PERSEUS

PROMOTING ECONOMIC RESILIENCE AND SUSTAINABILITY OF THE EASTERN U.S. FORESTS

APRIL 30, 2025

YEAR 2 ANNUAL REPORT & YEAR 3 WORK PLAN

WELCOME

PERSEUS provides the necessary foundation for redefining national forest inventory in the U.S., while also providing the much-needed ability to project future forest conditions and provided ecosystem services across contrasting scales.

Funding for this project provided by USDA NIFA SAS, Award #2023-68012-38992.

PERSEUS PARTNERS

Purdue's **Institute for Digital Forestry** focuses on the measurement, monitoring and management of urban and rural forests to maximize social, economic and ecological benefits.

purdue.ag/digitalforestry

UMaine's **Center for Research on Sustainable Forests** conducts and promotes interdisciplinary research on issues affecting the management and sustainability of northern forest ecosystems.

crsf.umaine.edu

UGA's **School of Forestry and Natural Resources** integrates academic research and financial methods to provide education and service to forest industry, investors and landowners throughout the world.

warnell.uga.edu

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Nontechnical Summary

Forests provide many benefits, such as timber and fiber production and carbon sequestration, but their long-term sustainability is increasingly threatened by various changes such as insect outbreaks, extreme weather, evolving markets and land-use changes. More detailed and accurate information is needed to allow landowners, managers and policymakers to make economical and data-driven decisions that will affect the delivery, sustainability and resilience of forest resources.

The goal of the Promoting Economic Resilience and Sustainability of the Eastern U.S. Forests (PERSEUS) project is to provide sound science, outreach and educational opportunities that lay the foundation for a major fundamental change in forestry. More specifically, PERSEUS aims to (1) create a set of digital tools and wall-to-wall forest mapping products that will provide detailed and near real-time measurements, (2) build and apply a framework to visually represent current and future forest trends, (3) engage with stakeholders to develop data-driven management practices, and (4) establish educational and training programs that support students and professionals in understanding and making use of digital technologies. PERSEUS will provide a foundation for redefining forest inventory in the United States while also providing the much-needed ability to predict future forest conditions.

Working with stakeholders, PERSEUS will provide (1) user-friendly tools and programs to better measure and monitor forests like never before, (2) sustainable forest management practices, and (3) a platform to optimize regional efforts in building environmentally and economically sustainable forests, especially on private lands in the rural United States. Moreover, the project will train diverse cohorts of students and professionals to build a digitally competent workforce. Successful completion of the project will increase physical goods such as food, water, fuel and timber provided by forest ecosystems, and improve operational efficiency in forests across the eastern United States. In particular, measurement tools developed by PERSEUS will modernize and inform forest management by creating digital inventory tools that empower stakeholders to better understand the potential impacts of their decisions on a local and regional scale. The resulting framework will provide a "digital bridge," enabling landowners and stakeholders with practical tactics and forest simulation to inform decision- and policy-making. Complementing this, the digital forestry educational programs developed by PERSEUS will generate a diverse workforce capable of carrying and optimizing these tools into the future.

Major Goals of the Project

PERSEUS will provide scientifically sound information, outreach and educational opportunities that lay the foundation for a paradigm shift in forestry toward data-driven, artificial intelligence (AI)-supported forest management systems that increase both the provision of ecosystem services and operational efficiency. PERSEUS will develop measurement and monitoring tools, data-driven decision systems and management practices through a unified effort of automated measurement, integrated multi-objective modeling, engaged data-driven management and a digitally competent mindset in students and professionals.

OBJECTIVE 1

Measurement Automation: Develop scalable automated data capture systems with integration of multimodal, multiplatform and multitemporal data to assist stakeholder data-driven forest management practices and decision-making.

OBJECTIVE 2

Model Integration and Application: Create a multimodel ensemble that is locally calibrated and capable of projecting forest ecosystem services under a range of conditions.

OBJECTIVE 3

Informed and Engaged Management: Encompass stakeholder actions, motivations and values to inform the development and implementation of optimized data-driven management systems that increase the capacity of forest production and ecosystem services.

OBJECTIVE 4

Digitally Competent Mindset: Contribute to measurable national impacts through the development of educational programs for digitally-competent and capable practitioners, managers and researchers who can pipeline into successful academic, industry or governmental careers.

Project	Year 1				Year 2				Year 3				Year 4				Year 5			
Project month	1	4	7	10	13	16	19	22	25	28	31	34	37	40	43	46	49	52	55	58
Calendar year	2023			2024				2025				2026				2027				
Task Calendar month	Apr	Jul	Oct	Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct	Jan
1.1 iForester			1	-	-	1														
1.2 StemMapper				2	-	-	2	3	-	-	-	3								
1.3 Data Coverage				4	-	-	-	4				5	-	-	5	-	-	5		
2.1 Landowner Optimization										6	-	-	-	-	-	6				
2.2 Broad Simulation										7	-	-	-	-	-	7				
2.3 Value Chain												8	-	-	-	8	-	-	-	8
2.4 Data Visualization				9	-	-	9	-	-	9			10	-	-	10	-	-	-	10
3.1 Stakeholder Perceptions				11	-	-	-	11												
3.2 Scenario Development				12	-	-	12	-	-	12	-	-	12							
3.3 Focused Outreach														13	-	-	13	-	-	13
3.4 Technology Application					14	-	-	-	-	14	-	-	-	-	14	-	-	-	-	14
4.1 Learning Communities				15	-	-	-	15	-	-	-	15	-	-	-	15	-	-	-	15
4.2 Interns and Fellows				16	-	-	-	16	-	-	-	16	-	-	-	16	-	-	-	16
4.3 Curriculum Development				17	-	-	-	17	-	-	-	17								
4.4 Online Certificate												18	-	-	-	18	-	-	-	18

Gray shading indicates completed months and red text indicates Year 2 deliverable.

Deliverable and iterations

Objective 1

1 Smartphone application
2 Hardware integration
3 Data analytics
4 Data fusion
5 Scaling

Objective 2

6 Optimization-model ensemble
7 Simulation model ensemble
8 Efficiency simulations
9 Geospatial information system
10 Online optimization platform

Objective 3

11 Identify stakeholder needs
12 Conduct what-if scenarios
13 Small-group workshops
14 Remote training events

Objective 4

15 Established learning communities
16 Recruited interships/fellowships
17 Proposed new digital forestry curriculum
18 Online certificate and online learning modules

PROGRAM EVALUATION

The PERSEUS project is organized with a leadership team consisting of the project director (Purdue University [Purdue]) and two co-directors (University of Georgia [UGA] and University of Maine [UMaine]) as well as an overall project manager and three site managers respective to their university. The PERSEUS project contains four broad objectives, and each objective has an objective lead per university to ensure project goals are being met. The University of Southern Maine's Data Innovation Project (DIP) conducts the PERSEUS external evaluation. DIP evaluators collected data via meeting feedback surveys from the July 2024 Annual Retreat and the November 2024 All Hands Virtual Meeting. During the 2024 retreat, the evaluation team led a real-time polling session to collect evaluation and continuous quality improvement data. This data was triangulated with a post-session meeting feedback survey to provide feedback regarding staff, faculty and student perspectives to leadership.

