North Atlantic Commission

NAC(03)6

Report to the NAC on US Activities Regarding Acid Rain

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At the Nineteenth Annual Meeting of NASCO, the North American Commission identified the possible adverse impact acid rain was having on wild salmon stocks. Given the importance of the issue, it was suggested that the US and Canada endeavor to meet intercessionally to consider the causes, effects and mitigation options of acid rain. The Parties agreed to report back to the 2003 NAC meeting on the results of the bilateral consultations and to consider possible future actions that could be taken to begin to address this problem.

In the fall of 2001, the signatories of the Maine Atlantic Salmon Technical Advisory Committee (TAC) requested guidance from the TAC proper to resolve whether or not water quality issues are a concern to the management of Atlantic salmon, specifically water quality issues associated with acidification and endocrine disrupting chemicals. In March 2002, a water quality ad hoc committee to the TAC presented a report to the TAC signatories intended to specifically address their concerns based on the best available information. In summary, the committee believed that there was sufficient evidence that several water quality parameters are affecting the restoration of Atlantic salmon in Maine rivers of which acidification and endocrine disruption are of the greatest importance.

In December, 2002, the project SHARE* Research and Management Committee reorganized and established the goal of trying to address the concerns that acidification may be adversely affecting the restoration of Atlantic salmon in Maine rivers. The first task of the committee was the coordination of a Water Chemistry Forum and Workshop (held in Orono, ME on March 26, 2003), which presented information on the water chemistry of Maine's coastal rivers and associated threats, and developed a course of action to address any identified problems. The outcome of the workshop was the reaffirmation that pH-related factors may indeed be inhibiting the survival and restoration of salmon. Atlantic salmon and water quality scientists and managers participating in the forum recommended that the implementation of a pilot liming project should be investigated to determine its potential benefit to Atlantic salmon restoration. A summary of the findings is attached.

A Muliti-Agency Task Force has been created with the mission of researching, coordinating, and steering the development of both a possible liming study and long-term management actions should be formed as soon as possible. Task Force members include: fisheries managers, fisheries biologists, soil scientists, water chemists, ecologists, permitting officials, and non-governmental conservation organization representatives. A pilot liming project in one of the downeast Maine rivers is now being planned for either 2004 or 2005.

Status and Trends of Water Chemistry in Maine Atlantic Salmon Watersheds

A Report on the Conference Findings & Round Table Discussion

Held at the Black Bear Inn
Orono, Maine
March 26, 2003

Prepared for the
PROJECT SHARE
RESEARCH AND MANAGEMENT COMMITTEE
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Trout Unlimited

INTRODUCTION

In response to recent findings and concerns regarding the effects of acidity and pH-related water chemistry on Atlantic salmon in Maine rivers, the Project SHARE Research and Management Committee and the Atlantic Salmon Federation hosted a one day workshop to present current information on water chemistry in the Maine Atlantic salmon rivers and discuss future science and management efforts. This workshop was planned and coordinated by the Project SHARE Research and Management Committee whose mission is to provide capacity to facilitate and coordinate research related activities on Maine's salmon rivers and serves as a conduit for the transfer and exchange of scientific data and information between state and federal agencies and the public sector.

The conference included presentations from five salmon biology and water chemistry specialists in the morning session (see agenda below) followed by a facilitated round table discussion among fisheries managers, biologists, and water chemistry specialists. The goal of the conference was to hear the latest information on relevant salmon issues, discuss threats associated with water chemistry, and develop a course of action to address identified threats.

It should be noted that much of the conference discussion regarding pH focused on those Atlantic salmon rivers that have experienced acidic pH levels (< 6.0) either as base line or in response to precipitation events. Those rivers include the Narraguagus, Pleasant, Machias, East Machias, and Dennys Rivers. Collectively these are referred to as the Downeast (DE) rivers. Recent MDEP data indicate that the Sheepscot and Ducktrap Rivers and Cove Brook do not generally experience such low pH extremes.

This report summarizes the morning presentations and the round table discussion. It also states some general conclusions and suggests recommendations for future management and research actions.

