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Impacts of Lime Treatment on Trout Ponds in the Five Ponds Wilderness of the Adirondack Park

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"Impacts of Lime Treatment on Trout Ponds in the Five Ponds Wilderness of the Adirondack Park"

by

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Abstract:

Addition of calcium carbonate ($CaCO_3$) to lakes in the form of agricultural limestone is a management technique used in the Adirondack Park in New York State to mitigate the effects of acidic precipitation on aquatic ecosystems. We used a combination of in situ and laboratory experiments as well as field sampling of two neighboring ponds in the Five Ponds Wilderness with different liming histories to test whether the application of limestone can have significant effects on survivorship and community composition of aquatic organisms. Within *in situ* mesocosms or laboratory microcosms survivorship was decreased for crustacean zooplankton, amphipods and odonata nymphs at concentrations of one ton per surface acre of lime and higher; the New York State Department of Environmental Conservation (NYSDEC) applies lime at one ton per surface acre. Tamarack Pond has been managed by lime addition and brook trout stocking and the aquatic insect community is significantly different than that of Slender Pond, which has never been limed or stocked, even though the two ponds share a water source. This difference may be attributable to predation impacts of fish on aquatic insects, making the link between liming and insect faunal compositions difficult to determine. This study suggests the short term impacts of lime treatment on biota may affect the biotic community of aquatic ecosystems on a longer time scale, and may need to be considered before a liming program is started. Including the volume of a body of water to be limed when determining lime additions would be an inexpensive way to limit the impact that treatment would have on the aquatic ecosystems of the Adirondack Park.

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Introduction:

Acidic deposition resulting from anthropogenic emissions of SO_x and NO_x has been and continues to be a major ecological stressor in the Adirondack Park of New York State and other susceptible regions around the world (Cogbill 1976, Schofield 1976, Likens and Butler 1981, Muniz 1984, Miskimmim et al. 1995, Ormerod and Durance 2009, Angeler and Goedkoop 2010). Acidification of aquatic ecosystems has been shown to simplify food webs, so that they are dominated by a few acid tolerant species (Simpson 1983, Simpson et al. 1985), as well as cause declines in fish populations, or even extinctions linked with mortality during sensitive life stages (Schofield 1976). There is a widespread interest in these effects because of the impacts on recreational fisheries.

In the Adirondack Park brook trout (*Salvelinus fontinalis*) is a major target species for recreational fishermen that is negatively impacted by the effects of acid rain. Precipitation falling on this region has a low pH, generally in the range of 4.0-4.3 (Likens et al. 1996). This is well below the pH level of 5.6 which is the point where aquatic ecosystems are considered strongly acidic (Hornstrom, 2002). Acid deposition in areas of bedrock with an associated low acid neutralizing capacity (ANC) has been shown to cause the extinction of common recreational fish species such as brook trout (*S. fontinalis*), lake trout (*S. namaycush*) and brown bullhead (*Ictalurus nebulosis*) (Schofield, 1976).This makes their preservation, as well as that of other game fish species, a major objective of agencies such as the New York State Department of Environmental Conservation (NYSDEC).

In an attempt to restore acidified bodies of water to a more neutral pH, therefore making conditions more suitable for aquatic organisms, the NYSDEC uses addition of a base as a management technique. Agricultural lime, which contains calcium carbonate ($CaCO_3$), is applied to the target lakes at one ton per surface acre (Dr. Chris vanMaaren pers. comm.). This form of management is common around the world where acid precipitation is prevalent, and its application is associated with an increase in pH and ANC (Yan et al. 1996, Ormerod and Durance 2009, Angeler and Goedkoop 2010). Despite these positive results, the biological communities of limed lakes, compared to those found in circumneutral bodies of water, have shown marked changes that may be attributable to the necessity of repeated application of the base, constituting a pulsed ecosystem level disturbance (Ormerod and Durance, 2009). It has been noted that even when a liming program is able to achieve conditions similar to those of a neutral ecosystem in a similar region, the faunal communities are not the same (Appleberg et al. 1995).

