machias A	MAC_A	Upstream: -50	591593	4973453	185
Machias B	MAC_B	50	591639	4973269	179
Machias C	MAC_C	100	591663	4973176	179
Machias D	MAC_D	300	591851	4973029	169
Machias E	MAC_E	500	592019	4972811	172
Mopang A	MOP_A	Upstream: -50	583685	4969333	299
Mopang B	MOP_B	50	583689	4969055	308
Mopang C	MOP_C	100	583691	4968932	308
Narraguagus A	NAR_A	Upstream: -50	573453	4966060	275
Narraguagus B	NAR_B	50	573457	4965720	284
Narraguagus C	NAR_C	100	573458	4965628	283
Narraguagus D	NAR_D	300	573503	4965474	267
Narraguagus E	NAR_E	500	573527	4965289	275
Old Stream A	OLD_A	Upstream: -50	599789	4976693	172
Old Stream B	OLD_B	50	599811	4976560	170
Old Stream C	OLD_C	100	599858	4976509	169
Old Stream D	OLD_D	300	599813	4976460	167
Old Stream E	OLD_E	500	599876	4976426	171

* In graphics and statistics, the upstream site is designated with distance = -50 m

Table 2. Complete chemical data for all samples collected in this research. Charge balance and Na:Cl ratio were calculated, all other values were measured in the laboratory.

Sample ID	Record Type	Date	Closed-cell pH	Air-equilibrated pH	ANC (ueq/L)	Specific Conductivity (uS/cm)	DOC (mg/L)	Ca (ueq/L)	Ca (mg/L)	Mg (ueq/L)	K (ueq/L)	Na (ueq/L)	Total Al (ug/L)	Cl (ueq/L)	NO3 (ueq/L)	SO4 (ueq/L)	Charge Balance	Na:Cl
Machias-A	Reg	12/30/2004	6.16	6.81	74.27	24.40	11.0	112.51	2.25	38.03	11.06	87.64	114.80	51.6	2.01	44.1	1.05	1.70
Machias-A	*Rep*	*12/30/2004*				*24.33*												
Machias-B	Reg	12/30/2004	6.20	6.81	75.19	24.45	11.0	111.54	2.24	37.86	11.04	87.69	117.90	50.9	1.97	43.4	1.05	1.72
Machias-B	*Rep*	*12/30/2004*			*75.16*													
Machias-C	Reg	12/30/2004	6.14	6.75	73.27	24.35	11.1	109.73	2.20	37.47	11.04	88.42	124.10	52.4	2.04	44.4	1.04	1.69
Machias-C	*Rep*	*12/30/2004*		*6.83*														
Machias-D	Reg	12/30/2004	5.89	6.73	68.25	27.43	11.7	107.16	2.15	41.83	11.96	108.55	146.50	76.1	1.63	47.6	1.03	1.43
Machias-D	*Dup*	*12/30/2004*	*5.90*	*6.75*	*67.89*	*26.85*	*11.6*	*101.78*	2.04	*40.47*	*11.49*	*106.50*	*142.50*	*74.6*	*1.58*	*47.1*	*1.00*	1.43
Machias-D	*Rep*	*12/30/2004*		*6.81*														
Mopang-A	Reg	12/30/2004	5.88	6.80	64.52	23.87	7.1	91.86	1.84	37.44	10.36	89.92	65.21	60.4	0.94	49.6	1.06	1.49
Mopang-B	Reg	12/30/2004	5.89	6.77	62.77	23.82	7.2	88.54	1.77	36.51	10.32	90.06	69.67	61.0	0.90	49.9	1.04	1.48
Mopang-B	*Dup*	*12/30/2004*	*5.89*	*6.65*	*61.87*	*23.75*	*7.1*	*88.82*	1.78	*36.68*	*10.37*	*90.39*	*64.60*	*61.4*	*0.95*	*50.1*	*1.05*	1.47
Mopang-B	*Rep*	*12/30/2004*						*88.62*	1.78	*36.45*	*10.28*	*89.69*		*60.8*	*0.90*	*49.6*		1.47
Narraguagus-A	Reg	12/30/2004	6.07	6.93	91.59	41.64	11.2	148.29	2.97	49.89	11.44	193.51	144.70	173.2	2.96	57.6	1.03	1.12
Narraguagus-A	*Rep*	*12/30/2004*		*6.94*	*91.68*													
Narraguagus-B	Reg	12/30/2004	5.95	7.00	100.66	40.43	9.7	129.13	2.59	44.35	11.51	200.99	128.10	152.7	3.14	62.3	1.03	1.32
Narraguagus-B	*Rep*	*12/30/2004*			*102.24*													
Narraguagus-C	Reg	12/30/2004	6.11	6.69	92.23	28.28	11.5	139.65	2.80	45.89	10.54	89.85	159.40	63.0	3.02	53.7	1.02	1.43
Narraguagus-C	*Rep*	*12/30/2004*			*96.24*													
Narraguagus-D	Reg	12/30/2004	6.11	6.93	94.28	28.11	11.4	141.27	2.83	46.21	10.46	90.04	148.60	63.5	3.01	54.1	1.02	1.42
Narraguagus-D	*Rep*	*12/30/2004*						*141.73*	2.84	*46.32*	*10.46*	*90.21*		*63.4*	*3.04*	*54.2*		1.42
Narraguagus-E	Reg	12/30/2004	6.14	6.87	84.39	26.58	10.9	132.32	2.65	44.66	10.63	85.28	135.60	60.5	2.77	49.8	1.04	1.41
Old-A	Reg	12/30/2004	6.09	6.93	95.94	29.90	12.4	147.49	2.96	54.18	8.52	99.17	141.20	76.2	1.01	54.4	1.03	1.30
Machias-B	Reg	01/27/2005	6.14	6.87	90.86	25.05	9.9	118.84	2.38	39.42	11.99	93.87	115.40	53.5	2.77	44.2	1.06	1.76
Machias-B	*Dup*	*01/27/2005*	*5.73*	*6.81*	*91.11*	*25.21*	*10.0*	*119.10*	2.39	*39.47*	*12.50*	*94.67*	*115.70*	*53.8*	*2.76*	*44.6*	*1.06*	1.76
Machias-B	*Rep*	*01/27/2005*			*90.88*													
Old-A	Reg	01/27/2005	6.25	6.98	146.96	32.62	8.3	166.21	3.33	57.55	10.37	108.97	98.54	76.7	1.82	54.8	1.04	1.42
Narraguagus-A	Reg	02/24/2005	6.26	7.15	133.73	29.23	7.3	157.85	3.16	47.51	11.55	85.95	96.12	51.1	4.00	52.2	1.07	1.68
Narraguagus-B	Reg	02/24/2005	6.27	7.13	132.38	31.70	7.2	157.91	3.16	47.77	11.43	101.01	108.60	69.2	3.93	52.2	1.06	1.46
Narraguagus-C	Reg	02/24/2005	6.32	7.14	132.18	30.52	7.3	156.34	3.13	47.29	11.38	97.58	90.99	65.3	3.90	51.7	1.06	1.49
Narraguagus-C	*Rep*	*02/24/2005*				*31.03*												
Old-A	Reg	02/24/2005	6.27	7.10	117.98	30.35	8.7	144.05	2.89	51.25	9.20	104.50	117.60	74.4	2.25	50.8	1.04	1.41
Old-A	*Rep*	*02/24/2005*			*116.68*	*30.18*												
Old-B	Reg	02/24/2005	6.29	7.09	119.20	30.96	8.7	145.12	2.91	51.55	9.38	109.32	117.10	78.7	2.35	51.5	1.04	1.39
Old-B	*Rep*	*02/24/2005*						*146.36*	2.93	*51.85*	*9.40*	*109.55*		*77.9*	*2.34*	*51.0*		1.41
Old-C	Reg	02/24/2005	6.30	7.09	120.90	31.28	8.8	144.88	2.90	51.54	9.57	111.27	113.70	80.5	2.37	51.8	1.03	1.38
Old-C	*Rep*	*02/24/2005*		*7.08*														
Old-D	Reg	02/24/2005	6.34	7.03	118.27	31.39	8.6	139.27	2.79	50.27	9.32	111.20	122.90	80.9	2.44	52.0	1.02	1.37
Old-D	*Rep*	*02/24/2005*			*117.78*													
Machias-A	Reg	03/19/2005	6.09	6.83	70.00	22.85	9.8	109.37	2.19	36.12	11.47	83.27	120.90	46.7	2.39	42.2	1.10	1.78
Machias-B	Reg	03/19/2005	6.11	6.79	74.19	23.05	9.8	109.88	2.20	36.14	11.78	84.54	128.10	47.8	2.38	42.0	1.08	1.77
Mopang-A	Reg	03/19/2005	6.07	6.46	61.25	21.71	5.6	84.52	1.69	33.13	10.80	82.47	63.20	53.1	1.20	47.3	1.08	1.55
Mopang-A	*Rep*	*03/19/2005*			*60.92*			*85.45*	1.71	*33.42*	*10.80*	*82.55*		*53.5*	*1.27*	*48.0*		1.54
Mopang-B	Reg	03/19/2005	6.06	6.77	58.97	21.78	5.6	88.13	1.77	33.95	10.76	82.96	58.14	53.7	1.20	47.3	1.11	1.55
Mopang-C	Reg	03/19/2005	6.07	6.76	61.18	21.50	5.5	85.16	1.71	33.39	10.93	83.24	60.16	53.6	1.19	47.0	1.09	1.55
Mopang-C	*Rep*	*03/19/2005*												*53.5*	*1.20*	*47.0*		

