HTIRC
HARDWOOD TREE IMPROVEMENT & REGENERATION CENTER

2023 ANNUAL REPORT

In partnership with:

PURDUE UNIVERSITY | Forestry and Natural Resources

USDA Forest Service
U.S. DEPARTMENT OF AGRICULTURE

TABLE OF CONTENTS

ABOUT HTIRC

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).

HTIRC's strategic objectives are 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.

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.

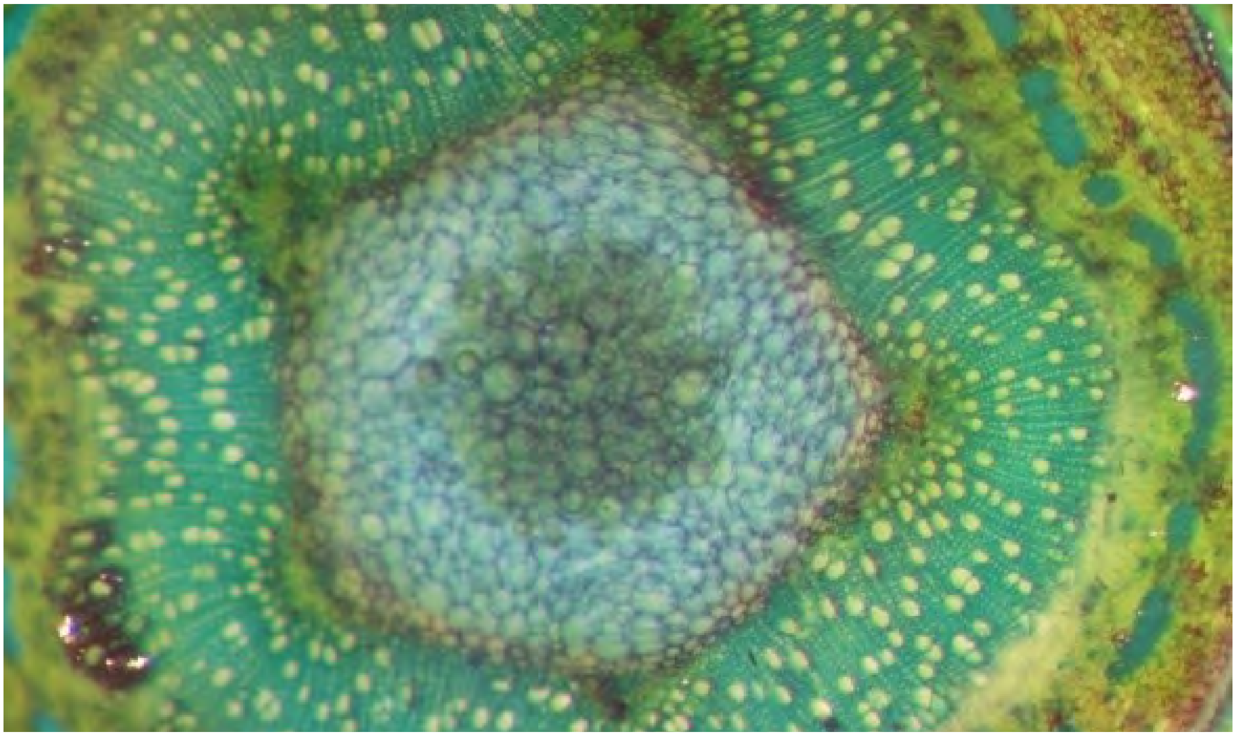
The Hardwood Tree Improvement and Regeneration Center (HTIRC) was conceived in 1998 to address a perceived void in hardwood tree improvement research in the Central Hardwood Forest Region (CHFR) and is committed to enhancing the productivity and quality of CHFR trees and forests for the economic and environmental benefits they provide. 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.

Hardwood Tree Improvement and Regeneration Center
Purdue University

715 Mitch Daniels Blvd.
West Lafayette, IN 47907-2061

htirc.org

htirc@htirc.org



2023 HIGHLIGHTS

PERSONNEL

- We bid farewell to Keith Woeste, Project Leader, USDA Forest Service NRS-14, as he moved on to become National Program Lead for the Genetics and Biodiversity Conservation R&D deputy area of the Forest Service.
- Vikram Chhatre joined USDA Forest Service unit as a research geneticist.
- Heather Dawson joined the team as an Administrative Assistant.
- Rebekah Shupe has left in pursuit of a new path. We welcome Katie Grong to the position of Research Associate.
- Bryce Chupp began working in the tree improvement program as a technician.

RESEARCH

- Published a new HTIRC strategic plan (https://htirc.org/wp-content/uploads/2024/01/Copy-HTIRC-2023-27-Strategic-Plan.pdf)
- Supported 11 ongoing projects as part of our stakeholder-driven, project-based funding model.
- HTIRC continued to be active in the Center for Advanced Forestry Systems (CAFS) with three funded projects. Also participated in the 2023 CAFS Industrial Advisory Board annual meeting, held in Louisville, Kentucky, which featured a full day of presentations from CAFS scientists, and a field tour focused on white oak management.
- Shaneka Lawson, Research Plant Physiologist, USDA Forest NRS 14, received the 2023 USDA Forest Service NRS Station Director's Award in the category of "Excellence in Equity Action" for her efforts and contributions to the Forest Service and research community.

EDUCATION/OUTREACH

- HTIRC annual meeting was held on February 24th at the Wright Center.
- We supported 8 MS students, 10 PhD students, 6 postdocs, 5 undergraduate research technicians.
- Kelsey Tobin and Alison Ochs graduated with PhD degrees.
- Bowen Li, Molly Barrett, Sayon Ghosh, and Caleb Kell earned MS degrees.
- We published the 2022 HTIRC annual report, and provided programming to key stakeholder groups and produced or updated a variety of online resources, including videos, publications, webinars, and interactive tools.
- Participated in the production of the Deer Impact Toolbox, part of the Integrated Deer Management Project at Purdue University.
- The HTIRC conducted a range of programs, workshops, courses, and field days to share information and engage with landowners, natural resources professionals, educators, and industry stakeholders. These programs covered conservation tree planting, forest management, invasive species, and pesticide applicators training.

EXECUTIVE COMMITTEE

To help us deliver on our strategic objectives, an 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:

- John Brown (Pike Lumber)
- Dan Dey (USDA Forest Service)
- James Jacobs (USDA Forest Service)
- Dana Nelson (USDA Forest Service)
- Guillermo Pardillo (ArborAmerica)
- John Siefert (Indiana DNR Division of Forestry)

PARTNERS AND COLLABORATORS

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.

ARBORAMERICA, INC.: Is 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.

TREE PRO: The leading U.S. manufacturer of tree protection products.

SAM SHINE FOUNDATION: Upon the direction of the founder, Sam Shine, this foundation's mission is of long-term conservation, preservation, and restoration of natural ecosystems while focusing on maintaining and enhancing native wildlife habitats associated with unique lands and waters.

USDA FOREST SERVICE EASTERN REGION STATE, PRIVATE AND TRIBAL FORESTRY: Collaborates with states, other federal agencies, tribes, landowners, and other partners to protect, conserve, and manage forests and community trees across 20 Northeast and Midwest 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
Heather Dawson | Administrative Assistant
Lenny Farlee | Sustaining Hardwood Extension Specialist
Elizabeth Jackson | Engagement Specialist
Rhonda Taylor | Laboratory Manager Genomics and FESSL

PROJECT SCIENTISTS

Vikram Chhatre | USDA Forest Service, Research Geneticist
Anna Conrad | USDA Forest Service, Plant Pathologist
John Couture | Plant-Insect Chemical Ecology
Songlin Fei | Measurements & Quantitative Analysis
Morgan Furze | Plant Physiology
Rado Gazo | Wood Processing
Ayman Habib | College of Engineering
Brady Hardiman| Urban Ecology
Eva Haviarova | Wood Products Engineering
Joseph Hupy | School of Aviation and Transportation Technology
Douglass Jacobs | Forest Biology
Michael Jenkins | Forest Ecology
Shaneka Lawson | USDA Forest Service, Research Plant Physiologist
Jingjing Liang | Quantitative Forest Ecology
Carrie Pike | USDA Forest Service, Region 9 Regeneration Specialist
Michael Saunders | Forest Biology/ Ecology of Natural Systems
Guofan Shao | Forest Measurement and Assessment/GIS
Song Zhang | College of Engineering
Mo Zhou | Forest Economics and Management

POSTDOCTORAL RESEARCH ASSOCIATES

Dennis Heejoon Choi
Aziz Ebrahimi
Rastiveis Heidar
Behrokh Nazeri
Bina Thapa
Andrei Toca

GRADUATE STUDENTS

Mikaela Agresta | MS
Olivia Bigham | MS
Aishwarya Chandrasekaran | PhD
Kelly French | PhD
Elias Bowers Gaffney | MS
Scott Gula | PhD
Yunmei Huang | PhD
Brianne Innusa | MS
Ellie Joll | MS
Minjee (Sylvia) Park | PhD
Summer Rathfon | MS
Tawn Speetjens | PhD
Thad Swart | MS
Wang Xiang | PhD
Zhihen Yin | PhD

TECHNICAL STAFF

Brian Beheler | Farms Manager
Don Carlson | Forester
Bryce Chupp | Technician
Clayton Emerson | Assistant Property Manager
Katie Grong | Research Associate
Caleb Kell | Operational Tree Breeder
Ron Rathfon | Extension Forester
Caleb Redick | Research Associate
James Warren | USDA Forest Service
Cameron Wingren | Unmanned Aerial Systems Data Collection Specialist

DIRECTOR'S REPORT

I am pleased to share the 2023 HTIRC Annual Report, which details how the Center worked to further our mission of advancing the science and application of tree improvement, management and protection of hardwood forests. As a group, the scientists and staff at the USDA Forest Service NRS-14 and Purdue University worked collaboratively to draft new strategic plan and chart a roadmap for the future growth and success of the HTIRC. We also sought and incorporated feedback from a broad stakeholder group and our Executive Committee to ensure that our mission and work remain relevant to your needs. This plan will guide our work through 2027 and provides a framework by which we will achieve key objectives in the areas of research, Extension, and teaching.

Despite record low income from the van Eck Forestry Foundation for Purdue University last year, we continued to support research through our stakeholder-driven, project-based funding model. Since 2019, we have funded 18 projects in total and, in this annual report, we detail progress made on our 11 ongoing projects that directly serve our strategic objectives and reflect our continued commitment to meeting the needs of our stakeholders. Training the next generation of researchers and practitioners in the science and practical aspects of tree improvement, hardwood forest management, and protection is at the core of our mission. This year, we provided support through our project-based funding model to eight MS and 10 PhD candidates, six postdoctoral researchers, and five undergraduate research technicians.

This past year also marked personnel changes for the center. In March, Keith Woeste left his position as Project Leader of the Forest Service unit at Purdue (NRS-14) to become the National Program Lead for the Genetics and Biodiversity Conservation R&D deputy area of the USDA Forest Service. In this new role he will help ensure that relevant Forest Service actions and recommendations are informed by the best possible genetic data, analysis, and science delivery. I would like to thank Keith for all his work to advance the mission of the HTIRC over the years and wish him much success in his new position. Vikram Chhatre joined the USDA Forest Service staff at Purdue as a research geneticist, bringing expertise in bioinformatics, data science, genetics, genomics, and forest population genomics. Previously, he served as a senior research scientist at the University of Wyoming for six years. During his tenure, he collaborated with the National Institute of Health's IDeA Network for Biomedical Research Excellence program (INBRE) and was actively involved in teaching bioinformatics courses and workshops. We also welcomed Katie Grong, a research associate funded by the USDA Forest Service and HTIRC, to continue the important work of creating a directory of genetic tree improvement trials previously undertaken by Rebekah Shupe. Additionally, we were happy that Heather Dawson joined us as the new Administrative Assistant, as she brings valuable expertise to our team. Finally, 2023 was a productive year for our tree breeding program, with Caleb Kell graduating with an MS in Forest Science from Purdue and taking on the full-time role as our Operational Tree Breeder. Bryce Chupp also joined the effort as a technician after graduating from Purdue with a BS in Entomology.

We remain strongly committed to connecting our partners, collaborators, and stakeholders with the resources and products of the center through technology transfer. In 2023, we produced or updated various online resources and engaged with stakeholders through online and in-person programs to share the latest information on hardwood management, invasive species, tree identification, and more. We continue to work closely with partners and stakeholders to understand their needs and distribute research-based information effectively. Your guidance and input are crucial to the continued success of the HTIRC, and we look forward to advancing our mission together.

Best,

Matthew Ginzel
HTIRC Director

HTIRC
HARDWOOD TREE IMPROVEMENT
& REGENERATION CENTER

CENTER FOR ADVANCED FORESTRY SYSTEMS

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 was 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 continues our involvement with CAFS through 2024. CAFS couples support of HTIRC partners with investments from NSF to support research projects that aim to solve complex, industry-wide problems. Funding from NSF CAFS supports projects that address CAFS research themes as part of our HTIRC project-based funding model. In addition to the core funding 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, member of the HTIRC Executive Committee, serves as our representative to the IAB.

In CAFS Phase III, HTIRC Purdue participates in three collaborative research projects with partners across other CAFS university sites. The HTIRC Purdue site is leading a project related to using hyperspectral imaging to evaluate forest health risk, which aligns with two HTIRC-funded projects (PI John Couture) and has been presented at CAFS meetings by Sylvia Park, a PhD candidate at Purdue HTIRC. Another 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 funded HTIRC project on soil suitability indices for black walnut (PI Shaneka Lawson) and another project supported by Indiana DNR to investigate hardwood plantation performance on mine reclamation sites across Indiana (PI Douglass Jacobs). The last 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) with a Purdue HTIRC postdoc, Andrei Toca, presenting the results at CAFS meetings.

In 2023, we held our CAFS IAB annual meeting in Louisville, Kentucky, during June 21-22, which included a full day of presentations from CAFS scientists and a field tour on white oak management. Our next IAB meeting will be June 12-13, 2024, in Madison, Wisconsin.

NSF CAFS website: https://iucrc.nsf.gov/centers/center-for-advanced-forestry-systems

Center for Advanced Forestry Systems

NSF

The digital forestry group, led by Songlin Fei, had a fruitful year in 2023. The group was promoted to the Institute for Digital Forestry in August 2023. The goal of the institute is to leverage digital technology and multidisciplinary expertise to measure, monitor and manage urban and rural forests to maximize social, economic and ecological benefits. HTIRC has provided critical support over the years for the early inquiries by scientists affiliated with the institute, helping Purdue University to be recognized as one of the international leading institutes in digital forestry.

The digital forestry team had significant growth in 2023. It currently has a total of 33 researchers, nine professional staff members, and 60 postdocs and graduate students, representing 13 departments/units within and outside Purdue University. The team has continued its advances in diverse research areas, focusing on inventory automation, disease and disturbance monitoring, and management optimization. Various research papers have been published and intellectual properties have been filed. The team has also increased its collaborations with government agencies, industrial partners, private companies, and other key stakeholders in the Central Hardwood Forest Region. Collaborating with groups inside and outside Purdue, the Institute for Digital Forestry currently has a total funding of $44 million across 35 research projects.

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

INVESTIGATORS

- **Mo Zhou,** *Associate Professor, Forestry and Natural Resources, Purdue University (mozhou@purdue.edu)*
- **Mike Saunders,** *Professor, Forestry and Natural Resources, Purdue University*
- **Jingjing Liang,** *Associate Professor, Forestry and Natural Resources, Purdue University*
- **Jim Warren,** *Biological Scientist, USDA Forest Service*
- **Lenny Farlee,** *Sustaining Hardwood Extension Specialist, Purdue University*
- **Elizabeth Jackson,** *Executive Director, Walnut Council/IFWOA, Engagement Specialist, Purdue University*
- **Sayon Ghosh,** *Graduate Student, Forestry and Natural Resources, Purdue University*

PROJECT OBJECTIVES

- Building the first spatially-explicit plantation growth & yield model for selected hardwood species;
- Quantifying the cost, return, and effectiveness of different thinning schedules and determining the optimal one with the highest profitability;
- Developing a suite of Extension tools to allow landowners and other stakeholders to perform the same analysis based on user-defined conditions.

ABSTRACT

This project provides user-friendly tools to make better stand establishment and thinning decisions in black walnut plantations. To supplement the existing HTIRC database, new measurements of diameter at breast height (DBH), height, and crown radius were completed on selected HTIRC plots. A model of optimal stand establishment was developed and then dovetailed with a spatially-explicit, early-rotation thinning model. The outputs were next fed into the USFS Forest Vegetation Simulator (FVS) to project the growth and yield from mid-rotation until the final harvest. We investigated several scenarios combining various planting densities, site productivities, thinning treatments, expected proportions of veneer sawlogs, and rotation lengths, to quantify the respective profitability. Additionally, we incorporated risk into these projections by assuming random timings and different severities of windthrow. Finally, we developed an Extension tool for landowners to calculate the profitability under different scenarios.

APPROACH

- Estimated the growth of black walnut under different planting densities and thinning treatments
  - Developed a nonlinear, multi-stage model of stand establishment that minimized establishment costs while ensuring free-to-grow status by year 5, and crown closure by year 10;
  - Built a spatially-explicit thinning model based on HTIRC data to simulate crop tree release between years 10 and 20;
  - Projected archetypal stands from the spatially-explicit, early stand models with FVS, including thins at year 20 and between years 35 and 45, leaving only crop trees for the final harvest.
- Estimated the total merchantable volume and derived profitability in two-year intervals over a plantation's lifecycle;
- Performed stochastic simulations of windthrow damages and estimated financial losses from the mid-rotation till the final harvest;
- Quantified the impacts of varying discount rates, site productivities, percentages of veneer sawlog, and rotations on the stand value;
- Utilized R shiny to develop an interactive Extension tool for landowners.