Status and Trends of Water Chemistry in Maine Atlantic Salmon Watersheds

AGENDA

Presentations

9:00	**Steve Kahl** – Status and trends of surface waters in the northeastern US as a result of changes in acidic deposition
9:30	**Mark Whiting** – Acidic episodes in the Downeast salmon rivers in 2002
10:00	**Tom Clair** – Long and short term changes in water chemistry in Nova Scotian salmon streams: past conditions and predictions for the future
10:30	**Break**
11:00	**Ivan Fernandez** –Soil leaching and water chemistry
11:30	**Steven McCormick**– Physiological consequences of acid/aluminum and contaminants exposure in Atlantic salmon
12:00	**John Kocik** – Effects of episodic acidification on Atlantic salmon (*Salmo Salar*) smolts
12:30	**Lunch**
1:30	**Steve Kahl** – Measurements of pH: the persistently problematic parameter for policy planning

Round Table Discussion

2:00	Introduction to PM Session.
2:10	Summarize the morning's presentations. Review Abstracts.
2:25	Does the information presented this morning support the assertion that current pH-related water chemistry is a threat to Atlantic salmon?
3:00	If the evidence does not fully support pH-related water chemistry as a threat, then what information is needed? What are the other possible water chemistry threats?
3:30	Where do we go from here? What action items should be created? Who will be the responsible party for the action items?
5:00	Closing Remarks

ROUND TABLE PARTICIPANTS

Steve Kahl, University of Maine
Mark Whiting, Maine Department of Environmental Protection
Thomas Clair, Environment Canada
Ivan Fernandez, University of Maine
Stephen McCormick, Conte Anadromous Fish Research Center
Joan Trial, Maine Atlantic Salmon Commission
Fred Whorisky, Atlantic Salmon Federation
Sherrie Sprangers, University of Maine at Machias
Russ Danner, Maine Department of Inland Fish and Wildlife
Paul Nickerson, US Fish and Wildlife
Mary Colligan, NOAA Fisheries

PART ONE
SUMMARY OF THE MORNING'S PRESENTATIONS

Status and trends of surface waters in the NE US as a result of changes in acidic deposition – S. Kahl

- In response to reductions in atmospheric emissions, atmospheric sulfate deposition has decreased significantly in Maine in the past twenty years.
- In response to reduced atmospheric sulfur, NE surface waters have experienced slight increases in pH and acid neutralizing capacity (a measure of buffering capacity).
- Possibly, counteracting these improvements is an increase in dissolved organic carbon, which may impart natural acidity and a reduction in base cations, which are generally derived from the local soil.
- NE surface waters are recovering but at a slower rate than other areas, such as the Adirondacks.
- The natural acidity of the area must be considered since local soils have a low natural pH (pH ~ 3 to 4) and a low calcium content. Waters that drain wetlands in Downeast Maine often have a pH of 3 to 5.
- There is no direct evidence that acidification from acid rain has occurred in the DE rivers. We have evidence that the only sites that have acidified significantly during the past 100 years in eastern Maine had been marginally acidic for hundreds of years, due to natural factors. Similarly, we also lack evidence that base cations have declined recently in the main stem rivers. It is possible that the present low calcium status has been the norm at these sites. We are collecting new data that will address this question at sites for which we have reliable historical data in the 1980s.

Acidic episodes in the Downeast salmon rivers – M. Whiting

- Data from the Downeast rivers and tributaries indicate that summer base flow pH values are generally above 6.0.
- All of the Downeast river mainstems, however, experienced pH values below 6.0 in the spring of 2002, and some were below pH 5.0 (Pleasant R and Tunk Stream). In addition, many tributaries were also affected.
- The Machias River and two of its tributaries, Mopang Stream and Old Stream, were less affected, but low pH values were found in smaller tributaries in the Machias River watershed.
- Low pH values coincided with low Ca (< 2.0 mg/l) and high exchangeable Al (0 to 106ug/l).
- The lowest pH values occurred in association with high flow and were episodic in nature.
- These conditions lasted for at least 8 weeks in the spring of 2002 and occurred again in association with fall precipitation events (but did not last as long).