Sample ID	Record Type	Date	Closed-cell pH	Air-equilibrated pH	ANC (ueq/L)	Specific Conductivity (uS/cm)	DOC (mg/L)	Ca (ueq/L)	Ca (mg/L)	Mg (ueq/L)	K (ueq/L)	Na (ueq/L)	Total Al (ug/L)	Cl (ueq/L)	NO3 (ueq/L)	SO4 (ueq/L)	Charge Balance	Na:Cl
Old-A	Reg	03/19/2005	6.21	6.48	70.57	23.50	8.8	104.08	2.09	41.25	9.10	87.17	127.30	63.1	1.68	41.2	1.06	1.38
Old-A	*Rep*	*03/19/2005*		*6.62*														
Old-B	Reg	03/19/2005	6.23	6.73	86.78	25.86	8.8	125.33	2.51	44.82	9.68	90.42	127.00	66.0	1.30	46.4	1.07	1.37
Old-C	Reg	03/19/2005	6.20	6.79	90.17	26.09	8.8	127.39	2.55	44.77	9.87	90.71	137.60	66.6	1.25	47.3	1.06	1.36
Old-D	Reg	03/19/2005	6.21	6.87	88.65	26.35	8.8	124.92	2.50	44.62	9.82	91.11	122.70	66.6	1.25	47.3	1.06	1.37
Old-D	*Rep*	*03/19/2005*			*89.78*													
Machias-A	Reg	03/30/2005	5.74	6.22	38.62	17.20	10.7	74.89	1.50	26.40	9.75	60.80	126.40	31.1	1.21	32.2	1.04	1.96
Machias-A	*Rep*	*03/30/2005*						*75.40*	1.51	*26.47*	*9.74*	*60.73*						
Machias-B	Reg	03/30/2005	5.79	6.21	39.60	17.53	10.5	74.33	1.49	26.30	10.04	63.21	124.70	33.2	1.23	32.1	1.04	1.90
Machias-B	*Rep*	*03/30/2005*				*17.50*												
Machias-C	Reg	03/30/2005	5.79	6.21	36.64	16.15	10.2	70.82	1.42	24.85	9.34	58.99	122.20	30.8	1.13	30.1	1.04	1.92
Machias-D	Reg	03/30/2005	5.76	6.16	40.33	17.14	10.5	74.42	1.49	26.11	9.72	62.35	131.30	33.0	1.20	32.2	1.03	1.89
Machias-E	Reg	03/30/2005	5.78	6.11	38.11	16.82	10.3	71.25	1.43	25.20	9.63	61.29	127.40	32.3	1.19	31.9	1.02	1.90
Mopang-A	Reg	03/30/2005	5.77	6.39	38.43	17.15	7.3	63.19	1.27	25.27	9.27	63.95	75.09	38.9	0.64	34.9	1.04	1.65
Mopang-A	*Rep*	*03/30/2005*																
Mopang-B	Reg	03/30/2005	5.80	6.40	40.80	17.35	7.1	64.59	1.29	25.81	9.35	65.31	75.28	39.6	0.63	35.0	1.05	1.65
Mopang-B	*Rep*	*03/30/2005*		*6.41*										*39.6*	*0.64*	*35.0*		
Mopang-C	Reg	03/30/2005	5.68	6.37	35.84	16.50	7.3	63.42	1.27	25.73	9.54	65.67	69.81	40.6	0.61	35.1	1.07	1.62
Mopang-C	*Rep*	*03/30/2005*			*36.17*													
Narraguagus-A	Reg	03/30/2005	6.03	6.52	51.88	16.42	8.2	83.22	1.67	27.58	9.23	50.57	121.10	25.6	1.41	35.1	1.05	1.98
Narraguagus-A	*Rep*	*03/30/2005*												*25.6*	*1.39*	*35.1*		
Narraguagus-B	Reg	03/30/2005	5.99	6.47	49.40	21.67	8.0	84.86	1.70	28.55	9.57	87.61	108.00	66.9	1.41	35.6	1.05	1.31
Narraguagus-B	*Rep*	*03/30/2005*		*6.51*														
Narraguagus-C	Reg	03/30/2005	5.99	6.45	49.43	19.44	8.2	81.25	1.63	27.80	9.17	72.03	108.00	49.5	1.36	35.4	1.03	1.45
Narraguagus-D	Reg	03/30/2005	5.92	6.54	50.27	18.68	8.0	83.22	1.67	28.29	9.38	67.83	114.20	45.2	1.36	35.3	1.05	1.50
Narraguagus-D	*Rep*	*03/30/2005*		*6.56*														
Narraguagus-E	Reg	03/30/2005	5.95	6.43	49.33	18.60	8.1	84.12	1.69	28.35	9.48	66.42	112.40	43.2	1.38	35.6	1.06	1.54
Old-A	Reg	03/30/2005	5.80	6.43	47.45	19.91	9.9	79.90	1.60	32.03	8.74	70.91	120.00	48.8	0.75	35.8	1.01	1.45
Old-B	Reg	03/30/2005	5.91	6.40	56.98	20.04	9.4	87.10	1.75	33.23	9.30	70.80	129.90	48.7	0.66	36.7	1.01	1.45
Old-B	*Rep*	*03/30/2005*				*20.07*												
Old-C	Reg	03/30/2005	5.93	6.49	52.64	19.66	9.2	85.01	1.70	32.36	8.83	68.96	122.60	47.0	0.64	35.7	1.03	1.47
Old-C	*Rep*	*03/30/2005*			*52.13*			*87.22*	1.75	*32.81*	*8.91*	*69.50*		*48.0*	*0.64*	*36.1*		1.45
Old-D	Reg	03/30/2005	5.92	6.51	52.97	20.30	9.3	87.02	1.74	33.28	9.13	71.29	116.30	48.3	0.63	36.7	1.04	1.48
Old-D	*Rep*	*03/30/2005*			*54.47*	*20.20*												
Old-E	Reg	03/30/2005	5.88	6.44	55.13	20.23	9.4	86.86	1.74	33.22	9.34	72.22	129.40	48.8	0.72	36.8	1.03	1.48
Machias-A	Reg	04/5/2005	5.43	5.95	24.62	17.4	9.8	63.09	1.26	25.48	10.73	62.90	118.10	37.6	1.06	38.2	1.03	1.67
Machias-B	Reg	04/5/2005	5.79	6.18	38.78	18.52	10.2	78.89	1.58	27.93	10.93	66.52	121.70	39.0	1.46	37.3	1.04	1.71
Machias-B	*Dup*	*04/5/2005*	*5.80*	*6.27*	*44.26*	*18.58*	*10.0*	*78.77*	1.58	*27.91*	*10.95*	*66.41*	*115.70*	*39.2*	*1.46*	*37.2*	*1.02*	1.70
Machias-B	*Rep*	*04/5/2005*			*41.37*													
Machias-C	Reg	04/5/2005	5.78	6.31	33.75	17.79	10.1	77.88	1.56	27.68	10.96	68.46	123.40	41.4	1.43	37.6	1.07	1.65
Machias-D	Reg	04/5/2005	5.80	6.33	38.41	18.41	10.1	79.37	1.59	28.08	11.03	67.49	121.20	40.0	1.46	37.6	1.05	1.69
Machias-E	Reg	04/5/2005	5.76	6.18	26.02	17.01	6.3	56.33	1.13	24.88	7.68	69.89	160.30	38.7	0.41	49.5	1.05	1.80
Machias-E	*Rep*	*04/5/2005*						*56.56*	1.13	*24.94*	*7.66*	*69.78*		*38.9*	*0.39*	*49.5*		1.79
Mopang-A	Reg	04/5/2005	5.65	6.30	29.22	16.78	6.6	57.75	1.16	24.51	9.77	65.76	73.25	43.2	0.45	39.3	1.05	1.52
Mopang-B	Reg	04/5/2005	5.83	6.46	36.36	17.83	6.2	65.54	1.31	26.87	10.07	68.85	58.15	45.7	0.57	41.4	1.07	1.51
Narraguagus-A	Reg	04/5/2005	5.92	6.48	43.22	16.93	7.7	80.10	1.61	26.78	10.82	53.60	100.70	33.6	1.04	38.7	1.06	1.60
Narraguagus-A	*Rep*	*04/5/2005*				*16.84*												
Narraguagus-B	Reg	04/5/2005	5.94	6.46	40.30	19.18	7.9	79.22	1.59	26.99	10.58	71.32	100.90	53.4	1.01	38.6	1.05	1.34

