HTIRC
HARDWOOD TREE IMPROVEMENT
& REGENERATION CENTER

STRATEGIC PLAN
2023-2027

In partnership with:

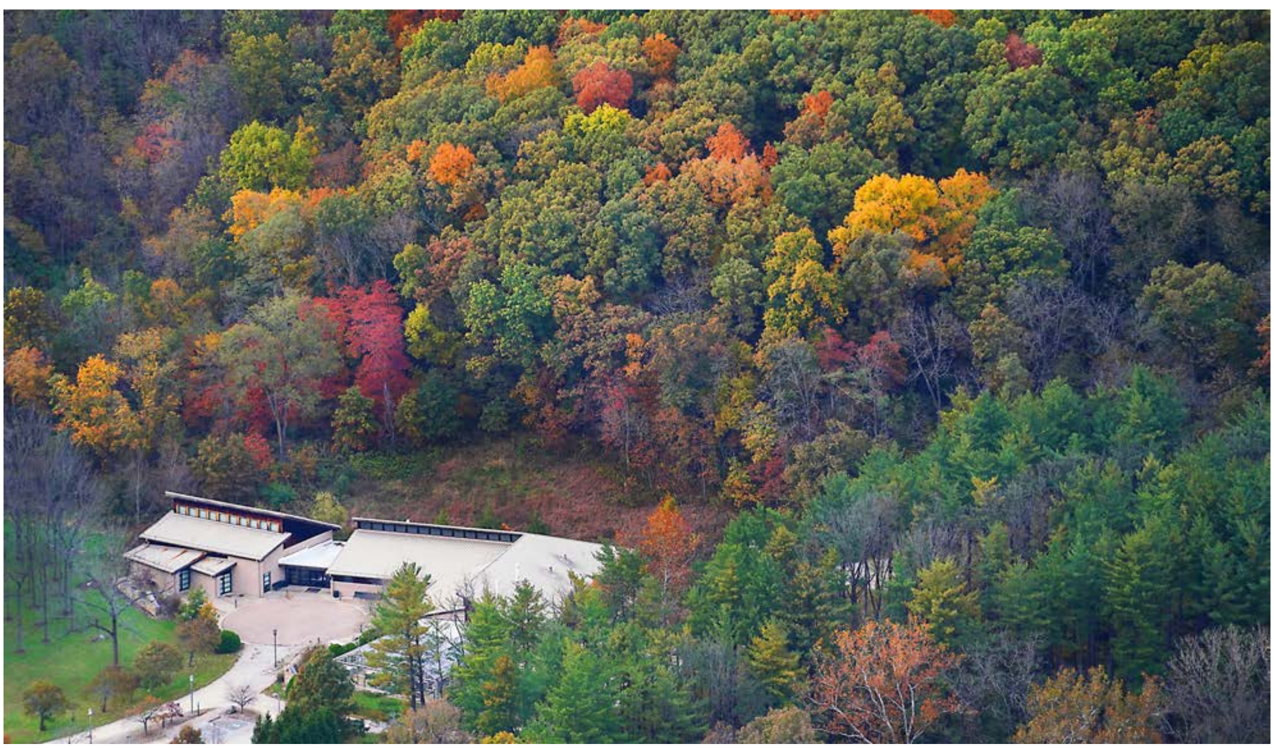
PURDUE UNIVERSITY | Forestry and Natural Resources

USDA Forest Service
U.S. DEPARTMENT OF AGRICULTURE

The mission of the Hardwood Tree Improvement & Regeneration Center (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*.

The HTIRC will accomplish its mission during 2023-27 through five strategic directions:

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



I. INTRODUCTION

The HTIRC is a collaborative partnership between the USDA Forest Service Northern Research Station and Purdue University — focused on the advancement of hardwood-focused research, development, and technology transfer in the Central Hardwood Forest Region (CHFR). Increased demand for hardwood products and ecosystem benefits makes it vital that we increase the quantity, quality, productivity, and health of forests within the CHFR.

From its beginning, the HTIRC has been unique in several ways. The HTIRC is:

1. Focused solely on hardwood forests and the associated hardwood products industry;
2. A university/federal partnership which includes close intellectual and financial collaborations with state, federal, and private organizations; and
3. Generating basic knowledge and technologies about hardwood tree genomics, improvement, regeneration, conservation, protection, and utilization for stakeholders throughout the CHFR.

HISTORY OF THE HTIRC AND OPERATING ENVIRONMENT

The HTIRC was established in 1998 to address a perceived research gap in hardwood tree improvement within the CHFR. At the time, the region was facing a significant shortage of hardwood seedlings, estimated at 25 million to 50 million trees annually. Most of the seedlings produced in state nurseries lacked genetic information, as they relied heavily on seed collectors who obtained material from wild populations. Consequently, most seedlings were unimproved and exhibited unknown genetic quality and diversity.

The hardwood industry expressed concerns about the future availability and quality of the timber resource, which is crucial for lumber and manufacturing sectors. Due to political and social pressures, federal forests had significantly reduced the annual volume of harvested hardwood timber, a trend that continues to persist today. Private woodlots now contribute a substantial portion of hardwood timber and veneer, but they often lack sustainable management practices. This is mainly because the tenure of land ownership is relatively short compared to the timber rotation length, and forest fragmentation leads to decreasing parcel sizes. Woodlots are also increasingly being converted for non-forestry purposes, such as residential or commercial development, or they are preserved solely for recreational value. Consequently, the current harvesting of timber exhibits diminished size and quality compared to historical levels, influenced by various social and ecological factors. Additionally, the hardwood industry has shown concerns regarding the underutilization of new biotechnologies, primarily developed for conifer-based systems, which have the potential to enhance wood quality, growth, and resistance to pests through tree improvement activities.