Chemical changes to surface waters when $CaCO_3$ is applied are rapid, with circumneutral pH being achieved in only days or weeks (Weatherly, 1988). These changes have been associated with initial decreases in phytoplankton (Weatherly, 1988), zooplankton (Dillon et al. 1977, Yan et al. 1996) and benthic invertebrates (Scheider and Dillon 1976). Decreases in these populations might suggest difficulties in successful reestablishment of viable populations, depending upon colonization rates. The goal of this study is to determine the extent of short term impacts of lime treatment in the Five Ponds Wilderness of the Adirondack Park. Specifically the following hypotheses will be tested:

(1) Biological communities of a historically limed and stocked pond in the Five Ponds Wilderness will differ significantly in community structure and diversity when

compared with a similar pond that has never been limed or stocked.

(2) Changes in the pH and conductivity of pond water treated with lime will be rapid in this region due to a low ANC of the ecosystem.

(3) Survivorship of zooplankton, invertebrates and fish will be decreased with the addition of lime to artificial mesocosms at varying concentration, with decreased survivorship associated with higher lime concentrations.

Study Site:

This study was performed in the Five Ponds Wilderness within the Adirondack Park of New York State at yhe State University of New York College of Environmental Science and Forestry (SUNY ESF) Cranberry Lake Biological Station (CLBS) at Barber Point. The station served as a base of operations and housed the lab where water properties analyses and survivorship experiments on plankton were carried out.

The Five Ponds Wilderness is a designated wilderness area by the NYSDEC, containing over 40,000 hectares of undeveloped forest between Cranberry Lake and Stillwater Reservoir NY. There are many bodies of water in this area, many of which harbor populations of brook trout (*Salvelinusfontinalis*), a popular game fish species. Application of lime to remediate these trout waters has been undertaken based on water chemistry analyses, as well as the yearly stocking of native strains of fish to replenish populations affected by low pH associated with acidic precipitation. Darning Needle Pond is located 5 kilometers to the south of the CLBS and has been stocked by the NYSDEC with four hundred 9 cm brook trout every year until 2010 (http://www.dec.ny.gov/outdoor/23227.html). This site served as the location for the survivorship study because this pond has never been limed by the NYSDEC and it contains fish (C vanMaaren, pers. comm.). The mesocosms were set up on the deeper southern end of the pond in approximately 1.5 to 2 meters of water, which varied throughout the ten week study due to precipitation events and beaver activity.

The second field site was located approximately 10 kilometers SSW of CLBS at Tamarack and Slender Ponds. These ponds sit on top of the watershed and are both fed from the same spruce wetland, draining in opposite directions. Both were affected heavily by a microburst event in 1995 where high winds blew down nearly every tree around the ponds and both have a beaver presence with dams in the outflows, which hold more water than otherwise would be retained within the basins. The main difference between the two ponds is that Tamarack Pond has historically been limed by the NYSDEC in 1978, 1990 and 2006 (C vanMaaren, pers. comm.) and stocked with brook trout annually until 2010 (http://www.dec.ny.gov/outdoor/23227.html) while Slender has never been limed and never contained brook trout. Slender Pond is smaller in surface area (5.2 ha) and volume (161000 m^3) than Tamarack Pond (surface area of 6.8 ha, volume of 252000m^3), but has a greater max depth at 13.7 meters compared to Tamarack's 9.4 meters and faster flushing rate at one year compared to Tamarack's one and a half years (adirondacklakessurvey.org).

Materials and Methods:

The first part of the study consisted of a community comparison between a limed and stocked pond (Tamarack) and a pond which has never been limed or stocked (Slender). Two hundred aquatic insects were collected from each pond and identified to genus. Comparisons were made utilizing a Sorenson's Community Comparison, Simpson's Diversity Index and an assessment of feeding group abundance. Six minnow traps were set in each of the ponds for 16 hours to compare the fish communities. Measurements of pH and conductivity were also made for comparison.

The second part of this study was an experiment that tested the effects of adding agricultural lime at an equivalent of 1 ton per surface acre to increasing volumes of water. Water collected from Darning Needle Pond was placed into three 5 gallon buckets, the first containing 5,000mL, the second containing 10,000mL and the third containing 20,000mL. The lime was added to each and the combination was stirred once, then pH and salinity/conductivity data was recorded using a YSI multiprobe, starting before lime was added until 50 hours after the addition.