Sample ID	Record Type	Date	Closed-cell pH	Air-equilibrated pH	ANC (ueq/L)	Specific Conductivity (uS/cm)	DOC (mg/L)	Ca (ueq/L)	Ca (mg/L)	Mg (ueq/L)	K (ueq/L)	Na (ueq/L)	Total Al (ug/L)	Cl (ueq/L)	NO3 (ueq/L)	SO4 (ueq/L)	Charge Balance	Na:Cl
Narraguagus-C	Reg	04/5/2005	5.92	6.48	41.55	20.99	7.7	81.09	1.63	27.53	10.89	84.17	102.00	67.0	1.08	39.3	1.05	1.26
Narraguagus-C	*Rep*	*04/5/2005*		*6.44*														
Narraguagus-D	Reg	04/5/2005	5.92	6.43	42.79	20.77	7.6	81.55	1.63	27.75	10.65	79.50	94.04	62.0	1.05	40.1	1.05	1.28
Narraguagus-D	*Rep*	*04/5/2005*			*43.15*													
Narraguagus-E	Reg	04/5/2005	5.91	6.35	41.10	19.26	7.7	80.39	1.61	27.17	10.49	69.07	104.40	51.2	1.02	38.6	1.06	1.35
Narraguagus-E	*Rep*	*04/5/2005*		*6.43*														
Old-A	Reg	04/5/2005	5.77	6.34	39.11	18.43	9.3	73.25	1.47	30.22	9.02	67.14	101.10	48.1	0.64	35.0	1.01	1.40
Old-B	Reg	04/5/2005	5.92	6.38	52.30	19.46	8.8	88.24	1.77	32.92	9.66	65.03	109.30	44.6	0.54	39.8	1.04	1.46
Old-C	Reg	04/5/2005	5.93	6.54	52.75	19.04	8.7	88.65	1.78	32.93	9.53	64.76	109.00	44.6	0.53	39.8	1.04	1.45
Old-C	*Rep*	*04/5/2005*			*53.42*	*18.94*												
Old-D	Reg	04/5/2005	5.95	6.59	52.53	19.32	8.6	89.23	1.79	32.94	9.63	64.62	106.00	44.4	0.55	39.7	1.04	1.45
Old-D	*Dup*	*04/5/2005*	*5.92*	*6.54*	*52.43*	*19.2*	*8.6*	*89.39*	1.79	*32.90*	*10.66*	*67.02*	*109.60*	*47.2*	*0.64*	*40.0*	*1.05*	1.42
Old-E	Reg	04/5/2005	5.94	6.49	52.47	19.16	8.5	86.77	1.74	32.47	9.69	65.48	108.30	45.3	0.54	39.9	1.03	1.45
Old-E	*Rep*	*04/5/2005*		*6.57*														
Machias-A	Reg	4/21/2005	6.20	6.31	58.72	19.44	9.1	87.57	1.75	29.27	10.58	70.50	116.00	38.4	0.91	37.5	1.04	1.84
Machias-A	*Rep*	*4/21/2005*				*19.41*												
Machias-B	Reg	4/21/2005	6.13	6.50	58.11	19.35	8.8	88.74	1.78	29.52	10.30	71.35	114.20	39.3	0.89	37.4	1.06	1.81
Machias-C	Reg	4/21/2005	6.07	6.55	57.46	19.18	8.9	89.03	1.78	29.55	10.41	71.37	113.90	39.3	0.90	37.5	1.07	1.82
Machias-D	Reg	4/21/2005	6.10	6.58	58.15	19.25	8.9	88.82	1.78	29.50	10.36	70.92	114.40	39.0	0.89	37.5	1.06	1.82
Machias-D	*Rep*	*4/21/2005*		*6.67*				*89.04*	1.78	*29.57*	*10.37*	*71.03*						
Machias-E	Reg	4/21/2005	6.14	6.56	58.10	19.47	8.9	88.01	1.76	29.44	10.44	72.43	119.90	40.4	0.89	38.0	1.05	1.79
Machias-E	*Rep*	*4/21/2005*			*55.33*									*40.4*	*0.89*	*38.0*		
Mopang-A	Reg	4/21/2005	6.19	6.54	50.61	19.06	5.2	72.29	1.45	28.58	9.48	75.89	50.00	47.6	0.40	44.9	1.07	1.60
Mopang-B	Reg	4/21/2005	6.18	6.65	53.05	19.50	4.9	74.90	1.50	29.36	9.52	76.96	45.61	49.0	0.46	45.4	1.08	1.57
Mopang-C	Reg	4/21/2005	6.18	6.70	54.45	19.75	5.0	74.83	1.50	29.33	9.89	78.27	46.48	50.5	0.47	45.7	1.07	1.55
Mopang-C	*Rep*	*4/21/2005*		*6.71*	*54.44*													
Narraguagus-A	Reg	4/21/2005	6.36	6.57	99.91	22.92	7.1	121.94	2.44	36.77	11.39	72.19	93.21	37.9	0.85	47.4	1.06	1.91
Narraguagus-B	Reg	4/21/2005	6.43	6.79	99.80	27.15	7.0	121.55	2.44	37.00	11.45	104.91	90.99	71.3	0.83	48.9	1.05	1.47
Narraguagus-B	*Rep*	*4/21/2005*				*27.16*		*122.28*	2.45	*37.19*	*11.48*	*105.18*						
Narraguagus-C	Reg	4/21/2005	6.52	6.91	95.68	25.28	7.1	121.33	2.43	37.01	11.56	89.51	90.06	57.6	0.80	47.5	1.06	1.55
Narraguagus-C	*Dup*	*4/21/2005*	*6.58*	*6.92*	*97.81*	*25.24*	*7.1*	*123.24*	2.47	*37.36*	*11.48*	*89.53*	*93.00*	*57.1*	*0.80*	*47.5*	*1.06*	1.57
Narraguagus-D	Reg	4/21/2005	6.52	6.90	98.69	24.53	6.9	122.53	2.46	37.21	11.76	87.65	89.93	55.2	0.78	47.3	1.07	1.59
Narraguagus-E	Reg	4/21/2005	6.55	6.96	99.24	24.95	6.9	122.78	2.46	37.25	11.84	87.19	85.68	54.8	0.81	47.8	1.06	1.59
Narraguagus-E	*Rep*	*4/21/2005*		*6.94*	*99.23*													
Old-A	Reg	4/21/2005	6.30	6.61	84.27	23.63	8.5	104.08	2.09	38.20	10.37	86.95	105.00	56.3	0.54	44.1	1.02	1.54
Old-A	*Rep*	*4/21/2005*		*6.87*														
Old-B	Reg	4/21/2005	6.33	6.76	81.61	23.46	8.0	107.04	2.15	38.74	9.20	84.15	102.50	54.3	0.54	45.6	1.04	1.55
Old-B	*Rep*	*4/21/2005*			*84.13*													
Old-C	Reg	4/21/2005	6.34	6.81	83.80	23.53	7.9	108.87	2.18	39.10	9.18	82.77	104.60	52.8	0.52	46.5	1.04	1.57
Old-D	Reg	4/21/2005	6.30	6.86	84.75	25.00	7.9	112.44	2.25	40.04	9.48	90.07	116.10	63.7	0.60	47.3	1.04	1.41
Old-E	Reg	4/21/2005	6.32	6.87	85.32	24.08	7.8	111.97	2.24	39.76	9.32	87.92	115.60	57.4	0.59	47.1	1.05	1.53
Old-E	*Rep*	*4/21/2005*						*125.98*	2.52	*41.63*	*9.22*	*86.64*		*57.4*	*0.59*	*47.1*		1.51

Table 3. Analytical Methods for the University of Maine Laboratory.

Analyte	*Method*	*Reference*
pH, closed cell	Electrode	Hillman *et al.*[6], EPA 19.0[5]
pH, aerated	Electrode	Hillman *et al.*[6], EPA 5.0[5]
Specific conductance	Wheatstone bridge	EPA 120.1[2],EPA 23.0[5]
True color	Spectrophotometer, 457.5 nm	EPA 110.2[2]
ANC	Gran Titration	Hillman *et al.*[6], EPA 5.0[5]
Anions: Cl, NO_3, SO_4	Ion chromatography	EPA 300.0[1]
Pre 1999 analysis methods for Ca, Mg, Na, K, and Al		
Calcium	AAS with $N_2$0-acetylene flame	EPA 215.1[2]
Magnesium	AAS with $N_2$0-acetylene flame	EPA 242.1[2]
Sodium	AAS with air-acetylene flame	EPA 258.1[2]
Potassium	AAS with air-acetylene flame	EPA 273.1[2]
Aluminum (total)	AAS with graphite furnace	EPA 200.9[1]
1999 to 2003 methods for Ca, Mg, Na, K, and Al		
Calcium	Inductively Coupled Atomic Emission Spectroscopy (ICP)	EPA 200.15[10]
Magnesium	Inductively Coupled Atomic Emission Spectroscopy (ICP)	EPA 200.15[10]
Sodium	Inductively Coupled Atomic Emission Spectroscopy (ICP)	EPA 200.15[10]
Potassium	Inductively Coupled Atomic Emission Spectroscopy (ICP)	EPA 200.15[10]
Aluminum (total)	Inductively Coupled Atomic Emission Spectroscopy (ICP)	EPA 200.15[10]
2003 to present methods for Ca, Mg, Na, K, NH_4		
Calcium	Ion Chromatography (IC)	ASTM D 6919-03[11]
Magnesium	Ion Chromatography (IC)	ASTM D 6919-03[11]
Sodium	Ion Chromatography (IC)	ASTM D 6919-03[11]
Potassium	Ion Chromatography (IC)	ASTM D 6919-03[11]
Ammonium	Ion Chromatography (IC)	ASTM D 6919-03[11]
2003 to present methods for Al		
Aluminum (total)	AAS with graphite furnace	EPA 200.9[1]
Dissolved Organic Carbon	IR C analyzer, persulfate oxidation	EPA 415.1[2]
Ammonium (prior to 2003)	Autoanalyzer	EPA 9.0[5] and

