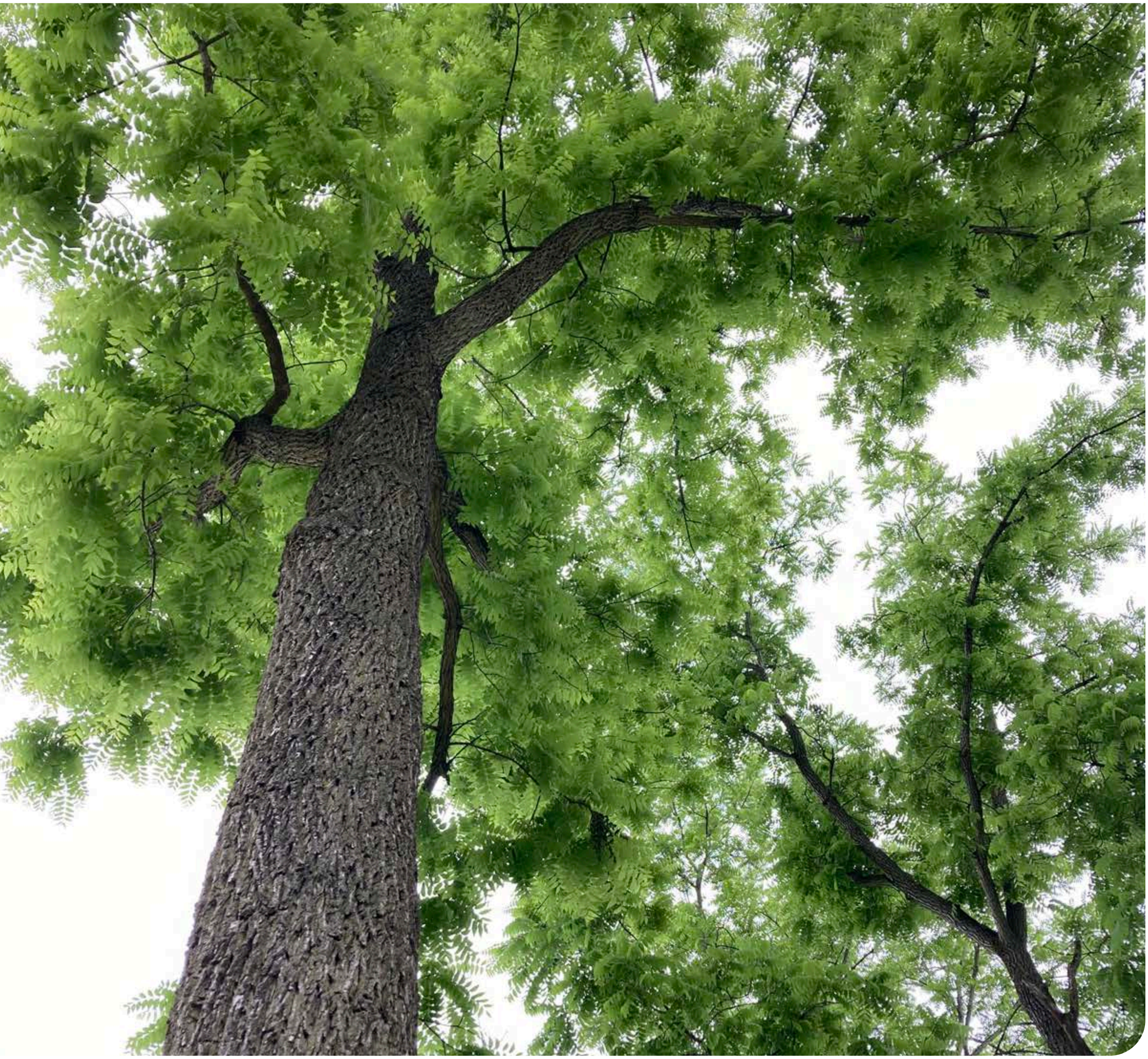
HTIRC
HARDWOOD TREE IMPROVEMENT & REGENERATION CENTER

2020 ANNUAL REPORT



Purdue University — Forestry and Natural Resources

Forest Service — U.S. Department of Agriculture

ABOUT HTIRC

The Hardwood Tree Improvement and Regeneration Center (HTIRC) was conceived in 1998 to address a perceived void in hardwood tree improvement research in the Central Hardwood Forest Region (CHFR) and is committed to enhancing the productivity and quality of CHFR trees and forests for the economic and environmental benefits they provide. Scientists at the HTIRC are using conventional tree improvement breeding as well as molecular and genetic technologies to improve the wood quality, growth characteristics, and insect and disease resistance of trees like black walnut, black cherry, red and white oaks, butternut and American chestnut. Research in tree breeding, tree nursery practices, tree plantation establishment and management, and Central Hardwoods silvicultural systems is aimed at increasing the regeneration success rate for high quality hardwood trees and forests.

Our mission is to advance the science and application of tree improvement, management, and protection of hardwood forests, with emphasis in the Central Hardwood Forest Region.

Hardwood Tree Improvement Center
Purdue University

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PERSONNEL

- Dr. Richard Meilan (Purdue FNR faculty member) announced his retirement effective January 1, 2020. We wish Rick the best in retirement!
- Dr. Anna Conrad (US Forest Service, Research Plant Pathologist) joined the HTIRC staff in November 2019. We extend a warm welcome to Anna and look forward to working closely with you.
- HTIRC lost a great supporter this year with the passing of Scott Brundage in August. Scott was a longstanding cooperator of the HTIRC and served on the Advisory Committee from the beginning. We are thankful for his service and are grateful for his contributions to forestry and the HTIRC.

RESEARCH

- HTIRC project-based funding model transitioned from academic year to fiscal year. The call for proposals this spring resulted in 10 submissions. The HTIRC Executive Committee selected 4 projects for funding that will start in July 2021.

OUTREACH/EDUCATION

- Technical knowledge transfer pivoted entirely onto virtual platforms this year. HTIRC extension staff, led by Lenny Farlee, produced an excellent series of videos on hardwood management that are posted on our website at https://htirc.org/resources/landowner-information/.
- Extension staff have also begun working on other landowner–oriented videos, in collaboration with Indiana Division of Forestry. The series is titled "Woodland Stewardship for Landowners."
- This year HTIRC had a PhD student, Andrea Brennan, successfully defend her dissertation. She has since moved on to a research position with the Morton Arboretum in Chicago. Congratulations, Andrea!

STAKEHOLDERS

AMERICAN CHESTNUT FOUNDATION: The goal of the ACF is to restore the American chestnut tree to our eastern woodlands to benefit our environment, our wildlife, and our society.

AMERICAN FOREST MANAGEMENT, INC.: The largest forest consulting and real estate brokerage firm in the United States.

ARBORAMERICA, INC.: Devoted to the development of genetically superior, intensively cultivated, fine hardwood plantings that are offered as a long-term investment opportunity.

FRED M. VAN ECK FOREST FOUNDATION: Supports our research program in hardwood tree improvement and regeneration efforts.

INDIANA DEPARTMENT OF NATURAL RESOURCES, DIVISION OF FORESTRY: The Division's mission is to manage, protect and conserve the timber, water, wildlife, soil and related forest resources for the use and enjoyment of present and future generations, and to demonstrate proper forest management to Indiana landowners.

INDIANA FORESTRY AND WOODLAND OWNERS ASSOCIATION: IFWOA's mission is to promote good stewardship of Indiana woodlands.

INDIANA HARDWOOD LUMBERMEN'S ASSOCIATION: A trade association whose members share a passion for creating the world's finest hardwood products and a determination to maintain the sustainable productivity of our nation's forest resources.

NATIONAL HARDWOOD LUMBER ASSOCIATION: NHLA's mission is to serve members engaged in the commerce of North American hardwood lumber through education, promotion, advocacy, and networking.

NELSON IRRIGATION: Recognized as a world leader in state-of-the-art water application products for agriculture and industrial applications.

STEELCASE, INC.: The global leader in office furniture, interior architecture and space solutions for offices, hospitals, and classrooms.

USDA FOREST SERVICE NORTHEASTERN AREA STATE AND PRIVATE FORESTRY: Collaborates with states, federal agencies, tribes, landowners, and other partners to protect, conserve, and manage forests and community trees across 20 Northeastern and Midwestern states and the District of Columbia.

WALNUT COUNCIL: A science-based organization that encourages research, discussion, and application of knowledge about growing hardwood trees.

RESEARCH TEAM

LEADERSHIP AND STAFF

Matthew Ginzel | *Director*
Janis Gosewehr | *Administrative Assistant*
Lenny Farlee | *Sustaining Hardwood Extension Specialist*
Elizabeth Jackson | *Engagement Specialist*
Weston Schempf | *Research and Communications Coordinator*
Lydia Utley | *Data Analyst*
Nathan Hilliard | *Laboratory Manager*
Patrick O'Neil | *Genomics Laboratory Manager*

PROJECT SCIENTISTS

Anna Conrad | *US Forest Service, Pathologist*
John Couture | *Entomology*
Songlin Fei | *Measurements & Quantitative Analysis*
Rado Gazo | *Wood Products and Industrial Engineering*
Brady Hardiman | *Urban Ecology*
Joseph Hupy | *School of Aviation and Transportation Technology, Purdue University*
Douglass Jacobs | *Forest Biology*
Michael Jenkins | *Forest Ecology*
Shaneka Lawson | *US Forest Service, Research Plant Physiologist*
Jingjing Liang | *Quantitative Forest Ecology*
Carrie Pike | *US Forest Service, Region 9 Regeneration Specialist*
Michael Saunders | *Forest Biology/ Ecology of Natural Systems*
Guofan Shao | *Forest Measurement and Assessment/GIS*
Keith Woeste | *US Forest Service, Molecular Geneticist*
Mo Zhou | *Forest Economics and Management*

POSTDOCTORAL RESEARCH ASSOCIATES

Rucha Karve
Indira Paudel
Christopher Smallwood
Andrei Toca
Zhaofei Wen

GRADUATE STUDENTS

Molly Barrett | *MS*
Sara Cuprewich | *MS**
Aziz Ebrahimi | *PhD*
Sayon Ghosh | *PhD*
Scott Gula | *MS*
Alison Ochs | *MS*
Brande (Bee) Overbey | *PhD*
Minjee (Sylvia) Park | *PhD*
Sarah Rademacher | *MS*
Summer Rathfon | *PhD*
Ben Rivera | *MS*
Kelsey Tobin | *PhD*
Rebekah Dickens Ohara | *PhD*
Geoffrey Williams | *PhD**
Recep (Rich) Yildiz | *MS*

* *van Eck Scholar*

TECHNICAL STAFF

Brian Beheler | *Farm Manager*
Don Carlson | *Forester*
Caleb Kell | *Research Forestry Technician*
James McKenna | *USDA Forest Service, Operational Tree Breeder*
Caleb Redick | *Research Associate*
James Warren | *USDA Forest Service, Biological Scientist/Operational Tree Breeder*
David Mann | *Research Assistant*
Rebekah Shupe | *Research Associate*

Despite the unprecedented challenges brought on by the pandemic, the HTIRC had a productive year, and our Annual Report details many of the ways the center worked to deliver on our mission in 2020. Through our project-based funding model, we are currently supporting 13 ongoing projects and look forward to funding additional projects in the coming year. In this Annual Report, we share second-year progress reports from our first round of funding and first-year reports from our most recently funded projects. The HTIRC Executive Committee reviewed and selected each of these for funding, and a special thanks goes to them for their vision and continued leadership and engagement. These key research projects directly serve our strategic research objectives and also reflect our commitment to serving the needs of our stakeholders. All of these projects have important and direct implications on our strategic objectives, particularly as we transition to a new digital and technology-driven era. Funding from the Fred M. van Eck Forestry Foundation continues to be strong, and we anticipate to be able to support additional research into the future.

This year also brought changes to the Center. Dr. Anna Conrad was hired as a Research Plant Pathologist for NRS-14 of the USFS Northern Research Station and HTIRC. Her research employs knowledge of the mechanisms underlying tree-pathogen interactions to develop practical, field-deployable tools to improve forest health and facilitate resistant tree breeding and disease management. Also, Dr. Rick Meilan retired from Purdue at the end of the year, and we are thankful for his many contributions in teaching, mentoring, scholarship and service to the HTIRC over his career. We wish him the very best on his retirement! Finally, we mourned the loss of Scott Brundage in August. Scott was a consulting forester in Missouri and a longstanding cooperator of the HTIRC, serving on our Advisory Committee since the beginning. We pay tribute to his life of service and are grateful for his contributions to the HTIRC.

We remain steadfast in our commitment to connect our partners, collaborators, and stakeholders with the people, information, and products of the center. In light of COVID-19, we explored new ways to engage stakeholders this year and used technology to deliver educational programs and extension products to a broad audience. In closing, I greatly appreciate the efforts of our advisory committee, staff, project scientists and students in supporting and conducting cutting-edge research that is relevant to all of you. I look forward to continue working together to advance the science and application of tree improvement, management, and protection of hardwood forests in the years to come.

Matthew Ginzel
HTIRC Director

HTIRC™
HARDWOOD TREE IMPROVEMENT
& REGENERATION CENTER

ACTIVITIES

The mission of the HTIRC is to advance the science and application of tree improvement, management, and protection of hardwood forests, with emphasis in the Central Hardwood Forest Region (CHFR). We seek to develop research and technology-transfer programs that provide knowledge focused on the establishment and maintenance of sustainable, genetically diverse native forests and the development of highly productive woodlands that provide a wide array of products and services.

HTIRC'S STRATEGIC PLAN ARTICULATES DIRECTIONS TO:

- Produce hardwood trees with desirable traits, using both classical tree breeding and novel tree improvement techniques.
- Improve management strategies and techniques to enhance the ecological sustainability and economic benefits of hardwood forests.
- Develop and demonstrate strategies to address existing and emerging threats to hardwood forests.
- Engage stakeholders and address their needs through communicating research findings and management recommendations.
- Educate future leaders in tree improvement, management, and protection of hardwoods.

Our research and development objectives are centered on the improvement, management, and protection of hardwoods in the CHFR. These objectives represent a balanced portfolio that includes low-risk projects that will provide short-term incremental gain and higher-risk projects that could lead to rapid and significant innovation.

We are also committed to connecting our partners, collaborators, and stakeholders with the people, information, and products of the HTIRC through our technology-transfer efforts. Our plan articulates a pathway by which we will engage a broad audience to explain the benefits of forest research, management, and tree improvement for people and the environment.

EXECUTIVE COMMITTEE

To help us deliver on our strategic objectives, a HTIRC Executive Committee was formed from members of our existing Advisory Board. Duties of the Executive Committee include the timely oversight of all HTIRC activities, as well as providing input to the FNR Department Head and HTIRC leadership in the form of recommendations as they relate to annual research budget allocations. The membership of the Executive Committee is as follows:

- John Brown *(Pike Lumber)*
- Dan Dey *(US Forest Service)*
- Jennifer Koch *(US Forest Service)*
- Dana Nelson *(US Forest Service)*
- Guillermo Pardillo *(ArborAmerica)*
- Jack Seifert *(Indiana DNR)*

The HTIRC at Purdue University, along with Oregon State University, co-founded the only forestry-based National Science Foundation (NSF) Industry/University Cooperative Research Center (I/UCRC). The NSF I/UCRC Center for Advanced Forestry Systems (CAFS) was established in 2006 to address challenges facing the wood products industry, landowners, and managers of the nation's forestland. CAFS originally included North Carolina State University, Oregon State University, Purdue University, and Virginia Tech. Since then, CAFS expanded to nine distinct university sites that include the above in addition to: Auburn University, University of Georgia, University of Idaho, University of Maine, and University of Washington.

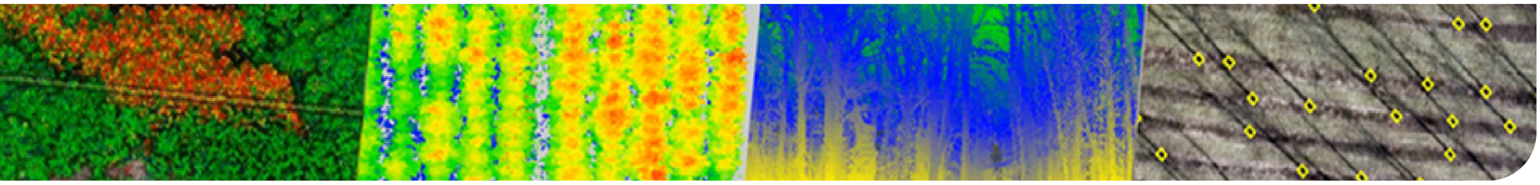
HTIRC Purdue has been part of CAFS during Phase I (2006-2011) and Phase II (2012-2017). At the end of 2019, NSF awarded our Phase III CAFS proposal, which will continue our involvement with CAFS until 2024. CAFS couples support of HTIRC partners with investments from NSF to support research projects that aim to solve complex, industry-wide problems. In addition to the funding support from NSF for CAFS, there is opportunity to apply to NSF for supplemental grants that support fundamental research and research experience for undergraduate students.

A CAFS Industrial Advisory Board (IAB) reviews ongoing and completed activities and selects new projects. In addition, the IAB provides input to NSF on the functioning of the Center. The IAB strongly influences the priority given to various research projects. Each university site appoints a representative to the IAB, which provides direction to CAFS's operation and research activities. Guillermo Pardillo, a member of the HTIRC Executive Committee, will serve as our representative to the IAB.

In CAFS Phase III, HTIRC Purdue is participating in three new collaborative research projects with partners across CAFS university sites. The HTIRC Purdue site is leading the first related to using hyperspectral imaging to evaluate forest health risk, which aligns with two current HTIRC-funded projects (PI John Couture). The second project involves assessing and mapping regional variation in site productivity, a project led by North Carolina State University, for which we are contributing from a current funded HTIRC project on soil suitability indices for black walnut (PI Shaneka Lawson). The third project deals with intraspecific hydraulic responses of commercial tree seedlings to nursery drought conditioning, which is led by the University of Idaho site, and the HTIRC Purdue site is participating with results for black walnut funded by a USDA NIFA grant (PI Douglass Jacobs). Funding from NSF CAFS will go to support additional projects that address CAFS research themes as part of our HTIRC project-based funding model.

NSF CAFS website: https://crsf.umaine.edu/forest-research/cafs/

INTEGRATED DIGITAL FORESTRY INITIATIVE (IDIF)



Advancements in digital technology have revolutionized society and daily life. Smartphones today put more computing power in our pockets than the computer onboard with the Apollo Mission. Yet studying and managing forest resources still primarily relies on antiquated, imprecise, and tedious tools like sticks and tape measures. These manual methods are costly in terms of time and labor and are inherent sources of error. More importantly, reliance on such traditional methods prevent us from taking full advantage of the critical services that forests provide (e.g., clean water, timber, fiber, and fuel) and limits our ability to minimize public hazards such as forest fire and pest outbreaks.

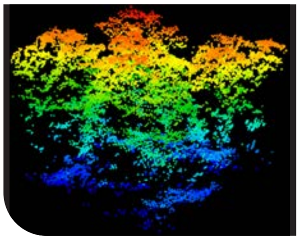
The overarching goals of Purdue's **iDiF Initiative** are: (1) to revolutionize forestry with an effective digital system for precision forest management that maximizes the social, economic, and ecological benefits of urban and rural forests, and (2) building globally competitive next-generation workforce for the information age. The **iDiF Initiative** will harmonize four key components of digital age technology – Internet of Things (IoT), Big Data, Artificial Intelligence (AI), Edge and Cloud Computing – to advance the following:

- AI-assisted automated **M**easurement with multi-platform and multi-scale data
- IoT, Big Data, and Edge and Cloud Computing-enabled precision forestry
- Large-scale forest health (fire, disease, disturbance) **M**onitoring
- Workforce education of digitally-competent **M**indset (undergraduate and graduate)

Forests support over 11 million jobs (one of the major employment opportunities in rural America) and over $77 billion in timber-based products across the U.S. economy. Forests also provide vital ecosystem services, including flood control, nutrient management, and recreational amenities. The major impacts of digital forestry include but are not limited to:

- Improved data and tools for management decisions and policy making
- Enhanced forest sustainability for timber & biomass supply, non-timber products, wildlife and recreation, water supply, and carbon sequestration, etc.
- Economic growth from timber as well as investment companies and small landowners
- Forest risk reduction (e.g., fire & disease outbreak) and mitigation
- Sustainable workforce development and employment in rural America, narrowing the digital divide
- Educated workforce for the information age

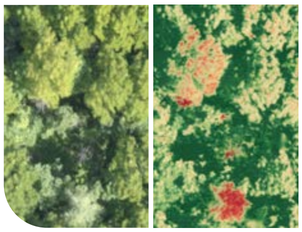
The iDiF Initiative is part of the Plant Science 2.0 of the Purdue Next Moves. The team consists of over a dozen faculty members from various nationally-ranked programs (Forestry and Natural Resources, Computer Graphics Technology, Electrical and Computer Engineering, Aviation Technology, Environmental and Ecological Engineering, Civil Engineering, and Information Studies) across multiple colleges. The team has various ongoing digital forestry-related projects (see next page for details). The team is supported by Purdue Research Computing that offers world-class cloud computing and a network of supercomputers optimized for GPU-based applications, such as Machine Learning.