KEY FINDINGS

- As shown in Table 1, without considering the risk of windthrows, denser plantings create moderately better financial returns for black walnut plantations. A site with high productivity can lead to a significantly greater net present value than a site with low productivity.
- As shown in Table 2, even under the risk of windthrows, the expected stumpage value at the final harvest was still higher on higher productivity sites. Similarly, although a longer rotation exposed a plantation to a higher probability of financial losses, it still achieved considerably greater expected stumpage values at the final harvest.

Table 1. The profitability metrics of a black walnut plantation at the end of the projection period (96 years), assuming herbicide treatments and deer fencing during establishment, 5% veneer of the total merchantable volume, no risk of windthrow, and a 3% discount rate. tpa: trees per acre. NPV: net present value. LEV: land expectation value. EAI: equivalent annual income. B/C ratio: benefit/cost ratio. The real price of black walnut was assumed to appreciate based on the annual rate of increase in the real price, revealed by the historical prices between 1957 and 2018 in Indiana.

Planting Density (trees/ac, tpa)	Site Index (SI) High: SI = 100 Average: SI = 65	NPV	LEV	EAI	B/C Ratio	Break-Even Age (year)
1210	High	$2,313	$2,457	$73	1.7	64
1210	Average	$330	$351	$10	1.1	84
640	High	$2,483	$2,638	$79	1.9	62
640	Average	$624	$663	$19	1.3	78

Table 2. The probability of the stumpage value falling within a certain range by the end of a rotation under the risk of windthrow. For instance, for a planting density of 1210 trees per acre, high site index (SI), and 5% of final volume in veneer, there is a 40% chance that stumpage value will be between $0-2,500 per acre and a 60% chance between $10,000-20,000, dictated by the occurrence of a severe windthrown event in that stand.

60-YEAR ROTATION									
Planting Density (trees/ac)	SI	Veneer %	Probability of stumpage value ($/acre)						
			0-2.5k	2.5-5.0k	5.0-7.5k	7.5k-10k	10k-20k	20k-30k	>30k
1210	High	0%	0.39			0.61			
		5%	0.40				0.60		
	Average	0%	0.41	0.59					
		5%	0.40		0.60				
640	High	0%	0.40			0.60			
		5%	0.41				0.59		
	Average	0%	0.41	0.59					
		5%	0.41		0.59				

75-YEAR ROTATION									
Planting Density (trees/ac)	**SI**	**Veneer %**	**Probability of stumpage value ($/acre)**						
			0-2.5k	**2.5-5.0k**	**5.0-7.5k**	**7.5k-10k**	**10k-20k**	**20k-30k**	**>30k**
1210	High	0%	0.52	0.06			0.42		
		5%	0.48	0.09	0.02				0.41
	Average	0%	0.48	0.09			0.42		
		5%	0.47	0.09	0.02		0.42		
640	High	0%	0.53	0.04			0.43		
		5%	0.48	0.09				0.42	
	Average	0%	0.52	0.06			0.42		
		5%	0.50	0.07	0.02		0.42		

90-YEAR ROTATION									
Planting Density (trees/ac)	SI	Veneer %	Probability for stumpage value ($/acre)						
			0-2.5k	2.5-5.0k	5.0-7.5k	7.5k-10k	10k-20k	20k-30k	>30k
1210	High	0%	0.52	0.14	0.05				0.29
		5%	0.47	0.09	0.05	0.05	0.04		0.29
	Average	0%	0.50	0.18	0.04		0.28		
		5%	0.47	0.09	0.08	0.05	0.02		0.29
640	High	0%	0.54	0.13	0.04			0.29	
		5%	0.49	0.09	0.06	0.05	0.02		0.29
	Average	0%	0.52	0.17	0.02		0.29		
		5%	0.49	0.08	0.11	0.03	0.01		0.29

MANAGEMENT IMPLICATIONS

- Model results demonstrate the importance of selecting high-quality sites for black walnut plantations, both in terms of increased profitability but also reduced risk associated with windthrow (i.e., by reducing rotation length).
- Pruning and thinning does increase potential returns, mostly by increasing the proportion of veneer in stand. These treatments, however, do not abate the risk of windthrow causing significant damage and loss of stumpage value.
- Model results provide an initial approximation of potential losses from windthrow and can be used to approximate insurance value for investments in walnut plantations.
- Users should recognize the model is projecting results that are not verifiable with current data from actual plantations. Data from black walnut plantations more than 30 years old is rare. As more data becomes available, this model may be refined.
- Economic returns on different grades of black walnut can vary widely over time. There are many grades of walnut veneer and each has a range of market values that also change regularly. These values provided here are for comparison only and do not represent a high-confidence prediction of future values.

PRECISE QUANTIFICATION OF FOREST DISTURBANCES WITH UAS

INVESTIGATORS

- **Joseph Hupy,** *Associate Professor, School of Aviation and Transportation Technology, Purdue University (jhupy@purdue.edu)*
- **Songlin Fei,** *Professor, Forestry and Natural Resources, Purdue University*
- **Jarred Brooke,** *Extension Wildlife Specialist, Forestry and Natural Resources, Purdue University*
- **Guofan Shao,** *Professor, Forestry and Natural Resources, Purdue University*

PROJECT OBJECTIVES

This proposal directly addresses HTIRC Organizational Objective 4:

- Develop digital forestry technologies
- Tools developed in this proposed project can greatly enhance our ability to address HTIRC Strategic Goals 2 and 5:
  - Improve management strategies and techniques to enhance the ecological sustainability and economic benefits of hardwood forests
  - Educate future leaders in tree improvement, management, and protection of hardwood.

KEY FINDINGS

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

Objective 1. 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 over several timber stands over a three-year period resulting in a robust data set for further analysis.

- In years one and two, significant progress was been made by the research team toward development and refinement of data collection methods and standards (Figure 1). Two graduate students were funded through this HTIRC funding. Zach Miller successfully completed and defended his master's thesis on the topic. Out of this thesis, he and a group of co-authors have successfully published in the *Journal of Forestry*, and in *Drones Journal*. Cameron Miller also engaged in one year of data collection related to the funding.
- Despite the difficulties presented by the Covid-19 outbreak, Zach Miller was able to work with another graduate student, Cameron Wingren, in the summer and fall of 2021 to transfer research methods and results information for a smooth transition. The intent was for Cameron to focus more on the temporal recovery component and explore data collection with LiDAR on the UAS. In early fall 2022, however, Cameron was hired on as UAS coordinator for the digital forestry initiative and is now funded by that. Cameron is still engaged in data collection prior to and after disturbance events at Purdue forest properties but is not pursuing the research under a thesis option.
- Flights over controlled burn disturbances on Purdue properties were performed during spring, summer, and fall of 2020 and 2021. This was done mainly to establish data collection workflows and to determine data processing times over a landscape known not to present difficulties in data processing and for proximity to Purdue University. Flights performed at sites containing woodlots of varying canopy structure and harvest type presented a variety of difficulties and issues that led to adjustments to determine ideal altitude and flight path overlap. During this time, it was determined that mature, dense canopy forests do present some issues, but methods are being refined to fly these at higher altitudes. Some sites also presented difficulties regarding access, airspace restrictions, and ground- based flight hazards such as power lines. Recent data collection efforts are currently focused on controlled burns at Martell Forest and Purdue Wildlife Area. Another area of focus is a data collection of flights over PI Joseph Hupy's property in a northern mixed forest of the Upper Peninsula of Michigan. Data was collected in fall 2021, then again in spring 2022 in leaf off, then again for leaf on prior to timber harvest. Data collection at this location has continued in the spring and fall,

with the results undergoing analysis, and with potential to pursue future funding and publications. The property is unique for the fact that its forest was unhealthy with an infestation of black spruce beetle, and a ground fire prior to harvest, and with a temporal data set monitoring regrowth since harvest occurred over an 80-acre area in summer 2022. The diverse forest cover of multiple species of conifer deciduous mixed-age tree growth also makes for promising future research.

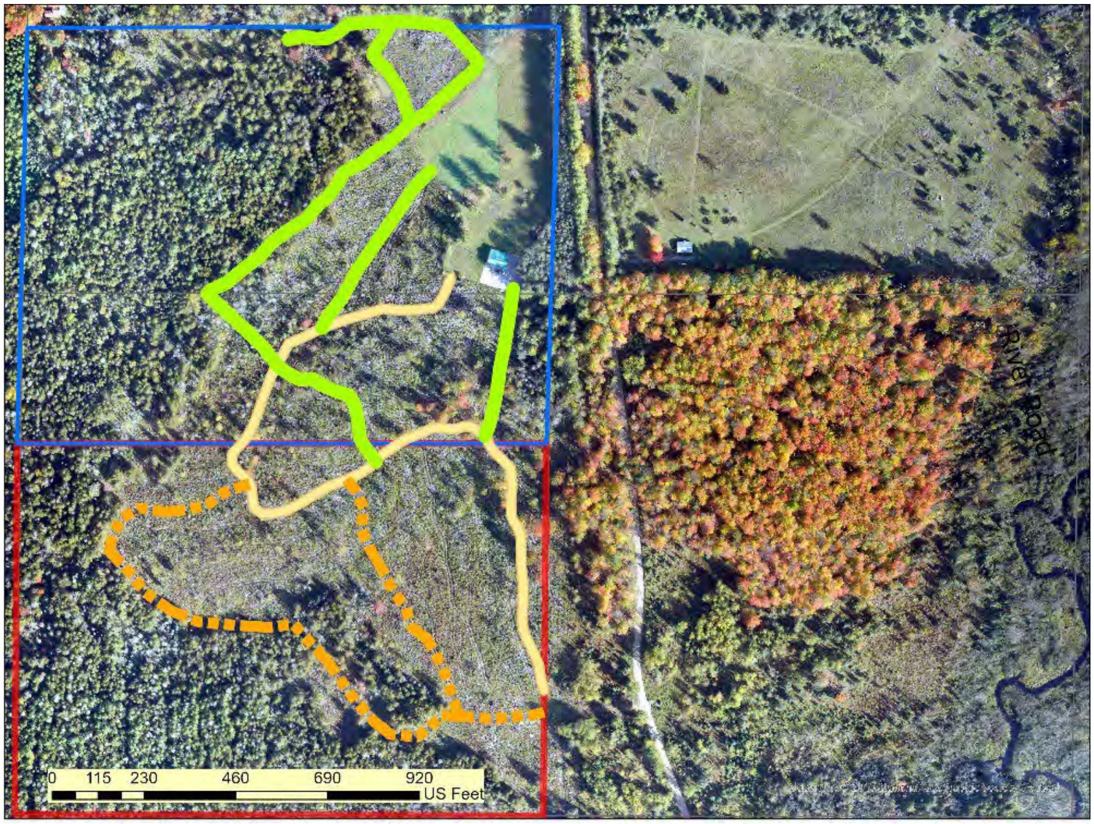


Figure 1: Northern mixed forest in October 2023 showing newly placed trails after August 2022 harvest.

Objective 2. 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.

- Zach Miller was able to streamline processing and classification methods over a Purdue Wildlife Area burn disturbance site, and the Volz timber harvest site. Both sites were chosen due to the quality of the imagery gathered and processed. Although many harvest sites were flown over, issues with the forest canopy prevented quality processing of this data and resulted in an incomplete orthomosaic. The Volz 125 site as seen in Figure 2 is one of three timber harvest study sites that was used with Pike Lumber as a stakeholder
- Joseph Hupy is working on bringing in a master's or PhD student interested in classification methods with disturbance datasets to continue with planned disturbance research. The work demonstrated by the student shows promise. The student will be funded outside of the grant as a teaching assistant and external funding will be pursued for the student to continue what was started with this research.

Figure 2. High-Resolution RGB Orthomosaic of the Volz 125 forest plot before (a), during (b), immediate post harvest (c) and 30 days after harvest (d) events.

Objective 3. 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.

- Immediately after receiving notification of funding in early 2020, the PI, Joseph Hupy, worked with his graduate student Zach Miller on connecting with stakeholders to identify timber stands that reflected diverse canopy structure and timber harvest methods. Zach Miller reached out to multiple stakeholders, mainly those in charge of state forest lands and timber companies involved with managing a variety of private timber plots.
- Zach Miller primarily worked with Pike Lumber over the spring and summer of 2020 and 2021. He was told of timber plots that were going to be harvested, the type of harvest to occur, and a projected timber harvest date. In keeping open these lines of communication, Zach was able to capture a wide variety of timber plots before a harvest event. Some of those plots have not yet been harvested, but the relationship and communications allow for Zach to be notified when those plots will be harvested in the upcoming months.
- Relationships with Pike Lumber and other stakeholders allowed for flights to be conducted over 10 different disturbance plots. Eight of those plots were forms of timber harvest disturbance, and two were related to controlled burn disturbance (Figure 2.) Communication will continue with the stakeholders to discuss which sites will have follow-up flights occur, and to possibly include new sites that contain harvest methods or timber of noted interest.
- Relationships are forming with stakeholders in a northern mixed forest to explore these methods outside of temperate deciduous forests. Funding for this research will expire on January 31, 2024, but flights will continue on the northern mixed forest plot, and work will continue with pursuing additional funding and to bring in stake holders from other forest environments.

PRODUCTS

Publications

- Miller, Z.; Hupy, J.; Hubbard, S.; Shao, G. (2022) Precise Quantification of Land Cover before and after Planned Disturbance Events with UAS-Derived Imagery. Drones 6, 52. https://www.mdpi.com/2504-446X/6/2/52
- Cromwell, C.; Giampaolo, J.; Hupy, J.; Miller, Z.; Chandrasekaran, A. (2021) A Systematic Review of Best Practices for UAS Data Collection in Forestry-Related Applications. Forests. 12(7):957. https://www.mdpi.com/1999-4907/12/7/957
- Miller, Z.; J.P.; Hupy, A.; Chandrasekaran, G.F. Shao; S. Fei. 2018. Application of Post-Processing Kinematic Methods with UAS Remote Sensing in Forest Ecosystems *Journal of Forestry*.
- Miller, Zachary. 2021. Quantification of Land Cover Surrounding Planned Disturbances using UAS Imagery. *M.S. Thesis, School of Aviation and Transportation Technology, Purdue University*

Presentations

- Hupy, J.P. (2022) Nature Conservancy and Purdue Extension UAS Workshop. UAS Sensor Data Collection Strategies. Wright Forestry Center.
- Hupy, J.P.; Wingren, C. (2022) Digital Forestry UAS Presentation. DNR Forestry Division Annual Meeting. Brown County State Park, IN.
- Hupy, J.P. (2020, August). Precise quantification of forest disturbance with unmanned aerial systems. Oral Presentation. Ecological Society of America, Purdue University - School of Aviation and Transportation Technology, West Lafayette
- Hupy, J.P. (2020, February). Utilizing Unmanned Aerial Systems and Geospatial Technology for Wildlife Conservation. Keynote/Plenary Address. Indiana Chapter of the Wildlife Society 2020 Spring Meeting, Purdue University - School of Aviation and Transportation Technology, West Lafayette, IN

ISSUES

- The primary issue faced by the research team was the timing of the "shelter in place" order during the early stages of Covid-19. This timing of this order came about in the early spring as planning was in place to hire undergraduate field assistants to aid in ground truthing. Despite this unforeseen hindrance, the amount of planning already done, and the fact that the work was being done within the state allowed for a great deal of data collection to occur. Before the Covid-19 lockdown, Zach Miller had already established several study sites with Pike Lumber and was able to further communicate via email and phone.
- Another issue encountered was the quality of data over some of the mature deciduous forest mixed canopies, despite flying at the 400-foot maximum altitude allowed by the FAA. The density of the canopy presented challenges with being able to process the data to generate the required orthomosaic for classification purposes. The issue was discussed with the graduate student Zach Miller, and it was determined that because the trees presented themselves as a 100-foot ground obstacle, flights could legally be conducted at altitudes of 500 feet. A refinement in methods and approaches by flying at higher altitudes with more overlap has presented itself to resolve this issue.
- Plans to bring in a graduate student for fall 2023 fell through due to the student being unable to acquire a visa. The no-cost extension was sought to cover that student for fall 2023, but now with that student unable to attend, the project will come to a close in January 2024.

PARTNERS/COLLABORATORS

- Joey Gallion, Forest Inventory Program Manager, Indiana DNR (RETIRED)

USING REMOTE SENSING TO CHARACTERIZE STRESS EPIDEMIOLOGY IN HARDWOOD FOREST STANDS

INVESTIGATORS

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

PROJECT OBJECTIVES

Managed forest systems contribute substantially to local, national, and global economies. Pests and pathogens have the largest negative impact on forest growth and productivity. The main objective of this proposal is to integrate multi-spatial and temporal scale remote sensing (RS) products with forest management scenarios. Specifically, we will focus on three areas of forest management: 1) tracking insect pest and pathogen incidence, severity, and spread, 2) early detection of drought stress-related symptoms, and 3) optimize RS acquisitions to determine the number of collections appropriate to make an informed management decision.

ABSTRACT

Previous postdocs Ali Masjedi and Behrokh Nazeri have coordinated manned aircraft flights over the Indiana location. Unfortunately, Covid-19 restrictions stopped travel to MO during 2020 and 2021, but plans were being adjusted to meet the stated goals of this proposal. We found that remotely sensed hyperspectral data can discriminate American chestnut (*Castanea dentata*) trees infected with chestnut blight (*Cryphonectria parasitica*) from non-diseased trees 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, the Purdue Digital Ag seminar series, the NSF CAFS updates, and have received social media attention. Concepts from this grant are resulted in a successfully funded USDA Tactical Sciences for Agriculture Biosecurity grant in 2021 with a focus on tracking invasive species. New butternut work was highlighted in 2023 IEEE International Workshop on Metrology for Agriculture and Forestry (MetroAgriFor) in Pisa, IT, and is accepted and being processed for publication in the IEEE Xplore digital library.