		Bran & Luebbe 780-86T[7]
Silica	Autoanalyzer	EPA 22.0[5] and Bran & Luebbe 785-86T[7]
Total Hg	CVAFS dual gold trap	EPA 1631[8]
MethylHg	Distillation, Aqueous Ethylation, Purge and Trap, and CVAFS	EPA 1630[9]

AAS=atomic absorption spectrophotometry IR=Infrared Spectrophotometry
CVAFS=cold vapor atomic fluorescence spectrometry

Method references:
[1.] Methods for the Determination of Inorganic Substances in Environmental Samples, EPA 600/R-93-100, 1993.
[2.] Methods for Chemical Analysis of Water and Wastes, EPA 600/4-79-020, 1979, Revised 1983.
[3.] Standard Methods for Examination of Water and Wastewater, 18th ed. 1992.
[4.] Methods for the Determination of Metals in Environmental Samples, EPA 600/4-91/010, 1991, Supplement 1, EPA 600/R-94/111, 1994.
[5.] Handbook of Methods for Acid Deposition Studies: Laboratory Analysis For Surface Water Chemistry, EPA 600/4-87-026, 1987.
[6.] Hillman,D.C., J. Potter, and S. Simon, 1986. Analytical methods for the National Surface Water Survey, Eastern Lake Survey. EPA/600/4-86/009, EPA Las Vegas.
[7.] Bran & Luebbe Manual
[8.] Mercury in Water by Oxidation, Purge and Trap, and Cold Vapor Atomic Fluorescence Spectrometry, EPA 821-R-99-005, 1999
[9.] Methyl Mercury in Water by Distillation, Aqueous Ethylation, Purge and Trap, and Cold Vapor Atomic Fluorescence Spectrometry, EPA Draft, 1998
[10] EPA 200.15, Determination of Metals and Trace Elements in Water by Ultrasonic Nebulization Inductively Coupled Plasma-Atomic Emission Spectrometry. Rev. 1.2, 1994.
[11] ASTM D 6919-03 Standard Test Method for Determination of Dissolved Alkali and Alkaline Earth Cations and Ammonium in Water and Wastewater by Ion Chromatography. Annual Book of ASTM Standards, Vol 11.01, 2003.

Table 4. Precipitation and snowfall amounts for Wesley, ME, 5 km east of Old Stream. Data extracted from National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) Cooperative Summary of the Day for December 2004-April 2005. April 2005 data were preliminary. Only those days with precipitation and/or snowfall were included in this table.

Year	Month	Day	Total Precip.* (inches)	Snowfall (inches)
2004	12	2	1.39	
2004	12	8	0.24	0.3
2004	12	9	0.08	0.3
2004	12	11	0.33	0.5
2004	12	12	0.24	
2004	12	14	0.14	0.5
2004	12	19	0.15	1.5
2004	12	20	0.05	1
2004	12	21	0.02	0.5
2004	12	24	1.02	
2004	12	25	0.01	
2004	12	27	0.2	4
2004	12	28	0.08	2
2005	1	1	0.17	0
2005	1	3	0.36	3
2005	1	7	0.22	2
2005	1	8	0.06	2
2005	1	9	0.16	1.7
2005	1	11	0.1	1.2
2005	1	13	0.21	2
2005	1	14	0.03	0
2005	1	15	0.21	0.2
2005	1	17	0.14	3
2005	1	18	0.05	2.5
2005	1	20	0.26	6
2005	1	21	0.6	14
2005	1	23	0.05	0.5
2005	1	24	0.15	4
2005	1	27	0.01	0.5
2005	2	4	0.24	0.6
2005	2	9	0.01	
2005	2	11	0.87	9
2005	2	12	0.19	5
2005	2	13		0.2
2005	2	14		0.3
2005	2	15	0.01	0.3
2005	2	16	0.65	1
2005	2	17	0.44	
2005	2	22	0.18	5
2005	2	23	0.1	2.5
2005	2	24	0.02	1
2005	2	25		0.3
2005	2	26	0.01	0.5
2005	3	1	0.1	2
2005	3	2	0.32	4
2005	3	3	0.02	1
2005	3	7		0.3
2005	3	8	0.01	0.2
2005	3	9	2.91	3
2005	3	10	0.08	1.5
2005	3	12	0.16	3
2005	3	13	0.09	2
2005	3	15	0.16	4
2005	3	16	0.04	1.5
2005	3	29	2.22	
2005	3	30	0.59	
2005	4	21	0.56	1

* includes rain, melted snow, hail, sleet, and any other precipitation.

Table 5. Summary statistics for selected chemical parameters for the four streams studied in this research. Elements of interest for this report are Ca, Cl, and Na, all of which were most variable in the Narraguagus River.

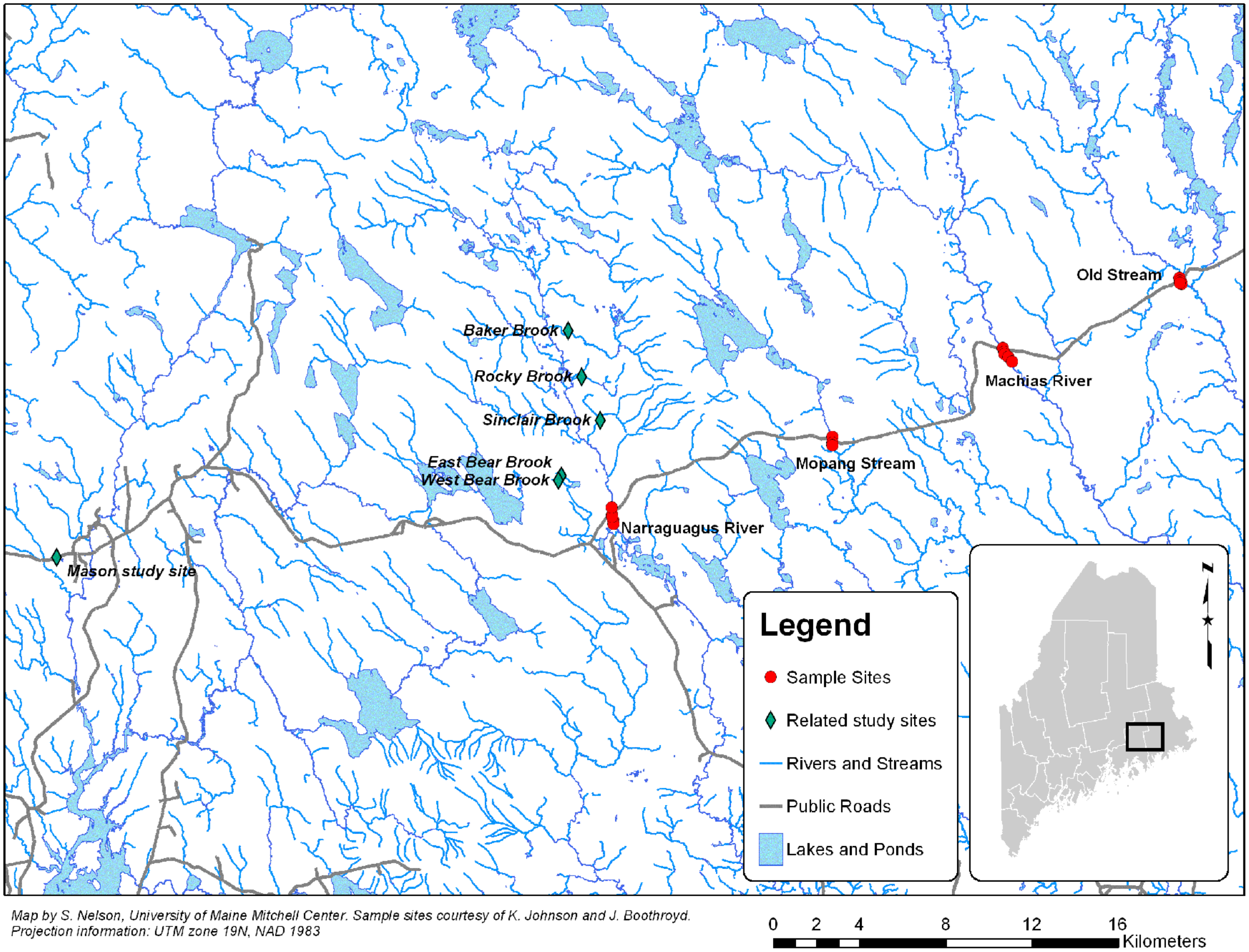
River		Air-equilibrated pH	ANC (μeq/L)	DOC (mg/L)	Ca (μeq/L)	Mg (μeq/L)	Na (μeq/L)	Cl (μeq/L)	SO_4 (μeq/L)
Machias River	N of cases	22	22	22	22	22	22	22	22
	Minimum	5.95	24.6	6.3	56.3	24.9	59.0	30.8	30.1
	Maximum	6.87	90.9	11.7	119	41.8	109	76.1	49.5
	Median	6.42	57.8	10.1	87.8	29.4	70.7	39.3	37.6
	Mean	6.45	53.2	9.9	88.3	30.8	74.2	42.4	38.8
	Standard Dev	0.29	18.6	1.1	18.1	5.5	12.9	10.3	5.3
Mopang Stream	N of cases	13	13	13	13	13	13	13	13
	Minimum	6.30	29.2	4.9	57.7	24.5	64.0	38.9	34.9
	Maximum	6.80	64.5	7.3	91.9	37.4	90.1	61.0	49.9
	Median	6.54	53.1	6.2	74.8	29.3	77.0	49.0	45.4
	Mean	6.57	49.8	6.2	75.0	30.0	76.1	49.0	43.3
	Standard Dev	0.18	12.2	0.9	11.6	4.4	9.4	7.3	5.6
Narraguagus River	N of cases	23	23	23	23	23	23	23	23
	Minimum	6.35	40.3	6.9	79.2	26.8	50.6	25.6	35.1
	Maximum	7.15	133.7	11.5	158	49.9	201	173	62.3
	Median	6.69	91.6	7.7	122	37.0	85.9	57.6	47.4
	Mean	6.72	78.9	8.3	113	36.3	90.8	64.0	45.4
	Standard Dev	0.27	32.2	1.5	29.7	8.6	36.3	33.5	8.2
Old Stream	N of cases	25	25	25	25	25	25	25	25
	Minimum	6.34	39.1	7.8	73.3	30.2	64.6	44.4	35.0
	Maximum	7.10	147.0	12.4	166	57.5	111	80.9	54.8
	Median	6.73	83.8	8.8	107	39.1	87.0	56.3	45.6
	Mean	6.71	79.6	8.9	111	40.5	84.7	59.3	44.2
	Standard Dev	0.25	28.6	0.9	26.0	8.3	16.1	12.8	6.3