3D structure from aerial LiDAR

AERIAL TREE INVENTORY WITH LIDAR AND UAS IMAGES

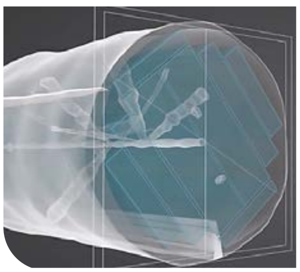
- AI-assisted automation of individual tree recognition and delineation
- Remote measurement of biometrics (size, biomass) in planted and natural forests



Pair of forest images showing stress early detection (red color)

MONITOR STRESS EPIDEMIOLOGY

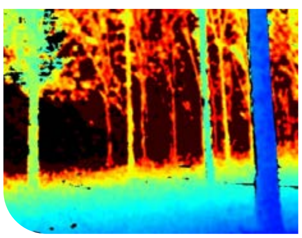
- Detection and tracking pest insect and pathogen incidence with machine learning on multi-temporal data
- Monitoring drought symptoms with multi-sensor platforms



Glass-view log from CT-scanning

PRECISION MANAGEMENT

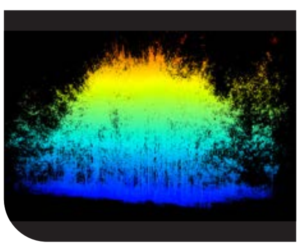
- Geo-referenced and image-assisted biometric evaluation for precision tree growth and yield modeling
- Log and lumber processing optimization with CT scanning



Digital depth view from LOGS

AUTOMATED TREE INVENTORY WITH PHOTOGRAMMETRY

- Low-cost Optical Gauging System (LOGS) with stereo cameras and machine learning for speedy automated tree measurement



Terrestrial LiDAR for tree structure

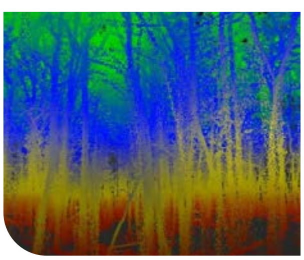
TREE HEALTH & QUALITY ASSESSMENT WITH LiDAR

- Ground-based LiDAR for precision tree structure characterization
- Analytical framework to assess quality and health of hardwoods on LiDAR data

Detection of fire disturbance (dark colored squares)

UAS DISTURBANCE DETECTION

- Feature-based high-resolution classification on multi-temporal data for planned and unplanned disturbance (fire, wind-throw, and logging)



High-res LiDAR for tree inventory

LiDAR FOR HIGH-RESOLUTION FOREST INVENTORY

- Backpack/UAS system/platform and algorithms for fine-detail, automated measurements and trait characterization for forest plantations

IMPROVING ESTABLISHMENT PRACTICES OF PURE AND MIXED HARDWOOD PLANTATIONS BY REFINING SOIL SUITABILITY INDICES FOR BLACK WALNUT

INVESTIGATOR(S)

- **Shaneka Lawson,** *Research Plant Physiologist, USDA Forest Service (USDA-FS), Adjunct Assistant Professor, Purdue University*
- **James Warren**, *Biological Scientist, USDA Forest Service*

PROJECT OBJECTIVES

Improving establishment practices of pure and mixed hardwood plantations by refining soil suitability indices for black walnut.

- Test the framework of the Wallace & Young (NRCS) black walnut suitability index at three black walnut planting sites.
- Intensively sample soils at three black walnut and three Northern red oak sites to obtain physiological data.
- Investigate and analyze soil data in conjunction with planted black walnut family data to look for trends.

ABSTRACT

Black walnut forestry within the Central Hardwoods Region (CHR) has progressed primarily based on studies of trial and error among plantations. Although black walnut wood has been used for everything from gunstocks in the Revolutionary War to the finely crafted furniture of today, gaps exist in our knowledge base regarding the most efficient methods of growing this prized wood. Increased temperatures, insect pests, and numerous issues regarding planting site suitability have hindered our ability to consistently produce the most desirable nuts, lumber, and veneer. While considerable information regarding walnut growth remains anecdotal, researchers at the Hardwood Tree Improvement and Regeneration Center (HTIRC) have collected data regarding growth and performance of walnut families placed into both plantations and seed orchards. Remiss in those data were comprehensive soil studies to evaluate whether nutrient accumulations or other soil characteristics assisted with the observed superior growth of certain trees included in the study. As soils are composed of mixtures of clay, organic matter, sand, and silt, combinations of these materials can lead to a pH-balanced, nutrient-rich environment across or in pockets of a site. Superior trees planted in shallow, nutrient poor-soils likely demonstrate poor growth and may be removed from a breeding program unwittingly. Information gained from this proposal can increase planting success, help inform thinning decisions, and likely lead to greater economic values gained from timber stands and seed orchards.

APPROACH

STUDY SITE DESCRIPTIONS

- Seven ≥0.5 Ha sites (4 black walnut, 3 Northern red oak; 5 Indiana, 2 Michigan)
- Local temperature and precipitation data will be obtained from the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information, National Weather Service, and Climate.gov sites (https://www.ncei.noaa.gov/, https://www.weather.gov/ind/, https://www.climate.gov/maps-data/dataset/past-weather-zip-code-data-table) to exclude effects from weather anomalies and other natural disasters (tornado, unprecedented flooding, etc.).
- Soils initially described using the NRCS Global Soils Regions map (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/use/?cid=nrcs142p2_054013).
- The Natural Resources Conservation Service (NRCS) in Indiana Soils site, the Web Soil Survey and joint

Purdue University – US Department of Agriculture integrative soils map for Indiana the (https://www.nrcs.usda.gov/wps/portal/nrcs/in/soils/, https://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx, https://soilexplorer.net/) will be used to classify soils.

MODEL EVALUATION

- The Wallace and Young model presumes black walnut tree heights can be used to predict soil depth.
- Cross validation will be used for model evaluation.
- Results from this study could have **major** implications for future forest management and plantation development plans.

SITE AND STAND DATA TO INCLUDE

- Height data and site characteristics such as pH, soil depth (divided by organic layer and horizon), soil texture, bulk density, and nutrient loads (N, P, K).
- Climate data (temperature and precipitation) and proximity to active crop fields.

STATISTICAL ANALYSES OF TRAITS

- Independent and comparative site regression analyses
- Analyses performed in SAS or R (https://cran.rproject.org/web/packages/asremlPlus/index.html).

KEY FINDINGS/ACCOMPLISHMENTS

PROJECT PROGRESS

- All sites have been visited with 100% of samples submitted for analysis* (COVID-19 related lab closure)
- Data from 2 sites (1-walnut, 1-northern red oak) have been received and graphed with GIS
- A number of evaluated traits show variability

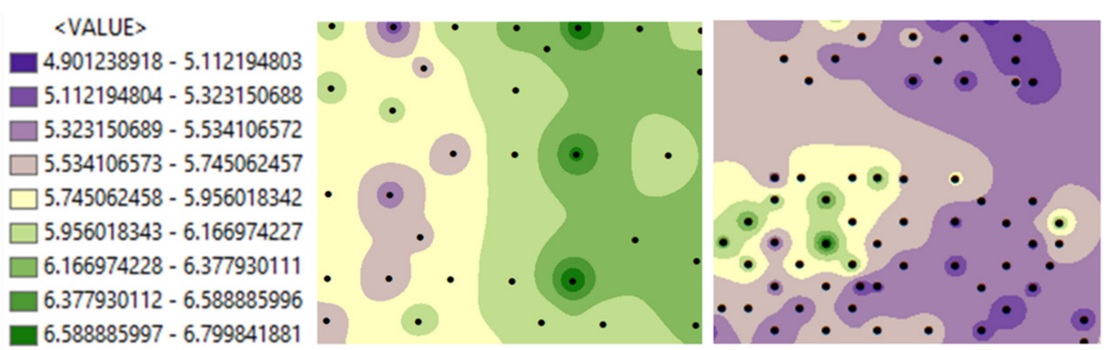


Illustration of pH variability within and between sites.

DISSEMINATION / EXTENSION EFFORTS

- Six presentations of the project (2 HTIRC, 2 NC State, 1 Mississippi State, 1 New York Park Service)
- One modified presentation to a high school (Purdue Polytechnic High School)
- Nine selected highlights: (2 Forest Service featured highlights (NRS and FS homepages), 2 NRS Twitter highlights, 2 Purdue FNR Facebook and department highlights); 3 newsletter articles (1 HTIRC and 2 (1 local, 1 International) Black Sorority newsletters)
- Two virtual field presentations to interested parties at NC State

FUTURE PLANS

DISSEMINATION / EXTENSION EFFORTS

- Perform comparative analyses of findings with walnut and northern red oak to poor, marginal, and good soil sites to provide proof of concept.
- Presentations: (Northeastern Area Association of State Foresters Forest Utilization Committee, International Wood Collectors Society Great Lakes, and the Walnut Council [multiple states]).
- Overlay new soil analyses with coarse soil maps from the United States Department of Agriculture Soil Conservation Service.

PARTNERS/COLLABORATORS

PARTNER AND STAKEHOLDER GROUPS

- Walnut Council, Tree Farm, Society of American Foresters, various forestry and woodland owner organizations and agencies

COLLABORATING INVESTIGATORS

- **Carolyn "Carrie" Pike,** *Regeneration Specialist, USDA-FS, Northeastern Area State & Private Forestry, Forestry and Natural Resources, Purdue University*
- **Lenny Farlee,** *Sustaining Hardwood Extension Specialist, Forestry and Natural Resources, Purdue University*
- **James "Jim" McKenna,** *Operational Tree Breeder, USDA-FS, NRS, Forestry and Natural Resources, Purdue University*
- **John Kabrick,** *Research Forester, USDA-FS, NRS, Department of Agriculture, Food and Natural Resources, University of Missouri-Columbia*
- **Shalamar Armstrong,** *Assistant Professor, Department of Agronomy, Purdue University*
- **Mary Beth Adams,** *Research Soil Scientist, Emeritus, USDA-FS, NRS, Morgantown, WV*

USING TERRESTRIAL LASER SCANNING TO ASSESS TREE HEALTH AND QUALITY (IDIF)

PRINCIPAL INVESTIGATORS:

- **Brady S. Hardiman**, *Assistant Professor, Forestry and Natural Resources, Purdue University, (bhardima@purdue.edu)*
- **Songlin Fei**, *Professor, Forestry and Natural Resources, Purdue University*

PROJECT OBJECTIVES

- Develop a suite of tools including affordable, off-the-shelf TLS hardware and user-friendly analytical software that will ingest TLS data and output metrics of stand inventory and tree quality and health that are of interest and utility to both researchers and industry professionals.
- Evaluate the ability of TLS to reliably quantify tree and stand level indicators of quality and health.
- Share tools and methods with HTIRC researchers and stakeholders in trainings and workshops.

ABSTRACT

In July/August 2020, we completed a third round of data collection at Martell in plots varying in species composition and planting density (Figure 1) using the Leica BLK360 terrestrial laser scanner (TLS). Annual scans of forest structure will allow us to identify patterns in the development of canopy structure and how competition and stand diversity after this developmental trajectory.

We formalized our ongoing collaboration with Dr. Jian Jin (Purdue ABE) who is leading the development of an analytical workflow to derive a suite of structural metrics related to tree health and quality. The multiple years of data we have collected contribute to a robust and growing dataset for the development and refinement of a generalizable, automated workflow to extract structural features indicative of tree health and quality. This workflow uses contemporary machine-learning methods that will allow sophisticated analysis of LiDAR point clouds that can provide essential, usable information to forest managers. While this research-grade workflow is still in development, it will eventually be integrated into a user-friendly platform that can be distributed to HTIRC stakeholders and collaborators.

APPROACH

- We will develop methods to assess the health and quality of trees and to inventory stands using data acquired from TLS systems. The efficacy of these methods will be evaluated by comparing to conventional forestry mensuration techniques.
- **Field Measurements:** Our study will be conducted using HTIRC plantations of important hardwood species throughout Indiana. We will select plantation sites based on the availability of forest inventory data and existing assessments of health and quality. We will partner with HTIRC members and stakeholders to conduct additional field measurements within plantations using conventional methods and evaluation criteria to assess tree health and quality. Tree attributes (Table 1) will be measured with standard forest inventory tools (diameter tapes, clinometer, laser range finder, etc.) available in the Hardiman lab.
- **Terrestrial Laser Scanner:** TLS data will be acquired using a Lecia BLK360 Scanner (Lecia Geosystem AG), currently available in the Hardiman Lab. The scanner emits infrared laser pulses to measure distance from the scanner while it slowly rotates. The resulting point cloud can contain up to 80 million points each at sub centimeter resolution (6mm accuracy at 10m); these scans will be used to produce a high-resolution digital rendering of each tree in a stand. The measurement speed of the scanner is less than 3 minutes for a full hemisphere scan at the highest resolution setting, including co-registered spherical color and thermal images, reducing time spent conducting field measurements. Early tests of the TLS system accuracy suggest an average difference of <5mm between TLS-based estimates of stem diameter and those obtained from a diameter tape. For comparison, multiple people using diameter tapes to measure the same tree often obtain values that differ by at least this much.
- We will collect TLS scans in both leaf-off season, when foliage will not be an obstacle for measuring tree stem attributes, branch size, and top of the tree, and during the growing season when we can observe tree health from leaves that reflect different amounts of energy based on health conditions. In addition to structural data obtained from the LiDAR capabilities of the BLK360, the instrument also has three calibrated digital cameras that allow it to collect panoramic, high-resolution hemispherical color images, and panoramic thermal images with an integrated infrared sensor. Traditional vegetation indices (such as NDVI and EVI) can be generated using these combined images; a tree health map will be developed based on tree characteristics, such as leaf color and temperature, and crown condition.
- **TLS Analytical workflow:** The limiting factor in successful use of TLS technology to assess forest health and quality from stem to stand is in the extraction of meaningful information from the raw 3D point clouds these instruments generate. We will develop an automated analytical workflow that will ingest 3D point cloud data from TLS systems and from it generate stand inventory data including height, stem numbers, diameter distribution, etc. Our longer-term goal is to expand this automated processing software to also calculate tree attributes that are indicative of health and which contribute to/detract from eventual timber quality (Table 1). We will recruit 1 PhD graduate student and undergraduate students with backgrounds in engineering, computer science, and 3D animation to develop user-friendly tools that can be distributed widely for application of TLS technology in forest management and tree improvement. PIs Hardiman and Fei have extensive experience deriving useful forest information from remote sensing technologies and in mentoring students in these skills, especially LiDAR. Hardiman and Fei are currently collaborating on using the BLK360 to characterize the 3D distribution of leaves and branches within the canopy volume and linking these assessments of canopy structural complexity to light interception, which drives forest growth rates.

KEY FINDINGS /ACCOMPLISHMENTS

- New TLS data were acquired at Martell Forest in summer 2020, employing a new deployment schema that allows registration of LiDAR point cloud features with specific trees in each plot. This approach is a necessary and important advance over previous methods, which produced data that were agnostic to the orientation of the point cloud with respect to the plot layout. The new data will allow more detailed ground truthing of features extracted from TLS data.
- Our analytical workflow in development can, from an undifferentiated 3D point cloud, identify individual stems and estimate diameter, biomass, height, stem straightness, and taper (Figure 3). This workflow can quantify these features with accuracy that meets or exceeds conventional, manual methods while increasing replicability and reducing variation arising from repeat observations by multiple different people. We are working to refine this workflow to improve automation and ease of use and will continue adding capability to quantify new features indicative of tree health and quality.

FUTURE PLANS

- We are expanding and deepening our ongoing collaborations with research teams throughout the College of Engineering. These teams possess substantial expertise in machine learning methods for feature extraction and quantification as well as in development of processing and analysis workflows. In particular, the feature extraction component of this workflow will not only aid in quantification of tree health and quality, but will be useful for a related project led by Dr. Ayman Habib, who is developing a backpack-mounted terrestrial LiDAR system. This system uses integrated GPS to locate and identify individual trees, but the accuracy of GPS when operating under a canopy is reduced. We are coordinating our efforts to use feature recognition (based on our feature extraction) to improve spatial location and mapping (SLAM) capacity with the backpack system.
- In summer 2021, we will collect lidar data from additional HTIRC planted stands that represent a wider array of species, ages, tree health, and management conditions to test our workflow. We will begin testing the accuracy of our workflow outputs against conventional manual methods for quantifying these same indicators of tree health and quality.

PARTNERS/COLLABORATORS

- **Ayman Habib,** *Professor, Civil Engineering, Purdue University*
- **Gord McNickle,** *Assistant Professor, Botany and Plant Pathology, Purdue University*
- **Jian Jin,** *Associate Professor, Agricultural and Biological Engineering, Purdue University*

NATURAL AND ARTIFICIAL REGENERATION GROWTH RESPONSE OF WHITE OAK ACROSS LIGHT AND UNDERSTORY COMPETITION GRADIENTS (YEAR 2)

PRINCIPAL INVESTIGATORS:

- **Mike Saunders,** *Associate Professor, Forestry and Natural Resources, Purdue University, (msaunders@purdu.edu)*
- **Mark Coggeshall,** *Adjunct Assistant Professor, College of Agriculture, Food & Natural Resources, University of Missouri*
- **Molly Barrett,** *Master's student, Forestry and Natural Resources, Purdue University*

PROJECT OBJECTIVES

- Compare the interacting effects of prescribed fire and expanding group shelterwood systems on short-term natural regeneration response of oak species; and
- Compare the short-term effects of light levels and competition control on underplanted white oak of several controlled seed sources.

ABSTRACT

Prolonged regeneration failures of white oak (*Quercus alba*) are leading to conversion of many oak-hickory stands into more mesic species, and general decreased resilience of Central Hardwood forests to climate change. While natural regeneration patterns of white oak have been studied for decades, surprisingly few studies have investigated artificial regeneration of the species in natural forests through enrichment and/or underplanting. This research seeks to both investigate natural and artificial regeneration responses to a gradient of light and understory competition gradients in a natural forest setting.

To document natural regeneration responses, more than 400 permanent plots and 160 gap-based transects were sampled in an existing long-term silvicultural trial of expanding group shelterwood systems during summer 2020 (Figure 1). Overstory tree, sapling, and seedling densities were quantified both by species and by location within the gap or forest matrix. Data have been entered and proofed; summary and analysis began in spring 2021. Early results suggest that stocking of competitive oak has waned from that reported by Skye Greenler from two years after overstory harvest (Figures 2 and 3).

To document artificial regeneration responses, an underplanting study is being overlain on newly harvested replicates of the expanding group shelterwood study. Seedling from three seed sources were grown at the Vallonia State Tree Nursery; at least 440 (22% germination rate), 375 (19%), and 715 (28%) viable seedlings were produced from Illinois, Arkansas, and Indiana sources, respectively (Figure 4). In addition, 2-0 white oak from the Wilson State Nursery in southwestern Wisconsin was purchased for this study. Planting sites were selected in February 2021 and are currently being prepared (i.e., fencing, planting locations, slash removal) for underplanting in April 2021.