The annual implementation survey, deployed from December 2024 to January 2025, collected information about PERSEUS project engagement, collaboration and leadership to evaluate ongoing and future project implementation strategies. The key findings included an increase in PERSEUS-related goals, roles and involvement over time, high levels of current and future collaboration plans, and overall positive sentiment about the project. Respondents indicated areas for improvement related to communication and collaboration. Looking ahead, the leadership team's ongoing commitment to using participant feedback to shape future project meetings, project-wide and core-specific communications and networking opportunities will continue to foster inter- and intra-disciplinary research opportunities and facilitate shared learning.

In Year 3, the evaluation team will conduct a partnership self-assessment with the project leadership as well as the objective leads to gather information about the project's synergy, leadership, efficiency, administration/management decision-making and benefits/drawbacks to participation. Key informant interviews will be conducted virtually with a sample of core faculty and students to reflect on the project's provision of information, outreach and educational opportunities. A bibliometrics analysis will be developed to monitor research productivity. DIP will continue to participate in the monthly Sustainable Agricultural Systems (SAS) evaluation Community of Practice meeting led by the University of Wisconsin-Madison Division of Extension and record annual outputs, as outlined in the evaluation's logic model.

Objective 1 Measurement

AUTOMATED (RESEARCH)

Develop, evaluate and integrate sensors, multistream data and AI algorithms to create a set of digital tools and wall-to-wall coverage data that will provide refined, near real-time, and spatially explicit measurements. Novel data acquisition systems and data analytics will be developed to better measure and monitor timber and fiber production, greenhouse gas mitigation (carbon sequestration, wildfire fuel assessment) and other ecosystem services for every acre across the eastern United States.

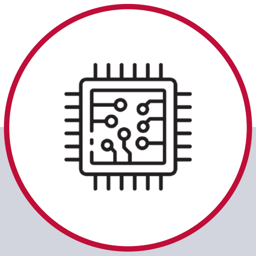
Task 1.1 **iForester (months 1-36):** Develop an integrated AI-assisted iForester (measurement tool — ground truth/inventory measurements) smartphone application that automatically inventories major tree species for the Eastern U.S. Forest with two key functions: (1) AI-assisted species recognition using tree bark and (2) Light Detection and Ranging (LiDAR)-Red Green Blue (RGB) image-enabled measurements of key tree biometric measures.

Task 1.2 **StemMapper (months 1-36):** Create a LiDAR-based and AI-assisted StemMapper (proximal and near proximal remote sensing-derived models and products) to provide stem-level inventory at the stand and tract level with large-scale automated inventory for multi-objective, data-driven management for forestry professionals.

Task 1.3 **Data Coverage (months 1-54):** Generate multiscale data products (e.g., fiber, habitat, carbon) with higher spatial and temporal resolution for every acre across the eastern United States to facilitate both local- and regional-level management optimization.

DELIVERABLES YEAR 2

SMARTPHONE APP



HARDWARE INTEGRATION

DATA ANALYTICS

DATA FUSION

ACCOMPLISHMENTS IN YEAR 2

Task 1.1 iForester: Enhanced mobile AI-based segmentation algorithms and the height measurement module were tested using diverse tree data from Indiana, combining field observations with iPhone scans for analysis. AI significantly improved segmentation accuracy. Using mobile Segment Anything Modeling (SAM), 547 out of 562 trees were successfully segmented with over 97% accuracy. For height measurement, experimental results demonstrated an error margin within 1 foot for the first 16 feet of the log. iForester Diameter at Breast Height (DBH) and height measurements were used to initiate hardwood tree scaling, grading and pricing modules with Doyle, Scribner and International scales for estimating traditional board foot volume of standing trees. A significant number of southern tree species were imaged to inform the identification aspect. The iForester smartphone application is available to the general public, providing forest professionals and others with an accessible tool for preliminary forest inventory knowledge. Presently, 988 users have downloaded the application.

Task 1.2 StemMapper: User feedback was integrated in the proximal BackPack system design. The changes include the adoption of a less-expensive Global Navigation Satellite System/Inertial Navigation System (GNSS/INS) position and orientation system, facilitating expedited processing and derivation of the system's position and orientation (i.e., BackPack trajectory or path). A new LiDAR sensor with more spinning beams and higher pulses per second yielded derived point clouds with higher point density and level of detail. The upgraded power supply allows for almost two continuous hours of operation as well as a significant reduction in system weight. Similar LiDAR design improvements to the near proximal uncrewed aerial system (UAS) yielded more spinning beams and higher pulses per second. A benchmarking UAS with more precise GNSS/INS and LiDAR was developed to evaluate the quality of the derived point clouds as well as forest inventory biometrics (tree detection, segmentation, localization, height and DBH).

BackPack point cloud generation algorithms — Integrated Scan Simultaneous Trajectory Enhancement and Mapping (IS^2-TEAM) and Generalized Trajectory Enhancement and Mapping (G-TEAM) — were refined using acquired point clouds in natural and plantation forests in Indiana, Maine, Georgia and Alabama. To improve UAS trajectory quality, the G-TEAM algorithm was modified to mitigate the impact of lower-quality GNSS/INS trajectory for UAS missions in areas with poor distribution of GNSS satellite constellation and longer distances to reference stations. The integration of UAS and BackPack images and LiDAR data resulted in more tractable species identification and process augmentation to improve the quality of the BackPack Trajectory Enhancement and Mapping (TEAM).

Forest inventory algorithms have been developed to facilitate full automation and straightforward implementation by low-experienced users, with early adopter feedback used to improve the user experience in deriving forest biometrics from BackPack and UAS datasets.

Task 1.3 Data Coverage: The Maine statewide biomass map was updated using forest inventory data to calibrate a TensorFlow-based machine learning (ML) model that interprets three-dimensional (3D) point clouds acquired by the U.S. Geological Survey (USGS) 3D Elevation Program (3DEP) airborne LiDAR over multiple years. Forest Inventory and Analysis (FIA) measurements were employed to calibrate stand growth models and normalize biomass estimates to reflect conditions in 2023.