Table 6a. Inputs of Na, Cl, and water in rain gauges (Wesley, ME NCDC), wet-only precipitation (BBWM, Bear Brook Watershed in Maine, 2.5 km northwest of Narraguagus), and throughfall (Acadia National Park) for periods analogous to those sampled for this research. Ranges are given for throughfall that represent different vegetation types, where open field precipitation yields the lowest estimate and coniferous vegetation yields the highest estimates for Na and Cl.

Date stream samples collected (this project)	Date inputs measured	Input type	Na (kg/ha)	Cl (kg/ha)	Water (mm)
12/30/2004	12/30/2004	Wesley, ME NCDC			100.3
	12/3/04 - 1/13/05	BBWM Wet deposition	22.1	24.0	73.4
	12/15/04-12/28/05	Acadia Throughfall	20.7 - 75.5	23-92	33.4-39.8
02/24/05	02/24/05	Wesley, ME NCDC			139.4
	1/14/05 - 2/22/05	BBWM Wet deposition	6.0	6.3	66.2
	12/29/04-3/5/05	Acadia Throughfall	97.3-234	104-245	226-228
03/19/05	03/19/05	Wesley, ME NCDC			99.1
	2/23/05 - 3/15/05	BBWM Wet deposition	6.8	6.7	114.8
	3/6/05-3/16/05	Acadia Throughfall	44.3-99	47.4-109	64-121
03/30/05	03/30/05	Wesley, ME NCDC			71.4
4/5/2005	4/5/2005	Wesley, ME NCDC			0.0
	3/16/05 - 4/5/05	BBWM Wet deposition	23.9	26.3	119.7
04/21/05	04/21/05	Wesley, ME NCDC			14.2
	4/6/05 - 4/21/05	BBWM Wet deposition	0.2	0.2	15.6

Table 6b. Estimated road salt input for each sample site. Inputs were calculated by assuming a semi-circular area of influence on each sample point (see Figure 9). The distance of road that affects the point is therefore two times the distance from the road, and the area of the hypothetical 'watershed' is one-half of pi times the distance from the road, squared. Maine DOT estimates an application rate of 14 tons/lane mile. We estimated for 2 lanes. These estimated inputs that would affect the sampling points decrease with distance from the road, due to 'dilution' by the larger watershed area, an exponential increase in relation to the increase in road length affected.

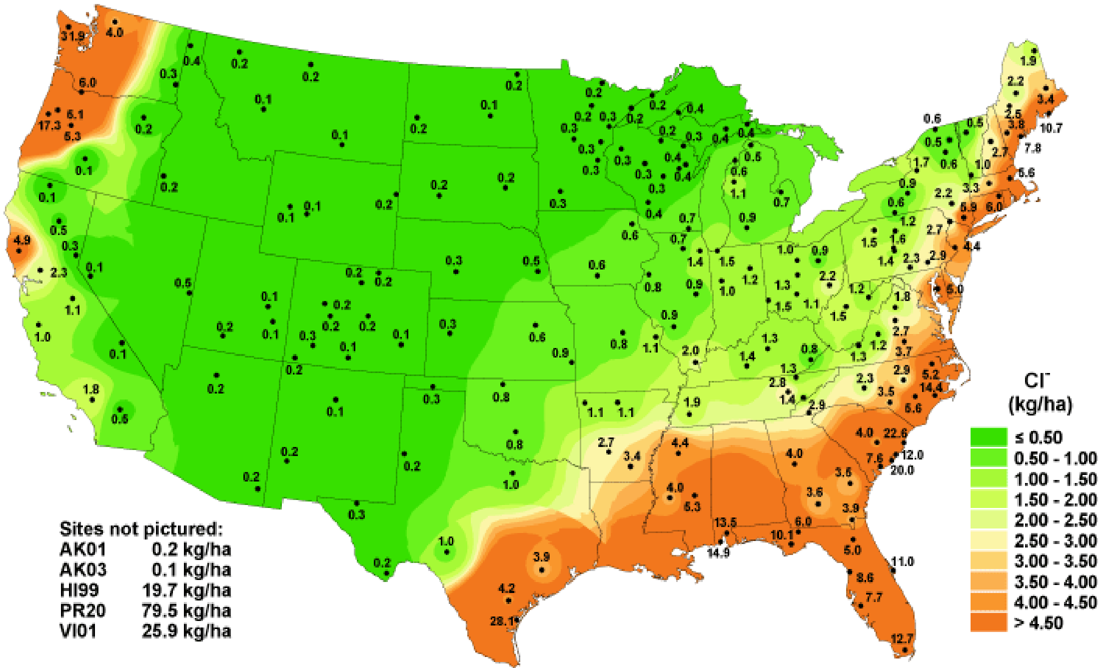
Distance from Route 9	Estimated road length salted (m)	Estimated watershed area (km^2)	Road Salt application rate (ton/lane mile)	**Input of road salt (kg/ha)**	
				Na	**Cl**
-50	0	n/a	0	**0**	**0**
50	100	16	14	**77**	**77**
100	200	63	14	**38**	**39**
300	600	565	14	**13**	**13**
500	1000	1571	14	**8**	**8**



Map by S. Nelson, University of Maine Mitchell Center. Sample sites courtesy of K. Johnson and J. Boothroyd.
Projection information: UTM zone 19N, NAD 1983

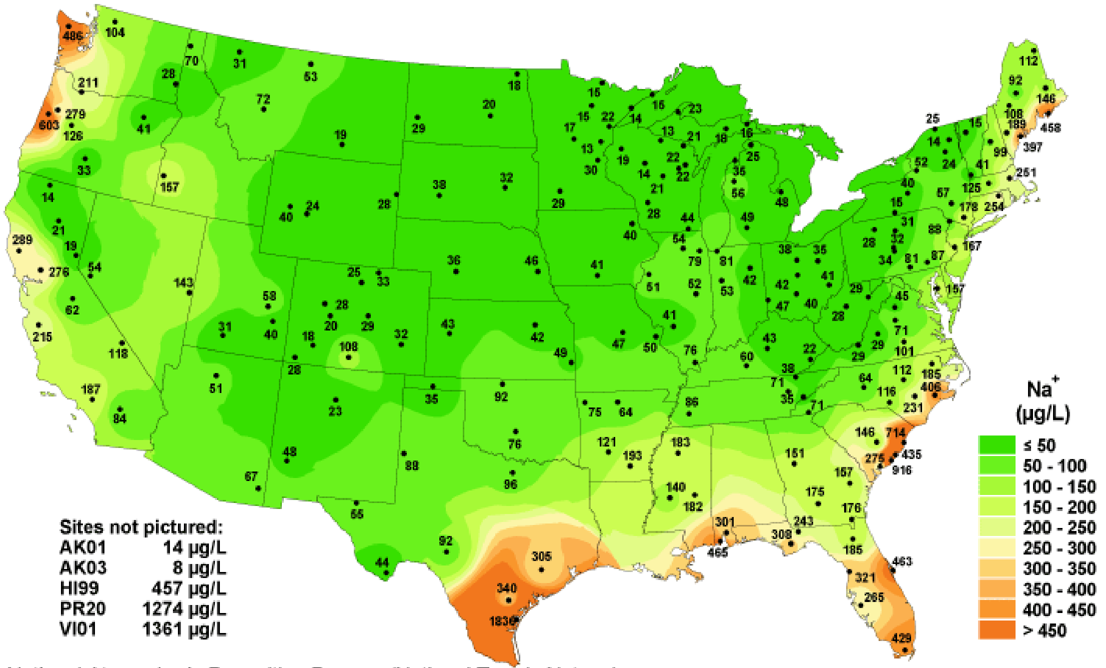
Figure 1. Map of sites sampled for this research, and for related research in the area. The Mason study site was evaluated for road salt effects (Mason *et al.*, 1999). Bear Brook Watershed sites provided wet deposition data. Rocky, Baker, and Sinclair Brooks are reference sites, part of other salmon-related research in the area.