Darning Needle Pond acted as a field site for the final portion of this study, consisting of survivorship tests to determine if organisms at different trophic levels were impacted by the application of lime. Eighteen homemade enclosures were constructed according to designs by Amy Galford in the The American Biology Teacher (2000), and staked into the muddy substrate of the pond. Northern redbelly dace, amphipods and anisopteran Odonata nymphs were collected directly from Darning Needle Pond. Three 95 liter mesocosms were filled with 10 northern redbelly dace at each concentration of lime, ranging from the control of no lime added, to equivalents of ½ ton per surface acre, 1 ton per surface acre and 2 tons per surface acre. Four 10 liter mesocosms were filled with 20 Anisopteran Odonata nymphs each and the same lime concentrations were applied. Finally four 2 liter mesocosms were filled with 30 amphipods each and lime applied at the same concentrations as the dace and Odonata tests. Each mesocosm was monitored daily and data was recorded on the number of organisms dead and alive in each, as well as pH levels, for ten days. New organisms were collected and placed in the mesocosms between each treatment. This data was analyzed using an ANOVA and Tukey's test to determine if a significant change in survivorship occurred among treatments.

The survivorship experiment for plankton was carried out in the lab and required some special considerations. A sample of plankton was collected from Darning Needle Pond and divided into three groups, of three five gallon buckets by taking random 100mL subsamples of organisms and water from the original sample. The 5 gallon buckets contained 5 liters of pond water each and lime was added at equivalents of ½ ton per surface acre and 2 tons per surface acre with a control of no lime added. Data was collected on the proportion of surviving plankton every three days by taking subsamples of 100mL in the same way that the original plankton were taken from the pond sample. These subsamples were preserved in 70% ethanol and data on the surviving proportion was calculated using rose bengal dye. The dye identifies any organism that was alive upon preservation by turning them pink. An ANOVA test was used to find any significant differences between treatments.

Results:

Community Comparison:

The most obvious difference between Slender Pond and Tamarack Pond is that there is no fish population in Slender, while there is abundant fish in Tamarack (Table 1). The Adirondack Lakes Survey Corporation found similar results in 1987 when they carried out a survey of these two bodies of water.

Table 1: Fish species collected in Tamarack and Slender Ponds.

Tamarack Pond	Number Collected	Slender Pond
brook trout (*Salvelinusfontinalis*)	7	No fish collected
northern redbelly dace (*Phoxinuseos*)	1210	
Pumpkinseed (*Lepomisgibbosus*)	28	

The aquatic insect communities also showed marked differences between the two ponds. A Sorenson's Community Comparison showed that the two ecosystems are only 43.9% similar in their insect communities. Despite this both ponds were actually quite diverse, Tamarack being less diverse at a Simpson's Diversity Index value of 0.79, compared to Slender Pond which had a Simpson's Diversity Index value of 0.85. Despite the high diversity index value, the aquatic insect community of Tamarack Pond appeared to have lower abundance (it took a greater amount of time to collect 200 organisms) and it was dominated by a few functional groups, with a higher diversity of Odonate predators compared to Slender Pond (Table 2).

Table 2: Aquatic insects collected in Tamarack and Slender Ponds.

Tamarack Pond	Number Collected	**Slender Pond**	Number Collected
Ephemeroptera			
Leptophlebiidae *Leptophlebia*	88	Leptophlebiidae Leptophlebia	61
Odonata			
Coenagrionidae *Enellagma*	9		
Gomphidae *Gomphus*	5		
Aeshnidae *Aeshna*	15	Aeshnidae *Aeshna*	4
Aeshnidae *Basiaeshna*	2		
Libellulidae *Libellula*	18	Libellulidae *Libellula*	3
Libellulidae *Leucorrhinia*	3		
Libellulidae *Ladona*	8	Libellulidae *Ladona*	2
Libellulidae *Sympetrum*	1		
Corduliidae *Dorocordulia*	3		
Corduliidae *Cordulia*	9	Corduliidae *Cordulia*	3
		Coenagrionidae *Chromagrion*	1
		Coenagrionidae *Nehalennia*	3
		Corduliidae *Somatochlora*	1
		Lestidae *Lestes*	38
		Aeshnidae Anax	1
Coleoptera			
		Dytiscidae *Graphodorus*	2
		Dytiscidae *Hydroporous*	4
		Gyrinidae *Gyrinus*	28
Hemiptera			
Nepidae *Ranatra*	2	Nepidae *Ranatra*	1
		Corixidae *Hesperocorixa*	20
		Notonectidae *Notonecta*	11
Trichoptera			
Limnephilidae *Limnephilus*	27	Limnephilidae *Limnephilus*	11
Phryganeidae *Banksiola*	2	Phryganeidae *Banksiola*	6
Phryganeidae *Ptilostomis*	1		
Phryganeidae *Fabria*	6		
		Limnephilidae *Nemotaulius*	1
Diptera			
Chironomidae *Chironomous*	3	Chironomidae *Chironomous*	3
Tanypodinae *Procladius*	6	Tanypodinae *Procladius*	4
		Tabanidae *Merycomyia*	1
Megaloptera			
Sialdidae *Sialis*	2		