IS^2-TEAM and G-TEAM capabilities have been improved, including airborne datasets for ensuring that BackPack point clouds are well-aligned with large-scale data captured by airborne systems (e.g., statewide and Geiger-mode LiDAR data). Larger-area coverage data acquisition systems were initiated for use with both high-altitude uncrewed aerial (cargo) and crewed airborne systems.

Wall-to-wall LiDAR-based mapping efforts were calibrated and validated at Howland Forest, Maine. Using a high-precision global positioning system (GPS) to measure trees across 52 plots provided robust field data, with ground truth data of tree size and species required for biomass estimation and remote sensing model development.

PLANS FOR THE COMING YEAR, APRIL 2025–MARCH 2026

DELIVERABLES YEAR 3

DATA ANALYTICS

DATA FUSION

SCALING

Task 1.1 iForester: Efforts will focus on seamlessly integrating tree height and AI segmentation algorithms into the application, as well as incorporating tree grading algorithms to provide commercial log and biomass values. Iterations of the species classification algorithm based on tree surface patterns and size data will continue along with additional acquisition of southern forest tree species images to help train the tree species identification module.

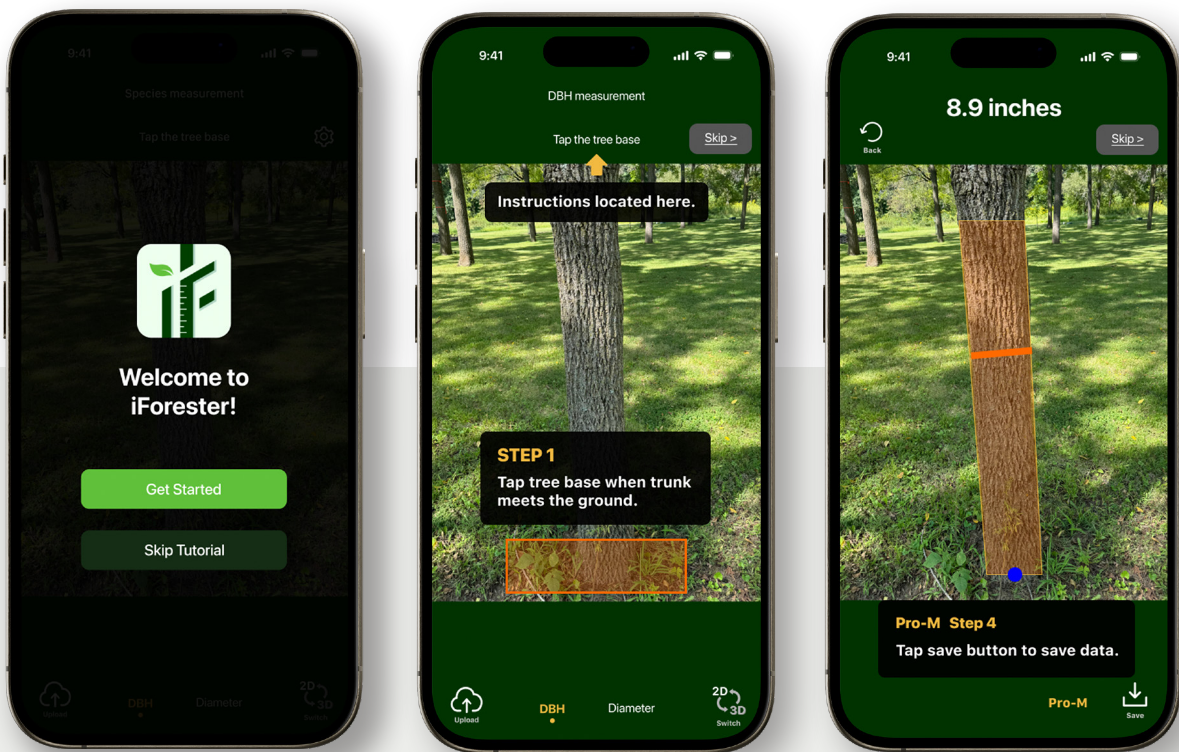
Task 1.2 StemMapper: UAS and BackPack TEAM efficiency improvements will continue while ensuring alignment with large area LiDAR coverage from legacy geospatial data and airborne systems. BackPack trajectory improvements in data acquisition efficiency will follow a three-stage strategy: (1) real-time optimized path planning using collected BackPack data without the need for prior/external map data, (2) using UAS map data for offline optimized trajectory designs coupled with real-time navigation for either relying on the onboard GNSS/INS unit or (3) relying on collected BackPack and UAS map data. Linking image and LiDAR data for improved TEAM will encompass more complete information for tree species identification. Identification will be augmented by integrating RGB/LiDAR and hyperspectral data from the high-altitude/wide-area coverage airborne systems.

Task 1.3 Data Coverage: The first version of the Maine biomass map will be published. It will include detailed documentation of the Oak Ridge National Laboratory Distributed Active Archive Center (DAAC) and a thorough description of the methods, data processing workflows and data uncertainties. Subsequent versions will incorporate multiple LiDAR datasets, such as Global Ecosystem Dynamics Investigation (GEDI), Goddard's LiDAR, Hyperspectral and Thermal Image (G-LiHT), and additional 3DEP airborne LiDAR data, leveraging multitemporal data for annual estimates and offering new insights into interannual variability and long-term forest dynamics.

Improved models will be developed for estimating biomass, volume, basal area and species groups for less intensively managed and natural pine-hardwood forests of the Piedmont area of the South (based on Talladega National Forest data). Models will include woody debris and fuel loads for less intensively managed upland pine-hardwood systems of the South, integrating field measurements with GEDI data for broad scale estimation.

One of the most significant advantages of using data-driven AI to generate a canopy height model (CHM) using spaceborne remote sensing data is that the process does not require manual data generation for training. It uses canopy height from GEDI LiDAR to train multitemporal spaceborne remote sensing data. The model demonstrated higher accuracy when tested in North America versus state-of-the-art global CHM models, using USGS 3DEP CHM as a reference.

BackPack/UAS/high-altitude geospatial data will be integrated to generate accurate alignment of high-resolution data/products for enhancement of high-altitude/wide-area coverage airborne data.



Download on the App Store

Objective 2 Modeling

INTEGRATED MULTI-OBJECTIVE (RESEARCH)

Leverage Objective 1 to construct and apply an integrated framework for modeling current and future forest ecosystem service trends due to various changes such as insect outbreaks and extreme weather for multi-objective optimization at the landowner scale, while providing multistakeholder simulations and tradeoff analyses of forest management at the regional scale. Develop a generalized simulation/optimization framework to inform regionally appropriate data-driven resilience solutions.

