Effects of acid deposition on *Pinus strobus* and *Acer saccharum* in Northern Michigan forests

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General Ecology Spring 2010

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Abstract

Human induced acid deposition can result in significant changes in ecosystems and be monitored through tree growth. However, research on the effect of acid deposition on tree growth in relatively low deposition areas and between tree species has been greatly understudied. Thirty *Pinus strobus,* White Pines, and thirty *Acer saccharum,* Sugar Maples, were cored on the University of Michigan Biological Station property in Pellston, Michigan. Their annual growth rings were counted and analyzed using sulfuric and nitric acid deposition and precipitation data collected from 1979-2008. In general, tree growth in both species declined over thirty years at a similar rate. Overall acid deposition was a significant predictor of increasing tree growth in *P. strobus* and *A. saccharum*. Sulfuric and nitric acid were significant predictors of increasing tree growth in *P. strobus*. Only nitric acid significantly predicted increasing tree growth in *A. saccharum*. However, buffering capacity may be playing a large role in trees resisting acid deposition and ecological changes. These results suggest that acid deposition may have a beneficial effect on tree growth.

Introduction

The effects of human induced acid deposition, which encompasses acid rain, on natural systems are largely unknown. However, strong anecdotal evidence and various scientific experiments have begun to observe significant changes in ecological processes. Forests are a sensitive and representative habitat that can reveal these effects in many different ways. To study the long-term ramifications of anthropogenic influences on acid production and deposition we can look at specific tree species within the forest to give us insight into how human activities are affecting forest ecosystems.

Acid Deposition and Tree Growth

While acids occur naturally in the atmosphere, the increased levels added by current and past populations of humans are causing levels of acidity, in precipitation, that may affect tree sensitivity and growth. An increase in soil acid levels from the atmosphere is referred to as acid deposition and can occur in two forms. Wet deposition adds acidity to the soil through a precipitation event such as snow, fog, mist, or a commonly referenced source; acid rain (Likens 2010). Dry deposition settles upon the structure of the tree and is usually carried to the ground through gravity (Likens 2010). The acids that are deposited in these processes are nitric and sulfuric acids and are created mainly through power generation in coal-fired plants, vehicle emissions, and factories emissions. Sulfuric acid is often the more prevalent in deposition because of higher output levels (Likens 1996). However, sulfuric acid has also undergone a sharper decline in output because the main source, power plants, is easier to regulate through technology and scrubbing mechanisms (Likens 1996). Nitric acid from vehicular emissions is harder to regulate and therefore decrease, because of extended vehicle life and business interest. While nitric and sulfuric acids have steadily increased in output since the mid 1800's, the creation of the Clean Air Act in 1970 and the subsequent amendments in 1990 that established the Acid Rain Program have succeeded in stabilizing, and in some areas, decreasing the concentration of acids in the atmosphere (Likens 1996).

Increased acid deposition is ecologically important because of negative impacts it can have on minerals in the soil, such as calcium (Tomlinson 2003). The loss of calcium in the soil from increased acid is a good indicator of decreased growth in a tree (Tomlinson 2003). As a result of decreasing soil nutrients, species can also be more vulnerable to environmental stresses such as insect infestation or drought (Driscoll 1998).

Tree growth is determined by factors such as light, precipitation, and soil nutrients. Lateral growth, or trunk expansion, is caused by the buildup of xylem tissue over time and is visible in cross sections of tree rings. Tree rings are created through growth in the vascular cambium as xylem tissue carries water and nutrients throughout the tree. The seasonality of temperate forests causes differentiation between vascular cambium from one year to the next because the trees experience both early and late growth, which respectively cause light and dark rings, to signify a year. The size and shape of the rings are mostly based on abiotic factors such as light availability, moisture, and nutrients. A large ring indicates increased growth and favorable conditions while smaller or inconsistent rings indicate poor conditions or stresses. Since tree ring size is responsive to external factors they provide a useful way to look at the effects of acid deposition on growth.

Previous Research

Previous studies on acid deposition in trees have focused either on highly sensitive areas or in areas with high deposition rates (Likens 1996, Duchesne *et al.* 2002). Likens (1996) conducted a study in New Hampshire and focused primarily on nutrient leaching in a high deposition region, the northeastern United States. Other studies that looked at similar species to our study, specifically *A. saccharum*, looked only at the effects on one species to see how it was reacting to acid deposition over time (LeBlanc 2002). The researchers focused on soil nutrients as an intermediary for measuring growth and did extensive testing of nutrients as an indicator of deposition (LeBlanc 2002). Previous research at UMBS has focused on different tree species and used an un-standardized measurement to calculate growth (Deline 2002). Researchers also have used manipulative studies to add acid into the soil at high rates to observe the long term trends of acid through an accelerated process (DeHayes 1999).

