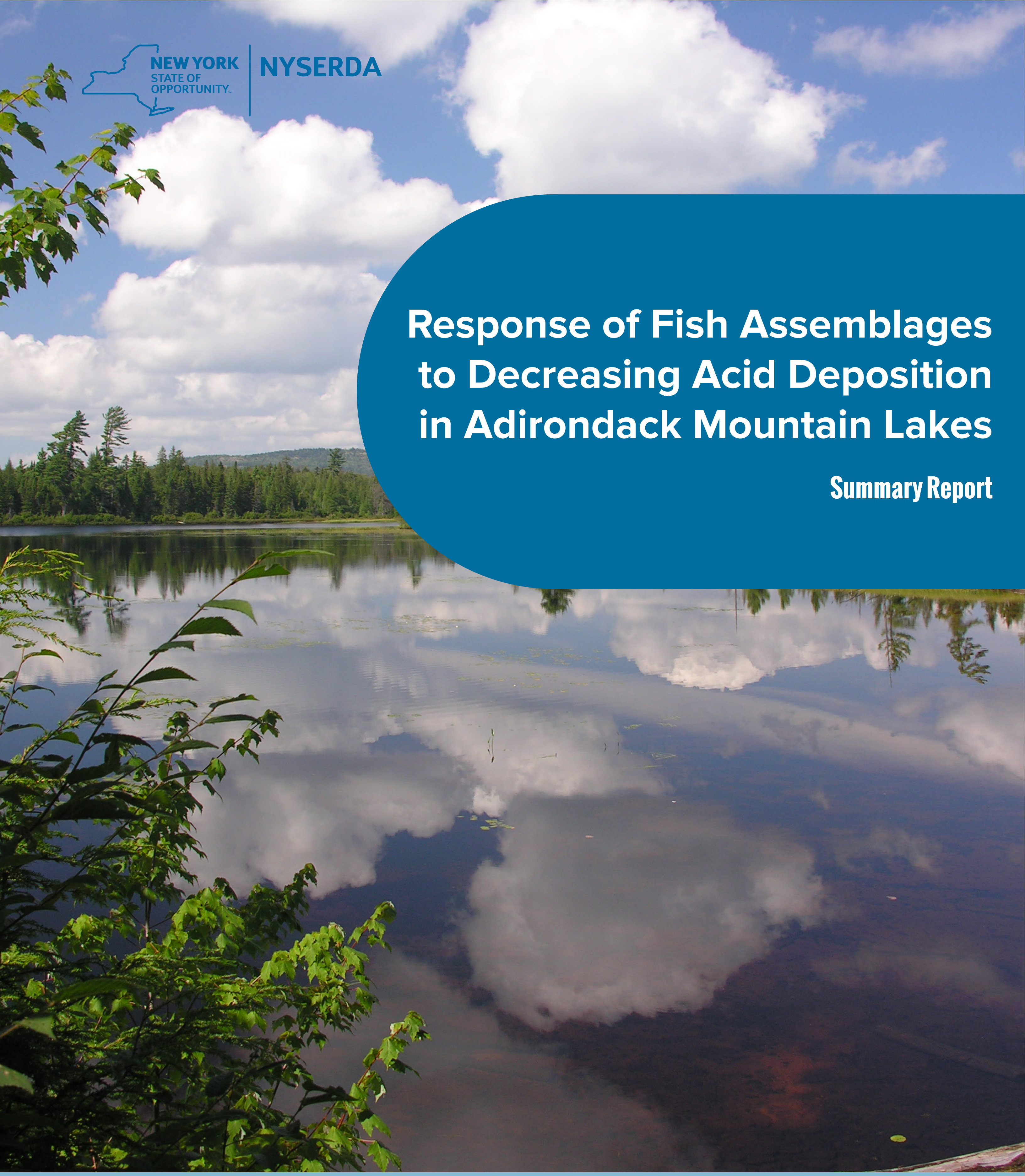


Response of Fish Assemblages to Decreasing Acid Deposition in Adirondack Mountain Lakes

Summary Report

December 2016

Report Number 17-01

NYSERDA’s Promise to New Yorkers:

NYSERDA provides resources, expertise, and objective information so New Yorkers can make confident, informed energy decisions.

Mission Statement:

Advance innovative energy solutions in ways that improve New York’s economy and environment.

Vision Statement:

Serve as a catalyst – advancing energy innovation, technology, and investment; transforming New York’s economy; and empowering people to choose clean and efficient energy as part of their everyday lives.

