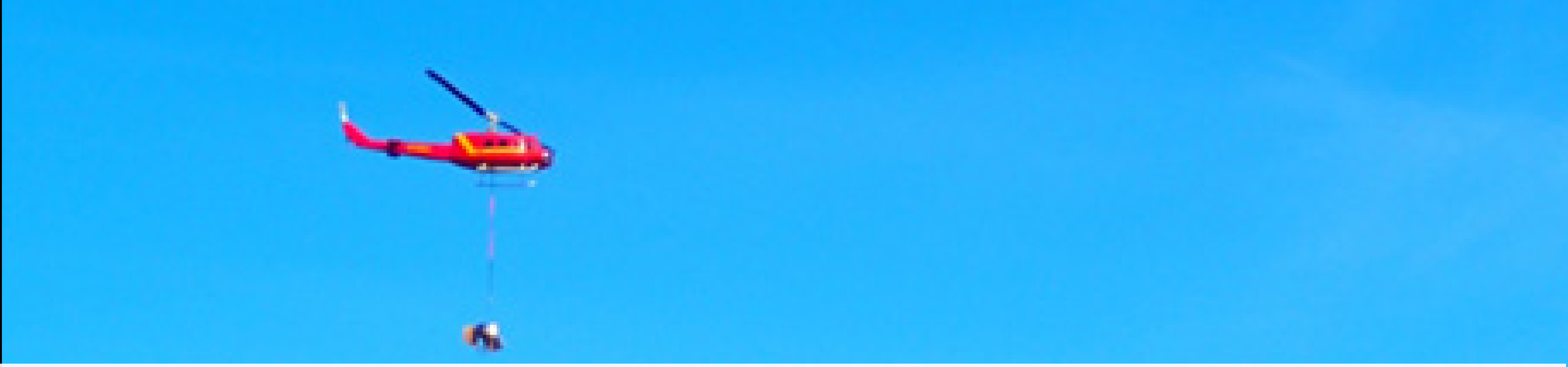

Effects of Watershed and In-Stream Liming on Macroinvertebrate Communities in Acidified Tributaries to Honnedaga Lake, NY

Summary Report | Report Number 18-18 | October 2018

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Cover photo: Aerial application of lime to the watershed of an acidified Honnedaga Lake tributary, NY.
Courtesy of Daniel Josephson

Effects of Watershed and In-Stream Liming on Macroinvertebrate Communities in Acidified Tributaries to Honnedaga Lake, New York

Summary Report

Prepared for:

New York State Energy Research and Development Authority

Albany, NY

Gregory Lampman,
Program Manager

Prepared by:

U.S. Geological Survey

Troy, NY

S.D. George
B.P. Baldigo
G.B. Lawrence
Project Managers

and

Colgate University

Hamilton, NY

R.L. Fuller
Project Manager

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Notice

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Abstract

Liming techniques are being explored in many regions as a means to accelerate the recovery of aquatic biota from decades of acid deposition. The preservation or restoration of native sportfish populations has usually been the impetus for liming programs, and as such, less attention has been paid to its effects on other biological assemblages such as macroinvertebrates. In 2012, a program was initiated using in-stream and aerial (whole-watershed) liming to improve water quality and Brook Trout (*Salvelinus fontinalis*) recruitment in three acidified tributaries of a high-elevation lake in New York State. Concurrently, macroinvertebrates were sampled annually between 2013 and 2016 at 3 treated sites and 3 untreated reference sites to assess the effects of each liming technique on this community. Despite improvements in water chemistry in all three limed streams, our results generally suggest that neither liming technique improved the condition of macroinvertebrate communities. The watershed application caused an immediate and unsustained decrease in the density of macroinvertebrates driven largely by a one-year reduction of the acid-tolerant *Leuctra* stoneflies. The in-stream applications appeared to reduce the density of macroinvertebrates, particularly in one stream where undissolved lime covered the natural substrate. The inability of either liming technique to improve the condition of macroinvertebrate communities may be partly explained by the persistence of acidic episodes in all three streams. This suggests that in order to be effective, liming programs should strive to eliminate even temporary episodes of unsuitable water chemistry.

Keywords

Liming; Acid Deposition; Macroinvertebrates; Adirondack Mountains; Streams; Water Chemistry

Acknowledgments

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1 Focus

The purpose of this study was to evaluate the effects of watershed and in-stream liming on macroinvertebrate communities in acidified tributaries to Honnedaga Lake, located in the southwestern Adirondack Mountain region of New York State. This study is part of a larger effort to assess the ability of in-stream and watershed liming to accelerate chemical and biological recovery of acidified streams. Macroinvertebrates were sampled annually between 2013 and 2016 at three treated and three untreated reference sites to determine if either technique improved the condition of this community and/or promoted the recolonization of acid-sensitive species. This information is critical to 1) improve understanding of liming as a tool to accelerate the recovery of ecosystems impacted by acid deposition and 2) inform natural resource managers of the potential effects (positive or negative) that liming programs aimed at restoring sportfish populations may have on macroinvertebrate communities.

