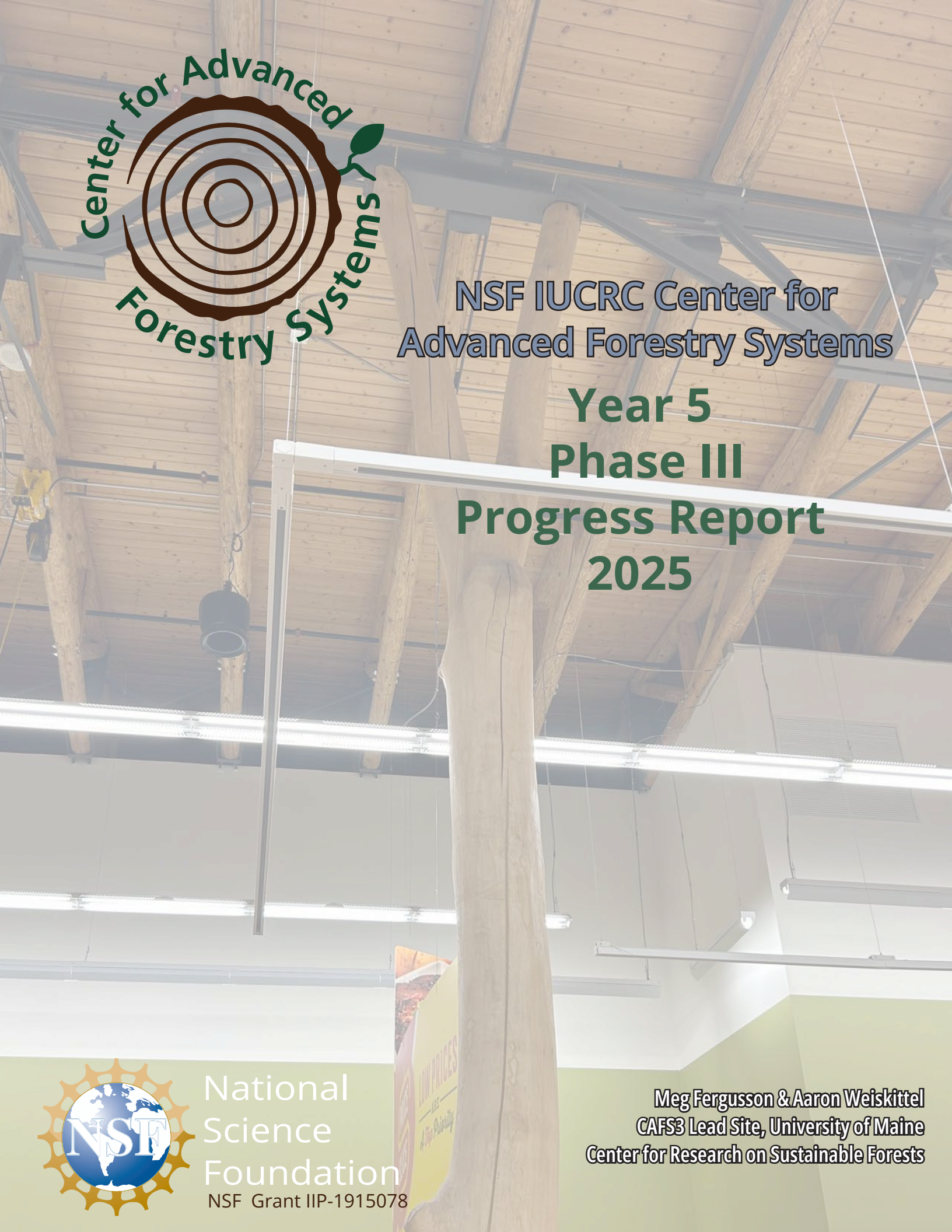


NSF IUCRC Center for Advanced Forestry Systems

Year 5 Phase III Progress Report 2025

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

National Science Foundation
NSF Grant IIP-1915078

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.

Center for Advanced Forestry Systems

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

1865 THE UNIVERSITY OF MAINE

Center for Research on Sustainable Forests

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

Director's Letter

As the Center for Advanced Forestry Systems (CAFS) concludes its fifth and final year of Phase III, its fifteenth year of existence, and effectively graduates from the National Science Foundation's Industry-University Cooperative Research Center (IUCRC) program, it is evident that this has been a period of remarkable growth and achievement. This report highlights the progress made in achieving CAFS's mission to optimize forest management systems through collaborative research with a diverse array of university, private, and public partners across the US. This past year has also been my sixth year as CAFS Director, and I would like to express my gratitude to the University of Maine and Center for Research Sustainable Forests' Meg Fergusson for their unwavering support since we became the CAFS Lead Site in 2018.

I strongly believe CAFS continues to demonstrate its value as a national organization by coordinating collaborative research activities across multiple sites. The program now encompasses 26 projects, nearly 70% of which are multi-site collaborations. This collaborative model accelerates research and development, helping the sector stay ahead in the highly competitive global market, and allows for the effective dissemination of technological advancements, enhancing the understanding and implementation of new technologies among industry members. In the past year, CAFS added four collaborative research projects that are jointly funded with the Partnership for Small Area Estimation (PSAE; https://www.ncasifoundation.org/projects/small-area-estimation-partnership/). I believe this synergistic funding approach is what will sustain CAFS into the future.

As always, CAFS remains dedicated to training future forestry leaders and innovators. Through its support of students, staff, and post-doctoral fellows, CAFS is helping to address the critical shortage of skilled professionals in the forestry sector. CAFS is also building a pipeline to two-year forestry programs at numerous sites through NSF's Skills Training in Advanced Research & Technology (START) program. Through numerous projects between two- and four-year universities, CAFS has increased engagement with numerous students that might lead to future undergraduate school studies or direct employment with CAFS industry members. Also, CAFS has provided direct, hands-on training of graduate students with involved Industry Advisory Board (IAB) members through NSF's Non-Academic Research Internships for Graduate Students (INTERN) Program. In short, our list of CAFS alumni is diverse and growing, which reflects our deep commitment to the sector.

