NSF I/UCRC Center for Advanced Forestry Systems

2020 (Year 1) Phase III Progress Report

National Science Foundation

Meg Fergusson & Aaron Weiskittel
CAFS3 Lead Site, University of Maine
Center for Research on Sustainable Forests

Vision

To actively support the US forest industry by solving problems with targeted, applied, and collaborative research coordinated across multiple universities.

Mission

To optimize genetic and cultural systems to produce high-quality raw forest materials for new and existing products by conducting collaborative research that transcends traditional species and disciplinary boundaries.

Objectives

Serve as national organization for R&D relevant to the forest industry

Coordinate and perform national research activities across multiple sites that align with the prioritized needs of forest industry

Document and communicate key research outcomes to relevant stakeholders

Provide a long-term strategic vision for research needs of forest industry

Convene leading scientists from academia and industry who are prepared to address new/unforeseen challenges to the forest industry, such as changing markets

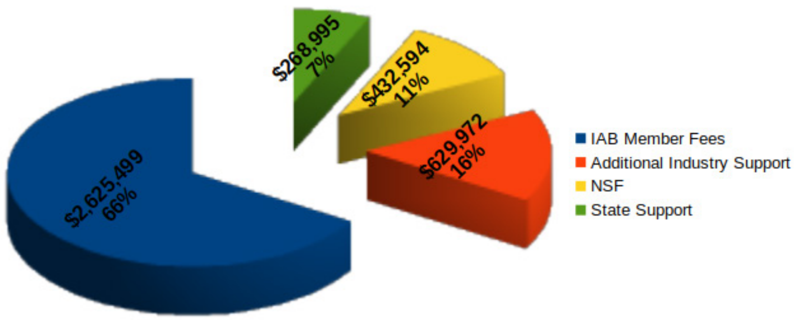
Create national networking opportunities for universities and forest industry

The University of Maine became the lead site for CAFS in 2016. The CAFS program is led by Dr. Aaron Weiskittel, Director of UMaine's Center for Research on Sustainable Forests.

crsf.umaine.edu/forest-research/cafs

FY21 Budget

$3.7M across 6 sites and 138 IAB members



Phase III Research Roadmap

	2019	2020	2021	2022	2023	Outcomes
All CAFS Sites						IAB Meetings, evaluation, undergraduate education, publications, attendance at national meetings, securing of additional research support
Theme 1: Forest Modeling & Decision-Support Tools Primary IAB Partners: American Forest Management, Green Diamond, Campbell Global						Provide IAB members with improved tools that allow better and more precise forest management and planning
Project 1: Assessing and mapping regional variation in potential site productivity Lead Partners: NCSU, UI, UGA, UW, PU						Better understand how potential site productivity differs across the key forest regions in the US, the most influential factors, and produce high-resolution maps for IAB members to aid planning
Project 2: Assessing and mapping regional variation in site carrying capacity Lead Partners: UI, UM, OSU, VT, UGA, UW						Derive consistent estimates of maximum stand density index, evaluate most influential factors, and provide high-resolution maps to aid management
Project 3: Evaluation and refinement of regional GY models Partners: UM, VT, UGA, OSU, PU						Using the outcomes from Projects 1 and 2, evaluate regional growth and yield behavior and refine as possible
Theme 2: Effective Use of Remote Sensing Technologies Primary IAB Partners: JD Irving, Rayonier, Weyerhaeuser						Evaluate and leverage emerging remote sensing technologies to improve planning
Project 4: Mapping species composition and past disturbance using optical sensors Partners: UI, UM, UGA						Optimal sensors like Landsat and Sentinnel-2 offer the ability to annual map species composition and past disturbance, but have yet to be tests across the US
Project 5: Improving efficiency and accuracy of Enhanced Forest Inventories derived from LiDAR Partners: UW, OSU, UGA, UM						LiDAR is becoming increasingly used to produce Enhanced Forest Inventories, but uncertainties on ground data, necessary metrics, and modeling method remain.
Project 6: Using hyperspectral imaging to evaluate forest health risk Partners: VT, NCSU, OSU, UM						Forest health risks are extensive and difficult to detect. Hyperspectral imaging from terrestrial and/or airborne sensors can help detection and quantification
Theme 3: Improved Silvicultural Practices Primary IAB Partners: Hancock Forest Management, International Forest Company, Molpus Timberlands Management						Forest managers have a variety of silvicultural regimes to select from, but it is often unclear on selecting the best practices for each site
Project 7: Quantifying long-term gains using advanced genetics Lead Partners: PU, UGA, OSU, NCSU						Tree genetics has seen significant advances in recent years due to better breeding practices and cloning, but a synthesis of the long-term potential effects of these practices across multiple species has yet to be presented
Project 8: Modeling forest response to early stand treatments Lead Partners: UW, UI, NCSU, VT						Vegetation management is critical to successful rotations, but its prediction is complicated by a variety of factors such as the type and extent of competing vegetation. Leveraging long-term datasets, the outcomes of contrasting treatments would be assessed and modeled.
Project 9: Identifying type and level of response to forest fertilization Lead Partners: UW, UI, NCSU, PU						Forest fertilization is a widely used silvicultural practice that is difficult to predict. Using long-term and newly available data, methods to improve predictions of forest responsiveness would be evaluated.
Project-wide activities informed by Research Plan	Incorporation of advanced and emerging technologies Delivery of multi-platform, decision-support tools Harmonization, and synthesis of available regional datasets to generalize trends Multi-disciplinary, knowledge to action, and stakeholder-drive framework					

Forests

are vital to the world’s economic, ecological, and social health.

Forests provide numerous ecosystem services, particularly sustainably managed forests.

Economic opportunities exist to meet increasing demand for wood produts from an increasing global population, rising living standards, greenhouse gas policies, bioenergy, and advances in green building technologies.