Water Properties Experiment:

Equivalents of one ton per surface acre of lime added to varying volumes of water from Darning Needle Pond demonstrated how pH increased depending on the amount of water in each bucket (Figure 1). The greatest and most rapid increase in pH was observed in the container where one ton per surface acre of lime was added to 5000ml of water. A similar trend was seen when conductivity was measured with nearly double the value observed in 5000ml of pond water compared to the 20,000ml of pond water (Figure 2).

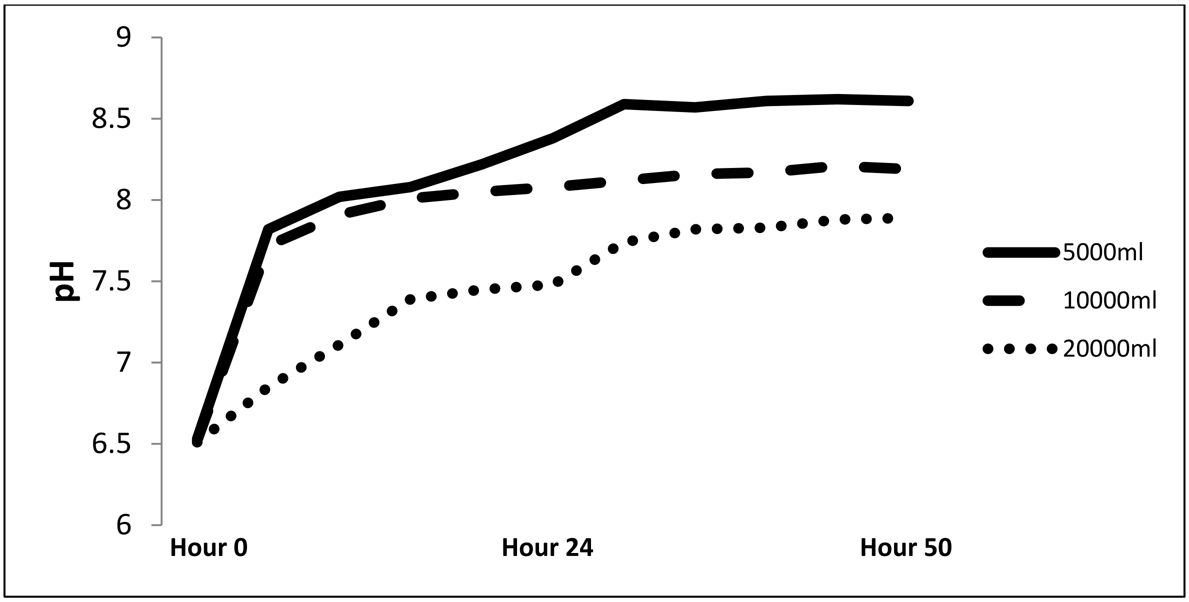

Figure 1: pH change in varying volumes of water collected from Darning Needle Pond with additions equivalent to one ton per surface acre of agricultural lime

