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Determining the effectiveness of the Clean Air Act and Amendments on the recovery of surface waters in the northeastern US

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Overview of activities during 2008. A schematic summary of progress on the project plan is provided below and discussed on the following pages.   We are concluding the third year of this five year project that supports the needs of EPA for meeting the Congressional mandate for the agency to assess the effectiveness of the Clean Air Act Amendments of 1990.   Field work and data assessment are on schedule, and the supplemental zooplankton component is well underway.

The lead organization for the project is now the University of New Hampshire, effective November 1, 2008.   Field and laboratory assistance continues from the University of Maine. The ongoing logistical and fiscal transition from PSU to UNH will be a major focus in 2009, to assure continuity of project management and data quality. We anticipate that the PSU lead project analyst, Adam Baumann, will become a UNH employee in early 2009, to facilitate a transparent transition in methods and QA/QC.

Project Activity	2006			2007				2008				2009				2010				2011
	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
project period	■	■	■	■	■	■	■	■	■	■	■	■	▦	▦	▦	▦	▦	▦	▦	▦
funding received	■	■	■	■																
RLTM outlets				░				■				▦				▦				▦
RLTM drainage lakes		■	■		■	■	■		■	■	■		▦	▦	▦		▦	▦		
RLTM seepage lakes		■	■		■	■	■		■	■	■		▦	▦	▦		▦	▦		
original LTM lakes			■				■				■				▦				▦	
HELM subset							░				■				▦				▦	
BBWM - EB	■	■	■	■	■	■	■	■	■	■	■	▦	▦	▦	▦	▦	▦	▦	▦	▦
TIME New England		■				■				■				▦				▦		
TIME Adirondacks		■				■				■				▦				▦		
sample analyses		■	■	■		■			■		■	▦		▦			▦		▦	▦
zooplankton analyses			■			■			■		■									
annual report				■				■				■				▦				▦
annual data report	■				■					▨										

▦ = project plan   ▨ = in progress   ■ = completed   ░ = cancelled (weather)

Project background

Objectives. This proposed research is part of the EPA program to collect long-term data on the trends and patterns of response in surface waters sensitive to acidic deposition.   The goals and methods are hierarchical from intensive site-specific to regional statistical populations. The objectives are to:

1) document the changes and patterns in aquatic chemistry for defined sub-populations and sites that are known to be susceptible to acidification or recovery;

2) evaluate linkages in changes in surface waters, if any, to changes in deposition that are related to regulatory goals;

3) characterize the effectiveness of the Clean Air Act Amendments in meeting goals of reducing acidification of surface waters and improving biologically-relevant chemistry in the northeastern US; and

4) provide information for assessment of the need for future reductions in atmospheric deposition based on the rate of recovery (or not) of the systems under study.

In 2008-09, we area also evaluating changes in biological condition using zooplankton collected in 2004 under separate funding from 145 ELS-II lakes in the northeast, as part of our 20th anniversary re-analysis of the Eastern Lake Survey (see Rosfjord *et al*., 2007).

Approach. The schedule of tasks ranges from weekly to annual, continuing data records that now range from 16 to 25 years. We will evaluate chemistry on a weekly basis year-round at the small watershed-scale at BBWM, weekly during the spring melt period at LTM lake outlets when seasonal conditions warrant, quarterly in LTM, and annually during the historical index period for the HELM and TIME lakes.   These project components provide a *statistical framework* for inferring regional chemical patterns using TIME and LTM (and ELS-II under separate funding). The *long-term records* of LTM, HELM and BBWM provide information on seasonal and annual variability, and provide a seasonal context for the annual surveys.

Expected Results. This information is fundamental for EPA to meet the Congressional mandate for reporting on the effectiveness of the Clean Air Act Amendments (CAAA). The highly effective combination of site-specific data within the regional context will provide for the recognition and understanding of declining SO_4, base cation depletion, and changes in N-saturation or DOC contributions to acid-base status.   The results are also central to the decisions on additional emission reductions that may be needed to produce recovery.

Project Status: Water Chemistry

Field sampling. All project field objectives in 2008 were accomplished as planned. Sample collection and analysis has continued on schedule. Spring sampling of drainage lake outlets was prioritized for spring 2008 due to near-record snowpack in the region. However, lack of rainfall during snowmelt limited the excursions in magnitude of runoff.

