Harvard Forest Summer Research Program in Ecology

26th Annual Student Symposium

August 2, 2018

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Harvard Forest Fisher Museum
Petersham, Massachusetts

Photographs by Sarah Plisinski and 2018 Summer Research Program students.

Cover photo Sarah Plisinski

INTRODUCTION TO THE HARVARD FOREST

Since its establishment in 1907, the Harvard Forest has served as Harvard University's outdoor classroom and laboratory focused on forest biology and ecology. Through the years, researchers at the Harvard Forest have concentrated on forest management, the development of forest site concepts, the biology of trees, plant ecology, soil processes, forest economics, landscape history, conservation biology, and ecosystem dynamics.

Today, this legacy is continued by faculty, staff, and students who seek to understand historical and modern changes in the forests of New England and beyond. Their research has informed conservation and management as well as enhanced appreciation of forest ecosystems and their histories. This activity is epitomized by the Harvard Forest Long Term Ecological Research (HF LTER) program, which was established in 1988 with funding from the National Science Foundation (NSF).

Physically, the Harvard Forest is comprised of more than 3,750 acres of land in the north-central Massachusetts town of Petersham and surrounding areas. These acres include mixed hardwood and conifer forests, ponds, streams, extensive spruce and maple swamps, fields, and diverse plantations. Additional land holdings include the 20-acre Pisgah Forest in southwestern New Hampshire (located in the Pisgah State Park), which had been a 300 year -old forest of white pine and hemlock when it was blown down in the 1938 Hurricane; the 100-acre Matthews Plantation in Hamilton, Massachusetts, which is largely comprised of plantations and upland forest; and the 90-acre Tall Timbers Forest in Royalston, Massachusetts.

In Petersham, a complex of buildings that includes Shaler Hall, the Fisher Museum, and the John G. Torrey Laboratories provide office and library space, laboratory and greenhouse facilities, and a lecture room for seminars and conferences. Ten colonial-style houses provide accommodations for staff, visiting researchers, and students. Extensive records, including long-term data sets, historical information, original field notes, maps, photographic collections, and electronic data are maintained in the Harvard Forest Archives.

Administratively, the Harvard Forest is a department of the Faculty of Arts and Sciences (FAS) of Harvard University. Faculty associated with the Forest offer courses through the Department of Organismic and Evolutionary Biology (OEB), the Harvard Kennedy School (HKS), and the Freshman Seminar Program. Close association is also maintained with Harvard University's Department of Earth and Planetary Sciences (EPS), School of Engineering and Applied Science (SEAS), School of Public Health (SPH), and Graduate School of Design (GSD). The Harvard Forest's affiliations outside of Harvard University include close ties with the University of Massachusetts departments of Biology, Natural Resource Conservation, and Computer Science; the Marine Biological Laboratory's Ecosystems Center; and the University of New Hampshire's Complex Systems Research Center.

The staff and visiting faculty work collaboratively to achieve the research, educational, and management objectives of the Harvard Forest. Regular meetings with the HF-LTER science team, weekly research seminars and lab discussions, and an annual ecology symposium provide for an infusion of outside perspectives. The four member Facilities Crew undertakes forest management and physical plant activities.

ABOUT THE 2018 SUMMER RESEARCH PROGRAM

The Harvard Forest Summer Research Program in Ecology attracted a diverse group of students to receive training in scientific investigations and experience in long-term ecological research. The 2018 program was co-directed by Aaron Ellison and Audrey Baker Plotkin, and coordinated by Manisha Patel with assistance from Sarah Plisinski and Morgan Zielinski (proctors). All students worked closely with mentors on various research projects from field and laboratory experiments to computer based soft-ware development. The program included weekly seminars from scientists, a career panel, workshops, and field excursions. The Harvard Forest Summer Research Program in Ecology culminates in the Annual Student Symposium held on August 2nd, 2018, where students present their research findings to an audience of scientists, peers, and family.

2018 Summer Research Program Students & Mentors

2018 SUMMER RESEARCH PROGRAM SEMINARS AND WORKSHOPS

Seminars

Wed., May 30	Forest Walk *David Foster, Harvard Forest*
Wed., June 6	Forest Microbial Ecology and Evolution in the Anthropocene *Kristen DeAngelis, University of Massachusetts – Amherst*
Wed., June 20	The PEcAn Project: Putting ecosystem model-data fusion in your pocket *Mike Dietze, Boston University*
Wed., June 27	Remote Sensing of Forest Disturbances: Bugs, Trees, and Lasers *Crystal Schaaf and Peter Boucher, UMass–Boston*
Wed., July 11	Career Panel – *Jessica Dietrich, The Nature Conservancy* *Jessica Shue, Smithsonian Environmental Research Center* *Christopher Wellens, Berkshire Botanical Gardens*
Wed., July 18	New ways to explore forest ecology integrating tree ring and classical *Rubén Delgado, Harvard Forest*
Wed., July 25	Giant panda conservation: historical achievements, current challenges, and future strategies *Dong Chen, Institute of Earth Environment, Chinese Academy of Sciences*

Workshops

Thurs., May 24	Discussion on Summer Program - Educational Activities *Manisha Patel, Harvard Forest*
Thurs., May 31	How to write and review a Research Proposal *Meghan Blumstein, Department of Organismic and Evolutionary Biology*
Thurs., June 7, 14, 21	Reproducible Research with R – part 1, 2, & 3 *Matthew Lau, Harvard Forest*
Mon., June 11	Communication Workshop *Clarisse Hart, Harvard Forest*
Mon., June 11	*Case Studies on Matters of Integrity for Undergraduate Researchers in the Social, Life, Applied Sciences, and Humanities. *Logan McCarty, Department of Physics*
Thurs., June 14	Review Panel on Research Proposals *Summer Students, Harvard Forest*
Thurs., June 21	Basics to ArcGIS *Brian Hall, Harvard Forest*
Thurs., July 12	Field ID walk *Aaron Ellison & Audrey Barker Plotkin, Harvard Forest*
Thurs., July 26	Presentation and Poster Workshop *Aaron Ellison, Harvard Forest*

**Responsible Conduct in Research workshop was held in Paine Hall-Harvard University, Cambridge, MA.*

FUNDING FOR THE 2018 SUMMER RESEARCH PROGRAM

The Harvard Forest Summer Research Program in Ecology in 2018 was supported by the following organizations:

National Science Foundation

REU Site: A Forest full of Big Data: the Harvard Forest Summer Research Program in Ecology 2015-2019 (DBI-1459519)
HFR LTER V: New Science, Synthesis, and Strategic Vision for Society (DEB-1237491)
Collaborative Research:
Bringing End-to-End Provenance to Scientists (ACI-1450277)
EAGER-NEON: Using Intraspecific Trait Variation to Understand Processes Structuring Continental-scale Biodiversity Patterns (EF-1550770).
NERC: Addressing the plant growth source-sink debate through observations, experiment, and modeling (DEB-1741585)

Institutions

Bates College
STEM-Faculty Student Summer Research Grant

Bryn Mawr College
Summer Science Research Program

Harvard University
Faculty of Arts and Sciences
Living Diorama Scholarship Fund
Reuben Tom Patton Scholarship Fund
Department of Organismic and Evolutionary Biology