Meetings

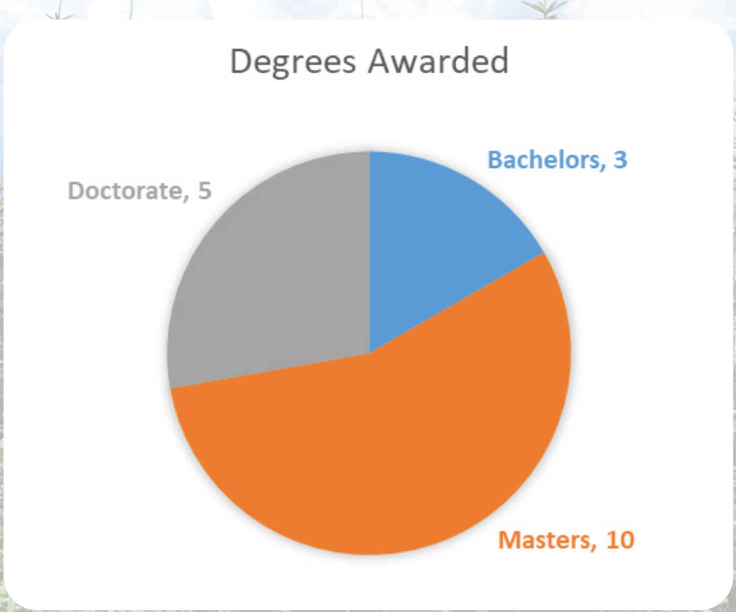
In-person internal advisory board (IAB) meetings have been held annually since 2008. Site directors, researchers, and members of site cooperators and invited and encouraged to attend. Due to Covid-19 restrictions, UMaine pivoted to host two remote IAB meetings in 2020 for project progress updates and stakeholder interaction.

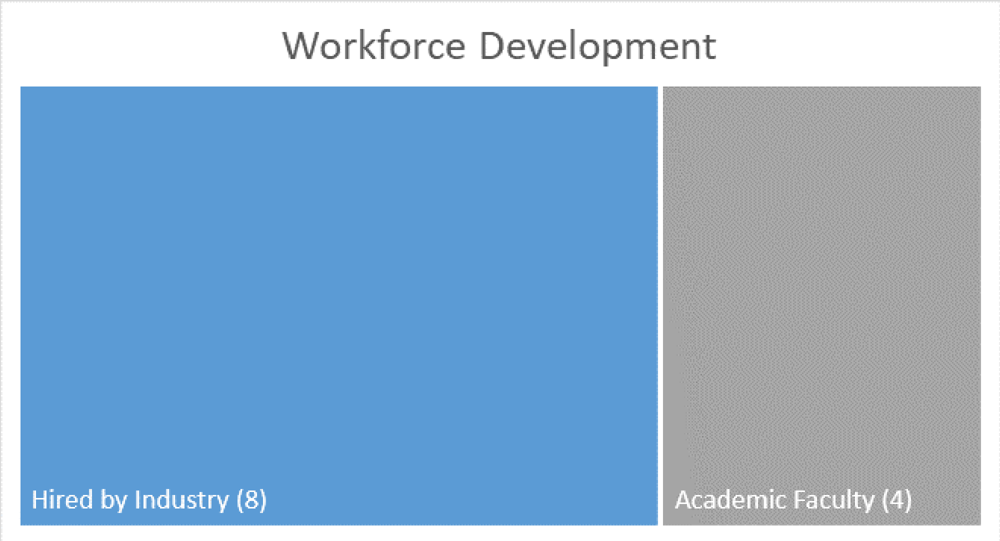
Research

conducted by CAFS increases the competitiveness of forest products industries and forest landowners by solving problems at multiple temporal and spatial scales, and by determining fundamental solutions that transcend traditional tree species, regional, and disciplinary boundaries. Industrial members benefit by becoming knowledgeable about a wider range of technological capabilities. In addition, technology transfer between CAFS scientists and member personnel fosters rapid implementation of new technologies.

2020 Impacts

Despite the shutdowns associated with the global pandemic, CAFS researchers were able to continue their research and share it with the broader scientific community through refereed publications and virtual presentations at scientific meetings. Graduate student training is featured in CAFS research and technology transfer, allowing them to gain valuable knowledge of applied problem-solving using interdisciplinary techniques across multiple scales. CAFS sites aggressively recruit graduate students from among under-represented groups in a concerted effort to increase the diversity of the workforce for both academia and industry in this traditionally diversity-deficient discipline. CAFS research activities allow undergraduate students to experience the excitement of forest science and mentorship to pursue graduate education.





Project Highlights

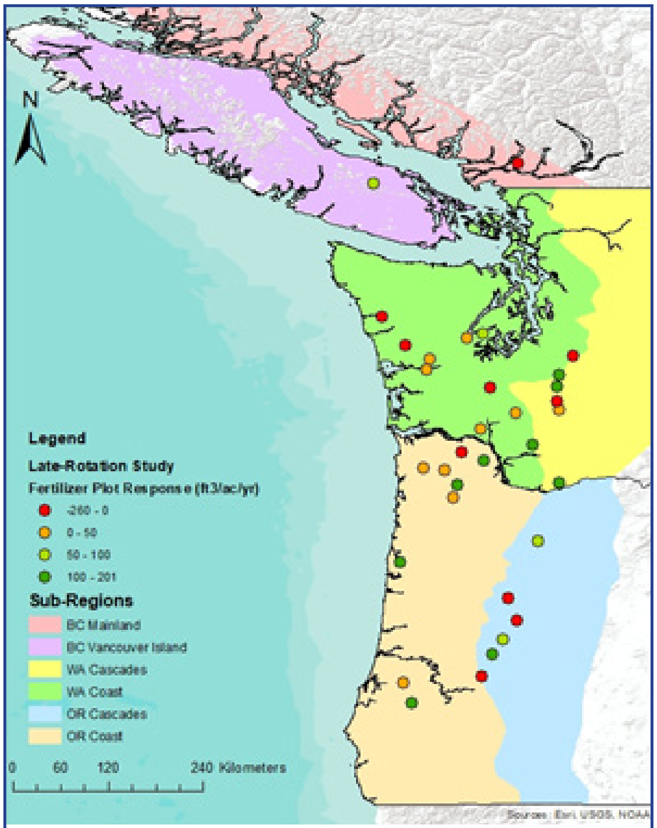
Stand and Tree Responses to Late-Rotation Fertilization

Eric Turnblom, Kim Littke, Jason Cross, Mason Patterson, and Rob Harrison (UW)

The study is designed to estimate a regional nitrogen fertilization response (RRE) for Douglas-fir on late-rotation stands from paired-plots in randomly located late-rotation stands within four distinct regions of Washington and Oregon and two regions in British Columbia. This study will provide a much-needed examination of the economics involved with late-rotation fertilization.

