a. Project Title: Radial growth analysis of 13 sources of *Castanea dentata* growing in common garden on the Green Mountain National Forest, VT.

b. Summary: Spring phenology, foliar frost damage, and shoot winter injury have been assessed on trees representing 13 American chestnuts sources growing at the species' northern range limit in a provenance study on the Green Mountain National Forest (VT). We propose annual growth ring analyses to determine the impact of early springs, frost events, winter shoot damage, and local climate on growth of American chestnut sources. American chestnut sources with fast growth and limited winter injury and spring frost damage should be considered in restoration efforts in the northern part of the range.

c. Principal Investigators and Institutional Affiliation:

Paul Schaberg
Research Plant Physiologist
Northern Research Station
U.S.D.A. Forest Service

Gary Hawley
Research Associate
Rubenstein School of Environment and Natural Resources
The University of Vermont

d. Duration of project:
12 months

e. Total amount requested:
We are requesting $3715 to support a dendrochronology technician, supplies and travel-related expenses to collect increment cores from approximately 100 American chestnut trees representing 13 American chestnut at our existing provenance study. In addition to collecting cores, the technician will measure annual growth rings and crossdate all cores for accuracy.

f. Short and long-term goals:
Our short-term goals are to better understand the direct impact of spring phenology (budbreak and leaf-out), spring frost events, shoot winter injury and local climate drivers on annual growth of American chestnut sources in a provenance study at the northern limit of the species' historical range. Collection of tree increment cores will allow us to fully quantify annual growth (basal area increment, earlywood and latewood area) for the period of our previous data collections (2012-2016) and determine the impact of spring frost events and shoot winter injury on growth. Our long-term goals are to determine which sources are best adapted to local climate/weather events and make recommendations to TACF to help better inform their breeding program decisions and current restoration efforts. Further, with deregulation of a transgenic American chestnut on the horizon, the need to better understand the existing diversity within the American chestnut population is of timely importance. For landscape-scale restoration, a clonal tree will need to be incorporated into American chestnut with sufficient

genetic diversity to overcome inbreeding depression, and an understanding of the trade-offs of utilizing multiple American chestnut genetic sources will better inform that effort.

g. Narrative:

Introduction:

An important consideration for American chestnut restoration is the careful selection and inclusion of chestnut sources that are appropriately adapted to the broad variation of climate regimes experienced throughout the species' native range. This is particularly pertinent at the northern limit of American chestnut's range where warming of annual temperatures has been well-documented. In Vermont, average temperatures have increased 1.5°C since 1941 (Galford et al. 2014). In the northeastern U.S. average annual and winter temperatures have risen by 1.1°C and 2.2°C, respectfully, since 1970 (Hayhoe et al. 2007, USGCRP 2009). Over the last century, surface air temperatures have warmed by 0.08°C/decade with even greater warming occurring over the last three decades of 0.25°C/decade in the northeastern US (Hayhoe et al. 2007). Winter temperatures have shown the greatest increase (0.7°C/decade) compared to summer temperatures (0.12°C/decade) since about 1970 and climate models predict that annual average surface temperatures in northeastern North America will increase 2.9-5.3°C by 2070-2099 (Hayhoe et al. 2007). Indeed, there seems to be no end in sight to rising temperatures in the northeast. At the writing of this proposal, summer of 2018 in Burlington, VT has broken several temperature records including warmest July (mean temp = 24.4°C, max temp = 30.7°C), the greatest number of days $\geq$ 29.4°C (21 days), and all-time highest minimum temp (26.7°C) (NWS Burlington). Concurrent with rising temperatures is the occurrence of extreme weather events such as the "polar vortex" during the winter of 2013-2014 that saw an extended period of below average winter temperatures in the northeast (Galford et al. 2014).