Analytical. Analyses are complete for all samples collected through 2008, except for total aluminum.   The delay in Al analyses was caused by equipment problems that have since been

resolved.   Inter-laboratory comparisons and audit comparisons are underway between PSU, UNH, and UMaine to facilitate the laboratory transition to from PSU to UNH.

Samples from East Bear Brook at BBWM, which are collected on a regular basis year around, continue to be analyzed in a contract laboratory at UMaine.

Data reporting. All data collected through 2005 have been delivered to EPA. The next delivery of data to EPA is expected in June 2009, after evaluation of inter-laboratory comparisons and regular QA analyses by PSU and UMaine.

Presentation of findings. Several publications and presentations have resulted from this project since the final report for the previous LTM/TIME grant, listed at the end of this report.   We recently published an overview paper on Maine high elevation lakes in Lakeline (Baumann and Kahl, 2007). These results will be incorporated in Baumann's MS thesis to be completed in 2009.

New developments: Co-PI Webster is now affiliated with Michigan State University, and will continue her role in publishing this work as co-PI.

PIs Kahl and McDowell each spoke independently this month with the consulting firm *Ross & Associates Environmental Consulting* that has been enlisted by EPA OAR to evaluate the TIME/LTM programs as the planned transition of management of the programs proceeds from ORD to OAR.

There are fiscal issues surrounding the transition from PSU to UNH. We will request of USGS a re-budget of year 2 monies to address these issues when PSU is finally able to report the status of the project accounts. Among the unresolved issues is that PSU has been unable to finalize a sub-contract for services that have already been provided by the University of Maine during year 2.

Recent publications and presentations *using related project information*
        (current year listings are in **bold**)

Baumann, A.J. and J.S. Kahl, 2007. Chemical trends in Maine High Elevation Lakes. LakeLine 27:30-34.

Campbell, J, J. Hornbeck, M. Mitchell, M. Adams, M. Castro, C. Driscoll, J.S. Kahl, and others, 2004. Input-output budgets for inorganic nitrogen for 24 watersheds in the northeastern United States. Water Air Soil Pollut., 151:373-396.

Dupont, J., T. Clair, C. Gagnon, D. Jeffries, J.S. Kahl, S. Nelson, and J Peckenham, 2005. Estimation of critical loads of acidity in the northeastern US and eastern Canada. Environ. Monit. Assess. 109:275-291.

Hunt, K., J.S. Kahl, J. Rubin, and D. Mageean, 2007. Assessing the science-based needs of stakeholders; a case study on acid rain research and policy. Journal of Contemporary Water Research and Education, 136: 68-79.

Kahl, J.S., J. Stoddard, R. Haeuber, S. Paulsen, R. Birnbaum, F. Deviney, D. DeWalle, C. Driscoll, A. Herlihy, J. Kellogg, P. Murdoch, K. Roy, W. Sharpe, S. Urquhart, R. Webb, and K. Webster, 2004. Response of surface water chemistry to changes in acidic deposition:

implications for future amendments to Clean Air Act. Environmental Science and Technology, Feature Article 38:484A-490A.

Lawler, J., J. Rubin, B.J. Cosby, I. Fernandez, J.S. Kahl, S. Norton, 2005. Predicting recovery from acidic deposition: Applying a modified TAF (Tracking Analysis Framework) Model to Maine' High Elevation Lakes, Water Air Soil Pollut. 164:383-389.

Norton, S., I. Fernandez, J.S. Kahl, and R. Reinhardt, 2004. Acidification trends and the evolution of neutralization mechanisms through time at the Bear Brook Watershed, Maine, USA. Water, Air, Soil, Pollution Focus 4:289-310.

Rosfjord, C., K. Webster, J.S. Kahl, S.A. Norton, I. Fernandez, and A. Herlihy, 2007. Anthropogenically-driven changes in chloride complicate interpretation of base cation trends in lakes recovering from acidic deposition. Environ Sci Technol, 41:7688 -7693.

Rosfjord, C., J.S. Kahl, K. Webster, S. Nelson, I. Fernandez, L. Rustad, and R. Stemberger 2006. Acidic deposition-relevant changes in lake chemistry in the EPA Eastern Lake Survey, 1984-2004. Final report to USDA NSRC, Durham, NH. 69 p.