Year Four Progress

- Soils in the Pacific Northwest have responded the best to N fertilization
- Focusing fertilization on responding, late-rotation stands that are 8-10 years to harvest can decrease the risk and cost of fertilization
- 38 installations have been measured for two-year fertilizer response
- Greater volume response per tree on installations with low PRS NO3 adsorption (<50 mg)
- Response was greater in predicted response regions from the Paired-Tree study



Two-year plot response (ft^3/ac/year) in each ecoregion of the coastal Pacific Northwest.

Future Plans

- Continue measuring installations until harvest
- Analyze fertilizer response per tree and per plot over time
- Understand how tree nutrition affects response
- Determine average regional response to fertilization and economic returns
- Incorporate results into growth models

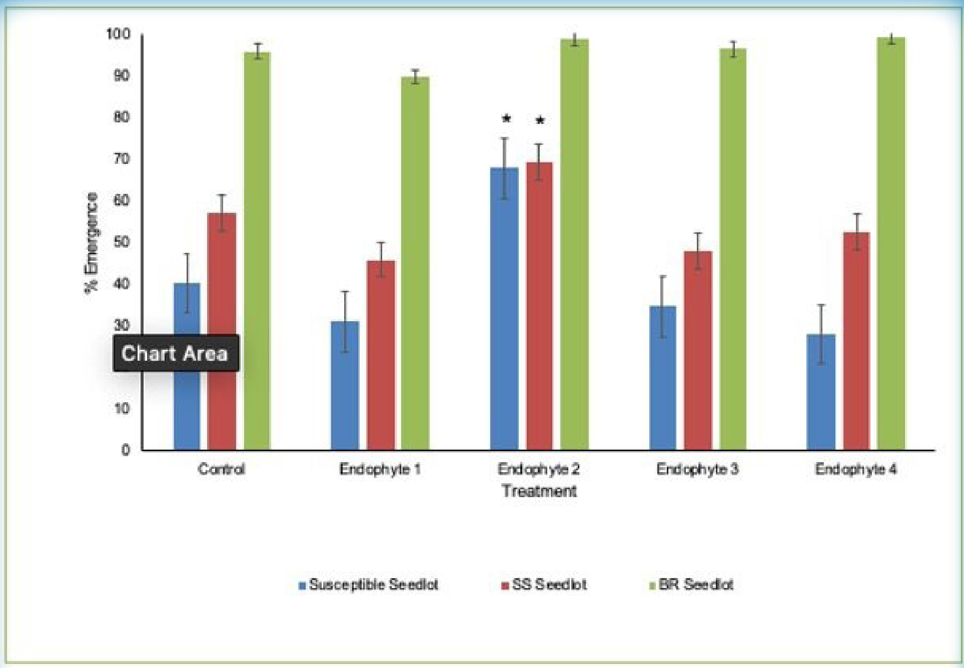
Improving White Pine Seedling Survival by Combining Blister Rust Resistance with Defense-Enhancing Endophytes

George Newcombe (UI), Marc L. Rust (UI), Mary Frances Mahalovich (USDA Forest Service), Greg Adams (J.D. Irving), David Miller (Carleton University), Mark Coleman (UI)

An investigation into whether endophytes with antagonistic properties to Western white pine seeds and seedlings could improve genetic resistance.

Year Four Progress

- Planted inoculated seedlings in nursery beds. Did not see expected disease symptoms and resistant responses. CDA Nursery re-inoculated with rust
- Continued to score seedlings for disease symptoms and resistant responses, begin preliminary analysis of needle spot symptoms
- Endophyte species: #1, #3 *Penicillium*; #2 *Streptomyces*; #4 *Bacillus*
- While the endophyte infection appeared to be low (10% for *X. ellisii* and 1% for *H. pinicola*), significantly higher percentages of seedling infection are usually seen over time as the trees grow larger.



* Indicates significance ($p < 0.05$)

Future Plans

- Final scoring of seedlings for disease symptoms and resistant responses, analyze data and write final reports and publications.
- Results from this ongoing study will provide information on how successfully western white pine seedlings can be colonized with six different endophytes and how the presence of those endophytes impacts resistance levels of both resistant and susceptible seedlings inoculated with WPBR in the nursery.

Analysis of Aboveground Nutrient Biomass on LTSP Sites Due to the Effects of Site, Harvest Removals, Weed Control, and Compaction

Kim Littke, Eric Turnblom, and Rob Harrison (UW)

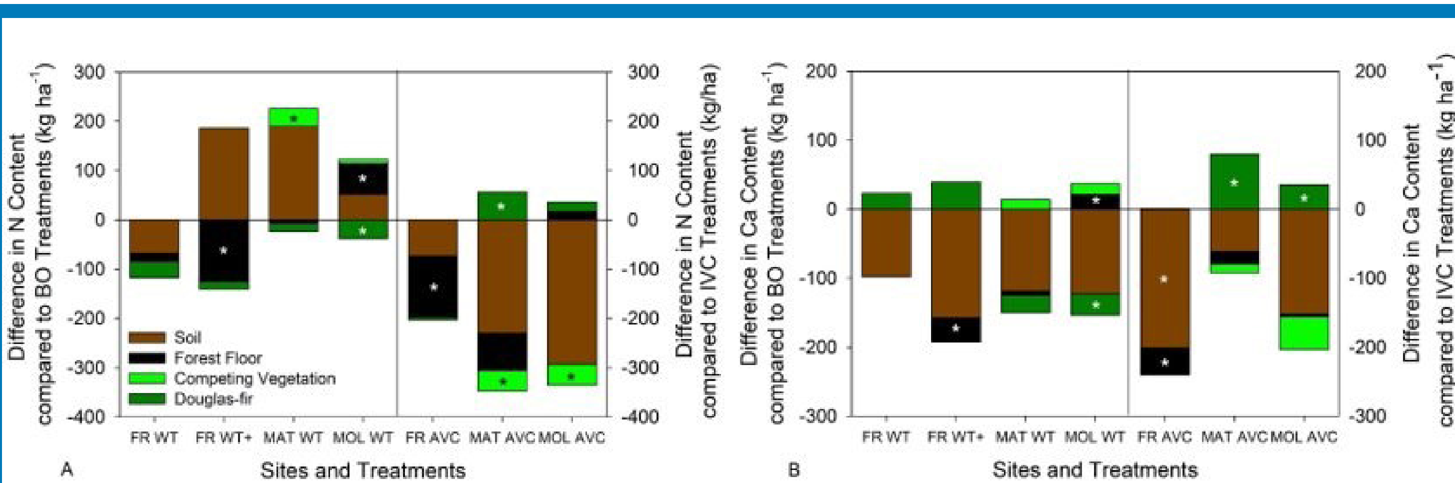
A long-term soil productivity study on the effects of intensive forest management on soil and site productivity to determine treatment effects on Douglas-fir biomass and aboveground and belowground nutrient pools.