Mount Holyoke College
Miller Worley Center for the Environment Summer Leadership Fellowship

Wellesley College
Georgeanne Miller Mulhern Fund

26th ANNUAL HARVARD FOREST STUDENT SYMPOSIUM SCHEDULE

THURSDAY, AUGUST 2nd FISHER MUSEUM

Welcome - Audrey Barker Plotkin

8:15 A.M.	**Session I: From Below to Above Ground**	
Eva Paradiso *Wellesley College*	The role of root morphology in predicting root respiration in six temperate tree species	20
Juan Rodriguez *Brown University*	Scaling and Energy Partitioning Across Tree Sizes	24
Nia Riggins *Bryn Mawr College*	What does the future hold for the Harvard Forest Megaplot? Seedling Abundance, Diversity, and Mortality	23
Ruth van Kampen *Bates College*	Physiological strategies for conserving water and using sunlight in four New England trees	27
Katja Diaz-Granados *Harvard University*	Hydraulic Capacitance in Four Temperate Tree Species	13
Brooklynn Davis *Harvard University*	No short-term respiratory response in soils surrounding white pines in chilling experiment	12
Emory Ellis *Hampshire College*	Water access and silica uptake in *Acer rubrum, Fagus grandifolia, and Castanea dentata*	15
	Break	
10:15 A.M.	**Session II: Plant Invasions & Ants**	
Seanne Clemente *University of Guam*	Impact of *Cirsium vulgare* on the Plant Community Structure of a New England Grassland Ecosystem	11
Shreena Pyakurel *Mount Holyoke College*	Does *Trifolium repens* facilitate the invasion of *Cirsium vulgare*? A spatial and greenhouse study	22
Jerilyn Jean M. Calaor *University of Guam*	The influence of nitrogen fixers on invasion dynamics in grassland plant communities	10
Max Ferlauto *Juniata College*	The Effect of *Alliaria petiolata* on Ant Communities: A Pilot Study	16
Monica Velasco *California Baptist University*	Reidentification of the *Aphaenogaster*	28
Grace Duah *Muhlenberg College*	Incidence of Camponotus species among the four dominant tree species at Harvard Forest	14
Maggie Anderson *Lawrence University*	Do Deciduous Trees Make More Ants? Tree productivity and ant biodiversity in New England Forests	7
	Lunch	

26th ANNUAL HARVARD FOREST STUDENT SYMPOSIUM SCHEDULE

THURSDAY, AUGUST 2nd FISHER MUSEUM

1:00 P.M.	**Session III: Provenance-Based Debugging for R**	
Joseph Wonsil *Carthage College*	Using Provenance to Make a Better Debugger	31
Orenna Brand *Columbia University—NYC*	Increasing the Use of Provenance Through User-Friendly Debugging in R	9
1:45 P.M.	**Session IV: Land Use from Past to Future**	
Kyra Hoerr *Bryn Mawr College*	Land Use and Disturbance History at NEON-LTER Sites	18
Jonathan Hamilton *Harvard University*	Applying the Wildlands and Woodlands vision to the Pioneer Valley	17
Annina Kennedy-Yoon *Harvard University*	Multivariate Analysis of the Towns within the Pioneer Valley	19
Evan Waldmann *University of Central Florida*	Simulating effects of forest management practices in a fire prone region of the Northwestern US	29
	Break	
3:00 P.M.	**Session V: Forest Structure and Composition**	
Meghan Slocombe *Greenfield Community College*	An exploration of lichen communities within Harvard Forest in relation to changing tree demographics	26
Laura Puckett *Virginia Tech*	An Analysis of Tree Competition within Harvard Forest and its Effects on Growth and Mortality	21
Emilio Arias *Emroy University*	Is red maple the new red oak?	8
Saloni Shah *Boston University*	Comparative Species Composition Analysis of New England and Harvard Forest from the mid- 1900's to the Present	25
4:00 P.M.	**Session VI: Science Communication**	
Kyle Wyche *University of Pittsburg*	#WitnessTree A Tweeting Tree??	32
Faizal Westcott *UMass—Boston*	Science Communication Through Film	30
4:45 P.M.	**Session VII: Ticks in Massachusetts**	
Aaron Ellison	Tick Study	

Maggie Anderson

Lawrence University
Mentor: Aaron Ellison
Group Project: Does a foundation species control biodiversity of ants?

Do Deciduous Trees Make More Ants? Tree productivity and ant biodiversity in New England Forests

Energy availability has long been considered a limiting factor of biodiversity. However, this relationship between species diversity and ecosystem energy availability remains poorly understood. The Energy Limitation Hypothesis states that the rate at which energy enters an ecosystem limits the species diversity in an area by limiting the density of individuals. Previous studies have applied this hypothesis to ant assemblages on a global scale but have not yet tested it within a single forest ecosystem. Tree productivity contributes largely to ecosystem functionality and rates of net primary production (NPP) can be used to estimate ecosystem energy availability in forest ecosystems. Our project examines the relationship between tree NPP and species diversity of New England ant species. We found that rates of NPP were higher in deciduous trees –particularly red oaks– and that higher tree productivity was associated with higher ant species diversity. Our results suggest that ant taxa are better able to make nests and forage in the energy-rich leaf litter surrounding deciduous trees. We therefore expect to see increased ant species diversity and changes in community composition as hardwood trees succeed stands of softwood trees–especially Eastern Hemlocks– in the forests of New England.

Emilio Arias

Emory University

Mentor: Audrey Barker Plotkin

Group Project: Shifting dominance of red maple and red oak

Is red maple the new red oak?

In eastern North American forests, red maple has replaced the once-dominated oaks. However, oaks continue to dominate permanent plots at the Harvard Forest. In 1984 Craig Lorimer hypothesized that red maple would overtake red oak once they are released from suppression in the understory. Lorimer created life tables that display changes in diameter class of red maple and concluded that red maple was likely to become increasingly important. In a similar fashion, I created updated life tables for both red maple and red oak for the plots in Lorimer's analysis, to examine whether red maple has progressed to the overstory as predicted. Analysis of these tables indicate that red oak continues to have a larger proportion of trees in the overstory while red maple is more prevalent in the understory. Additionally, red oak diameter growth was higher than red maple, and few red maples ascended to the overstory in the past 40 years. The Harvard Forest plots have experienced very low canopy disturbance in the past 50 years and it is unclear whether red maple will retain the capacity to grow into the canopy when disturbance occurs. Timber harvest is the largest cause of adult tree mortality in the northeast. Therefore, extending this study to analyze pre- and post- harvest plot data can showcase to what extent removal of red oak in the canopy allows the understory red maple to gain dominance.