In addition to research, CAFS is committed to translating research findings into practical applications for the sector. Going forward, CAFS wants to ensure that our research outcomes are effectively adopted by sector partners. As CAFS enters a new phase, our commitment to innovation and sustainability remains steadfast. The transition from NSF funding to a self-sustaining model presents both new opportunities and challenges. To ensure long-term viability, CAFS has developed a comprehensive business plan that includes strategies such as a tiered membership model, securing federal grants, and expanding research to include emerging technologies. These plans will ensure CAFS can maintain its position as the premier forestry research collaborative in the US, driving innovation in forest management, genetics, decision-support tools, and remote sensing applications, leading to the digital transformation of our sector.

Overall, the success of CAFS is a testament to the power of collaboration. We are grateful for the continued support of our members, partners, and collaborators. Together, we can continue to shape the future of forestry and ensure the continued health and productivity of our nation's forests for generations to come. I am excited to see where CAFS heads next with your support.

Aaron Weiskittel
Director, Center for Advanced Forestry Systems
Director, University of Maine Center for Research on Sustainable Forests

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 products from an increasing global population, rising living standards, greenhouse gas policies, bioenergy, and advances in green building technologies.

Meetings

Convening in Madison WI in June 2024, the CAFS IAB meeting with project updates that seek to optimize genetic and cultural management regimes to produce high-quality raw forest materials for new and existing products. Nearly 40 site directors, industry representatives, and researchers attended the IAB and field tour.

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.

Highlights

Key Considerations

- Final year of NSF support before officially graduating from the IUCRC program
- Member and researcher collaboration and engagement remain high
- Building options for long-term sustainability
- Ongoing incorporation of advanced & emerging technologies
- Synthesis of regional datasets
- Continued program support will need synergistic partnerships, improved coordination across the forest sector, increased investment in forests (R&D)
- Demonstrated the ability and importance of multi-site, cross-regional collaboration

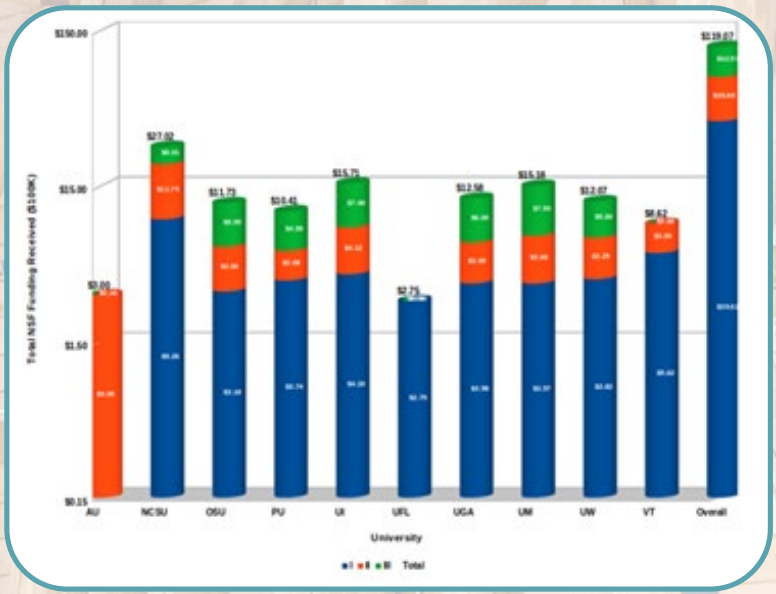
Meetings

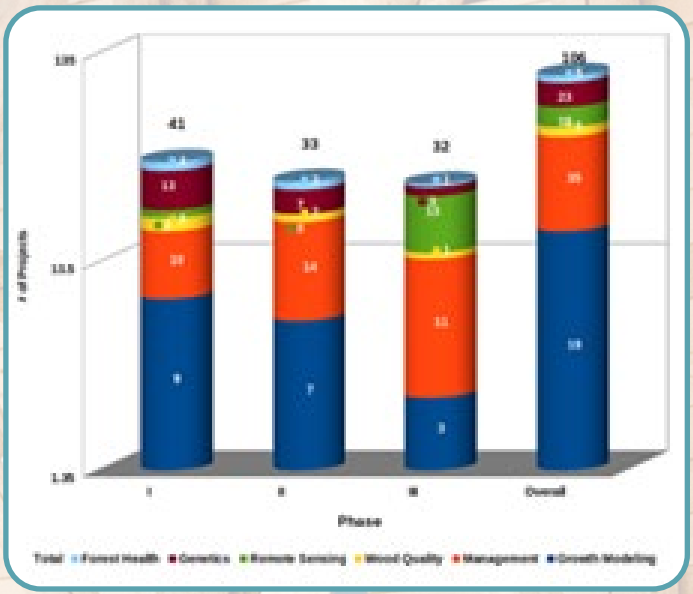
- In-person IAB held in Madison, WI in June 2024
  - This meeting concludes the NSF's Phase III for CAFS; CAFS research and organization will continue for one year on a no-cost extension
  - 38 industry members and researchers attended in person; an additional 24 joined remotely
  - Sites are still eligible for NSF supplemental funding opportunities (see INTERN and START projects in this report)
  - IAB meeting held in conjunction with the National Council for Air and Stream Improvement (NCASI) Biometrics Working Group
- Virtual IAB held October 2024; 64 industry members and researchers attended, including 2 former IAB Executive Committee chairs.
  - 95% of the surveyed CAFS IAB members were supportive of future sustainability as an IUCRC with current structure following graduation
  - 74% of the surveyed CAFS IAB members believed the CAFS technology roadmap reflected IAB needs very well, while nearly 90% thought it reflected IAB needs moderately well or better
  - 100% of the surveyed CAFS IAB members supported future more targeted and specific RFPs for the IUCRC

Field Tour

- WholeTrees CEO and co-founder Amelia Swan Baxter showcased round timber for a variety of custom-designed structural systems such as beams, columns and trusses with trees from sustainably managed forests
- Visit to the University of Wisconsin Arboretum for tree scanning and remote sensing overview by Dr. Phil Townsend