APPROACH

- Expand an existing silvicultural study and document longer-term natural regeneration patterns in response to prescribed fire and varying levels of overstory harvest.
- Collect white oak seed from multiple geographic sources to allow comparison of broad-scale climate impacts.
- Underplant 1-0 and 2-0 white oak stock into plots overlaying the silvicultural study, thereby creating a gradient of overstory light levels and understory competition levels (through active weeding).
- Track survivorship and growth of white oak seedlings over at least 5 years.
- Identify ideal combinations of residual overstory density/shade and duration of weed control that lead to successful underplantings of white oak.

KEY FINDINGS

Preliminary results from gap-based transects and permanent monitoring plots show that tulip poplar and white oak are the most abundant species on south-facing slopes. Proportionally, tulip polar represented 50% of the large seedlings (60 cm tall to 1.5 cm DBH) and oaks represented 10% (Figure 2), split mostly among white (61%), black (21%), northern red (13%) oak species. Forty other species comprised the remaining 40% of seedlings measures. On north-facing, more mesic sites, tulip poplar regeneration comprised 56% of stems (Figure 3), while oaks decreased to only 2%. Thirty-two other species comprised the remaining 42% on these sites.

FUTURE PLANS

- Conclude the analysis and prepare a manuscript of 5-year regeneration response of replicates 1 and 2 as part of a M.S. thesis (to defend in fall 2021).
- Install four experimental plantings at NSA Crane and one demonstration planting at Lugar Farm (Figure 5) in spring 2021. Maintain weed control and periodically measure seeding survival and growth through Summer and fall 2021.
- If white oak survival is high in underplanted plots (i.e., low need for re-plants), prepare harvests at Southern Indiana Purdue Agricultural Center, Miller, and an unnamed local site for expansion of underplanting study in spring 2022 or 2023.

PARTNERS/COLLABORATORS

This work is also supported by a cooperative agreement with the U.S. Department of the Navy (Cooperative Agreement Number N62470-19-2-4014) and by the USDA-NIFA McIntire-Stennis Cooperative Forestry Research Program (Project: IND011557MS). We thank the staff of the NSA Crane Environmental Team, most notably Rob McGriff and Trent Osmon, for conducting the shelterwood harvests, providing regulatory oversight, and helping with fieldwork logistics. We also thank Jim McKenna and the staff of the Vallonia State Tree Nursery for their help in producing the seedlings for the underplanting study.

FIGURES

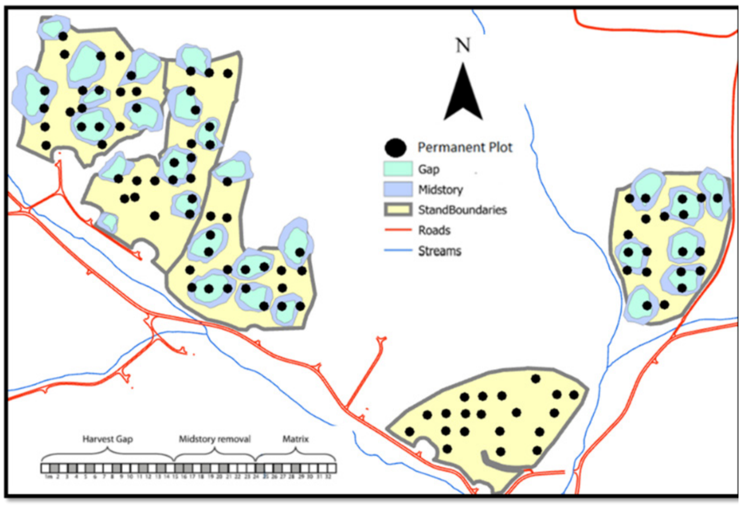


Figure 1. Map of one replicate of expanding group shelterwood study. Harvested groups can have half or all trees removed; groups are surrounded by an area where midstory trees have been also removed. Both permanent plots and temporary harvest gap transects (only shaded quadrants within inset figure) were measured in Summer 2020.

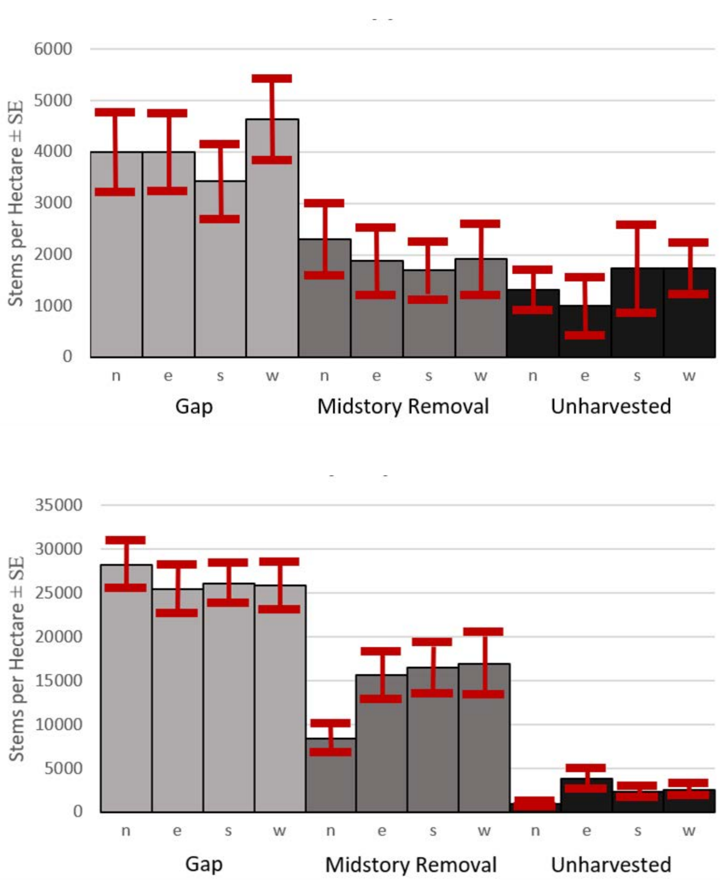


Figure 2. Mean (±standard error) stems per hectare of large seedlings (60 cm tall to 1.5 cm DBH) for oak species (top) and tulip poplar (bottom) on south-facing slopes, 5 years after group shelterwood harvest. Please note differences in y-axis scale.

Figure 3. Typical regeneration response of tulip poplar and other aggressive species after 5 years within the harvested groups, particularly on mesic, north-facing slopes.

Figure 4. Oak seedlings (with a volunteer cottonwood) in a bed at the Vallonia State Tree Nursery being used in this study. Seed sources planted are from Indiana, Illinois and Arkansas and were lifted as 1-0 stock in March 2021. Older 2-0 stock from Wisconsin will also be used in the underplantings.

Figure 5. Early picture of the demonstration planting at Lugar Farm (as of March 2021). Deer fencing is using a combination of wooden posts and t-posts that are overlain with 1.5" PVC pipe.

PRODUCTIVITY-DIVERSITY RELATIONSHIPS IN HARDWOOD PLANTATIONS

INVESTIGATOR(S)

- **Douglass F. Jacobs**, *Fred M. van Eck Professor, Forestry and Natural Resources, Purdue University, (djacobs@purdue.edu)*
- **John Couture**, *Assistant Professor, Entomology, Forestry and Natural Resources, Purdue University*
- **Lenny Farlee**, *Sustaining Hardwood Extension Specialist, Forestry and Natural Resources, Purdue University*
- **Brady Hardiman**, *Assistant Professor, Forestry and Natural Resources, Purdue University*
- **Gordon McNickle**, *Assistant Professor, Botany and Plant Pathology, Purdue University*

PROJECT OBJECTIVES

- Characterize the productivity-diversity relationship in the mixed species experiment, partitioning productivity into leaves, wood and roots.
- Determine if and how functional traits that drive competitive interactions change with diversity and tree density.
- Disseminate our findings to HTIRC stakeholders and professionals through extension field days and programming.

ABSTRACT

Productivity and species diversity are correlated, but the mechanistic causes of the productivity-diversity correlation remain unresolved. Mixed species plantations should be more economically productive than single species plantations, but it is currently not possible to predict how many (and which) species should be planted to maximize timber production and economic value. Indeed, the productivity-diversity relationship shows that the same number of species can produce very different production outcomes, suggesting the importance of selecting compatible species and applying effective management. Rigorous field experiments are needed to examine mechanisms supporting this relationship. Using a 13-year-old experiment of three fine hardwood species planted as monocultures and species mixtures at varying densities, we are characterizing the productivity-diversity relationship over three growing seasons by studying functional, chemical, and structural traits, as well as above- and below-ground productivity. An improved understanding of the productivity-diversity relationship in mixed hardwood stands will generate plantation management advice; we will disseminate findings to landowners in the Midwest with extension field days and programs. In 2020, 3 HTIRC graduate students continued their research on this project: Kliffi Blackstone (PhD, McNickle) is evaluating leaf litter, tree growth, dendrochronology, and physiological traits. Madeline Montague (MS, Jacobs) is studying belowground processes. Taylor Nelson (MS, Couture) is examining canopy processes. We also continued collection of environmental data and 3D TLS (Terrestrial Laser Scanning) repeat scans in 2020.

APPROACH

NET PRIMARY PRODUCTIVITY (NPP)

- Partitioning NPP into leaves, stems and roots
- For contemporary stem growth, measurements of tree diameter at breast height (DBH) in 2017, 2018 and 2019 were taken
- To estimate growth back to the initial planting date in 2007, basal wood cores from three trees of each species per plot were taken, and dendrochronology is used to estimate NPP
- The area of each tree ring as a basal area increment (BAI) was calculated and used to estimate the productivity-diversity relationship

ROOT PRODUCTIVITY AND NON-STRUCTURAL CARBOHYDRATE (NSC) STORAGE

- Belowground productivity rates are quantified by isolating a single year of root growth using polypropylene mesh ingrowth cores
- 112 ingrowth cores were installed in October-December 2018 and were retrieved at the same time in 2019
- Root samples were extracted from soil, weighed and ground with liquid nitrogen; the proportion of roots from each species in each soil core layer was quantified using quantitative PCR
- Tracked NSC concentrations throughout American chestnut (leaves, branches, bole, and roots) to characterize seasonal NSC dynamics, and scaled concentration measurements to pool sizes using a custom-built allometric model

Mesh ingrowth cores

Ingrowth core incubating in the field.

Roots and mycorrhizae extracted from ingrowth cores.

CANOPY PROCESSES

- Midseason green-leaf samples, in addition to weekly senescent leaf material, were collected. Samples were flash frozen, freeze dried, and milled into powder before being tested for nitrogen content via combustion reaction, and nitrogen resorption efficiencies (NRE) was calculated to determine the influence of biodiversity and competition
- To estimate the influence of biodiversity and competition on canopy chemical profiles and insect feeding behavior, foliar tissue was collected at three time points (June, August, and October) in 2018 and 2019. All samples are flash frozen, freeze dried, and milled into powder and stored for further chemical analyses.
- To assess canopy damage, we imaged the October foliar collections and calculated the percent missing tissue. Insect material fluxes (frass, or fecal material, and green leaf material produced from incompletely consumed leaf material) were collected monthly from May to October.

ENVIRONMENTAL EFFECTS

- HTIRC funds were leveraged, in May 2019, to upgrade dataloggers network to a new model capable of uploading data in real time.
- Solar-powered dataloggers run a suite of sensors that measure light, air temperature, relative humidity, volumetric soil water, and soil water potential at 5-minute intervals running continuously since early June 2019
- Measurements are uploaded to the cloud daily via cellular uplink and are available to all project researchers through a web interface.
- Leica BLK360 terrestrial laser scanner (TLS) used to acquire a second round of 3D LiDAR point clouds from the center of each of 63 plots in the study design

KEY FINDINGS

NET PRIMARY PRODUCTIVITY

- The relationship thus far was not positive, as is common
- Lack of a positive relationship between diversity and productivity in our plots creates an unexpected but testable hypothesis that there are not niche differences among our species
- Using a relatively new branch of theoretical ecology called "modern coexistence theory" (MCT) revealed small niche differences among the three species used in this study
- That discovery implies that density impacts competitive strategies, and this is heightened when compounded with diversity

ROOT PRODUCTIVITY AND NSC STORAGE

- Found that coarse roots were the largest and most dynamic NSC pool
- Additionally, there was a strong planting density × species composition interaction for chestnut root NSC pools, indicating that neighbor identity affects NSC storage

CANOPY PROCESSES

- Our findings suggest that as diversity increases, trees become less efficient at resorbing nitrogen during senescence, and more so when competition (i.e., plant density) decreases. These responses, however, vary among species
- Outcomes suggest that trees adjust physiological process to conserve foliar nitrogen, opposed to losing it in leaf litter, when in the presence of other individuals who take up soil nitrogen in a similar manner
- Results from 2018 and 2019 suggests that patterns of canopy damage, while low (although characteristic of damage levels of endemic insect herbivore populations), vary among levels of diversity and competition

ENVIRONMENTAL EFFECTS

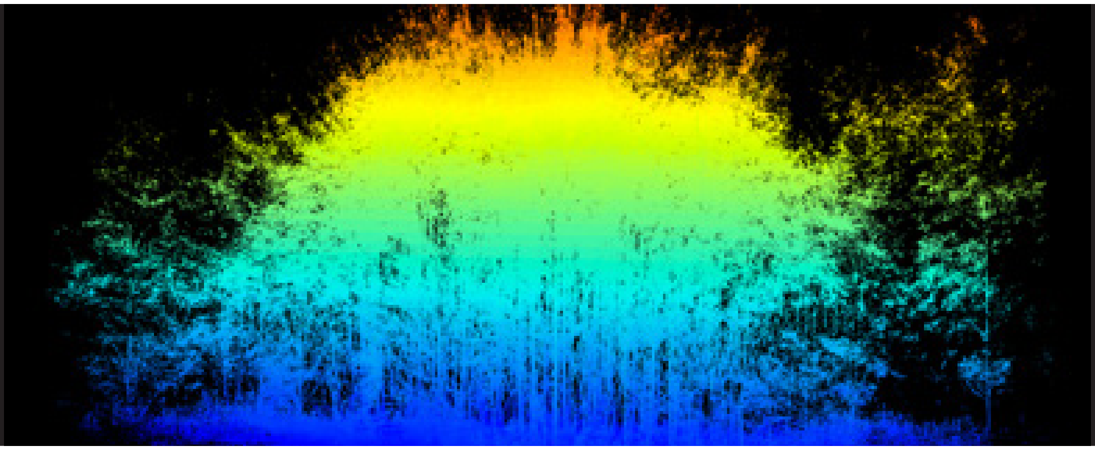
- Data are being processed in collaboration with Dr. Jian Jin (Purdue ABE) to derive structural features of interest including diameter, height, leaf area, and other metrics of tree growth and wood quality

FUTURE PLANS

NPP

A new project was begun in 2020 that considers the effect of plant-soil feedback in order to address the question, *"What is the species diversity of the understory ground canopy, and is this affected by the density and diversity of the tree species planted there?"* The hypothesis is that a decrease in density with an increase in tree diversity should give way to a larger variety of understory species, as the tree species would alter the biotic and abiotic soil community, but with more tree diversity there is also a complex soil trophic interaction, biota diversity, and thus trait diversity. Data is under analysis, but preliminary results suggest potential growth difference between treatments. Seeds from the quadrants were also collected for a comparable greenhouse experiment to occur in 2021.

We will continue to estimate productivity using the aforementioned NPP response variables. It is possible that the diversity–productivity relationship may change through time. These results deviate from our initial hypotheses, but we believe that they provide important insight into the development of mixed species forest plantations. Specifically, we think we can develop methods to identify species mixtures for which we would expect a positive diversity-productivity relationship, or a negative/absent diversity-productivity relationship. We can then use this knowledge to develop recommended species mixes that would increase timber production.



Terrestrial LiDAR data acquired from the mixed species stands.

UNDERSTANDING AND MANIPULATING PLANT-SOIL FEEDBACKS TO MANAGE THE INVASIVE SHRUB *LONICERA MAACKII*

INVESTIGATOR

- **Michael Jenkins**, *Professor, Forestry and Natural Resources, Purdue University, (mjenkins@purdue.edu)*

PROJECT OBJECTIVES

The overall objective of this research project is to determine the role of pathogens and AM fungi in driving or inhibiting *Lonicera* invasion in hardwood forests.

- Predict soil biotic characteristics that favors *L. maackii* invasion
- Determine the sharing of belowground pathogens and arbuscular mycorrhizal fungi between *L. maackii* and native plant species
- Measure nutrient transfer from *L. maackii* to native seedlings as a function of season of treatment.

ABSTRACT

After we completed our first field sampling in five sites near West Lafayette in October 2019, soil samples were brought back to the Université de Montréal and kept in cold storage for use as microbial inoculum for a greenhouse experiment, and seeds extracted from *L. maackii* fruits were germinated to produce plants for a greenhouse experiment that was initiated on March 28, 2020. We grew seven pseudoreplicates for each of the 50 soil inocula (10 replicate soil samples x 5 sites) for a total of 350 pots. Plants were grown in the soil inocula for 5 months and harvested to separate shoot and root biomass. Shoots were air-dried and weighed to quantify *L. maackii* performance. We have scanned over a third of the root systems to quantify total root length production and average root diameter; this effort is ongoing. After scanning, root subsamples will be examined under the microscope for colonization by fungal endophytes (pathogens and mutualists). In July, we will begin extracting DNA from another subsample to characterize molecular structure of the root microbiome and determine whether pathogen loads are higher in more heavily invaded sites. Extractions will be completed in September 2021.

APPROACH

In our study, employees controlled greenhouse experiments to examine belowground relationships between *L. maackii* and its native competitors. Our experiments are constructed using plant material and soil collected from invaded sites. We also use multiple laboratory analyses to examine individual plant responses to experimental treatments and quantify the response of the belowground microbial community to treatments.

KEY FINDINGS

Our study is ongoing, and we need to complete experiments before we will have results to share.

FUTURE PLANS

Our study has been greatly affected by the pandemic-caused closing of the Canada-US border. While all the field collecting is done locally in Indiana, all of the experiments are conducted in Canada. In 2020, co-PI Chagnon was unable to travel to Indiana to collect field samples for our next round of experiments. With the border still closed, and the field season rapidly approaching, we are planning to have PI Jenkins collect field soil and root samples under the remote supervision of Chagnon and measure cover of the herbaceous layer by species. We will also collect seeds from ectomycorrhizal (two *Quercus* species, *Tilia americana, Carya* spp.) and arbuscular (*Fraxinus americana, Acer saccharum, Gleditsia triacanthos,* and *Juglans nigra*) native tree species for an experiment to address objective 3. Our ability to collect samples in Indiana for use in Canada is dependent on our ability to ship soil and plant material across the international border. We are currently checking with UPS to determine weight limits and the process to submit a copy of our permit for their review. Unfortunately, the specialized facilities and equipment needed to conduct the experiments for this study are not available to the PIs at Purdue.

PARTNERS/COLLABORATORS

- **Pierre-Luc Chagnon (Co-PI)**, *Université de Montréal, Institut de Recherche en Biologie Végétale, Montréal, Canada*

This project is a collaborative effort between the HTIRC and Université de Montréal, Institut de Recherche en Biologie Végétale.

TREE INVENTORY WITH AERIAL REMOTE SENSING (IDIF)

INVESTIGATOR(S)

- **Songlin Fei**, *Professor, Forestry and Natural Resources, Purdue University, (sfei@purdue.edu)*
- **Guofan Shao**, *Professor, Forestry and Natural Resources, Purdue University*

PROJECT OBJECTIVES

- Develop tools for automated detection and delineation of individual trees and measurement of biometrics for hardwood species using low-density aerial LiDAR. Tools developed from this objective can be applied at stand, landscape, and possibly state level using freely available aerial LiDAR.
- Develop algorithms for automated detection and delineation of individual trees and measurement of biometrics for hardwood species using UAS orthophotos. Tools developed from this objective can be applied on the stand level and can be employed cheaply and as frequently as the user desires.
- Disseminate tools to stakeholders and managers. We will coordinate with other iDiF projects to disseminate our developed tools and products to HTIRC stakeholders and other natural resource managers.

