

# **Integrating effects of climate change, acidic deposition and insect defoliation on sugar maple (*Acer saccharum*) growth and yield in the Northern Forest**

Theme #3

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- *Soil fertility, namely calcium, is highly correlated with mean growth rates of sugar maple in the late 20<sup>th</sup> century, coinciding with a period of declining annual growth rates.*
- *Sugar maple growth sensitivity to many key climate variables has changed over the past century.*
- *Combined effects of soil fertility and climate explain large amount of variance of annual growth increments, but the drivers of growth decline may be attributable to additional factors as well.*

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<http://www.nsrcforest.org>

# Project Summary

Sugar maple (*Acer saccharum* Marsh) growth has been declining throughout most of the Northern Forest, however the complete cause of this growth decline is not fully understood. In this region, sugar maple has three primary stressors: climate change, acidic deposition (leads to depletion of soil nutrients), and insect defoliation.

Each one can directly affect sugar maple growth, but in combination these factors may have more complex effects on sugar maple growth and health across a heterogeneous landscape.

We studied the sensitivity of sugar maple growth to climatic variability and how climate-growth relationships might vary across different soil fertility groups, representing nutrient availability due to acid rain. We hypothesized that severely nutrient-poor sites would exhibit different and overall lower climate sensitivities than sites with higher nutrient availability. Growth of sugar maple was evaluated based on a tree-ring network that incorporated local climate variability and landscape-scale gradients in soil chemistry and nutrient availability, especially calcium.

We found that sugar maple growth has a complex relationship with combined soil chemistry and climatic conditions as some cases presented possible interactions while others proved inconclusive. Soil acidification does, however, have long-term impacts on mean sugar maple growth rates, but other factors may also be contributing to these changes such as tree size and insect defoliation. Sugar maple's persistence in the Northern Forest will be heavily influenced by the effects of local soil fertility and climate trends.

Many climate-driven growth models assume constant growth-climate sensitivity (*e.g.*, climate envelope models). However, our findings suggest that the growth-climate relationship for sugar maple does change over time. In effect, we suggest that the strongest growth models will need flexible, time-dependent parameters (*e.g.*, time-varying parameter regressions, mixed effects models) to account for these changes. We present a preliminary mixed effects model, outlining the many factors (climate, soil fertility, tree age) directly impacting growth.

Overall, this work presents evidence of rapidly changing growth sensitivities to climate and illustrate the importance of soil fertility, namely calcium, on sugar maple growth. These findings aid in management decision-making and regional adaptation efforts in the Northern Forest region.