Long- and short-term changes in water chemistry in Nova Scotia salmon streams: past conditions and predictions for the future – T. Clair

- Present day acid deposition, water chemistry, and soil chemistry data were inputted into the Model of Acidification of Groundwater in Catchments (MAGIC) in order to estimate 1) pre-industrial water chemistry conditions and 2) potential future changes in water chemistry under three future acid deposition scenarios.

- Model results indicate that water chemistry remained relatively unchanged until the 1950s, and maximum acidification took place from 1970 to the early 1980s.
- The main effects of acid deposition have been a decrease in pH and an increase in base cations to surface waters, as the ion exchange processes released soil cations into surface waters. These have been reversed since the late 1980's.
- Surface water forecasts were examined under three scenarios: a) no change in atmospheric deposition from Year 2000 values, b) 10%, and c) 20% sulfate reductions per decade.
- The model indicates that the more rapid the reduction in acid deposition, the faster recovery will be, and that although surface water acidity will recover within a few decades, base cations in most streams will not recover to pre-industrial levels within the next 100 years.
- Another statistical model indicates that short-term acid pulses have decreased in severity in the past 20 years and that further sulfur-emission reductions will improve this situation.

Soil leaching and water chemistry – I. Fernandez

- Soils are complex due to horizons (layers with very different physical and chemical properties), high spatial heterogeneity, often undefined flow paths for water, and a wide range of soil water retention times.
- Maine soils are naturally young, acidic (pH ~3's for O horizons, 4-5 for mineral horizons), shallow, highly stratified, and low in base cations.
- Both natural and anthropogenic disturbances, including land use history, influence surface water chemistry.
- Management alternatives require more information regarding soils, atmospheric inputs, and the consequences of a changing global climate.
- Land management planning for reduced acidity could include conversion to hardwood riparian forests, periodic burns, the use of selective forest harvesting methods, and redirection of water surface or subsurface flow.
- Studies indicate that acid deposition causes calcium to leach out of the soil, often resulting in an initial increase in surface water calcium. As acid deposition continues, calcium is ultimately depleted from surrounding soils, which eventually results in a decrease in surface water calcium and often an increase in acidity.

Physiological consequences of acid/aluminum and contaminants exposure in Atlantic salmon – S. McCormick

- Monitoring of outmigrating smolts in the Narraguagus and Dennys River in 2002 indicated that smolt development and the ability to adjust to saltwater were compromised.
- Gill Na, K-ATPase (the enzyme responsible for saltwater tolerance) was measured in the outmigrating smolts and found to be at well below normal levels. Hatchery/normal gill Na, K-ATPase in smolts is ~ 8-12 umol ADP/mg protein/hr. Narraguagus smolts had values of 1-5 umol ADP/mg protein/hr and Dennys River smolts had values of 1-3 umol ADP/mg protein/hr.
- Low gill Na, K-ATPase values occurred in association with low pH values (pH < 6.0) during the smolt migration period (late April to early May).
- The gill is the major site of toxic action and the severity of physiological effects may increase with lower pH, higher aluminum, lower calcium, and lower dissolved organic carbon.

- Seawater tolerance in smolts can be compromised within 48 hours by levels of acid and aluminum that are within the range measured for several Maine rivers.
- Sensitivity to pH changes with fish life stages and smoltification appears to be the most sensitive stage.

Effects of episodic acidification on Atlantic salmon (*Salmo Salar*) smolts – J. Kocik

- Recent Atlantic salmon population data indicate 1) declines in the number of redds produced from 1970 to 2000, 2) moderate parr production with some years of poor production, 3) low numbers of smolts produced, and 4) poor overwinter survival of smolts in most years. The Narraguagus River has the capacity to produce 12,000 smolts, however only 1,400 smolts were produced in 2002.
- In this experiment, Atlantic salmon smolts were exposed to three pH treatments 1) ambient (control), 2) chronically acidified, or 3) episodically (2 of 7 days) acidified river water for 31 days and then transferred to 34‰ seawater.
- The results indicate that chronically acidified smolts did not grow in length or weight and experienced an increase in hematocrit, reduced gill ATPase, and a disruption of the osmoregulatory function (a loss of sodium and chlorine while in freshwater and an uptake of sodium and chlorine while in seawater).
- The results also indicate that episodically acidified smolts fed little and experienced an increase in hematocrit, reduced gill ATPase, and an uptake of sodium and chlorine while in seawater.
- The effects of episodic acidification were less severe than then those associated with chronic acidification.
- Continual low pH can disrupt osmoregulation and smoltification and may impede and slow transition to seawater and episodic effects may be just as substantial.