Forest managers also expressed concerns about the loss of genetic quality in remaining hardwood woodlots and natural forests. They observed reduced straightness and vigor in trees managed for future timber harvests compared to previous generations. This phenomenon may be attributed to past forest harvest practices, including selective harvesting of only the "best" trees, which might have resulted in irreversible loss of genetic quality in the remaining stands.

Since the establishment of HTIRC, new challenges have arisen and existing ones have become more urgent. Invasive plants and insects have altered the ecological dynamics of forest environments throughout the CHFR, posing threats to the functional existence of many hardwood species. Furthermore, climate change may have consequences for the ecological dynamics of hardwood forests. Heavy deer browsing and competition from invasive plants hinder the regeneration of high-value hardwood species, and reliable regeneration of species (e.g., oaks) is a continuing management challenge. Collectively, these factors contribute to a simplified forest condition, leading to a gradual loss of essential resources within the forest products industry. This loss undermines the industry's ability to maintain a desired product mix and profitability in the face of changing market conditions.

IMPORTANCE OF THE CHFR

*Consumer demands for high-quality hardwoods in the **Central Hardwood Forest Region (CHFR)** are projected to surpass the region's productive capacity unless alternative materials are embraced. The CHFR encompasses over 300 million acres, spanning 15 states and six major geologic zones. It serves as the primary hardwood timber-basket in North America, contributing to a forest products industry valued at $13.5 billion in Indiana alone (Indiana DNR, 2016). This industry supports the production of dimensional lumber, veneer, and barrels.*

Land ownership in the CHFR is primarily in the hands of private landowners, followed by industry and public agencies. Afforestation, the deliberate planting of trees, has been a long-standing practice among landowners in the region. Species such as oak, black cherry, and black walnut are commonly chosen due to their consistent economic and wildlife value. Additionally, the CHFR plays a critical role in providing habitat for numerous threatened and endangered plant and animal species.

However, agriculture poses a significant challenge to the forestry sector in the CHFR. Corn and soybean production dominate land-use practices, resulting in less than 20% of the original forestland remaining in Indiana. Similar trends can be observed in other CHFR states, including Ohio, Illinois, and Iowa, where a strong agricultural sector competes with forestry and other natural resource management objectives.

Natural forests in the CHFR exhibit irregular age structures that often contain multiple age classes and diverse species compositions. Large-scale tree plantings typically do not align with selective harvest practices. Furthermore, many forests in the region have been subjected to harvesting methods that led to poor regeneration, degraded stands and low-quality timber. Afforestation efforts, which involve converting unsuitable fields to forest or woodlands, necessitate intentional tree planting. In states like Indiana, tree planting initiatives closely align with the Conservation Reserve Program and other incentive programs, where landowners receive federal support for establishing and managing forested areas.

MISSION

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*. We seek to develop research and technology-transfer programs that provide knowledge focused on the establishment and maintenance of sustainable, genetically diverse native forests and the development of highly productive woodlands that provide a wide array of products and services.

II. STRATEGIC PLAN

A. FORMULATION OF STRATEGIC PLAN

The goal of the HTIRC strategic-planning process was to create a plan that sets the directions and focus of research, educational, and outreach programs that meet stakeholder needs for the five-year period from 2023-2027.

Our planning process began by soliciting input from our stakeholders and advisory committee members on their research, outreach, and Extension priorities for the HTIRC in October 2021. HTIRC staff and scientists then met regularly during spring and summer of 2022 to discuss the stakeholder feedback considering the current strategic plan. This input was used to guide development of a new Strategic Plan and inform our revised research priorities. We then solicited feedback on proposed research and development strategic directions from the Advisory Committee at our annual meeting.

B. STRATEGIC DIRECTIONS AND OBJECTIVES FOR 2022-2027

The five strategic directions for the HTIRC are to:

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

C. STRATEGIC DIRECTIONS 1-3: RESEARCH AND DEVELOPMENT

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

IMPROVEMENT

There is a continuing need to identify robust genetic markers closely aligned with specific genes associated with important traits, such as tree resistance and resilience to insects, diseases and environmental stress, and associated stress-response genes. In addition, several HTIRC plantings are mature enough to calculate genetic gains associated with metric traits such as growth, form, and merchantable volume. Sustained improvement of the genetic quality and regeneration success of the fine hardwood tree species in the HTIRC portfolio will be realized through application of classical breeding, genomics, and seed production technologies — all of which will lead to healthier and more productive forests when combined with appropriate silviculture.

UNDERSTAND THE INFLUENCE OF GENETICS IN HARDWOOD TREES AS IT RELATES TO DESIRABLE TRAITS

- Conduct quantitative genetic analyses to estimate key genetic parameters, including heritability and breeding values.
- Increase the speed and accuracy of breeding through the use of advanced phenotyping and genomic tools (e.g., SNP, QTL, GBLUP).
- Determine the relative importance of genotype and environment to traits in hardwoods.
- Define, characterize, and monitor desirable tree forms.

EXPLORE THE POTENTIAL FOR BIOTIC RESISTANCE IN SOME IMPORTANT HARDWOOD TREE SPECIES

- Develop a strategy for screening and selecting disease and insect resistance in species of concern.

ADDRESS THE CURRENT LACK OF IMPROVED SEED / PROPAGULE SOURCES FOR IMPORTANT HARDWOOD TREE SPECIES IN THE CHFR

- Implement breeding plan and strategies for deploying advanced-generation seed orchards for all species in the HTIRC portfolio, beginning with northern red oak, white oak, and black walnut.
- Develop a plan for prioritizing seed orchard management and distribution of seeds from improved material to partners (e.g., state and private nurseries) through material transfer agreements.