# Background and Justification

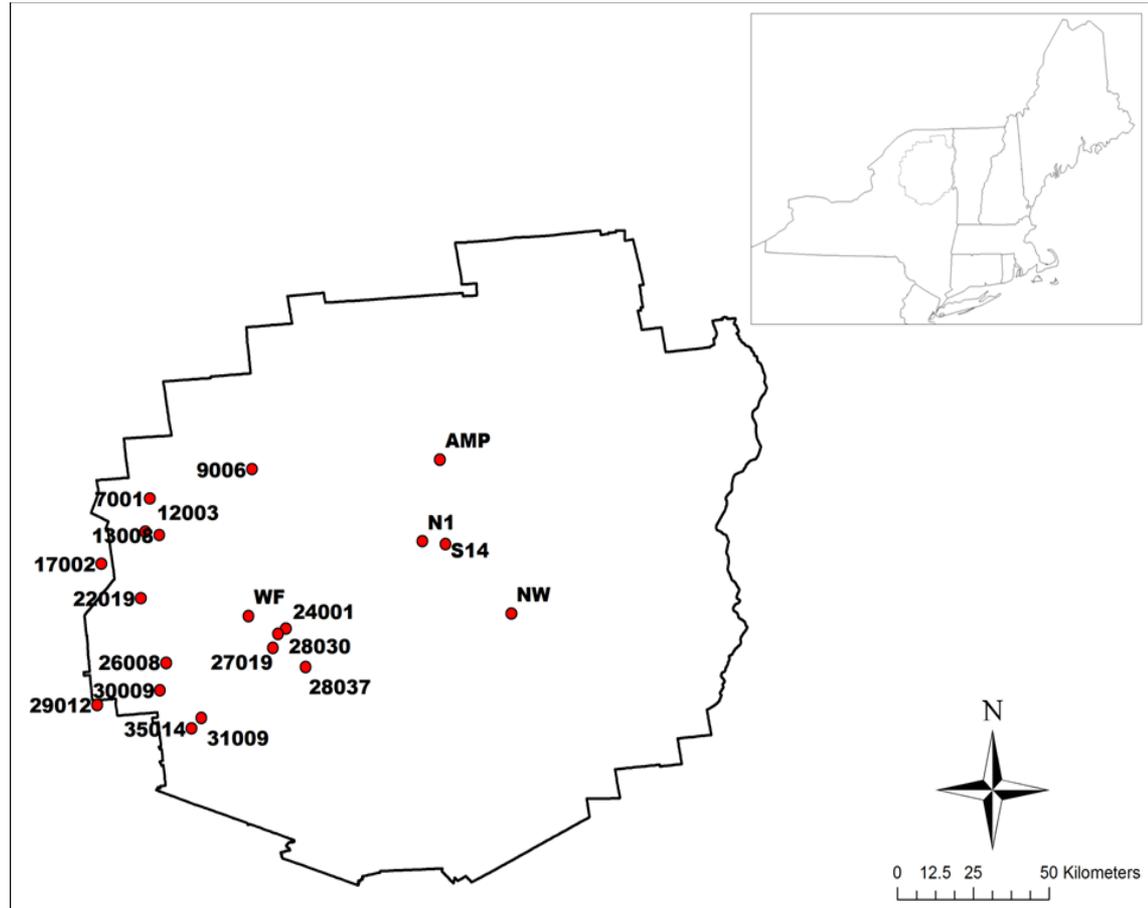
- Sugar maple (*Acer saccharum* Marsh) is one of the most ecologically and economically important tree species in the northern hardwood forests of eastern North America.
- Sugar maple growth decline and increased mortality has been observed in northern hardwood forests  
e.g. Kolb and McCormick 1993; McWilliams et al. 1996; Long et al. 1997; Allen et al. 1992, 1995, 1999; Sullivan et al. 2013
- Sugar maple is sensitive to effects of acid deposition from acid rain Sullivan et al. 2013; Bailey et al. 2005; Horsley et al. 2000
  - Sensitive to calcium availability Duchesne et al. 2002; Sullivan et al. 2013
- Species habitable range is expected to shift north as climate warms Iverson and Prasad 1998, 2002
- Tree-ring analysis shows evidence of declining sugar maple growth sensitivity to climate since 1970 Gavin et al. 2008

# Background and Justification

- Multiple interacting drivers may be contributing to growth decline and increased mortality Gavin et al. 2008; Horsley et al 2000
- If soils are limiting to growth, can climate also limit growth?
  - Is climate sensitivity higher where soil chemistry conditions are not limiting?
- No previous research has analyzed the combined effects of climate and acid deposition on sugar maple growth.

# Methods

- We selected 18 upland hardwood forest sites, capturing relative differences in soil fertility (exchangeable Ca and Al). Sullivan et al. 2013
- Sample plots established at each site, with increment cores taken from 15 trees for each site.
- Soils data collected by collaborator's research group (G. Lawrence).
- Climate data retrieved from PRISM monthly product. Daly et al. 2002