NSF Center Funding





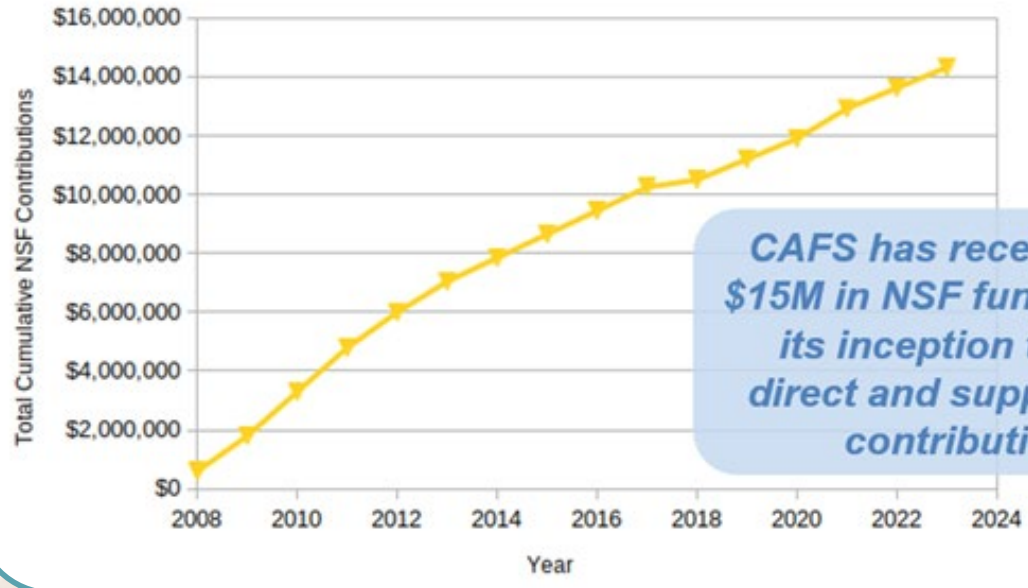
CAFS Research

NSF funding has benefited multiple CAFS-affiliated universities, forestry-related industries, and scientists

In Phase III, funding and membership remained stable, projects increased, and 70% of projects are multi-site

NSF Support

IUCRC



CAFS has received over $15M in NSF funding since its inception through direct and supplemental contributions.

NSF CAFS IUCRC: Then and NOW

We have a long history of a successful national public-private-academic partnership.

2007	2009	2010	2012	2017	2018	2019	Graduation Dec 2024
CAFS Started (Phase 1)	Additional CAFS Sites (Phase 1)	Additional CAFS Sites (Phase 1)	CAFS Phase 2 Begins	CAFS Phase 2 Ends	Change of Lead Site	CAFS Phase 3	

Forest Centric Research Relevancy Improvement Model

IUCRC

A national public-private-academic R&D consortium is needed, which CAFS fulfills.

Local & Regional

FOREST PRODUCTIVITY COOPERATIVE

Stand Management Cooperative

PMRC

Forest Industry

SUSTAINABLE & THRIVING FOREST-ECONOMY

National Applied Research

NCASI

Desired Outcomes

- Synergistic partnerships
- Leverage key resources and expertise
- Increased investment in forests including R&D
- More integrated and effective messaging
- Improved coordination across the sector
- Recognition of the broader importance of forests

Center for Advanced Forestry Systems

2024 CAFS Phase 3 Progress Report

From the NSF 2024 Annual Evaluation Report

CAFS Site Directors remain fully engaged and responsive to various requests. Faculty involvement at each of the CAFS Sites remains diverse and new projects are always been actively recruited given the evolving nature of faculty positions and IAB research priorities. Currently, CAFS has an active research portfolio of 27 IAB-approved projects with good representation across sites and faculty of varying career stages. During Phase 3, there has been active recruitment of faculty from underrepresented backgrounds, which has resulted in an increased representation of female faculty. This will continue to be a priority for CAFS going forward.

Both undergraduate and graduate students as well as post-doctoral researchers are actively involved with CAFS. The majority of IAB-approved research projects involve students and they are actively encouraged to present their research at all CAFS IAB events. In addition, many of the CAFS sites have actively pursued NSF supplemental funding opportunities like INTERN, REU, and START, which have strong student involvement and outcomes regularly presented to the IAB. Several highlights include Haley Anderson at the University of Idaho who completed a NSF INTERN and is now working to finish her MS. Two graduate students (Emily Von Blon and Stephanie Winters) at Oregon State University will finish their degrees at the end of this academic year in 2025.

There is high interaction and synergy across all CAFS participants, which primarily happens during our annual IAB meetings, particularly between CAFS researchers and IAB members. During these two-day events, informal social hours and banquets are used to ensure interaction. Each in-person IAB meeting includes a full-day field tour that also increases interaction between meeting participants. In between IAB meetings, regular communications from the CAFS lead sites and informal meetings are used to increase engagement.

The CAFS lead site maintains an active email contact list and sends regular CAFS updates. A key aspect of CAFS Phase 3 is recruiting new members and ensuring sustainability following successful graduation.

The CAFS research roadmap was developed at the start of Phase 3 and has been regularly presented to the IAB for input. Many of the current IAB-approved projects are working to address aspects of the research roadmap, while there are still some additional opportunities for future efforts. The roadmap identifies particular IAB members and areas where they could provide leadership or collaboration with key CAFS researchers. The roadmap identifies both key research priorities and needs that have been expressed by the IAB. This roadmap is annually updated and reviewed to ensure it reflects the current research gaps and voids. A key selection criteria for both proposal development and approval by the IAB that aligns with the research roadmap. One of the challenges with CAFS research is the length and complexity it takes for completion.