Cover Image: Bog Lake near Sabattis, NY. Photo credit to Barry Baldigo

Response of Fish Assemblages to Decreasing Acid Deposition in Adirondack Mountain Lakes

Summary Report

Prepared for:

New York State Energy Research and Development Authority

Albany, NY

Gregory Lampman, Senior Project Manager

Prepared by:

U.S. Geological Survey

Troy, NY

Barry P. Baldigo, Project Manager

and

New York State Department of Environmental Conservation

Ray Brook,

Karen M. Roy, Project Manager

and

Syracuse University

Syracuse, NY

C.T. Driscoll, Project Manager

NYSERDA Report 17-01 NYSERDA Contract 41878 December 2016

Notice

This report was prepared by U.S. Geological Survey, New York State Department of Environmental Conservation, and Syracuse University in the course of performing work contracted for and sponsored by the New York State Energy Research and Development Authority (hereafter “NYSERDA”). The opinions expressed in this report do not necessarily reflect those of NYSERDA or the State of New York, and reference to any specific product, service, process, or method does not constitute an implied or expressed recommendation or endorsement of it. Further, NYSERDA, the State of New York, and the contractor make no warranties or representations, expressed or implied, as to the fitness for particular purpose or merchantability of any product, apparatus, or service, or the usefulness, completeness, or accuracy of any processes, methods, or other information contained, described, disclosed, or referred to in this report. NYSERDA, the State of New York, and the contractor make no representation that the use of any product, apparatus, process, method, or other information will not infringe privately owned rights and will assume no liability for any loss, injury, or damage resulting from, or occurring in connection with, the use of information contained, described, disclosed, or referred to in this report.

NYSERDA makes every effort to provide accurate information about copyright owners and related matters in the reports we publish. Contractors are responsible for determining and satisfying copyright or other use restrictions regarding the content of reports that they write, in compliance with NYSERDA’s policies and federal law. If you are the copyright owner and believe a NYSERDA report has not properly attributed your work to you or has used it without permission, please email print@nyserda.ny.gov

Information contained in this document, such as web page addresses, are current at the time of publication.

Preferred Citation

New York State Energy Research and Development Authority (NYSERDA). 2016. “Response of fish assemblages to decreasing acid deposition in Adirondack Mountain lakes – Summary Report.” NYSERDA Report 16-40s. nyserda.ny.gov/publications

Acknowledgments

This research was funded by a grant from the New York State Energy Research and Development Authority Environmental Monitoring, Evaluation, and Protection Program under the direction of Gregory Lampman in cooperation with the New York State Department of Environmental Conservation, Syracuse University, and the U.S. Geological Survey. All fish and chemistry data from the Adirondack Long-Term Monitoring lakes were collected by the Adirondack Lakes Survey Corporation (ALSC). The work by the ALSC was performed with funding support from the New York State Energy Research and Development Authority, the New York State Department of Environmental Conservation, and the U.S. Environmental Protection Agency's Long-Term Monitoring Network.

Table of Contents

List of Figures

1 Focus

This project evaluated the response of fish assemblages to changes in acid deposition and water quality in 43 Adirondack Mountain lakes that were monitored by the Adirondack Lakes Survey Corporation (ALSC) and the New York State Department of Environmental Conservation (DEC) between 1984 and 2012. Mean Acid Neutralizing Capacity (ANC) has increased significantly and mean inorganic aluminum concentration has decreased significantly in the 43 lakes during the 28-year period, which suggests that corresponding changes in fish communities are to be expected. Analysis of changes in the composition of fish assemblages in lakes recovering chemically from acidification is valuable because the results might provide direct evidence of potential ecosystem benefits resulting from national regulations limiting nitrogen and sulfur oxide emissions in a region that was one of the most severely impacted by acid rain in the late 1900s.

Figure 1. Bubb Lake near Eagle Bay, NY.

Source Photo credit G. Lampman.