Figure 1. Honnedaga Lake, NY

Source photo credit Daniel Josephson.

2 Context

Acid deposition has been one of the greatest threats to aquatic and terrestrial ecosystems in parts of eastern North America over the past half century. The origins, severity, and extent of this acidification are well documented in papers such as Driscoll et al. (2001), Burns et al. (2011), and many others. In short, deposition of sulfuric and nitric acids from fossil fuel combustion during the mid- to late-20th century acidified soils and surface waters in many regions with base-poor soils. As soils became more acidic, the inorganic form of aluminum was increasingly mobilized, and surface waters became episodically or chronically toxic to many aquatic organisms. Following passage of the Clean Air Act Amendments (CAAA) in 1990 and other clean air rules, deposition of sulfate and nitrate has decreased significantly, and water quality has improved in most acid-impacted regions of the United States. Despite the decreasing toxicity of surface waters, acidic episodes still occur, particularly in streams, and the recovery of aquatic biota has generally lagged behind chemical recovery.

Liming techniques are being explored as a means to accelerate the recovery of aquatic biota from decades of acid deposition in many regions (Clair and Hindar, 2005; Lawrence et al., 2016). The Adirondack Mountains of New York State are an acid-sensitive region that received some of the highest levels of acid deposition in the United States, and therefore are a prime location to evaluate the potential of liming to restore acidified ecosystems. For this reason, the New York State Department of Environmental Conservation (DEC) has maintained a lake liming program since 1959 to sustain or restore trout populations in acidified ponds and lakes of the Adirondack Mountain region of New York State. However, less is known about the ability of liming to restore acidified stream ecosystems. In 2012, a program was initiated using in-stream and aerial (whole-watershed) liming to improve water quality and brook trout (*Salvelinus fontinalis*) recruitment in three acidified tributaries of a high-elevation Adirondack lake. As part of this effort, macroinvertebrate communities (the focus of this report) were studied to determine if the lime applications accelerated their recovery or caused unintended negative impacts.

3 Goals and Objectives

The primary objective of this investigation was to evaluate the ability of watershed and in-stream liming to accelerate biological recovery, i.e., improve the condition of macroinvertebrate communities, in small acidified streams of the Adirondack Mountain region. This information will inform future restoration efforts and best management practices for accelerating the recovery of acidified ecosystems.

4 Study Area and Methods

The Honnedaga Lake watershed (Figure 2) lies in the Adirondack Mountain region which has received some of the highest levels of acid deposition in the United States over the past half century. The lake has a surface area of 312 ha, sits at an elevation of 701 m, and has a watershed with soils and underlying geology that impart a naturally low acid-buffering capacity, resulting in high vulnerability to acidification. Consequently, by 1960 the surface pH of Honnedaga Lake dropped below 5 and the native brook trout population, now regarded as one of the extant heritage strains in New York State, persisted only in a few well-buffered tributaries (Josephson et al., 2014). Following implementation of the CAAA, however, lake water chemistry is improving, and adult brook trout are slowly recolonizing the lake. Despite these positive developments, most tributaries to the lake remain chronically or episodically acidified, which is believed to limit the degree of biological recovery.