In addition to an overall warming climate in the northeast, the arrival of spring is occurring earlier. In Vermont, spring arrival is occurring earlier at a rate of 2-3 days/decade, thus extending the growing season by 3.7 days/decade (Galford et al. 2014). Temperature records from 1916-2003 indicate the advancement of first leaf-out by 0.4 days/decade and between 1970 and 2000, this rate increased to 2.2 days/decade (Hayhoe et al. 2007). Polgar et al. (2014) compared leaf-out phenology data of 43 temperate woody species growing in Concord, MA originally recorded by Henry David Thoreau during the 1850s to current leaf-out observations (2009-2013) in the same area and found that 23 temperate woody species leafed out as much as 18 days earlier than in Thoreau's time. This trend in advancing leaf-out is expected to continue and some models predict that by the end of the century tree leaf-out may occur almost three weeks earlier than present day leaf-out (Hayhoe et al. 2007).

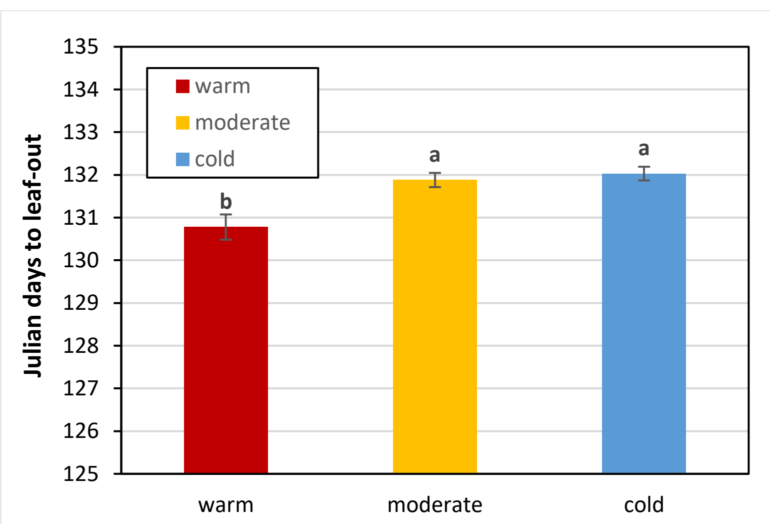
Although early leaf-out may extend the typical growing season, thereby allowing for greater photosynthetic gain, it may also increase the risk of foliar injury and loss of sensitive new foliage when exposed to spring frost events (Augspurger 2009). In 2007, an above-average warm March that caused plants to break dormancy early was followed by a significant frost event in the eastern U.S. (Gu et al. 2008). Temperatures during the freeze event reached as low as -7°C causing significant necrosis to new foliage, shoots and flowers across temperate forests and crops throughout the eastern U.S. (Gu et al. 2008). Similarly, in 2010, the northeastern U.S.

experienced an unusually warm spring causing leaf-out to occur 10-14 days earlier than normal. This was followed by a freezing event (May 9-11) that resulted in widespread foliar damage, particularly at higher elevations throughout the region (Hufkens et al. 2012). The occurrence of future spring warming trends and freeze events like those that occurred in 2007 and 2010 are uncertain though predictions suggest they may occur with greater frequency (Inouye 2000, Polgar and Primack 2011).

Considering these changes in climate (early arrival of spring, warmer winter and annual temperatures) it seems prudent that efforts to restore American chestnut should consider the influence of a changing climate when choosing sources best suited for survival, particularly at the northern edge of chestnut's former range. It has been established that American chestnut seed from warmer regions is less cold tolerant than those from colder regions (Saielli et al. 2012). Likewise, American chestnut shoots from warm temperature zones are more susceptible to shoot winter injury than sources from cold temperature zones (Saielli et al. 2014). Through a collaborative effort between the U.S. Forest Service, The American Chestnut Foundation, and The University of Vermont, a provenance study of American chestnut sources representing the species' historical range (NC, VA, MD, PA, NJ, NY, VT, ME) was established in 2009 on the Green Mountain National Forest in central Vermont where spring budbreak, leaf-out, susceptibility to spring foliar frost damage, and shoot winter injury were assessed from 2012-2016.