Orenna Brand

Columbia University
Mentors: Emery Boose, Elizabeth Fong, Barbara Lerner
Group Project: Data Provenance in R

Increasing the Use of Provenance Through User-Friendly Debugging in R

For scientific results to be verified and expanded upon, they must be reproducible by other scientists. Precise reproducibility has historically been difficult to achieve; however, information about how data are analyzed can yield more transparent and repeatable results. This information is referred to as provenance—the record of all elements that contribute to a piece of data, including its intermediate values, operational dependencies, and computing environment. Essentially, it is documentation of how the data came to be in its current state. Our group previously developed tools that collect and visualize provenance in the R statistical language, such as RDataTracker and DDGExplorer, and that utilize the captured provenance, such as Rclean and Encapsulator However, more novel applications are afforded by this information, including tracing data lineage and debugging. We developed an R package, provDebugR, which uses provenance to facilitate postmortem debugging, or identifying and resolving issues in a script after it has completed execution. Through an iterative process of informally obtaining and integrating feedback from scientists, we implemented our application with intuitive functionality that lowers the barrier of entry and increases work efficiency. Features include an interactive graphical user interface and the ability to debug chunks of code at a time. Though the practice of collecting and archiving provenance is growing in popularity, it has yet to be fully integrated into existing workflows. The development of software applications that leverage the power of provenance, such as provDebugR, is important for shifting the focus from visualizing provenance to deriving meaningful insights.

Jerilyn Jean M. Calaor

University of Guam
Mentor: Martha Hoopes
Group Project: Invasion Dynamics at Harvard Farm

The influence of nitrogen fixers on invasion dynamics in grassland plant communities

Plant interactions have the potential to greatly influence community composition. The effects of these plant interactions become more important in increasingly rare habitats, like New England grasslands. Within a long term-study to assess the effects of grazing and mowing as grassland management regimes on plant communities, we are interested in the facilitative effects of non-native, nitrogen-fixing *Trifolium* species. Specifically, we are interested in the idea that *Trifolium* may facilitate non-native species at the expense of natives. To explore such facilitative effects, we surveyed plant species richness and cover in paired 1x1m plots with and without *Trifolium*. We found both higher species richness and diversity in plots with *Trifolium*. *Trifolium* appeared to have no significant effect on percent cover of natives and non-natives, but percent cover of invasives was significantly higher in plots with *Trifolium*. In the greenhouse, we explored the effects of soil type and plant litter by growing non-native and invasive plants in three soil types (potting, field, or *Trifolium*) with three litter treatments (no litter, general leaf litter, or *Trifolium*). Growth of all plants was highest in potting soil but variable between field and *Trifolium* soil. As for the effects of litter, growth was highest with no litter. *Trifolium* litter had negative effects on non-natives and positive effects on invasives when compared to leaf litter. Overall, the field and greenhouse results suggest *Trifolium* may facilitate invasive species and not non-native species generally.

Seanne Clemente

University of Guam
Mentor: Martha Hoopes
Group Project: Invasion Dynamics at Harvard Farm

Impact of *Cirsium vulgare* on the Plant Community Structure of a New England Grassland Ecosystem

With the decline of agriculture and the subsequent mass reforestation of New England in the past century, the extent of the region's grassland ecosystems has been markedly reduced. These grasslands serve as crucial habitats and breeding grounds for a large variety of regional wildlife species and have become a target for conservation and management to avoid returning to a forested landscape. Landscape management regimes (such as mowing or cattle grazing) remove woody biomass and reintroduce agricultural pressures that historically maintained these grasslands. A potential issue with this solution, however, is that such regimes can facilitate the spread and establishment of invasive species.

Here, we investigate the impact of invasive bull thistle (*Cirsium vulgare*) on the plant community structure of a Central Massachusetts grassland maintained by yearly mowing. We conducted plant censuses in plots with and without *C. vulgare* present and determined that total species richness is significantly higher in plots containing *C. vulgare*. This was likely explained by differences in non-native species richness, which was significantly higher in the presence of *C. vulgare.* Through a greenhouse study, we aimed to determine whether *C. vulgare* affected the growth and establishment of native and invasive plants differently. We found that litter had a negative effect on the growth of three native plants (*Oxalis stricta, Potentilla simplex, Erigeron canadensis)* and three non-native plants (*Rumex acetosella, Rosa multiflora, Polygonum aviculare).* Future measurements of plant biomass will confirm the significance of this trend.

Brooklynn Davis

Harvard University

Mentors: David Basler, Tim Rademacher

Group Project: Quantifying the impact of experimentally-induced stress on the physiology and silica uptake rates of temperate forest ecosystems

No short-term respiratory response in soils surrounding white pines in chilling experiment

Atmospheric carbon dioxide concentrations have reached 400ppm as the natural carbon cycle continues to be warped by anthropogenic emissions and land-use changes (Carlowicz, 2012). In an attempt to understand this dynamic cycle, much experimental focus has been put on photosynthesis, as it removes carbon from the atmosphere; however, respiration is an overshadowed but equally if not more important process, as plants release carbon back into the atmosphere as a metabolic byproduct. Soil respiration is the main metabolic path by which the carbon sequestered by terrestrial plants is returned to the atmosphere (Liu et al., 2014). This study focused on the relationship between carbon availability and soil respiration rates by manipulating carbon transport in eastern white pines (*Pinus strobus*) through stem chilling and measuring the CO2 emission response. Based on current knowledge of the carbon cycle, soil respiration rates were expected to remain consistent and then decrease after inhibition of carbon flow from the white pine stems. In comparison to a control treatment, there was no significant respiratory response within the first 40 days of stem chilling; however, a longer delay is highly probable, as similar systems have been shown to take more than 14 months (i.e. longleaf pine, Aubrey & Teskey 2017). Therefore, we will continue monitoring soil respiration rates in order to capture the response time for this system. This study of the dynamic relationship between carbon availability and soil respiration in temperate forests leads to improvement of the carbon budget, ultimately as part of a platform of change in current carbon budget models and climate change resolutions.

Katja Diaz-Granados

Harvard University

Mentors: Craig Brodersen, Brett Huggett, Jay Wason

Group Project: Structure and function of New England forest trees: Predicting future forest composition by looking back in time

Hydraulic Capacitance in Four Temperate Tree Species

One of the ways in which plants mitigate hydraulic dysfunction is through transient water storage and release, a trait measured as hydraulic capacitance, or the amount of water that can be released per unit change in water potential or pressure. Water is stored in and around the transpirational stream of water, such that if the plant begins experiencing water stress, additional water can be released into the conducting vessels to prevent the water potential from fluctuating dangerously. Hydraulic capacitance is understood to be dependent on three sources of water, each of which corresponds to a separate phase when plotted as a water release curve. The first two of these, capillary spaces and elastic tissues, were studied using multi-year stems and current year stems taken from four tree species (*Fagus grandifolia*, *Fraxinus americana*, *Quercus rubra* and *Acer rubrum*) at the Harvard Forest Common Garden in Petersham, Massachusetts. By measuring water potentials using a thermocouple psychrometer and plotting these against water content, it was found that there was little difference between capacitance for tissue type. However, the reliance on capillary water versus water from elastic tissues appeared to differ at the species level, suggesting that the four species were employing different strategies for auxiliary water use.