# Methods

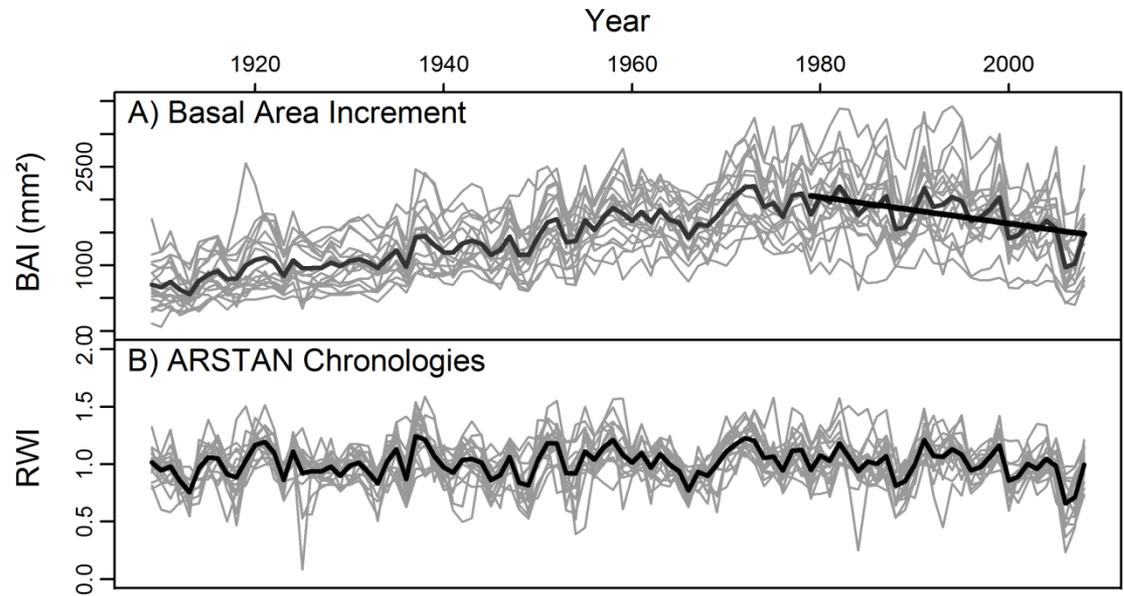
- Soils Data: 10 x 10cm pin block of forest floor material taken for organic soil horizons (Oe, Oa, A). 3-5 small soil pits per plot taken for mineral soil horizon (B). All horizons were oven-dried and chemically analyzed. The chemical results used in this study are pH (in distilled H<sub>2</sub>O), exchangeable Ca, Mg, Al (KCl extraction) and base saturation. Chemical analysis, in addition to soil sampling, was conducted by Sullivan *et al.* (2013).
- Climate Data: Gridded historical climate (GHC) estimates of monthly temperature (Tmax and Tmin) and precipitation (PPT) provided by the Parameter-elevation Regressions on Independent Slopes Model (PRISM).
- Growth Data: Increment cores from 15 healthy sugar maple trees per site were collected evenly across sample plots, with 2 series per tree. The minimum DBH threshold was 30 cm. Tree-ring increments were measured on a sliding stage micrometer (Velmex Corporation, Bloomfield, NY) using MeasureJ2X. Quality of cross-dating and measurement accuracy of the raw tree-ring series was assessed in COFECHA. Growth data was calculated as basal area increment (BAI) using `bai.out` function in `dplR` package in R. After cross-dating, this study had 18 sites, 50 plots, 242 trees, and 450 series.

# Analysis

- Site-level ring-width index chronologies developed using standard dendrochronology practices in ARSTAN 4.1, removing age-related trends and release events attributed to stand dynamics Cook 1985
- We used correlation screenings to evaluate influence of soil chemistry (exchangeable Ca, Al, Mg, pH, base saturation) and climate on sugar maple growth in the 21<sup>st</sup> century.
- Used principal components analysis (PCA) to reduce number of soil chemistry variables and quantify soil fertility.
- Used moving-window correlation screening and time-varying parameter regression models to evaluate changes in growth sensitivity to climate across soil fertility groups.
- Preliminary linear mixed model developed that incorporate climate, soil chemistry, climate, and tree age.

# Results

Figure 1. Declining growth of *Acer saccharum* across a network of upland forests (n=18) in the Adirondack Mountains, NY (USA). Plots for A) basal area increments (BAI) averaged by site (grey lines) and across the region with Theil-Sen slope (black lines), B) ARSTAN chronologies for each site (grey line) and averaged across the region (black line).