Chloride ion wet deposition, 2003



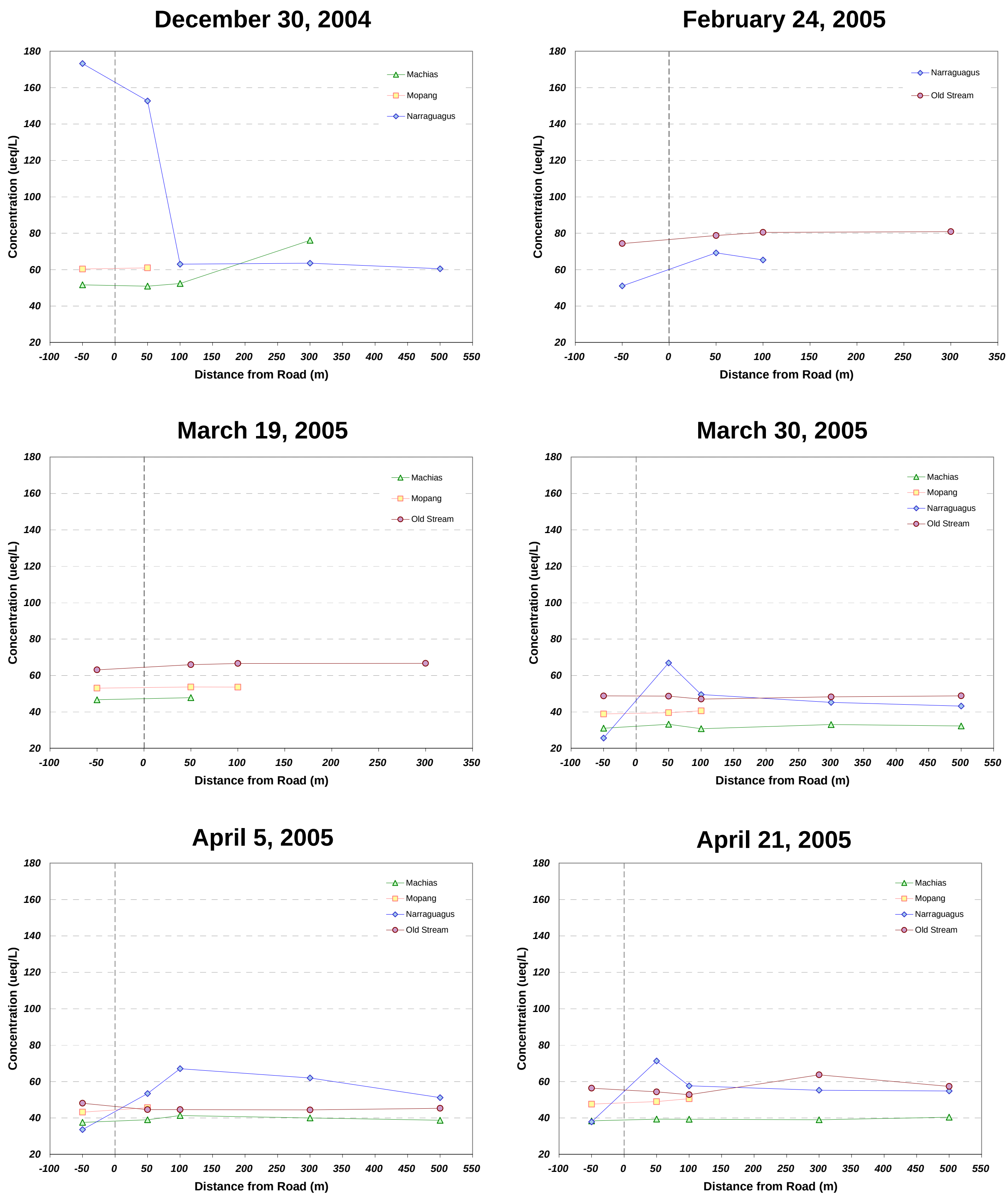
National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu

Sodium ion concentration, 2003



National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu

Figure 2. Chloride and sodium wet deposition for the U.S., 2003. Isopleth maps show areas with highest deposition along the coasts, due to marine inputs. Figures from the NADP/NTN, accessed online, 2005.



December 30, 2004

February 24, 2005

March 19, 2005

March 30, 2005

April 5, 2005

April 21, 2005

Figure 3. Chloride (Cl) concentrations in four Downeast streams, above and below Route 9, plotted for each sampling date in winter 2004/5. The X-axis shows distance from the road, where -50 meters is the upstream, presumably unaffected, site.

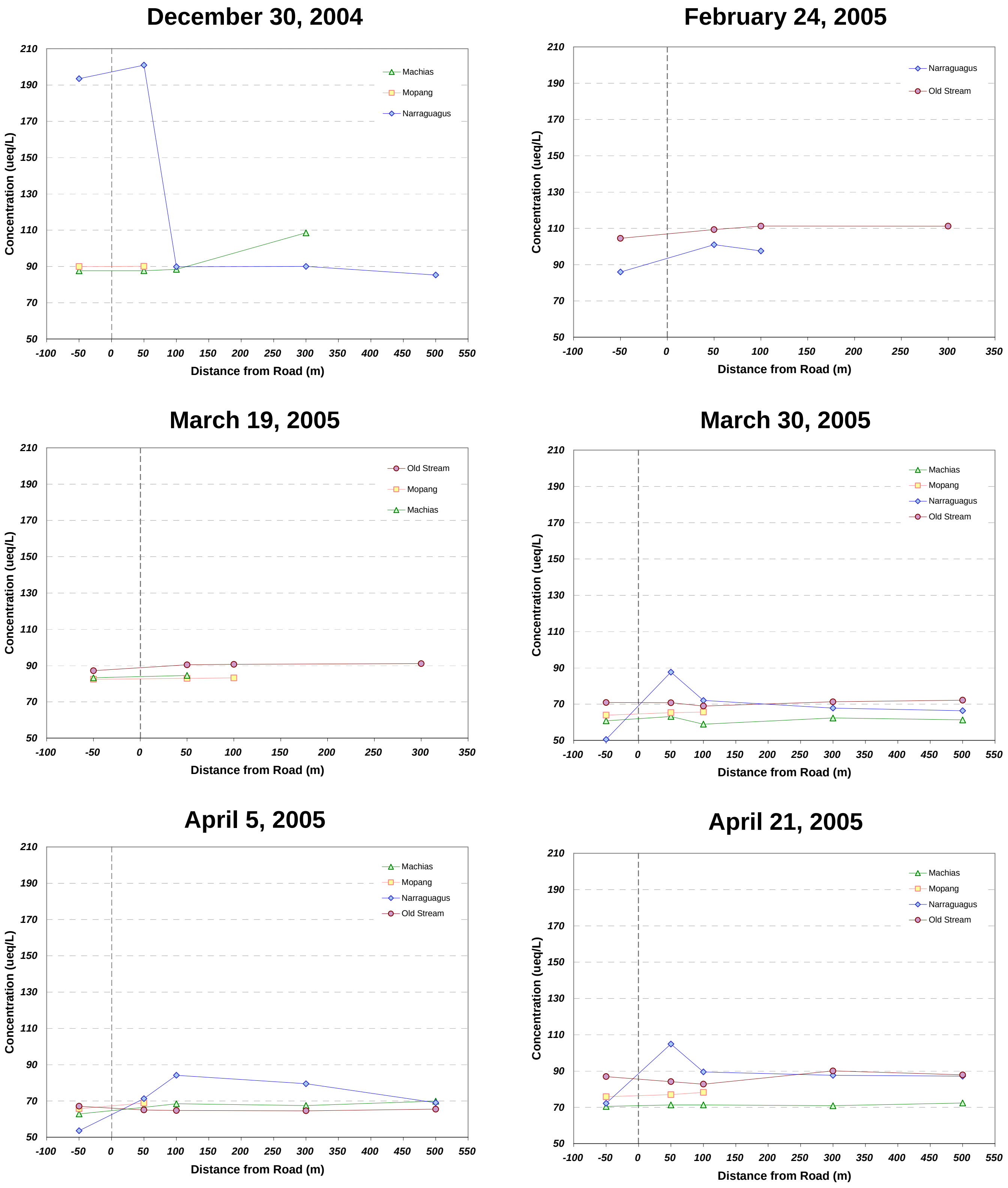
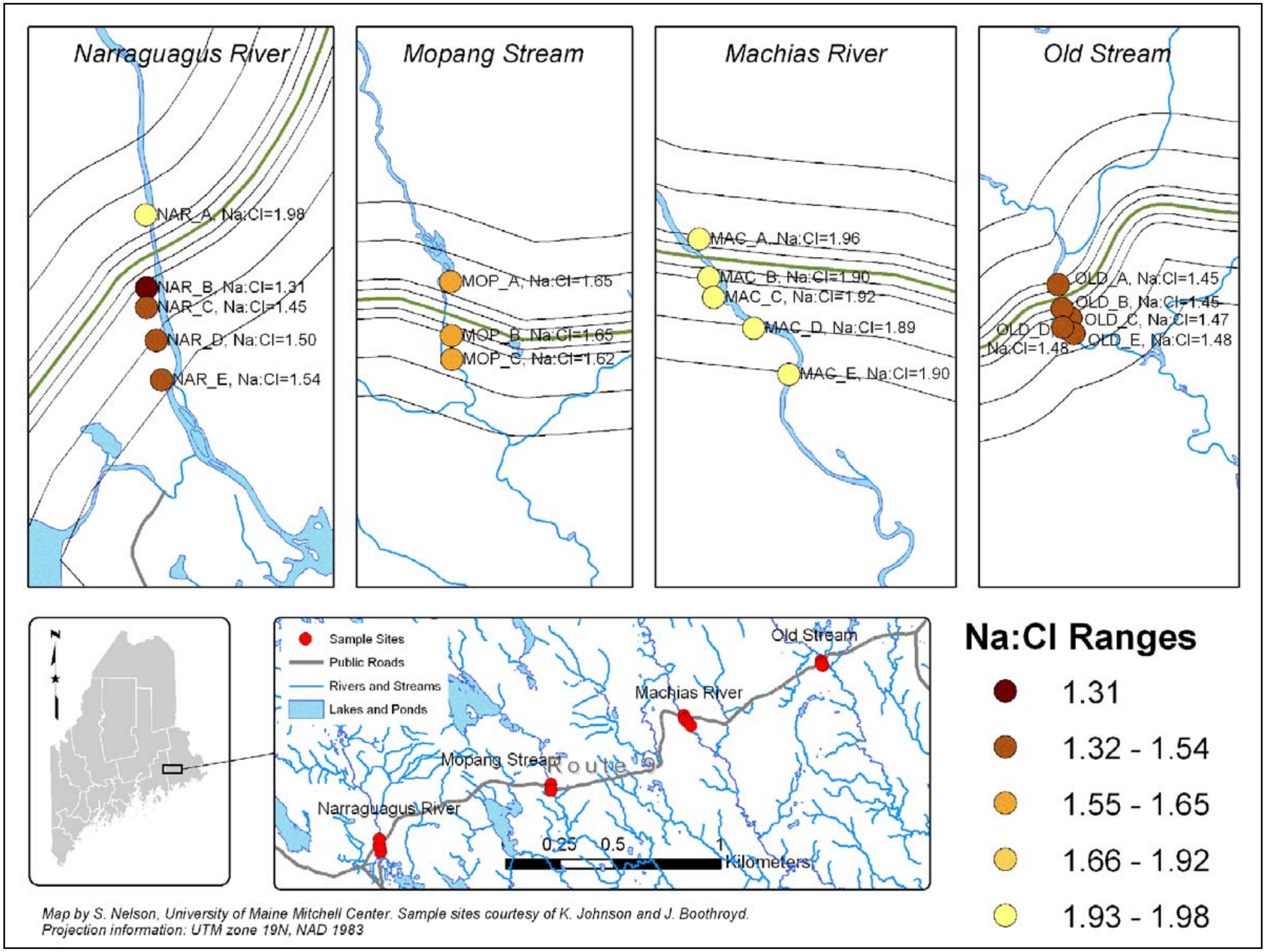