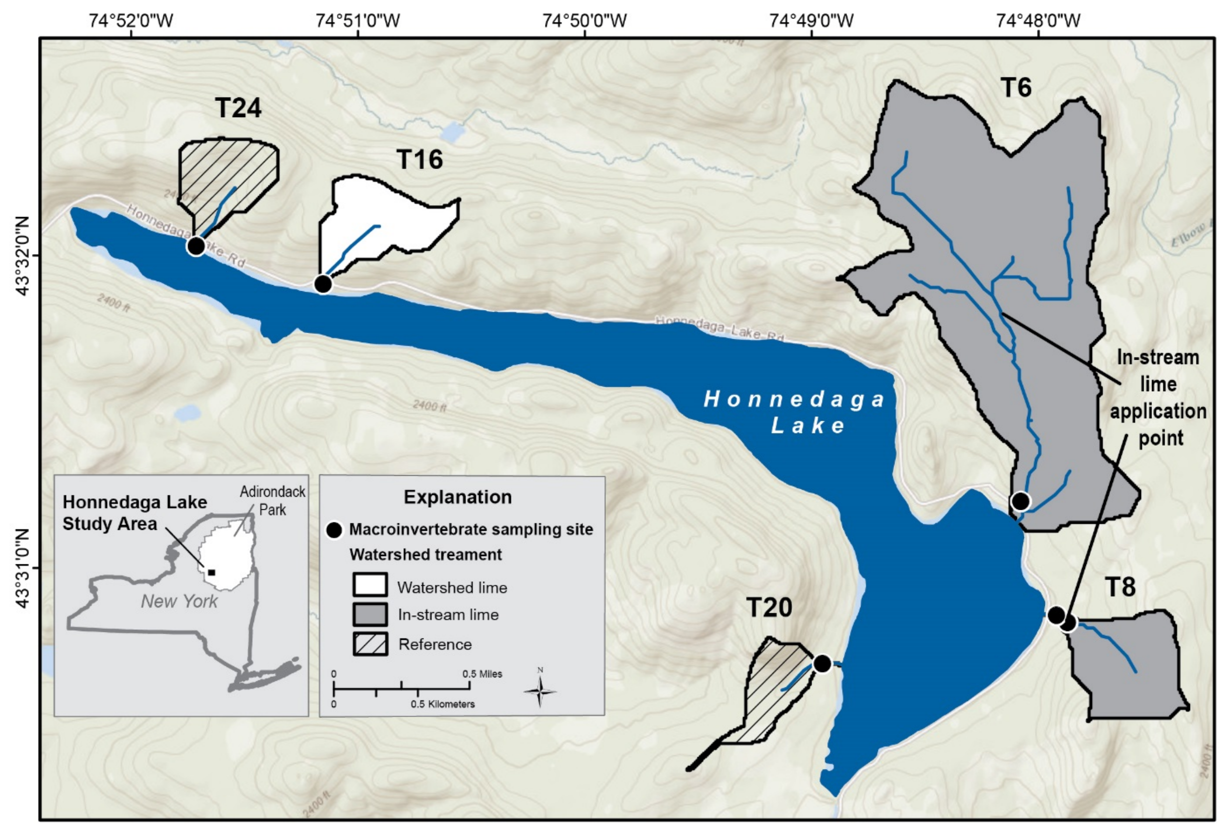
Three tributaries with varying degrees of acidification were selected for liming. Each was considered to have the potential to support brook trout recruitment in the presence of improved water quality. A 30-ha watershed drained by the chronically acidic tributary stream T16 received a single dose of 136 Mg of pelletized limestone evenly distributed (1.4 Mg Ca ha^{-1}) by helicopter application on October 1–3, 2013. The in-stream liming was applied as annual doses of pelletized limestone to the episodically acidic tributary stream T8 from 2012 to 2015 and the chronically acidic tributary stream T6 from 2012 to 2016 following the doses and schedule listed in Table 1.

Macroinvertebrate communities were monitored at six study sites within five streams: T16, T8A (50 m upstream of lime application point), T8 (50 m downstream of lime application point), T6 (1200 m downstream of the lime application point), and at two unlimed reference streams, T24 and T20 (Table 1, Figure 2). Sampling was performed annually at each site from 2013 to 2016 using artificial substrate baskets samplers (Figure 3). Ten rectangular baskets filled with gravel were deployed at each site in pairs for a total of five replicates per site. After a colonization period of two months, organisms were extracted from the baskets and a randomly selected 200-organism subsample was identified to the lowest possible taxonomic resolution (usually genus or species). These data were analyzed using the following metrics of macroinvertebrate community condition: taxa richness (number of different taxa in the sample), total macroinvertebrate density, and the acid biological assessment profile (acidBAP). The acidBAP is a multimetric index of acidification impacts that ranges from 0 (severe effects from acidification) to 10 (no effects from acidification) (Baldigo et al., 2009; Burns et al., 2008).

Stream-water samples were collected for chemical analysis at or near all six macroinvertebrate sites (and from one additional site T6A located upstream of the T6 lime application point) one or more times during most months from 2012 to 2016. These samples were analyzed for pH, inorganic aluminum (Al_i), and base-cation surplus (BCS). Inorganic aluminum is a form of Al that is mobilized under low pH conditions and causes toxicity to aquatic biota at values greater than 2 µmol/L (Baldigo et al., 2007; Driscoll et al., 2001). The BCS is a chemical index of acidity similar to acid-neutralizing capacity but relates more closely to the mobilization of Al_i in the soil. Values of BCS greater than zero indicate that the watershed buffering of acidic deposition is sufficient to prevent the toxic forms of Al from entering surface waters, whereas BCS values less than zero indicate Al_i mobilization and show a strong negative correlation with Al_i concentrations in surface waters (Lawrence et al., 2007).

Figure 2. Map of Honnedaga Lake

Tributaries where macroinvertebrates communities were sampled each summer from 2013 to 2016 to evaluate the effects of two liming techniques.



Base from ESRI World Topographic Map; NAD 1983 UTM Zone18N
Stream network from USGS StreamStats 2017

Table 1. Liming information for Honnedaga Lake tributaries

Liming information for six sites where macroinvertebrate communities were sampled in 2013-2016.