The research that currently exists focuses primarily on the addition of acid through time and the resulting tree growth and inhibition within a specific species (Leblanc, 1990). Our research aims to use historical data to compare many different factors to account for the complexity of the eco-system into which acid is deposited. Douglas Lake and the University of

Michigan Biological Station (UMBS) property are situated in a relatively low deposition region and on limestone bedrock, which can result in significant buffering of acidity (USDA 1991). Our study will investigate the effects of relatively low acid in buffered soil to look at the effects of acid precipitation compared to external factors on growth. Also, many previous studies detailing the effects of acid deposition, including all UMBS studies, have mostly used "un-standardized tree ring width, which is problematic in forest decline studies." (LeBlanc 1990). Our study will adjust for this by using basal area increment (BAI) measurements to more accurately reflect growth over time. BAI is a helpful unit of measure because it standardizes tree growth over time as the circumference of the tree expands to decrease variability in ring size based on age (LeBlanc 1991).

Local Ecosystem and Trees

In Pellston, Michigan at the University of Michigan Biological Station (UMBS), the National Atmospheric Deposition Program (NADP) maintains a monitoring station and has assessed that acid deposition in Northern Michigan is fairly low compared to other regions in the Northeast and Midwest (Figures 1-1.5). The acid level is also fairly constant between our sample sites for each year so tree species would have experienced similar, if not the same, amounts of acid deposition (Figures 1-1.5). However, acid deposition over time changed, as evidenced by the maps showing changes from 1994 to 2004 (Figures 1-1.5). Our study sites are located so closely to each other that any differences in precipitation would also have been negligible (Figure 2).

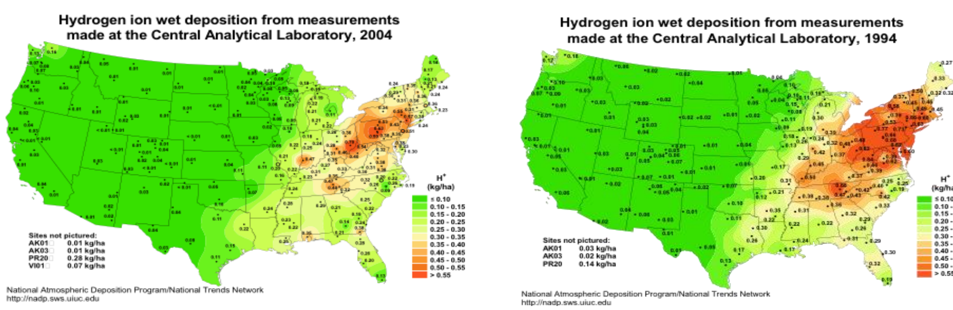

Figure 1-1.5: Maps of acid deposition in 2004 and 1994

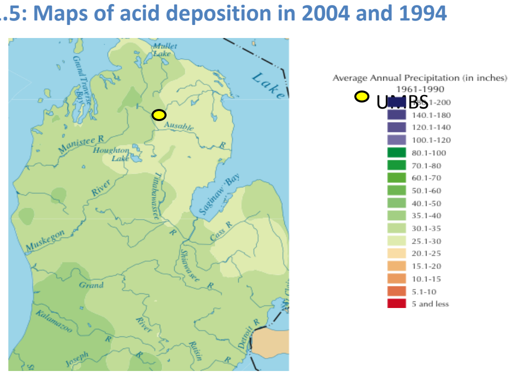

Figure 2: Map of precipitation in Michigan

Within a forest ecosystem, specific species will respond more or less dramatically to acidity in the soil. Surrounding UMBS property and Douglas Lake, two species of trees are common that grow on distinct soils and provide a comparison between deciduous and coniferous trees. *Pinus strobus*, Eastern White Pine, grows best in highly disturbed soils that have acidity between 4.0 and 7.0 and highly buffered soils. *Acer saccharum,* Sugar Maple, grows best in soils that center around a pH of 7.0 but can reach levels as low as 3.7 and as high as 8.0 and soils with lower buffering capacity (Salzberg and Burger 2006).

Questions

Therefore we aim to investigate the effects of acid deposition on tree growth of *A. saccharum* and *Pinus strobus* in Northern Michigan through three closely related questions.

This study examines the effects of acid deposition on the tree growth of *A. saccharum*, and *P. strobus*. To our knowledge, it is the first study to examine and compare the effects of various acids on these two tree types on UMBS property through the following three questions:

1. Has acid deposition over the past 30 years had an effect on the growth of *A. saccharum* and *P. strobus*?
2. If there is a significant effect on growth due to acid, is the effect due to nitric or sulfuric acid, or a combination of both?
3. Are external factors more important to growth than acid deposition?

Materials and Methods

Sample Site

This study was conducted on UMBS property in two different forest locations centering around 45° 33' 10" N, 84° 47' 2" W. The property is composed of both deciduous and coniferous trees. Specifically, Grapevine Point and Pine Point are the two forests that border either side of the Biological Station along South Fishtail Bay in Douglas Lake (Figure 3).