2 Context

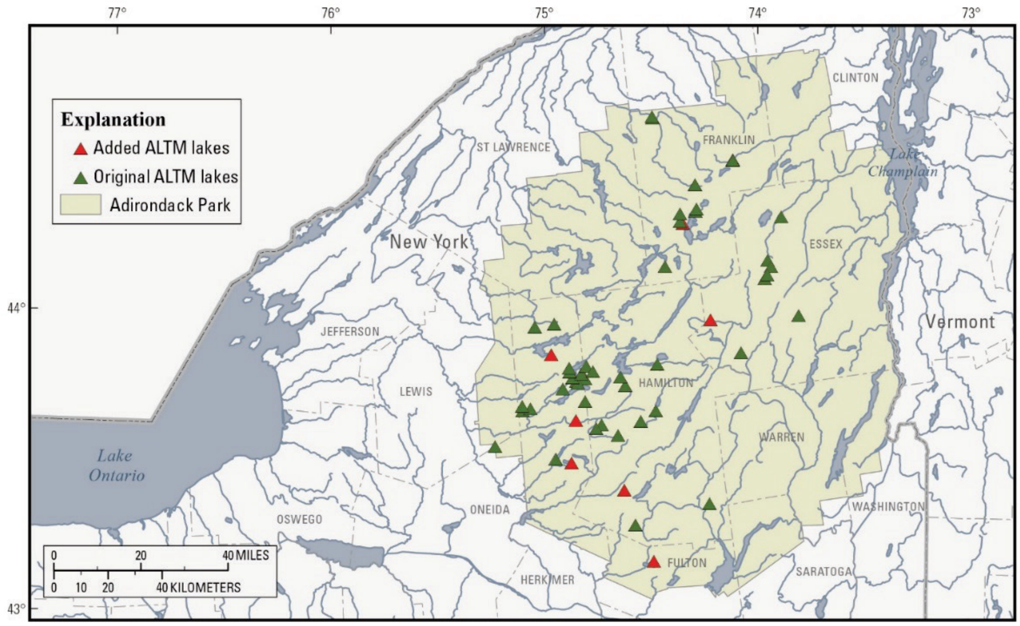
Acid deposition has severely affected terrestrial and aquatic ecosystems in the Adirondack Mountains of upstate New York and across other regions of North America. Regulations intended to directly reduce the emissions of nitrogen and sulfur oxides and deposition of acids have been implemented by the U.S. Environmental Protection Agency (EPA) since the 1990s. Environmental agencies are eager to understand if and how the chemistry and biology of aquatic ecosystems have changed in response to decreases in acid rain in order to (a) document the degree, extent, and rate of ecosystem recovery and (b) assess the effectiveness of methods used to characterize fishery and ecosystem recovery. Understanding if and how fish assemblages respond to decreasing rates of acid rain and improvements in water quality is important to the management and protection of lake ecosystems in this region and nationwide.

3 Goals and Objectives

The primary objective of this investigation was to determine if implementation of the 1990 Clean Air Act amendments and other regulations have significantly improved impaired fish assemblages in 43 lakes that were monitored in the Adirondack Park between 1984 and 2012.

Figure 2: Map showing the locations of 52 Adirondack Long-Term Monitoring lakes (from Baldigo, Roy, & Driscoll 2016).

Base from the National Map. Universal Transverse Mercator projection, zone 18, WGS84, 1:1,000,000



4 Study Area and Methods

The Adirondack Lake Survey Corporation (ALSC) and DEC monitored water chemistry regularly and conducted three fish-community surveys (from 1984–1987, 1994–2005, and 2008–2012) in 43 of 52 Adirondack Long-Term Monitoring (ALTM) lakes. The ALTM lakes are distributed across the Adirondack Park (Figure 2) and vary widely in elevation, volume, watershed area, and lake area (Table 1). Forests of the region are generally classified as northern hardwoods with red spruce and balsam fir dominating at higher elevations. Mean annual precipitation across the region ranges from approximately 79 to more than 160 cm. The pH of precipitation averaged about 4.1 during the 1980s and 5.0 during 2013, yet sulfate and nitrate concentrations in deposition currently remain among the highest in the Northeast. Most surface waters across the western and southwestern parts of the Adirondacks are especially dilute, with negative or low levels of acid neutralizing capacity.

Table 1. Physical characteristics of 43 Adirondack Long Term Monitoring lakes where fish assemblages were surveyed during three periods, 1984–1987, 1994–2005, and 2008–2012 (modified from Baldigo, Roy, & Driscoll 2016).