Recent presentations using project information

Kahl, J.S., 2008 (invited). Twenty year changes in spatial patterns of Cl distribution in the northeastern US. NH Water Conference, April, 2008)

Kahl, J.S., 2007 (invited). Using societal-based incentives to address new threats to New England Lakes. Day-long short course in New England Lake Science Academy, Camp Kieve, Maine. July, 2007.

Kahl, J.S. 2006 (invited). Acid rain in New England: using high elevation lakes as sentinels of change. Maine Mountain Conference, October 21, 2006. Rangeley, Maine

Kahl, J.S., *et al*., 2006 (invited). The design of a national mercury monitoring network: Learning from the EPA acid rain experience. The Eighth International Mercury Conference, Madison WI, August 8, 2006.

Kahl, J.S. *et al*., 2006. Obfuscation of trends in base cations by regional salt contamination. Hubbard Brook Committee of Scientists annual meeting, July 12, 2006.

Kahl, J.S., 2006 (invited). 'Natural and human-derived sources of acidity in Maine Atlantic Salmon Rivers'. Atlantic Salmon Commission workshop on acidity, Bangor ME. April 10, 2006.

Kahl, J.S., 2005 (invited). The intersection of environmental science and environmental policy. NH Charitable Foundation Lakes Region annual meeting, Meredith, NH, September, 2005.

Kahl, J.S., 2005 (invited). Tracking response and recovery in surface waters in the northeastern US. Annual meeting of the Ecological Society of America, Montreal, August, 2005.

Kahl, J.S., and Catherine Rosfjord, 2005 (invited). Acid rain and the Clean Air Act in the northeastern US. Annual meeting of the NH-ME Androscoggin River Watershed Council, Bethel, June, 2005

Kahl, J.S., 2005 (invited). Developing a lake research agenda for NH. NSF workshop on lake research infrastructure in the northeast, Colby Sawyer College, April 2005.

Kahl, J.S., S. Nelson, and A. Grygo, 2004. Surface water chemistry data for the northeastern US for interpreting climate and acid rain trends. Northeast Ecosystems Research Consortium meeting, Durham, NH, October, 2004.

Kahl, J.S., K. Webster, M. Diehl, and C. Rosfjord, 2004. Successes of the Clean Air Act Amendments of 1990. Maine Water Conference invited plenary talk, Augusta, ME, 2004.

Kahl, J.S. and K. Johnson, 2004. Acid-Base Chemistry and Historical Trends in Downeast Salmon Rivers. Maine Water Conference, Augusta ME, April 2004.

Kahl, J.S., 2004 (invited). The Clean Air Act Amendments of 1990; testing a program designed to evaluate environmental policy. Lecture, Colby College. April, 2004

Nelson, S.J., I. Fernandez, S. Norton, B. Wiersma, L. Rustad , J.S. Kahl, 2008. The Bear Brook Watershed in Maine: Long-term research supporting climate change inquiry. Hydroclimatic effects on ecosystem response: participant workshop, Syracuse, NY, September 19, 2008.

Nelson, S.J., N. Kamman, D. Krabbenhoft, J.S. Kahl, K. Webster, 2008. Evaluating spatial patterns in mercury and methyl mercury in northeastern lakes: Landscape setting, chemical climate, and human influences. Northeastern Ecosystem Research Cooperative Conference, Durham, NH, November 12-13, 2008.

Nelson, S.J. 2008. Evaluating spatial patterns in mercury and methyl mercury in northeastern lakes: landscape setting, chemical climate, and human influences. Maine Water Conference, Augusta, ME, March 19, 2008.

Project Status: Zooplankton status and trends

Co-Investigators:
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Objectives:

The objectives of our research are to analyze cladoceran body size and species richness of cladocerans in zooplankton samples collected during the 20th anniversary re-sampling of 145 lakes in the Northeastern US in 2004 (Rosfjord 2004; Rosfjord et al. 2007). These lakes were originally sampled in 1984 and 1986 as part of the EPA Eastern Lake Survey (ELS). Over that time, the ELS lakes underwent an marked decrease in SO_4 and an increase in DOC and Cl (Rosfjord et al., 2007; Rosfjord, 2004). Recovery of ANC was less than expected due to divergent trends in Ca+Mg (Figure 1). Lakes influenced by road salt tended to increase in cations while the unaffected lakes had, on average, a loss of cations over the 20 year period (Rosfjord et al. 2007).