Expected five-year activities and outputs in this strategic direction:

- Develop screening protocols to facilitate rapid identification of insect and disease resistance and identify associated gene markers.
- Identify genes active during the regulation of desirable traits (including resistance to heat, drought and extreme weather events) in black walnut and understand the timing for their expression.
- Report genetic gain and trait correlation estimates of trees currently within HTIRC tree-improvement programs.
- Assess and curate existing plantings and provide improved seed for planting new seed orchards.

Long-term research and development outcomes in this strategic direction:

- Genomic tools will accelerate breeding for disease resistance in threatened species.
- Improved restoration success of threatened species.
- Genetic gains obtained through improved breeding, selection, and propagation techniques.
- Seed / propagule sources for improved hardwood tree species.

MANAGEMENT

Successful regeneration of native hardwood stands with high-value tree species continues to elude stakeholders throughout the CHFR. Likewise, many plantations in the CHFR are reaching an age where thinning and other mid-rotation treatments should be applied. Tests of new approaches to silvicultural management of both native stands and plantations will be installed. Regeneration success of the fine hardwood tree species in the HTIRC portfolio will be realized through application of genetics and modeling to develop refined management prescriptions.

REFINE SILVICULTURAL METHODS TO IMPROVE OAK REGENERATION IN NATURAL STANDS

- Assess the effects of prescribed fire in mature oak-dominated stands and woodlands being regenerated.
- Demonstrate gap-based approaches to regenerate oak.
- Test underplanting and enrichment planting cultural regimes for hardwood forests.
- Assess influence of management on wood quality and value.

DEMONSTRATE EARLY- TO MID-ROTATION MANAGEMENT PRACTICES IN PLANTATIONS AND NATURAL STANDS

- Determine effects of thinning on growth and potential grade of black walnut.
- Evaluate the utility of pre-commercial crop tree release and thinning treatments in young stands and plantations.
- Demonstrate the utility and marketability of small-diameter material from pre-commercial thinnings.
- Evaluate the influence of management regimes on above- and below-ground carbon capture.

IMPROVE ESTABLISHMENT PRACTICES OF HARDWOOD PLANTATIONS

- Understand edaphic factors that limit productivity of planted hardwoods.
- Develop a “cultural options” model for plantation establishment.
- Quantify competition effects and ecosystem functioning and resilience of monoculture vs. mixed hardwood plantations.

- Expand research into regeneration practices and the role of seedling traits in determining seedling establishment success for potential assisted migration studies.

Expected five-year activities and outputs in this strategic direction:

- Elucidate the short-term economic and ecological tradeoffs in use of prescribed fire for oak regeneration in mature CHFR forests.
- Monitor and publish a replicated study of expanding group shelterwood systems in the CHFR to successfully regenerate oak.
- Publish a web-based model of the marginal costs of plantation-establishment practices (e.g., fertilization, deer fencing) as affected by site quality and species.
- Develop guides to restore hardwoods through enrichment plantings in intact forests.
- Improve recommendations for species selection in pure and mixed plantations on a variety of sites.
- Install and evaluate hardwood mixed-species competition studies.

Long-term research and development outcomes in this strategic direction:

- Compare oak regeneration response in expanding group shelterwood systems to traditionally applied selection systems.
- Quantify ecological impact of prescribed fire on mature oak forests.
- Provide alternatives to traditional even- and uneven-aged silvicultural systems to improve ecosystem resiliency.
- Increased growth, quality, and composition of hardwood plantations and enhanced end-of-rotation value.
- Refine recommendations of mixed-species plantings (i.e., proportion of each species and density of planting).

PROTECTION

Forests throughout the CHFR are threatened by invasive plants, pests, pathogens, high ungulate populations, and climate change. Active research to quantify the impacts of these agents on regeneration, health, and productivity of CHFR forests is critical to maintaining the economic and ecological services derived from these forests.

DEVELOP AND DEMONSTRATE STRATEGIES TO ADDRESS EXISTING AND EMERGING THREATS TO HARDWOOD FORESTS

- Determine the rates and patterns of spread and impacts (ecological and economic) of major introduced and / or invasive forest plants, insects, and pathogens.
- Develop and demonstrate management strategies to address existing and emerging pests and pathogens of hardwood trees.
- Evaluate tradeoff between effectiveness and ecological impacts of control treatments for invasive pests, plants, and pathogens.
- Identify the response of forests to overstory species loss resulting from invasive insects and pathogens.
- Understand impacts of climate change on forests and develop strategies to maintain or improve forest health due to altered natural disturbance regimes.
- Develop techniques and materials based on ecophysiological characteristics to aid in the restoration of threatened hardwoods (e.g., butternut, chestnut, etc.).

Expected five-year activities and outputs in this strategic direction:

- Understand impacts on forest regeneration that will include both direct effects (e.g., mortality, competition) and indirect effects (elimination of competitors, changes in microenvironment, and alterations to ecosystem processes).

- Improvement of American chestnut and butternut, informed by a better understanding of ecophysiology (i.e., resistance to environmental stresses, including drought and frost; site preferences) of hybrid and / or backcrossed disease-resistant stock butternut relative to their progenitors.

Long-term research and development outcomes in this strategic direction:

- Develop recommendations for limiting ungulate herbivory on natural and artificial regeneration.
- Produce a series of best management practices for TCD in black walnut plantations.
- Reduce species loss to pests, pathogens, and invasive competitors.
- Integration of remote sensing into current technologies and methods to improve pre-visual detection of pests and pathogens.