Lake/Pond Name	Elevation (m)	Max depth (m)	Mean depth (m)	Volume (10^4 m^3)	Surface area (ha)	Watershed area (ha)
LITTLE HOPE POND	517	6.2	3.5	10.0	2.8	53.6
BIG HOPE POND	517	11.5	5.8	51.6	8.9	119.2
EAST COPPERAS POND	480	6.4	4.1	14.8	3.6	13.0
MIDDLE POND	483	3.3	1.5	36.9	24.3	187.1
SUNDAY POND	495	11.0	5.4	21.9	4.0	21.5
SOCHIA POND	495	5.5	3.1	5.0	1.6	9.6
OWEN POND	514	9.4	3.7	28.4	7.6	1159.0
HEART LAKE	661	16.8	5.1	54.5	10.7	69.3
MARCY DAM POND	720	2.4	0.7	0.8	1.2	1177.2
GRASS POND	381	7.0	4.2	6.8	1.6	29.5
LITTLE CLEAR POND	381	14.0	5.5	10.2	1.9	18.0
LOON HOLLOW POND	605	11.6	3.4	19.1	5.7	55.2
WILLYS LAKE	632	13.7	4.9	118.8	24.3	158.2
MIDDLE SETTLEMENT L	526	11.0	3.4	54.5	15.8	114.3
GRASS POND	549	5.2	1.5	7.8	5.3	272.0
MIDDLE BRANCH LAKE	496	5.2	2.1	36.3	17.0	129.6
LAKE RONDAXE	524	10.1	3.0	273.3	90.5	14155.6
MOSS LAKE	536	15.2	5.7	259.8	45.7	1234.6
BUBB LAKE SSTA1	554	4.3	2.1	38.5	18.2	199.1
DART LAKE	537	17.7	7.3	380.7	51.8	10804.5
WINDFALL POND SSTA1	591	6.1	3.2	7.8	2.4	41.1
WEST POND SSTA1	581	5.2	1.5	15.2	10.4	99.6
SQUASH POND SSTA1	653	5.8	1.4	4.5	3.3	125.1
CONSTABLE PD SSTA1	580	4.0	2.1	43.5	20.6	937.4
LIMEKILN LAKE	575	21.9	6.1	1147.6	186.9	1409.7
SQUAW LAKE	646	6.7	3.4	124.9	36.4	182.7
INDIAN LAKE	654	10.7	3.0	98.1	33.2	1121.4
BROOK TROUT LAKE	724	23.2	8.4	242.0	28.7	165.7
LOST POND	717	1.2	0.7	3.2	4.4	173.8
BARNES LAKE	395	10.1	4.5	13.1	2.9	6.5
NORTH LAKE	555	17.7	5.7	1010.7	176.8	7700.8
WILLIS LAKE	400	2.7	1.6	22.9	14.6	136.4
JOCKEYBUSH LAKE	599	11.3	4.5	78.6	17.3	160.0
CLEAR POND	584	24.4	9.2	651.1	70.4	565.0
NATE POND	613	6.4	2.3	19.4	8.3	89.2
LONG POND	574	4.0	2.0	3.3	1.7	29.6
CARRY POND	652	4.6	2.2	6.2	2.8	20.8
LAKE COLDEN	843	7.3	2.3	35.5	15.4	656.3
AVALANCHE LAKE	873	7.0	3.3	14.6	4.4	115.2
LITTLE SIMON POND	546	32.0	11.0	631.3	58.1	774.0
SAGAMORE LAKE	580	22.9	10.5	713.1	68.0	4723.0
RAQUETTE LAKE RES	564	3.0	1.6	2.4	1.5	305.5
QUEER LAKE	597	21.3	10.9	596.0	54.5	375.4

Fish assemblages were surveyed in the 43 ALTM lakes during 1984–1987, and in 52 ALTM lakes during 1994–2005 and 2008–2012, following standard ALSC methods. Analyses focused only on those 43 lakes surveyed during all three periods and excluded data (in individual lakes) for any species stocked less than five years (before any survey) and observations obtained using non-standard gear (during any period). Briefly, fish assemblages in each lake were surveyed once in either the spring (April–June) or fall (September–November) between 1984 and 1987. Several types of gear were used to document the diversity of fish species in each lake. Between zero and four (occasionally more) experimental Swedish gill nets were set per lake depending on lake's surface area. Modified Alaska or Oneida trap nets were also used in place of, or along with, the experimental gill nets in several lakes to reduce mortality. At least one minnow trap and one monofilament or multifilament gill net was also set in the littoral zone of each lake to sample juvenile fish and small minnow species. All gear was typically set overnight, but sometimes retrieved sooner to reduce mortality, predation, or overcrowding. The number of each species captured and total length and weight from all fish or from a subsample of up to 20 individuals of each species were recorded. The number of each species (and total for all species) was divided by the number of net sets to estimate the species (and total) catch per net night (CPNN) in each lake. Water chemistry for all study lakes was determined from samples collected 1.5 m below the surface at the deepest part or middle of each lake in July or August during the 1984–1987 survey and from monthly samples collected closest to the date that fish and chemistry were first sampled, during the second and third survey periods. The chemistry data were analyzed to determine if the mean concentrations of pH, ANC, calcium (Ca), dissolved organic carbon (DOC), and inorganic aluminum (Ali) from the 43 lakes differed between the three survey periods and if the distribution of measures for each chemical constituent and the three fish metrics differed between the three survey periods. The relations between the fish metrics and ANC, pH, and Ali were also analyzed to evaluate the strength of relations and estimate the potential change in fishery metrics expected with observed changes in chemistry over the three periods.

5 Project Findings

Results from the study are summarized below and described in greater detail by Baldigo et al. (2016).