Project Highlights

Ongoing Projects

Lead Site	PI	Project/Title	Status 2024
UW	Turnblom et al.	16.69 Stand and tree responses to late rotation fertilization	Continuing
UI*	Kimsey et al.	19.75 Assessing & mapping regional variation in site carrying capacity across the primary forest types in the US	Continuing
NCSU/UGA*	Cook et al.	19.76 Assessing & mapping regional variation in site productivity across the primary forest types in the US	Continuing
UI*	Nelson/Jacobs/Gonzalez	20.78 Intraspecific hydraulic responses of commercial tree seedlings to nursery drought conditioning	Continuing
UM	Legaard/ Weiskittel	20.79 Multi-regional evaluation of new machine learning algorithms for mapping tree species distribution and abundance	Continuing
PU*	Couture/Jacobs	20.80 Using hyperspectral imaging to evaluate forest health risk	Continuing
OSU*	Hatten	20.81 Resilience of soil organic matter to harvesting: A global study of long-term soil productivity experiments	Continuing
UW*	Turnblom and Cross	20.82 Stand response to thinning: Enhancing response prediction through modeling	Ending
UW	Littke	20.84 Physiologic response to commercial fertilization programs in Pacific Northwest forest plantations	Continuing
OSU*	Gonzalez	21.85 Variation in productivity, wood quality and soil carbon of nine conifer species across a gradient in water deficit	Continuing
NCSU*	Trlica	21.87 Linking leaf area index and remote sensing across different forest types	Continuing
UGA*	Dahlen et al.	21.88 Quantifying silvicultural treatment effect on lumber quantity and quality in loblolly pine	Continuing
UGA	Dahlen et al.	21.89 Quantifying carbon sequestration as a function of silvicultural treatment in loblolly pine	Continuing
UM*	Weiskittel et al.	21.92 UMaine START: UM & UMaine at Fort Kent	Continuing
UM*	Little	22.96 UMaine START: UM & Monroe Community College	Ending
NCSU	Pala	22.98 CAFS Interactive Mapping Platform (CAFSIMP)	Continuing
UGA*	Bullock et al.	22.99 Effects of dominant tree height definition on loblolly pine growth & yield model outputs	Ending
UM*	Premer et al.	23.100 Use of carbon isotopes for assessing site-specific response to thinning	Continuing
UI	Kimsey et al.	23.101 Site-stand dynamics & pine beetle mortality in Ponderosa pine ecosystems	Continuing
UI	Nelson et al.	23.102 Enhancing resistance to fungal pathogens in commercial tree seedlings	Continuing
OSU*	Mainwaring	23.103 Determination of crown morphological traits using laser scanning in Douglas-fir and loblolly pine genetics trials	Continuing
OSU*	Hailemariam et al.	23.104 Interplay between sampling design and small area estimation to improve forestland inventory	Continuing
UI*	Poolakkal et al.	24.105 Robust small-area estimation strategies for developing accurate stand-level diameter distributions	New
UGA*	Yank et al.	24.106 Integrating SAE methods with stand-level forest inventory and growth projection for southern pine plantations	New
OSU*	Joo et al.	24.107 Using SAE and 3D-NAIP/Sentinel-derived variables for multivariate prediction of stand attributes	New
OSU*	Mainwaring	24.108 The effect of silvicultural treatment on Douglas-fir stem form	New
UGA	Bullock	24.109 Throughfall reduction impacts on loblolly pine plantations pre- and post-thinning	New

(*indicates multi-site projects)

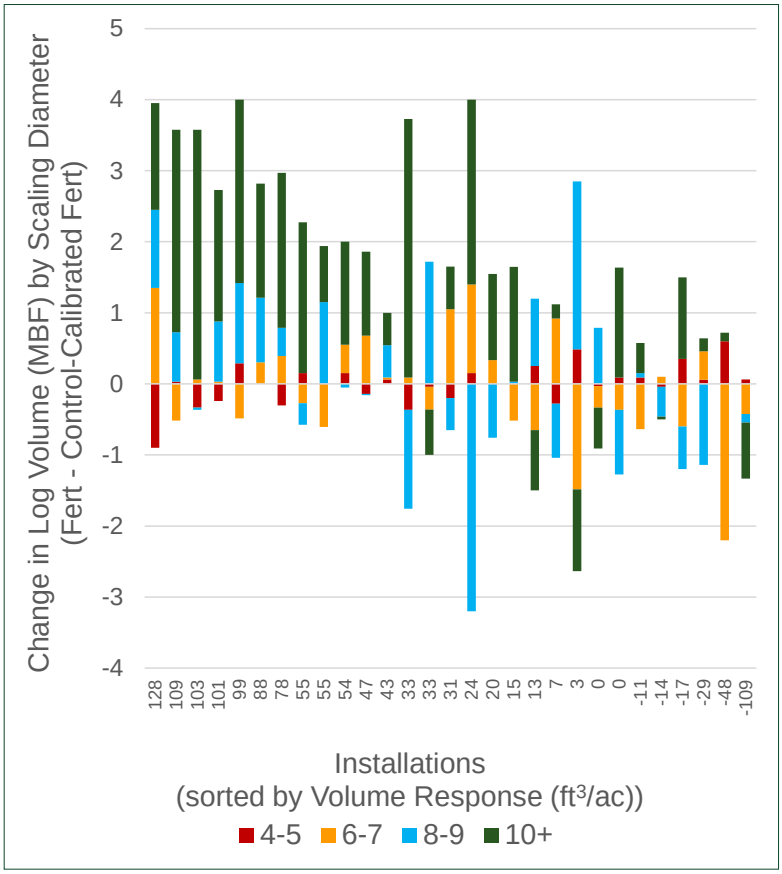
Stand and Tree Responses to Late-Rotation Fertilization

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. Plant root simulator (PRS) probes installed prior to installation; plots fertilized with urea at 200lb N/acre. This study examines the economics involved with late-rotation fertilization.