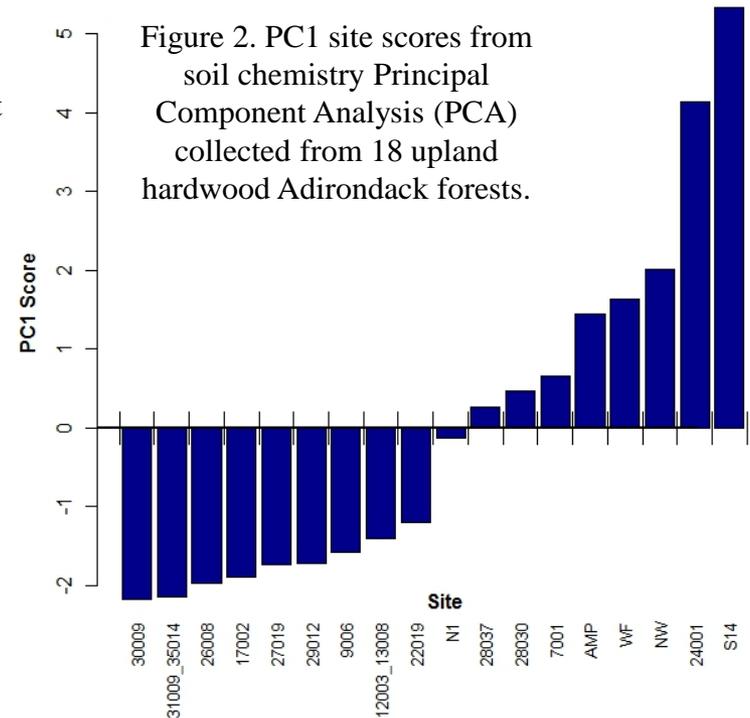


- BAI (top plot) indicated a declining growth rate since ~1980 (thick black line), which occurs for nearly 3 in 4 trees.
- Detrended site-level ARSTAN chronologies (bottom plot) removed long-term trends in data, allowing us to evaluate interannual climatic effects.

# Results

Table 1. Pearson's correlation coefficients (n = 18) between all sites' soil chemistry variables and mean BAI for last 30 years (1979-2008). Significant correlation coefficients (p < 0.1) are shown in bold.

	Al	BS	Mg	Ca	pH
<b>Oe</b>	-0.001	0.067	0.068	0.156	0.154
<b>Oa</b>	-0.246	0.238	-0.024	0.032	0.06
<b>A</b>	<b>-0.537</b>	<b>0.442</b>	0.308	<b>0.417</b>	0.121
<b>Upper B</b>	0.278	-0.03	-0.03	0.064	-0.04
<b>Lower B</b>	-0.045	0.01	0.01	0.207	0.267



- Soil chemistry correlations with mean BAI greatest in magnitude over last 30 years (1979-2008).
- Mean BAI exhibited strong positive correlations with A horizon base cation availability (base saturation, Ca, Mg) and negative correlations with aluminum.
- Principal component (PC1) positively correlated with exchangeable calcium and negatively correlated with aluminum; three soil fertility groups created using PC1.

# Results

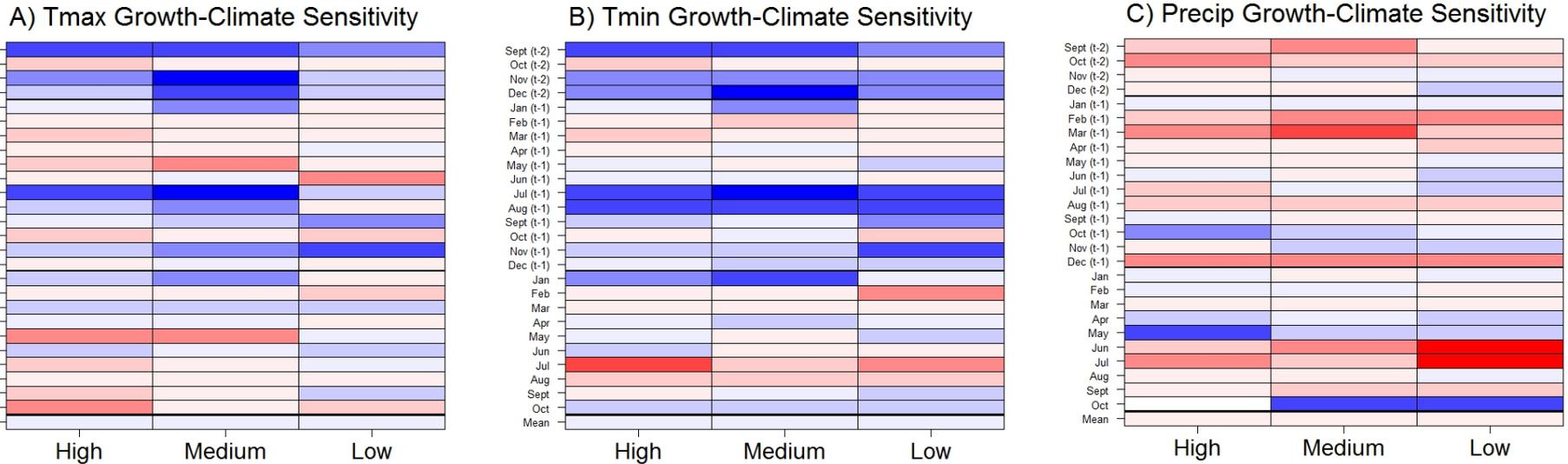


Figure 3. Pearson correlation coefficients, calculated for 1909-2008 ( $n = 100$ ), for each soil fertility group between ARSTAN growth indices and mean monthly A) TMax, B) TMin, and C) Precipitation. Rows range from January two years prior to ring formation to December of the year of ring formation. The darkest shade of each color is statistically significant at  $p < 0.05$ .