Because zooplankton were part of the 1986 ELS II sampling (Tessier and Horwitz 1992), we have a unique opportunity to interpret the biological relevance of chemical trends in pH, ANC and base cations. We focus our efforts for both measures on the cladoceran species assemblage,

which includes many sensitive species indicative of environmental stressors like acidity, nutrient enrichment, and indirectly to the effects of fish predation (e.g., the relative biomass dominance of small vs. large zooplankton species). Species assemblages have proven particularly sensitive to the affects of acidification (Locke et al. 1994, Yan et al. 1996) and calcium decline (Jeziorski et al. 2008). This sensitivity is similar or higher for the zooplankton than in other more commonly sampled organisms like fish and benthic invertebrates (Stemberger et al. 2001).

Analysis of zooplankton assemblages provides a critical element needed to understand the extent to which upper levels of the food web, from zooplankton to fish, have recovered from acid stress (Yan et al. 2003). Body size is an important structural feature of the zooplankton web that is highly responsive to fish predation due to size-selective predation on cladocerans by planktivorous fish. Zooplankton body size also has been used as an explanatory variable in studies evaluating relationships between nutrient loading and water clarity (Stemberger and Miller 2003); comparisons between clear and humic lakes; and, due to sensitivity to calcium concentrations, in assessing biological responses to declines in calcium in softwater boreal lakes (Jeziorski et al. 2008).

Approach:

The 143 Northeast lakes sampled in July-August 2004 represent a statistically-derived population of lakes (the ELS II population from 1986) with alkalinity less than 400 µeq/L. Water samples were collected for analysis of a suite of water chemistry variables, including pH, major anions and cations, ANC, color, DOC, and mercury (Rosfjord 2005). Zooplankton were collected during the 2004 field campaign using similar protocols to those employed in the 1986 ELS sampling (Tessier and Horwitz 1992; Stemberger and Lazorchak 1994). Zooplankton samples were collected using an 80 µ mesh vertical tow net through the water column from 1 meter off the bottom of the lake (determined with depth finder) to the surface. If the depth was less than 2 m, two tows were taken and pooled into the same bottle. The zooplankton were sedated with alka-seltzer in the net then rinsed into a 250 mL HDPE bottle, pre-loaded with a 4% sugar-buffered formalin solution. The bottles were labeled with the depth of the tow, sealed with electrical tape to prevent evaporation, and kept in warm storage. The net was rinsed in a vinegar solution between each lake to ensure that no zooplankton were transferred from one lake to another.

The ELS-II samples collected in 1986 were obtained from Rich Stemberger. The approximately 435 175 ml glass jars in the ELS-II collection were inventoried; some breakage of glass bottles and resultant sample loss occurred, but with three individual tows collected at each lake this did not result in a total loss of samples from any lake.

Prior to starting the analysis of body size, we collaborated with Dr. Hilary Snook at the EPA Region 1, to test the use of a flow-through cytometer (FlowCAM™, Fluid Imaging Technologies, 258 Cross Point Road Edgecomb, ME 04556) to automate image analysis of cladoceran body size. However, due to the presence of particles in the sample, incorrect orientation of specimens as they were photographed, and the inclusion of spines and antennae in the size analysis, we were unable to use this technology for the ELS samples.

Instead, we used a Nikon Coolpix 995 digital camera attached to a dissecting scope to take images of zooplankton from each sample. For size spectra analysis, we took images of the first 75 cladocerans encountered in the sample. Where sufficient individuals were available, we took additional images for a total of ~20 individuals of each cladoceran genus. We also took 20 images each of cylopoid and calanoid copepods. Body length was determined using ImageJ software (public domain, National Institute of Health). From these data we calculated body size metrics including features of the community size spectra (size frequency within size bins and quartiles); the Stemberger Index (means of functional groups of cladocerans); and size characteristics of individual genera such as *Daphnia*.

Our third task was to assess changes in species richness from 1986 to 2004. There are potentially serious issues with the taxonomic analysis of the 1986 samples, including possible non-recording of rare species and misidentification of some species. It is likely that we will need to revisit the 1986 samples as well as analyzing those from 2004, resulting in a doubling of the work effort from our earlier estimates. For this reason we will initially focus on the cladoceran species assemblage and assess changes in species richness from 1986 to 2004. Cladocerans are an acid-sensitive taxonomic group and are also subject to predation by fish, so we feel this group is a good place to start. Preliminary analyses of a set of Northeast lakes (including some ELS II and EMAP lakes), suggest strong relationships between species richness of cladocerans and ANC and base cations (unpublished data, R. S. Stemberger). These results are particularly promising because of the substantial changes in Ca+Mg between 1984 and 2004 observed in the ELS II lakes by Rosfjord (2005).