Grace Duah

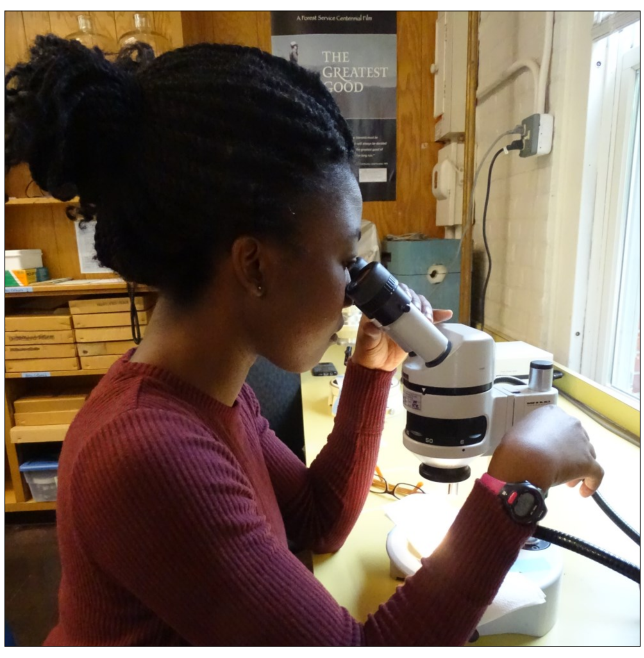
Muhlenberg College

Mentor: Aaron Ellison

Group Project: Does a foundation species control biodiversity of ants?

Incidence of *Camponotus* species among the four dominant tree species at Harvard Forest

The rapid death of Eastern Hemlocks is attributed to the Hemlock Woolly Adelgid (HWA), a non-native insect species that is indigenous to Japan. Many factors contribute to the spread of HWA, for example the dispersal behavior of HWA. Foundation tree species such as eastern hemlocks have anatomical and physiological characteristics that shape the forest community and structure. Ants (*Hymenoptera Formicidae*) are good forest bioindicators because they are very sensitive to ecological changes. This study design sampled for ants under the four main species of trees within the mega-plot a 35-hectare plot which contains both 'hardwoods' and 'softwoods'. We sampled in a concentrated plot within the mega-plot with dimensions of 20 x 320m. Additionally we selected for living trees that are greater than 10cm in diameter at breast height. We analyzed the data to see if there are differences in the occurrence of *Camponotus* species amount the four selected tree species. Furthermore, we did a Nested-Anova to calculate the effect of tree type. Additionally, we calculated the effect of Quadrant number (Tree location) nested in tree type (coniferous or deciduous). By studying the changes in the ecosystem, risk management strategist can predict the outcome of similarly scenarios and how to possibly prevent them.



Emory Ellis

Hampshire College
Mentors: Robinson Wally Fulweiler, Tim Rademacher, David Basler
Group Project: Quantifying the impact of experimentally-induced stress on the physiology and silica uptake rates of temperate forest ecosystems

Water access and silica uptake in
Acer rubrum, Fagus grandifolia, and Castanea dentata

The importance of the terrestrial silica cycling in regulating watershed silica export is an emerging research topic. Of particular interest is the role environmental stressors may play in altering plant silica uptake in the growing season and release during senesce. Silica is taken up by plants as a mechanism to combat both abiotic and biotic stressors. Of particular interest is the role of silica uptake in combatting water stress (e.g., drought). To date, most research on drought has been conducted on crop plants. However, forested ecosystems are known to be "hot spots" of silica cycling – mining it from soils and groundwater and depositing in their tissue. Here we examined the impact of water stress on silica uptake in three species: *Acer rubrum* (Red maple), *Fagus grandifolia* (American Beech), and *Castanea dentata* (American chestnut). We hypothesized that the water stressed trees would take up more silica as a way to preserve cellular structure and maintain photosynthesis as found in research on crop plants. To test this hypothesis, we measured biogenic silica concentrations in tree foliage weekly over a six-week period. Additionally, we quantified readily dissolvable silica from xylem and phloem as a way to estimate silica movement in the trees. If we observe higher concentrations in the water stressed trees then we would have preliminary evidence that trees, like crop plants, take up silica as a mechanism for drought resistance. Ultimately, this study will help further our understanding of silica cycling in forested ecosystems.

Max Ferlauto

Juniata College
Mentor: Aaron Ellison
Group Project: Does a foundation species control biodiversity of ants?

The Effect of *Alliaria petiolata* on Ant Communities: A Pilot Study

Ants make up an abundance of invertebrate biomass and have been proposed as ecosystem engineers and bioindicators. Few studies have examined the effects of exotic plants on native ant communities. Garlic mustard (*Alliaria petiolata*) is a native of Europe and has become an invasive herbaceous weed in new England forests. This pilot study examines relationships between ant communities and garlic mustard, including their abundance, richness, and ability to prey on or disperse garlic mustard seeds. I used pitfall traps and hand searches to collect ants from 15 garlic mustard invaded and noninvaded $1m^2$ plots in Harvard Forest. I also assessed bait removal (out of 5 *Trillium undulatum* seeds, garlic mustard seeds, tuna chucks and cookie crumbs) from caged bait trays. Ant nest abundance was significantly greater in plots without garlic mustard (1.87 ±0.08) than plots with garlic mustard (0.8±0.04) (p=0.005). Additionally, species richness was significantly greater in plots without garlic mustard (3.07±0.09) than plots with garlic mustard (1.67±0.07) (p=0.003). Average percent tuna bait removal was significantly greater in plots without garlic mustard (0.89±0.02) than plots with garlic mustard (0.21±0.01) (p=<0.001). Average percent cookie bait removal was also significantly greater in plots without garlic mustard (0.92±0.02) than plots with garlic mustard (0.29±0.03) (p=<0.001). However, there was little occurrence of trillium or garlic mustard seed removal in both garlic and non-garlic mustard plots. A continuation of this project should analyze the interplay of ants and garlic mustard on a larger scale with the inclusion of other soil organisms such as earthworms.

Jonathan Hamilton

Harvard University
Mentors: David Foster, Brian Hall, Jonathan Thompson
Group Project: Advancing Wildlands and Woodlands through Collaborative Conservation

Applying the Wildlands and Woodlands vision to the Pioneer Valley

To combat the deleterious effects of ongoing forest loss in New England, the Wildlands and Woodlands (W&W) initiative was developed to envision a forested landscape that supports farmlands and communities far more than an unplanned future would. Problematically, W&W applies to all of New England at once, leaving individual sub-regions questioning how they can contribute. To this end, I have started the process of creating a more specific, regional vision for the Pioneer Valley in Massachusetts for the use of Kestrel Land Trust. Using ArcGIS to analyze data such as protected open space layers acquired from the Harvard Forest, I generated a set of maps that imagine several distributions of forests and farmland within the Valley, each favoring a certain scenario of either increased forests or farmlands. By overlaying these visions, I then developed a scenario comparable to W&W. This combined map envisages the Pioneer Valley as 14% urban, 60-77% forested, 5-22% farmland, and 5% water/wetland in 2060, with at least the lower bounds (60% and 5%, respectively) for forest and farmland conserved. In running this analysis, an advancement toward achieving a W&W-influenced New England was made. That is, this vision delineated the conservation priorities for a manageable sub-region of New England. In creating more bottom-up visions like this, land trusts including Kestrel and regional conservation partnerships can better move toward accomplishing the objectives set out by Wildlands and Woodlands for the benefit of all who call New England home.