Figure 4. Sodium (Na) concentrations in four Downeast streams, above and below Route 9, plotted for each sampling date in winter 2004/5. The X-axis shows distance from the road, where -50 meters is the upstream, presumably unaffected, site.



Map by S. Nelson, University of Maine Mitchell Center. Sample sites courtesy of K. Johnson and J. Boothroyd.
Projection information: UTM zone 19N, NAD 1983

Figure 5. The ratio of sodium to chloride (Na:Cl) in the four study streams, March 30, 2005. Declines in Na:Cl downstream of roads indicates a road salt influence. Only the Narraguagus River showed spatial variability in Na:Cl on this and most other sampling dates.

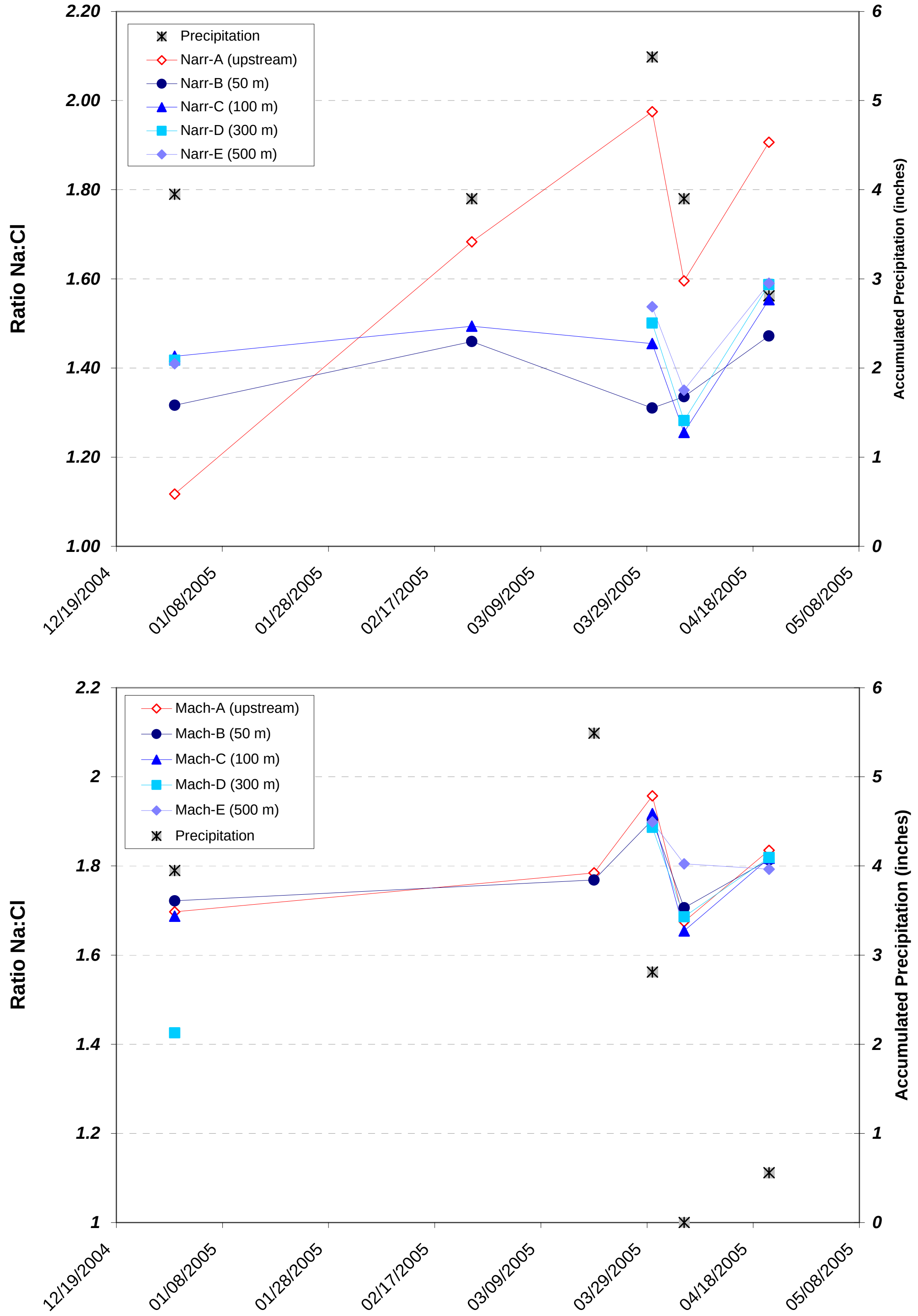


Figure 6. The sodium to chloride ratio (Na:Cl) for sites sampled along the Narraguagus River (top panel) and Machias River (bottom panel) for all sample dates in winter 2004/5. Snowfall and precipitation data from the NCDC (see Table 6a) are shown on the right Y-axis for each collection date. Na:Cl differs upstream of Route 9 for the Narraguagus, but not for the Machias.