Year Two Progress

- Recent soil sampling shows decreases in soil nutrients due to treatments (i.e., losses through leaching or removals and greater uptake by trees and understory)
- Whole tree removal resulted in lower Douglas-fir biomass at 15-20 years
- Annual vegetation control decreased soil, forest floor, competing vegetation, and total base cations
- Improved Douglas-fir biomass and nutrient contents account for losses

Future Plans

- Urea and lime fertilization to ameliorate losses from whole tree removal and vegetation control treatments
- Urea fertilization resulted in a large increase in nitrate through decreased soil pH and replaced Ca on the exchange sites
- Potential for increased leaching of Ca: Lime increased forest floor pH and forest floor and surface soil exchangeable Ca



Environmental Predictors of Form and Quality in Loblolly Pine

Cristian R. Montes, Joseph Dahlen and Bronson Bullock (UGA)

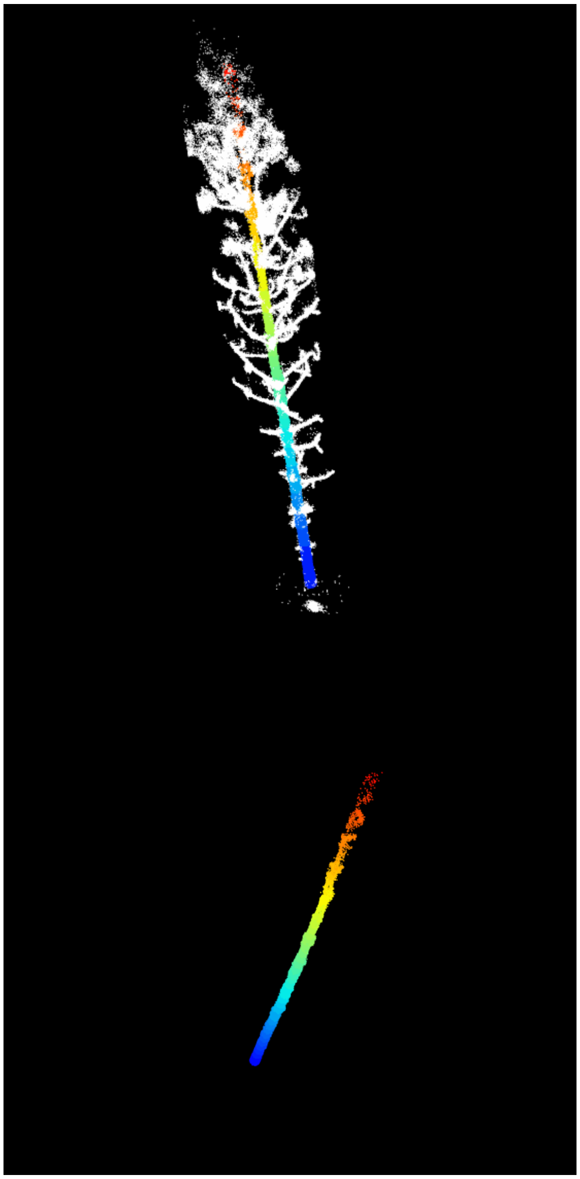
Goal is to develop a cost-effective methodology to assess stem quality using ground-based mobile LiDAR technology to reduce sampling cost while increasing the amount of information captured at the time of an inventory.

Year Two Progress

- Developed algorithm to isolate stems from branches
- Developed a method to straighten LiDAR data to avoid bias. The methodology maximizes the kernel density in the direction of the measurement
- Developed several methods to fit circle and ellipses to terrestrial mobile lidar values.
- Developed method to estimate height out of diameters measured along the height axis.
- Taper equations fitted locally; parameters interpolated as a function of environmental predictors.

Future Plans

- Pack algorithm for ground-based LiDAR into an R package.
- Test with other data (are phenotipic differences between genotypes?)



Graphic of algorithm used to isolate stems from branches.

Assessing & Mapping Regional Variation in Site Productivity

Rachel Cook (NCSU), Aaron Weiskittel (UM), Jeff Hatten (OSU), Cristian Montes (UGA), Mark Coleman (UI), Doug Jacobs (Purdue), Mark Kimsey (UI), Doug Maguire (OSU), Kim Littke (UW)