An emergent outcome that developed from this proposal, and is included in the 2022 funded HTIRC grant "Integrating morphology, genotype, and chemotype based methods to support HTIRC butternut conservation and resistance breeding efforts", is the use of spectral data to separate butternut (*Juglans cinerea*) and Japanese walnut (*Juglans ailantifolia*), both when infected and not infected with butternut canker disease (BCD).

APPROACH – Chestnut blight detection

- Collected and processed two years (2018-2019) of UAV hyperspectral and LiDAR data over a mixed species plot at Martell 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 manned hyperspectral data from a manned aircraft.
- Collected leaf samples (2019-2020) for stress-level chemical analyses and scored leaf blight (2018-2020).

KEY FINDINGS/ACCOMPLISHMENTS

UAV-based spectral data can discriminate American chestnut trees with and without blight (Figure 1). The ability of spectral data to classify blight, however, declines as additional classes of blight (e.g., none, mild, severe) are classified (Figures 2, 3) and classes become confused with each other (Figure 4).

Spectral bands that are important for classification shift depending on collection period (Figure 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

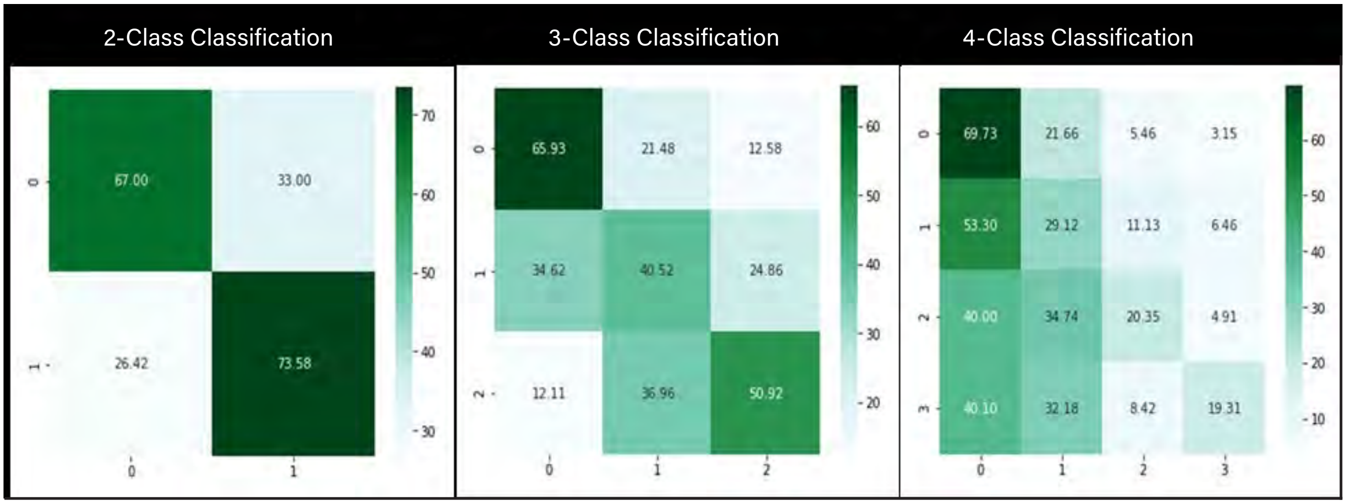


Figure 1. Classification accuracy of two-class (presence or absence) classification of chestnut blight in American chestnut trees using different spectral regions (visible and near infrared [VNIR]; shortwave infrared [SWIR]; and combined VNIR and SWIR). Classifications were made using support vector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

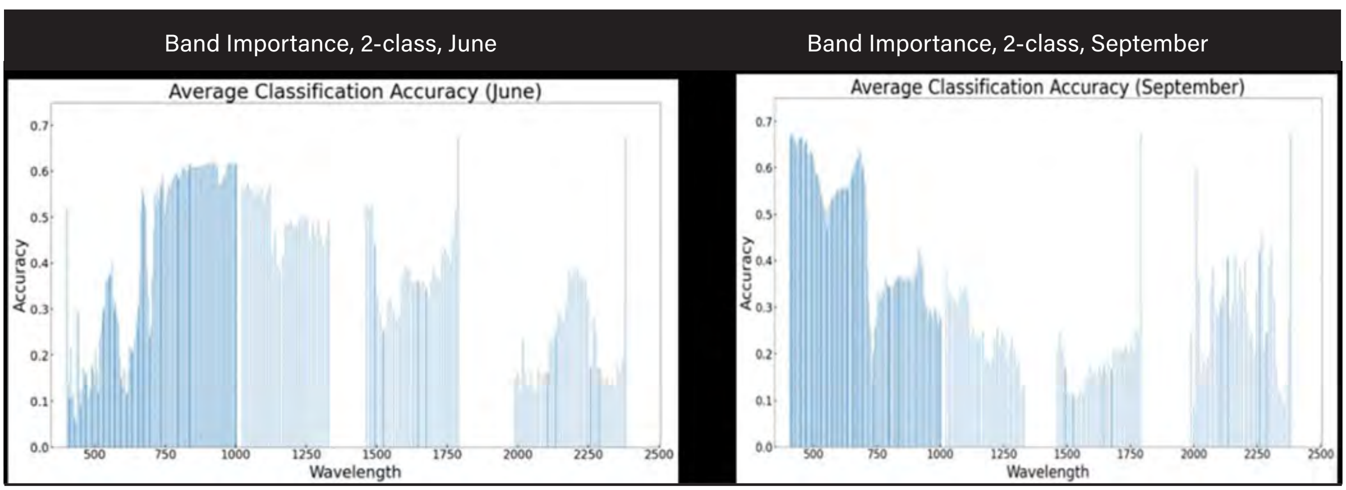


Figure 2. Classification accuracy of three-class (none, mild, or severe) classification of chestnut blight in American chestnut trees using different spectral regions (visible and near infrared [VNIR]; shortwave infrared [SWIR]; and combined VNIR and SWIR). Classifications were made using support vector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

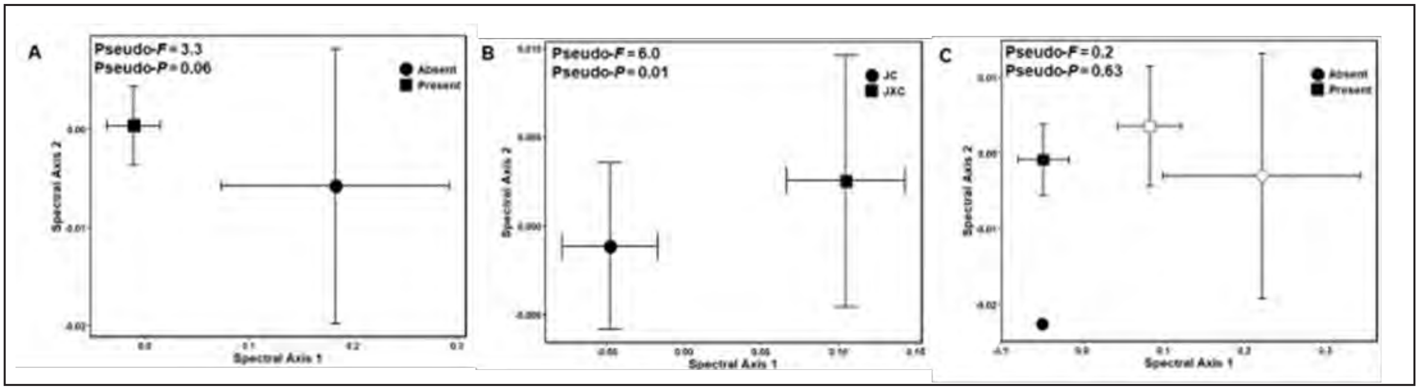


Figure 3. Classification accuracy of four-class (none, mild, moderate, or severe) classification of chestnut blight in American chestnut trees using different spectral regions (visible and near infrared [VNIR]; shortwave infrared [SWIR]; and combined VNIR and SWIR).

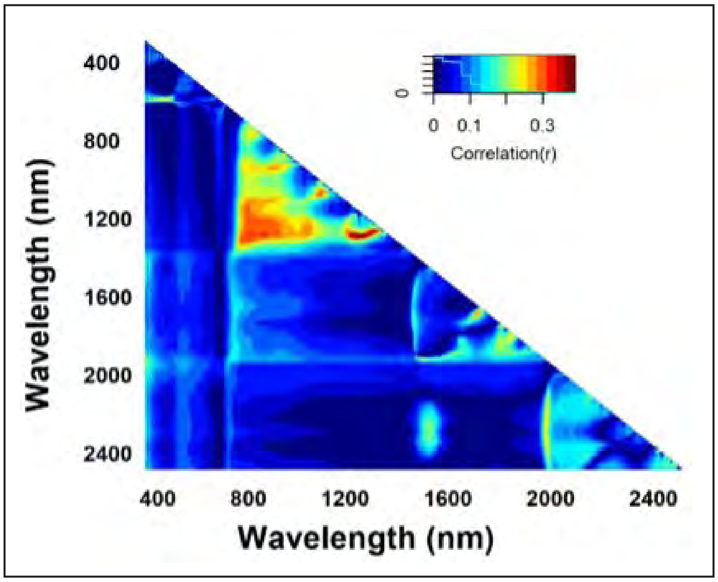


Figure 4. Confusion matrix for disease classification. For example, in the far-left panel, a 0 (no blight) is accurately classified 67% of the time and misclassified as having blight 33% of the time. Notice that as classes are added more classes are confused.

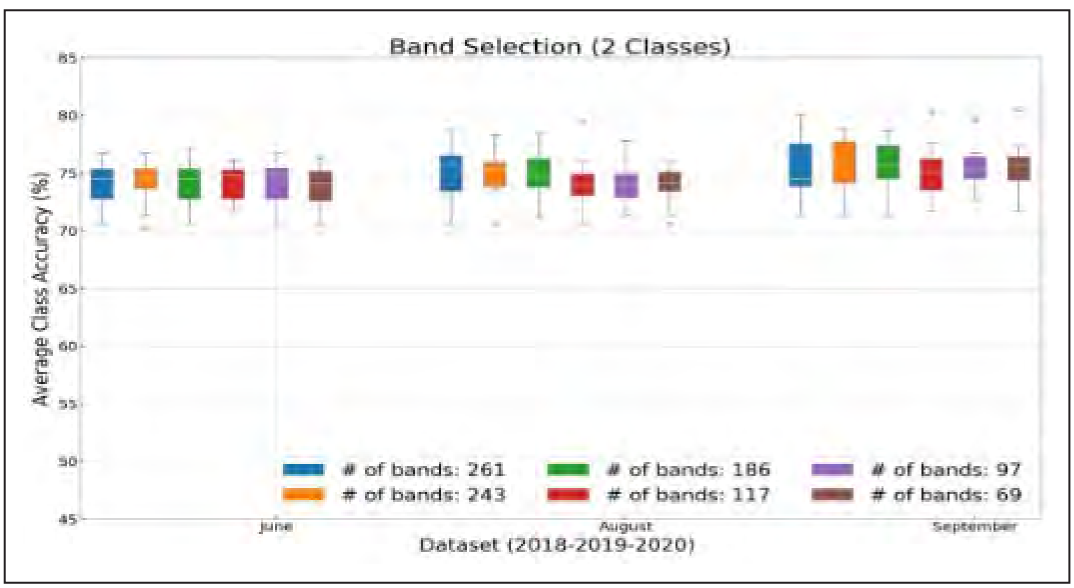


Figure 5. Importance of individual bands in classification accuracy in June (left) and September (right) collection periods. Notice how bands from 500-750 are less important in June, when the canopy is green, but shift to have considerable importance in September, as canopy senescence begins. Likely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

APPROACH

Butternut canker disease detection

- Collected and processed spectral data obtained from canopies of pure butternut and Japanese walnut with variable levels of BCD at Martell Forest in August 2022 to 1) identify BCD presence using spectral data and 2) differentiate pure butternut and Japanese walnut.
- Collected leaf samples for stress-level chemical analyses and scored BCD severity.

KEY FINDINGS/ACCOMPLISHMENTS

- Canopy spectral data can discriminate a) Juglans trees with and without BCD, b) pure butternut and Japanese walnut, and c) butternut and Japanese walnut with and without BCD (Fig. 6). Spectral changes associated with the red-edge region were the most influential in separating BCD-infected and non-BCD-infected Juglans (Fig. 7).
- Work was highlighted in 2023 IEEE International Workshop on Metrology for Agriculture and Forestry (MetroAgriFor) in Pisa, IT, and is accepted and being processed for publication in the IEEE Xplore digital library.

PARTNERS/COLLABORATORS

- University of Wisconsin-Madison

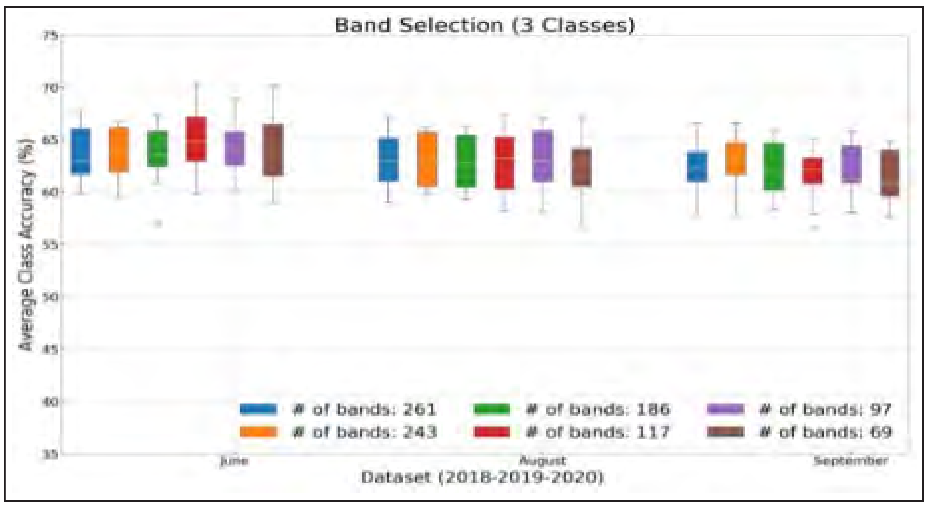


Figure 6. (a) Principal Coordinate Analysis using Euclidian distance of spectral data to separate between diseased (presence) and non-diseased (absence) trees, (b) butternut (JC) and hybrids (JXC), and (c) butternut (open points) and hybrids (black points) for diseased (squares) and non-diseased (circles) trees. Error bars represent ± 1 SE.

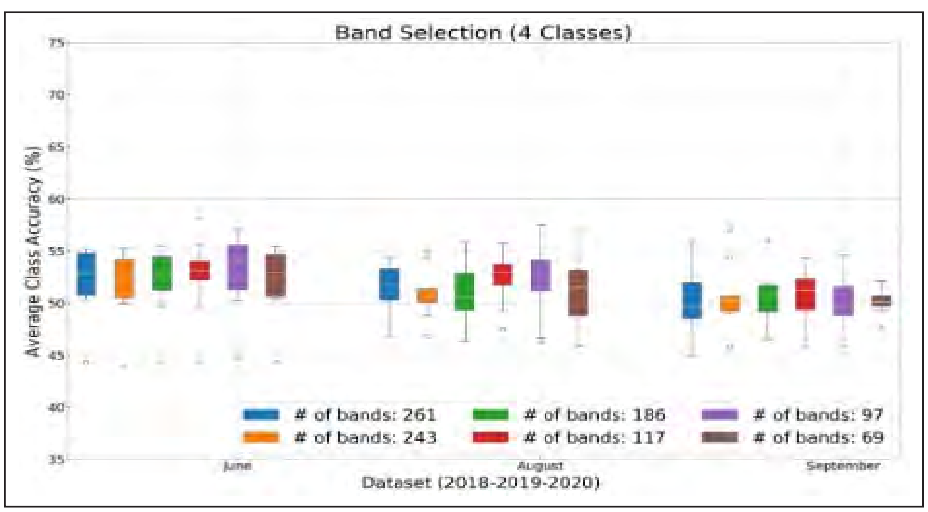


Figure 7. Normalized Differential Spectral Index (NDSI) showing the correlation of disease rating with variation in all possible wavelength combinations.

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

INVESTIGATORS

- **Guofan Shao,** *Professor, Forestry and Natural Resources, Purdue University (shao@purdue.edu)*
- **Keith Woeste,** *USDA Forest Service, National Program Lead for Genetics for the Research & Development Deputy Area.*
- **Yung-Hsiang Lu,** *Professor, School of Electrical and Computer Engineering, College of Engineering, Purdue University*

PROJECT OBJECTIVES

The long-term goal of this project is to develop a Low-cost Optical Gauging System (LOGS) for efficient forest inventory and data management. LOGS will allow HTIRC scientists to obtain accurate, up-to-date data on all the trees in their breeding program.

ABSTRACT

The team focused on three research activities: 1. Finalizing a journal article titled "Measuring tree stem diameters and straightness with depth-image computer vision," 2. Testing LOGS-based DBH measurements for walnut trees grown and maintained by ArborAmerica, and 3. Conducting field experiments on GPS accuracies for locating individual trees.

KEY FINDINGS

The team found that there were bias in DBH measurement, suggesting further refinement is needed before widespread application. Nevertheless, once this and other methods are fully operational, digital measurement technologies will provide an immense advantage in the field of forestry and natural resource conservation.

The team found that the mapping-grade GPS (Garmin 64S) can provide accurate tree location information (<2 m RMSE) when used at a distance of 5 m from the tree in a leaf-off season, but its accuracy decreases (>5 m RMSE) as the leaf density increases.