ABSTRACT

Sustainable forest management and precision tree improvement require detailed inventories of tree quantity and quality to support decision-making processes. Accurate forest inventory information can significantly impact the potential for forest resources to meet economic and ecological needs. Forest inventory data is currently collected using manual field sampling techniques, often relying on observations by trained experts, introducing substantial sources of error and reducing reproducibility of data collection effort. Recent technological advances offer new methods and techniques that can increase the accuracy of tree quantity and quality measurements, and are cheaper and faster than conventional approaches. As part of the integrated Digital Forestry (iDiF) initiative, we propose to revolutionize forest inventory by developing methods that take advantage of recent advances in aerial remote sensing technologies. Specifically, we plan to (1) develop tools for automated individual tree delineation and biometrics measurement for hardwood forests using freely available low-density aerial LiDAR; and (2) develop user-friendly analytical methods to catalyze usage of unmanned aerial systems (UAS) or drone remote sensing for rapid tree inventory by forestry industry professionals. Products from this project can provide forest and plantation managers much-needed information to improve hardwood forest management. The project will have strong potential impacts on the ecological health and economic profitability of forest ecosystems across Indiana, contributing to the development and sustainability of rural communities. The project will also help to build capacity in HTIRC's Digital Forestry initiative, allowing HTIRC to become a leader in this field.

APPROACH

LiDAR-based tree measure: We used a two-step segmentation procedure in delineate trees with low- density LiDAR: (1) identifying individual tree markers by detecting local height maxima detection; and (2) applying marker-controlled watershed segmentation for tree crown delineation.

Orthophoto-based tree measure: A visible-band sensor mounted on a DJI Phantom 3 Advanced multirotor aircraft was used for the airborne data acquisition. Captured images were combined to form a true orthophoto mosaic of the forest surveyed at a spatial resolution of 2.5 cm per pixel. A 3D digital surface model (DSM) was then created based on the orthophoto mosaic using photogrammetry software Pix4D.

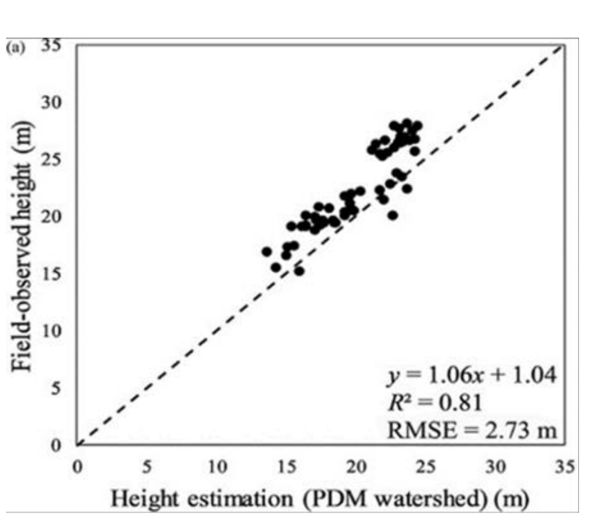
KEY FINDINGS

Two efforts have been made related to low-density LiDAR-based tree delineation. The first is to test the delineation of plantation trees with low-density LiDAR. We have successfully developed an algorithm to delineate a 60yr-old red oak plantation (Shao et al., 2018) and connected the relationship between aerial and terrestrial LiDAR (LaRue et al., 2020). We also tested the aforementioned algorithm for plantations with other species and in different age with the following key findings – low-density LiDAR can work only on larger plantation trees (>20yrs). We are developing a manuscript on this work. The second is to test the low-density LiDAR delineation in natural stands, which has been proven to be difficult at the individual tree level but has great implications at the plot-level, especially in height measurement. We are developing a manuscript led by the postdoc funded by the project.

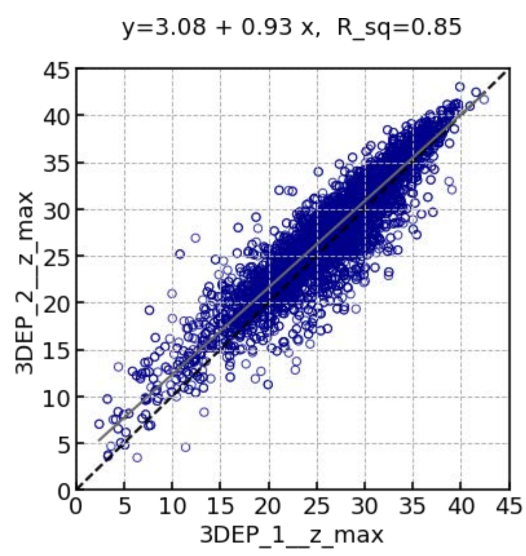
Regarding the effort of using UAS orthophotos, significant progress has been made. We have developed an algorithm along with a website for UAS orthophoto-based tree delineating for plantation forest, along with two manuscripts (Miller et al., 2021; Chandrasekaran et al., 2021). We also recently made a breakthrough in successfully creating a 3D cloud of trees, which allows the identification and measurement of deciduous trees in natural forests.

Research findings have been disseminated through publications, invited and contributed presentations, and stakeholder meetings. Invited presentations at high-level venues, such as the National Academy of Science and National FIA meeting, allows the broad dissemination of our research findings.

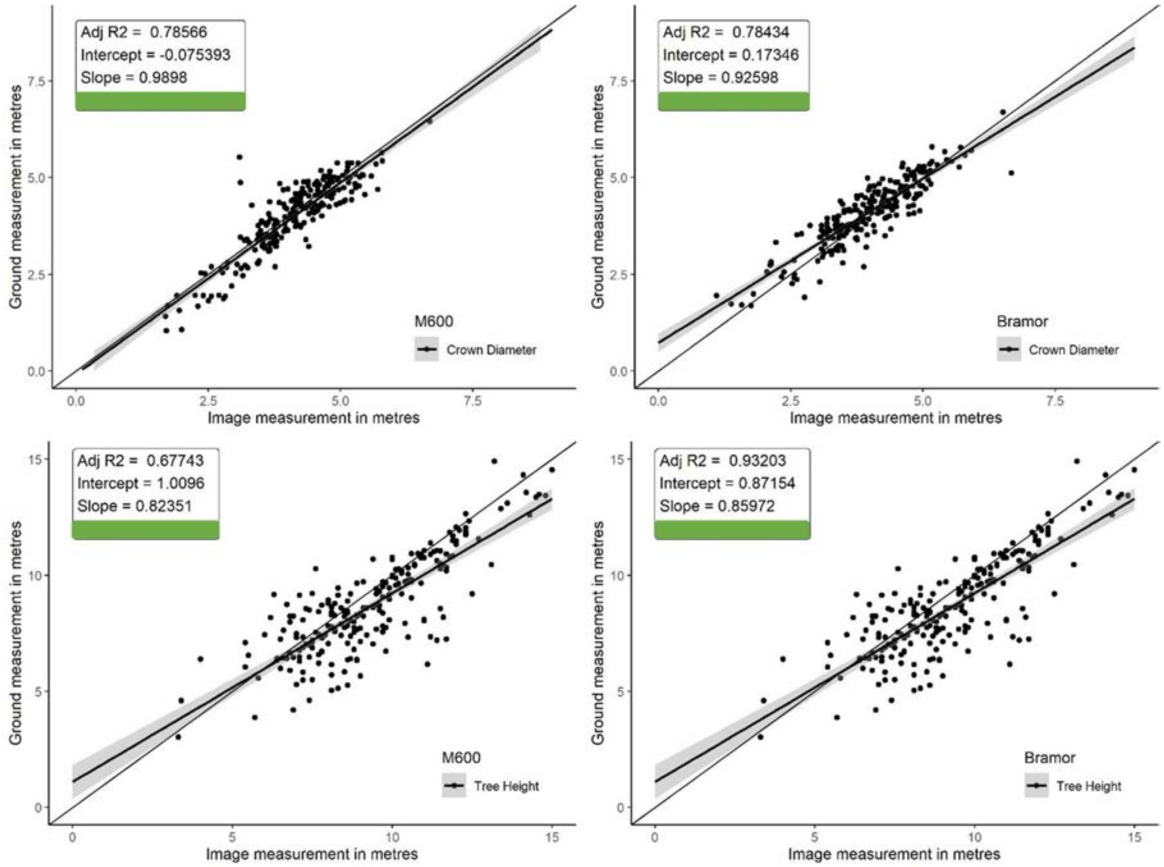
1. Low-density LiDAR-based plantation delineation is possible and with high accuracy for older plantations (Shao et al., 2018)



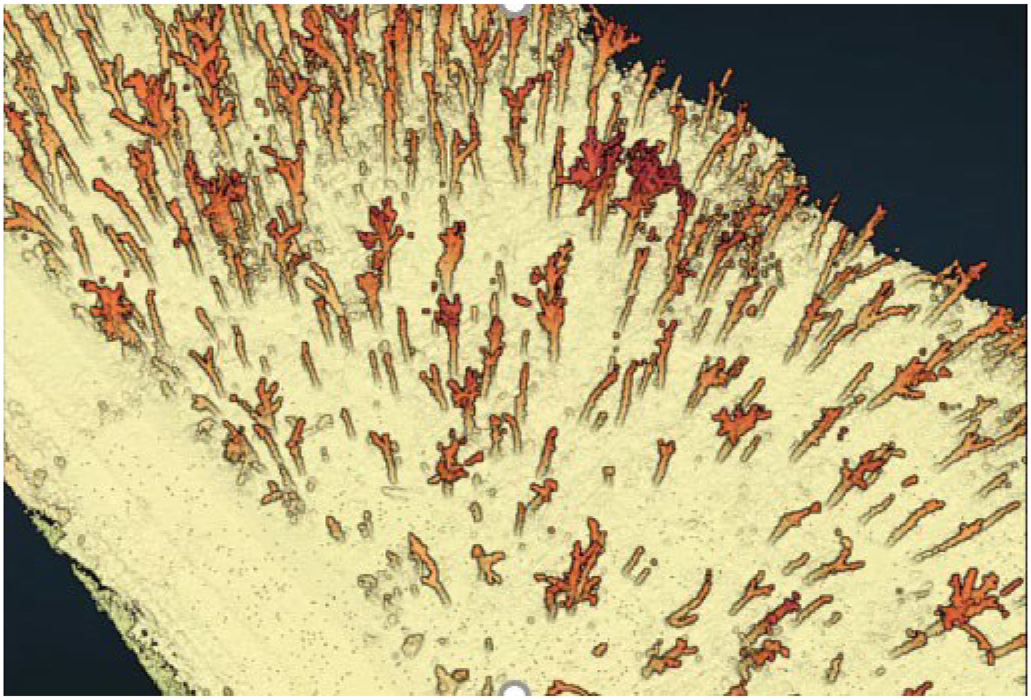
2. Low-density LiDAR can provide accurate tree height measure (Oh et al., in prep.)



3. Orthophoto-based plantation tree delineation is possible (Chandrasekaran et al., in review)



4. Orthophoto-based tree delineation in natural forest is also feasible, but more research is needed (a 3D point cloud of McCormick Woods)



5. The iDiF initiative has been taking root. We have recruited team members from various colleges across the campus.

FUTURE PLANS

We will continue to research the topic and disseminate our findings according to our plan. The COVID-19 pandemic has caused some negative impacts on the research progress. An extension might be requested.

PARTNERS/COLLABORATORS

- **Joseph P Hupy**, *Associate Professor, School of Aviation Technology, Purdue University*
- **Joey Gallion**, *Forest Inventory Program Manager, Indiana DNR*

CHARACTERIZING ABIOTIC AND BIOTIC TREE STRESS USING HYPERSPECTRAL INFORMATION (IDIF)

INVESTIGATOR(S)

- **John Couture,** *Associate Professor, Entomology, Forestry and Natural Resources, Purdue University, (couture@purdue.edu)*
- **Doug Jacobs,** *Fred M. van Eck Professor, Forestry and Natural Resources, Purdue University*

PROJECT OBJECTIVES

- Determine the ability of hyperspectral data to provide information related to tree status in response to abiotic and biotic stress
- Assess the reliability of hyperspectral information to scale from leaf, to tree, to stand level measurements
- Evaluate the validity of hyperspectral data to characterize stress responses over different spatial scales in different geographic locations.

ABSTRACT

Monitoring forest health is crucial to understanding function and managing productivity of forest systems. However, traditional estimates of tree health are time-consuming and challenging to collect because of the vertical and spatial scales of forest systems. This study evaluated the ability of a novel application of hyperspectral data to estimate foliar functional trait responses to multiple biotic and abiotic stressors and to classify different stress combinations. In a greenhouse environment, we exposed one-year-old black walnut (*Juglans nigra*) and red oak (*Quercus rubra*) seedlings to multiple stress factors, alone and in combination. We collected reference measurements of numerous leaf physiological traits and paired them with spectral collections to build predictive models. The resulting models reliably estimated most black walnut and red oak leaf functional traits with external validation goodness-of-fit (R^2) ranging from 0.37 to 0.90 and normalized error ranging from 7.5% to 18.3%. Spectral data classified different individual stress groups well, but the ability of spectral data to classify stress groups depended on whether the stress events were applied individually or in combination. High-dimensional spectral data can provide information about plant stress, improve forest monitoring in future predicted environments, and ultimately aid in management efforts in forest systems.

APPROACH

- Exposed young, potted trees of black walnut and red oak to combinations of water, nutrient, salt stress, pathogen inoculation (*Geosmithia morbida*, walnut only) and insect feeding (*Actias luna*, walnut only).
- Collected multiple physiological, anatomical, and chemical reference measurements.
- Built predictive models using paired spectral and reference data and used machine learning classification algorithms to cluster trees into stress categories based on spectra alone.
- Collected leaf, UAV, and manned aircraft hyperspectral data in a mixed planting containing American chestnut with variable levels of chestnut blight to determine how well predicted stress responses can scale across measurements (i.e., leaf, plot, stand).
- Collected stress responses of *Quercus* to combined drought and ozone stress (through collaboration with University of Pisa in Italy).

KEY FINDINGS

- Physiological and anatomical stress responses can be estimated using hyperspectral data (Fig. 1).
- Spectral data can classify water and nutrient stress (Fig. 2) and fungal inoculation (Fig. 3) prior to the onset of visible symptoms. Although for fungal classification, responses depend on other environmental factors and time.
- Ozone stress can be detected using spectral data prior to the onset of visible symptoms.

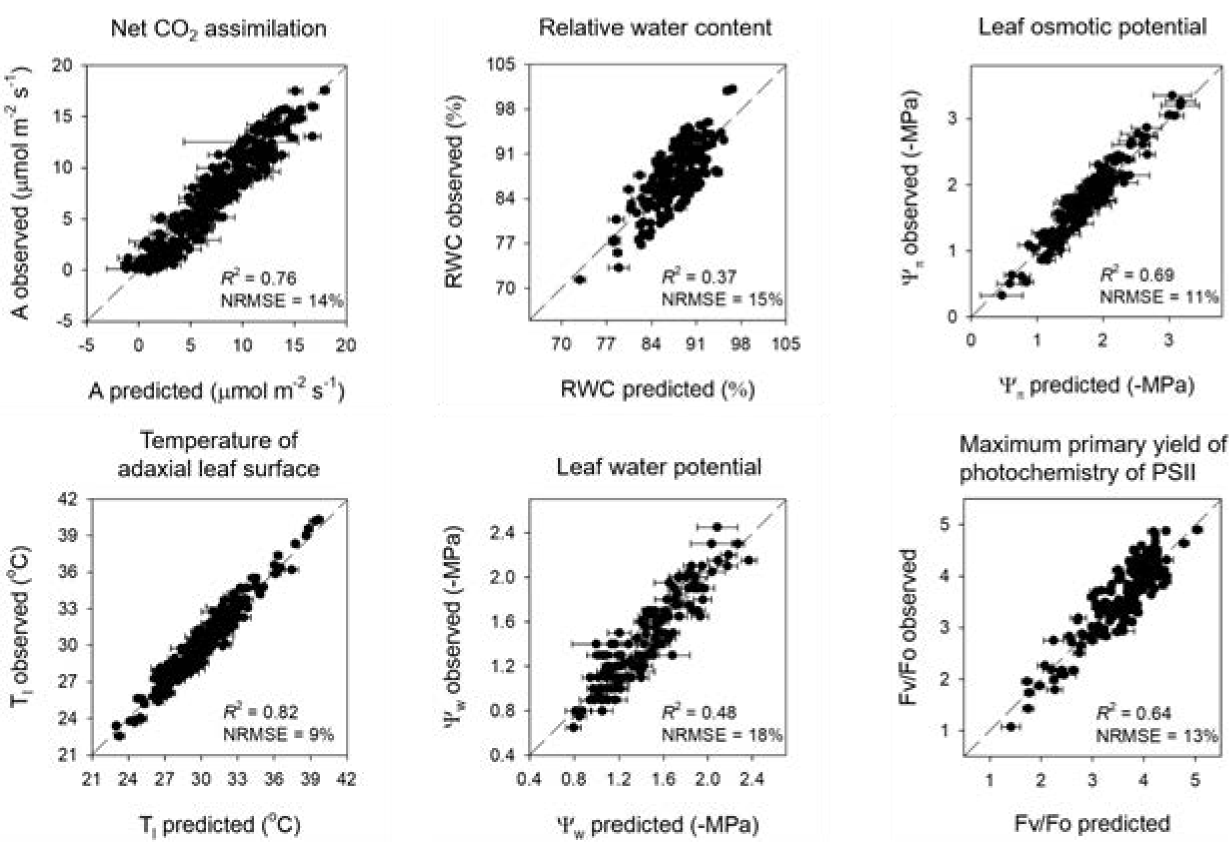


Figure 1. Observed vs predicted values of 6 key leaf traits for detection of stress responses in black walnut and northern red oak. Error bars for predicted values represent the standard deviations generated from the 500 simulated models. The dashed line shows 1:1 relationship.

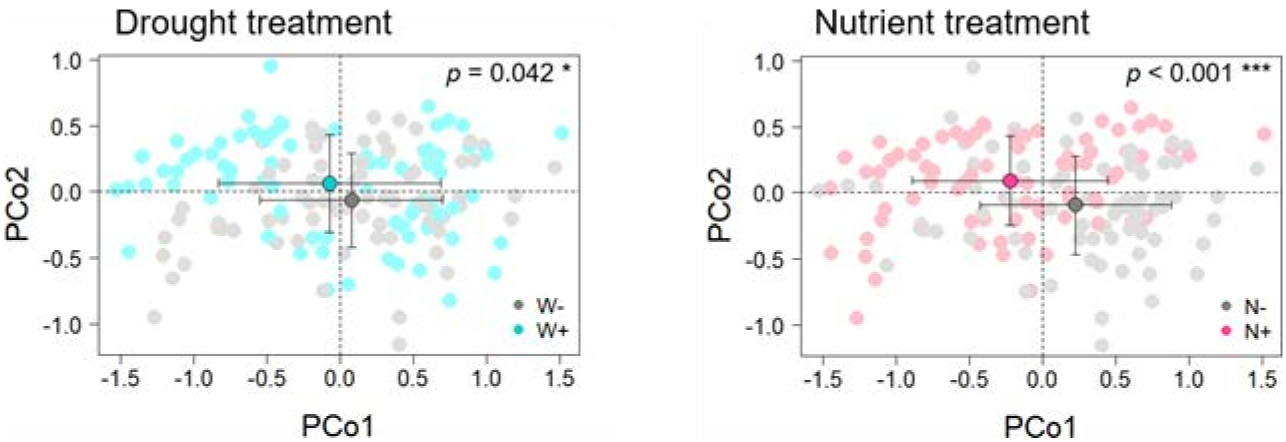


Figure 2. Scores (mean ± standard error) for the first and second components from principal coordinates analysis (PCoA) of reflectance data (400–2400 nm) collected from walnut leaves in 2018, showing the ability of spectral data to discriminate control (blue circle; W+) versus black walnut with drought stress (grey circle; W-) in the left panel and control (pink circle; N+) versus black walnut with nutrient deficiency stress (grey circle; N-) in the right panel. P-values from permutational analysis of variance for the effects of the drought and nutrient deficiency stress on full range (400–2400 nm) reflectance profiles of walnut leaves are shown in the top-right corners of panels.