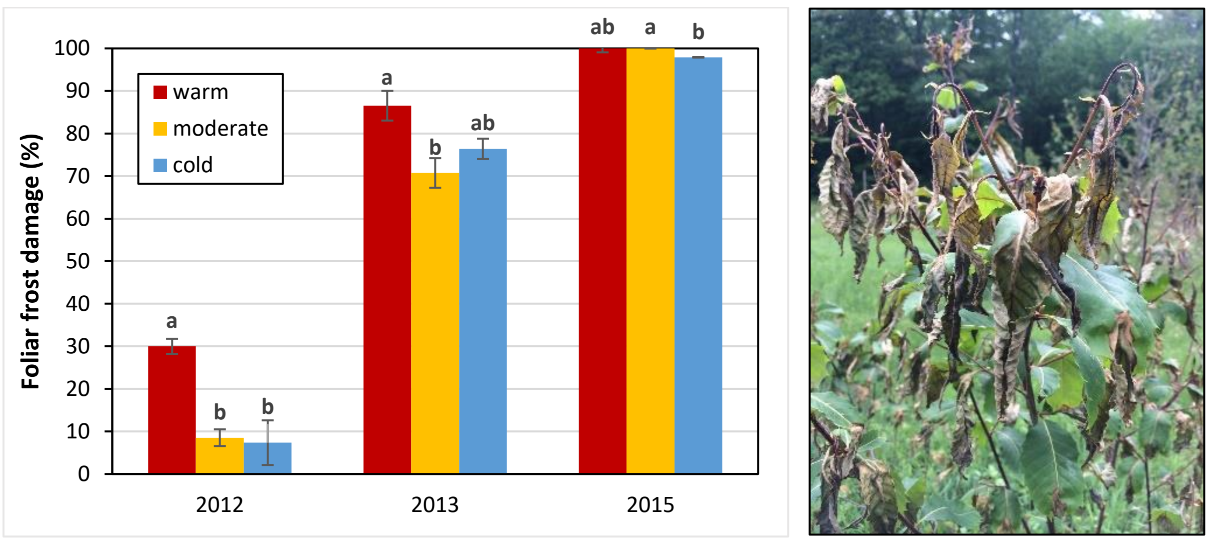
Preliminary results:
Trees were assessed both individually and grouped by temperature zones (warm – KY, MD, NJ, moderate – PA, NY, cold – VT, ME). Over five years, average leaf-out occurred significantly earlier in saplings whose origins are from the warm zone compared to those from cold and moderate zones (*P*=0.002, Figure 1).

Figure 1. Julian days (from January 1 to phenology ranking of 3.5 or greater; 2012-2016) to leaf-out among temperatures zones. Means (±1 SE) with different uppercase letters are significantly different.