PRODUCTS

Publications

- Tran, H., K. Woeste, B.W. Li, A. Verma, and G.F. Shao. 2023. Measuring tree stem diameters and straightness with depth- image computer vision. *Journal of Forestry Research* 34(5): 1395–1405. https://doi.org/10.1007/s11676-023-01600-x
- Estep, G.N., B.W. Li, G.F. Shao, C. Wingren, M.R. Saunders. Accuracy and Precision of Digital Forest Measurements. A poster presentation at FNR annual symposium, April 2023.
- Ward, A., A. Chandrasekaran, G.F. Shao, and K. Woeste. Tree Position Variations with GPS Distance to Trees in Leaf-off and Leaf-on Seasons. A poster presentation at the 2023 SAF National Convention, Sacramento, CA ▪ October 25-28, 2023.

PARTNERS/COLLABORATORS

- James Warren, Biological Scientist, USDA Forest Service
- Joey Gallion, Forest Inventory Program Manager, Indiana DNR (RETIRED)

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

INVESTIGATORS

- **Rado Gazo,** *Professor, Forestry and Natural Resources, Purdue University (gazo@purdue.edu)*
- **Bedrich Benes,** *Professor, Computer Graphics and Computer Science, Purdue University*
- **Songlin Fei,** *Professor, Forestry and Natural Resources, Purdue University*

OBJECTIVES

Objective 1. This objective focused on evaluating the existing image acquisition hardware at a cooperating sawmill, determining whether a hardware upgrade is needed, and performing such an upgrade.

Objective 2. This objective focused 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.

Objective 3. This objective focused on investigating the relationships between tree species, size, age, and growth rate over time to geographic location, site index, soil quality, and prior forest stand management techniques using the hardware and software system developed in the first two objectives.

SUMMARY OF ACCOMPLISHMENTS

Objective 1. The hardware system analysis was performed at the cooperating sawmill and it was determined that no immediate hardware update was required until the software developed under the second objective better informed new equipment parameters.

Objective 2.The majority of work was performed under this objective. A detailed description of the methodology, data collection, analysis, and results is available in a published paper available here:

> *Fanyou Wu, Yunmei Huang, Bedrich Benes, Charles C. Warner, Rado Gazo. Automated tree ring detection of common Indiana hardwood species through deep learning: Introducing a new dataset of annotated images. Information Processing in Agriculture, 2023. ISSN 2214-3173, https://doi.org/10.1016/j.inpa.2023.10.002.*

Objective 3.The geographic location and immediate past forest management at the sites from which our tree growth ring data was collected was provided by the cooperating sawmill. The relationship between the growth rate of various tree species, site characteristics, and forest management is being currently analyzed.

APPROACH AND KEY FINDINGS

Table 3 displays the performance for several species. Overall, the Area Under Curve (AUC) values for all species varied from 0.8-0.9 indicating that the segmentation model could rate the probability of the pixel inside a single picture. Not all species perform equally when we evaluate performance under the growth ring level. In particular, black walnut (F1=0.6341) and soft maple (F1=0.6621) had the lowest F1 scores. This agrees with our intuition and expectations since during the annotating step these two species were the two most difficult species to manually determine the growth ring edges.

Table 3. The performance over different species on clean surface.

Species	Common name	AUC	PREC	REC	F_1
Acer saccharinum	Soft maple	84.09%	0.5435	0.8534	0.6621
Acer saccharum	Hard maple	85.81%	0.6143	0.8743	0.7176
Carya spp.	Hickory	86.70%	0.6744	0.8828	0.7614
Celtis occidentalis	Hackberry	82.80%	0.6998	0.8684	0.7714
Fraxinus spp.	Ash	88.52%	0.8052	0.8878	0.8402
Juglans nigra	Black walnut	84.05%	0.5921	0.7067	0.6341
Liriodendron tulipifera	Yellow poplar	85.13%	0.5694	0.9012	0.6958
Prunus serotina	Cherry	85.92%	0.7011	0.7831	0.7338
Quercus rubra	Red oak	88.14%	0.6497	0.9163	0.7563
Quercus spp.	White oak	87.19%	0.6838	0.9097	0.7749
Tilia americana	Basswood	84.21%	0.7181	0.7964	0.7465

LIST OF PARTNERS/STAKEHOLDERS/COLLABORATORS

- Pike Lumber Company, Akron, IN – industrial partner

BACKPACK SYSTEM FOR HIGH RESOLUTION FOREST INVENTORY

INVESTIGATORS

- **Ayman Habib,** *Professor, Civil Engineering, Purdue University (ahabib@purdue.edu)*
- **Songlin Fei,** *Professor, Forestry and Natural Resources, Purdue University*

PROJECT OBJECTIVES

Objective 1. Optimize system integration, data logging, and deployment of Backpack LiDAR system

Objective 2. Develop data processing and biometrics extraction algorithms

Objective 3. Share tools and methods with HTIRC researchers and stakeholders in trainings and workshops.

APPROACH AND FINDINGS

To date, the research team has developed five backpack LiDAR systems

- For the different backpack systems, data acquisition protocols and user manuals have been established.
- The backpack systems have been used for several data acquisition campaigns at Martell Forest and ArborAmerica for both plantation and natural plots under leaf-off and leaf-on conditions. In addition to the deployment of the backpack LiDAR, UAV LiDAR missions have been conducted.
- Strategies have been developed for trajectory enhancement to mitigate GNSS signal outages while collecting data under forest canopy.
- Data analytics strategies have been developed for forest biometric extraction; including ground/non-ground filtering, individual tree detection and localization, tree height estimation, and DBH evaluation.
- A web portal has been developed for the visualization of point clouds and derived products.
- The research findings have been disseminated in several presentations, conference proceedings, and peer-reviewed journal papers.

Figure 1: Backpack system during a data acquisition campaign in Martell Forest

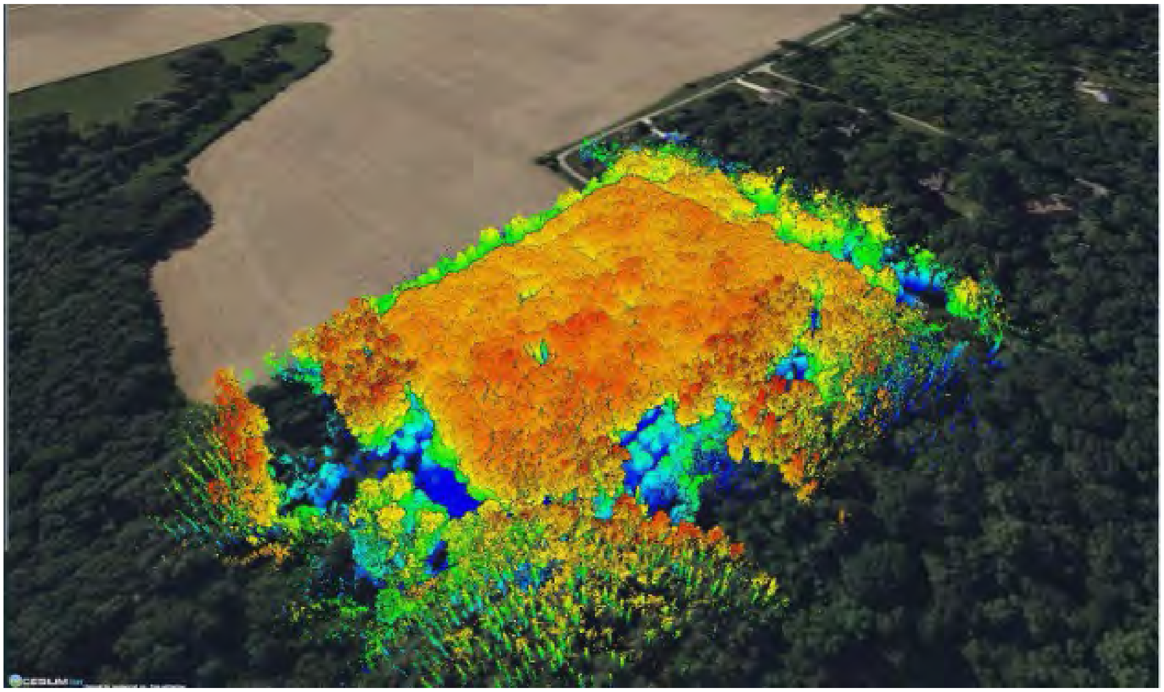


Figure 2: Sample point cloud derived from the Backpack System

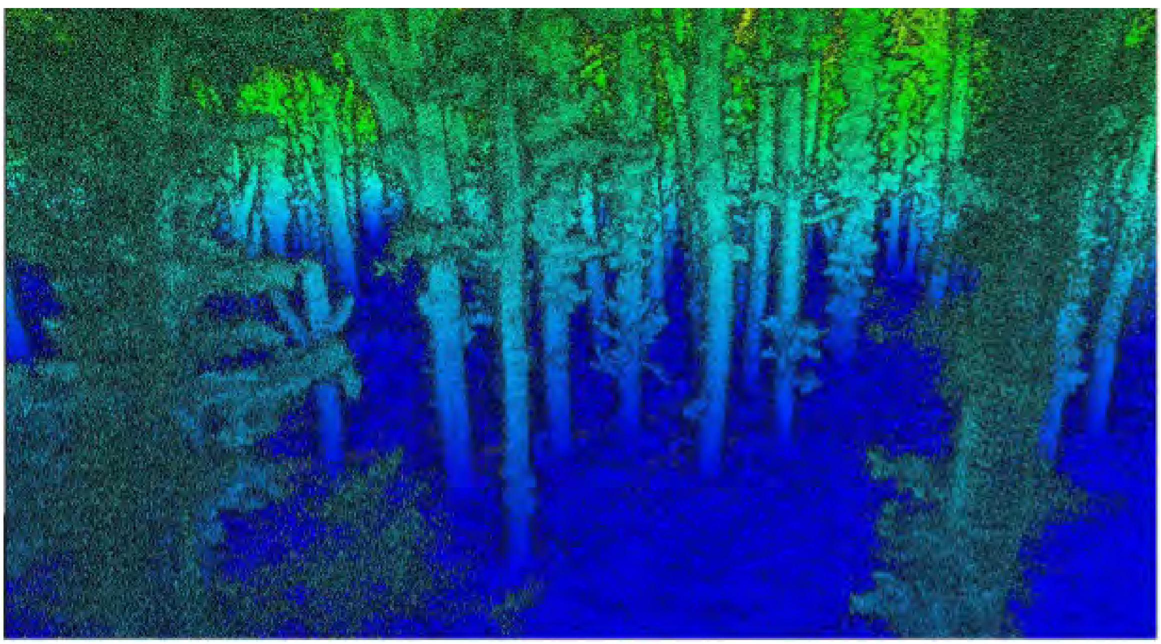


Figure 3: Close-up of a collected cloud in Martell Forest

PRODUCTS

Publications

- Zhou, T.; Ravi, R.; Lin, Y.-C.; Manish, R.; Fei, S.; Habib, A., 2023. In Situ Calibration and Trajectory Enhancement of UAV and Backpack LiDAR Systems for Fine-Resolution Forest Inventory. *Remote Sens. 2023*, 15, 2799. https://doi.org/10.3390/rs15112799.
- Habib, A., 2023. LiDAR Technology for Scalable Forest Inventory: Evaluating the Trade-offs between the Various Platforms. *GIM International*, Issue 2, 2023, pp. 9-11.
- Shao, J., Cheng, Y.T., Koshan, Y., Manish, R., Habib. A., and Fei. S., 2023. Radiometric And Geometric Approach for Major Woody Parts Segmentation In Forest LiDAR Point Clouds. IGARSS 2023 - 2023 IEEE International Geoscience and Remote Sensing Symposium, Pasadena, CA, USA, 2023, pp. 6220-6223, doi: 10.1109/IGARSS52108.2023.10281558.

- Rastiveis, H.; Zhou, T.; Zhao, C.; Fei, S.; and Habib, A., 2023. Automated Fine-Scale Forest Inventory using Backpack LiDAR – A Strategy based on Feature Extraction, Matching, and Tracking from Integrated Scans. Smart Forests: Close range sensing Workshop, the ISPRS 2023 Geospatial Week, Cairo, Egypt, September 2-7, 2023, Cairo, Egypt.
- Zhou, T.; Zhao, C.; Manish, R.; Fei, S.; and Habib, A., 2023. Forest Feature LiDAR SLAM (F2-LSLAM) and Integrated Scan Simultaneous Trajectory Enhancement and Mapping (Is2-Team) for Accurate Forest Inventory using Backpack Systems. Smart Forests: Close range sensing Workshop, the ISPRS 2023 Geospatial Week, September 2-7, 2023, Cairo, Egypt.
- Shao, J.; Habib.; and Fei, S., 2023. Semantic Segmentation of UAV LiDAR Data for Tree Plantations. UAV-based Mapping Workshop, the ISPRS 2023 Geospatial Week, September 2-7, 2023, Cairo, Egypt.
- Zhou, T.; Manish, R.; Fei, S.; and Habib, A., 2023. In-Situ Calibration and Trajectory Enhancement of UAV and Backpack LiDAR Systems for High-Resolution Forest Inventory. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLVIII-1/W1- 2023, 595–602, https://doi.org/10.5194/isprs-archives-XLVIII-1-W1-2023-595-2023, 2023.

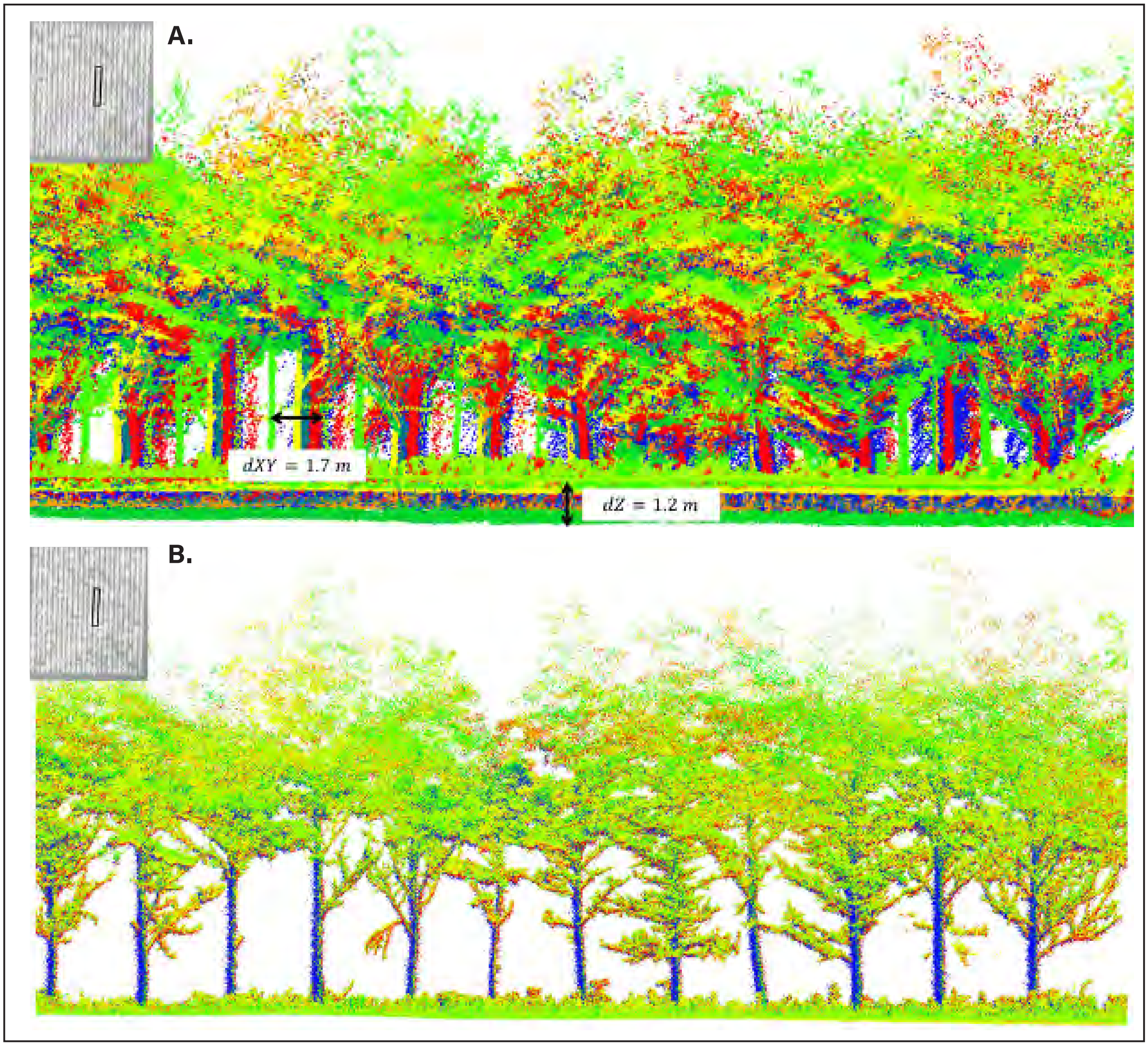


Figure 4: Point cloud before (a) and after (b) improving the backpack trajectory using the proposed trajectory enhancement procedure in this research.