Annual Progress

- 34 installations measured for fertilizer response at 4 years; 29 measured at 6 years
- 4 replacement installations established Spring 2024
- Produced on-line Shiny map of regional fertilizer response
- Published article in Soil Science Society of America Journal
- PRS NO_3 is a better predictor of soil N availability, site productivity, and fertilizer response than other N variables



Future Plans

- Continue to measure 6- and 8-year fertilizer response
- Determine economic returns from fertilization at 8 years and at harvest
- Estimate change in life cycle of carbon products due to fertilization

Member Company Benefits

- Average area-based volume response in 6 distinct zones
- Online map to determine estimated fertilizer response
- Greater understanding of nutrient availability in predicting fertilizer response
- Examination into the economics of late-rotation fertilization

Project Highlights

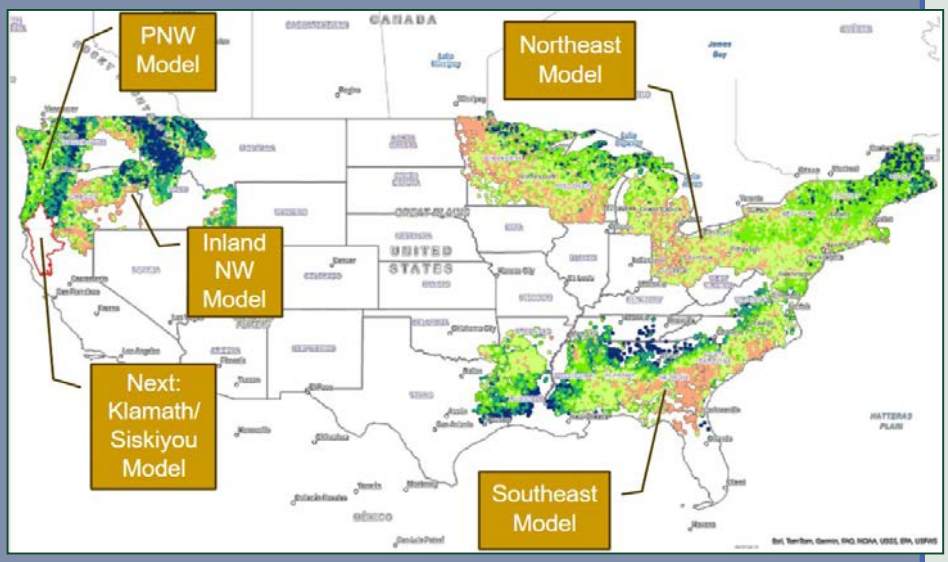
Assessing & Mapping Regional Variation in Site Carrying Capacity Across the Primary Forest Types in the US

Mark Kimsey (UI), Aaron Weiskittel (UM), Rachel Cook (NCSU), Cristian Montes (Rayonier), Doug Mainwaring (OSU), Eric Turnblom (UW)

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) standardize maximum carrying capacity modeling, and 3) create efficiencies for multiregional forest management organizations via species-site spatial models of SDImax for commercial species.

Annual Progress

- SDImax model: 13,461 plots/stands info post pre-processing and EDA
- Future SDImax under varying climate scenarios INW: at least 65% of the forest plots are expected to show a reduction of 5% or more in carrying capacity given GHG trajectories
- Northeast US modeling estimates of SDImax for species and forest types



Future Plans

- Finalize loblolly pine model with the most current FPC soils database
- Finalize northeast model; Re-run PNW model using standardized methods used for INW, SE, N; Create Klamath/Siskiyou model
- Develop projected climate SDImax models

Member Company Benefits

- Understand key drivers of forest carrying capacity across the US
- A GTR creating a pine management guide flexible to climate, species composition, site type, and method of measurement (LiDAR vs traditional stand exam)
- Consistent methodology/platform for identifying and managing forest density across multi-regional land holdings

Assessing & Mapping Regional Variation in Site Productivity

Rachel Cook (NCSU), Cristian Montes (Rayonier), Aaron Weiskittel (UM), Jeff Hatten (OSU), 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. The objective 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.

Annual Progress

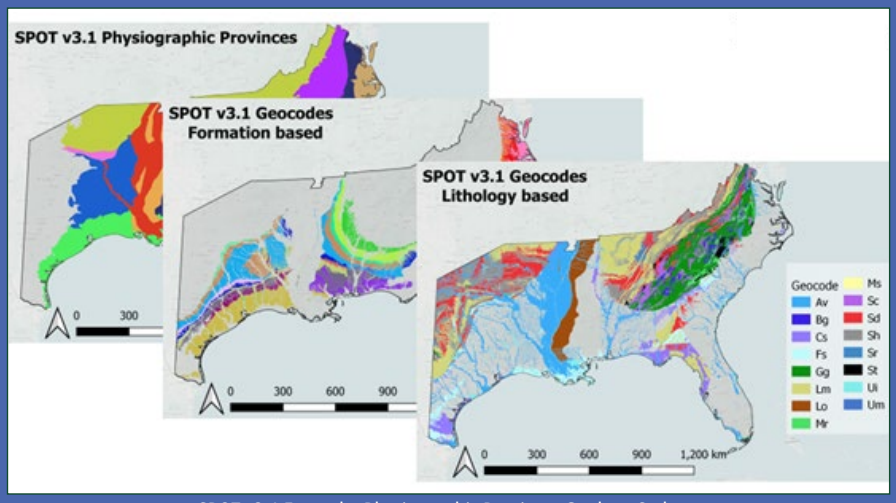
- Site Productivity Optimization of Trees: SPOT
- Collected USGS data across southeast US for large-scale site index mapping
- Developed web-based interface
- FPC has launched its v3.1 of the SPOT soil map for members
- SPOT v3.1 contains predicted SI for entire southeast US

Future Plans

- Look for "gaps" in actual v. potential productivity
- Incorporate satellite/drone LAI to refine predictions/productivity modeling
- Continent-scale C budget under varying scenarios

Member Company Benefits

- Improved metrics for assessing site productivity
- Simplified soil classification system for forest management
- Incorporate LAI to enhance predictive response
- Improve confidence of response and therefore return on investment



SPOT v3.1 Example: Physiographic Province, Geology Codes

Intraspecific Hydraulic Responses of Commercial Tree Seedlings to Nursery Drought Conditioning

Andrew Nelson (UI), Douglass Jacobs (Purdue), Carlos Gonzalez-Benecke (OSU), Andrei Toca (New Mexico University)

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.