Task 2.1 **Landowner Optimization (months 13-48):** Link available forest data (from PERSEUS and existing datasets such as FIA) to the integrated multimodel ensemble to optimize ecosystem services at a local scale (1–1,000,000 ha).

Task 2.2 **Broad Simulation (months 13-48):** Co-develop (with stakeholders) a dynamic simulation system to present broadscale (>1M ha) assessments of alternative policy and market scenarios, while facilitating fine-scale assessments of tradeoffs among management and ecosystem services for regional decision-making.

Task 2.3 **Value Chain (months 25-60):** Develop and refine methods to investigate potential efficiencies through forest management activities in the eastern United States.

Task 2.4 **Data Visualization (months 1-60):** Develop a cloud-based data warehouse to allow key project data to be stored, visualized and shared with stakeholders.

DELIVERABLES YEAR 2

GEOSPATIAL INFORMATION SYSTEM

ACCOMPLISHMENTS IN YEAR 2

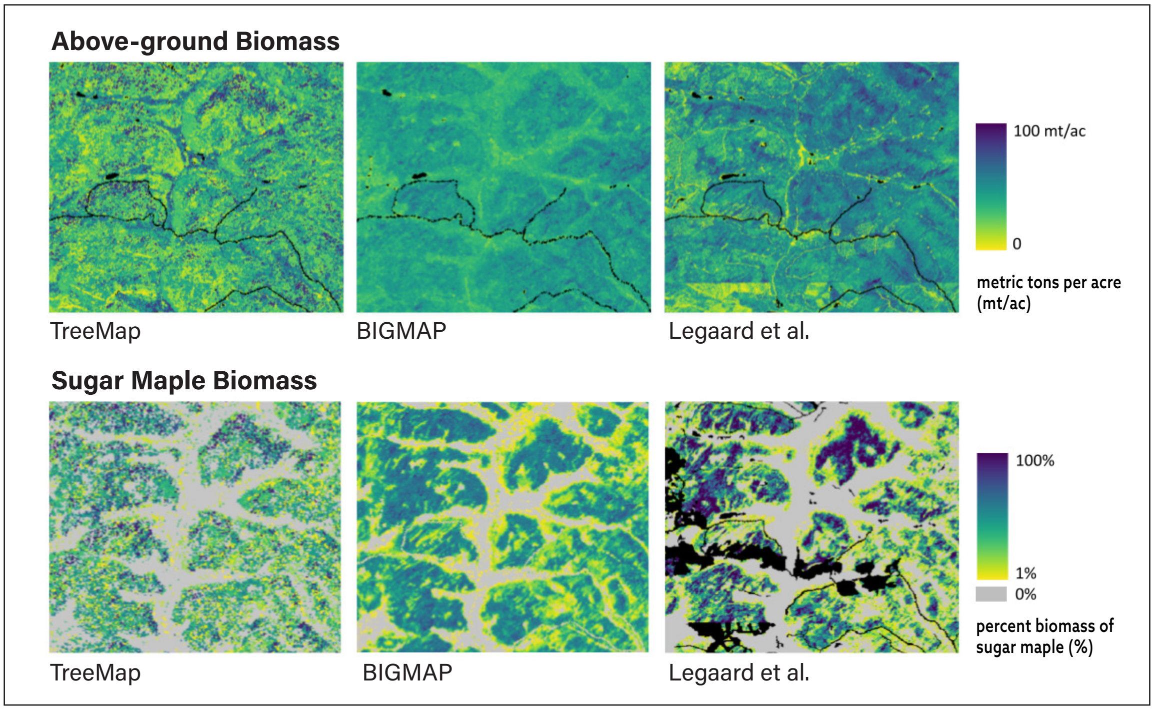
Task 2.2 Broad Simulation: Assessment of Maine multimodels (Forest Vegetation Simulator [FVS], LANDIS-II, Woodstock Optimization Studio, Harvest Choice Model [HCM]) continued, with efforts comparing data and assumptions used to estimate initial stand and landscape conditions and an attempt to harmonize the starting point of future projections. These Maine models are being adapted for Indiana and Georgia to expand regional decision-making frameworks. Assessment of LANDIS-II in the South was begun with a four-county test area in north Florida. Success was achieved in projecting forward the ecological conditions using TreeMap vegetation data and two hypothetical ecoregions. Near-term objectives are to add to the process the ability of LANDIS (Harvest Extension module) simulations for landowner behavior.

Existing LANDIS-based plus Extension model frameworks were updated and expanded to include extreme weather impacts and large mammal habitat suitability. The Maine Integrated Forest Sector Model (MIFSM) is fully operational (see Daigneault et al., 2024; Carovillano, 2024) and now includes habitat suitability for moose and deer, in addition to five other biodiversity indicators of interest to the Northeast United States. LANDIS-II projections have been integrated into MIFSM.

Large language model (LLM) systems have been developed using satellite imagery and weather projection data for seamless, goal-oriented urban and peri-urban building and tree planning strategies for desired social and economic outputs. The system processes a block layout alongside a natural language request and employs LLM computational reasoning and code-generating capabilities. A database of existing urban block layouts was constructed and enriched with socioeconomic and weather-related characteristics to enhance contextual understanding.

Fall season UAS data as well as leaf tissue samples and spectral data were collected to quantify stand composition in southern Indiana to initiate field protocol development and training for functional traits. Preliminary single variable and multivariate models were developed based on historical data to prepare for the summer campaign in Maine.

Task 2.4 Data Visualization: Incorporating the PERSEUS Delphi analysis, model and visualization frameworks have been discussed with internal and external partners to identify what resonates best with end users but is also feasible. There is no "one size fits all" decision support tool or visualization framework; thus, the aim is to



develop multiple outputs. A "static" visualization framework presents pre-populated model outputs for a suite of models and scenarios. Key outputs include standing inventory, timber harvest, carbon storage and sequestration, habitat conditions and water quality. Key drivers include weather changes, market demand and land-use policy constraints.

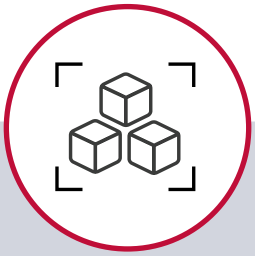
Natural and urban forests present similar challenges, e.g., occlusion, overlaps and lack of resolvability, to segment, locate and analyze in extremely dense environments. Research was conducted to extract accurate urban tree crowns, enabling species extraction at scale beyond LiDAR using satellite (SkySat in Brazil, Mexico, Kenya, India and Pakistan, and UAS National Agriculture Imagery Program (NAIP) data for the United States) and UAS data. A user-friendly dashboard application for the broad audience (including community foresters, arborists and ecosystem researchers) to use and analyze the large dataset is in progress. More than 2,000 urban trees were extracted in Chicago using a combination of computational geometry, graph-based methods and optimization techniques.