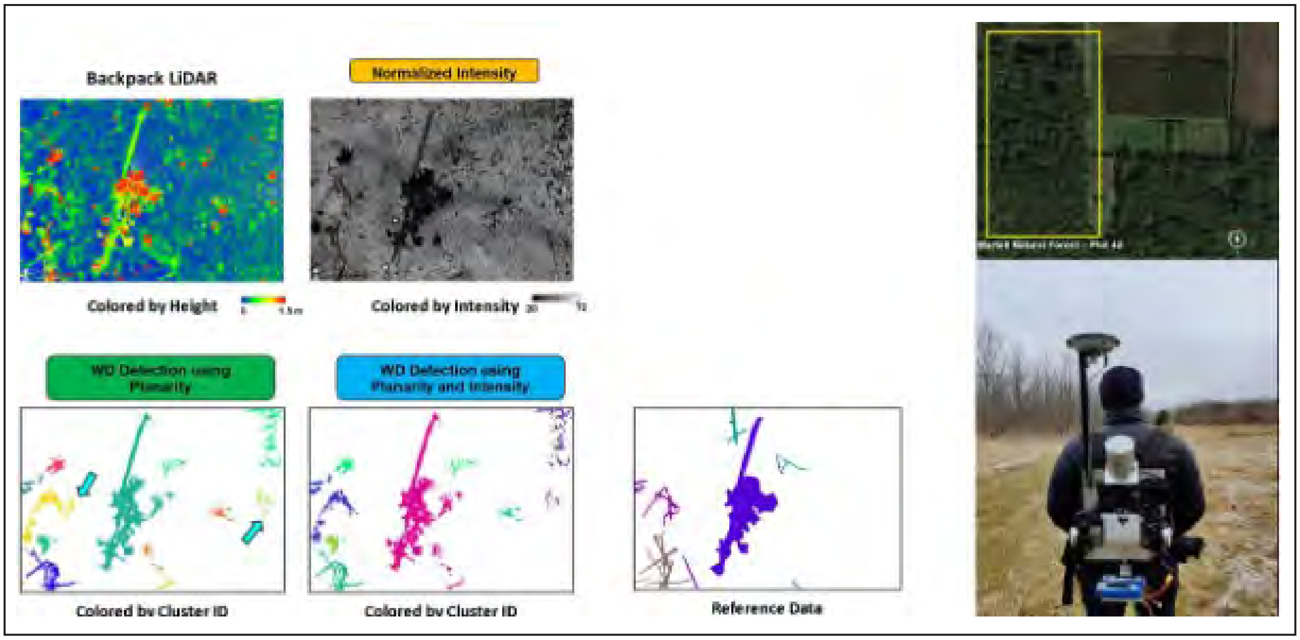


Figure 5: Preliminary results from using backpack LiDAR data for debris detection.

Patents

- Habib, A.; Fei, S.; 2023. System and Method for Calibration and Trajectory Enhancement of LiDAR Technologies. Provisional Patent Application Filed; OTC Track Code: 69979-01.

Presentations

- 3D-SLAM Strategies for Fine Scale Forest Inventory using Backpack LiDAR. GNSS Research Center, Wuhan University, October 11, 2023.
- Sensing and Data Analytics Technologies as Facilitators for Digital Forestry. Keynote, Smart Forests: Close range sensing Workshop, the ISPRS 2023 Geospatial Week, Cairo, Egypt, September 6, 2023, Cairo, Egypt.

Awards

- SPRS GSW2023 Best Workshop Paper Award. Zhou, T.; Zhao, C.; Manish, R.; Fei, S.; and Habib, A., Forest Feature LiDAR SLAM (F2-LSLAM) and Integrated Scan Simultaneous Trajectory Enhancement and Mapping (Is2-Team) for Accurate Forest Inventory using Backpack Systems. Smart Forests: Close range sensing Workshop, the ISPRS 2023 Geospatial Week, Cairo, Egypt, September 2-7, 2023.

FUTURE PLANS

- Continue with improving the GNSS/INS trajectory using tree and terrain features
- Improve the individual tree segmentation from derived point clouds
- Incorporate acquired imagery by the backpack for trajectory enhancement
- Expand the capabilities of the developed visualization portal
- Augment the trajectory enhancement by using publicly available elevation data (e.g., 3DEP data)

PARTNERS/COLLABORATORS

- Guofan Shao, Professor, Forestry and Natural Resources, Purdue University
- Joey Gallion, Forest Inventory Program Manager, Indiana DNR (RETIRED)

TESTING EFFICACY OF UNDERPLANTING AND ENRICHMENT PLANTINGS FOR STAND REGENERATION IN HARDWOOD FORESTS

INVESTIGATORS

- **Douglass F. Jacobs,** *Fred M. van Eck Professor, Forestry and Natural Resources, Purdue University (djacobs@purdue.edu)*
- **Don Carlson,** *Forester, Forestry and Natural Resources, Purdue University*
- **Ron Rathfon,** *Extension Forester, Forestry and Natural Resources, Purdue University*
- **Caleb Redick,** *Research Associate, Forestry and Natural Resources, Purdue University*
- **Michael Saunders,** *Professor, Forestry and Natural Resources, Purdue University*

PROJECT OBJECTIVES

- Re-visit and assess long-term (> 10 years) performance of hardwood enrichment plantings across the full network of available FNR trials and attempt to link success or failure to site conditions, silvicultural treatments at establishment, and/or subsequent management regimes.
- Evaluate hardwood tree responses to competition release for a sub-set of trials in Objective 1 that are at the appropriate developmental stage and have sufficient stocking of dominant or co-dominant trees.
- Establish and maintain a network of demonstration trials to be used as a resource for HTIRC / Purdue FNR Extension field days to communicate results of these long-term trials to landowners and foresters.

ABSTRACT

Oaks (*Quercus* spp.) and other valuable hardwood species provide important economic, ecological, and wildlife values, but regeneration failures in natural forests are common. Enrichment plantings may provide an alternative means to increase the abundance and diversity of advance reproduction of desirable hardwoods. Most of these studies have been short-term, however, with relatively few extending beyond 10 years. Thus, a more comprehensive knowledge of the longer-term responses of enrichment plantings is needed. We are taking advantage of a network of existing HTIRC / Purdue FNR enrichment planting demonstration trials and research experiments established over the past 20 years in natural forest stands on FNR woodlands throughout Indiana, with three main objectives. In Objective 1, we are assessing long- term performance of enrichment plantings across this network of sites. Using this data and an assessment of site conditions, we will develop models to best explain relative long-term success or failure of these plantings. For Objective 2, we will use a sub-set of trials from those in Objective 1 that are at the appropriate developmental stage and have sufficient stocking of future crop trees to examine responses to release from competition. In Objective 3, we will establish and maintain these sites as a network of demonstration trials to be used as a resource for HTIRC / Purdue FNR Extension field days to communicate results of these long-term trials to landowners and foresters. Our project will enhance knowledge of the long-term responses of these plantings specific to the relatively mesic site conditions characterizing Indiana and the surrounding region. Through our Extension and outreach efforts, we will ensure that these results are extended to forest managers and HTIRC stakeholders to help develop effective prescriptions for hardwood enrichment plantings.

APPROACH

Assess long-term performance of enrichment plantings

- We revisited each of the planting demonstration trials and research experiments (Table 1, Figure 1, page 28) to assess long-term performance.
- On each of the sites, we identified and recorded the number of planted trees by species, and measured their height, diameter (DBH), and competitive status (dominant/co-dominant, intermediate, or suppressed). These data are being compared to the original planting records to determine survival, growth, and vigor or planted trees by species (Table 1). Where possible, we are analyzing growth and survival by treatment. For example, at the 2013 SEPAC trial we are analyzing the effect of fencing and vegetation control treatments, while at the 2001 Nelson-Stokes trial we are analyzing the effect of regular thinning treatments.
- Simultaneously, we assessed competing tree species on each of the sites.
- Using this newly recorded data and a full assessment of site conditions, we will develop models (e.g., Figure 2, page 29) that best explain relative long-term success or failure of enrichment plantings.

Age	Location	Fencing	Species	N	Survival, Height, & Diameter by Crown Class in Larger Gaps								
					Suppressed			Intermediate			Codominant / Dominant		
					%	Ht. (cm)	DBH (mm)	%	Ht. (cm)	DBH (mm)	%	Ht. (cm)	DBH (mm)
20	Nelson-Stokes	None	Red Oak	308	33	569	41	5	989	75	2	1470	134
19	SIPAC	None	Red Oak	300	23	451	30	2	898	63	2	1118	103
12	Nelson-Stokes	Fence	Red Oak	140	21	293	16	15	389	19	17	562	34
		None		140	16	343	17	6	446	25	7	601	39
		Fenced	White Oak	80	24	279	15	8	291	12	3	368	21
		None		80	20	189	11	5	345	18	5	397	23
		Fenced	Red Oak	140	25	182	10	11	346	17	5	473	30
		None		140	28	230	12	11	358	18	6	413	23
		Fenced	White Oak	80	23	174	12	0	N/A	N/A	1	256	12
		None		80	39	176	11	11	221	12	3	326	21
8	SEPAC	Fenced	Red Oak	225	60	210	12	16	364	20	12	531	38
		None		225	63	225	11	19	417	22	8	612	41
		Fenced	White Oak	225	81	213	11	16	354	20	14	378	32
		None		225	71	211	11	13	425	26	9	476	32
		Fenced	Chinkapin Oak	225	12	268	12	1	497	20	4	534	36
		None		225	4	226	12	0	447	18	1	483	40
		Fenced	Chestnut	225	3	280	19	1	498	32	8	633	57
		None		225	4	262	18	3	647	32	10	725	61
10	Harrold	Fenced	Red Oak	79	13	647	63	6	946	83	13	1051	116
		None		92	3	892	56	2	849	54	2	1037	81
		Fenced	White Oak	87	40	630	69	5	847	65	3	78	84
		None		79	14	540	52	1	1038	66	0	N/A	N/A
		Fenced	Black Walnut	99	12	693	56	7	1118	84	38	1419	150
		None		119	11	765	71	12	957	120	39	1391	164
		Fenced	Tuliptree	42	0	N/A	N/A	14	1073	104	60	1618	208
		None		45	2	404	165	11	1073	143	64	1548	220

Table 1. Descriptive results from HTIRC / Purdue FNR enrichment trials measured in 2021-2023, including age of planting at measurement, location, presence/absence of deer exclusion fencing, species, number planted, and percentage of planted trees reaching a particular crown class as well as height, and diameter in larger gaps (> 0.4 ha).

Figure 1. Example of large container red oak shortly after planting into the largest (~0.4 ha) harvest gap treatment at SIPAC in 2003 (left). Planted red oaks and natural regeneration in the largest harvest gap size treatment at SIPAC in 2006 after four growing seasons (right).

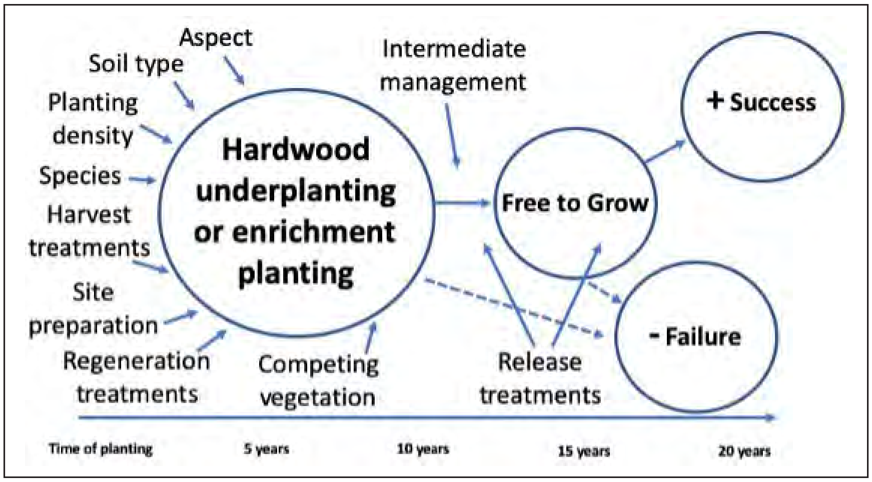


Figure 2. Example of factors that may help to explain relative success of underplanting and enrichment plantings.

Evaluate crop tree responses to release treatments

- We identified a sub-set of three trials (the 2001 and 2010 Nelson-Stokes plantings and one of the 2013 SEPAC trials) that were at the appropriate developmental stage (9-21 years old) and have sufficient stocking of dominant or co- dominant future crop trees to examine response to release from competition.
- To accomplish the release treatments, we used a split-plot design where half of the co-dominant and dominant trees in each replicate plot were randomly allocated to receive release or else designated as a control (no release). Release treatments in June 2022 consisted of a 3- or 4-sided crown release, which is appropriate for this developmental stage. We avoided 4-sided crown releases on trees that neighbored other good crop trees.
- In addition to release of our planted trees, at SEPAC we identified natural regeneration (60 stump sprouts and 60 seeded trees) of oak trees in a similar age class and competitive position on transects in the same stand as our other plots and released these trees in fall 2022, which will further allow for comparison of responses to release for planted trees vs. natural regeneration.
- To quantify response to release, all experimental trees were measured for height and DBH, as well as canopy volume (as a function of crown height and crown diameter) at time of release and will be measured after the 2024 and 2025 growing seasons.

KEY FINDINGS

- At Nelson-Stokes, northern red oaks after 20 years had 41% survival, an average diameter of 51 mm, average height of 669 cm, and 21% had a crown class of intermediate or above.
- At Block C1 at the SEPAC Biomass planting (Figure 3), overall survival was 68% after 8 years. For northern red oaks, average diameter was 23 mm inside fences and 18 mm outside fences, average height was 402 cm inside fences and 327 cm outside fences, and 53% had a crown class of intermediate or above inside fences and 43% had a crown class of intermediate or above outside fences. For white oaks, average diameter was 20 mm inside fences and 16 mm outside fences, average height was 324 cm inside fences and 265 cm outside fences, and 42% had a crown class of intermediate or above inside fences and 32% had a crown class of intermediate or above outside fences. For chestnuts, average diameter was 53 mm inside fences and 51 mm outside fences, average height was 605 cm inside fences and 574 cm outside fences, and 100% had a crown class of intermediate or above inside fences and 77% had a crown class of intermediate or above outside fences. For chinkapin oaks, average diameter was 22 mm inside fences and 21 mm outside fences, average height was 414 cm inside fences and 382 cm outside fences, and 52% had a crown class of intermediate or above inside fences and 33% had a crown class of intermediate or above outside fences.
- At the Nelson Stokes 2010 TNC planting in the unfenced midstory removal, overall survival was 48% after 12 years. For northern red oaks, average diameter was 15.6 mm, average height was 287 cm, and 38% had a crown class of intermediate or above. For white oaks, average diameter was 12.3 mm, average height was 193 cm, and 26% had a crown class of intermediate or above. In the unfenced and crown thinned treatment, overall survival was 29% after 12 years. For northern red oaks, average diameter was 24.1 mm, average height was 424 cm, and 45% had a crown class of intermediate or above. For white oaks, average

diameter was 15.2 mm, average height was 250 cm, and 33% had a crown class of intermediate or above. In the fenced and crown thinned treatment, overall survival was 45% after 12 years. For northern red oaks, average diameter was 22.4 mm, average height was 408 cm, and 62% had a crown class of intermediate or above. For white oaks, average diameter was 14.5 mm, average height was 288 cm, and 30% had a crown class of intermediate or above. In the fenced midstory removal, overall survival was 35% after 12 years. For northern red oaks, average diameter was 15.6 mm, average height was 262 cm, and 40% had a crown class of intermediate or above. For white oaks, average diameter was 12.2 mm, average height was 178 cm, and 6% had a crown class of intermediate or above.

- At Nelson-Stokes, northern red oaks after 20 years had 41% survival. Survival was higher in the block where thinning had been regularly performed (43%) than in the block where it was not done (37%), but this difference was not statistically significant. Competition had a large effect on height growth, with height increasing with greater freedom from competition, but this trend was only seen in the block where thinning had been done (F: 10.7, $p = 0.004$).
- At the SEPAC Biomass planting (Figure 3), overall survival was 68% after 8 years. Species interacted with treatment, as well as fencing, to affect survival. There were no clear trends across treatments, but the difference in survival by species was clearest in the control treatment. White oaks and northern red oaks had higher survival than chestnuts and chinkapin oaks. White oak in the control treatment (99±1%) had greater survival than northern red oaks, except for red oaks with vegetation treatments in the first year after planting (91±4%). Fenced white oaks had the highest survival (98±1%), followed by unfenced white oaks (90±5%) and all northern red oaks (which did not differ by fencing; 82-86%). Chestnuts (9-13%) and chinkapin oaks had the lowest survival. Fencing did not affect chestnut survival, but survival was lower for unfenced (4±2%) than fenced (13±6%) chinkapin oaks. Species had the greatest effect on heights (F: 29.9, $p <0.001$), followed by competition with neighbors (F: 9.4, $p = 0.002$). Chestnuts achieved greater height than any other planted species at 635±46 cm ($p < 0.002$ in all cases); northern red oaks were taller than white oaks on average ($p = 0.003$) at 417±41 cm vs. 338±41 cm, but chinkapin oaks were not significantly taller at 451±57 cm ($p = 0.075$). Height decreased with increasing competition, though there is some evidence that competition may be a higher order variable with reduction in height when competition is extremely low (i.e., lack of trainer trees).
- Don Carlson led an Extension day at Harrold Woodland on September 23, 2023, which highlighted the descriptive results in Table 1, page 28.

Figure 3. Aerial views of the unfenced (left) and fenced (right) plots at the C1 block of the 2013 SEPAC Biomass Planting.

FUTURE PLANS

- Continue to analyze the collected data.
- Analyze data with past thinning/release treatments as a factor to determine if they were effective.
- Measure responses to release treatments.
- Update FNR-225 (Enrichment planting of oaks, by Morrissey et al., 2007) with our project results.