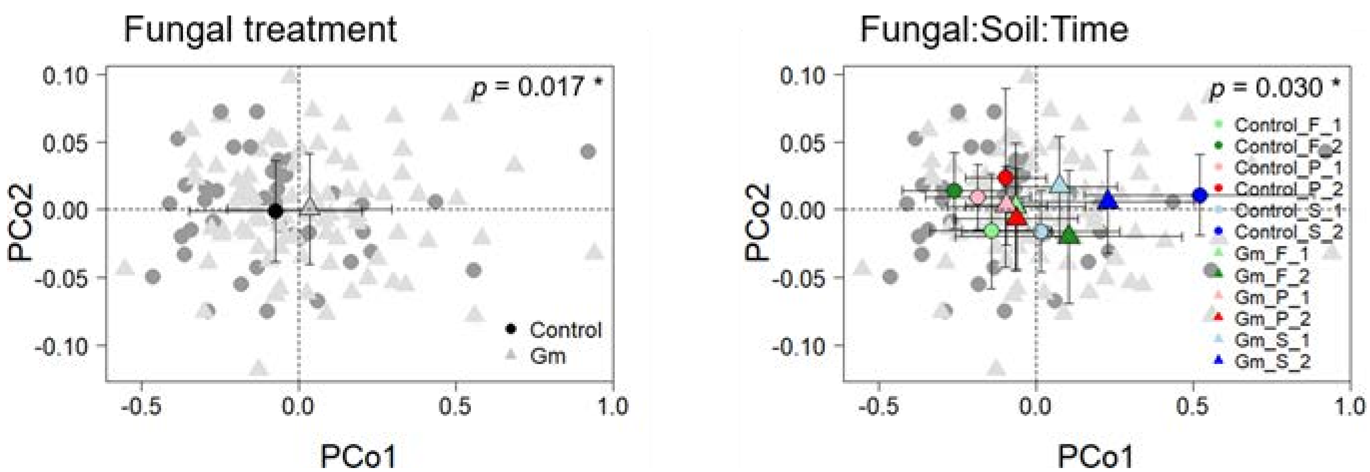


Figure 3. Scores (mean ± standard error) for the first and second components from principal coordinates analysis (PCoA) of reflectance data (400–700 nm) collected from walnut leaves in 2018, showing the ability of spectral data to discriminate control (black circle; Control) versus black walnut inoculated with the fungus Geosmithia morbida (grey triangle; Gm) in the left panel and the interactions among fungal treatment (circle; Control vs. triangle; Gm), soil type (green; forest vs. red; plantation vs. blue; sterile soil) and time length after fungal infection (light; 1 vs dark color; 2) in the right panel. P-values from permutational analysis of variance for the effects of the fungal infection, soil types, and time on reflectance profiles (400–700 nm) of walnut leaves are shown in the top-right corners of panels.

FUTURE PLANS

- Complete chemical analyses of stress across all studies and model using spectral data similar to physiological and anatomical data.
- Graduate student Sylvia Park will write complete manuscript communicating outcomes from data presented in figures for a peer-reviewed publication. She will also continue to analyze data from other studies.
- Compare leaf and UAV spectral data to assess scalability of spectral data across platforms.
- Park will write a short note about the potential of spectral data in field monitoring of plant stress to publish in the HTIRC newsletter.

PARTNERS/COLLABORATORS

- University of Pisa, Italy

ECONOMIC ANALYSIS OF GROWTH & YIELD AND THINNING DECISIONS ON HARDWOOD PLANTATIONS

INVESTIGATOR(S)

- **Mo Zhou,** *Assistant Professor, , Forestry and Natural Resources, Purdue University*
- **Lenny Farlee,** *Sustaining Hardwood Extension Specialist, Purdue University*
- **Elizabeth Jackson,** *Executive Director, Walnut Council/IFWOA. Engagement Specialist, Purdue University*
- **Jingjing Liang,** *Assistant Professor, Forestry and Natural Resources, Purdue University*
- **Yangyang Wang,** *Research Associate, Purdue University*
- **Jim Warren,** *Biological Scientist, USDA Forest Service*
- **Sayon Ghosh,** *Graduate Research Assistant, Purdue University*

PROJECT OBJECTIVES

- Building the first spatially-explicit plantation growth & yield model for black walnut and red oak
- Simulating various thinning frequencies, intensities, and patterns;
- Quantifying the cost, return, and effectiveness of different thinning schedules
- Determining the effectiveness of different incentive programs to improve investment profitability
- Developing a suite of extension tools based on Excel® to allow landowners and other stakeholders to perform investment analyses

ABSTRACT

The majority of NIPF hardwood plantations remain unmanaged despite the existence of multiple public incentive programs providing financial and technical assistance to management. This is partially due to a lack of research and extension tools enabling rigorous assessments of profitability of long-term investments in plantations. The aim of this project is to provide sound scientific evidence and user-friendly tools to help promote forest management on hardwood plantations of black walnut and northern red oak trees. We have completed new ground measurements of diameter at breast height (DBH), height, and crown radius on selected HTIRC plots to supplement the existing HTIRC database, which was lacking measurements of certain key tree attributes. We have developed crown-width models for both black walnut and northern red oak trees. We have begun to recalibrate the growth and yield models and compare the results to those calibrated without the new data. We have compiled the costs of a variety of silvicultural treatments and conservation payments. A beta version of the extension tool – Hardwood Plantation Financial Calculator V. 1 – has been developed. For the remainder of the project, we plan to finalize the growth and yield models and then parameterize the financial calculator and complete a user manual.

APPROACH

- Calibrate growth, yield, and crown width models for black walnut and northern red oak trees, respectively, with existing and new tree measurements on selected HTIRC plots.
- Quantify impacts of different thinning activities on plantation development and the associated return of investment.
- Use Excel ® and Microsoft Visual Basic ® to streamline simulations of growth, yield, and thinning activities, as well as attendant financial analyses.
- Design user-friendly interface in Excel ® so similar analyses can be performed by lay people.

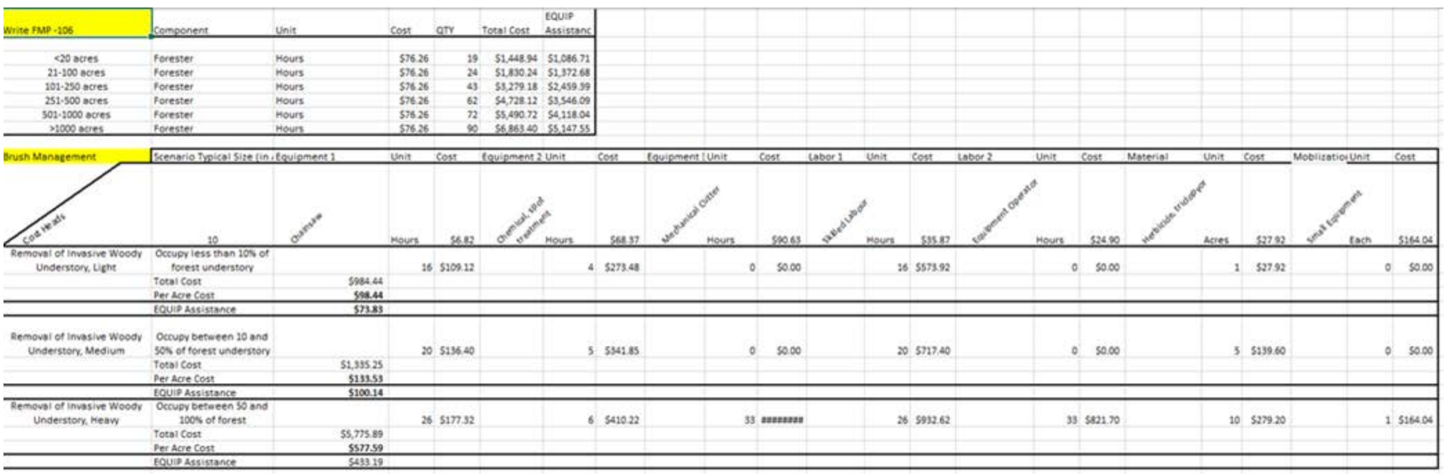
KEY FINDINGS

- Conducted ground measurements of diameter at breast height, height, and crown width of 861 black walnut trees and 754 northern red oak trees between October 2020 and January 2021 (Table 1).

Table 1. Ground measurements of HTIRC plots in year 1.

PLANTING	SPECIES	# OF TREES	LOCATION, CITY, COUNTY, STATE
139	Walnut	286	Lugar Farm, West Lafayette, Tippecanoe, IN
218	Walnut	575	Doak, Leroy, Lake, IN
115	Red Oak	754	Martell Forest, West Lafayette, Tippecanoe, IN

- Compiled a comprehensive database of costs of silvicultural treatments and conservation payments (Figure 1).



Write FMP -106	Component	Unit	Cost	QTY	Total Cost	EQUIP Assistanc
<20 acres	Forester	Hours	$76.26	19	$1,448.94	$1,086.71
21-100 acres	Forester	Hours	$76.26	24	$1,830.24	$1,372.68
101-250 acres	Forester	Hours	$76.26	43	$3,279.18	$2,459.39
251-500 acres	Forester	Hours	$76.26	62	$4,728.12	$3,546.09
501-1000 acres	Forester	Hours	$76.26	72	$5,490.72	$4,118.04
>1000 acres	Forester	Hours	$76.26	90	$6,863.40	$5,147.55

Brush Management	Scenario Typical Size (in	Equipment 1	Unit	Cost	Equipment 2	Unit	Cost	Equipment 3	Unit	Cost	Labor 1	Unit	Cost	Labor 2	Unit	Cost	Material	Unit	Cost	Mobilizatio	Unit	Cost
Cost Heads	10	Chainsaw	Hours	$6.82	Chemical, spot treatment	Hours	$68.37	Mechanical Cutter	Hours	$90.63	Skilled Labor	Hours	$35.87	Equipment Operator	Hours	$24.90	Herbicide, triclopyr	Acres	$27.92	Small Equipment	Each	$164.04
Removal of Invasive Woody Understory, Light	Occupy less than 10% of forest understory		16	$109.12		4	$273.48		0	$0.00		16	$573.92		0	$0.00		1	$27.92		0	$0.00
	Total Cost	$984.44																				
	Per Acre Cost	$98.44																				
	EQUIP Assistance	$73.83																				
Removal of Invasive Woody Understory, Medium	Occupy between 10 and 50% of forest understory		20	$136.40		5	$341.85		0	$0.00		20	$717.40		0	$0.00		5	$139.60		0	$0.00
	Total Cost	$1,335.25																				
	Per Acre Cost	$133.53																				
	EQUIP Assistance	$100.14																				
Removal of Invasive Woody Understory, Heavy	Occupy between 50 and 100% of forest		26	$177.32		6	$410.22		33	########		26	$932.62		33	$821.70		10	$279.20		1	$164.04
	Total Cost	$5,775.89																				
	Per Acre Cost	$577.59																				
	EQUIP Assistance	$433.19																				

Figure 1. Database of silvicultural costs and cost-share payments.

- Developed a beta version of Hardwood Plantation Financial Calculation V.1 (Figure 2).

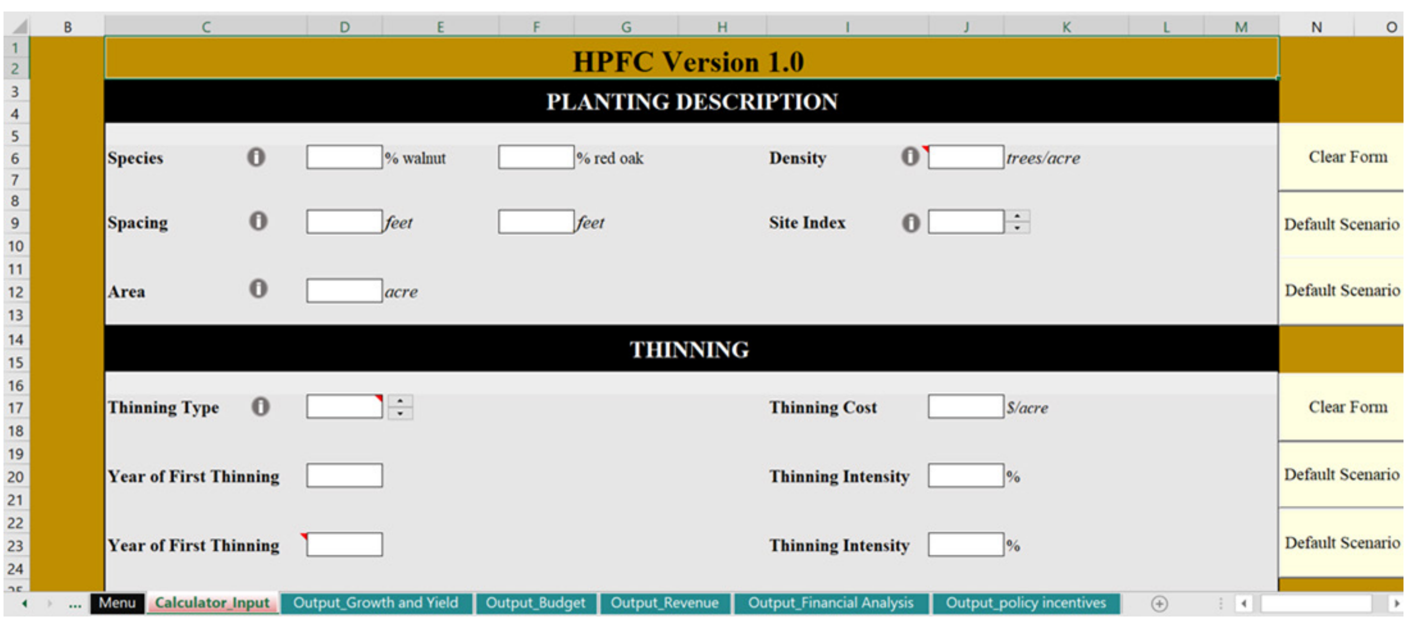


Figure 2. Beta version of Hardwood Plantation Financial Calculator 1.0.

- Calibrated crown width models for black walnut and northern red oak trees.

FUTURE PLANS

- Complete ground measurements of remaining red oak trees in spring 2021.
- Finalize growth and yield models for black walnut and northern red oak trees.
- Parameterize the Hardwood Plantation Financial Calculator with growth, yield, and crown width models.
- Test the financial calculator under different scenarios for accuracy and reliability.
- Complete a user manual for the financial calculator.

DEVELOPMENT OF MICROPROPAGATION AND REGENERATION SYSTEM FOR BLACK WALNUT

INVESTIGATOR(S)

- **Rucha Karve,** *Postdoctoral researcher, Forestry and Natural Resources, Purdue University, (rkarve@purdue.edu)*
- **Rick Meilan,** *Professor Emeritus, Forestry and Natural Resources, Purdue University*

PROJECT OBJECTIVES

- Establish sterile cultures of selected cultivars of black walnut
- Shoot multiplication and growth of healthy shoots
- Rooting and establishing plants in vitro
- Successful transfer to soil and acclimation to ex-vitro conditions, including establishment in greenhouse

ABSTRACT

Black walnut (*Juglans nigra*) is one of the most valuable hardwood tree species grown by the Indiana wood-products industry. Black walnut trees are both economically and ecologically important. Propagation of black walnut has always been challenging, largely due to difficulties associated with breaking dormancy and with rooting cuttings. This limitation precludes rapid generation of trees for silvicultural purposes and delays selections (e.g., disease resistance) in breeding programs. Thus, we propose to develop a robust and reliable micropropagation system to overcome these challenges. Funding from an HTIRC grant will be used to establish a micropropagation system for black walnut. Efficient rooting of the micro-shoots has been a major bottleneck in black walnut micropropagation and, hence, we will focus on using novel approaches to tackle this problem.

APPROACH

We hypothesized in our proposal that the amount of secondary metabolites may affect the growth response of genotypes in tissue culture. To test this hypothesis, we grew four genotypes – Purdue 1 (BW55), Tippecanoe 1 (BW130), Purdue 3 (BW132), and BW205 in tissue culture. We collected 1g of stem tissue between internodes two and four from seedlings of these genotypes and extracted the secondary metabolites in methanol overnight. When analyzed using HPLC, we confirmed that one of the main secondary metabolites in these genotypes was juglone. We then used the methanol extracts to determine the amount of juglone, using a fluorescence detector. We found that the amount of juglone was highest in BW205 and lowest in BW132, as shown in Figure 1A. Next, we evaluated the response of explants to different tissue-culture media at various stages in shoot development. We observed a positive correlation between juglone content and inhibition to shoot development, as shown by genotype-specific % shoot grown (Figure 1B).

During the first year, progress has been made toward our first objective – establishing sterile cultures of four different elite black walnut genotypes utilized by the HTIRC. We selected the above-mentioned genotypes to study response of each genotype to the media composition. Using nodal segments from ex vitro-grown seedlings as explants, we successfully developed a surface-sterilization protocol and established sterile cultures of all four genotypes, two of which are shown in Figure 2. For shoot induction, we used DKW media (Phytotech, Inc., USA) supplemented with cytokinins; benzyladenine (BA) and thidiazuron (TDZ).

The sterile materials from Objective 1 were transferred to media containing high levels of cytokinin to induce more than one shoot per explant. On an average, we obtained 3 to 4 shoots per nodal explant for all four genotypes. We observed that high amounts of cytokinin in the tissue culture medium caused callus formation at the base of the explants, which might be inhibitory for rooting in tissue culture. We are currently investigating effect of different media additives to minimize callus formation. These shoots were transferred to the media containing low to moderate amount of cytokinins to allow for shoot growth proliferation and to prime them for high-auxin media for rooting in Objective 3.

In order to expand leaf growth to maximize source to sink transport of carbohydrates for root initiation, it is important that shoots proliferate. For this purpose, we used larger containers to enhance shoot proliferation and expansion along with lowering the concentration of cytokinin (TDZ) and incorporating 1.5X IBA in the media. The expanded leaves grown on modified DKW RK8 are shown in Figure 3.

KEY FINDINGS

- We were able to demonstrate that there is a positive correlation between juglone content and *in vitro* growth response.

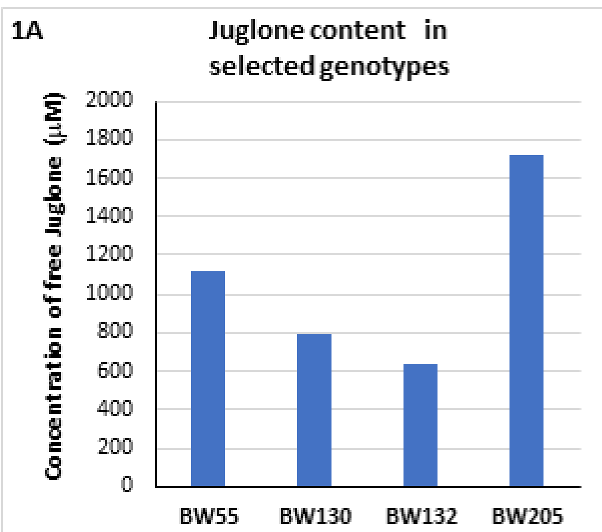


Figure 1A. Juglone content of different elite genotypes of black walnut. Each bar shows amount of juglone per gram of stem material from four seedlings of each genotype.

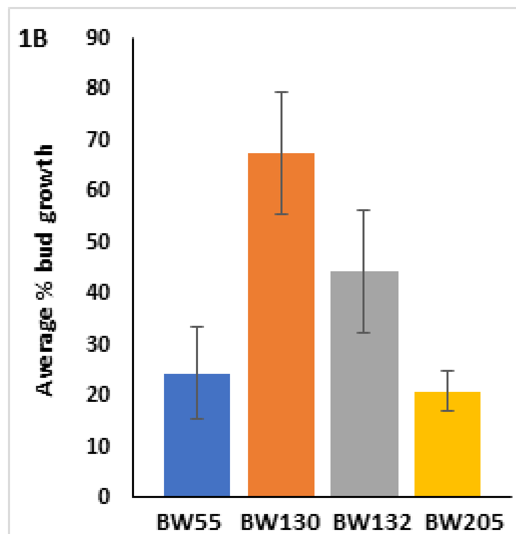


Figure 1B. Level of bud growth in each genotype. The data are an average of three independent biological replicates.

- We were also able to demonstrate that black walnut can be grown on solid tissue culture media conditions, which are more favorable than liquid cultures for acclimation of shoots generated through tissue culture.