Annual Progress

- In Year 4, the focus shifted to examining the effects of drought preconditioning on seedling performance under field conditions through our outplanting experiments
- Controlled environment and outplanting experiments suggest the presence of a drought memory in tree species that forms as a result of drought preconditioning
- These findings underscore the importance of drought memory for stress resistance in trees, influencing the capacity of forests to regenerate and respond to recurrent droughts and climate change
- The formation and expression of drought memory varied across species, highlighting the complexity of adaptive responses across different forest ecosystems

Future Plans

- Improve the method of measuring circle-fitting error for root diameter.
- Preparing manuscripts on simulated drought physiological response and outplanting performance.

Simulated outplanting controlled conditions: moisture, nutrient availability, temperature, & light

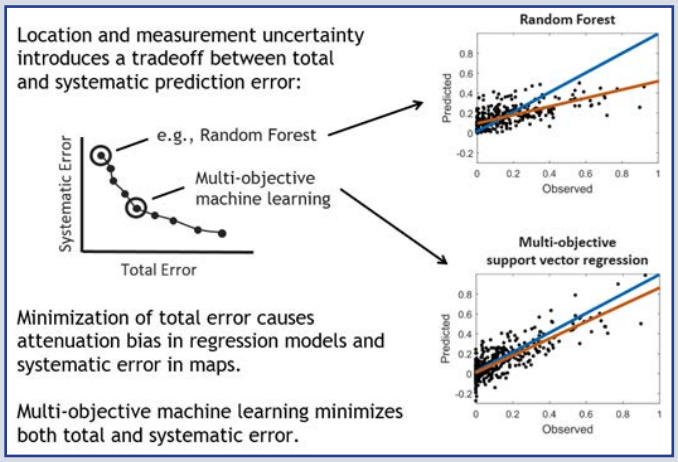
Member Company Benefits

- Species-specific drought conditioning protocols may help reduce reforestation costs associated with replanting failed plantations by tailoring phenotypes to match a broad range of site conditions across three major forestry regions of the US

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

Kasey Legaard, Aaron Weiskittel, Ken Bundy, Erin Simons-Legaard (UM)

This research specifically targets the problem of eliminating systematic map error 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).



Annual Progress

- Wrapping up statewide image processing (300+ Sentinel-2 images)
- Species and forest types mapped across northern Maine; just about ready to complete the remainder of the state
- Improved the effective resolution of species maps by modifying our production code
- Integrating newly developed forest maps with spruce budworm monitoring data to test for associations between forest conditions and population trend
- Developed and tested a prototype cloud-hosted geospatial database application to enable borderless, un-tiled raster data processing for large forest mapping project

Future Plans

- Completion of Maine state mapping projects over fall and winter
- Statewide seamless 1-meter DEM coverage to iron out some of the lingering issues with statewide NAIP processing.
- Use of 2021 and 2023/24 NAIP acquisitions for NAIP-based change mapping and updating of the 2021 Maine biomass and carbon maps
- Further evaluation of species maps and NAIP products against company data in Maine
- Species mapping trial in northern Idaho

Member Company Benefits

- Greater value from low-cost remote sensing and geospatial data
- Reduced time and cost for inventory and mapping

Using Hyperspectral Imaging to Evaluate Forest Health Risk

John Couture, Sylvia Park, Melba Crawford, Matthew Ginzel, Brady Hardiman, Douglass Jacobs (Purdue)
Aaron Weiskittel, Parinaz Rahimzadeh-Bajgiran, Peter Nelson (UM)
Cristian Montes (Rayonier), 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.

Annual Progress

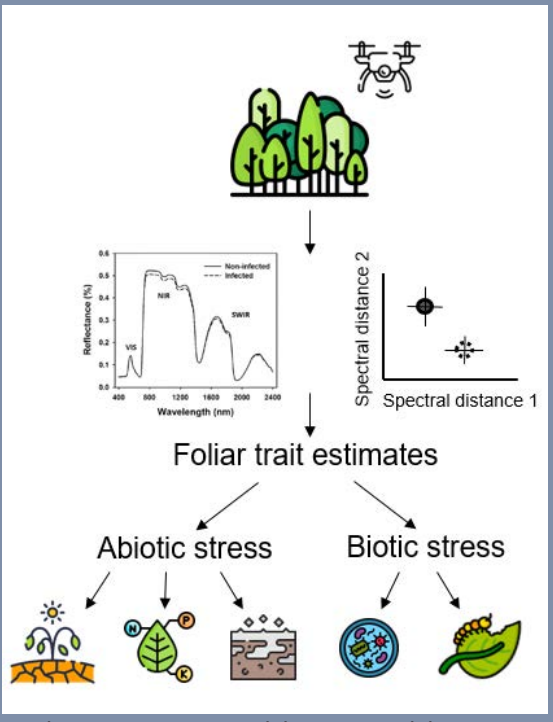
- Continued work on observed v. predicted trait responses to drought; trait responses to drought and nitrogen deficiency
- Leaf functional traits predicted from spectral data provide detailed information on shifts in tree health status.
- Using convolutional neural networks (CNN) for tree stress detection through anomalous spectral data and trait variation
- Spectral data separated from control and stressed trees, identifying anomalous data associated with stress, and spectrally-estimated trait data were able to identify individual stress conditions with high accuracy
- Individual traits important to classification were biologically related with tree stress conditions
- ✦ Paper on spectral wavelength range influences by Park et al. in revision

Future Plans

- ✦ Integrate multiple layers of stress-specific information using leaf trait predictions and hyperspectral phenotyping for stress-specific decision tree algorithms
- ✦ Framework for tiered forest health monitoring

Member Company Benefits

- ✦ National-scale project that will generate outcomes that can directly inform potential management decisions involving forest plantation management through more efficient and specific characterization of tree health using RS data