D. STRATEGIC DIRECTION 4: ENGAGEMENT AND EXTENSION

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

We will achieve this goal both by communicating state-of-the-art, science-based information, and technology and by linking stakeholder needs to the scientific community through:

1. Producing Extension publications and other media that communicate current knowledge, technology, policy, and management practices for distribution to CHFR resource professionals and land managers;
2. Developing and distributing communication and marketing materials to engage partners, collaborators, and stakeholders to support and further the HTIRC mission; and
3. Becoming a regional leader by participating in, developing, and hosting national and international conferences related to the HTIRC mission.

IMPROVED COMMUNICATIONS

- Highlight ongoing HTIRC activities and research results on the newly revised website, www.htirc.org.
- Review HTIRC Extension publications to edit and update information that reflects current knowledge, resources, and recommendations available.
- Provide a regular email newsletter and an annual report to partners and cooperators.
- Develop and conduct programs and workshops with cooperators in the CHFR to ensure relevance and visibility beyond Indiana.
- Streamline methods to distribute and access landowner resources and related HTIRC products (e.g., website, mailing lists, listserv).
- Connect to stakeholders through annual surveys to gather feedback regarding how our progress meets or exceeds their needs and expectations.

INCREASED VISIBILITY OF THE HTIRC

- Update website with resources related to establishment and management of hardwood trees and forests.
- Produce HTIRC faculty and staff videos and HTIRC lab and field site video tours.
- Participate with USFS communication and engagement to showcase HTIRC.
- Create video and in-person field demonstrations illustrating the value of select genetic seed sources, effects of deer browse, and other hardwood management and regeneration topics.

Expected five-year activities and outputs in this strategic direction:

- Create Extension materials related to each of the projects funded through the HTIRC stakeholder-driven funding model.
- Update Planting and Care of Fine Hardwoods Extension publications that reflect current knowledge of establishment and management of hardwood trees.
- Provide professional development and continuing education opportunities related to growth and management of hardwood trees and forests through partnerships with the Society of American

Foresters and the Indiana Conservation Partnership, composed of the USDA NRCS and FSA, IN Association of SWCDs, IN State Department of Agriculture, IN DNR, IN Department of Environmental Management and Purdue Extension.

- Educate landowners through the online and in-person Forest Management for the Private Woodland Owner course, providing approximately 24 hours of instruction in forest biology, ecology, planning, management, and connection to professional sources of advice and assistance.
- Produce a woodland management video series providing a short introduction to hardwood planting and management techniques.
- Create videos of HTIRC research and management results with applications for landowners and resource professionals.

E. STRATEGIC DIRECTION 5: EDUCATION

Developing future researchers and practitioners with expertise in the science and application of tree improvement, management, and protection of hardwood forests is a key objective of the HTIRC. This is accomplished by promoting the education and professional development of undergraduate students, graduate students, and postdoctoral research fellows.

Students will be educated and trained through a combination of coursework, specialized research projects, and opportunities to present their research at scientific conferences and Extension meetings. These students will become the next generation of leaders as Extension professionals, forest ecologists, forest geneticists, forest-health specialists, nursery managers, propagators, silviculturists, and tree-improvement specialists. Exposure to interdisciplinary research initiatives — and the broad range of end-goals of hardwood users (i.e., commercial, ecological, and conservation) — is a cornerstone of the HTIRC educational experience.

HTIRC students are defined as those students working with HTIRC-funded principal investigators to accomplish mission-oriented work as defined in this Strategic Plan. These students may be supported by a variety of funding sources, including through HTIRC-funded projects, and department, college, university, and external fellowships or extramural funds. Students in the HTIRC benefit from links to the expertise of HTIRC faculty, staff, and partners, priority access to HTIRC resources (i.e., equipment, supplies, and field sites), and opportunities to present or publish their work in HTIRC-sponsored venues.

Expected five-year educational activities and outputs:

- Educate and train 20 graduate students (as defined above), 10 undergraduate students (researchers), and five postdoctoral scientists at the HTIRC and prepare them for employment with universities, state, and federal agencies, NGOs, and private industry.

Expected five-year educational outcomes:

- Nationally and internationally, students will recognize the HTIRC as a preferred organization from which to receive education and training.
- Former HTIRC graduate students and post-doctoral scientists will continue or establish hardwood research programs, thereby increasing the level of research on hardwood trees.
- Former HTIRC undergraduate and graduate students will become leaders in management of hardwood resources across North America. They will play increasingly prominent roles in their organizations and professional societies.
- The diversity of graduate students recruited into HTIRC will rise by generating increased visibility of, and excitement for, the HTIRC program nationwide. Emphasis will be on maintaining an equitable gender balance and increasing the proportion of applications, successful recruitment, and degree completion of under-represented minorities through active recruitment and mentoring.

The overall quality of the HTIRC graduates will increase. Each MS student is expected to produce one refereed publication, and each PhD student is expected to produce two publications describing results of their research.

F. ORGANIZATIONAL OBJECTIVES

Beyond the five strategic directions, the HTIRC has several objectives related to organizational function and structure. We believe that achieving these goals within the next five years are essential to the HTIRC's long-term viability.

INCREASE AND EXPAND HTIRC PARTNERSHIPS

There is a recognizable need to renew emphasis on recruitment of new external HTIRC partners while working more closely with such existing partners. Specifically, we will develop a plan to enhance the HTIRC's research, extension, and educational capacity by including a broader range of expertise on the Advisory Board and framing our research directions based on their input. This expansion will enable us to be more responsive to our stakeholders, leading to the development and implementation of cutting-edge, integrated (education, outreach, and research/development) projects. Fostering and maintaining this enhanced level of communication with stakeholders and Advisory Board members will be a priority for HTIRC leadership and staff, with input from the Purdue University Forestry and Natural Resources Department Head.