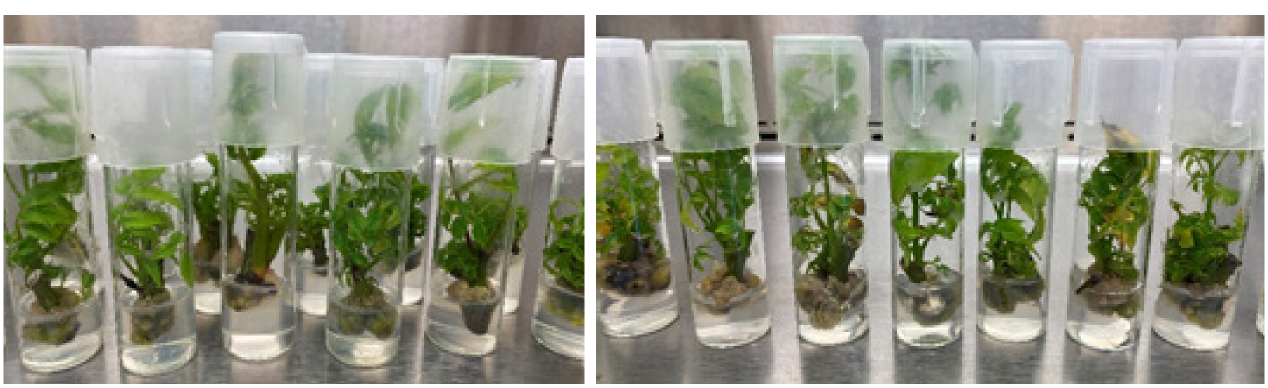


Figure 2. Shoots grown from nodal explants BW130 (left) and BW205 (right) on DKW media showing prolific leaf growth.

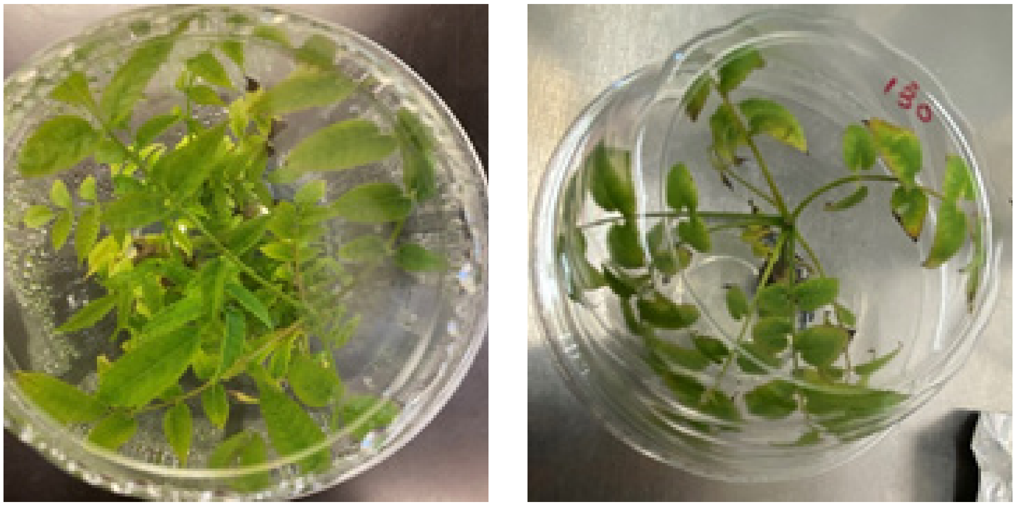


Figure 3: Shoots grown on modified DKW media showing expansion of leaves and stem growth.

FUTURE PLANS

During the second year of funding, we plan to establish the shoot cultures again from the newly available materials. Since there is a shortage of seeds for the selected genotypes, we will rely on the one-year-old seedlings provided by James McKenna. The new shoots from these seedlings will be used for generating nodal explants in tissue culture, with the media concentrations determined from the previous year. Since the shoots generated from summer and fall 2020 were not able to produce roots, the shoots have died, and hence we need to re-establish new shoots with the 2021 materials. Once the shoots are established, they will be tested for root induction on various rooting media with varying concentrations of phytohormones.

PRECISE QUANTIFICATION OF FOREST DISTURBANCES WITH UAS (IDIF)

INVESTIGATOR(S)

- **Joseph P Hupy,** *Associate Professor, School of Aviation and Transportation Technology, Purdue University, (jhupy@purdue.edu)*
- **Songlin Fei,** *Professor, Forestry and Natural Resources, Purdue University,*

PROJECT OBJECTIVES

The main goal of this research is to address how UAS can be properly utilized as an inventory mechanism prior to and after planned disturbance events. This is addressed through 3 primary objectives:

- Develop standardized data collection methods with UAS platforms prior to and after planned disturbance events, such as timber harvest and controlled burns. This data collection will occur at several timber stands over a 3-year period, resulting in a robust data set for further analysis.
- Develop feature-based classification methods using UAS imagery for rapid and accurate classification of fire disturbance, vegetation cover, and harvest treatment intensities. Classification and quantification of results will be verified through ground truthing.
- Work directly with forest professionals, managers, and other stakeholders to best gather and disseminate data sets that reflect a wide diversity of planned disturbances over an equally diverse type of forest stands.

ABSTRACT

Disturbances, either by unplanned natural events or planned management, can result in significant changes to forest communities with great spatial variabilities. Conducting accurate inventories (e.g., stand compositions, spatial patterns, and temporal trends) is necessary to document timber removal/loss and vegetation recovery for sustainable and profitable forest management, but inventories currently rely on coarse data and methods that are labor intensive and time consuming. For planned disturbance events, such as controlled burns and timber harvest, an accurate and real-time inventory of the forest community before and after a disturbance has implications for estimating accuracy and effectiveness of management implementation and consequent changes in forest regeneration and wildlife habitat. Data acquisition flights were conducted over timber harvest and controlled burn sites in the summer and fall of 2020. Due to COVID-19 restricting travel and the use of undergraduate researchers, ground truthing data were not gathered during this field campaign. Data collection with ground truthing is planned for the summer and fall 2021 season, with emphasis placed on streamlined data collection techniques learned in 2020. Methods using PPK technology related to this research have been accepted for publication in the *Journal of Forestry*, and the results of the 2020 data collection efforts are part of a graduate thesis being submitted to a special topics issue of *MDPI Forests*.

APPROACH

- Continue to work with FNR and IN DNR collaborators to gather imagery data reflecting a diverse array of planned disturbance types that best relate to monitoring hardwood forest health and regeneration, along with sites subjected to controlled burn treatments.
- Develop and refine processing and analysis methods of the imagery within related geospatial processing and analysis platforms.
- Engage in feature-based classification of ground covers over the mapped disturbance sites to determine post-disturbance growth patterns.
- Engage in communication with stakeholders to continue to refine methods and refine where and when to gather data in post-disturbance plots, and establish new plots as needed.

KEY FINDINGS

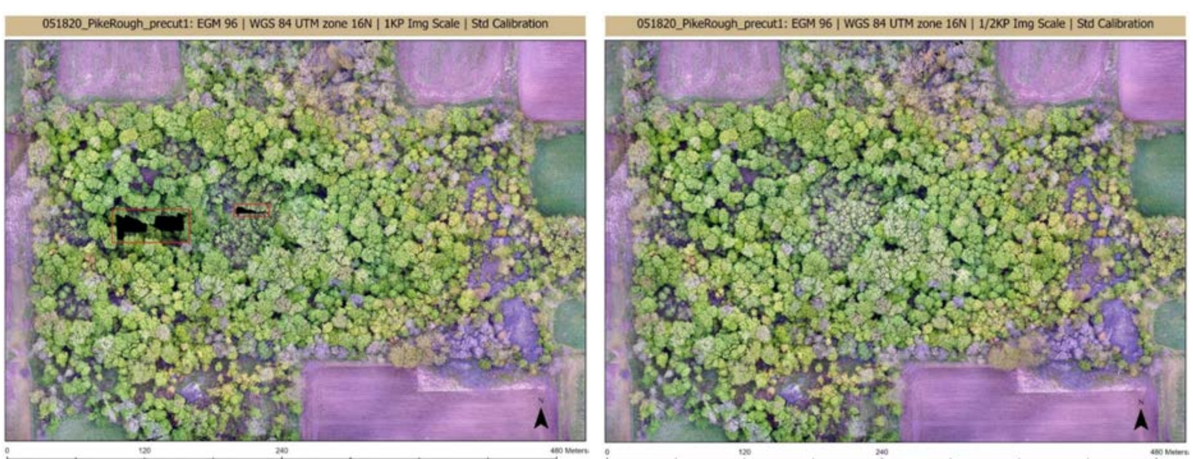
- Compared to prairie burn sites with minimal canopy cover, object-based classification of timber harvest sites was influenced more heavily by environmental factors such as wind, sun angle and brightness, but also mission parameters such as flight altitude, image overlap, and image cover outside of the study area.
- When classifying high-temporal prairie burn data sets, the effects of environmental conditions were negligible, and flight parameter adjustments were unnecessary, as these data sets were able to achieve classification accuracies of 79-85% despite some atmospheric differences in data collection times.
- When classifying harvest sites, however, the effects of wind, light, flight altitude relative to canopy height, plot perimeter coverage, and image overlap percentage were critical to produce land cover classifications at the same accuracy as prairie burn sites.
    - Flying at 400 ft *above* the forest canopy (which is still in compliance with FAA Part 107) results in:
        - A wider field of view. which helps with tying images together
        - Reduced motion blur and effects of wind
        - And, given the proper light exposure, a great view into the canopy gaps
    - Using an 80% or better overlap and sidelap between images is critical to producing usable orthomosaics for classification of dense canopy sites.
    - Ensuring a sufficient 1-2 image buffer between edge of study area is essential to minimize image distortion and provide the photogrammetric software necessary for ground references along the edge of the study area.
    - Sun exposure must be:
        - Consistent throughout the flight to reduce color or brightness variances of objects between images
        - Diffuse if possible (i.e., overcast or partly sunny), as bright sun contributes to overexposure of canopy and intense shadows in gaps
        - High sun angle allows for best visibility into gaps and reduces longitudinal shadows

Figure 1: Difference between initial and revised flight planning on orthomosaic quality.

- Very little to no wind is the final critical element to conducting flights for this application, as keypoint matching relies on objects not moving much between images.

2. Photogrammetric parameters affected the usability of dense canopy sites and contributed to reducing some of the effects of poor environmental conditions or flight parameters.

- For example, the first round of imaging at the Rough timber harvest site returned two gaps within the study area of the resulting orthomosaic when processed with the default parameters. When the keypoint image scale was set to *½ image scale*, the gaps were filled in and the overall keypoint matching improved significantly.
- This was done by adjusting the keypoint scale processing parameter to *½ image scale* with a *standard calibration* method. It performed the best at overcoming pixel differences as a result of wind, inconsistent lighting, and/or motion blur, when compared with *¼, 1, and 2 x image scale and alternative calibration* iterations.



Figures 2 and 3: Before and after data gap solved through keypoint scale adjustment.

3. Preliminary results suggest that cm-level object-based classification is possible with dense canopy sites.

- This is demonstrated by generalizing the land cover into 4 classes: bare ground, woody debris, understory vegetation, and canopy.
  - While these were good classes to demonstrate the feasibility of this application, the methods used here have the potential to be implemented for more specific management goals even down to the species level (i.e., invasive identification and quantification).
- Because the pixels making up our image is a known ratio (~2.1 cm2 / pixel), the area for each land cover class was determined to an overall accuracy of 78-87%.
- By doing this, property managers have the potential to leverage detailed metrics and visualizations of their properties for efficient management decisions, i.e., determining the percentage of woody debris (compared to what it was before the harvest) as it relates to management guidelines or objectives.

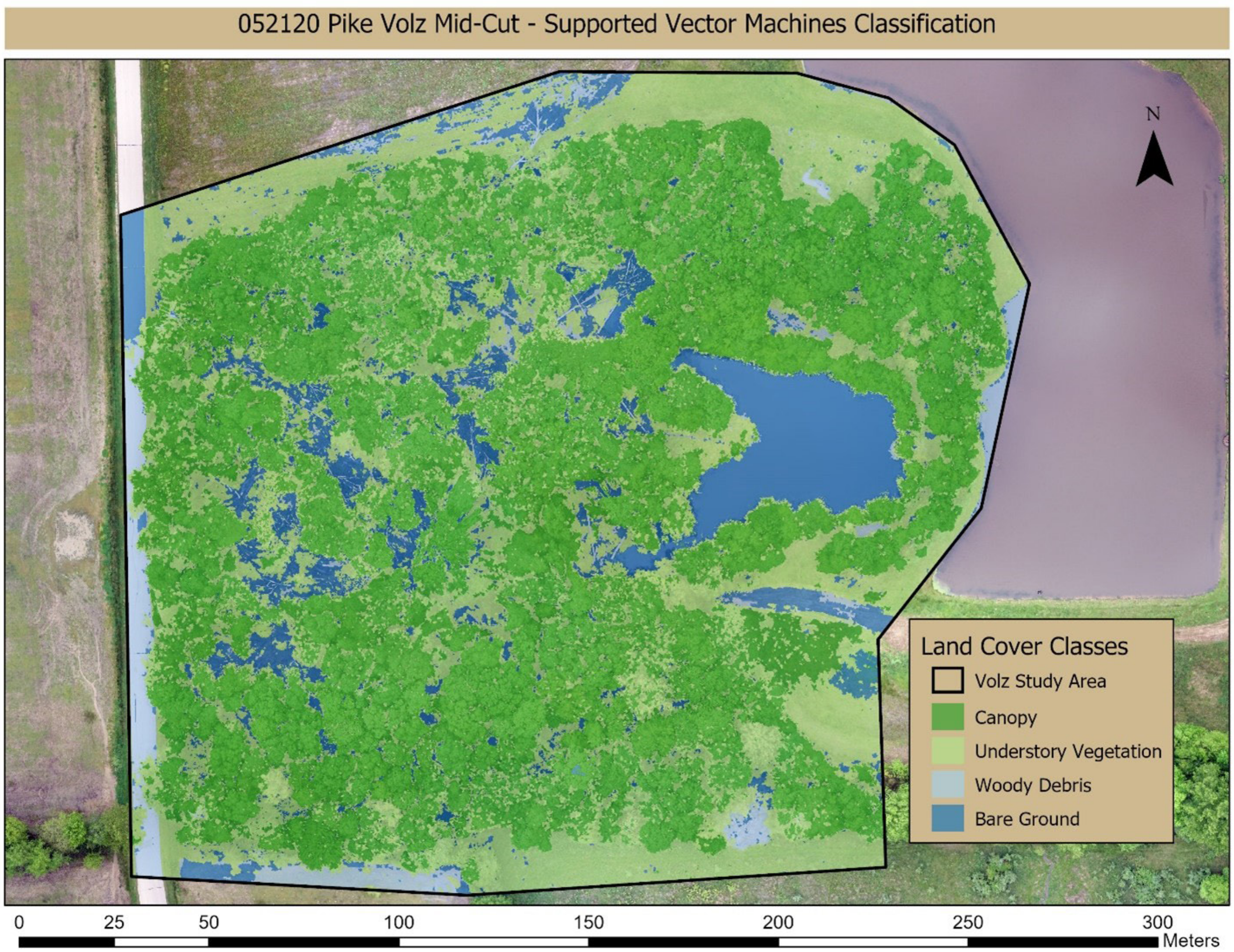


Figure 4: Preliminary classification of Volz site mid-harvest

4. Of the four supervised classification algorithms tested, Random Trees and Supported Vector machines outperformed ISO Cluster and Maximum Likelihood, and the best iterations of these classifications were produced from 80 samples for each class.

FUTURE PLANS

- Zach Miller, the current graduate student working on this project, is projected to complete his dissertation in May 2021.
- An incoming graduate student, Cameron Wingren, is projected to seamlessly pick up where Zach left off.
- The work Cameron will engage in will be primarily in the area of better refining the data collection, processing and analysis.
  - If COVID-19 restrictions ease, he will engage in ground truthing of the study sites.
  - He will continue to do flights over the harvested areas to examine regrowth patterns and refine classification methods.
  - He will also communicate with the stakeholder, Pike Lumber, to examine if other study sites are viable options for data collection.

PARTNERS/COLLABORATORS

- **Jarred Brooke,** *Extension Wildlife Specialist, FNR, Purdue University,*
- **Guofan Shao,** *Professor, Forestry and Natural Resources, Purdue University*
- **Joey Gallion,** *Forest Inventory Program Manager, Indiana DNR*

USING REMOTE SENSING TO CHARACTERIZE STRESS EPIDEMIOLOGY IN HARDWOOD FOREST STANDS (IDIF)

INVESTIGATOR(S)

- **John Couture,** *Associate Professor, Entomology, Forestry and Natural Resources, Purdue University, (couture@purdue.edu)*
- **Doug Jacobs,** *Fred M. van Eck Professor, Forestry and Natural Resources, Purdue University*
- **Brady Hardiman,** *Assistant Professor, Forestry and Natural Resources, Purdue University*
- **Matthew Ginzel,** *Professor, Entomology, Forestry and Natural Resources, Purdue University*
- **Philip Townsend,** *Professor, Department of Forestry and Wildlife Ecology, University of Wisconsin-Madison*
- **Melba Crawford,** *Professor, Agronomy, Civil Engineering, and Electrical & Computer Engineering, Purdue University*

PROJECT OBJECTIVES

The main objective of this proposal is to integrate multi-spatial and temporal scale RS products with forest management scenarios. Specifically, we will focus on three areas of forest management:

- Tracking insect pest and pathogen incidence, severity, and spread;
- Early detection of drought stress-related symptoms; and
- Optimize RS acquisitions to determine the number of collections appropriate to make an informed management decision.

ABSTRACT

Managed forest systems contribute substantially to local, national, and global economies. Pests and pathogens have the largest negative impact on forest growth and productivity. To date, previous postdoc Ali Masjedi and current postdoc Behrokh Nazeri have coordinated manned aircraft flights over the Indiana location. Unfortunately, COVID-19 restrictions stopped travel to MO during the past field season, but plans are being adjusted to meet the stated goals of this proposal. Analyses of current data suggest that remotely sensed hyperspectral data can discriminate American chestnut (*Castanea dentata*) trees infected with chestnut blight (*v*) from non-diseased with ~80% accuracy. As severity class of disease is expanded, meaning more classes are included, then accuracy declines and disease classes become confused with one another. Research and outcomes from this work were featured in the Purdue Digital Phenomics Advisory Board and have received social media attention. Concepts from this grant are being resubmitted to a USDA Tactical Sciences for Agriculture Biosecurity grant in 2021.

APPROACH

- Collected and processed two years (2018-2019) of UAV hyperspectral and LiDAR data over a mixed species plot at Martell research forest that includes American chestnut with variable levels of chestnut blight to 1) identify blight stress using spectral data and 2) track blight spread through time.
- Collected two years (2019-2020) of hyperspectral data from a manned aircraft.
- Collected leaf samples (2019-2020) for stress-level chemical analyses and scored leaf blight (2018-2020).

KEY FINDINGS

- UAV-based spectral data can discriminate American chestnut trees with and without blight (Fig. 1). The ability of spectral data to classify blight, however, declines as additional classes of blight (e.g., none, mild, severe) are classified (Fig. 2, 3) and classes become confused with each other (Fig. 4).
- Spectral bands that are important for classification shift depending on collection period (Fig. 5).
- Work was highlighted in 2020 Purdue Phenomics Advisory Board meeting, and a video describing work on this project has received social media attention. https://youtu.be/OWN4rF4KHJo

Classification Results (2 classes)

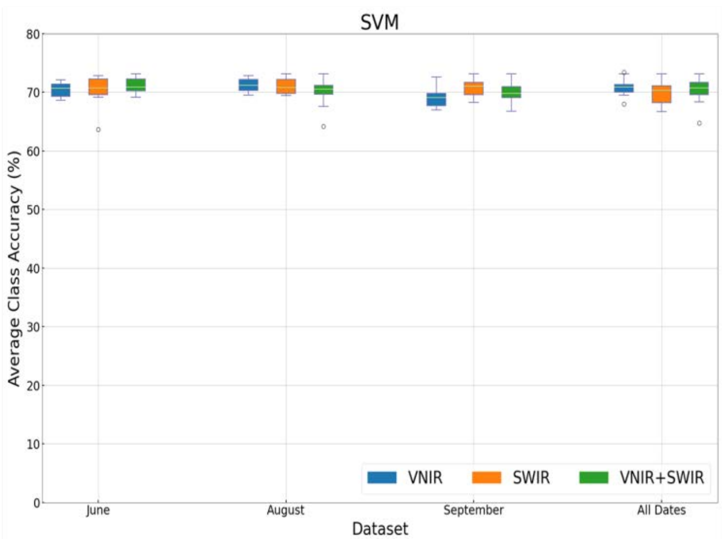


Figure 1. Classification accuracy of two-class (presence or absence) classification of chestnut blight in American chestnut trees using different spectral regions (visible and near infrared [VNIR]; shortwave infrared [SWIR]; and combined VNIR and SWIR). Classifications were made using support vector machine (SVM) algorithms.