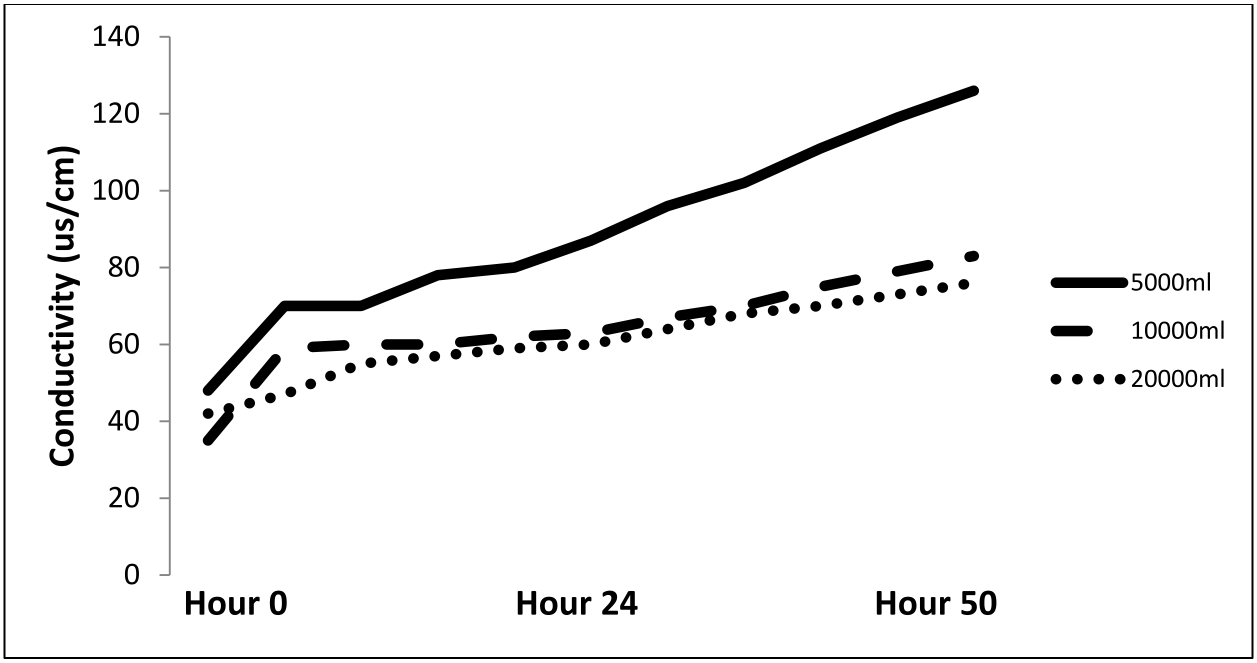

Figure 2: Conductivity change in varying volumes of water collected from Darning Needle Pond with additions equivalent to one ton per surface acre of agricultural lime

Survivorship Experiment:

Survivorship of zooplankton decreased with lime application (Figure 3). A two proportions z-test was used with a critical value of -1.645 (alpha of 0.05) to analyze significance of changes in survivorship. On day 3 the half ton treatment did not exhibit a significant decrease in survivorship compared to the control (z-value of 0.156) but there was a significant decrease in survivorship in the two ton treatment compared to the control (z = -2.808). In addition there was a significant decrease in survivorship between the half ton and two ton treatment on day three (z = -2.475). On day 6 both the half ton (z = -2.556) and two ton (z = -4.624) treatments showed decreased survivorship compared to the control, and the two ton treatment had significantly decreased survivorship compared to the half-ton treatment (z = -2.007). On day 9 both the half ton (z = -5.167) and two ton (z = -6.086) treatments had significantly decreased survivorship compared to the control. The half-ton treatment did not have significantly different survivorship than the two ton treatment on day 9 (z = -1.358).

