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Response of fish assemblages to declining acidic deposition in Adirondack Mountain lakes, 1984–2012

B.P. Baldigo [a,*], K.M. Roy [b], C.T. Driscoll [c]

[a] U.S. Geological Survey, New York Water Science Center, 425 Jordan Road, Troy, NY 12180, USA
[b] New York State Department of Environmental Conservation, 1115 State Route 86, Ray Brook, NY 12977, USA
[c] Syracuse University, Department of Civil and Environmental Engineering, 151 Link Hall, Syracuse, NY 13244, USA

HIGHLIGHTS

- Acidity of 43 long-term monitoring lakes has generally declined since the 1970s.
- Corresponding changes in community richness and fish catches were not evident.
- Fish metrics were weakly correlated with most acid-base chemistry parameters.
- Alternate monitoring plans are needed to quantify biological recovery in the region.
- Proactive stocking or liming could speed recovery of fisheries in Adirondack lakes.

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ABSTRACT

Adverse effects of acidic deposition on the chemistry and fish communities were evident in Adirondack Mountain lakes during the 1980s and 1990s. Fish assemblages and water chemistry in 43 Adirondack Long-Term Monitoring (ALTM) lakes were sampled by the Adirondack Lakes Survey Corporation and the New York State Department of Environmental Conservation during three periods (1984–87, 1994–2005, and 2008–12) to document regional impacts and potential biological recovery associated with the 1990 amendments to the 1963 Clean Air Act (CAA). We assessed standardized data from 43 lakes sampled during the three periods to quantify the response of fish-community richness, total fish abundance, and brook trout (*Salvelinus fontinalis)* abundance to declining acidity that resulted from changes in U.S. air-quality management between 1984 and 2012. During the 28-year period, mean acid neutralizing capacity (ANC) increased significantly from 3 to 30 μeq/L and mean inorganic monomeric Al concentrations decreased significantly from 2.22 to 0.66 μmol/L, yet mean species richness, all species or total catch per net night (CPNN), and brook trout CPNN did not change significantly in the 43 lakes. Regression analyses indicate that fishery metrics were not directly related to the degree of chemical recovery and that brook trout CPNN may actually have declined with increasing ANC. While the richness of fish communities increased with increasing ANC as anticipated in several Adirondack lakes, observed improvements in water quality associated with the CAA have generally failed to produce detectable shifts in fish assemblages within a large number of ALTM lakes. Additional time may simply be needed for biological recovery to progress, or else more proactive efforts may be necessary to restore natural fish assemblages in Adirondack lakes in which water chemistry is steadily recovering from acidification.

1. Introduction

Our understanding of the effects of acidic deposition on terrestrial and aquatic ecosystems has increased profoundly since the problem was first recognized approximately 50 years ago (Likens et al., 1972; Schofield, 1965). Watersheds across the southwestern Adirondack Mountains of New York commonly contain soils that are inherently low in base-cations (and the ability to neutralize inputs of strong acids) and also historically have received some of the highest inputs of acidic deposition in North

* Corresponding author.
E-mail addresses: bbaldigo@usgs.gov (B.P. Baldigo), karen.roy@dec.ny.gov (K.M. Roy), ctdrisco@syr.edu (C.T. Driscoll).

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America (Burns et al., 2011). As a consequence, soil and surface-water acidification from acidic deposition have caused chronic and episodic toxicity; and negatively affected biota in many lakes and streams across the region (Baker et al., 1996; Baldigo et al., 2007; Driscoll et al., 2001). With recognition of the adverse impacts on water quality and biology of surface waters in the Adirondacks and other acid-sensitive areas around the world (Beamish and Van Loon, 1977; Hesthagen, 1989; Rosseland et al., 1980), the U.S., Canada, and some European countries implemented regulations and policies such as the 1990 amendments to the U.S. Clean Air Act (CAA) of 1963 to lower rates of sulfur (S) and nitrogen (N) oxide emissions (Driscoll et al., 2010; Stoddard et al., 2003; Waller et al., 2012). While emissions of S peaked during the early to mid-1970s and N emissions peaked in the early 2000s, sulfate and nitrate concentrations in wet deposition declined by 74% and 65%, respectively, in the Adirondack region between 1980 and 2010 (Driscoll et al., this issue; Driscoll et al., 2001; Strock et al., 2014). Corresponding declines in mean concentrations of sulfate and nitrate (−47 μeq/L and −0.4 μeq/L, respectively) and increases in mean acid neutralizing capacity (ANC) (+12.6 μeq/L), evident in the Adirondack Long-Term Monitoring (ALTM) lakes of the Adirondack region from 1990 to 2010 (Stoddard et al., 2003; Strock et al., 2014), indicate the reductions in S and N emissions are improving the acid-base chemistry in surface waters (Waller et al., 2012). Additional declines in S and N emissions are also expected to be an indirect benefit of the 2015 Clean Power Plan which targets CO_2 emissions (Driscoll et al., *in review*).