Classification Results (3 classes)

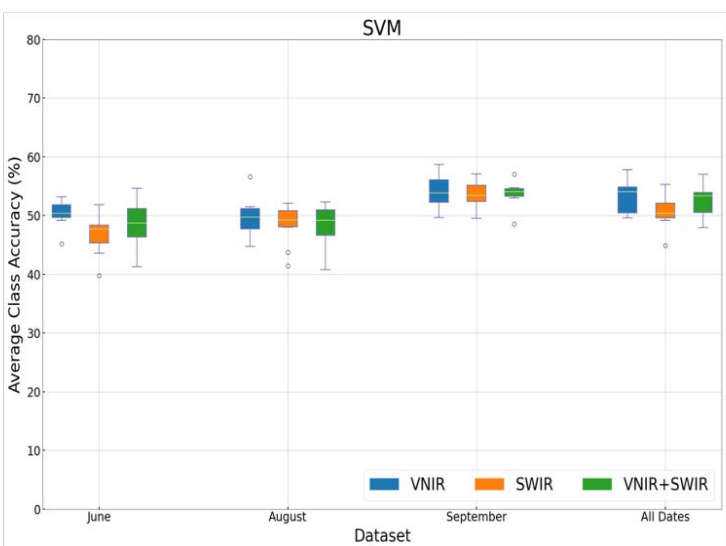


Figure 2. Classification accuracy of three-class (none, mild, or severe) classification of chestnut blight in American chestnut trees using different spectral regions (visible and near infrared [VNIR]; shortwave infrared [SWIR]; and combined VNIR and SWIR). Classifications were made using support vector machine (SVM) algorithms.

Classification Results (4 classes)

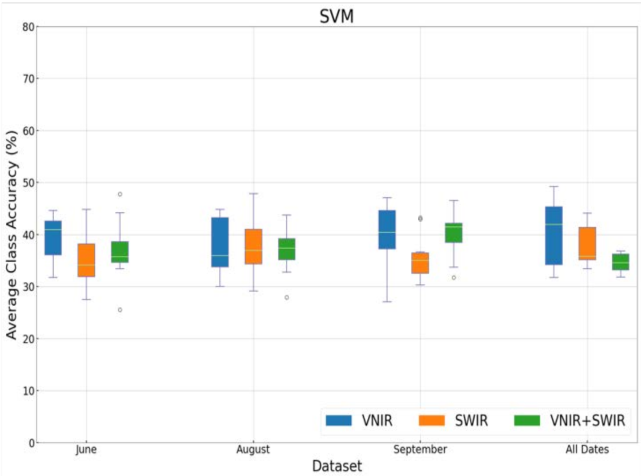


Figure 3. Classification accuracy of four-class (none, mild, moderate, or severe) classification of chestnut blight in American chestnut trees using different spectral regions (visible and near infrared [VNIR]; shortwave infrared [SWIR]; and combined VNIR and SWIR).

2-Class Classification

3-Class Classification

4-Class Classification

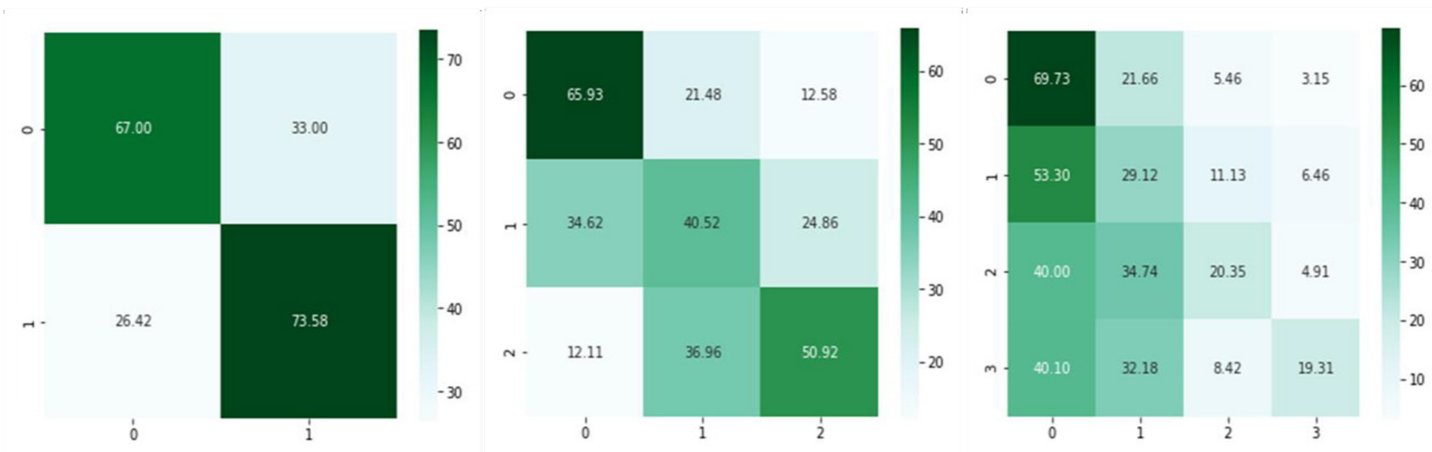


Figure 4. Confusion matrix based on classification. For example, in the far left panel, a 0 (no blight) is accurately classified 67% of the time and misclassified as having blight 33% of the time. Notice that as classes are added, more classes are confused.

Band Importance, 2-class, June

Band Importance, 2-class, September

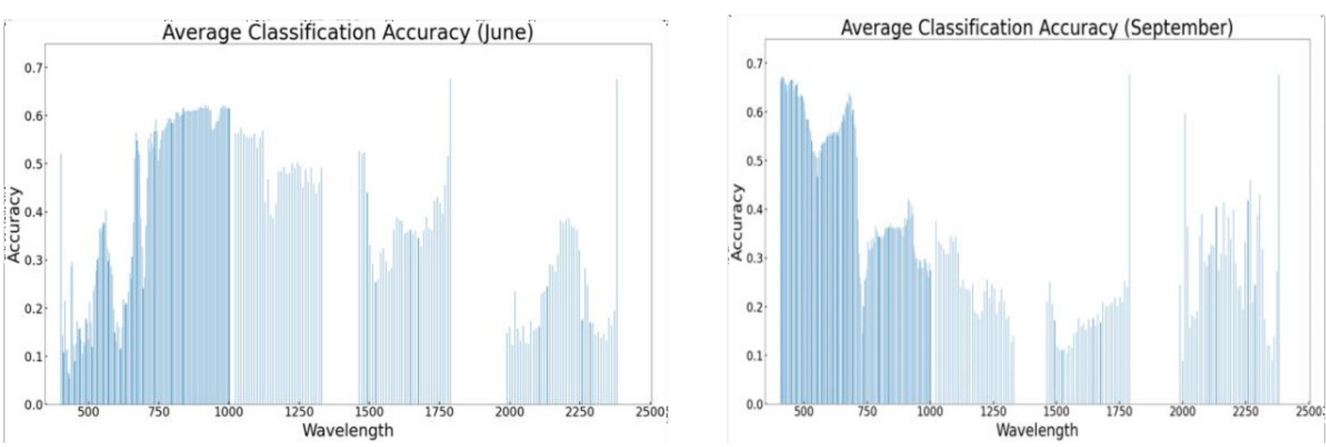


Figure 5. Importance of individual bands in classification accuracy in June (left) and September (right) collection periods. Notice how bands from 500-750 are less important in June, when the canopy is green, but shift to have considerable importance in September, as canopy senescence begins. Likely indicator of early canopy senescence in American chestnut trees with blight.

FUTURE PLANS

- Process 2020 UAV spectral and LiDAR data and process 2019-2020 manned aircraft spectral data
- Process 2019-2020 leaf samples for chemical stress signatures
- Score leaf blight for 2020 spectral collections
- Collect spectral data from manned aircraft, spectral and LiDAR from UAV platform, and leaf- level samples for 2021

PARTNERS/COLLABORATORS

- University of Wisconsin-Madison
- University of Florida (through developing external grants)
- Clemson University (through developing external grants)

A NEW, FASTER, CHEAPER, AND EASIER WAY TO MEASURE HTIRC PLANTATIONS (IDIF)

INVESTIGATOR(S)

- **Guofan Shao,** *Professor, Forestry and Natural Resources, Purdue University, (shao@purdue.edu)*
- **Keith Woeste,** *Molecular Geneticist, USDA Forest Service Project Leader, Adjunct Assistant Professor, Purdue University*
- **Yung-Hsiang Lu,** *Professor, School of Electrical and Computer Engineering, College of Engineering, Purdue University*

PROJECT OBJECTIVES

- To develop and demonstrate a portable device capable of real-time tree measurements of tree diameters at regular height intervals. Although the data processing of terrestrial stereoscopic photogrammetry is much faster than for the popular SfM photogrammetry (Figure 2), it cannot yet provide “real time” output, which we consider essential.
- To develop an algorithm to automatically locate (in a GIS framework) individual trees to avoid redundant tree measurements or skipped measurements on the ground. This functionality will also be helpful to take multiple measurements and obtain mean values for each tree, improving the accuracy of tree measurements.
- To demonstrate the integrated system with a broad range of HTIRC plantations and selected natural forest stands in Indiana. The system will be evaluated for use in a range of tree species and forest types.

ABSTRACT

HTIRC needs to acquire data from its many (more than 200) plantations. The time required to accurately measure and evaluate each individual tree is considerable, so relatively few plantations are measured each year. Furthermore, valuable information about tree form and quality is rarely obtained, in part because current rating systems are highly subjective and may be unreliable. Recent advances in image matching algorithms and computation technology have made Structure from Motion (SfM) photogrammetry an attractive solution to the need for accurate, low-cost measurement and assessment of individual trees. We have spent nearly two years developing an algorithm for terrestrial stereoscopic photogrammetry through an integration of SfM photogrammetry principles and images acquired with stereo cameras. We have shown through a series of experiments that this new algorithm increased the speed and accuracy of tree diameter at breast height (DBH) measurements for black walnut plantations in Martell Forest. We will incorporate this algorithm and relevant hardware into an operational Low-cost Optical Gauging System (LOGS). With such a digital system, HTIRC breeders will be able to automatically measure tree diameters at different heights along the stem for every tree in HTIRC plantations, and update the HTIRC database in a timely manner. With the resolution of a few technical issues, this research goal is feasible now. We will expand our existing research team, consisting of three faculty members and six undergraduate students, by hiring a graduate student as a technical consultant.

APPROACH

- We integrated a central processing unit, a mobile (hand-held) device and interface, a post-processing kinematic (PPK) GPS, and an IMU-ready stereo camera into a portable prototype. A surveyor will be able to monitor progress using a handheld device such as a smartphone.
- A fully automated tree inventory method must be able to "remember" which trees it has measured. We developed an algorithm to identify a tree as a distinct individual with a particular location. Because GPS signals are weak under tree canopies, the ordinary GPS methods are unreliable as a method for locating trees with high accuracy.
- The final LOGS system will automatically and in real-time locate trees, measure them, and provide verified data feedback to the operator. Tree measures taken by hand in HTIRC plantations will be compared with those derived using LOGS. We will also use information already in the database (for example, the location of missing trees) to calibrate the analysis.

KEY FINDINGS

- The research team has been expanded from six undergraduate students to 11 undergraduate students (Isabella Capuano, Nick Eliopoulos, Yiting Gan, Yi-Fang Hsiung, David Kopp, Zeren Li, Garret Martin, Sohan Pramanik, Yezhi Shen, David Siman, and Ganesh Viswanathan) and one PhD student (Yunmei Huang).
- The simple system equipped with a stereo camera proves reliable, accurate, and efficient for measuring tree DBH real-time (Fig. 1).
- The team has developed a qualitatively good neural network model for semantic segmentation of a stereo image containing the first 8 feet of a tree trunk into four separate classes: background, ground, trunk and branch (Fig. 2a & 2b):
- A second accomplishment is the development of a novel algorithm to compute location on a stereo image where the trunk and the ground intersect; it is used as a baseline to compute diameter at breast height (Fig. 2c):
- The team is making progress mapping trees surveyed with cameras. By integrating GPS coordinates at the beginning and ending points of survey, tree positions can be mapped out (Fig. 3):

Figure 1. Field testing.

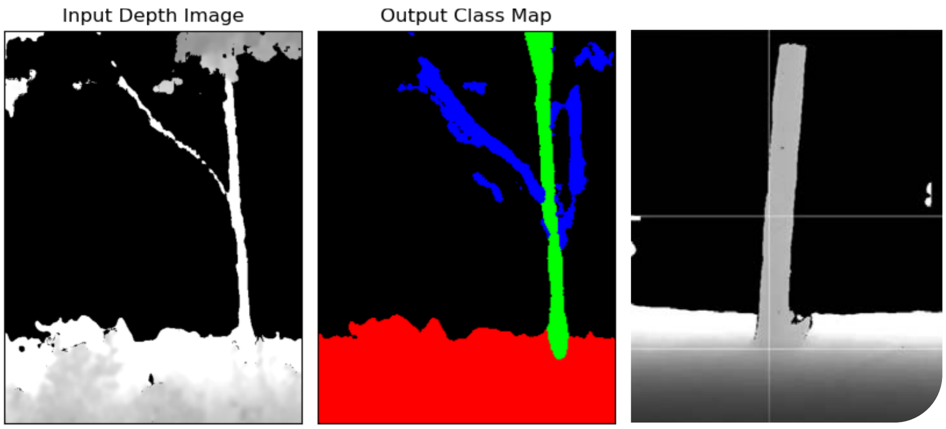


Figure 2. Semantically segmenting a stereo image (a) into four classes with a neural network model (b); automated detection of tree base (c).

Figure 3. A working version of a tree position map measured with a camera. The database includes tree ID (number), row number, DBH, and x, y coordinates.

FUTURE PLANS

- The team has developed a user's guide so that new team members will be able to utilize the hardware and software systems the seniors have developed. The research team is growing and becoming more focused on neural network applications (Fig. 4). The team bought a Realsense camera D455, a portable display, and two Power Banks (charger). We will start to build and test a backpack system in the summer.

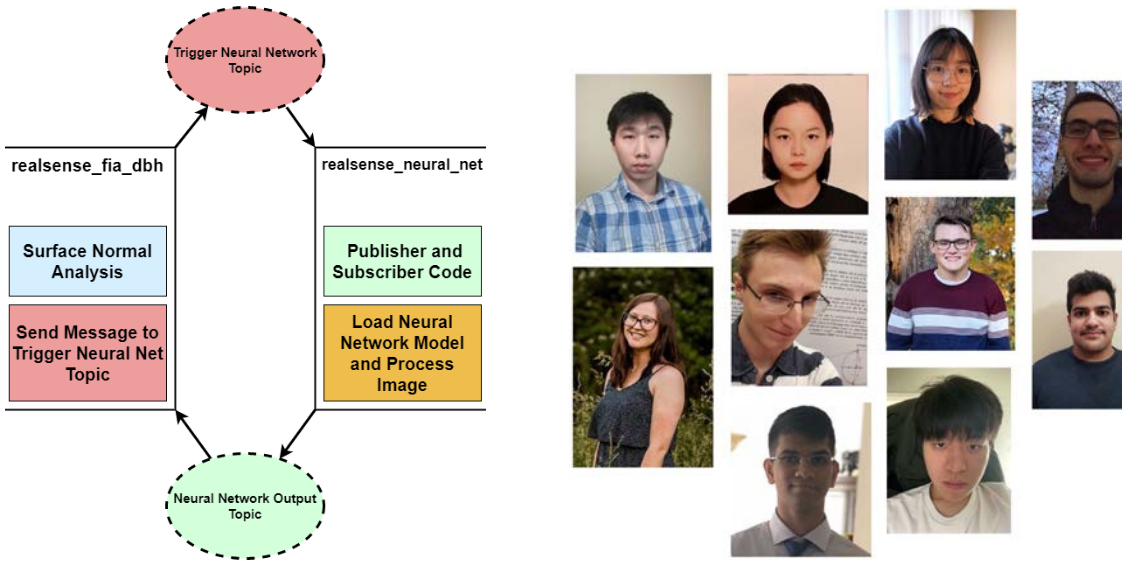


Figure. 4. An example of neural network applications (left) and the research team (right).

GEO-REFERENCED AND IMAGED-ASSISTED IN-SITU BIOMETRIC EVALUATION TOOL FOR PRECISION GROWTH AND YIELD MODELING (IDIF)

INVESTIGATOR(S)

- **Rado Gazo,** *Professor, Forestry and Natural Resources, Purdue University, (gazo@purdue.edu)*
- **Bedrich Benes,** *George W. McNelly Professor of Technology, Department of Computer Graphics Technology, Purdue University*
- **Songlin Fei,** *Professor, Forestry and Natural Resources, Purdue University*

PROJECT OBJECTIVES

- Develop appropriate image acquisition hardware and pilot-test it
- Develop software for image analysis and biometric data collection
- Relate tree biometric information to geo-location of origin

ABSTRACT

This project has three objectives. We are in the first year, during which we proposed to fulfill objective #1 and start working toward objective #2.

Objective #1 – This objective focuses on evaluating the existing image acquisition hardware at a cooperating sawmill, determining whether a hardware upgrade is needed, and performing such an upgrade. Immediately after project start date, PI and student traveled to the sawmill site and collected approximately 130 images of 10 species of logs using two mobile phones and one SLR camera. This was an initial sample to establish a baseline for high-quality images of clean log ends, indexed for size. Shortly after our visit on 02/24/20, the COVID-19 related travel and purchasing restrictions went into effect and no additional travel and hardware testing/ purchasing was possible. There is currently a delay toward fulfilling this objective, and we will continue our work toward fulfilling this objective as soon as restrictions are lifted. This is not all bad news, because having sufficient time to analyze the initial set of collected images and making substantial progress toward objective #2 gives us better understanding of hardware requirements and limitations.

Figure 1 a, b and c. Collecting and indexing images of log cross-sections in a log yard.

Objective #2 – This objective focuses on developing an image pre-processing method to remove artifacts such as saw marks and other noise, and on developing novel image analysis techniques to calculate log cross-section maximum, minimum and average diameter, detect pith and geometric center of the cross section, calculate tree age and growth rate using the growth ring analysis and potentially other biometric data. The early collection of baseline image data allowed us to work more extensively on this objective and make substantial progress in this area.

Figure 2. Real-life rough log surface.

APPROACH

The previous studies of log cross-section growth rings were performed using high-resolution images of smoothly cut surfaces for needs of dendrochronologists. In our application, this approach does not work because of the presence of significant saw marks (Figure 2). The approach that we use in this study utilizes machine learning by establishing an image-processing pipeline that consists of:

1. Edge image processing
2. Finding pith and radius
3. Detecting chain saw marks direction, and
4. Processing growth plot

We also developed software and user interface (Figure 3) to assist in image analysis.

Figure 3. Snapshot of developed image processing software tool.

KEY FINDINGS

- A video presentation of growth ring machine learning analysis is available here: https://youtu.be/AymmF-aWUvs
- A manuscript describing our initial pipeline establishment, Convoluted Neural Network training, accuracy results and limitations is nearly finished. Figure 4 shows a cross-section of sycamore log a) and the same log b) manually annotated (labeled) to train the neural network.