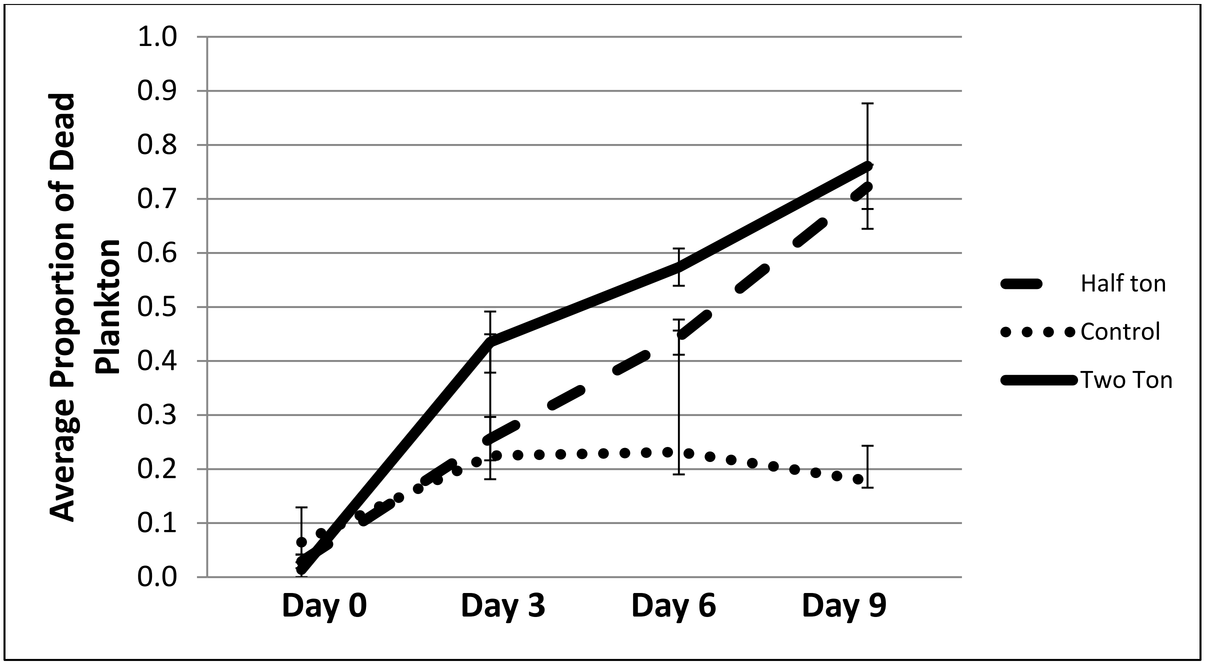

Figure 3: Survivorship of zooplankton under different levels of lime application.

An ANOVA analysis performed on the amphipod data yielded a p-value of 0.000 which is less than the alpha value of 0.050 showing that at least one of the treatment means was significantly different from the control of no lime added. A Tukey's test was performed that showed that there was not a significant difference between the one half ton per surface acre treatment and the control because a zero was present within the confidence interval of (-3.708 , 10.208). The results of the Tukey's test for the one ton treatment (confidence interval (4.292 , 18.208)) and two ton treatment (confidence interval (8.292 , 22.208) versus the control showed a significant difference for both, and because all values in the confidence interval were positive, the mean number of dead

Amphipods in these treatments was significantly greater than the mean number of dead Amphipods in the control. (Figure 4)

A Tukey's test was also used to compare the treatments to one another. The findings of this test were that the half ton treatment had significantly higher survivorship compared to the one ton treatment (confidence interval (1.042 , 14.958)) and the two ton treatment (confidence interval (5.042 , 18.958)). The one ton treatment was found to not be statistically different from the two ton treatment (confidence interval (-2.958 , 10.958)).

Anisopteran Odonata nymphs showed a negative survivorship response to lime treatment. An ANOVA analysis gave a p-value of 0.012 which is less than the alpha value of 0.050 meaning that at least one of the treatment means was significantly different from the control of no lime added. A Tukey's test determined that the mean number of dead nymphs in the one half ton treatment was not significantly different from the mean number of dead nymphs found in the control treatment of no lime added, with a confidence interval of (-0.194 , 8.694). The one ton per surface acre treatment resulted in a significantly higher mean number of dead Odonata nymphs than the control (confidence interval (1.056 , 9.944)). The two ton per surface acre treatment also resulted in a significantly higher mean number of dead Odonata nymphs than the control (confidence interval (0.556 , 9.444)) (Figure 4).

Tukey's test was also used to determine if there was any difference in the mean number of dead nymphs among the three treatments. The confidence interval comparing the first and second treatment was (-3.194 , 5.694), the confidence interval comparing the first and third trials was (-3.694 , 5.194), and the confidence interval comparing the one ton and two tons per surface acre treatment was (-4.944 , 3.944). Because zero is present in all of these confidence intervals there was no significant differences in the mean number of dead nymphs in any of the treatments.