- Aggregated into soil fertility groups, correlations between ARSTAN growth chronologies and climate variables calculated.
- Growth in low fertility groups have strong positive correlation with same year June and July precipitation (right plot).
- Growth in all soil fertility groups negatively correlated with prior year July and August Tmin (center plot).

# Results

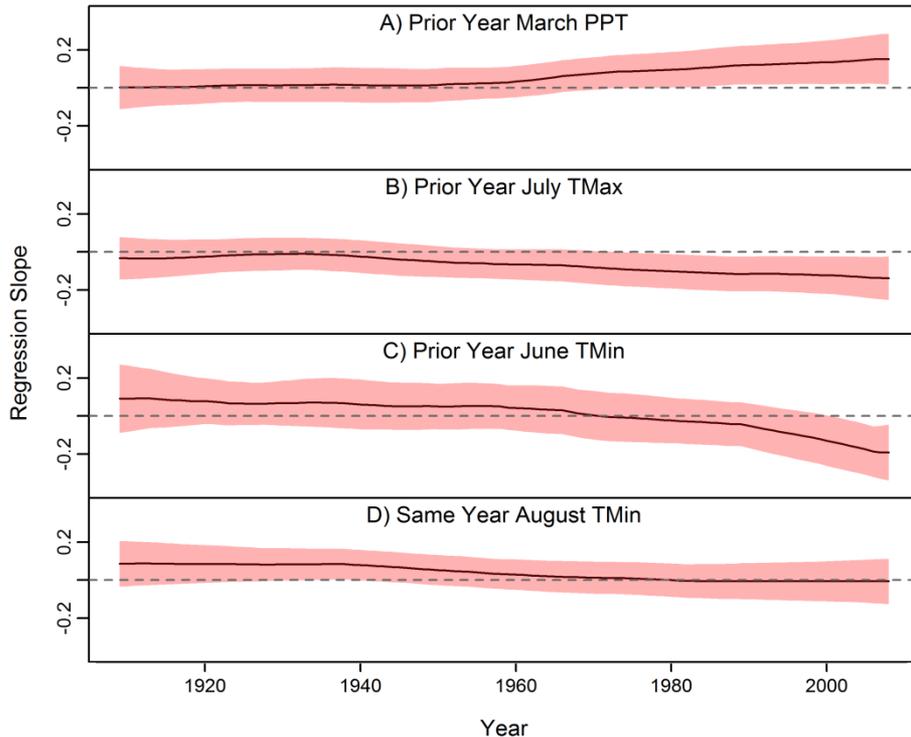


Figure 4. Changes in *Acer saccharum* growth sensitivity to climate. Time varying parameter (TVP) regression slope coefficients (black lines) plotted over time (1909-2008) for A) prior year March precipitation, B) prior year July precipitation, C) prior year July TMax, and D) same year August TMin. The red shaded area illustrates the 95% confidence interval.

- Lack of evidence to support hypothesis that changes in growth sensitivity to climate varied across soil fertility groups.
- However, there were several changes in regional growth-climate sensitivity.
- Growth sensitivity to prior year March precipitation has become more positive recently.
- Growth sensitivity to prior year July Tmax and June Tmin has become more negative.
- Growth sensitivity to same year August Tmin has diminished to zero.