USGS 3DEP and NAIP collections have been added to the Spatio-Temporal Asset Catalog (STAC) repository. Though available from Amazon Web Service and Microsoft Azure cloud computing platforms, they are not easily findable and accessible. A custom daily data ingestion script was developed to harvest the required information and update the STAC collections. The STAC repository web application, run at any location within the United States, generates a leaf-on CHM from leaf-off airborne USGS 3DEP LiDAR data and USGS NAIP aerial imageries.

PLANS FOR THE COMING YEAR, APRIL 2025–MARCH 2026

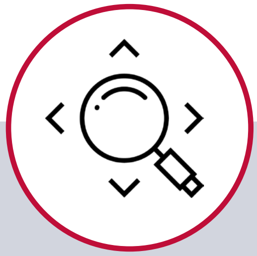
DELIVERABLES YEAR 3

GEOSPATIAL INFORMATION SYSTEM



OPTIMIZATION MODEL ENSEMBLE

SIMULATION MODEL ENSEMBLE



EFFICIENCY SIMULATIONS

Task 2.1 Landowner Optimization: Indiana and Maine forest health site data will be collected in spring/summer, including proximal and UAS hyperspectral measurements, standard leaf functional trait analyses, forest stand health assessments, community composition and DBH.

Task 2.2 Broad Simulation: The existing LANDIS plus Extensions model framework, including weather impacts and habitat suitability, will be refined. LANDIS input requirements and potential outcomes will be assessed in southern and Midwest forests for broad-scale modeling.

The Maine HCM will be expanded to more of the eastern United States, particularly Indiana and Georgia, using state-specific data. The timber supply model focusing on forecasting prices, supply and forest structure will be refined, and work will begin on integration into PERSEUS information systems. Variables include FIA forest attributes stumpage price, land value, ownership, conservation status and distance from mills and highways. Emphasis will be on producing a fully operational model.

Task 2.3 Value Chain: The Tree Planning LLM system will be enhanced for the ability to edit and design greenspaces and urban forests. This involves segmenting blocks into grey and green spaces and incorporating additional objects (e.g., trees, plants) to enable more nuanced analyses. The existing database will be expanded with geospatial urban forestry data derived from satellite imagery and related tools. Urban tree inventories will prioritize the refinement of forest tree crown localization and species extraction using a temporal approach incorporating seasonal and repeat imagery to enhance segmentation accuracy under variable lighting, occlusion and phenological conditions, especially in dense urban zones. Parallel efforts will focus on browser-based scaling accessibility and usability while continuing to facilitate dissemination of actionable data.

Task 2.4 Data Visualization: New data products will be added to the STAC repository, with those required for Tasks 2.1 and 2.2 prioritized.

Objective 3 Management

ENGAGED, DATA-DRIVEN (EXTENSION)

Engage stakeholders to develop data-driven management practices that can improve the sustainability and resilience of forest ecosystems in the eastern United States, based on outcomes from Objectives 1 and 2. Use-inspired, co-production model of research and Extension will be deployed to facilitate both (a) the successful development of the simulation/optimization system and (b) the actual adoption of data-driven management practices by stakeholders to build environmentally and economically sustainable forests, especially on private lands in rural states.

Task 3.1 **Stakeholder Perceptions (months 1-24):** Develop and conduct a survey of foresters and forest landowners concerning current forest practices and environmental challenges, and their interests in ecosystem services and alternative future scenarios.

Task 3.2 **Scenario Development (months 1-37):** Co-develop (with stakeholders) "what-if" scenarios to examine current and future risk perceptions from future weather patterns, available markets, or pests and the degree of support for forest management strategies.

Task 3.3 **Focused Outreach (months 25-60):** Assess end-user satisfaction through staggered, in-person or virtual participatory workshops with stakeholders across subregions to assess project outcomes and the general usability of the developed tools.

Task 3.4 **Technology Application (months 25-60):** Conduct training sessions for stakeholders on tool and system use.

DELIVERABLES YEAR 2

IDENTIFY STAKEHOLDER NEEDS

CONDUCT WHAT-IF SCENARIOS

REMOTE TRAINING EVENTS

ACCOMPLISHMENTS IN YEAR 2

Task 3.1 Stakeholder Perceptions: The Delphi process with forestry professionals was completed. Results are being used to further inform the development of technology and tools to ensure that they align with the needs and interests of the forestry community. PERSEUS Objective 2 has adapted their research priorities to align with these results.

Survey instruments were co-developed and implemented. One, led by UGA to be adapted for UMaine and Purdue, targeted forest businesses and industries; the other, led by Purdue and to be adapted by UGA and UMaine, targeted forest landowners. Both surveys were designed to gather quantitative data on individual perceptions, experiences and likelihood of using digital forestry technology.

Task 3.2 Scenario Development: A systematic literature review was conducted on forest landowner typologies to inform scenario development. Prior work on surveys of business owners, including baseline surveys done for digital forestry, were identified, collected and reviewed. Survey-based scenario development was employed instead of informal discussions. In response, a scenario development module was added to several disseminated surveys (i.e., business and Indiana and Maine landowners).

Task 3.4 Technology Application: Stakeholders were engaged in two single-day UAS and data processing workshops. One was in conjunction with the UMaine PERSEUS Year 2 Annual Meeting; the other was at Purdue's annual Institute for Digital Forestry retreat. Both workshops were attended by local/state Department of Natural Resources (DNR) forestry professionals and as well as academic members.

PLANS FOR THE COMING YEAR, APRIL 2025–MARCH 2026

DELIVERABLES YEAR 3

IDENTIFY STAKEHOLDER NEEDS

CONDUCT WHAT-IF SCENARIOS

REMOTE TRAINING EVENTS

Task 3.1 **Stakeholder Perceptions:** Surveys and focus groups will be conducted to finalize the sampling frame for state-level data collection from stakeholders. These may include (a) forestry professionals informed by the Delphi method and/or informed by landowners; (b) landowners informed by landowner focus groups and/or interviews; (c) business owners; and (d) technology needs and adoption, such as landowner interest in UAS certification, to understand potential educational opportunity needs.

Task 3.2 **Scenario Development:** Management approaches will be assessed based on landowner typology to feed into the scenario framework with initial findings through stakeholder and general perception survey analysis. Typologies will be determined by linking ownership and regional socioeconomic and FIA plot data to estimate forest management and harvest decisions over the previous 20 years. Assessment of the model and scenario framework developed by UMaine will be continued and expanded to all three regions.