The Northern Redbelly Dace (*Phoxinus eos)* did not show survivorship reaction to any of the lime treatments so no statistical analyses were performed (Figure 4).

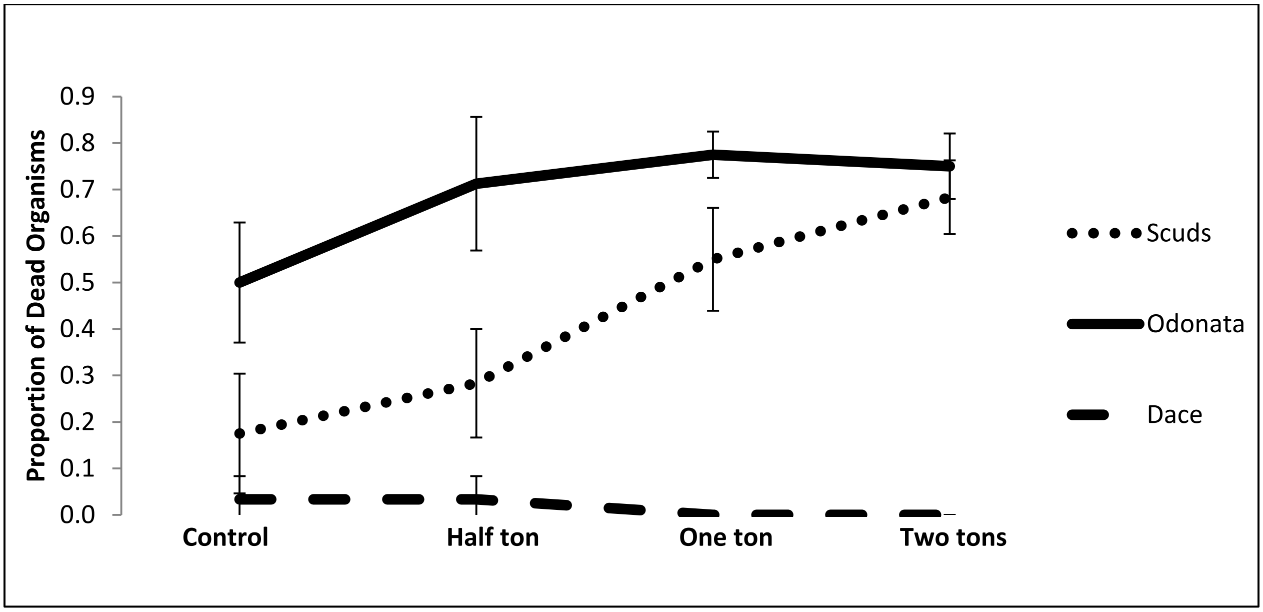

Figure 4: Mortality of organisms with increasing lime concentration after ten days. Control of no lime added, other values are equivalent values per surface acre.

Discussion:

The findings of this study may have important implications for fisheries managers in the Adirondack Park of New York State. Even though the precipitation falling on this region in recent years has increased in pH associated with a decrease in SO_x emissions (Driscoll et al. 2003), it is still acidic. The bedrock composition will continue to provide little buffering capacity as well, meaning that remediation by base addition will continue to be necessary. Based on the experimental results of this study, it would be important to carry out such treatment considering the volume of the water body to be limed, and how the chemistry of that water will change rapidly with the amount of base being added.

It is expected that the pH and conductivity will increase with the addition of agricultural lime to water. The rate at which these conditions change may vary, depending on the base neutralizing capacity of that water (Driscoll, 1985). Each lake to be limed should be considered independently to determine how much a given amount of lime will change the chemistry of a volume of its water. The goal should be to avoid extreme chemistry changes, such as rapid pH increase, over short time spans that might occur when large amounts of lime are added to a relatively small volume of water. Negative effects of pH shock including death of organisms was observed with addition of $Ca(OH)_2$, another form of lime used in acid remediation (Miskimmin et al. 1995). The addition of $CaCO_3$ has been shown less likely to cause such a pH shock (Driscoll et al. 1982, Kretser and Colquhoun 1984), however, changes in pH values from 4.9 to 9.4 and 4.6 to 9.1 following $CaCO_3$ addition to two Adirondack ponds has been observed (Fordham and Driscoll, 1989). Salinity changes have also been shown to cause significant ecological problems for aquatic ecosystems (Hart et al. 1990, Hart et al. 1991, Kefford et al. 2006, Muschal 2006).