ENHANCED DELIVERY OF GERMPLASM

There is a strong need to develop a policy and implementation strategy for delivering genetically improved planting stock derived from HTIRC research efforts. To address this need, a standing committee, composed of representatives of HTIRC leadership and Advisory Committee members, will be created to define a distribution policy and make decisions on the release of HTIRC germplasm to various customers — including collaborating scientists, land managers (public vs. private), and other interested stakeholders.

CENTRALIZE AND STANDARDIZE DATA RELATED TO ALL HTIRC-INSTALLED PLANTINGS

To optimize research priorities based on existing HTIRC plantings, we will complete the development of a database encompassing all trees (~130,000) in all plantings (175) — including tree location, pedigree information, and available growth data. The long-term goal is to become a centralized repository for additional USDA Forest Service and Purdue tree plantings in the CHFR. Specific database management activities are highlighted below. All field plantings will be assessed for future utility (i.e., survival, growth, site adaptability) in ongoing and future improvement efforts. Re-measurement of retained plantings will be scheduled based on past history and specific traits of interest.

1. *COMPLETE CENTRALIZATION OF ALL DATA RELATED TO HTIRC-INSTALLED FIELD TRIALS.*

Database completion will facilitate estimation of G x E effects in black walnut, red oak, white oak, black cherry, and butternut.

2. *DEVELOP A DATA "HYGIENE" PLAN TO STANDARDIZE ALL HTIRC IMPROVEMENT DATA.*

Maintain archival-quality, long-term data / metadata storage to facilitate / enable future USFS collaborative research across the CHFR.

3. *CENTRALIZE OTHER TREE GENETICS DATABASES.*

By centralizing other relevant tree genetics databases, we will:

a. Enhance future collaborations among other NRS units and institutions.

b. Capitalize on the value represented by unique 50- to 90-year-old plantings to advance scientific research (i.e., tree physiology, tree genetics, forest ecology); and

c. Address current/future tree genetic conservation efforts.

DIGITAL FORESTRY

We recognize the need to develop and refine forest improvement, regeneration, management, and protection tools that incorporate information from existing and emerging remote-sensing technologies (e.g., LiDAR, thermal, hyperspectral imagery) acquired from terrestrial, aerial, and satellite platforms. These technologies are becoming increasingly inexpensive and user-friendly and offer the potential to automate and standardize the many laborious and subjective forest measurements. Further, remote-sensing methods allow rapid scaling-up of plot and stand-level methods to the landscape level, improving forest management efforts throughout Indiana. Effective integration of remote-sensing technologies can contribute to and accelerate successful delivery of many other HTIRC objectives.

III. ORGANIZATIONAL DESIGN

The HTIRC is centered on the Purdue University campus in West Lafayette, Indiana. It also includes close collaborations with the (FS) Northeastern Area State and Private Forestry; USDA Forest Service National Forests Region 9; Indiana Department of Natural Resources Division of Forestry; Indiana Hardwood Lumbermen's Association; National Hardwood Lumber Association; ArborAmerica; Steelcase, Inc.; American Forest Management; Indiana Forestry and Woodland Owners Association; Walnut Council; the Fred M. van Eck Forest Foundation; and other organizations interested in improving the management of the Central Hardwood Forest.

A. LEADERSHIP

In close consultation with the FNR Department Head at Purdue University, the HTIRC is led by Director Dr. Matthew D. Ginzel, Professor, Departments of Entomology and Forestry and Natural Resources. The Director seeks to enable continued improvement of the HTIRC through active engagement with stakeholders, partners, and researchers, and encouraging increased participation by the HTIRC Advisory Board.

B. GUIDING PRINCIPLES

HTIRC will be guided by the following principles as it conducts research to meet the objectives outlined in this plan:

- Research will focus primarily on information that can be used by HTIRC stakeholders to enhance the improvement, management, and protection of hardwood trees in the CHFR.
- We will maintain a high degree of collaboration, coordination, cooperation, resource-sharing, and communication among HTIRC researchers in meeting research objectives.
- Funding will be managed in a clear, transparent manner and directed toward supporting strategic directions.
- We will maintain close contact with Advisory Committee and cooperating organizations to communicate the latest research results, identify research needs, and examine emerging hardwood tree improvement, management, and protection issues.
- Experimental design, methods, and procedures used in HTIRC research will achieve the highest standards.
- Because field research involves a substantial investment, every effort will be made to encourage projects led by research teams that include integrated questions and collaboration.
- All research projects will seek to optimize opportunities for leveraging through shared collaborations, in-kind contributions, and funding with other organizations that have similar goals and / or the required expertise.
- Research results from HTIRC projects will be rapidly communicated to stakeholders using the most effective means of communication (including oral presentations at Advisory Committee meetings and workshops, as well as web-based publications). Completed research will be promptly submitted for publication in refereed scientific journals.

C. OPERATIONS / ADMINISTRATION

ADVISORY BOARD

The HTIRC Advisory Board is made up of individuals from HTIRC partner organizations, including industry, state government, landowners, foresters, and scientists. The Advisory Board meets annually to receive updates on HTIRC research and provide input on research priorities. These meetings represent an important engagement and outreach effort for the HTIRC. Executive Committee is composed of five to six HTIRC Advisory Board members and their responsibilities 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. Such allocations may include (but are not limited to) graduate student and postdoctoral scientist support, and funding of pilot-scale research projects.