Task 3.3 **Focused Outreach:** A target audience outreach strategy will be developed with prototype materials and workshops based on key project plans and updated findings. The materials will be trialed with representative stakeholders, and iterated and disseminated through strategic outlets, with solicited input from key stakeholders.

Task 3.4 **Technology Application:** Successful adoption of new technologies relies heavily on meeting stakeholder needs and providing meaningful training opportunities. Key stakeholders and their needs will continue to be identified to improve offerings. This will entail developing detailed plans for training and soliciting input from other PERSEUS objective teams. Training opportunities will be finalized and disseminated to strategic outlets, followed by soliciting feedback on training events and refinement iterations. An Extension specialist will be hired (Purdue) and dedicated to outreach activities, including evaluating stakeholder digital technologies and assessing facilitators and barriers to adoption.

Objective 4 Mindset

DIGITAL COMPETENCE IN STUDENTS AND PROFESSIONALS (EDUCATION)

Develop a digitally competent mindset in students and professionals for data-driven natural resources management. Actively train or retrain diverse cohorts of students and professionals through immersive learning experiences and online learning opportunities to modernize a skilled workforce. Target recruitment at underrepresented and underserved rural communities to enhance the voices engaged in forestry and to upskill those typically overlooked for such opportunities.

Task 4.1 **Learning Communities (months 1-60):** Design project-focused learning communities that provide opportunities for data-science/engineering undergraduates to work on forestry issues and for forestry undergraduates to learn digital technologies.

Task 4.2 **Interns and Fellows (months 1-60):** Provide undergraduate internships and graduate fellowships for students interested in digital forestry, recruiting and effectively engaging students with all aspects of the research project.

Task 4.3 **Curriculum Development (months 1-60):** Develop curriculum aimed at expanding the digital awareness of students engaged in forestry via a wide selection of transdisciplinary courses corresponding to the data pipeline in Global Information System (GIS) science, UAS and remote sensing, and data science. Develop a professional master's in digital natural resources.

Task 4.4 **Online Certificate (months 25-60):** Develop online, cross-institutional digital forestry curricula for certificates including the core digital forestry curriculum — for example, undergraduate, graduate, bridging to professional science master's degree, and professional training, workforce development, Extension.

DELIVERABLES YEAR 2

ESTABLISH LEARNING COMMUNITIES

RECRUIT INTERNSHIPS/ FELLOWSHIPS

PROPOSE NEW DIGITAL FORESTRY CURRICULUM

ACCOMPLISHMENTS IN YEAR 2

Task 4.1 Learning Communities: Purdue offered two semesters of a Digital Forestry Vertically Integrated Projects (VIP) undergraduate course with two students enrolled. Purdue convened two terms of mechanical engineering senior undergraduate students engaged in the design and improving the BackPack LiDAR systems, which incorporated learning about the unique environment of collecting data in forested areas.

Purdue also convened a group of six first-semester graduate students on the topics of beginning research and successfully launching in graduate school. Fall term PERSEUS graduate student meetings included guest speakers from UMaine and UGA who shared their research, career journeys and perspectives on academic work. A questionnaire on professional development activities was again given to PERSEUS graduate students in January 2025. This survey assessed interest in topics and delivery methods for professional development activities. These activities were then developed and became the focus of the spring meetings on professional development topics, including "Managing your online research presence" and "The academic publishing process 101." All meetings provided a chance for students to ask questions and share any challenges or success stories they are experiencing. Five nonthesis UGA Master of Forest Resources graduate students (not funded by PERSEUS) assisted in the development of southwide GIS databases (e.g., roads, streams, soils, ownership).

Task 4.2 Interns and Fellows: The Summer 2024 cohort of PERSEUS undergraduate interns consisted of 11 Purdue undergraduate students who completed mentored research projects under the guidance of PERSEUS faculty. Cohorts met at least weekly to discuss progress on their research and a variety of professional development topics. Interns presented their research at Purdue's 2024 annual Institute for Digital Forestry retreat. The program was summarized in a document hosted on the Purdue PERSEUS webpage (https://ag.purdue.edu/digital-forestry/projects/perseus).

Six UGA interns were onboarded to assist with Objective 1 activities (wood bark image collection and database management as well as virtual reality (VR) capabilities and video library), Objective 2 (modeling) and Objective 4 (Online Learning in Applied Forestry [OLAF] AI course development).

Postdoctoral research fellow trainings included one UMaine fellow in development and implementation of Delphi technique; one UMaine fellow in group techniques for decision-making, collaborative research, survey design and systematic literature reviews; one Purdue fellow on survey sampling, mail survey development, and mail survey administration, as well as Delphi method; and one UMaine fellow in group techniques for decision-making. Postdoctoral research fellows and graduate students formed a working group to draft manuscripts and provide feedback among each other. Professional development activities for early career scientists encouraged collaboration across institutions.

Task 4.3 Curriculum Development: UMaine's big data Enhanced Forest Inventory and Analysis course was delivered in Spring 2024 for a mix of on-campus graduate students and postgraduates in the forestry workforce. This hybrid course used various modes of learning, including asynchronous video content (produced in collaboration with UMaine's Center for Innovation in Teaching and Learning), synchronous in-class discussions of conceptual materials and guided hands-on data analysis exercises that demonstrated applications of the forestry "big data" concepts and methods introduced by the video and discussion content. Students both reinforced and advanced their knowledge and practice of forest inventory approaches, from traditional ground-based plot networks to enhanced methods that incorporate remote sensing and ML models.

The course included both independent and group projects and featured guest lectures on FIA. This is a core course of the UMaine School of Forest Resources' newly developed graduate certificate program. Professionals earned continuing education credits for both Maine's state forester license and toward national Society of American Foresters (SAF) accreditation. The course, which is part of UMaine's new graduate certificate program, is offered every other year. The course has been updated and refined with input received from the broader PERSEUS team.

An all-day hands-on technology workshop was held during the summer PERSEUS annual meeting at UMaine as well at the Purdue summer annual meeting. The workshop included hands-on experience with various UAS platforms, recommendations and discussion from experienced UAS experts, and a demonstration of data processing and visualization using the Data to Science (D2S) platform. The UMaine workshop had nine facilitators and was attended by 23 participants, including two undergraduate and four graduate students, five faculty/staff and 12 local stakeholders (e.g., Maine Forest Service). The Purdue workshop had eight facilitators and was attended by 13 participants, including four Purdue graduate students or postdoctoral research fellows and nine local stakeholders (e.g., Indiana DNR, other university Extension).