5.1 Lake chemistry

Our analysis of temporal changes in acid-base chemistry of the 43 lakes confirmed that ANC and pH increased and Ali concentrations declined significantly between the first and third surveys. The ANC levels increased in 70% of the lakes between the first and second survey, and in 88% of the lakes between the first and third survey. Mean ANC levels for all lakes increased significantly from the first to second surveys, and from the first to third surveys (Figure 3A). The cumulative frequency distributions for ANC increased significantly between the first and third surveys (by approximately 25 µeq/L), but not between the first and second surveys (Figure 4A). Concentrations of Ali decreased in 74% of the 43 lakes between the first and the second surveys and in 95% of the lakes between the first and third surveys. The mean Ali concentrations decreased significantly between the first and second surveys and between the first and third surveys (by almost 2 µmol/L) (Figure 3D). The cumulative frequency distributions for Ali decreased significantly between the first and third surveys (by about 1.6 µmol/L), and between the first and second surveys (Figure 4B). The significant shifts in the distributions of ANC and Ali data from all 43 ALTM lakes confirm that the acid-base status of Adirondack lakes has improved on a broad scale over the study period.

5.2 Fish assemblages

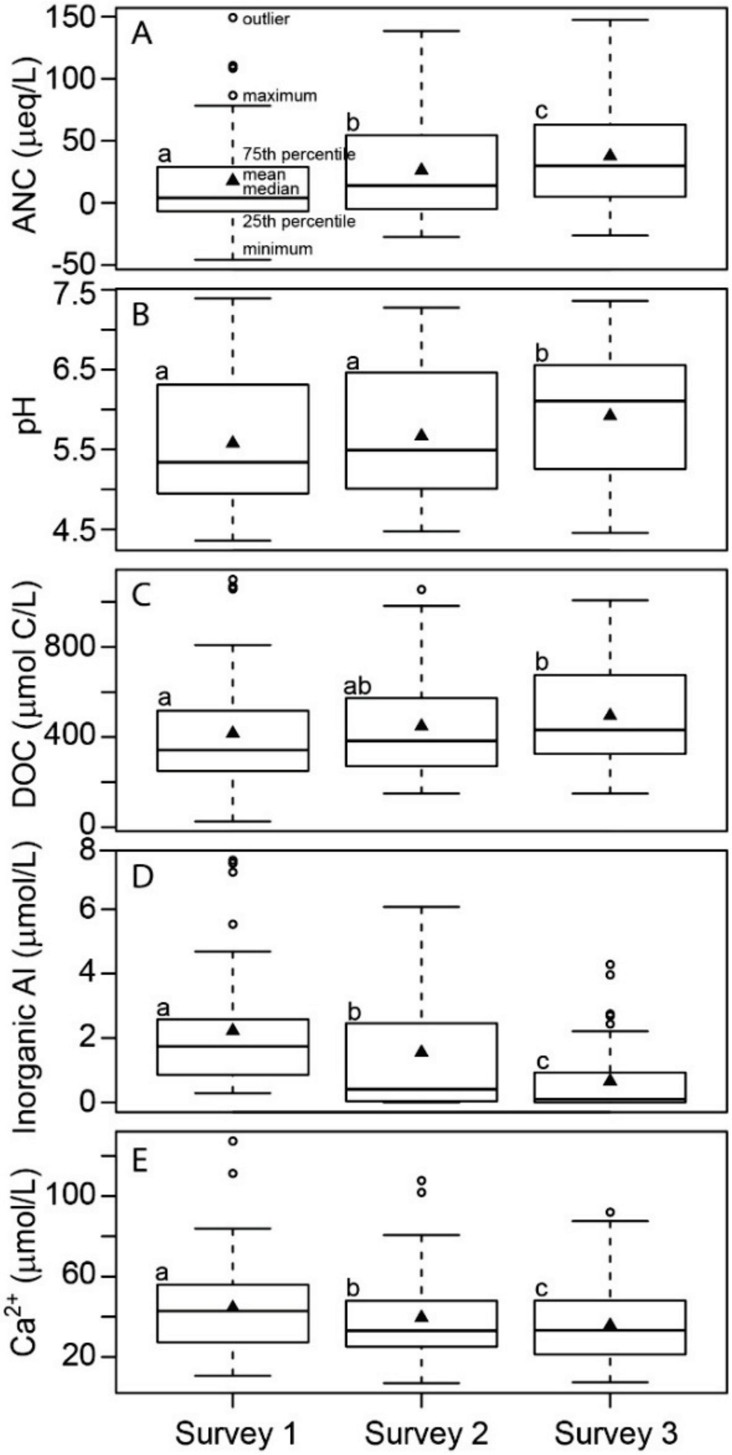
At the largest scale (all 43 lakes), the number of species in fish communities did not change significantly in response to improvements in acid-base chemistry between the first and second or between the first and third surveys (Figure 5A). The frequency distributions for species richness data from all lakes also did not differ significantly among any of the survey periods (Figure 4C). At a smaller (single lake) scale, however, species richness was higher in 42% of the individual lakes during the second survey, and in 33% of the lakes during the third survey when compared to the first survey. Although the number of fish species collected from individual lakes was highly variable through time, increases in the number of fish species in at least one-third of the ALTM lakes between 1984–1987 and 2008–2012 could be important to lake ecosystems across the region.