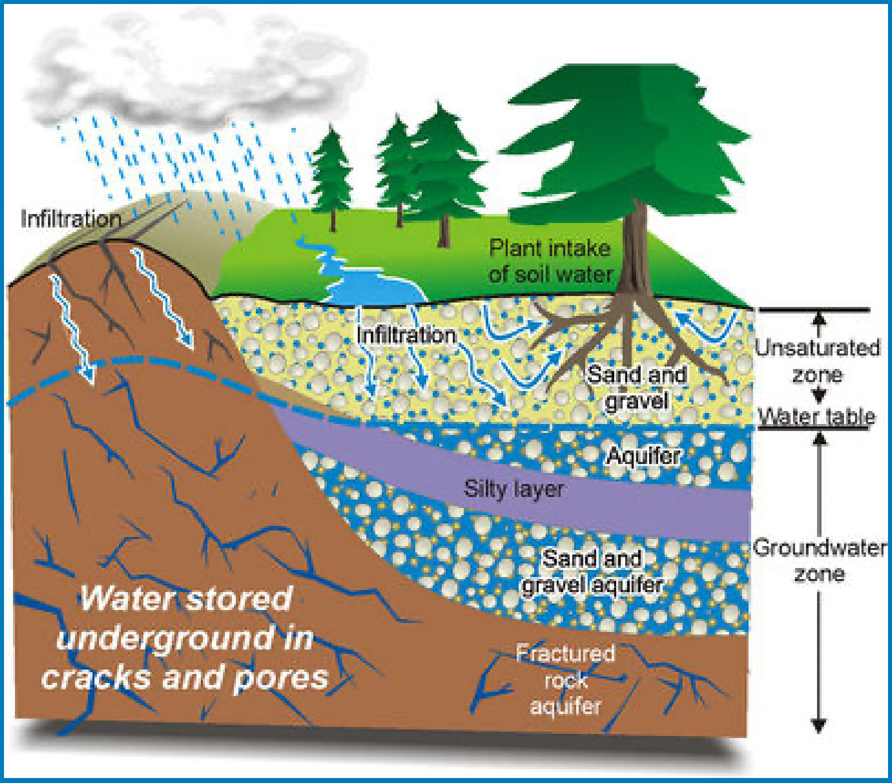
This project features cross-site collaboration and sharing of remotely sensed and empirical field data for spatial modeling of potential site productivity. Theobjective is to develop a consistent and biologically-meaningful metric of potential site productivity that can be related to a combination of environmental and edaphic factors and mapped across the various regions. Depth-to-water table has been linked to: Tree growth and height, Basal area, Foliar nitrogen, Needle length. Management factors that influence depth-to-water table: harvesting, bedding, thinning, prescribed fire.

Year One Progress

- Leveraging 40 years of data for ~14,000 sites and 19 million observations to assess depth-to-water table over time
- Data gathering and compilation and forest soil classification mapping have started
- Plans for data compilation, and preliminary derivation of several site productivity metrics have been outlined

Future Plans

- Develop base information as well as standardized methods to include environmental variables as predictors for stand productivity.
- Estimation of other ecological predictors.



Assessing & Mapping Regional Variation in Site Carrying Capacity Across the Primary Forest Types in the US

Mark Kimsey (UI), Aaron Weiskittel (UM), Eric Turnblom (UW), Cristian Montes (UGA), Rachel Cook (NCSU), Doug Maguire (OSU), and Mark Coleman (UI)

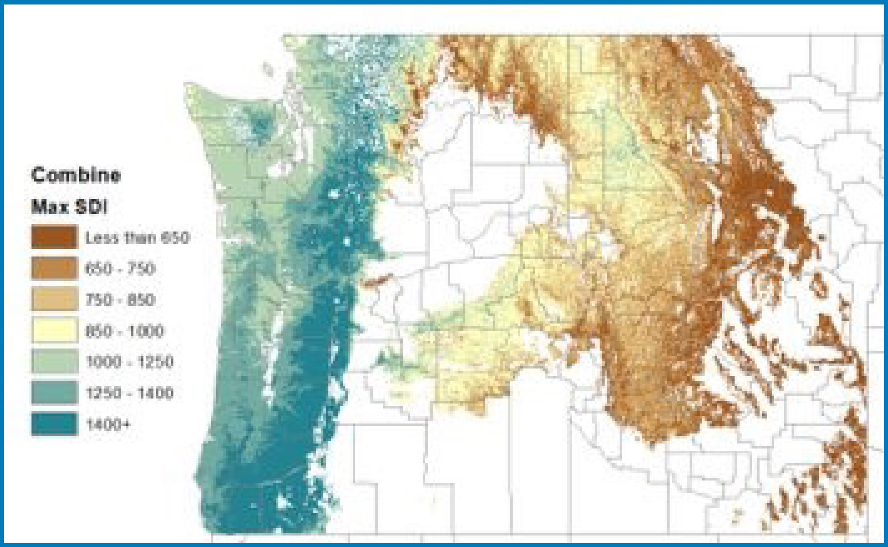
Maximum site carrying capacity determines the number of individuals of a certain size per unit of area that a defined stand can support and maintain. The objective of this research project is to 1) synthesize a nationwide forest measurements database from publicly available data and from CAFS members, 2) standardizing maximum carrying capacity modeling, and 3) provide regionally relevant, national forest carrying capacity models.

Year One Progress

- Data sharing agreements and transfer in place with CAFS members in the Southeast and Northeast regions
- Protocols and procedures developed for standardizing variable selection, extraction, storage and analysis
- Regional Northwest SDImax species models complete: Douglas-fir, western hemlock, ponderosa pine, grand fir, western larch and lodgepole pine

Future Plans

- Ongoing database recruitment and devlopment
- Regional SDImax species model rollout throught 2022 and 2023



Intraspecific Hydraulic Responses of Commercial Tree Seedlings to Nursery Drought Conditioning

Andrew Nelson (UI), Douglass Jacobs (Purdue), Carlos Gonzalez-Benecke (OSU)

Multi-institution project to examine drought-related physiological parameters (e.g., stem and root hydraulics, resistance to cavitation) and root morphological traits of various genotypes of western larch, black walnut, and coastal Douglas-fir from diverse maternal tree climates across each species' native range.

Year One Progress

- Project focuses on commercially important species Douglas-fir, western larch, and black walnut
- Measurements collected during seedling growth during nursery phase of the project
- Destructively sampled nursery seedlings measured in labs throughout the growth period and at the end of the nursery phase.