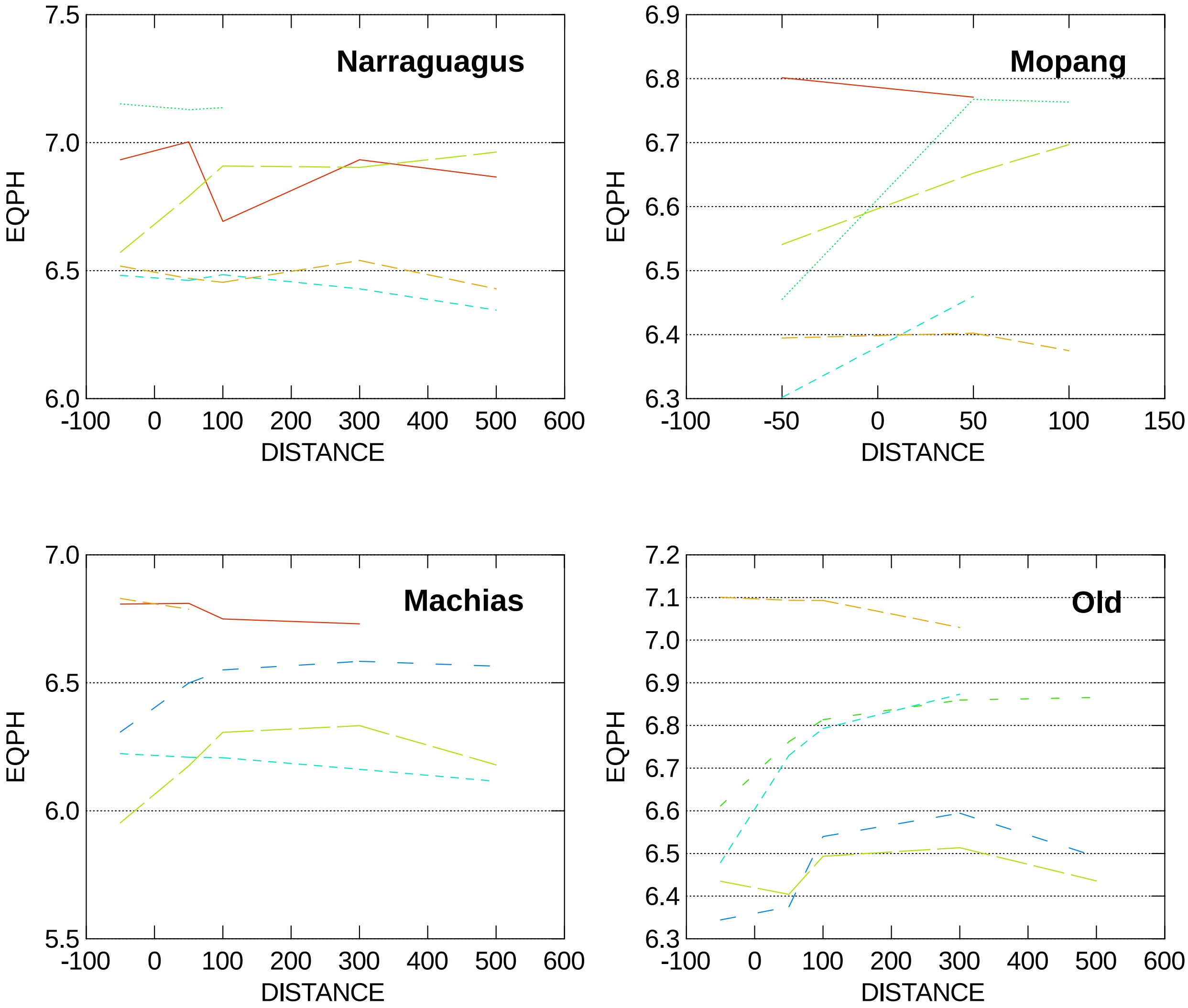


Figure 7. Air-equilibrated pH (EqpH) in four Downeast streams, winter 2004/5. EqpH is shown for sites upstream of Route 9 (-50 meter distance), and at 50-, 100-, 300-, and 500- meter distances downstream of Route 9. Note the scale on graphs – pH varied only a few tenths of a pH unit at most.

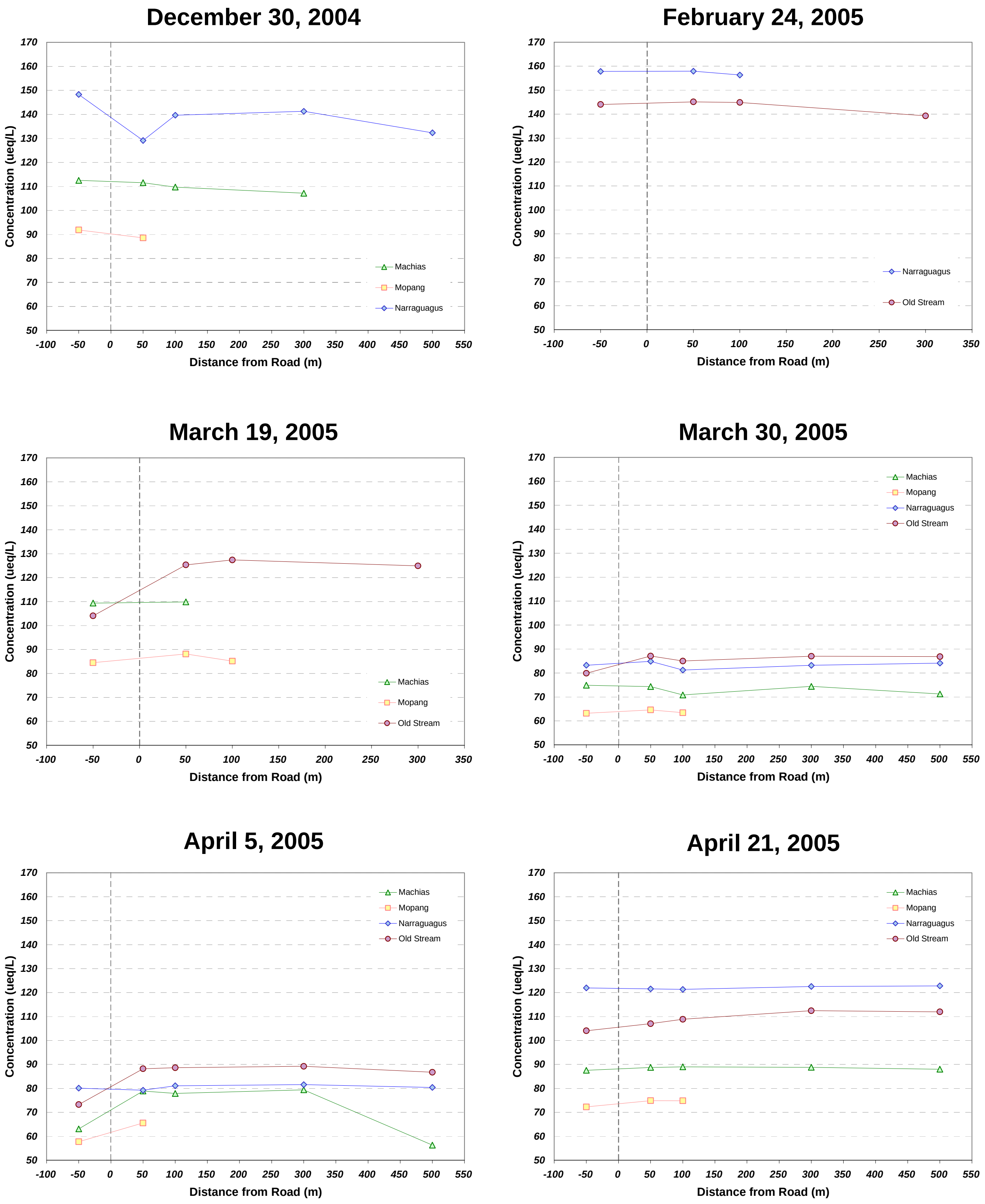


Figure 8. Calcium (Ca) concentrations in four Downeast streams, above and below Route 9, plotted for each sampling date in winter 2004/5. The X-axis shows distance from the road, where -50 meters is the upstream, presumably unaffected, site.

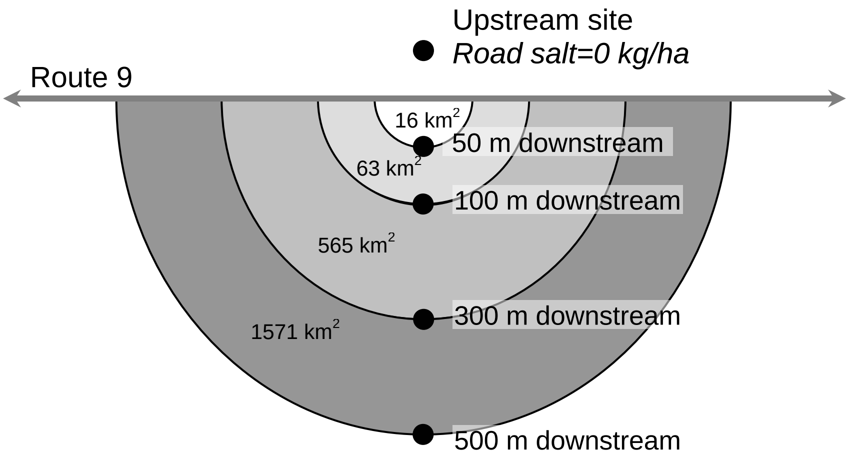


Figure 9. Schematic showing hypothetical watershed areas influenced by road salt for each downstream sampling site. We assumed a semi-circular shape and length of road affected was therefore two times the distance of a site from the road. Loading estimates produced from this calculation are included in Table 6b.