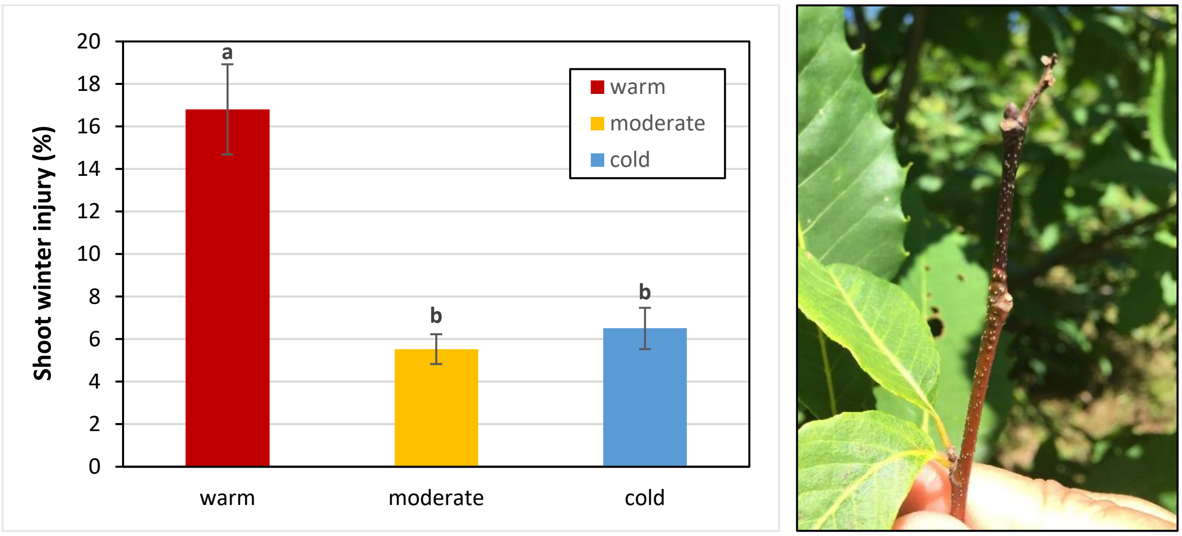
A significant frost event occurred in 2012, 2013 and 2015 which damaged sensitive new foliage (Figure 2). In 2012 an early frost event occurred from April 26 to April 30 with temperatures reaching as low as -4.5°C. Likewise, in 2013 a short-lived, but widespread frost event occurred from May 14-15 with temperatures reaching as low as -2.3°C. In both years, the warm temperature zone sources experienced the greatest amount of damage (2012, P<0.001; 2013, P=0.0174). In 2015, a particularly devastating frost event impacted the foliage of all trees on May 23 when low temperatures reached -3.9°C. Once again, sources from the warm temperature zone as well as the moderate temperature zone suffered the greatest amount of damage compared to cold temperature zone sources (P=0113). We propose that spring frosts may result in increased vulnerability of warm temperature zone sources to foliar frost damage.

Figure 2. Percent foliar frost damage among temperatures zones in 2012, 2013 and 2015. Means (±1 SE) with different uppercase letters are significantly different. Photo depicts frost damage that occurred in 2015.



Shoot winter injury results were consistent with those determined previously by Saielli et al. (2014) using a subset of the same trees. Shoots from warm temperature zone sources sustained three times as much winter injury compared to moderate temperature zone sources and nearly two and half times more than cold temperature zone sources (P<0.001, Figure 3).

Figure 3. Percent shoot winter injury among temperatures zones (2012-2016). Means (±1 SE) with different uppercase letters are significantly different. Photo shows damaged tip of shoot caused by winter injury.



Considering the visual and statistically significant impact of spring foliar frost damage and shoot winter injury among chestnut sources, we would like to investigate the impact on annual tree growth (basal area increment) to determine if these events and resulting tissue damage negatively impacted annual, earlywood and latewood growth among individual sources and temperature zone groupings. In addition, we would like to compare local climate measures of temperature and precipitation with these growth measures.

Methods:
Trees will be cored following standard dendrochronological techniques (Stokes and Smiley 1968). Two xylem increment cores (5 mm) will be collected from each tree as low as possible on the trunk and 180° from each other. Following collection, cores will be oven-dried, mounted, and sanded with progressively finer grit sandpaper (ranging from 220 to 800 grit, Figure 4). Annual whole-ring increments will be visually crossdated using the list method (Yamaguchi 1991), and microscopically measured to 0.001 mm precision using a Velmex sliding stage unit (Velmex Inc., Bloomfield, NY) and MeasureJ2X software (VoorTech Consulting, Holderness, NH). In addition, we will measure earlywood and latewood widths. The program COFECHA will be utilized to statistically crossdate ring series for the detection and subsequent correction of locally absent and/or false rings (Holmes 1983, Grissino-Mayer 2001).

Figure 4. Increment cores showing growth rings from a single American chestnut tree in our provenance planting.