Kyra Hoerr

Bryn Mawr College
Mentor: Sydne Record
Group Project: Implications of land-use history on biodiversity at co-located National Ecological Observatory Network and Long Term Ecological Research Network sites

Land Use and Disturbance History at NEON-LTER Sites

Disturbance and anthropogenic land-use generate a legacy that influences ecosystem structure and function for decades or longer. Therefore, it is crucial to understand the history of regions we study in order to contextualize the ecological patterns we observe today. This project reconstructs land use and disturbance history by utilizing data from two existing networks: the National Ecological Observatory Network (NEON) and the Long Term Ecological Research (LTER) network. The NEON collects standardized measurements from field sites across the U.S. representing various ecosystem types. The LTER supports 28 sites across the U.S. that have been collecting data for up to 38 years to study long-term ecological change. Cross NEON-LTER sites offer an opportunity to analyze standardized, cross-continental organismal patterns by examining differences in long-term land use within and across NEON-LTER sites. This study examined how land use and disturbance history vary within and across three sites and how these differences impact organismal pattern observed at these sites. Organismal data from NEON (including mammal, bird, and plant richness) and land use data from LTER were gathered and analyzed using a generalized linear model. This study found dramatic differences in disturbance frequency, intensity, and type across sites as well as differences in disturbance history within a given site. This study is meant to demonstrate the importance of considering past land use and disturbance when understanding and predicting broad ecological patterns.

Annina Kennedy-Yoon

Harvard University

Mentors: Brian Hall, David Foster

Group Project: Advancing Wildlands and Woodlands through Collaborative Conservation

Multivariate Analysis of the Towns within the Pioneer Valley

Are the demographics of a region indicative of the amount of land conserved of that region? This research examines potential correlations between demographic data and the amount of land conserved in the Pioneer Valley within Massachusetts. The goal of this research is to help land trusts identify landowners that are more likely to conserve their land but also to help develop a marketing strategy targeted towards the populations that historically have not conserved land. The only way to examine the effects of all of the variables at once was to use a multivariate analysis. I used R to run the analysis and group the towns within the region into distinct clusters, I then noted which clusters had higher amounts of conserved land and which variables might be influencing the clustering. The data shows that populations living in regions with high amounts of conserved land are those with more income from personal or family investments, whereas the populations living in regions with low amounts of conserved land have an especially low proportion of income coming from such investments. The populations that tend to conserve land have a high percentage of individuals employed in educational services, health care or social assistance, whereas populations living in regions with low amounts of conserved land tend to have a higher percentage of individuals employed in manufacturing and transportation. This methodology could be applied to a larger region in order to gain a better understanding of the potential correlations between population demographics and conserved land.

Eva Paradiso

Wellesley College

Mentor: Fiona Jevon

Group Project: Effects of tree community composition on soil and rhizosphere processes

The role of root morphology in predicting root respiration in six temperate tree species

Carbon allocated belowground to roots accounts for over half of net primary productivity, but the fate of that carbon is poorly understood. Absorptive fine roots release carbon dioxide through respiration and are the primary way in which roots acquire resources. Previous studies have looked specifically at root morphological traits including specific root length, root tissue density, and mycorrhizal colonization to distinguish roots by species. Other studies have found relationships between these morphological traits and root respiration within a single tree species. The objective of this study is to determine whether fine root morphological traits relate to respiration rate within or across tree species. We measured fine root respiration of six tree species which represent a diverse set of nutrient acquisition and growth strategies, including differences in shade tolerance, mycorrhizal type, and leaf habit. We found that tree species differ in specific root length, root tissue density, and percent mycorrhizae. Temperature and morphology were both related to root respiration and those relationships were consistent across species. This study provides a better glimpse into fine roots, what influences their respiration, and the carbon flux belowground.

From left to right: Fiona Jevon (mentor), Eva Paradiso

Laura Puckett

Virginia Polytechnic Institute and State University
Mentors: Timothy Whitby, Bill Munger
Group Project: Forest succession via tree mortality and the effects on carbon storage and sequestration in Harvard Forest

An Analysis of Tree Competition within Harvard Forest and its Effects on Growth and Mortality

It is known that competition between trees for sunlight and resources negatively affects their growth and can even lead to mortality. Most competition studies have either compared plot-level competition with growth over multiple years or the competition experienced by individual trees in a single growing season. Few studies have compared competition with growth and mortality of individual trees over multiple years. This study compares competition, growth, and mortality over ten years for eight permanent Harvard Forest plots associated with the EMS flux tower. An existing dataset of seasonal diameter at breast height (DBH) for each tree greater than 10 cm DBH was used, and the tree locations were mapped. Multiple competition indices based on DBH and distance between trees were computed for each tree at a yearly interval. The competition indices were analyzed in combination with annual DBH growth increment for each tree. A t-test showed significant differences between the mean competition index of alive trees and trees that eventually died. The linear regressions of annual growth increment as a function of competition index for each individual were negatively correlated, with an average coefficient of correlation between 0 and 0.4 for each species studied. This relatively small effect may indicate that the competition indices used are not sufficient to describe tree competition, or that the effect of competition on tree growth and survival is less influential than other factors. These results increase the understanding of background mortality near the EMS tower, which is an important factor in interpreting forest dynamics.

Shreena Pyakurel

Mount Holyoke College
Mentor: Martha Hoopes
Project: Invasion Dynamics at Harvard Farm

Does *Trifolium repens* facilitate the invasion of *Cirsium vulgare*? A spatial and greenhouse study

Many invasive species are particularly adept at accessing soil resources and use these resources to establish and expand their distribution. A grassland study at Harvard Farm in Petersham, Massachusetts, has recorded changes in community composition with grazing and mowing since 2014. In that period the percent cover of invasive species has increased every year and across all biomass removal treatments at the Harvard Farm. Our goal is to determine whether a nitrogen fixer, *Trifolium repens*, facilitates the growth of an invasive species, *Cirsium vulgare*.

In the greenhouse, we examined how soil, litter, and live individuals of *T. repens* affect growth of *C. vulgare*. In addition, to the greenhouse experiment we conducted 50m belt transects across Harvard Farm's three treatment areas (constant grazing, mowing, and rotational grazing) and surveyed percent cover of *T. repens* and stem counts of *C. vulgare*. Our results in the greenhouse generally showed a negative impact on *C. vulgare* growth in the presence of *T. repens* soil and litter. However, there is a positive trend with the presence of live *Trifolium*. In the field there was a slight positive correlation between the density of *T. repens* and *C. vulgare* in the grazing treatments, however there was a slight negative correlation in the constant grazing and mowing treatments. We hope to conduct further analysis to examine whether effects of *T. repens* vary for *C. vulgare* in different life stages.

Nia Riggins

Bryn Mawr College
Mentors: Sydne Record, John Grady
Group Project: Size-Energy Partitioning in a Temperate Forest

What does the future hold for the Harvard Forest Megaplot?
Seedling Abundance, Diversity, and Mortality

Forests are important because they benefit the economy, harbor biodiversity, store carbon, and are a valuable conservation mechanism. Unfortunately several trees are dying due to the invasive species such as *Tsuga canadensis* (eastern hemlock) being killed by the *Adelges tsugae* (hemlock wooly adelgid). *Tsuga canadensis* is a hypothesized foundation species that is prevalent in the eastern United States. This tree casts deep shade over the area it occupies. For this reason, *T.canadensis* has a big effect on understory plant abundance, diversity, and mortality because light limitation can affect how plants grow and survive. How will the absence of this *T. canadensis* affect seedling recruitment in the forest. To answer this question data was collected from the hemlock-dominated mega plot where adelgid was first found in 2009. Seedlings that reside in meter by meter plots were measured and identified, and hemispherical canopy pictures were taken to measure canopy openness. A total of 4,240 seedlings were measured with the top species found being *Acer rubrum* (red maple) at 2,557 seedlings and *T.canadensis* at 604 seedlings. Abundance changes as the amount of light available to the seedlings changes. The overall survivorship rate for the seedlings was 0.863 and mortality rate was 0.1587. It is necessary to study seedlings because they represent the future trees.