HTIRC STAFFING

To address the research priorities enumerated in this Strategic Plan, the HTIRC is composed of a diverse array of talented researchers, staff, postdoctoral associates, and graduate students, representing both the Purdue University FNR and Entomology departments, as well as the USDA Forest Service Northern Research Station. With the expertise represented by the HTIRC staff, we are ideally positioned to deliver the outcomes presented in this plan.

D. FUNDING

HTIRC core operating funds are provided by the Fred M. van Eck Forest Foundation, Purdue University Department of Forestry and Natural Resources and College of Agriculture, and the USDA Forest Service Northern Research Station. Funding for collaborative projects that advance the mission of HTIRC is provided by the USDA Forest Service Northeastern Area State and Private Forestry, private forest landowners, the hardwood forest products industry, and other external sources.

Scientists within HTIRC are expected to apply for grants from federal agencies, including the National Science Foundation, National Aeronautics and Space Administration, Animal and Plant Health Inspection Service, United States Department of Energy, and United States Department of Agriculture. In addition, grants will be sought from programs such as the Hardwood Forestry Fund, Walnut Council Foundation, American Chestnut Foundation, and Consortium for Plant Biotechnology Research.

The Indiana Hardwood Lumbermen's Association, National Hardwood Lumber Association, and Indiana Forestry and Woodland Owners Association have each made funding commitments. Landowner groups and other hardwood and conservation associations may be approached in the future to provide funding support.

Several private citizens have provided funds and land for endowments to fund scholarships, assistantships, and applied research. Future opportunities will be pursued as they arise. Moreover, funding sources for education (e.g., National Needs Fellowships and NSF-Research Experience for Undergraduates) will be explored.

New, incoming HTIRC graduate students, and will be financially supported by funded projects critical to this Strategic Plan. It is further expected that such students will work closely with both FNR and Forest Service scientists as they design and conduct their research.

E. PROGRAM EVALUATION

A program review will be conducted in 2027 to assess how well HTIRC has met the above strategic objectives. As part of this review, input will be solicited from the HTIRC Advisory Board members, Purdue University FNR Department Head, Assistant Director for Research from the USDA Forest Service Northern Research Station, scientists, stakeholders, and others associated with HTIRC. In addition, the Advisory Committee will provide annual feedback on research priorities and will suggest re-prioritization of objectives as necessary.

IV. ACCOMPLISHMENTS DURING 2017-2022

Under its 2017-2022 Strategic Plan, the HTIRC maintained important infrastructure (Pfendler Hall and the John S. Wright Forestry Center at Purdue), increased staffing, expanded collaborative networks, and directly supported research and Extension projects that contributed to its strategic directions and objectives. The advisory committee met annually, and research and Extension outcomes were often accomplished in direct collaboration with external partners and agencies.

The HTIRC published an annual report starting in 2018 that provided a detailed description of progress made on projects approved by the Executive Committee. The annual reports document HTIRC's accomplishments toward the strategic objectives identified in our previous strategic plan. Details of these accomplishments can be found by reviewing the annual reports on the HTIRC website (https://htirc.org/annual-report), as well as associated research reports and other publications that were produced from these works. The following provides a brief overview of accomplishments achieved since 2017 (please refer to the annual reports from prior years for additional information).

Additional Specific Accomplishments include:

Establishment of HTIRC Executive Committee and Stakeholder-driven Project-based funding model

- To help us deliver on our strategic objectives, an HTIRC Executive Committee was formed from members of our 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.
- Developed a stakeholder-driven project-based funding model to support research that directly advances the mission of the HTIRC. All proposals were evaluated and selected for funding by the HTIRC Executive Committee. This transparent funding mechanism supports both new and ongoing research efforts by HTIRC scientists, staff, postdocs, and graduate students.
- Funded 18 projects through the project-based funding model to directly address key strategic research objectives related to tree improvement, management, and protection and serve the needs of our stakeholders. See appendix for HTIRC-related publications.
- Mentored and trained 18 graduate students (9 PhD; 9 MS), five postdoctoral scientists, six undergraduate research technicians, and several visiting scientists in HTIRC mission-oriented work.

Tree Improvement

- Developed a database encompassing 226 unique HTIRC plantings containing 135,277 trees along with GPS coordinates for 88,861 individual trees. The database is currently used by several HTIRC-funded projects across plantings and families for leaf collections and genotyping. We have begun to analyze the heritability of measured traits in all species where data are available, and Euclidean coordinates created for the database allow for spatial analysis at the finest resolution possible. The standardization inherent to the database will allow for multiple environment analyses of families across sites.
- Created a directory, depository, and database for historical genetic and tree improvement trials. This resource is essential to help answer questions about the adaptability of our tree species to future climates.
- Since 2018, the HTIRC tree improvement program supported restoration and regeneration efforts in the central hardwood forest region by providing over 500,000 black walnut, 100,000 black cherry, 25,000 white oak, and 15,000 hybrid butternut seeds to the Vallonia state nursery; establishing five new seed orchards and expanding four others to increase the availability of genetically improved seed; establishing new butternut (3,500 trees) and American chestnut (800 trees) resistance screening blocks and progeny tests for black walnut (2,800 trees), white oak (1,200 trees) and a mixed planting of black walnut and black cherry (1,800 trees).
- Hired a new operational tree breeder and technical assistant to ensure the long-term continuity of our improvement program.
- Updating and refining breeding and distribution plans for all HTIRC target species.