A short technology demonstration and discussion titled "Advances in Digital Forestry" was held at the 2024 annual SAF meeting in Loveland, Colorado. This included an update on the various forest inventory methods and metrics produced using digital tools and technologies. Attendees at the demonstration and discussion included forest managers from across the country, researchers from various universities and representatives from private industry.

Purdue developed a Digital Data Acquisition Camp (DDAC) to pilot in Summer 2025. This immersive, hands-on camp will occur over three weeks and consist of four graduate-level credits. This course integrates UAS operations, photogrammetric and LiDAR methods of forest measurements, and environmental sensor networks and Internet of Things (IoT) for forest ecosystem management.

Purdue's Digital Ecology and Natural Resources (DENR) professional master's degree program is working through the university approvals process. The DENR professional master's degree will incorporate the DDAC as well as eight additional credits on more in-depth data acquisition techniques, 12 credits on GIS, three credits on ethics and six credits of an independent study capstone project.

Task 4.4 Online Certificate: New modules were added to UGA's OLAF courses on remote sensing and artificial intelligence. Continuing education credits will be certified by SAF. DENR professional master's at Purdue will include online and residential pathways to accommodate working professionals as well as traditional graduate students.

PLANS FOR THE COMING YEAR, APRIL 2025–MARCH 2026

DELIVERABLES YEAR 3

ESTABLISH LEARNING COMMUNITIES

RECRUIT INTERNSHIPS/ FELLOWSHIPS

PROPOSE NEW DIGITAL FORESTRY CURRICULUM

ONLINE CERTIFICATE/ MODULES

Task 4.1 **Learning Communities:** Learning communities will continue to undergo refinement to maximize engagement, including semiformal, non-course-based options that meet the needs of students and instructors while maximizing hands-on training and exposure to digital forestry technologies. PERSEUS graduate students will continue to meet monthly on various professional development topics.

Task 4.2 **Interns and Fellows:** A second cohort of PERSEUS undergraduate summer interns will be recruited at Purdue to complete mentored research projects in Summer 2025. This program also includes professional development activities and introduction to various digital tools and technologies.

Task 4.3 **Curriculum Development:** UMaine is developing a graduate-level course, Unoccupied Aerial Systems in the Forest Environment, that will provide training in small systems for aerial surveys in support of forestry and related natural resource applications. The course will include a combination of hands-on field work and computer-based activities. The course is expected to be offered in Fall 2025.

Purdue's DENR professional master's degree program plan of study will continue to be refined and new courses added as they are identified.

Task 4.4 **Online Certificate:** UMaine's big data in forestry course, Enhanced Forest Inventory and Analysis, will continue forward as an every-other-year offering at UMaine, to be delivered next in Spring 2026. Course development will continue in Year 3, notably with an emphasis on incorporating new data sets collected and technical workflows developed in the PERSEUS project. Specific examples include additional modules and training on the use of proximal sensing (i.e., terrestrial and UAS LiDAR) for forest inventory and monitoring.

UGA will continue to develop new OLAF modules and refine existing modules. Purdue's forthcoming DENR professional master's degree program includes an online pathway for working professionals.

ACADEMIC PRODUCTS

Publications Acknowledging PERSEUS Funding

Chivhenge, E., Ray, D.G., Weiskittel, A.R., Woodall, C., D'Amato, A. 2024. Evaluating the development and application of stand density index for the management of complex and adaptive forests. Current Forestry Reports, 10: 133–152. doi: 10.1007/s40725-024-00212-w.

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Foster, A.E., Rahimzadeh-Bajgiran, P., Daigneault, A., Weiskittel, A. 2024. Cost-effectiveness of remote sensing technology for spruce budworm monitoring in Maine, USA. Forests Monitor, 1(1): 66–98. doi: 10.62320/fm.v1.i1.14.

Goel, A., Song, H., Jung, J. 2025. Integrating sparse LiDAR and multisensor time-series imagery from spaceborne platforms for deriving localized canopy height model. IEEE Transactions on Geoscience and Remote Sensing, 63: 1–13. doi: 10.1109/TGRS.2025.3542685.

Huang, Y., Ou, B., Meng, K., Yang, B., Carpenter, J., Jung, J., Fei, S. 2024. Tree species classification from UAV canopy images with deep learning models. Remote Sensing, 16(20): 3836. doi: 10.3390/rs16203836.

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Jung, J., Fei, S., Tuinstra, M., Yang, Y., Wang, D., Song, C., Gillan, J., et al. 2024. Data to science: An open-source online platform for managing, visualizing, and publishing UAS data. Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping IX, 13053: 12–15. SPIE.

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Lee, T., Vatandaslar, C., Merry, K., Bettinger, P., Peduzzi, A., Stober, J. 2024. Estimating forest inventory information for the Talladega National Forest using airborne laser scanning systems. Remote Sensing, 16(16): 2933. doi: 10.3390/rs16162933.

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Roy, S., Wei, X., Weiskittel, A., Hayes, D.J., Nelson, P., Contosta, A. 2024. Influence of climate zone shifts on forest ecosystems in northeastern United States and maritime Canada. Ecological Indicators, 160: 111921.

Shao, J., Lin, Y.C., Wingren, C., Shin, S.Y., Fei, W., Carpenter, J., Habib, A., Fei, S. 2024. Large-scale inventory in natural forests with mobile LiDAR point clouds. Science of Remote Sensing, 10: 100168. doi: 10.1016/j.srs.2024.100168.

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Warner, C., Wu, F., Gazo, R., Benes, B., Kong, N., Fei, S. 2024. CentralBark image dataset and tree species classification using deep learning. Algorithms, 17(5): 179. doi: 10.3390/a17050179.

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Zhou, T., Zhao, C., Wingren, C.P., Fei, S., Habib, A. 2024. Forest feature LiDAR SLAM (F2-LSLAM) for backpack systems. ISPRS Journal of Photogrammetry and Remote Sensing, 212: 96–121. doi: 10.1016/j.isprsjprs.2024.04.025.

Conference Presentations Referencing PERSEUS Research

Airborne LiDAR for Fine Resolution Forest Inventory at a Scale: Investigation of Linear, Geiger, and Single Photon LiDAR. Ayman Habib, EFFICACI/TNC/Purdue Partner Meeting, October 4, 2024.

Are Remote Sensing-backed Forest Inventory Models and Maps Reliable for Large and Structurally Complex Forests? C. Vatandaslar, T. Lee, P. Bettinger, J. Stober, 14th North American Forest Ecology Workshop, June 27, 2024, Asheville, NC.

Building an Open Geospatial Data Ecosystem, Ideation Workshop: 3D Mapping of the Amazon. Jinha Jung, December 9-10, 2024, Princeton, NJ, 30 people.