Grapevine Point is composed primarily of *A. saccharum* at the site that we tested, and Pine Point is composed primarily of *P. strobus*. The records of acid deposition and precipitation come directly from UMBS property approximately one mile from each test site (Figure 3). We chose these sites because atmospheric conditions (sunlight, rainfall, etc.) and location in relation to the lake were similar. They were also close to the site of acid deposition measurement. Precipitation is a major determining factor of growth so an acid precipitation ratio was included in our calculations to account for precipitation as an underlying factor present in all samples. The constant nature of precipitation made it possible to look at growth between the two species. However, the content of the soil at our two sites could be very different in nutrient availability and buffering capacity, which could influence our data.

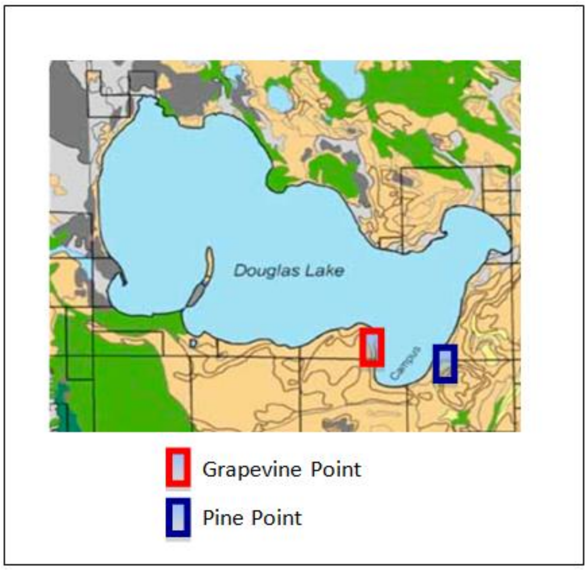

Figure 3: Map of Study Sites

Soil Analysis and Acid Deposition Data Collection

A soil analysis was conducted by gathering samples at the two different sites at both six inches and one-foot depths. Multiple depths of soil were tested to ensure that the pH of the O horizon (organic layer of the soil profile) was not influenced by leaf litter or other environmental factors that can change annually and would not be representative of our 30-year test period. The soil was tested in the chemistry lab at UMBS for buffering capacity by adding base (OH-) to the soil and measuring the change in soil pH. Buffering capacity measures the ability of soil to resist change from the addition of either acids or bases. The data from these tests showed both the initial pH of the soil and the relative buffering capacity of the sites through measuring the change in slope as more base was added to the soil.

The National Atmospheric Deposition Program (NADP) has collected data at UMBS outlining overall wet acid deposition, sulfuric acid, nitric acid, Ca, Mg, K, Na, NH_4, inorganic N, Cl, and precipitation from 1979 until present. The NADP outlines a standardized method for acid deposition collection, which requests that samples be taken in buckets before reaching the soil. Therefore, buffering capacities would not be represented in the acid deposition records and the soil could have the ability to neutralize deposited acid before it reached the trees. The data provided by NADP served as the basis of our analysis because it allowed us to compare historical records of abiotic factors and acid deposition to tree growth.

Growth Measurement

Tree cores are representative of tree growth because they show the yearly increase in vascular tissue. At our study sites, we took approximately 30 cores of each tree species along with the diameter at breast height (DBH). We obtained the cores by drilling perpendicularly into the tree at DBH with corers and extracting wood from the suspected center of the tree. We then glued the cores into a grooved wooden holder where they were sanded and examined with a dissecting scope and an incremental measuring machine. The incremental measuring machine measured the size of rings in millimeters to estimate tree growth between 1979 and 2009.

Statistical Analysis

Similar to previous studies involving tree growth and acid deposition (Duchesne *et al.* 2002; LeBlanc 1990), we converted ring increment data into basal area increments (BAI) to calculate the annual growth rates for the previous 30 years on our 60 sample trees. Basal area is the cross-sectional area of a tree taken at DBH. Using BAI allows for standardized growth rates by removing variation in radial growth attributed to increasing circumference. BAI also allows for comparisons among trees and between multiple sites (Duchesne *et al.* 2002). To convert ring increments into BAI, we used the following formula:

$$BAI = \quad (R \qquad R \quad),$$

Where *R* is the tree radius and *n* is the year of tree ring formation (Duchesne *et al.* 2002). We measured the width of each tree ring and used those measurements to calculate the annual BAI for each tree. After calculating the BAI for each year, we tested the data for normality and investigated the relationship between the variables by running simple correlations between an annual acid deposition-annual precipitation ratio and tree growth.