Site ID	Site Type	Liming date(s)	Lime Dose (Mg)	Ca Addition (Mg)	Stream Watershed Area (km2)
T16	Treatment, watershed	10/1-3/13	136	1.4 a	0.30
T24	Reference	-	-	-	0.25
T8A	Reference	-	-	-	-
T8	Treatment, in-stream	7/12/12, 6/19/13, 3/5/14, 6/16/15	4.5	1.38	0.37
T6	Treatment, in-stream	7/12/12, 6/19/13, 2/28/14, 6/16/15, 6/21/16	10.0	3.04	2.48
T20	Reference	-	-	-	0.18

[a] Ca dose for watershed T16 is listed as Mg Ca ha^{-1}

Figure 3. Artificial substrate basket samplers

A pair of artificial basket samplers in a tributary to Honnedaga Lake at the time of initial deployment.

Source photo credit Scott George.

5 Project Findings

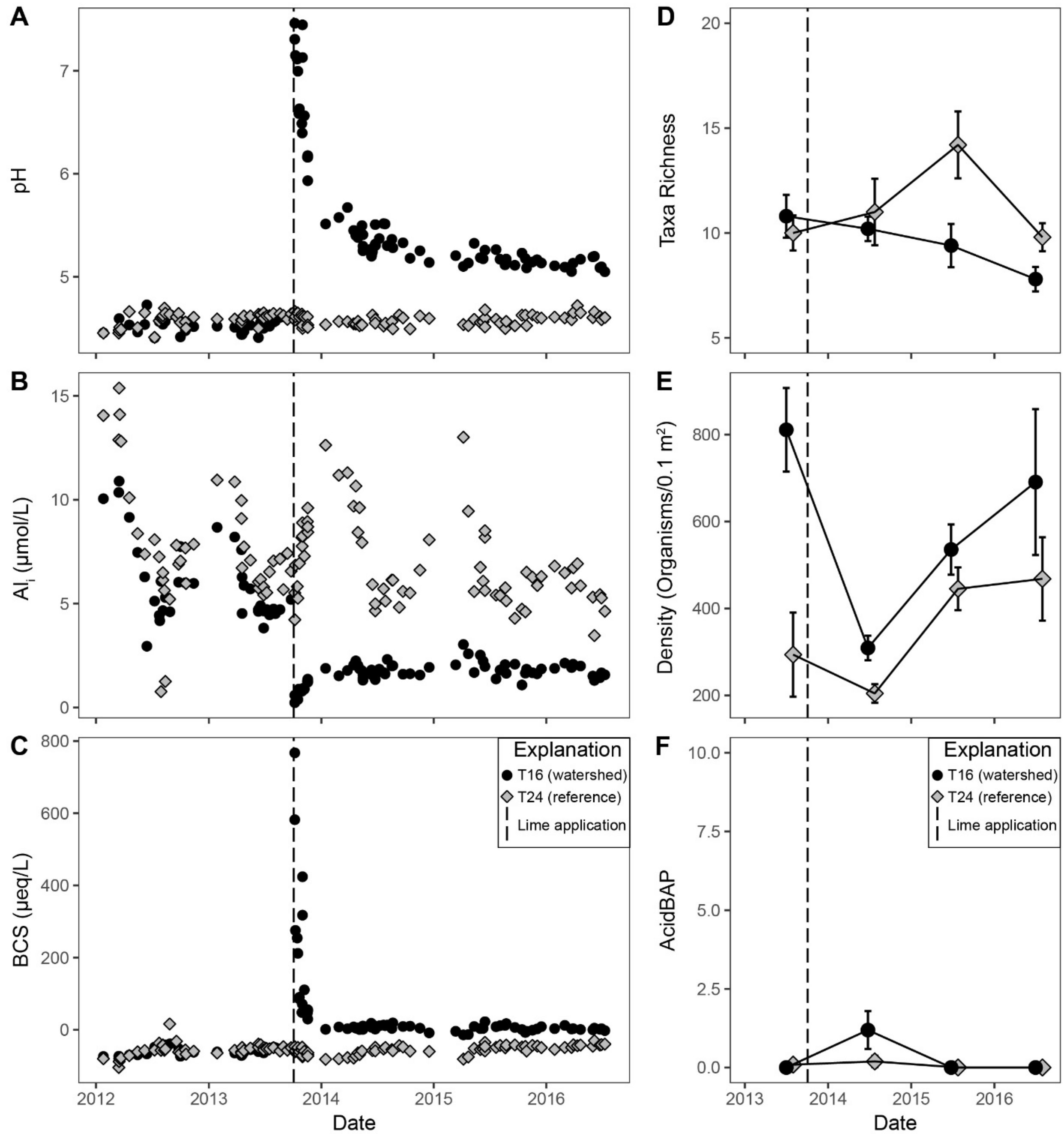
5.1 Watershed Liming

The effects of the watershed liming of T16 were determined by comparing water quality and macroinvertebrate communities with that from a comparable reference stream, T24, one year prior and three years after the lime application. The lime application to the T16 watershed had an immediate and marked effect on stream water chemistry. Prior to the lime application, pH was consistently less than 5, BCS less than -35 µeq/L, and Al_i concentrations greater than 4 µmol/L (Figure 4), all values that reflect harmful water chemistry for aquatic biota (Lawrence et al., 2008). The lime application caused a spike in pH and BCS, and a decrease in Al_i, but each parameter moderated quickly, and a relatively stable water chemistry regime ensued from 2014 to 2016 characterized by mean pH 5.3 (range 5.0 — 5.7), BCS 5.7 µeq/L (range -13.9 — 22.6 µeq/L), and Al_i concentration 1.8 µmol/L (range 1.1 — 3.0 µmol/L). In contrast, the reference stream T24 exhibited wide seasonal fluctuations in Al_i concentrations ranging from 0.8 – 15.4 µmol/L and water chemistry was generally at levels toxic to aquatic biota throughout the study.