Past research and monitoring of the chemical and biological responses to acidification in Adirondack lakes have been (and still are) critical to U.S. efforts to better understand the timing, severity, and extent of ecosystem impacts and develop emission targets for chemical recovery and the strategies to achieve proposed S and N emission targets (Greaver et al., 2012). In 1982, the ALTM program was initiated to characterize the acid-base chemistry of 17 Adirondack lakes on a monthly basis (Driscoll and Vandreason, 1993). This effort was followed by an extensive chemical and fishery survey of 1469 lakes conducted by the Adirondack Lakes Survey Corporation (ALSC), New York State Department of Environmental Conservation (NYSDEC), and others from 1984 to 1987 to ascertain the spatial extent and magnitude of acidification impacts throughout the Adirondack Region (Baker et al., 1990). Following this assessment, the original ALTM program was expanded in 1992 to monitor monthly chemistry (and conduct periodic fish resurveys) in 52 lakes (Fig. 1) across a broader range of lake sizes, drainage areas, and dissolved organic carbon (DOC) concentrations (Newton and Driscoll, 1990). Primary goals of the ALTM program were to document the responses of water chemistry and, where possible, fish assemblages to changing rates of acidic deposition in surface waters of the region and to improve our understanding of interrelated recovery processes (Roy et al., 2013).

Attempts to quantify changes or long-term trends in chemistry and biology of surface waters in the Adirondack region have been challenging because (a) the few research studies were not integrated; (b) continuous monitoring efforts largely focused on lake chemistry; and (c) biological assemblages were rarely quantified or monitored strategically. The effects of acidic deposition on acid-base chemistry and fish communities in Adirondack lakes (and to a lesser extent – streams), however, were documented during the 1980s and 90s (Baker et al., 1990, 1996; Colquhoun et al., 1984). Following the period of peak S and N emissions, surface-water concentrations of sulfate, nitrate, and inorganic monomeric Al_i have generally decreased, and the pH and ANC have generally increased significantly over time (Driscoll, 2011; Driscoll et al., *in review*; Lawrence et al., 2011; Stoddard et al., 2003; Waller et al., 2012). These results clearly indicate that implementation of the CAA and other emission regulations have improved water quality in lakes and streams of the Adirondacks. Unfortunately, few Adirondack lakes have long-term fishery data. The 1984–87 survey of 1469 lakes found that 346 (24%) were fishless and that 9 fish species (brook trout, *Salvelinus fontinalis*; white sucker, *Catostomus commersonii*; creek chub, *Semotilus atromaculatus*; common shiner, *Luxilus cornutus*; brown bullhead, *Ameiurus nebulosus*; pumpkinseed, *Lepomis gibbosus*; lake trout, *Salvelinus namaycush*; rainbow trout, *Oncorhynchus mykiss*; smallmouth bass, *Micropterus dolomieu*) and a sensitive-minnow group, were lost from numerous lakes probably due to acidification (Baker et al., 1990). Fish assemblages were resampled in all 52 ALTM lakes during 1994–2005 and again during 2008–12. While there has been a provisional analysis of changes in fish assemblages in 44 ALTM lakes between the first two survey periods (Roy et al., 2013), the occurrence frequencies for individual fish species in 43 ALTM lakes have not changed appreciably over time (Fig. S1) even though the acid sensitivity of each species differs greatly (Kretser et al., 1989). Because a comprehensive analysis of the potential changes in fish communities across the three survey periods has not been completed, the tangible effects of recent decreases in N and S emissions on biological recovery in Adirondack lakes – anticipated because of improvements in water quality across the region – remain unknown.

Whether recent regulations and declines in N and S emissions have stimulated recovery of biological systems in acidified lakes and streams of eastern North America is an important question for natural resource managers and for the promulgators of corresponding regulations. To address this question, the U.S. Geological Survey (USGS), NYSDEC, Syracuse University, and the New York State Energy Research and Development Authority initiated the present study. The main goal of this investigation was to evaluate if recent changes in acid-base chemistry have significantly affected fish assemblages in acidified lakes of the Adirondack region between 1984 and 2012 using existing data collected under the ALTM program. Our findings will have important implications for management of fisheries and water quality in lakes of the region. First, this work can be used to help define (or refine) chemistry-fish response models and detect chemical thresholds that limit the occurrence of selected indicator species or species groups. Second, the value of the original (1984–87) fisheries dataset and both resurveys will be assessed; i.e., results will help project and validate anticipated recovery of lake ecosystems and develop the strategies needed to more effectively monitor long-term changes in fish assemblages. Third, study results will apprise the need for additional remedial efforts to accelerate the chemical and biological recovery of previously acidified lakes. Lastly, our results will directly inform decisions regarding the new (impending) secondary standards for nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) and how fish resources may be adaptively managed in lakes across the Adirondack region.

2. Materials and methods

Large sets of ALTM lake chemistry and fishery data had to be compiled, standardized, and integrated for intended analyses. First, fish and chemistry data from the three surveys were acquired, standardized, and filtered (to exclude sites without comparable data from all 3 periods and records for stocked fish species). Second, acid-base chemistry (e.g., ANC, pH, inorganic monomeric Al) and fish community metrics (species richness and all species or total catch per net night (CPNN)) and brook trout CPNN were compiled for each lake and survey date. Third, the relations between the three fish-community metrics and ANC, Al_i, and pH were explored using regression analysis to predict potential temporal shifts in