To investigate the effect of acid deposition on the tree growth (i.e., BAI) and the acid deposition-precipitation ratio in *P. strobus* and *A. saccharum*, a linear regression was conducted to investigate the effects of general acid ions (H+) on tree growth. A final stepwise linear regression was performed to determine the effects and relevance of nitric and sulfuric acid on growth.

Results

Initial analyses examined correlations between acid levels, precipitation, and tree growth using standardized (BAI) measurements. We first observed the trends that tree growth experienced from 1979 to 2008 in millimeters. Both species experienced a decrease in the size of tree rings over time (Figure 4).

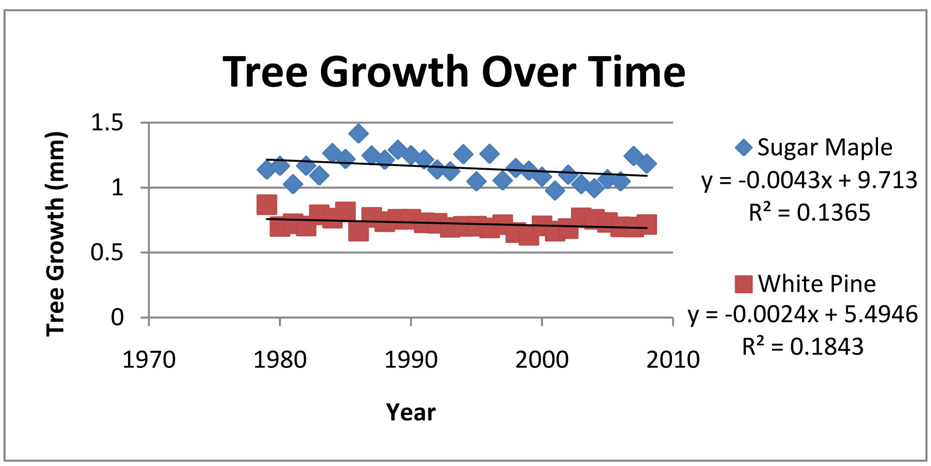

Figure 4: Tree growth over time

Question 1

Linear regression analyses showed the general acid-precipitation ratio significantly predicted positive annual tree growth (BAI) in both *A. saccharum* ($F = 75.830$, $p < .001$) and *P. strobus* ($F = 49.334$, $p < .001$) (Figures 5 & 6). Acid deposition explained 7.8% of variance observed in annual tree growth for *A. saccharum* and 5.2% of variance for *P. strobus*.