Predicting tree stresses with hyperspectral data

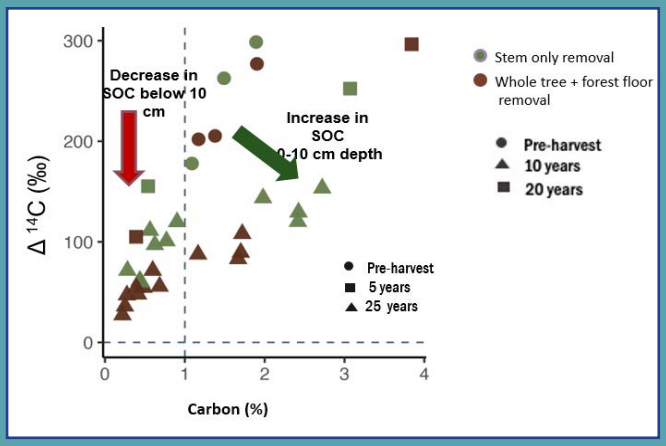
Resilience of Soil Organic Matter to Harvesting: A Global Study of Long-term Soil Productivity Experiments

Jeff Hatten (OSU), Stephanie Winters (OSU), Kim Littke (UW)

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. 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. The project will utilize three decades of archived and new data and samples from North American and New Zealand forest biomass harvesting studies in conjunction with detailed characterization of the mineralogy, soil carbon stabilization mechanisms, radiocarbon age, and biomarkers to elucidate mechanisms in soil carbon dynamics in disturbed and recovering systems.

Annual Progress

- The 0-10 cm SOC is mostly free light fraction and biomarkers indicate carbon here is of degrading angiosperm lignin
- Tarawera's (NZ) soil carbon is vulnerable to loss after a disturbance; there is a decrease in SOC and radiocarbon abundance in both treatments through time
- Soil carbon resilience is being derived from retained harvest residues and competing vegetation
- Retaining surface residues maintains labile carbon pools in the mineral soil



Future Plans

- Data analysis
- Manuscript preparation
- PhD defense

Member Company Benefits

- Enhanced understanding of SOC dynamics by providing data on how SOC responds to forest management practices across diverse forest types and soil conditions
- Evidence-based management practices for SOC conservation and management by identifying the mechanisms of SOC resistance and resilience
- Directly inform efforts to increase carbon sequestration in forest soils across the United States

Stand Response to Thinning: Enhancing Response Prediction through Modeling

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

FINAL REPORT

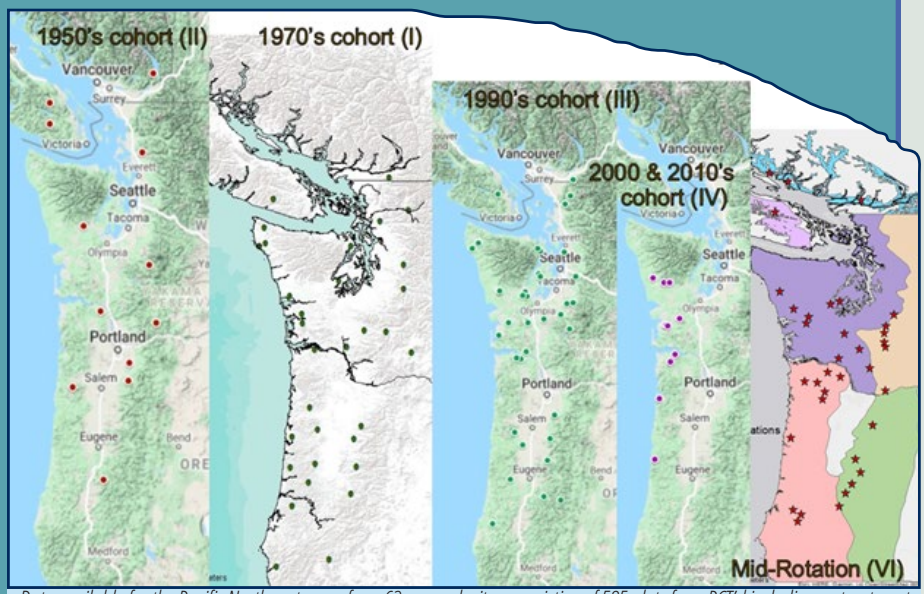
Forecasting yield is a primary objective of forest managers, who often use more than one tool for making predictions; stand level models are used for longer-term planning, while individual level models are often used for closer-to-harvest forecasts when needed. With this project we propose to build on 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.

Major Findings

- The PCT database was folded into the complete, well formatted PYC database
- Fixing the Chapman-Richards asymptote parameter to scientifically supportable values is much better than trying to fit them
- Refined planting density estimates (survival @ 3y) remains a key to differentiating between treatment yields
- Independent data set has been identified for benchmarking
- Updated model fitting process underway to incorporate climate effects
- Survival model for young Douglas-fir, western hemlock, and mixed stands in PNW region completed

Member Company Benefits

- Standardized framework for stand modeling
- Opportunity for further cross-regional collaboration
- Improved financial analyses and comparisons of silvicultural treatments (PCT, CT, FERT)
- Working Paper to be delivered to SMC membership detailing data, methods, and results



Data available for the Pacific Northwest come from 63 research sites, consisting of 585 plots from PCT'd 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. These data were augmented by in 2022 by RFNRP 207 plots consisting of spacing trials and both non-thinned and thinned regimes.

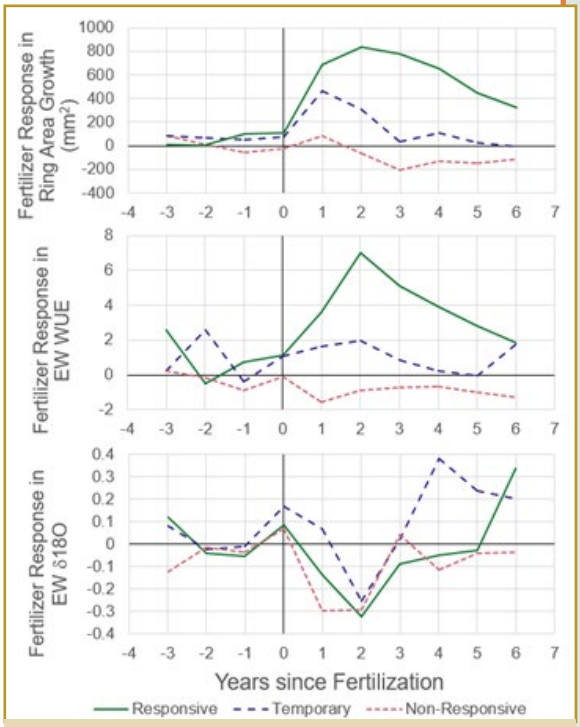
Physiologic Response to Commercial Fertilization Programs in Pacific Northwest Forest Plantations

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

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.