Future Plans

- Complete laboratory analysis and data synthesis of root hydraulics, stem microscopy, plant moisture stress, gas exchange, and biomass allocation
- Reciprocal drought treatments at Purdue University Controlled Environment Phenotyping Facility: Aboveground traits (height, width, color, and shape) with RGB cameras, hyperspectral imagery to link with nutrient content and stress reaction, X-ray CT root scanner non-destructively measures 3-D root system architecture
- Outplanting

➦Plant at reforestation/afforestation sites in respective regions

➦Raised beds for simulated drought experiments

Douglass-fir

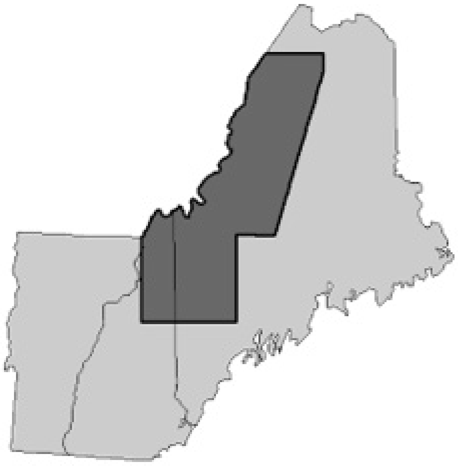
Black Walnut

Western larch

Multi-Regional Evaluation of New Machine Learning Algorithms for Mapping Tree Species Distribution and Abundance

Kasey Legaard (UM), Aaron Weiskittel (UM), Larry Whitsel (UM), Erin Simons_Legaard (UM)

For the past several decades, machine learning (ML) algorithms have been adopted and refined to improve forest map accuracy. However, several decades of data and algorithm development in satellite remote sensing have not yielded robust solutions for eliminating systematic map error. This research specifically targets this problem using a ML method that is capable of minimizing both total and systematic error in satellite-derived maps. This mapping approach combines the strength of Support Vector Machines (SVMs) to model complex, nonlinear relationships based on limited training data, a common condition in forestry applications, with the adaptability of a multi-objective Genetic Algorithm (GA).



Year One Progress

- Data acquisition and harmonization for 7 million acre Maine trial area
- Develop and validate maps of tree species relative abundance (% AGB) at 10 m pixel resolution
- Pool species predictions into canopy composition classes
- Develop and validate annual time series of forest disturbance

Future Plans

- Continued development of algorithms and code to construct and post-process composition data
- Wrap up primary software development
- Validation against FIA and CMS data
- AGB estimation based on automated machine learning methods, including LiDAR/Sentinel integration
- Multi-regional validation of composition, disturbance, AGB, and derivative products against FIA and CMS data
- High resolution land cover and forest type mapping for the state of Maine (1m and 10m) in collaboration with NOAA C-CAP

Using Hyperspectral Imaging to Evaluate Forest Health Risk

John Couture, Melba Crawford, Matthew Ginzel, Brady Hardiman, Douglass Jacobs (Purdue)
Aaron Weiskittel, Parinaz Rahimzadeh, Peter Nelson (UM)
Cristian Montes, Caterina Villari, Kamal Gandhi (UGA)

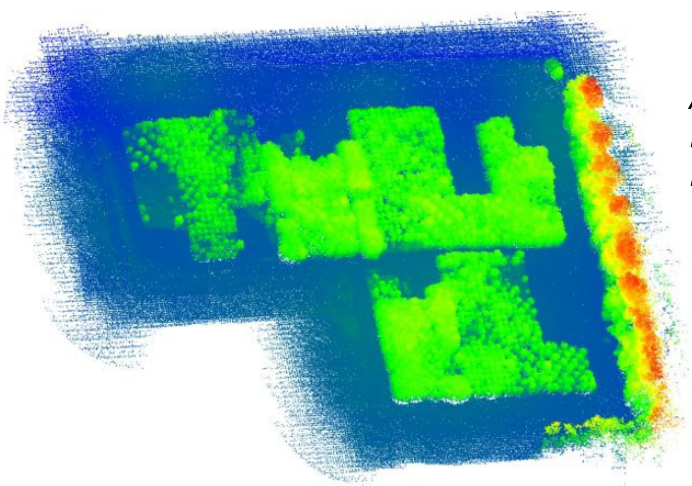
Forest systems face a diverse array of stressors of a scale and complexity previously unobserved. Incorporating digital approaches into forest monitoring and management has potential to mediate the negative impact of stressors on forests. Hyperspectral data is capable of rapidly generating tree biochemical and physiological status, especially in response to stress.

Year One Progress

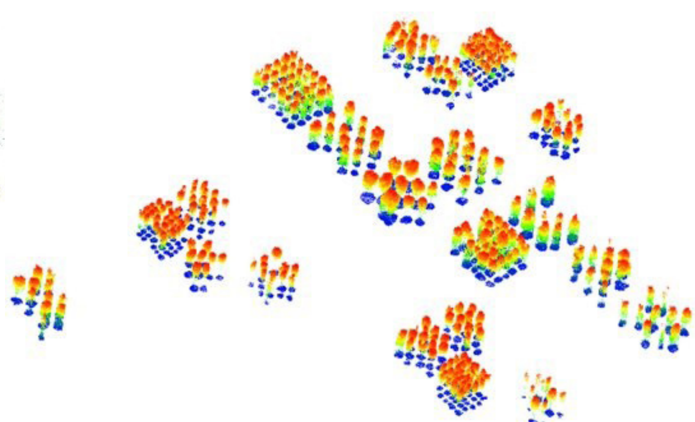
- Analyzed the ability of hyperspectral data to provide information related to tree status in response to abiotic and biotic stress
  ➦Test case: previsual disease detection in black walnut saplings and the influence of water stress on pathogen detection
- Assessed the reliability of hyperspectral information to scale from leaf, to tree, to stand, to landscape-level measurements
  ➦Test case: aerial detection of Chestnut blight in mixed species plantings

Future Plans

- Evaluate the validity of hyperspectral data to characterize stress responses over different spatial and temporal scales in different geographic locations



Aerial detection imagery of Chestnut blight using hyperspectral data--with individual tree extraction.



Resilience of Soil Organic Matter to Harvesting: A Global Study of Long-term Soil Productivity Experiments

Jeff Hatten (OSU), Stephanie Winters (OSU), Kim Littke (UW), Carlos Gonzalez (OSU), Doug Maguire (OSU), Aaron Weiskittel (UM)

Soil organic carbon (SOC) quantity and quality are linked to important soil functions including nutrient mineralization, aggregate stability, trafficability, and water retention and hydrologic processes. In turn, these soil functions are correlated with a wide range of ecosystem properties that are relevant to forest managers. This project will aim to elucidate the mechanisms that impart resilience to forest SOC after extreme disturbances across a wide range of soils and forest types.

Year One Progress

- Examination of the dynamics of soil carbon stabilization across archives of soils collected from widely applied long-term soil productivity experiments (LTSP) treatments (Currently – CA, ID, OR, NC, and New Zealand).
- Analyzed organic matter removal treatments over time

Future Plans

- Lab work and data analysis (biomarkers, 14C abundance, stable isotopes, etc.)
- Sample several sites for 3rd time points
- Determine the mechanisms that impart soil carbon resilience and resistance to change from forest harvesting.