Statistical analyses:
Raw ring width measurements will be averaged per tree followed by mean tree chronology standardization techniques to create ring-width index (RWI) chronologies. Basal area increment (BAI, converts diameter increments (cm/year) into basal area increments (cm^2/year) will be calculated from RWI thereby removing age/size related growth trends (West 1980). BAI chronologies will then be calculated per source to determine if differences exist using analyses of variance. Detrending methods using appropriate splines will allow us to compare annual total, earlywood and latewood growth to our measures of budbreak, leaf-out, spring foliar frost damage, and shoot winter injury as well as climate variables (monthly maximum temperature, minimum temperature, total precipitation, heating degree days and cooling degree days) obtained from the National Climate Data Center (NOAA National Climate Data Center 2018) during the period 2012-2016.

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Polgar CA, Primack BP (2011) Leaf-out phenology of temperate woody plants: from trees to ecosystems. New Phytologist 191:926-941.

Saielli, TM, Schaberg, PG, Hawley, GJ, Halman JM, Gurney, KM (2014) Genetics and silvicultural treatments influence the growth and shoot winter injury of American chestnut in Vermont. Forest Science 60:1068-1076.

Saielli, TM, Schaberg, PG, Hawley, GJ, Halman JM, Gurney, KM (2012) Nut cold hardiness as a factor influencing the restoration of American chestnut in northern latitudes and high elevations. Canadian Journal of Forest Research 42:849-857.

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h. Timeline:

November 2018	December 2018 - March 2019	April 2019 – July 2019
Collect cores at end of active growing season and during dormant period of blight fungus	Dry, mount, and sand tree cores; measure and cross-date annual, earlywood, and late latewood growth.	Perform statistical analyses that compare growth measures to environmental parameters and prepare manuscript.

i. How results will be measured and reported:

Results will be provided to TACF upon completion of the study. Our goals are to publish our results in a peer-reviewed journal as well as share this knowledge in poster form at TACF's annual meeting and other outlets when possible.

j. Breakdown of how and when funds will be spent:

Increment cores will be collected from approximately 100 trees in November 2018. This will require two technicians to travel from Burlington, (104 miles round trip at $0.54/mi) two or three times. Upon completion of this collection, increment cores will be prepared for analysis. This requires supplies such as plastic straws for storing and drying cores, wooden mounts, glue and tape for mounting the dried cores, and a variety of increasingly fine sandpaper for careful sanding of the cores in order to accurately measure annual, earlywood and latewood widths. Most of the funds will be used to pay for the services of a UVM dendrochronology technician to help collect the cores, as well as measure individual growth rings and crossdate them for accuracy ($21/hour, 40 hours/week for 4 weeks). A full-time U.S.D.A. Forest Service research technician will provide assistance for the field collection, preparation of cores and statistical analyses of resulting data. Principal Investigators will draft and publish a final manuscript.

Item	**Costs ($)**
Mileage	165
Core mounts	15
Consumables (straws, glue, tape, canned air, ethyl alcohol)	125
Sand paper for belt sander and hand sanding	50
UVM dendrochronology technician salary ($21/hour, 40 hours/week, 4 weeks)	3360
TOTAL	**3715**

k. Brief Curriculum Vitae for each Principal Investigator:

Paul G. Schaberg

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US Forest Service, Northern Research Station, 81 Carrigan Dr., Burlington, VT 05405

Tel: 802-656-1715; Fax: 802-656-8683; Web: http://nrs.fs.fed.us/people/pschaberg/#8819

Education

Ph.D. Botany, University of Vermont (UVM), Burlington, VT. 1996. Dissertation title: Cold-season photosynthesis of red spruce in Vermont. Advisor: Melvin Tyree

Teaching certification. 1989. Southern Connecticut State University, New Haven, CT. Certification to teach biological, physical and earth sciences at the secondary school level.

M.S. Forestry. UVM 1985. Thesis title: Detection of intracellular lead within stems of red spruce seedlings. Advisor: John Donnelly

B.S. Forestry with a coordinate major in Environmental Studies. UVM cum laude 1981.

Professional Experience

Research Plant Physiologist, USDA Forest Service (USDA-FS), Northern Research Station (NRS), 1995-present. Research emphasis: impacts of abiotic stressors (e.g., pollutant, nutrient and temperature perturbations) on the health and physiology of tree species.