Total CPNN from all lakes, like richness, did not change significantly in response to improvements in acid-base chemistry between the first and second or the first and third surveys (Figure 5B). The frequency distributions for total CPNN data from all study lakes also did not differ significantly among the three surveys (Figure 4D). Total CPNN was also higher in 37% of the lakes during the second survey, and in 30% of the lakes during the third survey as compared to the first survey.

Brook trout CPNN did not change significantly in response to improvements in acid-base chemistry between the first and second or first and third surveys in the lakes (Figure 5C). The frequency distributions for brook trout CPNN also did not differ significantly between the three surveys (Figure 4E). Brook trout CPNN was higher in 12% of the 43 lakes during the second survey, and in 19% of the 43 lakes during the third survey, as compared to the first survey.

Figure 3. Chemical conditions at 43 ALTM lakes during three survey periods (from Baldigo, Roy, & Driscoll 2016).

Chemistry data are from water samples collected at all 43 ALTM lakes once in July or August of the same year that fish were sampled once during each of the three survey periods (1984–1987, 1994–2005, and 2008–2012). Different letters denote significant differences among the three survey periods determined using repeated measures ANOVA on ranks and Tukey's multiple comparisons tests.



5.3 Study Implications

The lack of measureable recovery of fish assemblages in the 43 ALTM lakes between 1984 and 2012 has important implications for lake and fisheries management as well as ecological assessment programs. First, the lack of observable biological recovery does not discount the fact that the CAA and more recent emissions regulations have had their intended effects on water quality in Adirondack lakes. Although a broad recovery in lake fisheries is not apparent in our analyses, the water quality in most lakes has improved substantially over the past two to three decades and created conditions that should help shepherd the restoration of pre-acidification ecosystems in lakes across the region. If changes in acid-base chemistry of some ALTM lakes were too small to have affected resident biota, then additional management actions may be needed to accelerate chemical recovery (e.g., liming of lakes and watersheds or additional reductions in sulfur and nitrogen oxide emissions). Second, our findings suggest that the recovery of native fish species populations and functionally diverse food webs may require supplementary efforts to successfully reintroduce native species, especially fish, which are easily obstructed by barriers in headwater lakes with low connectivity. Such a solution (stocking of mature brook trout) helped expand and diversify the abbreviated food web in Brook Trout Lake (ALTM Lake 040874). In contrast, brook trout populations in another completely isolated (headwater) Adirondack lake (not included in this study) have recovered markedly because remnant populations remained in several tributaries with high ANC (refuges) and provided a connected source of fish to reestablish their lake populations when acidity and Ali levels decreased to survivable levels over the past decade. Third, the lack of detectable biological recovery points out the need to formulate more defensible pre-acidification target conditions for judging progress toward (and barriers to) biological recovery in individual lakes or groups of lakes. A number of investigators suggest progress should be gauged based upon the pre-acidification abundance, recruitment, and/or growth of “locally dominating” species. Fourth, the potential challenges to recovery of species’ populations, such as: (a) inadequate water quality, (b) the presence of physical barriers that block colonists, (c) too few colonists to establish viable populations, or (d) community-level confounding factors, need to be identified and resolved within target lakes to ensure that meaningful biological recovery can proceed. Fifth, the current assessment strategy (i.e., sampling methods and frequency) cannot generate measures of error for key fishery metrics, which hinders our ability to accurately define current conditions and assess the significance of temporal changes in fishery metrics within individual lakes and across groups of lakes. Future fish-survey methods and sampling strategies should be critically reviewed and revised to ensure that they will be able to generate accurate biological metrics with quantifiable levels of error.

Figure 4. The frequency distribution of chemical and biologic conditions at 43 ALTM lakes (from Baldigo, Roy, & Driscoll 2016).

Chemistry data are from water samples collected at all 43 ALTM lakes once in July or August of the same year that fish were sampled once during each of the three survey periods (1984–1987, 1994–2005, and 2008–2012). Different letters denote significant differences in the distributions among the three survey periods determined using two-sample Kolmogorov-Smirnov tests.