Juan Rodriguez

Brown University
Mentors: Sydne Record, John Grady
Group Project: Size-Energy Partitioning in a Temperate Forest

Scaling and Energy Partitioning Across Tree Sizes

In ecology, general patterns at many spatial and temporal scales have been noted and are important in numerous applications including the management of New England's Forests. At the level of the community, Metabolic Scaling Theory (MST) has made rather accurate predictions regarding the distribution of size and rate of biomass accumulation in large woody plants. However, critics of this theory have noted that MST lacks the complexities of low light levels experienced by smaller seedlings and saplings in forests. By taking measurements of these smaller woody-plants and combining them with census data from Harvard-Forest's MegaPlot, this work aims to provide insight on the individuals that should deviate most from this theory's predictions, and increase the range of measured sizes by several orders of magnitude. Analyses of the data indicate that the distribution of abundance in plants follows the predicted framework relatively closely, although there are some deviations in the largest and smallest individuals. However, estimates of growth in the smallest individuals, do not conform to predictions made by Metabolic Scaling Theory. This suggests that other factors size-dependent factors may have a profound influence on the smallest individuals which brings more complexity than contained in MST's simple framework. By looking at size-scales not normally considered by other works, these data provide insight on the complexities associated with fitting MST to real plant communities. These data work towards increasing our understanding of communities while also informing models predicting energy use, carbon sequestration, and future demographics of New England's Forests.

Saloni Shah

Boston University
Mentors: Audrey Barker Plotkin, Jonathan Thompson
Group Project: Shifting dominance of red maple and red oak

Comparative Species Composition Analysis of New England and Harvard Forest from the mid- 1900's to the Present

Across the eastern United States, historically dominant red oak and subordinate red maple trees appear to be shifting in abundance as red maples become more prevalent. This species composition shift has implications for forest carbon storage and timber markets as oak species store much carbon and are a valuable source of timber. However, in some sites including the Harvard Forest, red oak dominance continues to increase. I hypothesize that timber harvesting is selectively removing oak species across the region, thereby allowing red maple to recruit into the overstory, while the absence of harvesting in Harvard Forest allows oak species to remain dominant. To elucidate if and when Harvard Forest diverged from the rest of the region, I compared 50+ years of species composition data from historic Forest Inventory and Analysis (FIA) reports and Harvard Forest permanent plots. Then, to examine whether timber harvesting selectively alters species composition, a cluster analysis and a chi-square test were utilized on data before and after harvest from FIA plots that experienced a timber harvest in the past 10-20 years. Results so far demonstrate that oak species have been increasing and have either recently surpassed or remained dominant over red maples in Harvard Forest. Regionally, oak abundance has declined or remained stagnant while red maple has increased.

From left to right: Saloni Shah, Emilio Arias (team member)

Meghan-Grace Slocombe

Greenfield Community College
Mentors: Timothy Whitby, Bill Munger

Group Project: Forest succession via tree mortality and the effects on carbon storage and sequestration in Harvard Forest

An exploration of lichen communities within Harvard Forest in relation to changing tree demographics

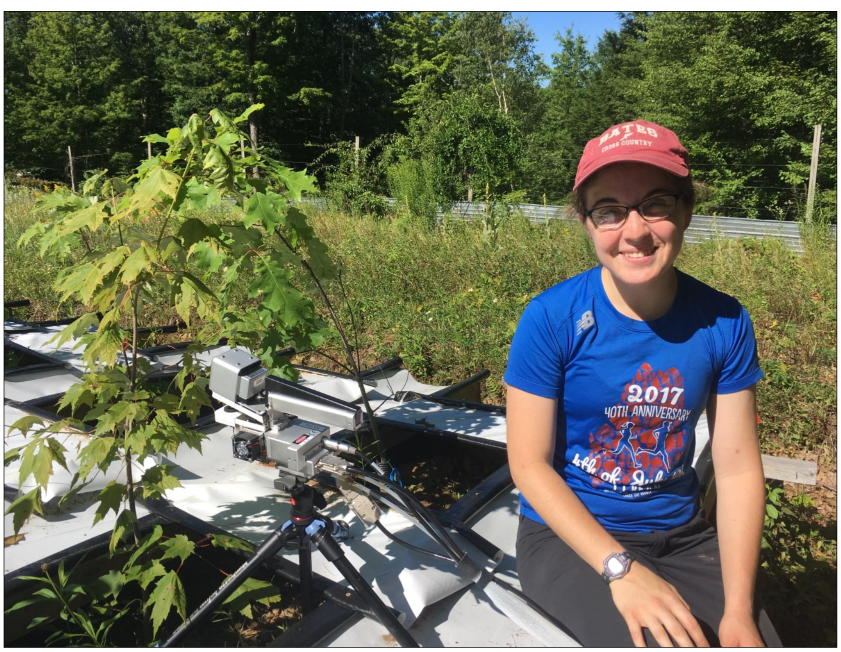
The increased mortality among hemlock populations in concurrence with the spread of the hemlock woolly adelgid, calls for an exploration of how changing tree demographics will affect the ecosystem as a whole. While there have been studies that focus on the effects of losing hemlock populations in Northeastern forests, there has been nearly no research on how a shifting tree demographic will result in altered regional lichen communities. In order to better understand the future lichen communities that might be found in these forests, and their potential impact on nutrient cycling, this study compares the varying species and percent cover of lichen on red maple (*Acer rubrum*, n=30), red oak (*Quercus rubra*, n=30), and hemlock (*Tsuga canadensis*, n=20) tree stems. The average lichen coverage of red oaks was approximately ten percent, red maples approximately nine percent and the coverage on hemlocks was approximately two percent. The average species richness of lichen found on red maples and red oaks was nearly double that found on hemlocks. Lichen community composition was also analyzed using non-metric multidimensional scaling. The data supports the idea that more lichen will be able to colonize tree stems as hemlock populations dwindle and hardwoods take their place. This increase in lichen biomass could increase the rate at which certain nutrients are cycled because of lichens' ability to absorb and fix nitrogen. This potential increase in useable nitrogen within the ecosystem could also increase an ecosystem's ability to gain biomass and thus store carbon.