Deputy Project Leader, NRS-16, Restoration & Conservation of Rural & Urban Forests, 2016-present.

Director's Representative for Burlington, USDA-FS-NRS, 2013-present.

Adjunct Associate Professor, Rubenstein School of Environment & Natural Resources (RSENR), 2005-present. University ties emphasize research collaborations, teaching, Diversity Task Force participation, student mentoring, advising and membership on graduate committees.

Fellow, Gund Institute for Ecological Economics, UVM, 2002-present.

Graduate Faculty, UVM, 1999-present.

Acting Project Leader, NE-4103, USDA-FS, NRS, part-time 1996–2005, full-time 2005-2007.

Adjunct Assistant Professor, UVM-RSENR, 1996-2005.

Biological Laboratory Technician, USDA-FS, NRS, 1989-1995. Research emphasis: examining the causes of red spruce decline.

Secondary School Science Teacher, Department of Education, Georgia, VT (full time fall 1989), Department of Education, Cheshire, CT (part-time substitute 1988-1989).

Research Assistant, UVM- RSENR, 1985-1986. Research emphasis: tree responses to pollution.

Biological Laboratory Technician, USDA-FS, NRS, 1985. Research emphasis: impacts of insect defoliation on sugar maple energy relations.

Graduate Research Fellow, UVM- RSENR, 1982-1984. Research emphasis: impacts of anthropogenic stresses on tree physiology.

Selected Recent Publications

Kosiba, A.M.; Schaberg, P.G.; Rayback, S.A.; Hawley, G.J. 2018. Exploring possible causes for the surprising recovery of red spruce growth in the northeastern United States. Science of the Total Environment. https://doi.org/10.1016/j.scitotenv.2018.05.010

Janowiak, M.K., A. D’Amato, C.W. Swanston, L. Iverson, F. Thompson III, W. Dijak, S. Matthews, M. Peters, A. Prasad, J.S. Fraser, L.A. Brandt, P.R. Butler, S.D. Handler, P.D. Shannon, D. Burbank, J. Campbell, C. Cogbill, M.J. Duveneck, M. Emery, N. Fisichelli, J. Foster, J. Hushaw, L. Kenefic, A. Mahaffey, T.L. Morelli, N. Reo, P. Schaberg, K.R. Simmons, A. Weiskittel, S. Wilmot, D. Hollinger, E. Lane, L. Rustad, P. Templer. 2018. New England Forest ecosystem vulnerability assessment: a report from the New England Climate Change Response Framework. USDA Forest Service General Technical Report NRS-173. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station.

Knight, K.S., L.M., Haugen, C.C. Pinchot, P.G. Schaberg, J.M. Slavicek. 2017. American elm (Ulmus americana) in restoration plantings: a review. In: Pinchot, Cornelia C.; Knight, Kathleen S.; Haugen, Linda M.; Flower, Charles E.; Slavicek, James M., eds. Proceedings of the American elm restoration workshop 2016; 2016 October 25-27; Lewis Center, OH. Gen. Tech. Rep. NRS-P-174. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station: 133-140.

Kosiba, A.M., P.G. Schaberg, S.A. Rayback, G. J. Hawley. 2017. Comparative growth trends of five northern hardwood and montane tree species reveal divergent growth trajectories and response to climate. Canadian Journal of Forest Research. 47:743–754.

Schaberg, P.G., P.F. Murakami, J.R. Butnor, G.J. Hawley. 2017. Experimental branch cooling increases foliar sugar and anthocyanin concentrations in sugar maple at the end of the growing season. Canadian Journal of Forest Research. 47:696-701.

Schaberg, P.G., Murakami, P.F., Hawley, G.J., Collins, K.M. 2017. American chestnut restoration in New England - cold damage as an added challenge. New England Society of American Foresters News Quarterly. 78(3): 8-11.

Pontius, J., J.M. Halman, P.G. Schaberg. 2016. Seventy years of forest growth and community dynamics in an undisturbed northern hardwood forest. Canadian Journal of Forest Research 46:959-967.