Measurements of pH: the persistently problematic parameter for policy planning – S. Kahl

- pH is difficult to measure in the DE rivers because 1) DE rivers are dilute, 2) electrodes are not designed for dilute waters, 3) accuracy is difficult to achieve when measuring units are 100 parts per trillion hydrogen ion (pH 7).
- When measuring pH, naturally occurring CO_2 should be taken into consideration because it may lower pH as much as two units. CO_2 is present in all field measurements but is equilibrated out in “Air Equilibrated Lab” samples. Therefore, field pH measurements are always lower than lab pH measurements because of presence of CO_2 in the field data.
- There are two types of recommended lab sampling methods for pH:
  1. **Closed Cell:** The sample is collected in a large syringe to prevent loss of CO_2, and pH is measured in a sealed chamber under controlled conditions. The sample retains the CO_2 from its original site and therefore, represents the fish’s true habitat. However, the CO_2 content may vary from site to site, season, and even time of day thereby making evaluation of trends and other factors difficult.
  2. **Air Equilibrated:** In this measurement**,** excess CO_2 is purged from the sample by bubbling with a standardized air of known CO_2. The advantage of normalizing the pH to a standard condition of CO_2 is that the variability from field conditions is eliminated, and the pH can be interpreted for the influence of factors such as natural organic acidity and acid rain.
- There is a need for quality control, quality assurance, and a standardization of methods regarding pH measurements and pH evaluation.

- Acid neutralizing capacity may be the preferred value to use when comparing or evaluating acid-related water chemistry trends.

PART TWO
DOES THE INFORMATION PRESENTED THIS MORNING SUPPORT THE ASSERTION THAT CURRENT pH-RELATED WATER CHEMISTRY IS A THREAT TO ATLANTIC SALMON?

There was a unanimous agreement among Round Table Participants that pH-related water chemistry may be a potential threat to Atlantic salmon. The group agreed that low pH is only one possible variable to explain the decline in salmon populations and that the occurrence of low surface water pH triggers a complex of potentially hazardous chemical interactions. As pH declines, calcium and acid neutralizing capacity (ANC) generally decrease, and exchangeable aluminum increases. In addition, dissolved organic carbon (DOC) may also increase. Together these reactions create a “pH-related water chemistry complex.”

The group also considered the following:

- Although recent studies clearly indicate compromised smolt development and a decline in salmon survivorship in association with low pH, it is not clear which part of the “complex” (low calcium, low ANC, high aluminum, or high DOC) is causing the population declines.
- In addition to the problems associated with the pH-related water chemistry complex, the episodic nature of the acid pulses may be acting as a shock to the fish’s system. However, episodic acid pulses are most likely not a new occurrence and may be part of the natural acidic process.
- pH is difficult to measure and evaluate. It may be more appropriate to use ANC as a measure of acidification rather than pH. ANC tells us more about the water chemistry.
- There is strong evidence to suggest that low surface water calcium may cause a calcium deficiency in salmon (and other fish). Fish have no known mechanism to adapt to low calcium availability.
- In order to better understand the effects of all of the pH-related variables, salmon survival studies and water quality monitoring sampling should coincide and include the full suite of water chemistry.
- Low pH may not be the “smoking gun.” All possible variables need to be investigated before management actions are taken.
- There is no direct or correlative evidence that the pH of DE surface waters has changed significantly over time.
- There is enough information to suggest that the DE watersheds (waters and soils) are naturally acidic, and that wild native salmon would have evolved or adapted to low pH values.