Project Status:

Zooplankton Database:
We have developed an access database that includes tables of water chemistry, zooplankton body size, and lake characteristics (morphometry, land use, etc) for the ELS II lakes. Appendix 1 shows the tables and relationships defined to date.

<u>Status of Body Size Analysis</u>

Images from all available zooplankton samples collected in 1986 and 2004 have been compiled. Image analysis for lengths will be completed in early 2009. Currently all the 1986 samples have been finished and we are about half-way through the 2004 images. These data will be entered into the access database to allow comparisons with changes in water chemistry across the ELS II lakes.

For lakes in subregion 1E (Maine), there is a wide range in size spectra in both 1986 and 2004 (Appendix 1) with no consistent change among years (Figure 1).
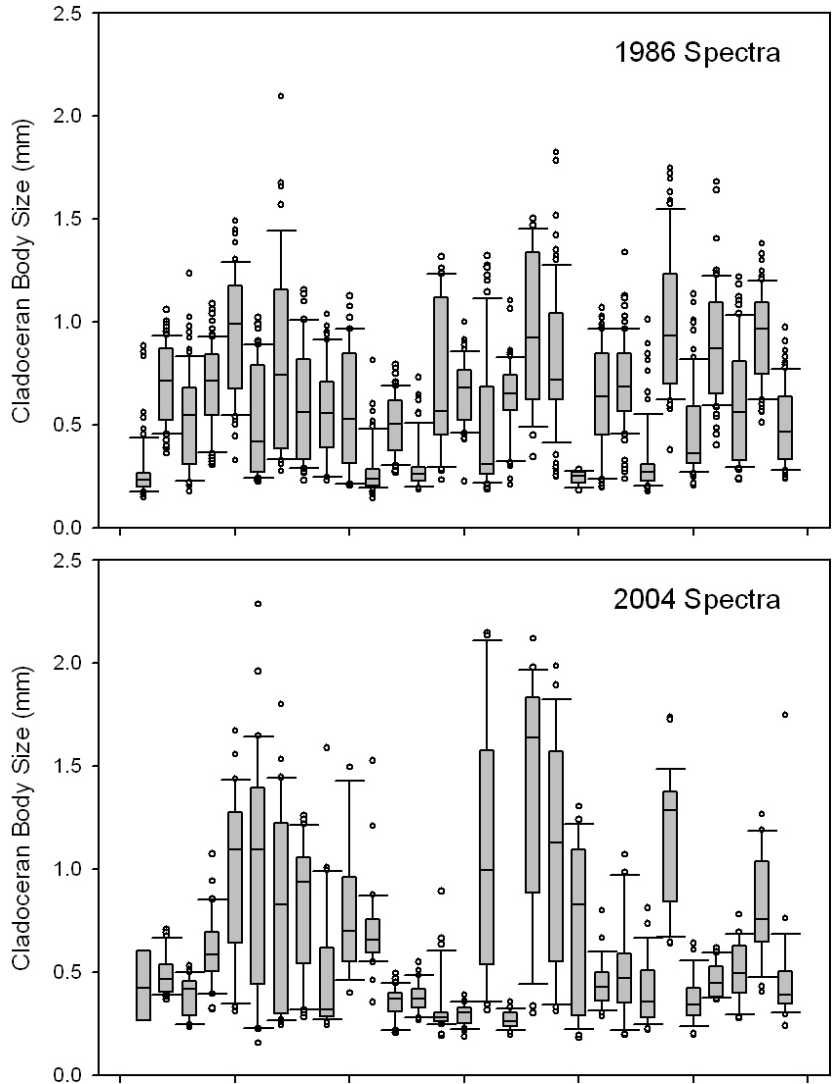
Figure 1. Size spectra of cladocerans (as box plots) in 1986 and 2004. Lakes are ordered by their calcium concentrations in 2004).