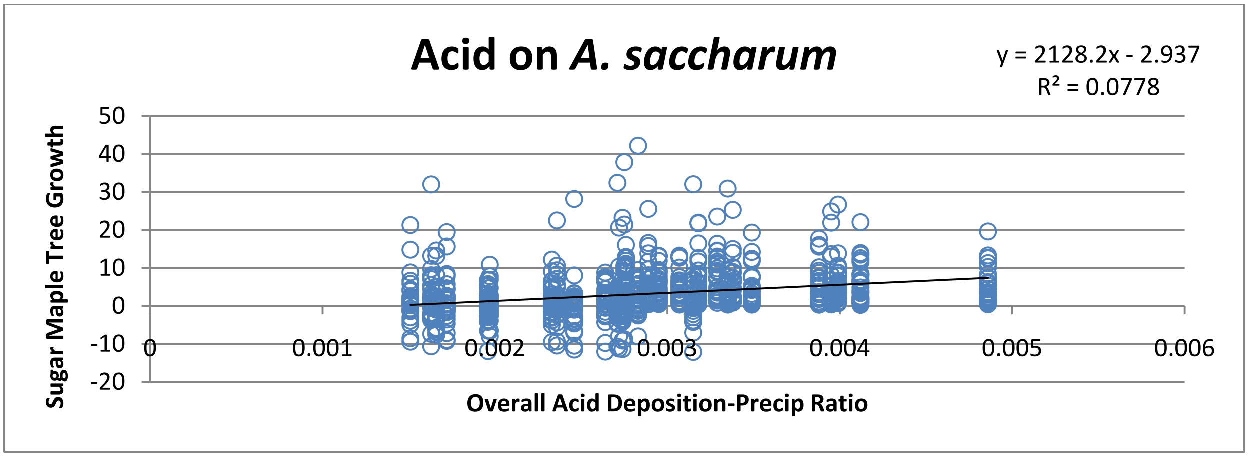

Figure 5: General acid versus growth trend for A. Saccharum

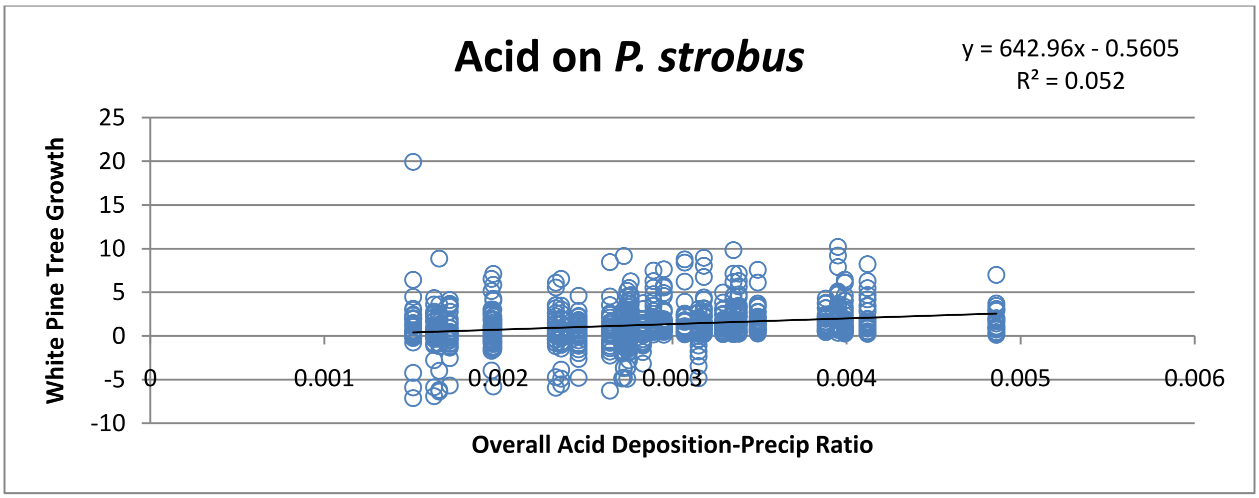

Figure 6: General acid versus growth trend for P. strobus

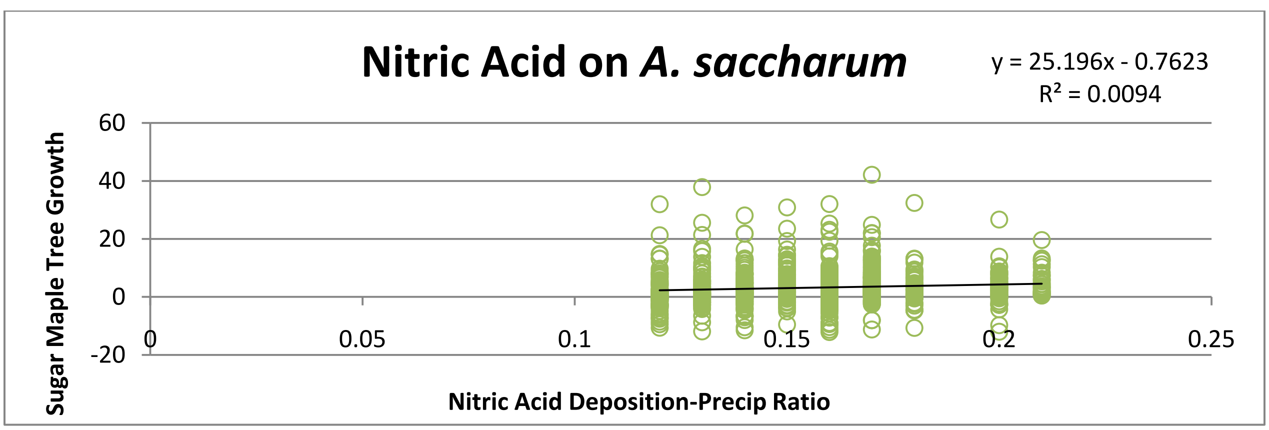

Figure 7: Nitric acid versus growth trend for A. saccharum

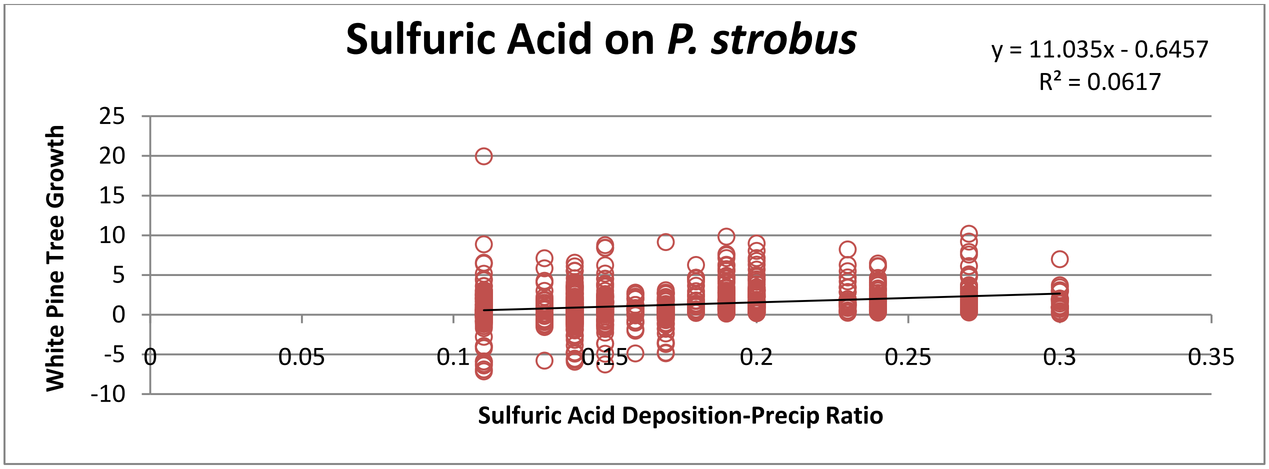

Figure 8: Sulfuric acid versus growth trend for P. strobus

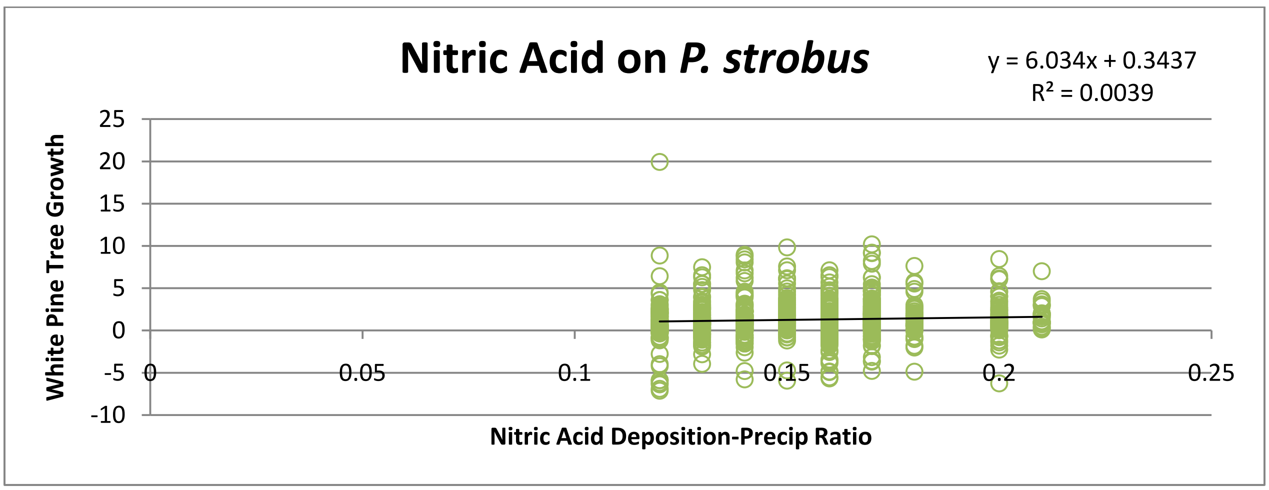

Figure 9: Nitric acid versus growth trend for P. Strobus

Question 2

The nitric acid-precipitation ratio was a significant predictor of increasing tree growth in *A. saccharum* (F = 42.315, $p < .01$) and *P. strobus* (F = 33.081, $p < .01$) using standardized (BAI) measurements (Figures 7 & 9). The nitric ratio explains 8.6% of the variance in tree growth in *A. saccharum* and 6.9% variance in *P. strobus*. The sulfuric acid-annual precipitation ratio was a significant predictor of increasing tree growth in *P. strobus* (F = 56.277, $p < .005$) with sulfuric ratio explaining 5.9% of the variance in tree growth (Figure 8).

Stepwise linear regressions revealed that general acid deposition-precipitation ratio had the greatest influence on annual *A. saccharum* growth (F = 75.830, $p < .01$) followed by the nitric acid-precipitation ratio (F = 42.315, $p < .01$). The sulfuric-precipitation ratio had the greatest influence on annual *P. strobus* growth (F = 56.277, $p < .001$) followed by the nitric-acid precipitation ratio (F = 33.081, $p < .01$).

Question 3

An x, y scatterplot was created using the soil analysis data (Figure 10). The data showed that the buffering capacity on Pine Point was higher at 1 foot (R^2=.7682) than at 6 inches (R^2=.8347). On Grapevine Point the buffering capacity was also greater at 1 foot (R^2=.9968) than at 6 inches (R^2=.9924), although the difference was relatively smaller. Between the two locations the buffering capacity is higher on Pine Point where *P. strobus* is located because the slope changes less over time indicating a higher ability to resist change.