PART THREE
WHAT OTHER INFORMATION IS NEEDED? WHAT ARE THE OTHER POSSIBLE WATER CHEMISTRY THREATS?

The Round Table Participants agreed that other water chemistry components should be considered when discussing the cause of salmon population declines. These factors could be acting alone or synergistically to compromise salmon health. All agreed that more information and studies are needed to better understand the full array of potential water chemistry threats. In addition to acidity, the group discussed the following as potential factors affecting salmon population declines:

- **Calcium**. Recent data indicate that calcium levels in DE rivers are below the stress threshold for most fish, i.e., less than 4.0 mg/L (less than 2.5 for most aquatic organisms).
- The source of calcium in the DE watersheds is the local, primarily granitic bedrock, which is naturally low in calcium. As calcium leaches out of soils, it is no longer found in surface waters and therefore no longer available to fish.
- Due to the absence of historical soil data, evaluation of current soil calcium levels is difficult to determine. There is some disagreement as to whether soil and water calcium levels have increased or decreased over time. Three tributaries in the Narraguagus have seen an increase in calcium levels over the last two decades.
- Small changes may have an effect on salmon health but there has not been sufficient testing or measurements to confirm this. Localized analysis is needed.
- Fish need calcium for bone and egg development, and they are unable to adapt to low calcium levels in surface waters. It is unclear which ion, if any, is taking the place of calcium on the gill or in the bloodstream. Calcium receptor cells located on gills have been studied but more information is needed.
- Hatchery biologists often consider local calcium levels when locating a hatchery. Although, calcium can be added to the water and/or diet of hatchery-raised fish, smolt health is ultimately determined by river calcium levels.

- **Other Divalent Cations.** Since positive and negative charges in the water are equal, calcium ions must be replaced with another divalent cation (e.g., Mg). Models show that reduced calcium levels in soils are leading to a shift in equilibrium. More studies are needed to look at the effects of these other cations and gill permeability.

- **Aluminum.** Calcium-poor soils are also the same soils that are dominated by aluminum. Although not a divalent cation, aluminum (trivalent) may be replacing calcium on fish gills. Aluminum has been proven to be toxic to salmon, but in the tannic Downeast rivers is largely found associated with DOC in a non-toxic form

- **Mercury.** Previous studies involving the effects of mercury on fish clearly illustrate its deleterious effects. More studies are needed to differentiate between the effects of various toxins.

- **Climate change.** Maine Atlantic salmon are at the southern edge of their natural range. Changes in global climate, specifically a warming trend, may ultimately cause the species distribution to shift further north. Furthermore, a warming trend could generate a change in precipitation. An increase in precipitation could exacerbate leaching and acidification, whereas a decrease in spring precipitation could alter flow during smolt migration.

- **Species Composition.** The introduction of exotic warm-water fish species increases the competition for food and habitat. Several of these exotic species are also known predators of juvenile salmon.

- **Loss of genetic variability.** The reduced number of fish may have caused a reduction in genetic variability and ability to adapt to changes in the environment.

- **Species Sensitivity.** Previous studies indicate that salmon are more sensitive to fluctuations and declines in pH. Other native and nonnative populations (e.g., smallmouth bass) appear to be less sensitive to low pH possibly.

- **Enrichment.** Productivity and nutrient levels may be less then what is necessary to maintain healthy salmon populations and smolt development. The possible decline in nutrient levels may be the result of a lack of quality organic matter and a change in the source of organic matter. It is not clear whether enrichment has declined over time; more studies are needed.

- **Pesticides and PCBs.** Many of the DE watersheds have experienced inputs of pesticides from the blueberry and forest-products industry, such as Hexazinone, Phosmet, Propiconazole, and Chlorothalonil. In addition, the Dennys River has experienced inputs of PCBs from illegal landfills. There is currently very little information regarding the effects of these toxins on salmon.

PART FOUR

A. WHERE DO WE GO FROM HERE? WHAT ACTION ITEMS SHOULD BE CREATED? WHO WILL BE RESPONSIBLE FOR THE ACTION ITEMS?

The Round Table Participants agreed that any potential management actions should focus on identifying the true cause of salmon population declines. There is some disagreement as to whether acid deposition is a true threat since there is no evidence that pH has declined in DE surface waters. Actions should focus not just on pH but also on calcium, aluminum, other nutrients, population dynamics, and general productivity.