Organizational

- Continued our involvement with the National Science Foundation Center for Advanced Forest Systems (CAFS). In 2009, the HTIRC, 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.
- The integrated Digital Forestry (iDiF) initiative, led by Songlin Fei, leveraged several HTIRC-funded projects to garner wide interest at Purdue and beyond. The goal of this group is to apply digital technology and multidisciplinary expertise to measure, monitor, and manage forests to maximize social, economic, and ecological benefits. The iDiF initiative was selected to be part of the Plant Science 2.0 institute in Purdue's Next Moves over the next five years and has secured over $20M in external grants – including a recent award from the USDA NIFA Sustainable Agriculture System (SAS) program focused on promoting economic resilience and sustainability of eastern US forests.

Extension and Engagement

- Began production of new HTIRC annual reports (2018-2021), distributed as hardcopies and available as PDF on our website.
- Coordinated and sponsored Extension workshops and field days to provide forums to share research discoveries among scientists and transfer technology to managers, including the annual HTIRC advisory committee meeting and field tour.
- Recruited and maintained professional staffing consisting of research scientists, two Extension specialists, two tree breeders, a data analyst, two laboratory managers, and an administrative assistant.
- Produced or updated a variety of online resources, including videos on hardwood management, invasive species, and tree identification. (https://htirc.org/resources/landowner-information/).
- Coordinated and sponsored multiple Extension workshops, field days, and research symposia (e.g., 21st Central Hardwood Forest Conference (CHFC), CAFS Industrial Advisory Board meeting) to share research discoveries among scientists and transfer technology to managers.
- Developed a new HTIRC website (www.htirc.org).
- Distributed an HTIRC e-newsletter to partners and cooperators on a biannual basis, describing research results and other information relevant to management of Central Hardwood Forests (https://htirc.org/resources/newsletters/).
- HTIRC staff and scientists served on boards or assisted with education programs for organizations including Walnut Council, Tree Farm, Indiana Hardwood Lumbermen's Association, American Chestnut Foundation, Society of American Foresters, Indiana Forestry and Woodland Owners Association.

Funding

- Secured funding for HTIRC work from numerous sources, including: USDA Forest Service Northern Research Station; Purdue University; van Eck Forest Foundation; USDA Forest Service State and Private Forestry; National Science Foundation; American Forest Management; ArborAmerica; American Chestnut Foundation; Indiana DNR Divisions of Forestry and Mine Reclamation; Indiana Forestry and Woodland Owners Association; Indiana Hardwood Lumbermen's Association; Walnut Council and others.

APPENDIX: SELECTED HTIRC PUBLICATIONS DURING 2018-2022

2018

Belair, E.P., **Saunders, M.R.**, Landhäusser, S.M. 2018. Growth traits of juvenile American chestnut and red oak as adaptations to disturbance. Restoration Ecology 26(4): 712-719.

Blood, B.L., Klingeman, W.E., Paschen, M.A., Hadžiabdić, Đ, **Couture, J.J.**, **Ginzel, M.D.** 2018. Behavioral responses of *Pityophthorus juglandis* (Coleoptera: Curculionidae: Scolytinae) to volatiles of black walnut and *Geosmithia morbida* (Ascomycota: Hypocreales: Bionectriaceae), the causal agent of Thousand cankers disease. Environmental Entomology 47(2): 412-421.

Clark, T.L., Iannone, III, B.V., **Fei, S.** 2018. Metrics for macroscale invasion and dispersal patterns. Journal of Plant Ecology 11(1): 64-72.

Cotrozzi, L., Townsend, P.A., Pellegrini, E., Nali, C., **Couture, J.J.** 2018. Reflectance spectroscopy: a novel approach to better understand and monitor the impact of air pollution on Mediterranean plants. Environmental Science and Pollution Research 25(9): 8249-8267.

Ebrahimi, A., Lawson, **S.S.,** Frank, G.S., **Coggeshall, M.V.**, **Woeste, K.E.**, **McKenna J.R.** 2018. Pollen flow and paternity in an isolated and non-isolated black walnut (*Juglans nigra* L.) timber seed orchard. PLoS ONE 13(12): e0207861.

Fahey, R.T., Alveshere, B.C., Burton, J.I., D'Amato, A.W., Dickinson, Y.L., Keeton, W.S., Kern, C.C., Larson, A.J., Palik, B.J., Puettmann, K.J., **Saunders, M.R.**, Webster, C.R., Atkins, J.W., Gough, C.M., **Hardiman, B.S.** 2018. Shifting conceptions of complexity in forest management and silviculture. Forest Ecology and Management 412: 59-71.

Feng, X., Yuan, X., Sun, Y., Hu, Y., Zulgigar, S., Quyang, X., Dang, M., Zhou, H., **Woeste, K.E.**, Zhoa, P. 2018. Resources for studies of iron walnut (*Juglans sigillata*) gene expression, genetic diversity, and evolution. Tree Genetics & Genomes 14: 51.

Frank, G.S., Nakatsu, C,H., **Jenkins, M.A.** 2018. Soil chemistry and microbial community functional responses to invasive shrub removal in mixed hardwood forests. Applied Soil Ecology 131: 75-88.

Frank, G.S., Rathfon, R.A., **Saunders, M.R.** 2018. Ten-year responses of underplanted northern red oak to silvicultural treatments, herbivore exclusion, and fertilization. Forests 9(9): 571.

Frank, G.S., **Saunders, M.R.**, **Jenkins, M.A.** 2018. Short-term vegetation responses to invasive shrub control techniques for Amur honeysuckle (*Lonicera maackii*[Rupr.] Herder). Forests 9(10): 607.