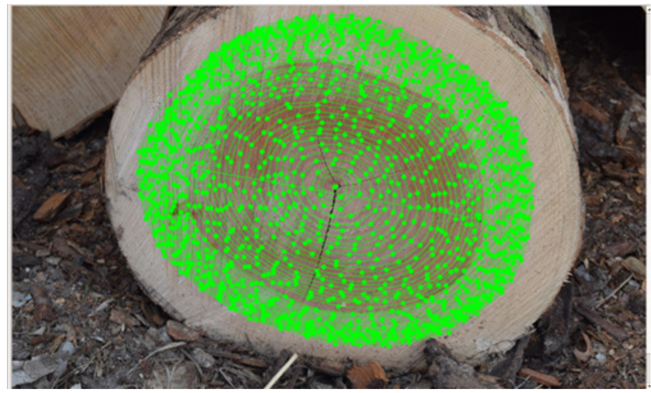


Figure 4. Sycamore cross-section (left) with manual annotation of growth rings (right).

FUTURE PLANS

Our work in the second year of this project is going to focus on acquiring larger sample (10 species and 20 cross sections per each specie) of images and labeling them to improve the CNN (Convoluted Neural Network) training, as well as resolving the hardware specifications.

PARTNERS/COLLABORATORS

- Pike Lumber Company, Akron, IN – industrial partner

OPERATIONAL TREE IMPROVEMENT REPORT

The COVID-19 pandemic seriously affected our operational improvement work last year. Caleb Kell and Jim McKenna were designated as "critical and essential" staff to keep up with the greenhouse and trees and scion wood that we had collected prior to the shutdown. Planting plans and all of our hopes for measuring remote plots were changed, and we accomplished much less than we had hoped.

MEASUREMENTS: We measured all three of our oldest (2007) northern red oak progeny tests and three 2009 red oak progeny tests. We did not complete our Rush County plot before the COVID-19 shutdown and still need to get log-length and timber quality data. In addition, we measured two tests that are part of a seven-plot series we call our "MOG Hybrid and pure butternut study." We have alternate rows of pure and hybrid butternut, with each row also having northern red oak and black walnut alternate with the butternuts down each row. The first of these is an afforestation site in Illinois at the Forest Glen Nature Preserve with Ken Konsis of the Illinois and National Walnut Council. The second plot is a reforestation planting in the Morgan-Monroe State Forest near Martinsville, IN, with the IN-DNR. Finally, we measured our third butternut screening plot planted in 2010 with our new Forest Service pathologist, Anna Conrad, and have a complete data set on DBH, potential log length, timber quality, and butternut canker disease status. Anna is also interested in studying walnut bunch disease, a virus-like organism that causes "bunch disease" or "witches' broom" on most all walnut species. We are still analyzing that data, but the results so far show that most of the resistance occurs in hybrids, as we have been finding consistently with our first and second screening blocks.

MANAGEMENT: In February before the pandemic, we assisted the Indiana TNC (The Nature Conservancy) with pruning butternut and black walnut that we had planted in 2013 and 2015. This site contains our first and only pure butternut progeny tests. The 2015 site is an upland site; the 2013 is a bottomland site.

We began marking our 2007 red oak progeny tests at Martell for thinning to remove the poorer tree of the two-progeny pairs we designed these blocks with. Our long-term goal of these red oak progeny tests is to open them up to become "improved seedling seed orchards." Due to the COVID-19 changes, we were not able to get any of the trees actually cut.

With the addition of Anna Conrad, we surveyed all of our butternut plantings near Purdue and at SEPAC for bunch disease and have plans to cut out and kill infested trees during the 2021 spring.

In spring 2020, we provided HTIRC pollination bags to an FNR undergraduate student who conducted an impressive study – to test if bush honeysuckle can self-pollinate – with Mike Jenkins and Rick Meilan. We also assisted HTIRC grad students in the Ginzel, Jacobs, Couture, Shao, Zhou, and Fei labs with trees, data, tools, and advice.

NEW PLANTINGS: We planted a new white oak progeny test adjacent to our last 2015 white oak progeny test at the FNR Herrmann Reserve site near Muncie, IN. This plot ended up as the one and only larger research planting we could plant. We planted nearly 40 elite and precocious families together as one large CRD (completely randomized) plot with nearly 1,400, 1-0 bareroot seedlings grown by our Vallonia State Tree Nursery cooperators.

The grafted elite black cherry seed/breeding orchard we established in Rush County, IN, in 2019 was completed last year with new grafted trees to ensure that we had 4 grafted trees of 15 elite clones. That orchard was set up as a 12-ft x 24-ft x 48-ft hexagonal design on just over one acre and should maximize early and middle age seed production.

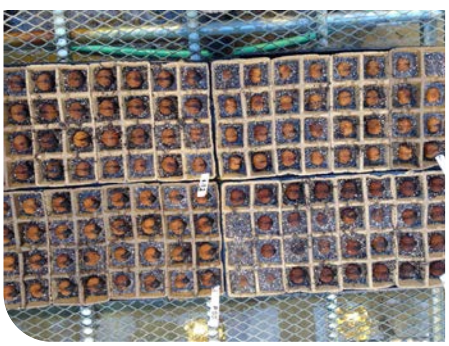
Some grafted American chestnuts from our 2019 TACF (The American Chestnut Foundation) grant work with Hill Craddock of the University of TN were planted in the Duke American Orchard at Martell Forest in May along with cross-pollinated seedlings we reported on last year with frozen and fresh pollen. We painted these with a flat interior white latex paint with a fungicide to protect them from blight – a treatment that is proving effective. Colleagues in TACF are now setting up a formal fungicide trial to optimize this important tool to keep American chestnut germplasm from dying before it can be bred. The trees all survived and will provide a source of new American chestnut diversity for future breeding. In efforts to further conserve American chestnut, a new seedling seed orchard was established in Clinton Co., IN, far away from previous blight-infested trees, and we plan to regularly treat them with fungicides to keep them alive for future breeding. Finally, a large batch of new F1 chestnuts that an intern cross-pollinated for us in 2018 with the IN-TACF was planted the Potawatomi Nature Park in northern Indiana.

Building on the success of our 2015 Forest Service State & Private Forest Health Grant to test new screening for resistance to butternut canker disease, we added an additional 60 seedlings from about 10 new families not previously screened (pure and hybrid) into our oldest screening block at Martell in mid-summer. The first batch of such seedlings, planted in 2015 that we reported on in 2018, are separating out very well into highly and moderately resistant categories, with the moderately susceptible dying out by six years and the highly susceptible dying off within 1 or 2 years.

SELECTIONS: We made numerous new butternut and hybrid butternut selections based on 11-year butternut canker disease ratings and collected scionwood from just over 20 of the best trees along with new scionwood from 15 of our highest yielding seed-producing resistant clones in our 2nd generation Pinney Purdue Agricultural Center orchard. A new breeding orchard design was established alongside a grafted American beech bark disease-resistant breeding orchard in 2021.

American chestnut seedlings that have not been bred yet and all of our surviving Duke Orchard clones that we didn't graft last year were identified and scionwood collected to graft in 2021.

Last, we assisted Rucha Karve grow seedlings of four of our most elite timber lines – as seedlings and newly sprouted seed to provide her material for her ongoing new tissue culture clonal propagation project.



GRAFTING: We multiplied new elite white oak clones selected by Lee Eckart and Danzer Forestland into both our precocious and elite white oak breeding orchards at the Martell Forest and Richard G. Lugar Farm again in 2020 to ensure that we have solid grafted trees and do not lose any of these clones. We are glad that we still have at least one strong successful graft from each clone.

New butternut selections were grafted onto 2-0 walnut seedlings from West Virginia; we couldn't get large enough caliper walnut from Vallonia Nursery in 2020. These had fairly lackluster takes at 35% overall (not unusual with butternut). Several of the clones had successful graft-takes that ended up with bunch disease that were separated and saved for Anna Conrad's new project.

We were planning to provide a training session for TACF folks coming to Purdue in mid-April for a meeting. Instead, they sent us scionwood collected from almost 20 wild trees in Connecticut, Maine, Pennsylvania, and Ohio. This was grafted onto our own rootstock and produced 16 clones with at least 1 viable graft.

CROSS-POLLINATION & POLLEN STORAGE: In 2020, we continued to test frozen pollen and now have two years of data on the effect of -20° C, stored for 1 year, compared to fresh pollen. In addition, we tested -20° C pollen stored for 2 years, and we also added a -80° C batch. Fresh pollen led to the highest seed set as in 2019 from our 2018 crosses; however, all frozen pollen treatments still worked, and the reduction in seed set was insignificant.

Besides our pollen storage crossing, we also crossed three of our trees with O x O pollen from SUNY under a strict APHIS permit obtained by Rick Meilan. These crosses turned out very well, and we shipped all the seed we produced to TACF cooperators in the Eastern U.S. who have set up field permits to test these Indiana O x O Americans amongst numerous other crosses from NY, ME, and VA in a common garden test planting in each state.

SEED HARVEST: A severe 8-hour freezing event on May 9, 2020, led to an absence of most black walnut (no butternut near Purdue) and very little red or white oak. However, American chestnut and some hybrid chestnut seed escaped the freeze and produced seed. We collected additional open pollinated families of these to add to our ongoing American chestnut germplasm plantings.

Black cherry seed production was low in our HTIRC orchards in 2020, but we utilized the abundant seed crop that we stored in 2019 to again (3rd consecutive year) provide the entire select cherry seed crop for our cooperators at Vallonia Nursery.

White oak was in short supply in fall 2020, nearly as low as 2019. We assisted Mike Saunders find decent stands containing enough acorns to collect a second year of Indiana seed to repeat his new study with four different provenances of white oak in 2022.

ENGAGEMENT AND EXTENSION

The role of HTIRC outreach is to connect our partners, collaborators, and stakeholders with the people, information, and products of the HTIRC. We also engage a broad audience to explain the benefits of forest research, management, and tree improvement for people and the environment. The following are utilized in our outreach/engagement efforts:

HTIRC NEWS

The HTIRC website and semiannual email newsletter are two of the methods used to connect with our partners, collaborators, and stakeholders. The HTIRC website (https://htirc.org) contains an updated list of publications reflecting research papers and landowner/land manager resources, as well as events involving HTIRC staff.

In spring 2020 we published our 2019 Annual report and produced an email newsletter in fall 2020. Newsletters are distributed to subscribers and posted on our website. The Fall/Winter 2020 newsletter included 10 articles highlighting recent research projects, publications, events, awards and recognition. Subscribe to the email newsletter or access past issues at https://htirc.org/resources/newsletters/

Some examples of HTIRC in the news:

- Purdue pursues industry hardwood partnerships through NSF-backed center, October 2020, Purdue College of Agriculture: https://ag.purdue.edu/stories/purdue-pursues-industry-hardwood-partnerships-through-nsf-backed-center/ (828 page views)
- Seed Propagation Protocol for Pure and Hybrid Butternut (*Juglans cinerea L.*), Spring 2020, RNGR: https://www.rngr.net/publications/tpn/63-1/
- Improving Growth of Black Walnut, October 2020, USDA Forest Service Featured Research: https://www.nrs.fs.fed.us/featured/2020/10/
- Saunders Looks at Impacts of Prescribed Fire on Quality, Economic Value, December 2020, Purdue Forestry & Natural Resources: https://ag.purdue.edu/fnr/Pages/SaundersPrescribedFire.aspx (165 page views)

For a complete listing of HTIRC-affiliated news stories, see our News Archive on our website (https://htirc.org/news/news-archive/).

EXTENSION PRODUCTS

A major focus in 2020 was moving to online programs, primarily videos on hardwood management, produced by Lenny Farlee. These are now posted at https://htirc.org/resources/landowner-information/ and include:

- ID That Tree series
- Woodland Management Moment Series
- FNR Ask the Expert series and various other woodland management videos

In cooperation with the Indiana Division of Forestry and Purdue Extension, we are producing a series of landowner-oriented videos, **"Woodland Stewardship for Landowners."** Several of these publications are completed and have been posted, and more will be posted in 2021. Topics include: Single Tree and Patch Cut Harvesting, Deer Damage to Young Trees, EQIP Programs, Foliar Spray, and several invasive plant ID and control videos.

The Planting and Care of Fine Hardwood Seedlings series provides practical information to landowners and managers for the establishment and management of hardwood trees in plantations and native forests. These publications are utilized by landowners and resource managers extensively, with over **26,000** publication downloads/views in 2020.

The national website for Thousand Cankers Disease, at https://thousandcankers.com/, includes the latest research publications, national news and state information about TCD. That website is managed by Liz Jackson at the HTIRC in cooperation with USDA Forest Service Forest Health Protection. It averages 250 views per month.

PROGRAMS

Due to the COVID-19 pandemic, many of the usual in-person training and field days were tabled or revised to online programs in 2020. The following programs were provided by Lenny Farlee and/or Liz Jackson:

- Landowners Conservation Tree Planting Workshops (in person)
- Forest Management for the Private Woodland Owner course
- Walnut Council Fall Field Day (in person)
- Forest Pesticide Applicators Continuing Education Program
- Walnut Council plantation management webinar series (8 sessions)

Some usual educational programs were tabled in 2020 and hope to be presented again in person as soon as safety allows:

- Natural Resources Conservation Service/Conservation Partnership Tree Planting Training
- Tree Farm Landowners Field Days

STAKEHOLDER ENGAGEMENT

We engage with partners, collaborators, and stakeholders through consultation, service on boards and committees, education events and field days, information sharing, and collaboration on projects. We also extend the reach to work with landowners and resource managers through education events and products. Members of the HTIRC staff serve on boards or assist with education programs for organizations including:

- The Walnut Council
- Tree Farm
- Indiana Hardwood Lumbermen's Association
- The American Chestnut Foundation
- Society of American Foresters
- Indiana Forestry and Woodland Owners Association

ANNUAL ADVISORY COMMITTEE MEETING AND TOUR

In September, HTIRC virtually hosted 25 attendees, in addition to members of the HTIRC advisory committee, to update them on the latest HTIRC research and field work. Topics presented by research scientists and students included new work in digital forestry and updates of ongoing funded projects.

EDUCATION

Developing future researchers and practitioners with expertise in the science and application of tree improvement, management, and protection of hardwood forests continues to be a fundamental objective of the HTIRC. We currently support one PhD student and one MS student with van Eck funds. One student graduated this year:

HTIRC STUDENTS WHO GRADUATED IN 2020

- **Andrea Brennan** (PhD – Jacobs) evaluated the use of hybrid butternut trees as a potential restoration tool through disease screening, assessment of environmental tolerances, and evaluation of perceptions to the use of hybrid trees for restoration.

CURRENT VAN ECK SCHOLARS

- **Minjee (Sylvia) Park** (PhD – Couture and Jacobs) is studying hyperspectral phenotyping of tree physiological responses to biotic and abiotic stresses.
- **Geoffrey Williams** (PhD – Ginzel) is characterizing community interactions that influence the severity of thousand cankers disease in eastern black walnut.
- **Molly Barrett** (MS – Saunders) is focused on regeneration response of oaks to prescribed fire and gap-based harvesting in the Central Hardwood Region (CHFR).
- **Sarah Cuprewich** (MS – Saunders) is quantifying various effects of prescribed fire on oak regeneration.
- **Aishwarya Chandrasekaran** (MS – Shao) is interested in the field of remote sensing and image processing.
- **Zachary Miller** (MS – Hupy) is studying using unmanned aerial systems (UAS) for geospatial data collection in forestry and conservation efforts.
- **Dr. Zhaofei Wen** (postdoctoral researcher with Songlin Fei) is interested in retrieving forest parameters (i.e., tree height, tree diameter, species composition, forest volume, etc.) at large scale using remote sensing and GIS technologies.

2020 RESEARCH PUBLICATIONS

HTIRC-related research papers published in 2020 are listed below. To see a listing of research from previous years, please visit the HTIRC website "Resources" tab: https://htirc.org/research/research-publications/

Brennan, A.N., McKenna, J.R., Hoban, S.M., **Jacobs, D.F.** (2020) Hybrid Breeding for Restoration of Threatened Forest Trees: Evidence for Incorporating Disease Tolerance in *Juglans cinerea*. Frontiers in Plant Science 11:580-693. https://doi.org/10.3389/fpls.2020.580693

Buongiomo, J., and **Zhou, M.** (2020) Consequences of discount rate selection for financial and ecological expectation and risk in forest management. Journal of Forest Economics 35(1): 1-17. http://dx.doi.org/10.1561/112.00000515

Carey, D.W., Allmaras, M., Bloese, P., Burke, D., Berrang, P., Dalton, L., Gettig, R., Hall, T., Hille, A., Kochenderfer, J.D., Lint, S., Mason, M. **McKenna, J.**, Rogers, S., Rose, J., Young, C., Konen, K., Koch, J.L. (2020) Beech Bark Disease Resistance Breeding Program in American Beech (abstract) In: Nelson. C., Kock, D., Sniezko, R.A., eds. Proceedings of the Sixth International Workshop on the Genetics of Host-Parasite Interactions in Forestry—Tree Resistance to Insects and Diseases: Putting Promise into Practice in Gen. Tech. Rep. SRS–252. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 170 p.

Chandrasekaran, A., et al. (2020) Delineation and measurement of hardwood tree plantations with UAS imagery. Journal of Forestry (*In review*)

Ebrahimi, A., Antonides, J.D., Pinchot, C.C., Slavicek, J.M., Flower, C.E., **Woeste, K.E.**, (2020). "The complete chloroplast genome sequence of American elm (*Ulmus americana*) and comparative genomics of related species." Tree Genetics & Genomes 17, 5. https://doi.org/10.1007/s11295-020-01487-3.

Ebrahimi, A., Lawson, S.S., McKenna, J.R., Jacobs, D.F. (2020) Morpho-Physiological and Genomic Evaluation of Juglans Species Reveals Regional Maladaptation to Cold Stress. Frontiers in Plant Science 11(229), 13 pp.

Eliopoulos, N.J., Shen, Y., Nguyen, M.L., Arora, V., Zhang, Y., **Shao, G.**, **Woeste, K.**, Lu, Y.H., (2020). "Rapid Tree Diameter Computation with Terrestrial Stereoscopic Photogrammetry." Journal of Forestry 118(4): 355-361. https://doi.org/10.1093/jofore/fvaa009

Haase, D.L., **Pike, C.**, Enebak, S., Mackey, L., Ma, Z., Silva, C. (2020) Forest Nursery Seedling Production in the United States—Fiscal Year 2019. Tree Planters' Notes 63(2). https://rngr.net/publications/tpn/63-2.

LaBonte, N.R., **Ebrahimi, A.**, **McKenna, J.R.** (2020) Developing Marker Assisted Selection for Breeding Blight-Resistant Hybrid Chestnut. The New Journal of The American Chestnut Foundation, Fall Edition pp. 29-31.

Li, Z., Yang, J., Shang, B., Xu, Y., **Couture, J.J.**, Yuan, X., Kobayashi, K., Feng, Z., (2020) Effects of elevated tropospheric O_3, water deficiency and nitrogen addition on phytochemical composition in Poplar saplings. Science of the Total Environment 707:35935.

Ma, W., Lin, G., and **Liang, J.** (2020) Estimating dynamics of Central Hardwood Forests using random forests. Journal of Ecological Modeling 419:108947 https://doi.org/10.1016/j.ecolmodel.2020.108947

Mason, C.J., Walsh, B., Keller, J., **Couture, J.J.**, Calvin, D., Urban, J.M., (2020) Fidelity and timing of attack patterns of spotted lanternfly (*Lycorma delicatula*) in ornamental trees in the suburban landscape. Environmental Entomology 49: 1427-1436. https://europepmc.org/article/med/32960283

McKenna, J.R., Ebrahimi, A., Moore, M., Rogers, S., Jacobs, J., Mack, L., Berrang, P. (2020) Screening Butternut (*Juglans cinerea*) and hybrids (*J. x cinerea*) for Resistance to Butternut Canker Disease. abstract) In: Nelson, C.D., Koch, J.L., Sniezko, R.A., eds. 2020. Proceedings of the Sixth International Workshop on the Genetics of Host-Parasite Interactions in Forestry—Tree Resistance to Insects and Diseases: Putting Promise into Practice. In Gen. Tech. Rep. SRS–252. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 170 p.

Miller, Z., Hupy, J., Chandrasekaran, A., Shao, G., Fei, S. (2020) Application of Post-Processing Kinematic Methods with UAS Remote Sensing in Forest Ecosystems. Journal of Forestry (*Accepted*)

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