Macroinvertebrate communities at T16 were found to be altered during the first sampling after the watershed lime application (2014) but generally reverted to their pre-limed condition by 2015–2016. Mean taxa richness at T16 declined gradually in each year following the lime application but was generally similar to that of T24 in most years (Figure 4D). Mean total macroinvertebrate density at T16 declined by 62% in the first year following the treatment but recovered steadily to near pre-treatment levels by 2016 (Figure 4E). These changes in density were driven largely by a crash (and subsequent recovery) of the acid-tolerant *Leuctra* stoneflies in 2014 following the treatment. The mean acidBAP score increased from 0 to 1.2 following the treatment but returned to 0 in 2015 and 2016 (Figure 4F), suggesting a small and unsustained increase in the proportion of sensitive taxa shortly after treatment.

Figure 4. Watershed liming effects

On treatment stream T16 compared to reference stream T24: Stream pH (A), Al_i (B), and BCS (C) concentrations of water samples collected from 2012 to 2016 and estimates of mean (± 1 standard error) taxa richness (D), total macroinvertebrate density (E), and acidBAP score (F) for macroinvertebrate samples collected from the reference stream (T24) and treatment stream (T16) during summer 2013-2016 in relation to watershed liming.



5.2 In-stream Liming

The in-stream liming at T8 and T6 generally increased pH and BCS and decreased Al_i concentrations following each annual application. The effects of the in-stream liming at T8 were determined by comparing water quality and macroinvertebrate communities with those of the unlimed reference site T8A over four years. Prior to the first lime application at T8, mean pH, BCS and Al_i were 5.6 (range 4.8 — 6.3), 20.5 µeq/L (range -32.1 — 109.5 µeq/L) and 1.7 µmol/L (range 0.6 — 5.7 µmol/L), respectively. In the first two to three months following each lime application at T8, pH and BCS spiked briefly and then moderated (Figure 5). The post-liming water chemistry regime at T8 was characterized by mean pH 6.9 (range 5.3 — 7.8), BCS 345.7 µeq/L (range -8.2 — 1661.5 µeq/L), and Al_i 1.0 µmol/L (range 0 — 3.2 µmol/L). In contrast, the reference site T8A exhibited lower pH and BCS and episodes of elevated Al_i concentrations peaking at 4.5 µmol/L during the same period (Figure 5).

The effects of the in-stream liming on water chemistry at T6 were assessed through a comparison between T6 and two reference sites, T6A and T20, whereas the macroinvertebrate response at T6 was assessed through a comparison with the reference site T20. Overall, the annual lime applications at T6 raised pH and BCS and decreased Al_i concentrations relative to the upstream chemistry reference site T6A (Figure 6). Prior to the first lime application at T6, mean pH, BCS and Al_i were 5.1 (range 4.7 — 5.4), -12.4 µeq/L (range -45.6 — 17.1 µeq/L), and 1.9 µmol/L (range 1.2 — 4.6 µmol/L), respectively (Figure 6). After the initiation of liming, the water chemistry regime at T6 was characterized by mean pH 6.1 (range 5.0 — 7.2), BCS 83.2 µeq/L (range -17.0 — 563.5 µeq/L), and Al_i 0.9 µmol/L (range 0.2 — 2.9 µmol/L). Not surprisingly, water chemistry at the reference sites T6A and T20 exhibited little or no change during the study period and Al_i concentrations peaked at 5.4 and 4.5 µmol/L, respectively (Figure 6).

The in-stream lime applications at T8 and T6 did not cause a widespread recovery of sensitive taxa and appeared to reduce the total abundance of macroinvertebrates. Mean taxa richness (Figure 5D) at the treatment site T8 ranged from 11.8 to 13.2 taxa and was always lower than the reference site T8A, which ranged from 14.4 to 17.8 taxa. Mean total macroinvertebrate density (Figure 5E) at T8 ranged from 100.1 to 235.6 organisms/0.1 m^2 and was always lower than T8A, which ranged from 437.0 to 886.0 organisms/0.1 m^2. Statistical analysis indicated this difference in density between the treatment and reference site was highly significant. The mean acidBAP score (Figure 5F) at T8 ranged from 2.6 to 3.7 compared to 1.9 to 4.1 at T8A and was generally similar between the two sites each year. Richness (Figure 6D) was similar between T6 and the reference site T20 during three of the four years, whereas the total density of macroinvertebrates (Figure 6E) was markedly lower at T6 during all four years. The mean acidBAP score, (Figure 6F) at T6 increased in each subsequent year, was greater than the reference site during the latter three years, and produced the highest value observed at any site in the entire study in the 2016 sample.