<u>Selected Recent Grants</u>

Restoring Dutch Elm Disease-tolerant American elm in the eastern United States. Manton Foundation, 2016-2018, $1,432,609. Research with James Slavicek, Kathleen Knight, Leila Pinchot, Keith Woeste (all NRS), and Christian Marks (The Nature Conservancy).

Understanding the Impacts of Ice Storms on Forest Ecosystems of the Northeastern United States. NSF-Ecosystems, 2015-2018, $1,178,612. Research with Charles Driscoll (Syracuse U.), John Campbell (NRS), Sarah Garlick (Hubbard Brook Research Foundation), Lindsey Rustad (NRS) and others.

Genetic adaptation and diversity of longleaf pine in light of a non-stationary world. Forest service Southern Research Station, 2015-2017, $17,000.Research with Kurt Johnsen, Craig Echt, Chris Maier, C. Dana Nelson (all Forest Service SRS), Steve McKeand (NC State), Lisa Samuelson (Auburn U.), and Gary Hawley (UVM).

A multi-tiered approach to understanding the current impacts and potential consequences of climate change on forest ecosystem structure and function. McIntire-Stennis Forest Research Program, 2014-2019, $782,000. Research with C. Adair, T. Donovan, C. Ginger, G. Hawley, R. Manning J. Murdoch, J. Pontius, S. Rayback.

Examining the possible causes and implications of the surprising growth resurgence of red spruce in the Northern Forest. Northeastern States Research Cooperative (NSRC), 2013-2016, $56,705. With S. Rayback and G. Hawley (UVM).

Using dendrochronology to interpret the response of trees to environmental change at the Vermont Monitoring Cooperative's Mount Mansfield study site and beyond. Vermont Monitoring Cooperative, 2012-2014, $40,000. With G.J. Hawley and S.A. Rayback (UVM),

Using Silvicultural Management and Genetic Selection to Assist in the Restoration of American Chestnut to the Northern Forest. NSRC Theme 3, 2012-2015, $94,961. With G. Hawley and J. Halman (UVM).

Assessing phenological differences among American chestnuts sources in a range-wide progeny planting. The American Chestnut Foundation 2012 Grant Program, 2012-2013, $5,000. With G.J. Hawley and J.M. Halman (UVM),

Gary Hawley

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Research Associate, The University of Vermont (UVM), Rubenstein School of Environment and Natural Resources Aiken Center for Natural Resources, Burlington, VT 05405. 802-656-2512

Education

Master of Science, 8/82 (UVM) Forest Genetics, Bachelor of Science, 6/78 (UVM)

Selected Recent Publications

Kosiba, A.M.; Schaberg, P.G.; Rayback, S.A.; Hawley, G.J. 2018. The surprising recovery of red spruce growth shows links to decreased acid deposition and elevated temperature. Science of the Total Environment. https://doi.org/10.1016/j.scitotenv.2018.05.010

Schaberg, P.G., P.F. Murakami, J.R. Butnor, G.J. Hawley. 2017. Experimental branch cooling increases foliar sugar and anthocyanin concentrations in sugar maple at the end of the growing season. Canadian Journal of Forest Research. 47:696-701.

Schaberg, P.G., Murakami, P.F., Hawley, G.J., Collins, K.M. 2017. American chestnut restoration in New England - cold damage as an added challenge. New England Society of American Foresters News Quarterly. 78(3): 8-11.

Engel, B.J., P.G. Schaberg, G.J. Hawley, S.A. Rayback, J. Pontius, A.M. Kosiba, E.K. Miller. 2016. Assessing relationships between red spruce woody growth and high-resolution pollution exceedance values. Forest Ecology and Management 359:83-91.

Halman, J.M., P.G. Schaberg, G.J. Hawley, C.F. Hansen, T.J. Fahey. 2015. Differential impacts of calcium and aluminum treatments on sugar maple and American beech growth dynamics. Canadian Journal of Forest Research 45:52-59.