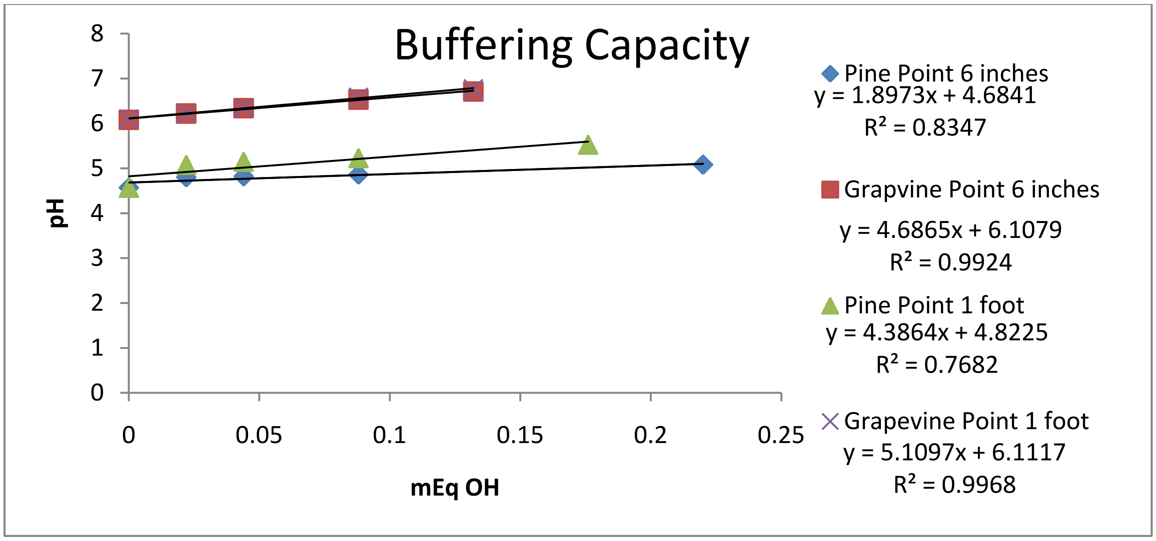

Figure 10: Buffering Capacity of Soils at Pine Point and Grapevine Point

Discussion

The effects of acid and human influence on natural systems are commonly assumed to be negative. However, when analyzing our data it seems that *A. saccharum* and *P. strobus* reflect opposite effects. There have been few studies looking at the effects of acid deposition on highly buffered soil in Northern Michigan using a standardized measurement system. However, previous research suggests that while acid deposition in other locations negatively impacts soil nutrient composition and tree growth (Tomlinson 2003) the forests of Northern Michigan have characteristics that defy this trend.

Question 1

We started analyzing our questions by considering the importance of acid on tree growth in general. Linear regressions revealed that standardized growth (BAI) increased in both *A. saccharum* and *P. strobus* as acid levels increased. The positive relationship between acid deposition and tree growth is unexpected. To investigate our results, we consulted literature about the frequency of this relationship and the factors present at our study sites that could contribute to growth when interacting with nitric and sulfuric acids.

A possible factor that could confound our data is the influence of solar input and precipitation events. In a year with many sunny days and few precipitation events, tree growth could be related to solar input instead of acid deposition. Since our data only used annual precipitation it would be noteworthy to do further research regarding the events of precipitation. If there were a mechanism that allowed acid to remain suspended in the atmosphere above the tree canopy, few precipitation events could account for the actual acid build up. Then the growth could be attributed to the many sunny days instead of the acid deposition occurring in a few great depositions. Further, nitric acid levels are known to vary according to the time of day with the day possessing a greater quantity of nitric acid and night acting as a sink (Kelley *et al.* 1980). Depending on the precipitation time of day the amount of nitric acid could vary resulting in different levels of deposition.

Question 2

Our results indicate that increased nitric acid levels influence growth in both *A. saccharum* and *P. strobus*. The correlation between sulfuric acid and growth was significant only in *P. strobus*. This is consistent with our prediction that nitric acid would have a greater influence on growth because sulfuric acid has been reduced significantly over time as a result of increased technology. The results regarding sulfuric acid are not consistent with our predictions because we thought that *A. saccharum* would be more sensitive to acid deposition. However, it responded only to nitric acid while *P. Strobus* responded to both. The results we discovered when analyzing buffering capacity could account for this difference because the soil buffering capacity was highest on Grapevine Point where *A. saccharum* was tested. Since sulfuric acid is decreasing and soil buffering is high, it seems logical that nitric acid would induce a response in *A. saccharum*.

To explain our results we consulted research regarding the possible beneficial effects of limited amounts of nitric acid on soils. There has been research in Michigan and the Pellston region exploring the positive relationship between nitrogen increases and tree growth. The researchers found that nitrogen deposition might temporarily increase tree growth as long as levels do not pass a tipping point (Pregitzer *et al.* 2008). The data also suggested that increasing nitric acid deposition may allow trees to store carbon more effectively and experience greater growth (Pregitzer *et al.* 2008). This is explained by mycorrhizae in trees, which have a nitrogen carbon exchange system in which the trees provide carbon to the mycorrhizae and receive nitrogen in return (Pregitzer *et al.* 2008). However, if atmospheric deposition of nitric acid increases the amount of nitrogen available to a tree, then the tree would be able to retain more carbon because it would be less dependent on the mutualistic relationship and could experience greater growth. Therefore, slight increases in nitrogen are, at least temporarily, beneficial to tree growth.