Ruth van Kampen

Bates College
Mentors: Brett Huggett, Craig Brodersen, Jay Wason
Group Project: Structure and function of New England forest trees: Predicting future forest composition by looking back in time

Physiological strategies for conserving water and using sunlight in four New England trees

Drought events are becoming more common with a warming climate; additionally, insects are migrating northwards and threatening the health of many New England forest ecosystems. It is important to study these effects in tandem to understand how forest tree species may respond and change their survival strategies in order to survive these global disturbances. Minimum stomatal conductance (g_{min}), stomatal response (SR), and water use efficiency (WUE) were measured and calculated for *Acer rubrum*, *Quercus rubra*, *Fraxinus americana*, and *Fagus grandifolia* saplings at the Harvard Forest Common Garden in Petersham, MA. Initial data suggests that *A. rubrum* had low g_{min} values, a fast SR, and high WUE, making it the best strategist among the four species studied. The worst strategist was *F. grandifolia*, as it had poor SR and WUE. *Q. rubra* and *F. americana* were both moderately successful strategists. Overall, more work will have to be done to characterize the strategies of these species especially as they pertain to their level of shade tolerance. Future work will include comparing the characteristics of first flush and second flush leaves of defoliated trees to determine what strategies these trees are employing to deal with defoliation and water stress. I hypothesize that defoliated and droughted trees will make the most extreme adjustments in the morphology and physiology of second flush leaves in order to account for the extreme loss of photosynthetic machinery.

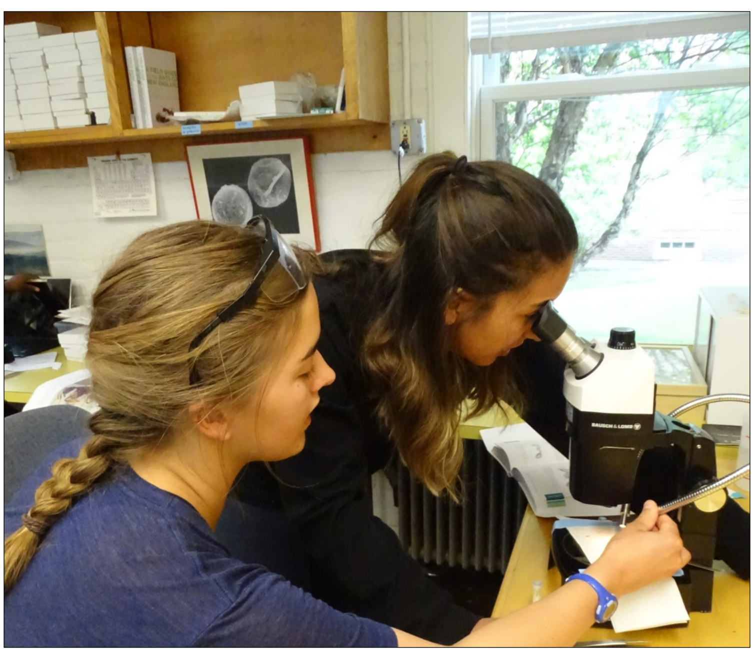


Monica Velasco

California Baptist University
Mentor: Aaron Ellison
Group Project: Does a foundation species control biodiversity of ants?

Reidentification of the *Aphaenogaster*

The genus *Aphaenogaster* has been a subject of scientific debate over its different species since the 1990's. Previously, many scientists had problems distinguishing the species *A. picea*, *A. fulva*, and *A. rudis*: the best method to distinguish among them is by looking at the karyotype of one of their eukaryotic cells. The problem with karyotyping is that it is inefficient with large number of specimens, so scientists have been looking at better ways to identify ants using morphology. A general survey conducted in 2007 collected ants from all over Massachusetts in the attempt to provide a baseline for future studies on climate change. Ant collection can reveal trends in climate change because ants serve as bioindicators of environments: certain ants will be found in areas depending on factors like humidity, temperature, and soil composition. Because this survey identified ants before more accurate practices looking at morphology came to place, most *A. picea* and *A. fulva* were identified as *A. rudis*. This is a problem because all these ants, despite being closely related, tell us different things about climate. For this reason, I gathered the ants from 2007 and reevaluated them. 40% of the ants analyzed were picea, 24% were *fulva*, and 25% of the vials were either empty or not found. 8 vials had the genus misclassified as *Myrmica* and the other 9% of the vials are still being investigated. Doing this reevaluation is imperative to conducting proper research on climate change and other future experiments.



From left to right: Maggie Anderson (team member), Monica Veslasco

Evan Waldmann

University of Central Florida
Mentors: Jonathan Thompson, Meghan Graham MacLean, Danelle Laflower
Project: Landscape simulation of coupled natural and human systems

Simulating effects of forest management practices in a fire prone region of the Northwestern US

Forest disturbances in the form of insects, pathogens, and natural disasters have become more prevalent over the last century; progressing into the 21st century, climate change is predicted to increase the frequency of such disturbances. Additionally, human response to this amplification has the potential to significantly alter the intensity and scope of these disturbances as a result of our ability to modify the landscape. In order to understand the extent of the effects that climate change, forest disturbances, and human response will have on forest dynamics, we simulated landscape change in a portion of the Klamath National Forest located in Northern California over 90 years (2010-2100).

Using LANDIS-II, a forest growth and succession model that allows for the explorations of biological and cultural systems that govern the landscape over time, we designed six scenarios that enabled us to project landscape change with and without climate change, fire activity, and human response in the form of land management practices. We modeled proactive, reactive, and mixed human responses based on existing fire management plans. By implementing maintenance of fuel breaks by the Forest Service, reduction of connected fuels by private owners, and execution of salvage logging across the landscape, this project demonstrates not only that it is possible to simulate dynamic human response through land use, but also that it can be an important factor to consider when analyzing the effects of forest disturbances over long timescales.

Faizal Westcott

University of Massachusetts-Boston
Mentors: David Buckley Borden, Aaron Ellison
Project: Hemlock Hospice Video

Science Communication Through Film

The multidisciplinary video production project is a creative opportunity that looks to test the theory and collaborative practice of art-based science communication with an ongoing Harvard Forest outreach initiative. The approximately 10 minute film documents the year-long art-based interpretive trail, Hemlock Hospice, and the collaborative process that went into making the trail, while also delivering a similar narrative; telling the story of the ongoing demise of the eastern hemlock tree due to the hemlock woolly adelgid and addressing the larger issues of human-impacted climate change. A minute-long teaser aims to capture the essence of the creative steps that were taken to create the main film and will be presented at the Summer Symposium.

From left to right: David Buckley Borden (mentor), Faizal Westcott

Joseph Wonsil

Carthage College
Mentors: Emery Boose, Elizabeth Fong, Barbara Lerner
Group Project: Data Provenance in R

Using Provenance to Make a Better Debugger

Provenance collection tools were created to increase reproducibility in science. RDataTracker is one such program created for provenance collection in R, a popular language for data analysis. Provenance holds a history of data, operations, and computing environment from the execution of a script. The existence of this record leads to transparency and reproducibility in science since an analysis is tracked through its execution. This study focuses on using provenance data in other novel ways. Provenance is, by nature, full of meaningful information about a script. We built a tool that can use it to highlight errors and irregularities. The result is a debugging package for R. We designed the package, provDebugR, to read in provenance and extract helpful data that is then presented to the scientist. Some unique features include tracking variable lineage, monitoring type changes, and searching for errors on Stack Overflow. We developed an interactive console interface similar to that of R's browser function to allow scientists to explore scripts in a more familiar way. They can step line-by-line through their code like a normal debugger; however, the scientist is not actually executing the code. Rather, they are stepping through the history of a previous execution stored in provenance. As a result, they can step forwards and backwards, and are not limited to moving one line at a time. It also provides the functionality to move immediately to any line number of their script. These features are only possible due to the provenance at the package's core.