BETTER BLACK WALNUT BY BREEDING WITHOUT BREEDING

INVESTIGATORS

- **Vikram Chhatre,** *(Current PI), USDA Forest Service, Forestry and Natural Resources, Purdue University (chhatre@purdue.edu)*
- **Keith Woeste,** *(Former PI) USDA Forest Service, National Program Lead for Genetics for the Research & Development Deputy Area*
- **Richard Cronn,** *Research Geneticist, Pacific Northwest Research Station, Corvallis, OR*
- **Denita Hadziabdic,** *Assistant Professor, Entomology and Plant Pathology, University of Tennessee*
- **Mo Zhou,** *Assistant Professor, Forestry and Natural Resources, Purdue University*
- **James Warren,** *Biological Scientist, USDA Forest Service*
- **Sarah Boggess,** *Lab Services Specialist, University of Tennessee*
- **Laura Hauck,** *Lab Services Specialist, USDA Forest Service*

Purdue Undergraduate Student Trainees

- Lina Bernabe
- Liam Gogel
- Dylan House
- Emily Lesinski
- Zachary Uebelhor

Funding Note: *This is year 3 of the project. However, no continuing funding was requested during year two. Subsequently, we requested, and received year two funding in the amount of $57,000 during fall 2023. The following pages describe work undertaken during year 3 of the project.*

PROJECT OBJECTIVES

This project proposes to identify superior black walnut parents by determining heritability of growth and form related traits using HTIRC's progeny trials across the state of Indiana. Phenotypic data collected from over 1200 progeny of 76 female parents will be analyzed together with genomic data from 156 Single Nucleotide Polymorphisms (SNPs) using a statistical framework called Genomic Best Linear Unbiased Prediction (G-BLUP). This approach, called breeding without breeding, is faster than classical breeding methods aimed at understand heritability in growth traits.

ABSTRACT

An innovative approach as an alternative to traditional and time-consuming tree breeding was demonstrated by El-Kassaby and Lstiburek (2009) in Douglas fir. We implement this approach to identify superior black walnut parents using families established in HTIRC provenance trials across several different locations in Indiana. We propose to genotype up to 3000 progeny of black walnut parents in HTIRC trials to first verify and identify sib-sib and sib-parent familial relationships using maximum likelihood parentage algorithms. Subsequently, we propose to combine the genotypes, established familial relationships and quantitative data on growth and form to analyze and identify superior black walnut parents with Genomic Best Linear Unbiased Prediction (G-BLUP) method. A total of 1224 progeny from 76 maternal parents have been genotyped at 156 single nucleotide polymorphisms. Growth and form data has also been recorded for a majority of the progeny. Verification of familial relationships is under progress.

APPROACH

- Sampling involves collection of vegetative buds or fresh leaves from each individual, which are subsequently used for DNA isolation.
- Phenotyping consists of recording growth traits such as diameter at breast height (DBH), main trunk form and crown measurements.
- Genomic methods are based on targeted genotyping of variable genomic sites using the Sequenom MassARRAY iPLEX Gold Platform. The SNP chip employed was developed by Co-PI Cronn using genomic variability in a range-wide sample of black walnut. The SNP chip genotypes 156 sites.
- Familial relationships are verified or identified using a maximum likelihood-based method implemented in CERVUS (Kalinowsky et al., 2007, Marshall et al.,1998) and COLONY (Jones and Wang, 2010).

- Genomic and phenotypic data are then combined and analyzed using the G-BLUP framework implemented in r- ASREML to identify black walnut parents with superior heritability in growth traits.

KEY FINDINGS AND ACCOMPLISHMENTS

- To date, we have collected leaf/bud tissue from more than 1400 samples (parents and progeny combined) from nine plantations at five different sites in Indiana (Table 1 & Figure 1).
- Phenotypes related to growth and trunk form were collected from all 1400 individuals; however, the crown measurements were recorded only for a subset of samples.
- Samples were processed in the laboratory of Co-PI Hadziabdic at University of Tennessee, and genotyping for 156 SNPs was completed by a commercial vendor, Neogen Inc. of Oregon.
- As of January 2024, we have obtained genotypic data for ≈1300 individuals from 76 families.

FUTURE PLANS

- Genotypic data will be used to verify known parent-progeny and sib-sib relationships, and to identify paternal parents using a maximum likelihood approach implemented in the software CERVUS (Kalinowsky et al., 2007, Marshall et al., 1998) and COLONY (Jones and Wang, 2010).
- If our data provides insufficient clarity on familial relationships, more progeny per family will be sampled and processed using the same methods during summer 2024. Additional families will also be sampled.
- Established familial relationships, SNP genotypes and growth and form trait data will be analyzed with G-BLUP to identify genetically superior parents.

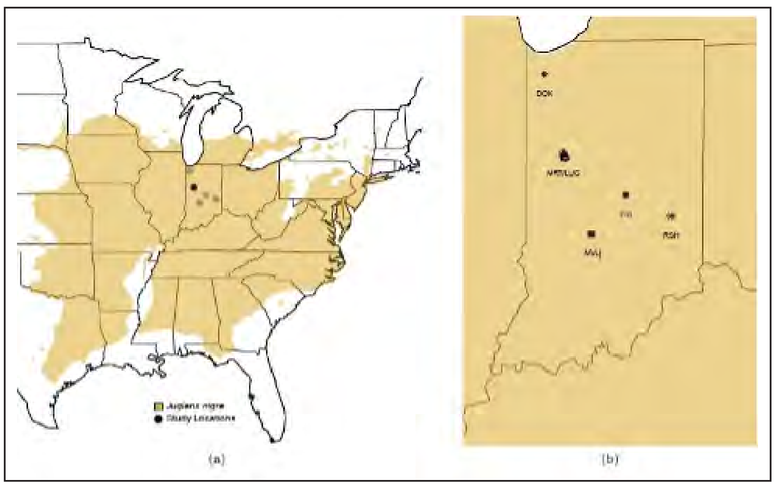


Figure 1. Locations of J. nigra *families under study.*

Table 1. Plantations with Black Walnut trials used in the current study.

Planting Yr	Plot Name	Latitude	Longitude	Rep. Fam.	N. Progeny
2002	Elite (MRT/LUG)	40.42413	-86.96376	13	99
2004	Fishers (FIS)	39.93523	-86.00163	26	78
2005	Gate 28 sprt seed (MRT/LUG)	40.38598	-86.95091	11	104
2005	Hazel Baker 1-0 sdl (MRT/LUG)	40.38478	-86.93435	32	436
2006	Hazel Baker (MRT/LUG)	40.38425	-86.93320	4	12
2006	Martinsville 3 (MVL)	39.46840	-86.52517	12	32
2008	Block Test Lugar (MRT/LUG)	40.42822	-86.95843	14	319
2011	Rush County (RSH)	39.68301	-85.30456	24	345
2012	Doak (DOK)	41.37020	-87.25306	12	144

REFERENCES

- El-Kassaby, Y.A., & Lstiburek, M. (2009). Breeding without breeding. Genetics research, 91(2), 111-120.
- Kalinowski, S.T.; Taper, M.L.; & Marshall, T.C. (2007). Revising how the computer program CERVUS accommodates genotyping error increases success in paternity assignment. Molecular Ecology, 16(5), 1099-1106.
- Marshall, T.C.; Slate, J.B.; Kruuk, L.E.B.; Pemberton, J.M. (1998). Statistical confidence for likelihood based paternity inference in natural populations. Molecular Ecology, 7(5), 639-655.
- Jones, O.R., & Wang, J. (2010). COLONY: a program for parentage and sibship inference from multilocus genotype data. Molecular Ecology Resources, 10(3), 551-555.

INDIANA'S FUTURE FORESTS: EMPTIED NICHE OCCUPATION IN AN ASH-LESS WORLD

INVESTIGATORS

- **Michael Saunders**, *Professor, Forestry and Natural Resources (FNR), Purdue University (msaunder@purdue.edu)*
- **Michael Jenkins,** *Professor, FNR, Purdue University*
- **Christopher Webster,** *Professor, College of Forest Resources & Environmental Science, Michigan Technological University*
- **Robert Morrissey,** *Owner, Branch Scientific Editing*
- **Thaddeus Swart,** *Research Assistant, FNR, Purdue University*

PROJECT OBJECTIVES

Identify the response of forests to overstory species loss resulting from emerald ash borer.

ABSTRACT

Emerald ash borer (EAB; *Agrilus planipennis*) likely has led to the decline of ash species (*Fraxinus* spp.) throughout the Central Hardwood Forest Region. Using long-term datasets predating EAB introduction, this study explored the impacts of ash mortality on forest regeneration, and how these shifts in regeneration may contribute to future structural and compositional changes.

Permanent monitoring plots were established across Indiana state parks and reference areas in 1996-97 on north-facing slopes of mesic, closed canopy, hardwood forests and remeasured in 2010-11. Species level data were collected for the seedling, sapling, and overstory layers on plots in parks that contained ash trees in 1996-97. While considerable ash regeneration was observed within the seedling layer in the 2010-11 resample, recruitment of those seedlings to the sapling layer has largely failed. Instead, shade- tolerant and invasive species have become established in the sapling layer. However, species responses were highly variable across parks. Blue ash (*Fraxinus quadrangulata*) has shown resistance to EAB and was widely present as living trees throughout this study. Our analyses suggest that ash may become functionally extinct in Indiana, even in late-successional forests. Our early findings prompt further investigation into the implications of ash species loss on the ecological health of closed canopy hardwood forests.

Key findings/accomplishments:

- The seedling layer has variable composition and density across parks, but generally contains high densities of ash and sugar maple (Figure 1). Most parks were dominated by the same groups of species in 2010-11 and 2023 and show only slight deviation between sampling periods, except for Potato Creek State Park. The stress of this non-metric multidimensional scaling (NMDS) is 0.123.
- Invasive species were not as common as expected in the seedling layer (Figure 1).

- The sapling layer is dominated by shade-tolerant and invasive species, with few ash seedlings successfully recruited into the larger size class (Figure 2). Unlike the seedling layer, the species influencing the sapling layer have changed between sampling periods at most parks. Most parks are moving away from key species such as white ash (*Fraxinus americana*), with the only notable exception being Wing Haven Nature Preserve. The stress of this NMDS is 0.140.
- Despite the many ash seedlings recorded in 2010-11, few are persisting into the sapling layer of 2023. Instead, shade-tolerant native species dominate the growing space, outcompeting ash and most invasive species.

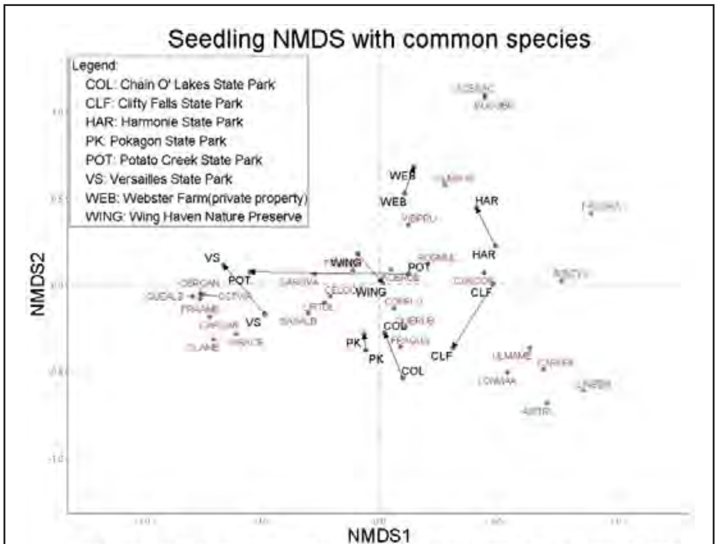


Fig. 1: The seedling layer is highly variable between parks. The beginning of the arrow indicates the centroid of each park in 2010/11 and the end of the arrow indicates the centroid of each park in 2023. Species that did not appear at more than six plots were removed for this ordination.

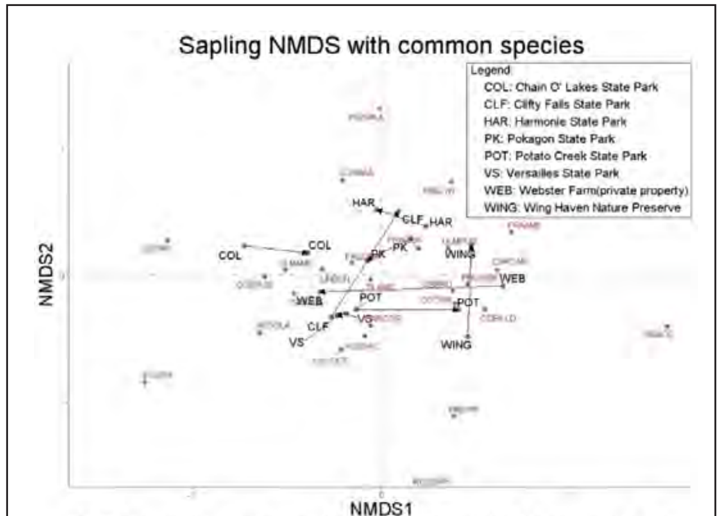


Fig. 2: The sapling layer indicates a trend of increasing dominance by shade-tolerant species while moving away from key species such as white ash (FRAAME). The beginning of the arrow indicates the centroid of each park in 2010/11 and the end of the arrow indicates the centroid of each park in 2023. Species that did not occur more than four times were removed from this ordination.

FUTURE PLANS

- We will continue to analyze the data and prepare a manuscript for submission to *Forest Ecology & Management* or a similar journal.
- Thad plans to defend his MS thesis in spring 2024.

PARTNERS

- Indiana Department of Natural Resources

INTEGRATING MORPHOLOGY, GENOTYPE, AND CHEMOTYPE-BASED METHODS TO SUPPORT HTIRC BUTTERNUT CONSERVATION AND RESISTANCE BREEDING EFFORTS

INVESTIGATORS

- **Douglass F. Jacobs,** *Fred M. van Eck Professor of Forest Biology, Forestry and Natural Resources, Purdue University (djacobs@purdue.edu)*
- **John Couture,** *Associate Professor, Entomology, Forestry and Natural Resources, Purdue University*
- **Aziz Ebrahimi,** *Graduate Student, Forestry and Natural Resources, Purdue University*
- **Anna Conrad,** *Research Plant Pathologist, USDA Forest Service*
- **Keith Woeste,** *USDA Forest Service, National Program Lead for Genetics for the Research & Development Deputy Area*
- **Carrie Fearer,** *Ohio State University*
- **Carrie Pike,** *USDA Forest Service, Eastern Region State, Private, and Tribal Forestry*

PROJECT OBJECTIVES

We are taking advantage of the network of existing butternut research plantings established over the past 20 years within the HTIRC tree improvement program. The HTIRC's butternut collection contains both butternut canker disease (BCD)- resistant selections and accessions from across butternut's natural range, some of which may no longer exist in natural populations due to BCD. The pedigrees and hybridity of this material has not been sufficiently characterized for its use in BCD resistance screening and butternut conservation. Our four main objectives are as follows:

1. Determine the pedigree of trees in HTIRC's butternut tree improvement collection.
2. Determine the relative accuracy of morphology, genotype, and chemotype methods.
3. Assess disease incidence and severity among genotypes in HTIRC's butternut tree improvement collection.
4. Determine potential for spectral-based data to assess disease incidence and severity.

ABSTRACT

Resistance to pest and disease threats may be obtained by hybridization between native species and their relatives. Butternut (*Juglans cinerea L.*) is a native hardwood tree species threatened by butternut canker disease (BCD). Hybrids between butternut and J. ailantifolia have resistance to BCD and form a key component of BCD resistance breeding programs, yet are difficult to distinguish from pure butternuts. In this project, we will integrate across three methods (morphology, genotype, and chemotype) to determine the pedigree of ~1,500 trees of interest in HTIRC's BCD resistance breeding program (Objective 1). We will distinguish among butternut, J. ailantifolia, and their hybrids including % hybridity (i.e., F1, F2 hybrid, BC1), and confirm chloroplast identity. We will then determine the relative accuracy of these three methods (Objective 2).

Additionally, we will assess incidence and severity of BCD and bunch disease among genotypes (Objective 3), and the potential for spectral-based (chemotype) data to detect disease incidence and severity (Objective 4). Combined, these three approaches will allow us to fully characterize the pedigree and disease resistance of the germplasm in the HTIRC butternut breeding program. This will enable us to detect unique sources of genetic diversity for conservation, to select the most butternut-like disease-resistant hybrids, to prioritize candidate trees for disease resistance screening, and to identify optimal germplasm for both pure butternut and hybrid seed orchards to support restoration in planted and natural forests. Project results will be disseminated via field days, Extension publications, and web resources.

This project will provide the first known comparison among morphology, genotype, and chemotype methods in determining hybridity in naturally hybridizing populations of a forest tree species. An approach that integrates phenotypes using advances in genetics and digital forestry should be a powerful tool for butternut resistance breeding and provide scalable, relevant methods for other species.

APPROACH

Morphology – We conducted detailed monitoring of bud break for butternut trees in Plot 51 at Martell Forest, West Lafayette, using a combination of manual observations and advanced drone imagery techniques. Our monitoring spanned from mid-April to mid-May, with the drone being deployed biweekly to collect RGB imagery data of the bud break progression. Additionally, we extended our data collection beyond spring. Monthly RGB data captures were conducted throughout the summer, providing insights into the trees' foliage development. In fall, specifically during September and October 2023, we focused on capturing leaf senescence data, which is crucial for understanding seasonal foliage changes. To achieve this, we employed drones equipped with RGB sensors, allowing for the acquisition of high-resolution color data. This approach enhances our understanding of the bud break phenomenon and gives us a comprehensive view of the trees' response to seasonal changes. Moreover, using drones for multi- spectral and hyperspectral data collection adds depth to our analysis, enabling a more nuanced understanding of the trees' health and environmental interactions.

Genotype – Several butternut trees in the HTIRC collection have been previously genotyped using Genotyping by Sequencing (GBS) technology. Our collaborator in Canada used GBS and exome capture to develop an interspecific panel focusing on 40 Single Nucleotide Polymorphisms (SNPs). This panel is being used for Agena Iplex Gold Mass-Array analysis. In the validation phase, we used 96 known butternut, Japanese walnut, and early-generation hybrids to assess the effectiveness of the interspecific panel. From this, we selected 32 markers that demonstrated high levels of polymorphism for the Mass-Array analysis. Subsequently, we extracted DNA from 550 samples and applied the Mass-Array technique to determine the hybrid status of these samples. Additionally, we are employing the GBS sequencing approach on a larger scale. DNA has been extracted from 960 samples, in Plots 51 and 53, also known as "Martell." These samples were processed into a sequencing library and submitted to the genomic center at UC Davis in December 2023 for further analysis. This comprehensive approach aims to enhance our understanding of butternut tree genetics, mainly focusing on hybridity and GWAS analysis.