One of the most striking changes in the ELS lakes over 20 years was a general decrease in calcium in lakes that were not affected by road salt. Declines in Ca below a threshold of ~75 ueq/L in boreal lakes in Canada, have been associated with loss of daphniids, typically the larger bodied cladocerans (Jeziorski et al. 2008). Because the zooplankton data from the ELS lakes provides an opportunity to test the applicability of the Canadian results, we present some preliminary results for the Maine lakes. Because daphniids are larger-bodied cladocerans, size spectra would be expected to be lower in low Ca lakes.

Plots of the 75th quartile from the size spectra in 1986 and 2004 from subregion 1E, do suggest that cladocerans in lakes with Ca < 75 show a signal of lower body size; however lakes with similarly low quartile values occur across the range of Ca in the study lakes (Figure 2). A range of factors, both abiotic (Ca, DOC, lake morphometry) and biotic (invertebrate and vertebrate predation), influence cladoceran body size and can be explored with the ELS III+ database.
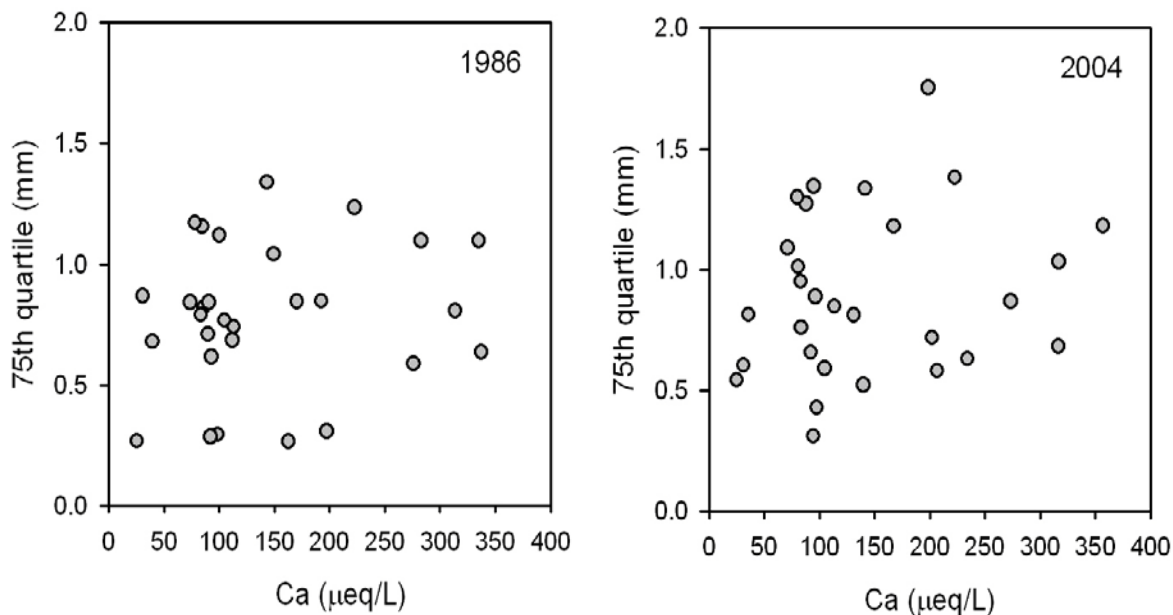

Figure 2. The 75th quartile value from the size spectra for cladocerans in 1986 and 2004 plotted against Ca.

Future work and planned products:

Manuscripts on (1) changes in cladoceran size spectra in relation to chemical changes in the ELS II lakes and (2) relationships between size spectra characteristics and landscape features of the ELS II lakes are planned. The ultimate policy-relevant deliverable will be a manuscript on inferences for biological recovery as a result of the Clean Air Act Amendments of 1990.
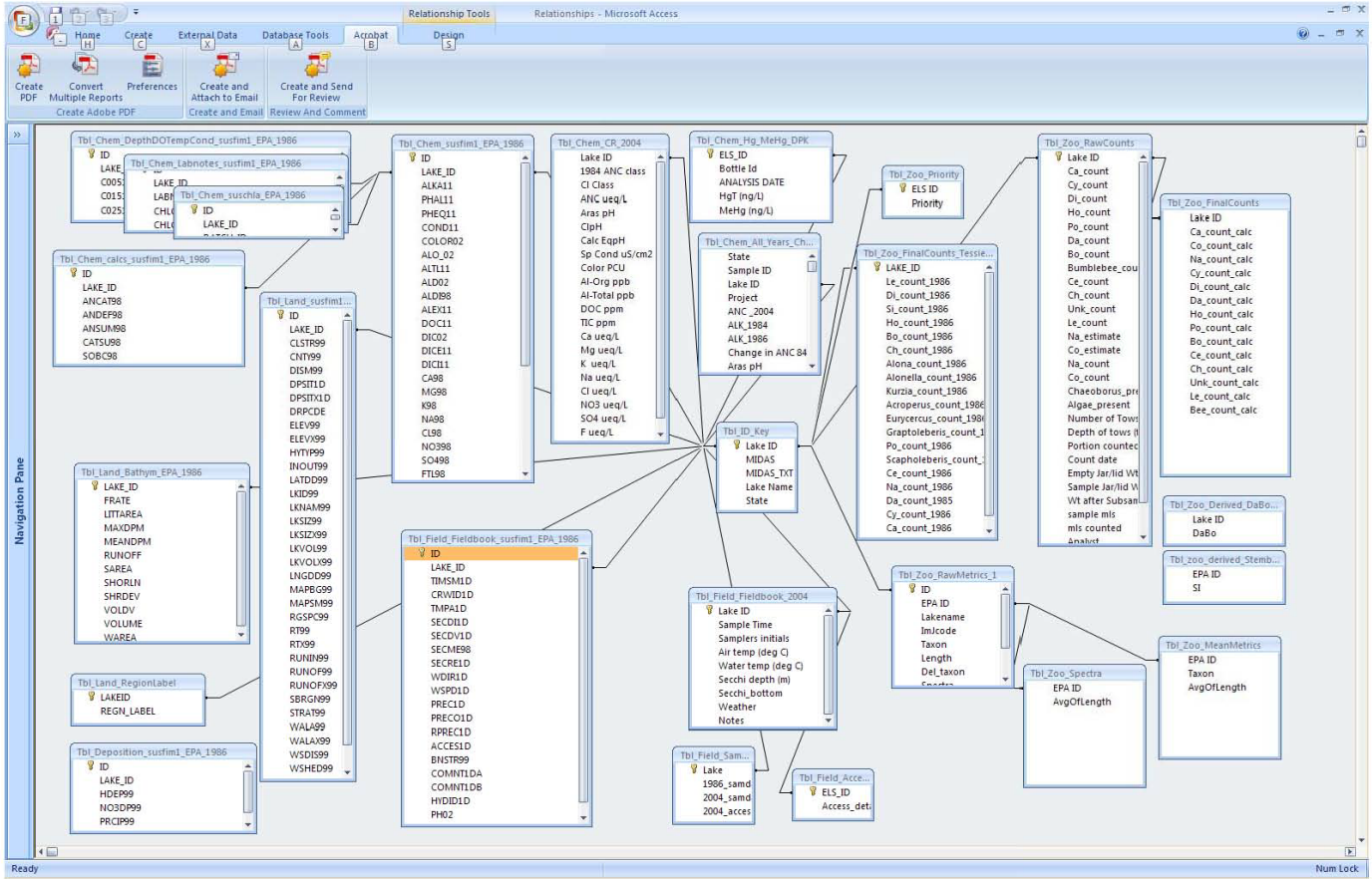
Importance

This research presents a unique opportunity to assess 18-year trends in lake condition at a regional scale within a statistically-based EPA population framework. This work is the only option for assessing biological response to CAAA policy. Until now, we have relied on biologically-relevant chemistry, which of necessity will remain the main tool for future assessments. However, integrating biological and water quality measures provides a more powerful assessment of regional trends in acid deposition and other anthropogenic stressors influencing lake ecosystems. This research would also contribute to development of lake indices using zooplankton body size that can be used in fisheries and lake management assessments.

Literature cited in this section:

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Locke, A., W.G. Sprules, W. Keller, and J.R. Pitblado. 1994. Zooplankton communities and water chemistry of Sudbury area lakes: related to pH recovery. Can. J. Fish. Aquat. Sci. 51: 151-160.

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Yan, N. D., Leung, B., Keller, W., Arnott, S.E., Gunn, J.J. & Raddum G. G. (2003). Developing conceptual frameworks for the recovery of aquatic biota from acidification: a zooplankton example. *Ambio* 32, 165-169.

Depiction of many of the tables and relationships in ELS-III+ database (MS Access 2007). Not shown are several tables summarizing results of GIS analyses performed in 2008 by S. Nelson, including percent impervious surface and landcover in the vicinity of each lake.