The group also agreed that fisheries and land managers should use an “adaptive management” approach in which data is used to guide a management action toward an initial goal. The management action is heavily monitored and the data is fed back into the management process. Key elements to this type of management are setting quantitative goals, measuring responses, and adjusting the action as more information is collected. The goal stays the same but the prescription is altered depending upon the outcome.

Gaps in the data and literature should be identified and researched either before or in conjunction with potential management actions.

Data Gaps:

Need more information regarding the link between fish and pH
Need to clearly identify which part of the "pH Complex" is compromising health
Water chemistry measurements need better QA/QC
Need more frequent water chemistry measurements and better spatial coverage
Need more baseline data on indicator species such as invertebrates

Is the current Clean Air Act emissions reductions enough to facilitate a recovery? Or should emissions reductions be increased in order to accelerate recovery? There is some disagreement as to whether this decision should be based on acidification models, since these models often do not agree with data from sites with long term monitoring. Some scientists contend that models are best used as learning tools rather than as predictive tools.

Agricultural Practices.
Cooperative Extension recommends the use of sulfur additives to blueberry fields in order to acidify the soil. It is unclear whether the recommended amounts or the number of farmers using this additive is enough to generate concern.

B. IS THERE A CONSENSUS TO INVESTIGATE THE POSSIBILITY OF CONDUCTING A LIMING STUDY?

The Round Table Participants agreed that there is a need to begin planning and investigating a pilot liming study. The group also agreed that such an undertaking should be well researched, well planned, fully funded, and consider potential ecological side effects. It should have a rigorous experimental design so that pH and calcium can be isolated as variables driving any future response.

Benefits to Liming
The salmon physiology studies presented today suggest that action should be taken quickly – before population numbers become too low to save. If the study is designed properly, results may be generated quickly and the project could be adapted accordingly. The major benefit to a liming study could be a possible resolution to the question of whether increased pH and calcium will increase salmon populations and improve smoltification.

Objectives
Before any management actions are taken, the long-term goal of the project should be clearly established. It may not be enough to say that the goal is "to improve water quality." Additionally, what hypothesis is being tested? There is some debate as to:

- What pH level the liming should attain (pH 6.0, 6.5, 7.0, etc)?
- How often it should attain that pH value (only during the spring smolt period, year round, etc)?
- Do we adjust the pH to attain a higher calcium level (>5.0 mg/l, >6.0 mg/l, etc)?
- Do we adjust the pH to attain a lower aluminum level?
- How long do we lime before we know we have generated a change?
- What are the short-term vs. long-term goals?
- How do we know if we are successful? What is our indicator?

Experimental Design Considerations
Once a clear objective is established, the following considerations should be made regarding the experimental design and methods:

1. Would use of specialized land management activities (e.g., conversion to hardwoods) rather than liming achieve the same effect but be less expensive and yield greater long-term results?
2. What will EPA/MDEP regulations allow? Can existing regulations be changed to allow for such a significant project?
3. What do other models tell us? Which model best suits our needs?
4. Is it necessary to conduct a paired-study?
5. Where to lime:
    a. Liming a tributary is faster and more cost effective but is short term and will need to be repeated.
    b. Choose spots based on priority habitat and severity of problem.
    c. Liming has been conducted in Nova Scotia on a small scale and appears to be effective.
    d. Whole watershed liming could effectively raise the soil pH and yield longer-term results. This could be accomplished by using an aerial application of lime pellets.
    e. A riparian application of lime might produce quick results and be cost effective.
6. When to lime:
    a. Headwater winter liming
    b. Year round
7. How long do we lime:
    a. Months, years?
8. Ecological Considerations:
    a. Monitoring of nutrient levels and indicator species such as invertebrates, algae, and aquatic plants should be built into the design.