Data to Science: Modular Open-source Ecosystem for High Throughput Phenotyping. Jinha Jung, Plant and Animal Genome 32 Conference, January 11, 2025, San Diego, CA, 150 people.

Deep Learning-based Method for Tree Trunk Detection and Species Recognition. Y. Huang, C. Warner, R. Gazo, S. Fei, American Geophysical Union, Fall Meeting, December 13, 2024, Washington, D.C.

Demonstrating a Carbon MMRV Prototype for ME's Working Forests: Results from a Stakeholder-driven, Landscape Model-data Framework. D. J. Hayes, X. Wei, E. Simons-Legaard, K. Legaard, A. Weiskittel, B. Cook, C. Woodall, Annual Meeting of the American Geophysical Union, Washington, D.C.

Discovering the Unseen: Modular Open-source Ecosystem for Geospatial Data Science. Jinha Jung, Institute for Plant Sciences Remote Sensing Workshop, December 13, 2024, West Lafayette, IN, 15 people.

Estimating Canopy Cover of Natural Forests Using Airborne Laser Scanning (ALS) Data: A Case from Alabama, USA. C. Vatandaslar, T. Lee, A. Peduzzi, P. Bettinger, K. Merry, J. Stober, IUFRO World Congress, June 28, 2024, Stockholm, Sweden.

Generative AI for Urban Structures and Forests. A. Firoze, D. Aliaga, 2024 USFS Forest Inventory and Analysis Science Symposium (virtual) November 21, 2024, 35 attendees.

Global Economic, Timber, and Carbon Implications of Alternative Forest Plantation Growth Pathways. A. Daigneault, IUFRO World Congress, June 28, 2024, Stockholm, Sweden.

GNSS Through the Trees: Smartphone Capabilities Under Forested Conditions. K. Merry, P. Bettinger, IUFRO World Congress, June 25, 2024, Stockholm, Sweden.

High Resolution Soil Moisture and Biomass Sensing Using S-Band Synthetic Aperture Radar on a UAV Platform. W. Li, M. Crawford, L. Azimi, M. Inggs, J. Garrison, American Geophysical Union, Fall Meeting, December 13, 2024, Washington, D.C.

Landscape-level Forest Ecosystem Service Impacts of Uneven-aged Forest Management. A. Daigneault, Society of American Foresters Convention, September 17–20, 2024, Loveland, CO.

Landscape-level Forest Ecosystem Service Outcomes of Uneven-aged Forest Management. C. Carovillano. IUFRO World Congress, June 28, 2024, Stockholm, Sweden.

Near Proximal and Proximal LiDAR for Fine Resolution Forest Inventory at a Scale. Ayman Habib, 2024 Forest Inventory and Analysis Science Symposium, November 21, 2024.

Near Proximal and Proximal LiDAR for Fine Resolution Forest Inventory at a Scale. Ayman Habib, 2024 USFS Forest Inventory and Analysis Science Symposium (virtual). November 21, 2024.

Near Proximal and Proximal Sensing for Fine Scale Forest Inventory. Ayman Habib, ASPRS Mid-South Regional Conference: Mapping, Monitoring, and Modeling for Climate Security, May 10, 2024, Oak Ridge National Laboratory.

Near Proximal and Proximal Sensing for a Sustainable Environment: Opportunities and Challenges in Forest Inventory and Smart Agriculture. Ayman Habib, GRASP Laboratory, School of Engineering and Applied Science, University of Pennsylvania, December 13, 2024.

Near Proximal and Proximal Sensing for a Sustainable Environment: Opportunities and Challenges in Forest Inventory. Ayman Habib, Annual Conference of the Egyptian-American Scholars (AEAS-S51), December 24, 2024, Cairo, Egypt.

Near Proximal and Proximal Sensing for a Sustainable Environment: Opportunities and Challenges in Forest Inventory. Ayman Habib, Keynote at the 2024 K-Geo Festa – Digital Earth: Better life for all, November 6, 2024.

Phenotypic Data Standardization and Management. Jinha Jung, Plant and Animal Genome 32 Conference, January 10, 2025, San Diego, CA, 50 people.

Proximal, Near-Proximal, and Airborne LiDAR for Fine Resolution Forest Inventory at a Scale. Ayman Habib, Institute of Digital Forestry Annual Meeting, August 1, 2024.

Remote Sensing of ME's Forests. Daniel Hayes, teacher's workshop, Challenger Center, Bangor, ME.

Smartphone Circular Plot Forest Inventory. Victor Chen, 2024 USFS Forest Inventory and Analysis Science Symposium (virtual).

Species Identification with Canopy Images and Deep Learning Techniques. Y. Huang, B. Ou, K. Meng, B. Yang, J. Carpenter, J. Jung, S. Fei, Ecological Society of America, August 7, 2024, Long Beach, CA.

Sustainability of Forest Industries and Their Linkages with Ecosystem Services. M. Tiwari, J. Siry, J. Abrams, PERSEUS Annual Meeting, Orono, ME.

Tree Species Identification from Point Clouds by Fine-tuning CLIP. J. Shao, S. Fei, American Geophysical Union.

OTHER PRODUCTS

Activities

- April 2024. Purdue University Spring Fest iForester Demonstration.
- February 2025. MSU Forest Carbon and Climate Program 2025 Learning Exchange Series: Addressing uncertainties in additionality for forest carbon offsets.
- March 2025. Purdue University 3rd Annual Digital Forestry Symposium "Cellphones to Satellites" (40 postdoctoral and graduate and undergraduate student presentations).

Events

- February 2024. North American Plant Phenotyping Network Annual Meeting, Data to Science Training Workshop.
- May 2024. PERSEUS Annual Meeting, Data to Science Training Workshop.
- September 2024 FOSS4G NA (Free and Open-source Software for Geospatial, North American) Annual Meeting. Data to Science Training Workshop.
- October 2024. IPPS (International Plant Phenotyping Symposium), Data to Science Training Workshop.

Other

- Purdue PERSEUS website: https://ag.purdue.edu/digital-forestry/projects/perseus.
- Spatio-Temporal Asset Catalog (STAC): https://stac.digitalforestry.org.
- UGA PERSEUS website: https://perseus.uga.edu.
- PERSEUS 2024. Undergraduate Summer Research Program Summary: https://ag.purdue.edu/digital-forestry/projects/perseus/_docs/perseus_ug_summer_2024_reserach_program_summary.pdf.

NOTES

PERSEUS

PERSEUS PARTNERS

PURDUE UNIVERSITY

THE UNIVERSITY OF MAINE

UNIVERSITY OF GEORGIA

APRIL 30, 2025

YEAR 2 ANNUAL REPORT & YEAR 3 WORK PLAN