Hansen, C.F., P.G. Schaberg, A.H. Strong, S.A. Rayback, G.J. Hawley. In Review. LiDAR remote sensing assessments of tree health and productivity in a northern hardwood forest. Canadian Journal of Forest Research.

Schaberg, P.G., P.F. Murakami, J.R. Butnor, G.J. Hawley.2017. Experimental branch cooling increases foliar sugar and anthocyanin concentrations in sugar maple at the end of the growing season. Canadian Journal of Forest Research. 47:696-701.

Kosiba, A.M., P.G. Schaberg, S.A. Rayback, G. J. Hawley. In Press. Comparative growth trends of five northern hardwood and montane tree species reveal divergent growth trajectories and response to climate. Canadian Journal of Forest Research. 47:743–754.

Engel, B.J., P.G. Schaberg, G.J. Hawley, S.A. Rayback, J. Pontius, A.M. Kosiba, E.K. Miller. 2016. Assessing relationships between red spruce woody growth and high-resolution pollution exceedance values. Forest Ecology and Management 359:83-91.

Selected Recent Grants

Restoring Dutch Elm Disease-tolerant American elm in the eastern United States. Manton Foundation, 2016-2018, $1,432,609. Research with Paul Schaberg, James Slavicek, Kathleen Knight, Leila Pinchot, Keith Woeste (all NRS), and Christian Marks (The Nature Conservancy).

Genetic adaptation and diversity of longleaf pine in light of a non-stationary world. Forest service Southern Research Station, 2015-2017, $17,000.Research with Kurt Johnsen, Paul Schaberg, Craig Echt, Chris Maier, C. Dana Nelson (all Forest Service SRS), Steve McKeand (NC State), Lisa Samuelson (Auburn U.).

A multi-tiered approach to understanding the current impacts and potential consequences of climate change on forest ecosystem structure and function. McIntire-Stennis Forest Research Program, 2014-2019, $782,000. Research with C. Adair, T. Donovan, C. Ginger, P. Schaberg, R. Manning J. Murdoch, J. Pontius, S. Rayback.

Collaborative Research: Understanding the Impacts of Ice Storms on Forest Ecosystems of the Northeastern United States. Hawley is collaborator with CoPIs Driscol (Syracuse), Canmobell (USFS), Garlick (HBRF), Rustad (USFS), Schaberg (USFS) and Hayboe (Texas Tech). Total grant $1,178,612. UVM Portion approx. $100,000

Silvicultural management and genetic Selection as tools to assist the restoration of American chestnut to the Northern Forest. USDA Forest Service Joint Venture. 2012-2017, $61,659. Research with P. Schaberg.

Biogeochemistry and physiology of yellow cedar in mixed species forests. USDA Forest Service Joint Venture. 2012-2017, $35,000. Research with P. Hennon, and D. D'Amore (USDA Forest Service, Pacific Northwest, AK).

A multi-tiered approach to understanding the current impacts and potential consequences of climate change on forest ecosystem structure and function. McIntire-Stennis Forest Research Program, 2014-2019, $782,000. Research with C. Adair, T. Donovan, C. Ginger, P. Schaberg, R. Manning J. Murdoch, J. Pontius, S. Rayback.

Examining the possible causes and implications of the surprising growth resurgence of red spruce in the Northern Forest. Northeastern States Research Cooperative (NSRC), 2013-2016, $56,705. With S. Rayback and P. Schaberg (UVM).

Using dendrochronology to interpret the response of trees to environmental change at the Vermont Monitoring Cooperative's Mount Mansfield study site and beyond. Vermont Monitoring Cooperative, 2012-2014, $40,000. With P. Schaberg and S. Rayback (UVM),

Assessing phenological differences among American chestnuts sources in a range-wide progeny planting. The American Chestnut Foundation 2012 Grant Program, 2012-2013, $5,000. With P. Schaberg and J.M. Halman (UVM),

i. The Co-PI's declare there are no known conflicts of interest or commitment.