Chemotype – Spectral data was collected from butternut trees at two Indiana sites: Martell Forest ("Martell"), and Southeast Purdue Agriculture Center, Butlerville ("SEPAC"). Martell has a high disease incidence compared to lower levels at SEPAC, offering a unique chance to study the effect of environmental conditions on disease in these trees within the same open-pollinated pure and hybrid butternut families. The study involves about 20 families, including both pure butternut and hybrids (~10 families per species), at each site. Approximately five trees per family were sampled in June, July, and August to monitor changes in foliar spectral profiles over time in pure and hybrid butternuts with varying levels of butternut canker disease severity. The process included collecting three leaves from a consistent canopy location per tree. Spectral data from these leaves' adaxial side was obtained using a near-infrared (NIR) spectroscopy with two complementary instruments, a VIS/NIR device, and a NeoSpectra Scanner scanning in the short-wave infrared region. In addition, the chlorophyll content and dry weight of leaves were measured alongside the spectral data. This approach will allow for a detailed analysis of the trees' responses to environmental factors and disease.

KEY FINDINGS AND ACCOMPLISHMENTS

- Monitoring bud break in butternut trees using manual observations and advanced drone imagery, from spring to fall, to gain comprehensive insights into trees' seasonal response and health through high-resolution, multi-spectral data collection, as well as to predict whether drone imagery data can be used to identify pure vs. hybrid butternuts.

- Butternut canker disease incidence, severity, and mortality have been recorded for each tree between 2020–2023. In addition, we continued to monitor for incidence of walnut witches' broom (WWB) and we are in the process of developing a rapid, molecular test using Recombinase Polymerase Amplification (RPA) for identification of WWB. The use of RPA would permit the detection of WWB in less than an hour and with readily available equipment.
- 550 individuals from the HTIRC collection, including both butternut and hybrid, have been processed to identify their hybridity using Mass Array methods.
- Developing a high-throughput genotyping by sequencing technique involves DNA extraction, library preparation, and sequencing of 960 individuals already submitted to the genomics center at UC Davis.
- The collected chemotypes from 2022 revealed disease-related shifts in foliar hyperspectral data, indicating its potential for identifying disease presence in pure butternut vs. hybrids, essential for developing high-throughput screening methods for this endangered species. Analysis of 2023 data is ongoing.
- Presented results from this project at scientific meetings and Extension events during 2023, including the Northern Nut Growers Association/Walnut Council, IEEE International Workshop on Meteorology for Agriculture and Forestry, and annual meetings of Digital Forestry, HTIRC, and Indiana Nut Growers.
- Published a manuscript on WWB (Fearer and Conrad 2023, *Plant Disease* 107:2624-2627)

FUTURE PLANS

- Monitoring of phenology will be recorded in spring 2024.
- Genotyping by Sequencing (GBS) for 540 individual trees will be processed.
- Spectral data analysis will be conducted.
- Analysis of drone imagery, including multi-spectral and hyperspectral data, will be performed.
- Genotype-phenotype association analysis will be conducted.

I-FORESTER: AI-ASSISTED SMARTPHONE APP FOR AUTOMATED TREE INVENTORY

INVESTIGATORS

- **Song Zhang,** *Professor, Mechanical Engineering, Purdue University (zhan2053@purdue.edu)*
- **Songlin Fei,** *Professor, Forestry and Natural Resources, Purdue University*

PROJECT OBJECTIVES

- Develop a device containing several RGB cameras and LiDAR cameras to reconstruct the accurate 3D geometry of target trees.
- Measure the orientations, diameters and heights with contactless method.
- Classify the sorts of trees based on the vein and size information.

ABSTRACT

The development of a contactless tree size measurement and species classification method is significant for forestry management and valuation. In May 2023, a new PhD student, Zhiheng Yin, joined this research group, collaborating with Wang Xiang on this innovative project. They have created an initial version of an app that begins by capturing a single snapshot of a tree, comprising a depth image and an RGB image. This data is used to generate a detailed 3D point cloud for each pixel of the RGB image, utilizing sparse LiDAR data. The raw 3D point cloud is then transformed to standardize the tree trunk's orientation, regardless of the angle at which the image was captured. The accuracy of the DBH estimation is further enhanced through the application of a pre-computed look-up table. Experimental results have shown that this method can achieve impressive measurement accuracy, with a mean absolute error of approximately 0.53 cm and a root mean square error of 0.35 cm for 294 trees, ranging in depth from 0.25 m to 5 m, using an iPhone 13 Pro. The team is also working on

algorithms for measuring tree height and species classification. This project holds great potential for positively impacting the ecological health and economic profitability of forest ecosystems in Indiana, thereby contributing significantly to the development and sustainability of rural communities.

APPROACH

- **LiDAR-based reconstruction:** We enhance the low-resolution 3D structure of a tree's surface using a combination of an RGB image and LiDAR depth information. This is achieved through the application of a pinhole projection model, aimed at reducing both memory requirements and computational expenses.
- **Orientation determination:** We determine the tree's orientation by aligning a line with the points situated in the central section of the tree's segmented area.
- **Diameter estimation:** We compute the diameter based on the geometry of an ideal circle.
- **Results optimization:** A pre-computed look-up table containing the capture distance, average chord depth and estimated diameter is employed to improve the diameter measurement results.

KEY FINDINGS AND ACCOMPLISHMENTS

- A conference paper has been published and a journal article will be submitted soon.
- A table that outlines the correlation among tree diameter, capture distance, average chord depth, and the preliminary estimated diameter can enhance the accuracy of diameter measurement outcomes.
- The basic graphical user interface (GUI) of our app has been created, shown in Figure 1. The process for estimating orientation is based on 2D analysis, ensuring low computational demand. We select the central pixels from each row and utilize their 3D coordinates to establish the orientation vector. Subsequently, we calculate the diameter at the designated tap point.
- Currently, the app can save the depth and RGB image and user inputs (species, true diameter, and notes) for each capture. For each captured sample, we also save a binary file containing all the attributes and original data (Figure 2).
- The app has been uploaded to the App Store for public release and has been under extensive internal test.

Figure 1. Measure tree diameter by tapping the tree image at an appropriate distance. To achieve accurate measurement, the tree bark occupies at least 70% of the screen width, as shown on the left image. Re-tap the image until the tree is clearly segmented. The ends of the red line should align with the boundary of the tree trunk, and the number (17.7 cm) on top of the right image shows the measured tree diameter.

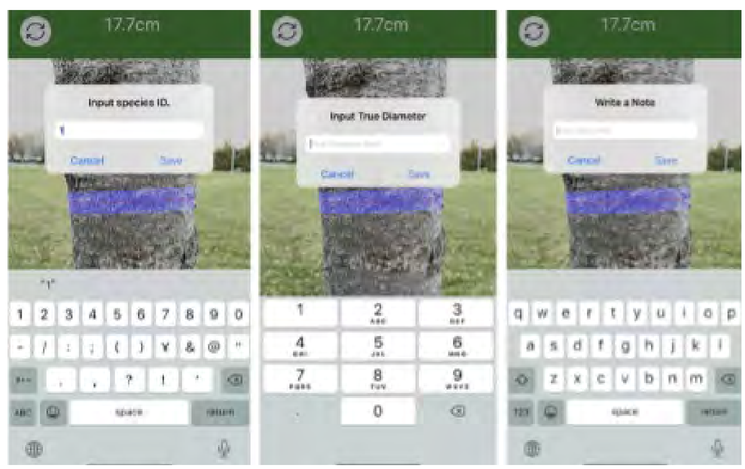


Figure 2. Save user inputs from left to right species, true diameter, and additional notes.

FUTURE PLANS

- Tree height measurement based on multi-view capture.
- Develop a phone-based AI model to classify tree species with the vein of tree surfaces and size information.

PARTNERS

- Our team collaborated with Professor Cheryl Qian's group on graphical user interface (GUI) design.

CREATING A DIRECTORY, DEPOSITORY, AND DATABASE FOR HISTORICAL GENETIC AND TREE IMPROVEMENT TRIALS

INVESTIGATORS

- **Katie Grong,** *Research Associate, Forestry and Natural Resources, Purdue University*
- **Songlin Fei,** *Professor, Forestry and Natural Resources, Purdue University*
- **Carolyn "Carrie" Pike,** *Regeneration Specialist, USDA-FS, Eastern Region State, Private, and Tribal Forestry, Purdue University, West Lafayette*

PROJECT OBJECTIVES

- Preserving historical documents and data from genetic and tree improvement trials in a digital format.
- Create a public directory, depository, and database of metadata and raw data of historical genetic and tree improvement trials.

ABSTRACT

Throughout the mid-to-late 20th century, federal, state, and tribal governments across the US established thousands of genetic and tree improvement field trials across the U.S. These studies were established primarily for hardwood and conifer tree species with commercial value to study genetic variation within and among different populations. Over time, however, many of these plantings have been abandoned or forgotten due to the retirement of key scientists, lack of funding, or a shift in funding priorities. Some plantings have been misplaced, but many plantings still exist on the landscape along with hard copies of data residing in offices and storage facilities, even though the plantings themselves were abandoned. This untapped resource is in demand by 21st-century scientists to help overcome seed shortages, and to better understand the effects of assisted migration on genotypes and provenances. Lastly, genetics trials may also be useful in the quest to locate seed sources with improved resistance to invasive pests. Locating these plantings, and their corresponding metadata, is essential to help answer questions about the adaptability of our tree species to future conditions.

APPROACH

- Used "A Guide to Forest Tree Collections of Known Source or Parentage" by Raymond Guries, Susanne Brown, and John Kress, "1981 Directory of Forest Tree Seed Orchards in the United States" by the USDA Forest Service, and "A Guide to Forest Genetics Field Trials at North Central Forest Experiment Station" by Jerry Van Cleve, Don Riemenschneider, and George Rink, and the HTIRC/Forest Service Plantings Database organized by James Warren to create a list of historical genetic tree plantings.
- Received data and information from the Tree Regeneration Center at Michigan State University, FERNOW Forest in Parsons, WV, Daniel Boone National Forest in Winchester, KY, and the OARDC at Ohio State University.
- Visited Vallonia State Nursery in Vallonia, IN, the University of Missouri in Columbia, MO, USDA Forest Service Region 9 Office in Milwaukee, WI, Cloquet Forestry Center in Cloquet, MN, Northern Research Station in Rhinelander, WI, and the Tree Regeneration Center at Michigan State University in East Lansing, MI, to digitally scan and physically collect the data of historical genetic tree plantings to digitize in an electronic format.
- Created a website for our directory, depository, and database for currently verified plantings and available data that can be accessed by interested researchers using Weebly and ESRI products. A "request and contribute" data feature was added to the website for users to view and request data for research purposes or communicate about planting information that could be added to the database.

2023 Progress

- Katie Grong was hired to continue work on the project.
- 237 plantings were added to the master list and 45 were confirmed.
- Generated a workflow for transcribing hard copies of data into a workable format that can be easily summarized using statistical programs.
- Digitized original document sources to increase ease and accuracy of inquiries for planting data. Relevant planting data from 2,796 pages spanning nine studies were digitized.

KEY FINDINGS

- Using the above approach, the existence of 2,168 plantings has been confirmed throughout 47 states. Of the 2,168, a total of 488 plantings were verified to be active and alive plantings, 268 were verified to not be recoverable, 48 were verified to be abandoned but not removed (inactive), and 355 have been confirmed to be active, but we are awaiting location information to verify.
- Out of the 2,168 plantings that have been confirmed, only 614 have an accompanying dataset. Some of the data that are available are very limited, but approximately 11% do include extensive data measurements and accompanying documents.
- Have digitized approximately 7% of collected data into a workable format for statistical programs.

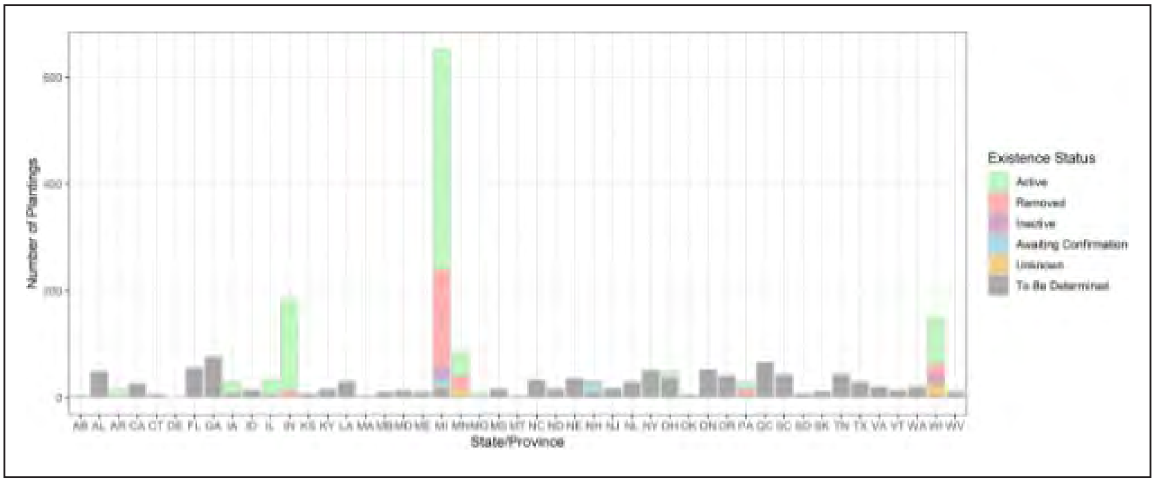


Figure 1. Genetic and tree improvement trials across 41 US states and 6 Canadian provinces and the count of active plantings (green), removed or dead plantings (red), alive but inactive plantings (violet), plantings without location data (blue), unknown plantings with no information to be found (yellow), and plantings yet to be verified (gray).

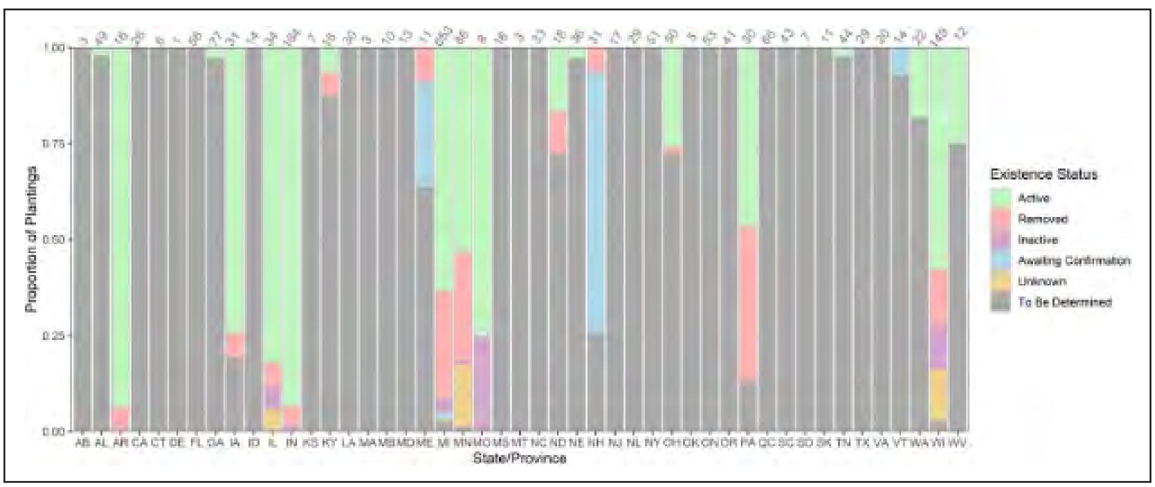


Figure 2. Genetic and tree improvement trials across 41 US states and 6 Canadian provinces and the proportion of active plantings (green), removed or dead plantings (red), alive but inactive plantings (violet), plantings without location data (blue), unknown plantings with no information to be found (yellow), and plantings yet to be verified (gray) with the count totals at the top of the figure.

PARTNERS/COLLABORATORS

- James Warren
- Yue "Shirley" Li
- Sungchan Oh
- Nicholas Labonte
- Paul Bloese
- Ron Zalesny
- Andrew David
- Gwen Short
- Brian Beheler
- Ed Bauer
- Raymond Guries
- Stuart Seaborne
- Philip O'Connor
- Mark Coggeshall
- Yvette Amerman
- Dave Horvath
- Kim Steiner
- John Kabrick
- Lauren Pile
- Travis Swaim
- Josh Abercrombie

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.