Hanks, L.M., Mongold-Diers, J.A., Atkinson, T.H., Fierke, M.K, **Ginzel, M.D.**, Graham, E.E., Poland, T.M., Richards, A.B., Millar, J.G. 2018. Blends of pheromones, with and without host plant volatiles, can attract multiple species of Cerambycid beetles simultaneously. Journal of Economic Entomology 3(2): 716-724.

Hardiman, B.S., LaRue, E.A., Atkins, J.W., Fahey, R.T., Wagner, F.W., Gough, C.M. 2018. Spatial variation in canopy structure across forest landscapes. Forests 9(8): 474.

Hefty, A.R., Aukema, B.H., Venette, R.C., **Coggeshall, M.V.**, **McKenna, J.R.**, Seybold, S.J. 2018. Reproduction and potential range expansion of walnut twig beetle across the *Juglandaceae*. Biological Invasions 20: 2141.

Jo, I., Potter, K.M., Domke, G.M., **Fei, S.** 2018. Dominant forest tree mycorrhizal type mediates understory plant invasions. Ecology Letters 21(2): 217-224.

LaBonte, N.R., Jacobs, J., **Ebrahimi, A.**, **Lawson, S.**, **Woeste, K.E.** 2018. Data mining for discovery of endophytic and epiphytic fungal diversity in short-read genomic data from deciduous trees. Fungal Ecology 35: 1-9.

LaBonte, N.R., **Woeste, K.E.** 2018. Pooled whole-genome sequencing of interspecific chestnut (Castanea) hybrids reveals loci associated with differences in caching behavior of fox squirrels (*Sciurus niger* L.). Ecology and Evolution 2018: 1-17.

LaBonte, N.R., Zhao, P., **Woeste, K.E.** 2018. Signatures of selection in the genomes of Chinese chestnut (*Castanea mollissima* Blume): The roots of nut tree domestication (PDF 257 KB). Frontiers in Plant Science 9: 1-13.

LaRue, Atkins, J.W., Dahlin, K., Fahey, R., **Fei, S.**, Gough, C., **Hardiman, B.S.** 2018. Linking Landsat to terrestrial LiDAR: Vegetation metrics of forest greenness are correlated
with canopy structural complexity. International Journal of Applied Earth Observation and Geoinformation 73: 420-427.

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Oren, E., Klingeman, W., Gazis, R., Moulton, J., Lambdin, P., **Coggeshall, M.V.**, Hulcr, J., Seybold, S.J., Hadziabdic, D. 2018. A novel molecular toolkit for rapid detection of the pathogen and primary vector of Thousand Cankers Disease. PLoS ONE 13(1): e0185087.

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Shamlu, F., Rezaei, M., **Lawson, S.**, **Ebrahimi, A.**, Biabani, A., Khan-Ahmadi, A. 2018. Genetic diversity of superior Persian walnut genotypes in Azadshahr, Iran. Physiology and Molecular Biology of Plants 24: 939.

Shao, G., Iannone III, B.V., **Fei, S.** 2018. Enhanced forest interior estimations utilizing LiDAR-assisted 3D forest cover map. Ecological Indicators 93: 1236-1243.

Shao, G., **Shao, G.**, Gallion, J., **Saunders, M.R.**, Frankenbert, J.R., and **Fei, S.** 2018. Improving Lidar-based aboveground biomass estimation of temperate hardwood forests with varying site productivity. Remote Sensing of Environment 204: 872-882.

Sloan, J.L., Jackson, G.S., **Jacobs, D.F.** 2018. Endogenous translocation patterns of current photosynthate in post-transplant *Quercus ruba* seedlings. Canadian Journal of Forest Research 48(9): 1067-1092.

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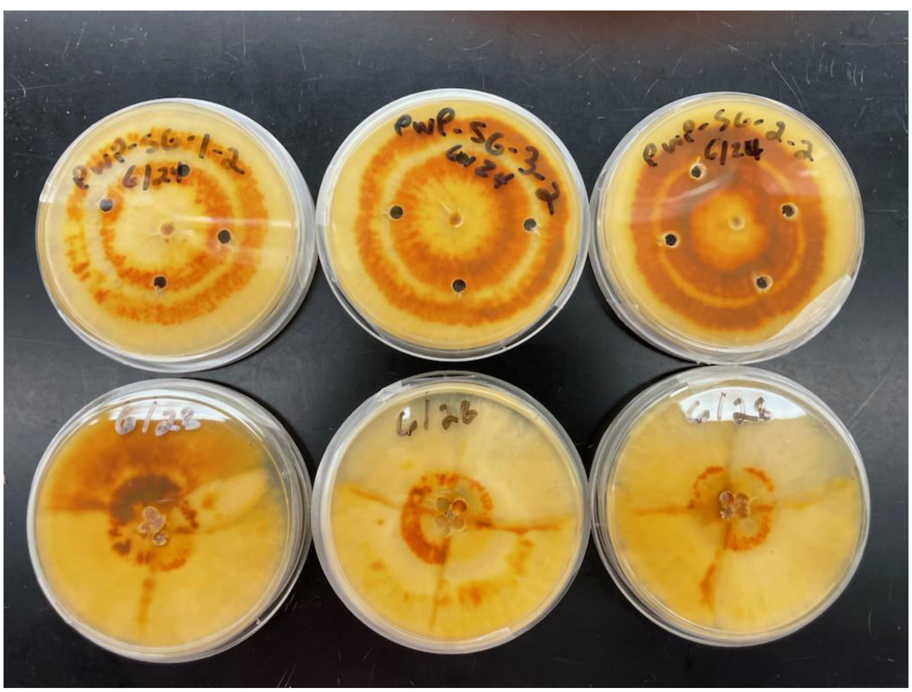

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