It is likely that the decrease in survivorship of all organisms except fish in this study was related to the rapid chemical changes associated with the addition of agricultural lime to the mesocosms. The use of northern redbelly dace in this study was due to our inability to catch young brook trout. Perhaps if juvenile trout or even fry were subject to similar tests they would exhibit a survivorship response. Even though the findings of this study do not show a direct impact on fish, they could be indirectly impacted if the survivorship responses of prey organisms that occurred in the mesocosms occur when lime treatment is undertaken.

All mesocosms were characterized by a rapid increase in pH in the first day, rising from the ambient pH of around 6.5, to a pH of 8 or more. However, the lowest concentration of lime in this study, an equivalent of one half ton per surface acre, added to water containing all types of organisms, did not result in a significantly decreased survivorship. The reason for this finding could be related to the water properties experiment where the greatest volume of water experienced similar pH and salinity changes as the lesser volumes, but at a slower rate. The lower amount of lime results in slower changes and less stress on aquatic organisms. It seems that slow introduction of smaller amounts of lime over time is a desired management practice that limits the impact on populations of aquatic life, although this could significantly increase the cost of liming programs.

Application of $CaCO_3$ has been shown to successfully restore conditions to those of circumneutral lakes (Ormerod and Durance 2009, Nyberg et al. 1986, Eriksson et al. 1983, Larsen and Hesthagen 1995). However, these conditions are not always associated with the return of original biota (Weatherly, 1988). This problem is often due to re-acidification events, and the need to apply lime repeatedly, constituting a pulsed ecosystem level disturbance that alters the community structure (Ormerod and Durance 2009, Angeler and Goedkoop 2010). Yan et al. described the changes of one zooplankton community where the *Bosmina longirostris* population crashed after treatment and another zooplankton, *Chydorus sphaericus*, filled in the open niche (1996).

The need to re-apply lime, and the effects on aquatic communities, seems to limit its usefulness as a management tool. When the survivorship study was being carried out, small scale re acidification events were observed within the ten days of data collection for each trial when it rained. The pH within the mesocosms would drop immediately following a precipitation event, and then begin to rise again as the $CaCO_3$ mitigated the change. It was obvious that this occurs regularly in the Adirondacks, and data from the long term monitoring program of the Adirondack Lakes Survey Corporation shows fluctuations in pH over time in all of the waters surveyed.

The community comparison of Tamarack Pond (limed and stocked with brook trout) and Slender Pond (never limed or stocked) showed that these management practices, perhaps in combination, are having impacts on surface waters in the Adirondack Park. The pH of Tamarack (6.53) is still greater than that of Slender (5.85), four years after the last lime treatment. The communities differed greatly, but the results of our comparison are not specific to lime treatment. It is likely that the presence of fish also has a large impact on the aquatic insect community in Tamarack Pond. It would be interesting to perform a stable isotope study on the prey and fish in this pond to determine the extent at which each type of fish is feeding upon insects. Predation does not explain why the insect community of Tamarack Pond is uneven, however, which might be a lingering effect of rapid changes in pH and salinity associated with lime treatment, and the survival of the tolerant species. Since the completion of this study liming and stocking of Tamarack Pond have not taken place, so it will be interesting to see how the insect and fish communities develop without these inputs.

Conclusion:

Lime treatment will continue to be necessary in the Adirondack Park, but the current practice of adding $CaCO_3$ in the form of agricultural lime at a concentration of one ton per surface acre may not be the best management practice to restore aquatic biota to acidified lakes. Recreational game fish are a main target of management in the Adirondacks, but impacts on the entire ecosystem as a result of base addition can affect the populations of these organisms. Based on this study, the best way to reclaim a body of water that has been acidified would be to slowly add small amounts of base so that chemistry changes are not rapid enough to cause kills of organisms. Because this procedure would prove expensive, at least considering the volume of a body of water instead of only the surface area might mitigate some of the unwanted impacts of lime treatment.

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