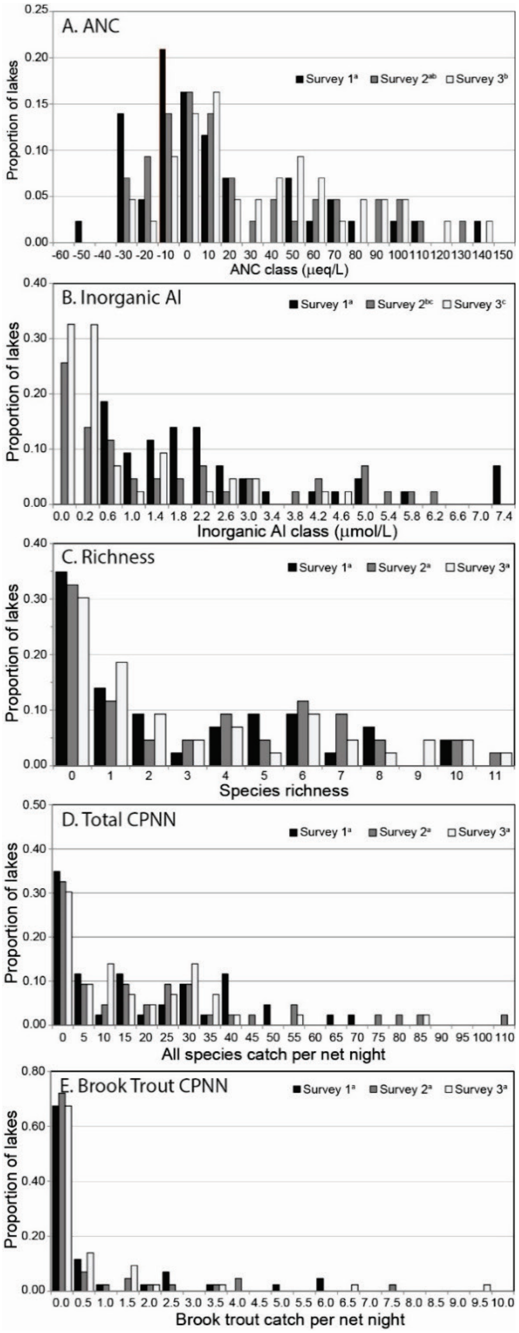
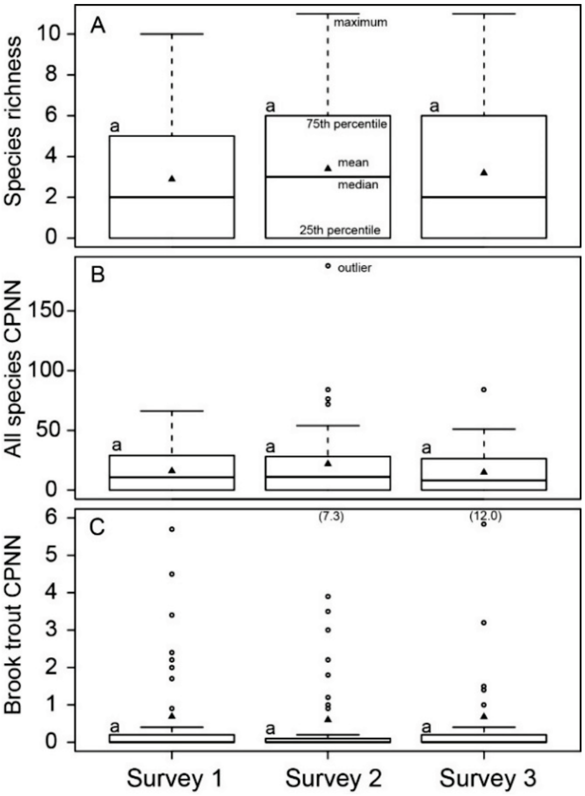


Figure 5. Fishery conditions at 43 ALTM lakes during three survey periods (from Baldigo, Roy, & Driscoll 2016).

Community and brook trout population data at 43 ALTM lakes sampled once during each of the three survey periods (1984–1987, 1994–2005, and 2008–2012). Different letters denote significant differences among the three survey periods determined using repeated measures ANOVA on ranks and Tukey's multiple comparisons tests.



Our findings may also have ramifications for the derivation and interpretation of critical and target loads for deposition of nitrogen and sulfur to watersheds that are presently (2015–2016) under review by the EPA. Critical loads may be used to establish secondary standards for atmospheric emissions of nitrogen (NO_x) and sulfur (SO_x) oxides, which will theoretically protect terrestrial and aquatic species (and their communities) from further adverse impacts and promote recovery of acidified ecosystems to an unimpaired or minimally acceptable condition. The standards, if implemented, will rely heavily on research that estimates thresholds or target deposition loads of NO_x and SO_x, below which significant harmful effects to sensitive elements of terrestrial and (or) aquatic ecosystems would not be expected. A number of acid-base chemistry parameters such as pH, ANC, and Ali have corresponding effect thresholds for several fish species. When these thresholds are exceeded, the health of resident species may decline, which can lead to mortality, reduced recruitment rates and population density, shifts in species distributions, and decreases in overall community diversity. The absence of notable recovery and high temporal variability in biological metrics from ALTM lakes, however, suggests that tangible biological responses to deposition loads of NO_x and SO_x that decrease below safe levels may not be evident or detectable for years or decades after chemical recovery occurs in the region. The lack of rapid biological responses to improving chemistry in ALTM lakes suggests that one or more acid-base chemistry variables may serve as acceptable surrogates for gauging the "potential" for biological responses to various target loads of NO_x and SO_x deposition. Accordingly, the specific biological response variables, and the sampling methods and frequency used to assess such responses, need to be revised to more precisely characterize biological recovery from acidification in ALTM lakes and in other lakes of the region.