Project Management
Round Table Participants agreed that a multidisciplinary task force composed of specialists from all of the lead agencies and organizations be formed to undertake the project. The following agencies and organizations have agreed to participate in a Liming Study Task Force:

- NOAA – funding and staff, John Kocik
- USFW – funding and staff, Tom King
- Maine Department of Environmental Protection – technical support, staff, Mark Whiting
- Maine Atlantic Salmon Commission – technical support, staff, Richard Dill
- Atlantic Salmon Federation – technical support, staff, John Burrows
- Project SHARE – technical support, staff, Steve Koenig
- Environment Canada – technical support, Tom Clair
- University of Maine – technical support, Steve Kahl

Funding
A liming study performed in the state of Maine will be a first-time undertaking. If properly conducted, the results could be critical for future success. A seminal project such as this requires full long-term funding (possibly > 2-3 years) and support in order to be effective.

There is currently no funding in FY 2003 budget, however, representatives from both USF&W and NOAA have agreed to support the project and seek funding for it.

C. *LONG-TERM SOLUTIONS*

Finally, several Round Table Participants suggested that liming the streams or the watershed is a short term solution that, if not handled properly, could draw attention away from other possible threats. Several long-term solutions were suggested:

1. Manage and convert buffer zones from conifers to hardwoods to promote greater ANC.
2. Build on existing efforts, such as those in Nova Scotia and Norway
3. Long-term and more comprehensive water quality monitoring
4. River-specific plans and surveys with coordinated monitoring
5. Coordinate water quality data with fish data
6. Increase communication among data-collecting agencies
7. Increase biomonitoring, especially aquatic invertebrates, algae, aquatic plants
8. Recovery Plan may need to be adjusted to reflect managing the pH-related water chemistry complex
9. Support further emissions reductions via the Clean Air Act.

PART FIVE
POST-CONFERENCE CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Weighing the evidence.
The results from the conference round table discussion indicate that 1) low surface water pH triggers a complex of chemical interactions involving calcium, aluminum, and ANC that is potentially hazardous to Atlantic salmon and 2) the question of whether the DE rivers have acidified over time is still debatable.

There is little disagreement that DE salmon smoltification is compromised but the reason for the compromise is not clear. Not only may the fish be responding to a complex of pH-related chemical reactions but they may also be experiencing shock as they transition from healthy hatchery conditions to the more stressful river conditions. A liming study, in which the individual components of the pH complex were carefully monitored, would potentially shed light on the cause of compromised smoltification.

There is still some debate as to whether the DE rivers have or have not acidified over time. There is little historical pH data on these rivers to confirm or refute acidification. The "natural" pH conditions of the aquatic and riparian community, however, should be considered when designing a liming study. The presence of naturally acidic soils and long established, acidophilic plant communities, (e.g., *Vaccinia, Sphagnum, Alnus, Picea,* Ericaceae) suggest that the DE watersheds may be naturally acid-adapted communities. Furthermore, acidic conditions are only found in the DE salmon rivers; all of the salmon rivers west of the Union River Watershed are generally not experiencing low pH levels. The DE rivers may have a natural geologic and ecosystem commonality that is different from the "western" rivers.

Smoking Gun
Fisheries managers and biologists have spent the last two decades investigating the cause of salmon population declines in light of improving river conditions (fewer dams, greater environmental restrictions, less point and nonpoint source pollution, and less acidic atmospheric deposition). The identity of a smoking gun has changed over time as researchers systematically test the long list of possible threats. A liming study will help to support or refute pH-related water chemistry as a possible smoking gun.

Risk Management
Managers and biologists agree that there is a need to investigate the possibility of conducting a liming study. The lack of historical pH-related data and the inability to identify an irrefutable smoking gun should not prevent fisheries managers from planning management actions. The major benefit to a properly planned and conducted study would be to further test the ecological and historical pH evidence and to test the assertion that salmon will respond to even minor changes in pH.

Traditional studies in which salmon are subjected to various inputs or conditions while in aquaria or hatcheries involve very little, if any, environmental risk. A liming study, on the other hand, will require the input of a "discharge" into a natural waterway. This type of manipulation has the inherent risk of causing an environmental and/or ecological imbalance. Mechanisms to reduce this risk (e.g., monitoring of indicator species, containment of study site) should be incorporated into the experimental design and adaptive management process.