Kyle Wyche

University of Pittsburgh
Mentors: Tim Rademacher, David Basler

Group Project: Quantifying the impact of experimentally-induced stress on the physiology and silica uptake rates of temperate forest ecosystems

#WitnessTree A Tweeting Tree??

The purpose of this project is to create a system for plants to communicate with humans in a way that humans will understand. This four-part automated system has been built on the Witness Tree, a red oak tree that has a century of environmental conditions stored in its wooden memory. First, a series of sensors including dendrometer bands, sap flow, and thermistors, are installed on the tree to collect data. Then a datalogger reads data from the sensors and transfers it to a computer in near-real time along with meteorological data from a local weather tower to determine the state of the tree and its environment. A series of scripts then run to create graphics, and corresponding reader-friendly messages. The final step is to run a script that searches for messages and graphics preset with specific publishing dates and then publishes those results to the public twitter handle @awitnesstree. Benefits of this system include providing unbiased data where the tree merely communicates it, in a time when #FakeNews is trending on twitter, and it broadcasts the importance of trees to a larger audience. Future plans for this project include creating a website that explains how this system works and where tools, such as code and instructions, for building these systems will be available online. In that way the Harvard Forest @awitnesstree will provide the means to creating a network of instrumented trees that communicate to humans about environmental changes.

From left to right: Brooklynn Davis (team member), Kyle Wyche

PERSONNEL AT HARVARD FOREST—2018

Aylward, Jason- Research Assistant

Barker-Plotkin, Audrey-Site and Research Manager

Boose, Emery-Information Manager

Bowlen, Jeannette-Accountant

Buckley Borden, David-Artist in Residence

Chiasson, Laurie-Administrative Assistant

Colburn, Elizabeth-Aquatic Ecologist

Donahue, Brian-Associate of Harvard Forest

Doughty, Elaine-Research Assistant

Duveneck, Matthew-Research Associate

Ellison, Aaron-Senior Research Fellow & Community Ecologist

Foster, David-Director of Harvard Forest

Grady, John-Post-Doc

Griffith, Lucas-Woods Crew

Hall, Brian -GIS Specialist

Hall, Julie-Assistant Data Manager

Hart, Clarisse-Outreach and Development Manager

Labich, William-Associate of Harvard Forest

Lacwasan, Oscar-Woods Crew

Laflower, Danelle-Research Assistant

Lee, Lucy-Computer Assistant

Levitt, James-Director, Program on Conservation Innovation

MacLean, Meghan-Research Associate

McAfee, Spencer-Wood Crew

Meskauskas, Jenny-Secretary

Meunier, Roland-Woods Crew

Meyer, Spencer-Associate of Harvard Forest

Morin, Alisha-Accounting Assistant

O'Keefe, John-Museum Coordinator (Emeritus)

Orwig, David-Senior Ecologist/ Forest Ecologist

Pallant, Julie-Information Technology and Archives Administrator

Patel, Manisha-Lab Manager and Summer Program Coordinator

Pederson, Neil-Senior Ecologist/ Forest Ecologist

Plisinski, Joshua-Research Technician

Rademacher, Tim-Visiting Researcher

Reardon, Deana-Interim Director of Administration

Record, Sydne-Harvard Forest Associate

Richardson, Lisa-Accounting Assistant

Robbins, Hannah-Regional Conservation Communications Manager

Robinson, Matthew-Woods Crew

Russo, Thomas-Woods Crew

Snow, Pamela-Schoolyard Program Coordinator

Thompson, Jonathan-Senior Ecologist/ Landscape Ecologist

VanScoy, Greta-Museum Coordinator

VanScoy, Mark-Field Instrument Specialist

Weiss, Marissa-Science Policy Exchange Coordinator

Werner, William-Visiting Researcher

Wisnewski, John-Woods Crew Supervisor

Yesmentes, Peter-Summer Program Assistant Cook

Zima, Tim-Summer Program Cook

Charney, Noah-Bullard Fellow

Knobloch, Nicole-Bullard Fellow

Schaaf, Crystal-Bullard Fellow

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Emilio Arias
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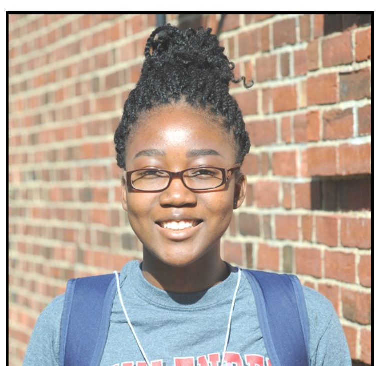
University of Guam

Brooklynn Davis
Harvard University

Katja Diaz-Granados
Harvard University



Grace Duah
Muhlenberg College

Emory Ellis
Hampshire College

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Juniata College

Jonathan Hamilton
Harvard University

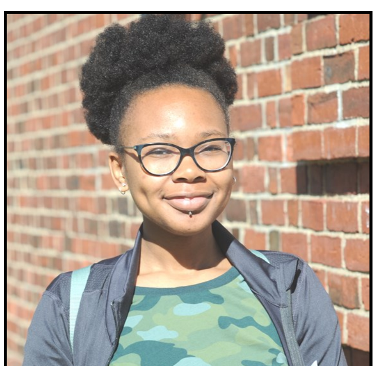
Kyra Hoerr
Bryn Mawr College

Aninna Kennedy-Yoon
Harvard University

Eva Paradiso
Wellesley College

Laura Puckett
Virginia Tech

Shreena Pyakurel
Mount Holyoke College



Nia Riggins
Bryn Mawr College

Juan Rodriguez
Brown University

<u>**2018 SUMMER RESEARCH PROGRAM STUDENTS**</u>

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Bates College

Monica Velasco
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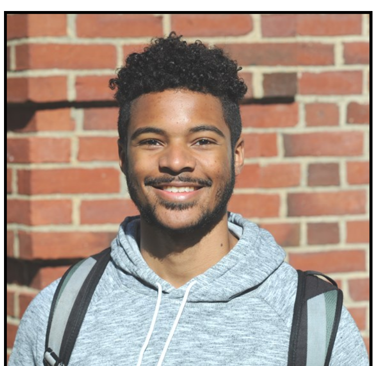
Evan Waldmann
University of Central Florida

Faizal Westcott
UMass —Boston

Joseph Wonsil
Carthage College



Kyle Wyche
University of Pittsburgh

Morgan Zielinski
Sarah Plisinski
2018 Proctors

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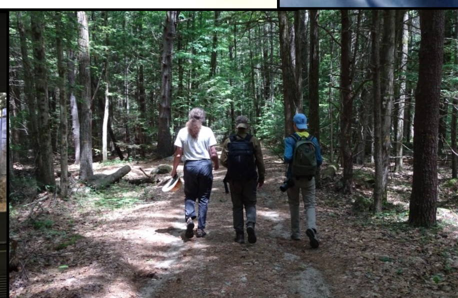


NASA





WARNING
RESEARCH
CAMERAS
IN USE 24/7
STUDENT:
CHOCO-TACO AFTER EVERY MEAL
STONE WALLS
IS THIS A HEALTHY SNACK?


EY SCHO