Figure 5. In-stream liming effects on treatment site T8 compared to reference site T8A

Stream pH (A), Al_i (B), and BCS (C) concentrations of water samples collected from 2012 to 2016 and estimates of mean (± 1 standard error) taxa richness (D), total macroinvertebrate density (E), and acidBAP score (F) for macroinvertebrate samples collected from the reference site (T8A) and treatment site (T8) during summer 2013-2016 in relation to four in-stream liming events.

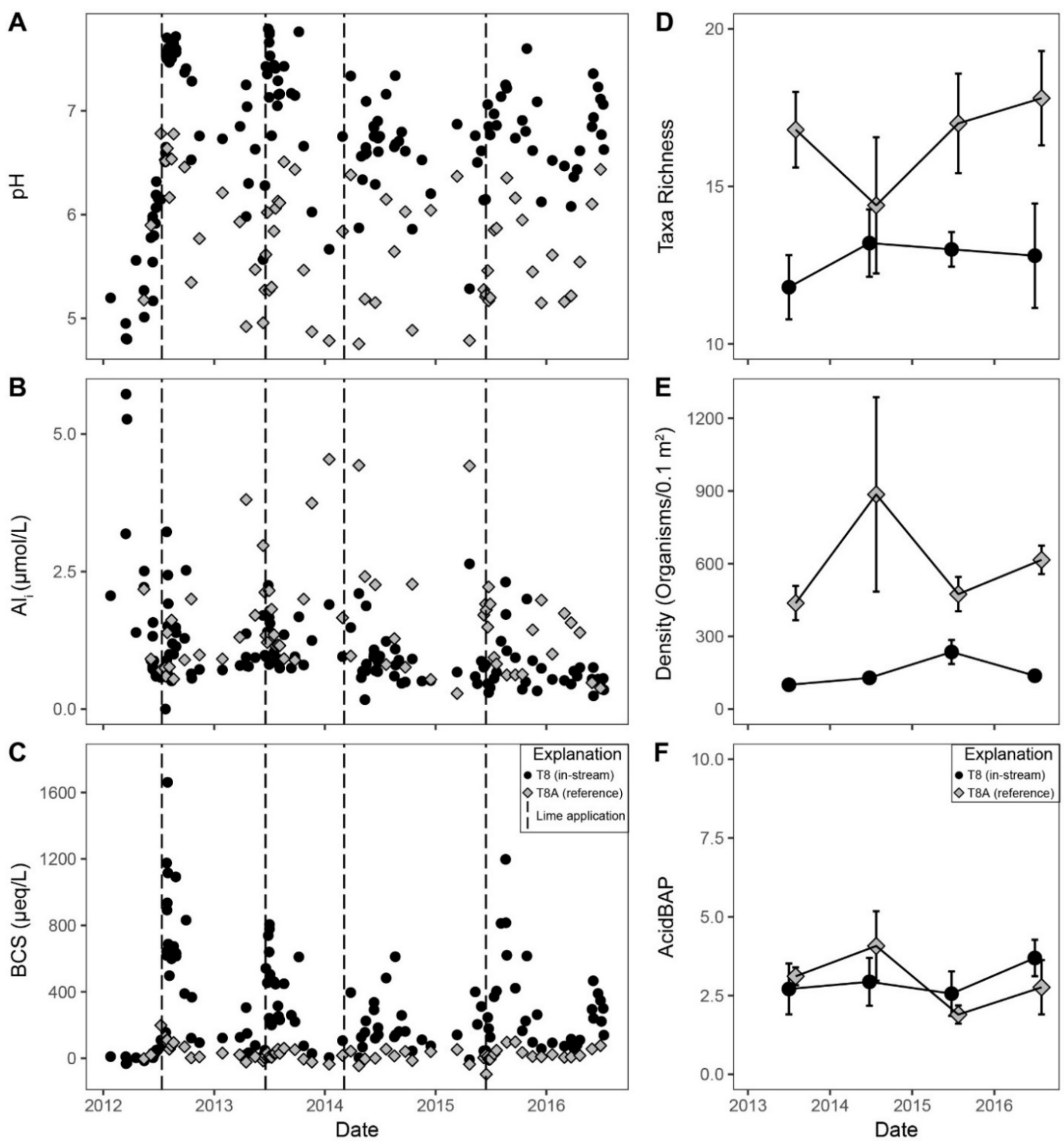
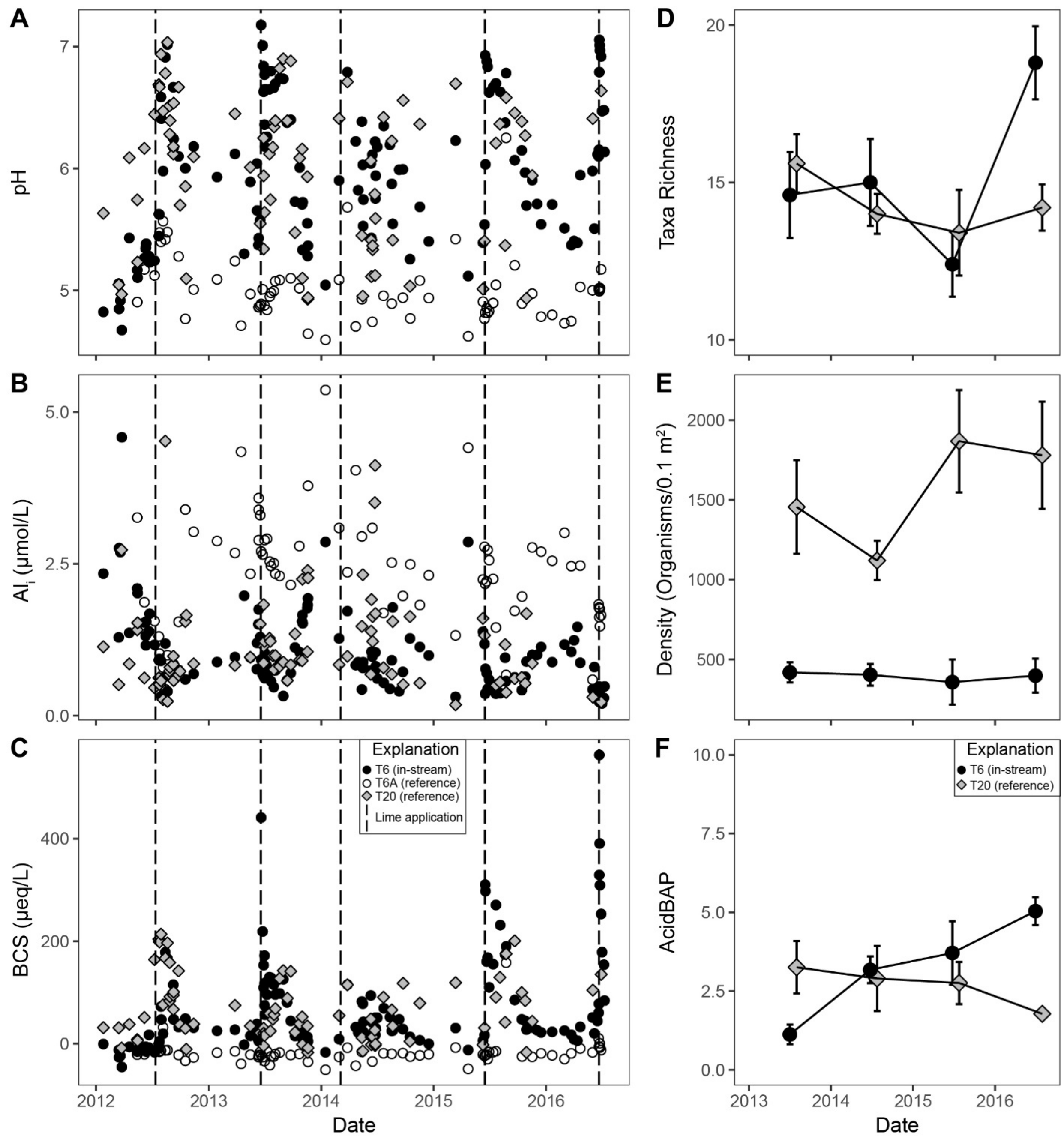