Stand Response to Thinning: Enhancing Response Prediction through Modeling

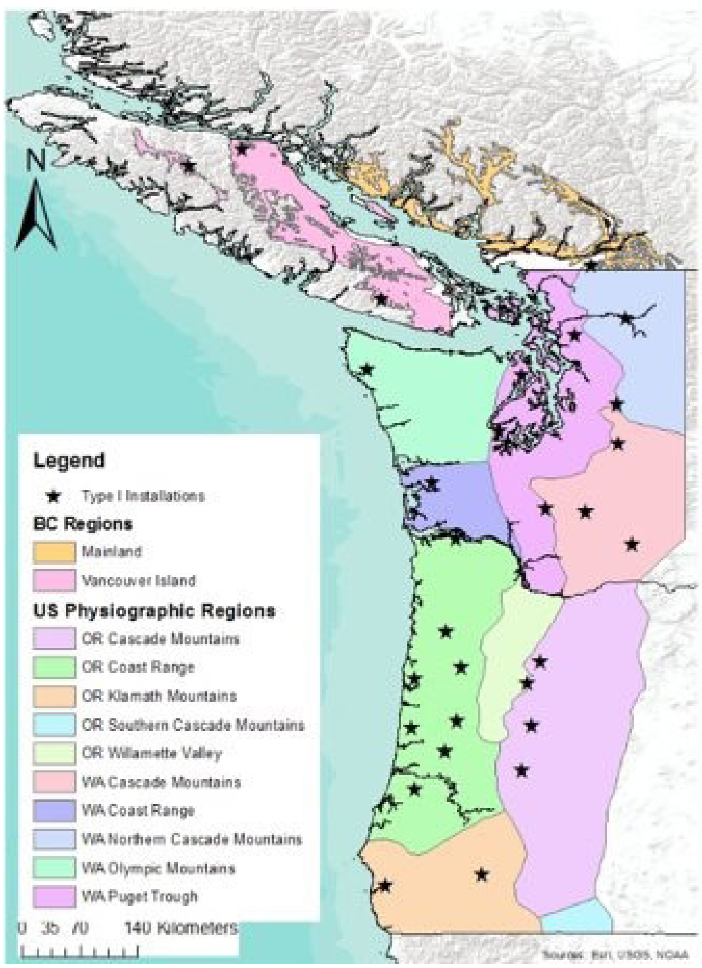
Eric C. Turnblom (UW), Jason C. Cross (UW), Aaron Weiskittel (UM),
Cristian Montes (UGA), Bronson Bullock (UGA)

Forecasting yield is a primary objective of forest managers, who often use more than one tool for making predictions; stand level models are used for longer-term planning, while individual level models are often used for closer-to-harvest forecasts when needed. With this project we propose to build on previous research in forming a predictive yield model, in which a set of stand attributes can be input to deliver yields of various volumetric units at future points in time as direct output.

Year One Progress

- Augment model to allow for silvicultural treatment variables (treatment type, treatment intensity/degree, time [years] since treatment)
- Refit the extant base stand yield model (untreated stands) within the SMC Plantation Yield Calculator (SMC-PYC) given another two full cycles of data collection

•Incorporate pre-commercial and commercial thinning effects using results of Bose et al. (2018) and Cross & Turnblom (2020)



Future Plans

•Further updates on PYC modeling

Version 2.0 : Baseline Equations

Version 2.1 : Version 2.0 + PCT effect

Version 2.2 : Version 2.1 + CT effect

•Benchmark Model with treatment augmentations (jackknifing, cross-validation)

•Expand efforts to other regions and develop data sharing plans

Data for the Pacific Northwest comes from 63 research sites consisting of 585 plots including no treatment controls, PCT only (varying timing and intensity), commercial thinning only (varying timing and intensity), and both combined, measured from two to nine times using a measurement interval of either two or four years.

Using Predictive Analytics to Decompose Site Index

Jason Cross and Eric Turnblum (UW)

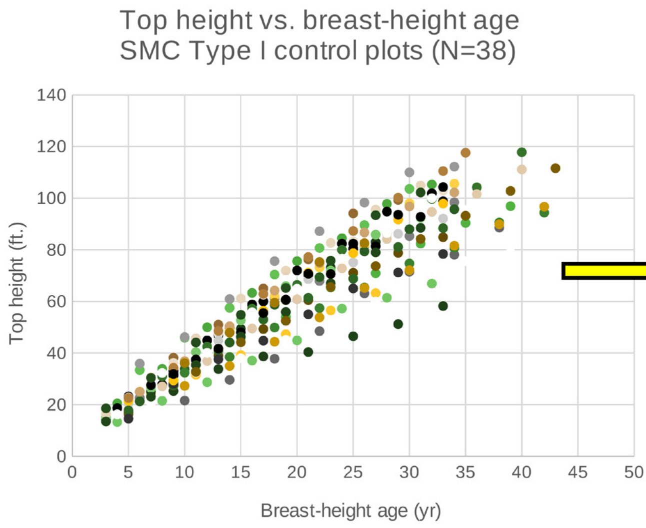
Site Index is an input in various growth and yield models, whose outputs support millions of dollars' worth of silvicultural decisions that include planting, pre-commercial thinning, and fertilization. Increased quantities of atmospheric carbon dioxide are contributing to changes in the observed ranges of factors once thought to be fixed when index values were conceived. Accounting for the effects of climate change requires investigation into the decomposition of site index into its additive subcomponents. The objective of this project is to verify and validate (elements of) growth & yield models, and improve their parameterization.