Lastly, our inability to accurately characterize and detect changes in highly variable fishery metrics such as species richness and abundance using gear that is selective to specific habitats and sizes (or age classes) of fish in lakes begs the question: could biological recovery be more effectively quantified or detected in another media (e.g., streams) of the region? Temperate lakes have been the focus of long-term monitoring of acid-base chemistry partly because summer conditions are stable for relatively long periods. The relatively large volume of most lakes and lack of variability in lentic hydrology means that temporal changes and trends in chemistry may be detected more readily in lakes than in streams. The relatively large volume and diverse/stratified habitats of lakes, however, make most biological-community surveys difficult and associated results imprecise. Most small fish species and early life stages of large species are seldom sampled effectively in lakes, whereas all large and small individuals can be efficiently collected in blocked stream reaches. Small fish species and early life stages of many fish are also often more sensitive to acidic conditions than are larger species and later life stages. In the United Kingdom, brown trout fry were found to be more sensitive indicators of biological recovery than parr, and juvenile brown trout were the earliest immigrants, in three of 22 streams (and lakes outflows) beginning to recover from acidification. Juveniles of the native and widely distributed brook trout have been used for more than three decades to quantify toxicity and biological impacts of acidification in Adirondack streams, thus, it could be an ideal indicator species for the region. Although stream chemistry is more dynamic temporally and less responsive than lake chemistry to decreasing trends in acidic deposition, stream habitat is less dimensional than lake habitat. As a result, most life stages, species populations, and biological communities (especially fish) are much easier to quantify in streams than in lakes. Thus, monitoring and analysis of temporal trends in stream biota could improve our ability to detect and characterize indicators of biological recovery in surface waters of the Adirondack region recovering from acidification.

6 Conclusions

The CAA and other federal regulations have clearly reduced emissions of NO_x and SO_x, acidic deposition, and the acidity and toxicity of waters in the ALTM lakes, but these changes have not triggered widespread recovery of brook trout populations or fish communities. The lack of detectable biological recovery appears to result from relatively recent chemical recovery and an insufficient period for species populations to take advantage of improved water quality. Recovery of extirpated species' populations may simply require more time for individuals to migrate to and repopulate formerly occupied lakes. Supplemental stocking of selected species may be required in some lakes with no remnant (or nearby) populations or with physical barriers between the recovered lake and source populations. The lack of detectable biological recovery could also be related to our inability to calculate measures of uncertainty or error and, thus, examine temporal changes or differences in populations and community metrics in more depth (e.g., within individual lakes) using existing datasets. Indeed, recovery of brook trout populations and partial recovery of fish communities are documented in several lakes of the region, both with and without human intervention. Multiple fish surveys (annually or within the same year) or the use of mark and recapture methods within individual lakes would help alleviate the issue (provide measures of error for key fishery metrics) within the context of a more focused sampling strategy. Efforts to evaluate and detect recovery in fish assemblages from streams may be more effective than in lakes because various life stages, species' populations, and entire assemblages are easier to quantify, with known levels of error, in streams than in lakes. Such long-term monitoring efforts could increase our ability to detect and quantify biological recovery in recovering (neutralizing) surface waters throughout the Adirondack Region.

7 Citation

Baldigo, B. P., K. M. Roy, and C. T. Driscoll. 2016. Response of fish assemblages to declining acidic deposition in Adirondack Mountain lakes, 1984–2012. Atmospheric Environment 146:223–235.

NYSERDA, a public benefit corporation, offers objective information and analysis, innovative programs, technical expertise, and support to help New Yorkers increase energy efficiency, save money, use renewable energy, and reduce reliance on fossil fuels. NYSERDA professionals work to protect the environment and create clean-energy jobs. NYSERDA has been developing partnerships to advance innovative energy solutions in New York State since 1975.

To learn more about NYSERDA's programs and funding opportunities, visit nyserda.ny.gov or follow us on Twitter, Facebook, YouTube, or Instagram.

New York State
Energy Research and
Development Authority

17 Columbia Circle
Albany, NY 12203-6399

toll free: 866-NYSERDA
local: 518-862-1090
fax: 518-862-1091

info@nyserda.ny.gov
nyserda.ny.gov