Figure 6. In-stream liming effects on treatment site T6 compared to reference site T20

Stream pH (A), Al_i (B), and BCS (C) concentrations of water samples collected from 2012 to 2016, and estimates of mean (± 1 standard error) taxa richness (D), total macroinvertebrate density (E), and acidBAP score (F) for macroinvertebrate samples collected from the reference stream (T20) and treatment stream (T6) during summer 2013-2016 in relation to five in-stream liming events.



5.3 Study Implications

Since the deposition of strong inorganic acids and resulting mobilization of Al_i was the primary agent for the impairment of aquatic biota in the study streams, it follows that a liming program that suppresses or eliminates acidification stress could accelerate the recovery of macroinvertebrate communities toward their pre-acidification condition. The water chemistry parameters monitored in this study indicate that liming improved water quality at all three treated streams, and therefore, succeeded in accelerating chemical recovery. Despite these improvements in water chemistry, results indicated that neither liming technique succeeded in promoting biological recovery by improving the condition of macroinvertebrate communities. Macroinvertebrate communities at all treatment and reference sites were dominated by acid-tolerant taxa and lime applications appeared to reduce the total density of organisms present.

The neutral or negative response of macroinvertebrate communities to in-stream liming observed in this study is not entirely unexpected. There are several mechanisms through which the in-stream point application of lime can negatively affect macroinvertebrate communities. For example, the deposition of undissolved lime on the stream bed can coat natural substrates and fill interstitial spaces, thereby reducing the quality of habitat available to macroinvertebrates (Fjellheim and Raddum, 1995; Keener and Sharpe, 2005). Field observations suggest natural substrates were effectively buried by lime at the T8 site, which was located approximately 50 m downstream of the application point. Second, in-stream liming can create a toxic mixing zone immediately downstream of the application point, which may adversely affect aquatic biota (Teien et al., 2004). Finally, the repeated application of lime causes large fluctuations in water chemistry immediately following each annual application which may stress acid-tolerant taxa.

It was hypothesized that watershed liming would be a more effective technique for restoring acid-impacted macroinvertebrate communities because it avoids many of the negative attributes of in-stream liming previously discussed. This hypothesis, however, was not supported by the macroinvertebrate data collected in this study, which showed an initially negative, but overall neutral, response to the watershed liming at T16. The initial negative response may be explained by the immediate chemistry shock from the lime application, which caused stream pH to increase by approximately three units (a 1000-fold decrease in H^+ concentration). Once water chemistry at T16 stabilized after the treatment, the post-liming water chemistry regime, although greatly improved, may still have been inadequate to support many acid-sensitive taxa. This new regime was characterized by mean Al_i concentrations less than 2 µmol/L but pH of only 5.3, well below most guidelines for the protection of aquatic biota. Furthermore, individual Al_i values ranged as high as 3.0 µmol/L, exceeding the 2 µmol/L-threshold commonly identified for toxicity to aquatic biota. Therefore, the persistence of toxic episodes at T16 may be partly or fully responsible for the lack of a detectable recovery of macroinvertebrate communities. Finally, although water chemistry stabilized in less than one year, a period beyond three years may be needed for the macroinvertebrate community to adjust to the new, less acidic chemical environment and for recovery to become evident. For example, the widespread acidic conditions of the Honnedaga Lake watershed may slow the recolonization of acid-sensitive species because few nearby source populations remain.

The findings from this investigation have important implications for the management and restoration of acidified ecosystems and provide direction for future research. Most notably, attempts to restore more natural or “pre-acidification” macroinvertebrate communities using either liming technique may be ineffective, at least over the short term. The results from this study and others (Clayton and Menendez, 1996) suggest in-stream liming often fails to restore macroinvertebrate communities to an unimpaired condition, especially within the vicinity of the lime application point. The deposition of undissolved lime and (or) establishment of toxic mixing chemistry appeared to strongly depress macroinvertebrate communities at the T8 site located 50 m downstream of the lime application point. Most studies of in-stream liming that identified positive effects on macroinvertebrate communities were conducted on large scales and found positive effects only at distances greater than 1.5 km downstream from the application point (Keener and Sharpe, 2005). Therefore, applying lime to long tributaries at points well upstream of the area in which positive effects are desired may be the best strategy for improving the condition of acid-impacted macroinvertebrate communities using in-stream liming. This study also failed to detect a recovery of macroinvertebrate communities during a three-year period following watershed liming. However, this study represents one of the few (Bradley and Ormerod, 2002) to evaluate the effects of watershed liming on lotic macroinvertebrate communities. The improved and stable water chemistry regime produced by the watershed treatment, relative to that produced by in-stream liming, suggests that this method should have the potential to accelerate the recovery of acid-impacted macroinvertebrate communities. Additional long-term studies, however, are needed to fully evaluate the effectiveness of this restoration technique.

6 Conclusions

In-stream and watershed liming accelerated chemical recovery in all three limed streams, but results generally suggest neither liming technique succeeded in accelerating biological recovery. At least during the four-year study period, liming did not improve the condition of macroinvertebrate communities. In fact, some evidence suggests liming may have adversely affected macroinvertebrate communities in one or more of the study streams. Changes in physical habitat and unstable water chemistry from the in-stream liming, and the persistence of acidic episodes in all three streams, are the most likely reasons for the lack of biological recovery.

These findings have value to natural resource managers who may wish to either understand the effects that liming programs aimed at restoring sportfish populations have on other biological assemblages, or apply lime strategically to accelerate the recovery of communities or entire ecosystems. Applying lime at points well upstream of the area in which positive effects are desired may be the best usage of in-stream liming. Furthermore, in-stream application strategies that minimize deposition and disruption of physical habitat may be more likely to benefit aquatic biota. More generally, the inability of either liming technique to improve the condition of macroinvertebrate communities may be partly explained by the persistence of acidic episodes in all three streams. Therefore, to be effective, liming programs should attempt to eliminate even temporary episodes of unsuitable water chemistry rather than just meeting minimal criteria the majority of the time.

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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