# Results

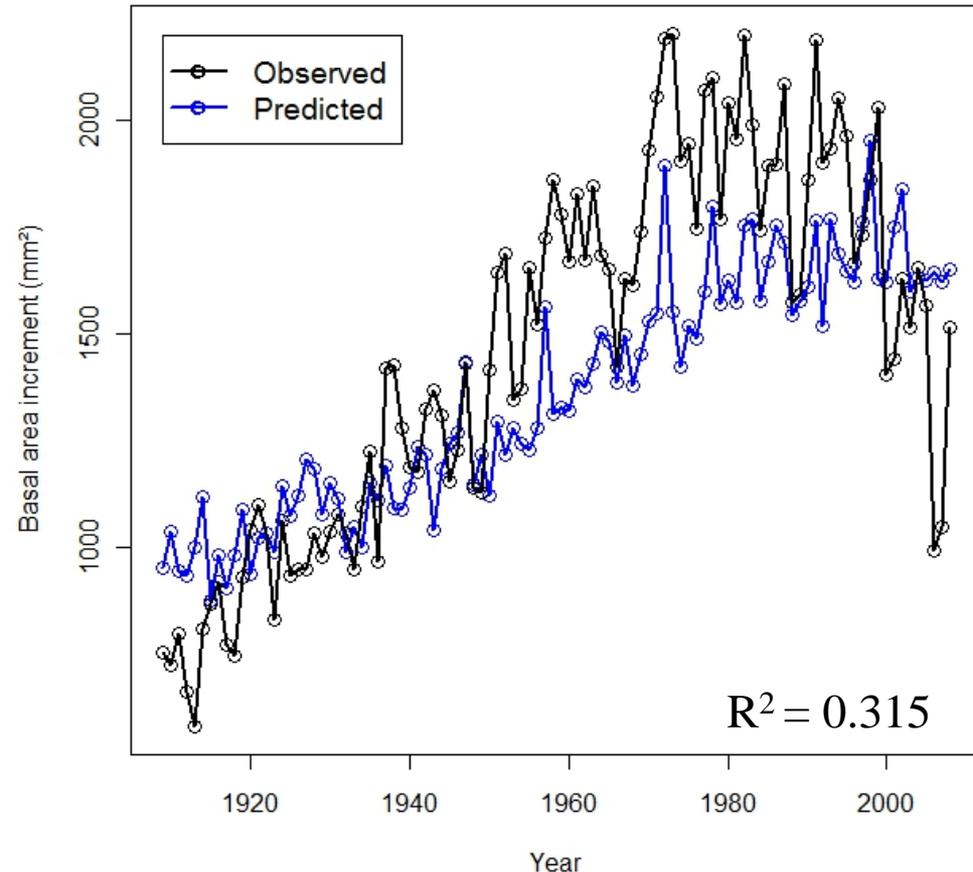


Figure 5. Preliminary model predicted mean BAI (blue points) and observed mean BAI (black points) plotted from 1909-2008. BAI was averaged for each year across all trees.

- Model results indicate that climate variables account for large portion of interannual growth variability.
  - Positive growth-climate coefficient for precipitation and negative for minimum temperature variables.
- However, long-term changes in growth (*e.g.*, growth decline after 1980) are not accurately predicted.
  - Most long-term changes in model driven by tree age, which is highly correlated with tree size.
- Model needs further parameterizations to address this issue.
  - Competition, time-varying soil chemistry product, disturbance history.

# Implications and applications in the Northern Forest region

- Study is largest of its kind in the Northern Forest region (242 sugar maple trees, 18 sites).
- Changing sensitivities to climate indicate unexpected changes in how sugar maple may respond to climate change.
- Relative differences in soil fertility, altered by acid rain, across the landscape has long-term consequences on the growth of sugar maple.
- When completed, growth-yield model will aid in management decision-making and regional adaptation efforts.

# Future directions

- Manuscript detailing declining growth rates of sugar maple currently in review (*Ecology*).
- Extending work to include sugar maple growth records across the US Northeast (Pennsylvania, New York, Vermont, New Hampshire).
- Working with G. Lawrence and C. Driscoll to incorporate time-varying soil chemistry product into analysis.
- Growth-yield model needs additional data (soil chemistry product) and parameterizations.

# List of products

- Paper in review with *Ecology*.
  - Bishop DA, Beier CM, Pederson N, Lawrence GB, Stella JC, Sullivan TJ. In review. Climatic and edaphic factors in regional growth decline of sugar maple (*Acer saccharum*). *Ecology*.
- Master of Science thesis completed in December 2013.
  - Bishop DA. 2013. Integrating effects of climate change and acidic deposition on Adirondack sugar maple (*Acer saccharum*) stands. M.S. Thesis. SUNY-ESF, Syracuse, NY.