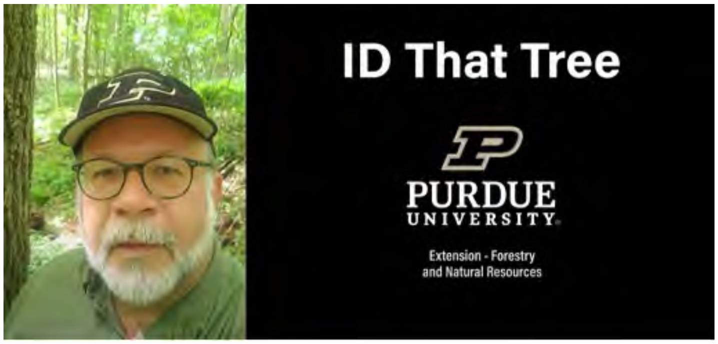
HTIRC NEWS

For the latest HTIRC news, check out these resources on the HTIRC website:

- E-newsletters, 677 subscribers - https://htirc.org/resources/newsletters/
- News archive - https://htirc.org/news/news-archive/
- Annual reports - https://htirc.org/annual-report/

EXTENSION PRODUCTS

In 2023 we produced or updated a variety of online resources, including videos on hardwood management, invasive species, and tree identification. These are posted at https://htirc.org/resources/landowner-information/ and https://www.purdue.edu/fnr/extension/ and include:



- *ID That Tree* series: Over 120 videos highlighting native and invasive trees and shrubs
- *Woodland Management Moment* series: This series covers various woodland management topics in short video messages to landowners.
- *Woodland Stewardship for Landowners* video series: Videos from this collaborative series between Purdue FNR and the Indiana Department of Natural Resources address management issues relevant to woodland owners.
- The *Planting and Care of Fine Hardwood Seedlings* publications provide 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.
- *Conservation Tree Planting* Webinar covers the steps to success for conservation tree plantings.
- *Invasive Species* Series: Tree of Heaven publication
- Songlin Fei, in collaboration with several partners, launched the Alien Forest Pest Explorer interactive web tool https://mapsweb.lib.purdue.edu/AFPE/
- The *Digital Forestry Initiative* has a data portal providing access to existing and new remote sensing data https://lidar.digitalforestry.org/

New Extension Products to be released in 2024

- Deer Impact Toolbox, part of the *Integrated Deer Management Project* at Purdue University. It includes:
  - Four publications in the series: Introduction to *White-Tailed Deer Impacts*, *Understanding White-Tailed Deer and Their Impact on Indiana Woodlands*, *Monitoring White-Tailed Deer Impacts*, *Managing White-Tailed Deer Impacts on Indiana Woodlands*
  - Deer impact monitoring method videos
  - Deer browse monitoring web tool

PROGRAMS

These programs shared the latest HTIRC information to landowners and/or natural resources professionals in a mix of online and in-person formats:

- Landowners Conservation Tree Planting Workshops
- Forest Management for the Private Woodland Owner courses
- Walnut Council Field Days
- Forest Pesticide Applicators Continuing Education Program
- IFWOA/Tree Farm Landowners Field Days
- Training for USDA, DNR, SWCD and other agencies on conservation practices
- Invasive Species field days and presentations
- Presentations at the Walnut Council annual meeting
- Silviculture Session for Illinois Beginning Landowners course
- Presentations at Green Industry continuing education programs

- Hoosier Hardwood Festival education programs
- Natural Resources Teacher Institute educator training program

We actively engage with our partners and many other groups, agencies and organizations with similar goals and interests to understand management and information needs and facilitate distribution of research-based tree and forest management information to appropriate audiences.

EDUCATION

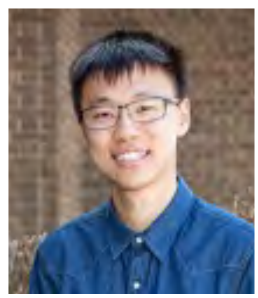
Developing future researchers and practitioners with expertise in the science and application of tree improvement, management and protection of hardwood forests is fundamental to the HTIRC. This year, through our project-based funding model, we supported 8 MS students, 10 PhD students, 6 postdocs, 5 undergraduate research technicians.

HTIRC STUDENTS WHO GRADUATED IN 2023

Molly Barrett, MS

Thesis title: "Regeneration Dynamics after Prescribed Fire & Femelschlag Harvests in Southern Indiana."

Advisor – Michael Saunders



Bowen Li, MS

Thesis title: "Using 3DEP LiDAR to Estimate Aboveground Carbon Stocks in Indiana State Forests."

Advisor – Guofan Shao

Sayon Ghosh, MS

Thesis title: "Economic Analyses of Forest Management Decisions for Hardwood Plantations."

Advisors – Mo Zhou & Jingjing Liang

Alison Ochs, PhD

Dissertation title: "Effects of Timber Management on Terrestrial Salamanders in Midwest Hardwood Forest."

Advisor – Michael Saunders

Caleb Kell, MS

Thesis title: "Comparative Silvics of Butternut Hybrids in Afforestation and Reforestation Plantings."

Advisor – Douglass Jacobs

Kelsey Tobin, PhD

Dissertation title: "Chemical Ecology, Microbial Dynamics, and Forest Health: Investigating Interactions Among Non-native Scolytine Beetles, Fungi, and Nematodes in Black Walnut Ecosystems."

Advisor – Matthew Ginzel

OPERATIONAL TREE IMPROVEMENT REPORT

The HTIRC's tree improvement program aims to enhance the resilience and economic value of the Central Hardwood Forest Region by developing and deploying populations of high-value timber species with enhanced characteristics for timber production and disease resistance. Using classical and molecular breeding techniques, the HTIRC's target improvement species are American chestnut, black cherry, black walnut, butternut, northern red oak, and white oak.

2023 was a highly productive year for the operational breeding program, with Caleb Kell stepping into the full-time Operational Tree Breeder position with a newly minted MS in Forest Science. Bryce Chupp also joined the effort as a full- time technician after graduating from Purdue with a BS in Entomology.

The HTIRC's new Savage pecan harvester, courtesy of the Rice equipment grant.

Several new assets were acquired in 2023 to aid the improvement program's field operations. The largest acquisition was a Savage 8042 pecan harvester funded fully through a Rice research equipment grant. Properly fitted, this machine will improve the HTIRC's capacity to provide seed to stakeholders. A walnut hulling machine produced by John Kelsey, a lifetime Walnut Council member, was also acquired by the HTIRC to speed up the arduous task of cleaning walnut and butternut seed. Rob Swihart's lab truck was transferred to the HTIRC as well, giving the HTIRC a dedicated vehicle for field work.

BREEDING SUMMARIES BY SPECIES

American Chestnut

The HTIRC continues to hold and expand its grafted collection of American chestnuts for its resistance breeding mission. In May, we further expanded our grafted pure American chestnut clone bank at the Lugar Forestry Farm, bringing the total number of clones up to 47. Four new accessions were also grafted and will be added to the clone bank in May of 2024. Five thousand American chestnut seeds were harvested from the Duke orchard for use in conservation plantings and as rootstocks.

Newly planted third-year expansion of the HTIRC's transgenic American chestnut screening block.

The third installment of our transgenic field plantings was installed at Martell Forest, completing the establishment phase of our Darling 58 (D58) evaluation trial. Unfortunately, while the HTIRC has diligently worked to cross, plant and evaluate the D58 transgenic American chestnut, the ultimate goal of using this material as the keystone of the HTIRC's American chestnut breeding program is no longer feasible. A disclosure by the American Chestnut Foundation revealed that the Darling 58 pollen given to the HTIRC and other collaborators was in fact Darling 54 (D54).

Darling 54 is another transgenic American chestnut that was developed simultaneously with D58. Darling 54 has a serious issue associated with silencing of the SAL1 gene, which is crucial for management of drought and salinity tolerance.

Homozygous trees with two copies of the D54 transgene also experienced nearly total mortality due to the loss of both copies of SAL1. Because of this silencing issue, D54 was originally determined to be untenable for restoration efforts compared to Darling 58, which had no gene silencing issues. Tragically, Darling 54 was confused for Darling 58 as both trees were being forced for pollen in the same growth chamber, and pollen harvested from the D54 tree was mistakenly repropagated for multiple generations as D58.

Now knowing that our D58 trees are in fact D54 trees, the HTIRC is forced to re-evaluate its American chestnut breeding plans for the future. Despite their inherent issues, D54 trees still serve as a valuable demonstrator for the efficacy of the OxO gene in imparting blight resistance to the American chestnut (the issue with D54 is with the location of the transgene on the chromosome, not the OxO transgene itself). As such a demonstrator, inoculation and evaluation of our D54 transgenic screening blocks will continue through 2025, and results will be summarily published. Even with the D54 setback, the HTIRC still sees the inherent value of using transgenic American chestnuts for resistance breeding, and will continue to test and integrate new OxO constructs into its program as they become available. Renewed effort is also being placed into the backcross hybrid program, with the Lugar BC3 orchard being overhauled as a seedling seed orchard, and plans to create additional F1 Chinese x American hybrids are ongoing.

Black Cherry

At the Lugar Forestry Farm, the HTIRC's black cherry orchards produced a prolific crop in 2023, enabling the center to fulfill the Indiana Division of Forestry's annual needs for select black cherry. To alleviate lagging seed production, the Martell cherry clone bank was thinned to open up the crowns of remaining trees and improve access for harvesting equipment.

Future development of the HTIRC's black cherry program hinges on acquisition of second-generation selections from existing progeny tests (slated for 2026) and seed production from untested clones in its orchards and clone banks.

Black Walnut

The Purdue black walnut improvement program has been ongoing since 1966, when Walt Beineke made his first superior walnut selection. Fifty-eight years later, the HTIRC walnut program had a landmark year, establishing the first progeny tests derived from HTIRC advanced selections. Both tests are new collaborations. Mitch Hess, a Purdue FNR alumnus, provided property in Vermilion County, Illinois for one replicate, and the Sam Shine Foundation provided a planting site in Floyd County, Indiana, for the second replicate.

The HTIRC's new black walnut progeny test, planted into soybeans in Vermilion County, IL.

An extensive effort to measure all of the HTIRC's black walnut progeny tests began in November 2023, with 16 progeny tests measured by the end of January 2024. Data from these tests will be used for an extensive performance analysis of the HTIRC's walnut families, as well as choosing a new batch of second-generation advanced selections.

2023 was a very good year for black walnut, and a crew of HTIRC and FNR staff harvested more than 34,000 nuts for progeny testing and 200 bushels of walnuts for the Vallonia State Nursery. Most of the families harvested for testing have never been progeny tested before, presenting a unique opportunity to further evaluate the HTIRC's diverse black walnut collection. Clone banks and orchards at Martell and Lugar were also thinned in December 2023 to facilitate future seed production.

Butternut

The HTIRC's butternut improvement program aims to develop a population of butternut resistant to the invasive butternut canker fungus, while also serving to maintain one of the world's largest repositories of butternut germplasm for breeding and research purposes.

A substantial pure butternut harvest at the HNF butternut orchard at the OFS plant in Huntingburg, IN.

Selection of canker-resistant butternuts and butternut hybrids from butternut canker disease screening blocks remains a priority, with 20 new selections made in 2023. The Lugar second-generation canker-resistant butternut orchard continues to expand with new selections, and the incorporation of the adjacent backcross American chestnut planting into the orchard design provides expansion room for years to come.

New wild hybrid butternut germplasm was also collected from north-central Indiana to add to the HTIRC's germplasm collection.

Butternut seed crops were very strong in 2023. Over 17,000 nuts were harvested from the Pinney PAC resistant butternut orchard, with more than 8,000 of those seeds sent to the Indiana Division of Forestry for release to the public. The Hoosier National Forest butternut orchard in Huntingburg also yielded very well, with HNF staff pitching in to harvest over 40,000 pure butternut seeds in a single day.

Northern Red Oak

The consolidation phase of the HTIRC's red oak program continues, with the 2008 and 2009 Martell progeny tests marked for thinning into a seedling seed orchard. Red oak plantings in Rush County were also thinned to facilitate seed production.

White Oak

With continuing high demand for white oak by the forest products industry, the HTIRC is working to expand its white oak collections and tests to offset the potential loss of white oak genetics from forests throughout Indiana. Collections are being made of both plus-trees in natural forest stands and of elite selections in afforestation plantations. Both forms of collection ensure that the HTIRC has a highly diverse genetic pool for its breeding program. Due to Caleb Kell's time constraints associated with completing graduate school, only two elite selections and five plus-tree selections were grafted in 2023.

(Left) A hefty seed crop from a 5-year-old white oak bark graft. (Right) Future white oak progeny tests being sown at the Vallonia state nursery.

Future scion collections will be substantially larger to capture as much germplasm for testing as soon as possible.

Evaluations of current white oak accessions are ongoing, with both HTIRC white oak orchards producing another strong seed crop in 2023. Clones bark-grafted into the orchards in 2019 are beginning to produce crops large enough to evaluate, and the white oak progeny test sown in fall 2023 is the HTIRC's most diverse white oak progeny test yet. While being the perfect tool for the job, the HTIRC's new Savage pecan harvester didn't arrive until October 16, which was too late for all but the latest-ripening clones. The potential for future time savings afforded by this machine is substantial, as it collected several thousand acorns in the time it took to harvest a few hundred by hand. More than 45,000 acorns were collected from both orchards, with most going to the Vallonia State Nursery.

ACKNOWLEDGMENTS

Many thanks to Brian Beheler, Don Carlson, Clayton Emerson, Zach Uebelhor, Jim McKenna, Bob Hawkins, Rob Wink, Matt Ginzel, Allen Pursell, Mitch Hess, Phil O'Connor, Bryce Chupp, Bill Deeter and Andrew Coursey. Their support and expertise have been invaluable to the HTIRC tree improvement program.

APPENDIX

2023 RESEARCH PUBLICATIONS

- Estep, G.N.; Li, B.W.; Shao, G.F.; Wingren, C.; and Saunders, M.R. (April 2023) Accuracy and Precision of Digital Forest Measurements. A poster presentation at FNR annual symposium.
- Ethington, M.W. and Ginzel, M.D. (2023) Fungal, host and non-host volatiles modify attraction of the walnut twig beetle, Pityophthorus juglandis, to pheromone lures. *Agricultural and Forest Entomology* 25, 536-548.
- Habib, A. (2023) LiDAR Technology for Scalable Forest Inventory: Evaluating the Trade-offs between the Various Platforms. *GIM International*. Issue 2, 2023, pp. 9-11.
- Miller, Z.; Hupy, J.; Hubbard, S.; and Shao, G. (2022) Precise Quantification of Land Cover before and after Planned Disturbance Events with UAS-Derived Imagery. *Drones* 6, 52. https://www.mdpi.com/2504-446X/6/2/52
- Rastiveis, H.; Zhou, T.; Zhao, C.; Fei, S.; and Habib, A. (2023) Automated Fine-Scale Forest Inventory using Backpack LiDAR – A Strategy based on Feature Extraction, Matching, and Tracking from Integrated Scans. Smart Forests: Close range sensing workshop, the ISPRS 2023 Geospatial Week, Cairo, Egypt, September 2-7, 2023, Cairo, Egypt.
- Sadof, C.S.; McCullough, D.G and Ginzel, M.D. (2023) Urban ash management and emerald ash borer (Coleoptera: Buprestidae): facts, myths, and an operational synthesis. *Journal of Integrated Pest Management* 14, 14-3.
- Shao, J.; Cheng, Y.T.; Koshan, Y.; Manish, R.; Habib. A.; and Fei. S. (2023) Radiometric and Geometric Approach for Major Woody Parts Segmentation in Forest LiDAR Point Clouds. IGARSS 2023 - 2023 IEEE International Geoscience and Remote Sensing Symposium, Pasadena, CA, USA, 2023, pp. 6220-6223, doi: 10.1109/IGARSS52108.2023.10281558.
- Shao, J.; Habib.; and Fei, S. (2023) Semantic Segmentation of UAV LiDAR Data for Tree Plantations. UAV-based Mapping Workshop, the ISPRS 2023 Geospatial Week, September 2-7, 2023, Cairo, Egypt.
- Tobin, K.N., and M.D. Ginzel (2023) The ambrosia beetle Anisandrus maiche (Stark) is repelled by conophthorin and verbenone and attracted to ethanol in a dose-dependent manner. *Agricultural and Forest Entomology*, 25,103-110.
- Tran, H.; Woeste, K.; Li, B.W.; Verma, A.; and Shao, G.F. (2023) Measuring tree stem diameters and straightness with depth-image computer vision. *Journal of Forestry Research* 34(5), 1395-1405. https://doi.org/10.1007/s11676-023-01600-x
- Ward, A.; Chandrasekaran, A.; Shao, G.F.; and Woeste, K. (October 25-28, 2023) Tree Position Variations with GPS Distance to Trees in Leaf-off and Leaf-on Seasons. A poster presentation at the 2023 SAF National Convention, Sacramento, CA.
- Williams, G.M. and M.D. Ginzel (2023) Functional roles of nematodes associated with the walnut twig beetle and eastern black walnut in the inland northwest. *Forest Pathology*, e12791
- Zhou, T.; Manish, R.; Fei, S.; and Habib, A. (2023) In-Situ Calibration and Trajectory Enhancement of UAV and Backpack LiDAR Systems for High-Resolution Forest Inventory. Int. Arch. Photogramm. Remote Sensing. Spatial Inf. Sci., XLVIII-1/W1-2023, 595-602, https://doi.org/10.5194/isprs-archives-XLVIII-1-W1-2023-595-2023, 2023
- Zhou, T.; Ravi, R.; Lin, Y.-C.; Manish, R.; Fei, S.; Habib, A. (2023) In Situ Calibration and Trajectory Enhancement of UAV and Backpack LiDAR Systems for Fine-Resolution Forest Inventory. *Remote Sensing*. 15, 2799. https://doi.org/10.3390/rs15112799
- Zhou, T.; Zhao, C.; Manish, R.; Fei, S.; and Habib, A. (2023) Forest Feature LiDAR SLAM (F2-LSLAM) and Integrated Scan Simultaneous Trajectory Enhancement and Mapping (Is2-Team) for Accurate Forest Inventory using Backpack Systems. Smart Forests: Close range sensing Workshop, the ISPRS 2023 Geospatial Week, September 2-7, 2023, Cairo, Egypt.

LEARN MORE ABOUT THE HTIRC

MATTHEW GINZEL

DIRECTOR OF HTIRC

Professor,
Departments of Entomology and Forestry and Natural Resources
mginzel@purdue.edu

HTIRC.ORG
HTIRC@HTIRC.ORG
(765) 496-7251

In partnership with:

Purdue University | Forestry and Natural Resources

USDA Forest Service
U.S. DEPARTMENT OF AGRICULTURE