We found in our research that Northern temperate ecosystems tend to have suboptimal nitrogen availability and that species in these forests tend to be efficient at retaining nitrogen. In addition to the Pregitzer study, other studies have also indicated that conifers in Northern temperate forests show significant increases in tree growth in response to nitrogen additions during the first stage of their growth (Abel et al. 1998, Thomas et al. 2010). This increased growth in response to added nitrogen can continue for several years, and in some cases, a permanent improvement of site quality and tree growth can occur even after the conifers reach their "saturation points" at which added nitrogen intake from deposition no longer aids growth (Abel et al. 1998).

It is possible that the *P. strobus* we sampled on Pine Point could be in a stage in which most of the trees are experiencing increases in growth in response to nitrogen. A study by Wendel and Smith (1990) found that conifers with DBH of 100 cm or more were common in forests in Michigan, Pennsylvania, and New England. The study also found that on average *P. strobus* grow 2.5 cm in DBH every 5 to 6 years. The average DBH of the *P. strobus* we sampled was 19.05 cm which would correspond to an average age of 40 years and a relatively young stage of life. Thus, there should be a positive relationship between nitric acid deposition and growth, and could explain the relationship that we found.

We also found that sulfuric acid was positively correlated with growth in *P. strobus*. This positive relationship could potentially be explained by the fertilizing effects of nitric acid overwhelming the effects that sulfuric acid would have on growth. One study stated that there might be cases where acidity caused by sulfur oxides is counteracted by fertilizer effects (Tamm 1976). Hence the positive fertilizer effects of nitrogen could be compensating for any negative effects of sulfuric acid in our study.

Question 3

Our results indicate a positive relationship between acid deposition and growth. However, we need to eliminate confounding variables that could be skewing this relationship in favor of growth. The limestone bedrock that is present at our study sites could be influencing our data as a component of buffering capacity. At our study sites, the soil at one foot on Grapevine Point has the lowest buffering capacity, which is consistent with our prediction that *A. saccharum* would be most sensitive to acid deposition. If a large amount of acid is already in the system the buffering capacity is closer to being met which gives it a relatively higher slope because it is changing more in response to added base. The buffering capacity was highest on Pine Point at 1 foot, where the least amount of organic matter and acidifying materials would be located. These results indicate that *P. strobus* on Pine Point should have the highest ability to resist acid deposition based solely on soil buffering which could be influenced by pine needles creating a constant level of acidity around conifers. The ability of soils to resist acid changed through buffering could be playing a large part in our positive growth trend and research comparing buffering capacity and other factors, such as light, to growth would be beneficial for future study.

Limitations and Further Research

Various limitations with our project design arose while conducting our research on acid deposition and annual tree growth as it became clear in our investigations that soil buffering could be a more relevant indicator. First, we chose our two sample sites based on availability of the targeted tree species, not soil characteristics such as buffering capacity. While the sites are both on UMBS property and have similar atmospheric conditions, there may be differences in nutrient availability that affect tree growth. Additionally, the two sites varied in buffering capacity thus influencing trees' ability to resist acid. Second, we chose two different tree species, *A. saccharum* and *P. strobus*, that possess different growth and tolerance characteristics. These two species differ in preferred soils, acid tolerance, and growth rates. The disparities in sample site and tree species' traits make it difficult to compare our results so we chose to interpret our results independent of one another.

When further exploring the results of acid deposition on tree growth, an analysis of buffering capacity between sites would be helpful in choosing initial sample sites and drawing conclusions. If different species were to be compared across sites to investigate the relative growth of similarly aged trees, soil characteristics must be similar and buffering capacity should be analyzed before determining the sample site. In addition, if different soil sites are chosen, the same tree species should be studied on each site in order to account for variation in species characteristics. Our central question did not focus on soil buffering capacity but since it plays a large role in tree growth, it would be interesting to test growth as a result of buffering capacity instead of acid deposition. This project only considered precipitation and buffering capacity, so further research could investigate the effect of other abiotic factors such as temperature, nutrient availability, and sunlight.

Acid deposition and resulting tree growth can be an important indicator of overall forest health and the relationships that we found between positive tree growth and acid deposition can be important reflections of Northern Michigan's changing ecosystems.

Acknowledgements

We would like to thank Dave Karowe, Katie Goodall, Jesse Lewis, James LeMoine, Robert Vande Kopple, Michael Grant, Kat Williams, Sherry Webster, and Andrew Burton for helping to complete this project.

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