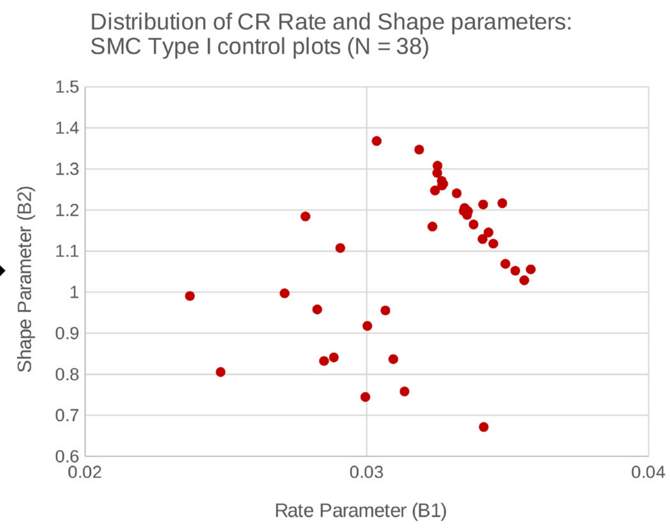
Year One Progress

- Parameter Prediction: Chapman-Richards, possibly modified-Weibull
- Gather base layers representing input variables (e.g. CAFS 19.75)
- Apply machine learning techniques to predict parameter values

Future Plans

- Build updated height / age curves for plot
- Prepare updated site index curve manuscript
- Assemble datasets base on bibliography results
- Prepare and analyze data





Physiologic Response to Commercial Fertilization Programs in Pacific Northwest Forest Plantations

Eric Turnblom (UW), Kim Littke (UW), Michael Premer (Rayonier)

Forest productivity is commonly limited by site nutrient availability, and deficiencies can result in extended rotations, forest health issues, and ultimately, unrealized volume gain. While fertilization is perhaps one of the most commonly applied silvicultural practices, little is known about the optimal timing and prioritization of lands for nutrient amendments. The goal of this project is to assess the role of silvicultural treatments on terrestrial C sequestration and commodity production across the Pacific Northwest Region of North America and synthesize these findings into management guidelines.

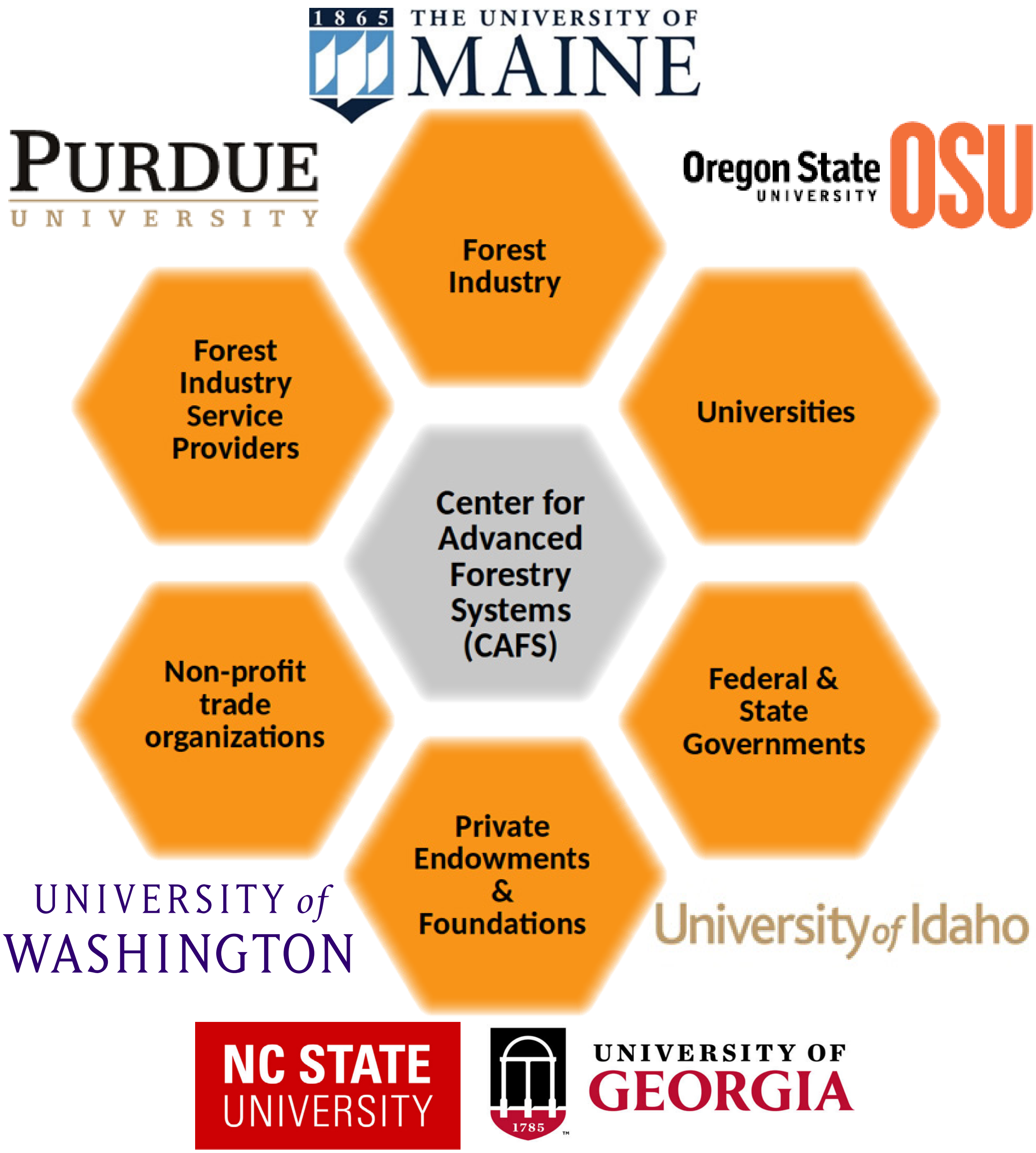
Year One Progress

- Sampled three Paired-Tree installations
- Cored up to twenty trees from each treatment (40 total per installation)
- Dried, mounted, and scanned all cores

Future Plans

- Sample remaining SMC Paired-tree installations
- Measure earlywood and latewood growth before and after fertilization on all trees
- Split cores into annual EW/LW 6 years following fertilization
- Composite by treatment and installation
- Isotopic composition ($\delta^{13}C$ and $\delta^{18}O$) will be analyzed at Northern Illinois University

CAFS Phase III projects address national and regional technological challenges with research questions aimed at specific multiple spatial and temporal scales, including molecular, cellular, individual-tree, stand, and ecosystem levels.



Report prepared by The University of Maine's
Center for Research on Sustainable Forests