Risks and Benefits
The potential benefits of a liming study are clear: 1) increased pH could increase overall aquatic productivity, and 2) we would gain a clearer understanding of the pH complex and its effect on salmon survival.

The risks to such a study are a more complicated. History and science tell us that altering one component of an ecosystem has the potential of causing significant and possibly negative effects in other components. Therefore, great care should be taken when considering whether to increase an element (i.e., calcium) and alter what could possibly be a naturally low pH level. The following ecological impacts should be considered:

- Currently little baseline information exists for invertebrates, algae, aquatic plants, and lake nutrients. These groups should be heavily monitored during the study.
- There is anecdotal evidence that suggests that additional calcium and/or increased pH may alter peatlands. Baseline information should be gathered prior to the study and monitoring should occur during the study.
- Some lake studies suggest that additional calcium may bind with phosphorous causing the phosphorous to settle out and become unavailable for plant growth. This could lower the productivity of lakes that are already classified as oligotrophic (low productivity).
- If DE rivers are naturally low pH, then acidification may be naturally excluding some exotic, invasive species. Increasing the pH may unintentionally create a better habitat for and increase the population of exotic species. Baseline information should be gathered prior to the study and monitoring should occur during the study.
- It should be noted that the form of calcium used in the project is significant since forms of CaOH (such as quicklime and slake lime from the cement industry) are frequently used as pesticides in the aquaculture industry for the control of soft-bodied invertebrates and macroalgae. Forms of $CaCO_3$ (such as crushed limestone) are considered safer.

Finally, it should be noted that while recent attention has been given to the details of a potential liming study, long-term solutions should not be ignored. It is clear that many related initiatives need to come together at one time in order to produce an effective result.

B. *RECOMMENDATIONS*

The following recommendations are made based on round table discussions and personal communications with Round Table Participants and other scientific professionals.

1. **Multi-agency Liming Study Task Force.** A Task Force with the mission of researching, coordinating, and steering the development of both a possible liming study and long-term management actions should be formed as soon as possible. Task Force members should include (see Part 4, Question B):
   fisheries managers
   fisheries biologists

soil scientists
water chemists
ecologists
permitting officials
nongovernmental conservation organization representatives

2. **Develop Proposal.** The Task Force should develop a Pilot Liming Study Proposal, which clearly justifies the project and its location, and clearly states the objectives, individual tasks, expected outcome, and evaluation methods. The Proposal can be used to raise funds and gather agency support.

3. **Literature search.** Research should begin immediately to explore and review exiting liming models with the purpose of identifying a "best fit" for the DE rivers. Models to review might include those in the Adirondacks (NY), Norway, Nova Scotia, and Ireland.

4. **Liming Workshop**. Few area professionals have experience in liming waterways. A workshop in which liming protocols, methods, and results are presented by experienced liming professional is recommended.

5. **Predictive Model.** It may be beneficial to create a predictive model that projects the ecological and environmental impact created when calcium and pH are increased. The MAGIC model may be a possible type of model.

6. **Baseline Inquiry.** Prior to study, a literature search should be conducted to establish baseline knowledge regarding other organisms that may be effected such as aquatic plants and

7. **Planning.** A strategic plan in which goal, objectives, specific strategies, action items, time frames, and lead agencies should be developed in order to establish and communicate multi-agency tasks and responsibilities.

8. **Project Administration.**
    a. **Coordination.** A coordinator should be hired who will have the responsibility of keeping the project on task and facilitating task force objectives.
    b. **Responsible Agency.** Funding for this project will most likely come from federal sources (possibly via NFWF). The lead agency would be responsible for administering the funds and either directly conducting the study or overseeing a contractor. Possible options for the responsible or lead agency are:
        i. State agency, such as the ASC
        ii. Federal agency, such as NOAA, USF&W
        iii. A Nongovernmental Organization, such as ASF or Project SHARE
        iv. University of Maine Research Unit