Annual Progress

- Dated and measured earlywood and latewood from 894 trees
- Up to 10 pairs per site split into earlywood/latewood 4 years prior to and 6 years post fertilization
- Examined differences between responding (4+ years), temporary response (0-2 years), and non-responding Douglas-fir installations
- Findings: hotter, drier climates increased water use efficiency (WUE), lower stomatal conductance
- Findings: colder, wetter June climates increased ring width index of control plots; less increase in RWI due to cooler, wetter climates in responsive installations



Responsive sites grew more ring area, responsive sites increased earlywood WUE over non-responsive sites, and there were few differences in δ18O between response types.

Future Plans

- Develop a model that predicts changes in ring growth according to climate and fertilization
- Propose silvicultural guidelines according to current and future climates
- Study design that can be applied to national forests

Member Company Benefits

- Recommendations for silviculture under future climate scenarios.
- Improved silvicultural recommendations for Douglas-fir plantations based on physiologic response

Variation in Productivity, Wood Quality and Soil Carbon of Nine Conifer Species Across a Gradient in Water Deficit

Carlos Gonzalez (OSU), Kim Littke (UW), Jeff Hatten (OSU), Doug Mainwaring (OSU), Maxwell Wightman (OSU), Aaron Weiskittel (UM), Emily Von Blon (OSU)

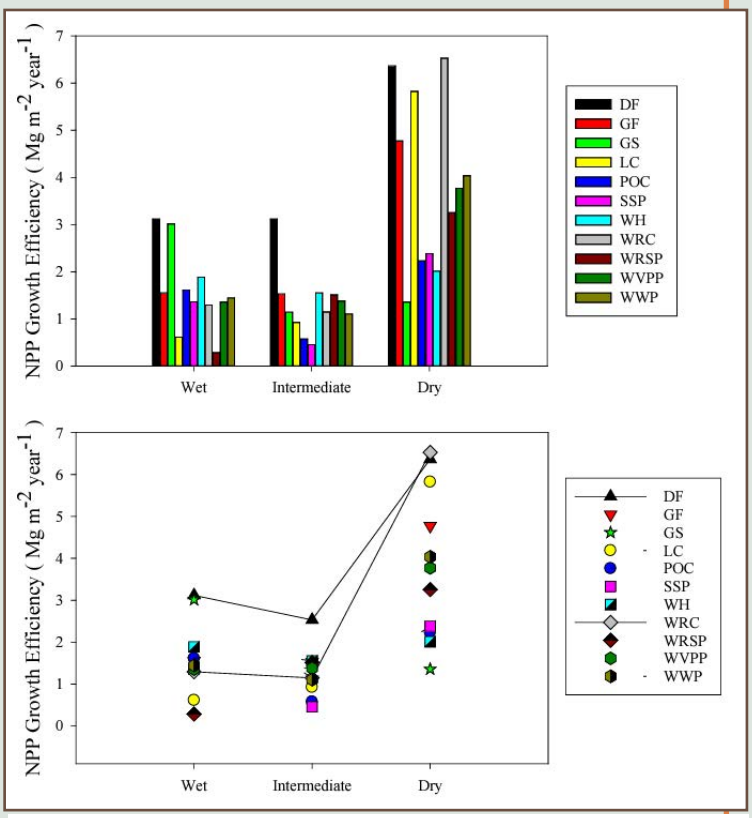
Climate change is expected to increase average temperatures and shift precipitation regimes, contributing to more severe and widespread disturbances. Higher evapotranspiration demands and the potential increase in water deficit can be detrimental to the growth and survival of tree species in the PNW. Understanding how commercially and ecologically valuable species are sensitive to climate can help to guide species selection and management decisions to enhance stand resistance and resilience to projected climate changes.

Annual Progress

- Soil samples from Dry site (soil samplers undergoing repair); extended from 1 to 3 samples per depth per plot
- Measure understory vegetation cover of UP plots
- Measure LAI
- Climate-growth relationships updated

Future Plans

- Ring-specific density
- Intrinsic water use efficiency during particularly droughty and wet years
- Calibrate 3-PG forest growth model from study data
- Evaluate climate change effects on growth of all species
- Manuscripts for publication



2024 Overstory growth efficiency.

Member Company Benefits

- Forest growth models to predict forest response to climate change and carbon sequestration potential
- Where proactive management is required across species ranges and prioritize the management of potentially vulnerable forests under climate change
- Where species are predicted to expand their range and inform assisted migration efforts

Leaf Area Index Estimates to Inform Midrotation Treatments

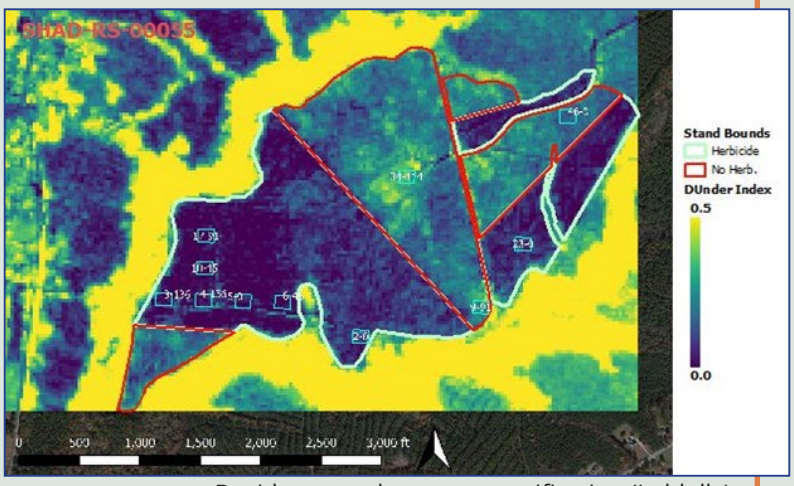
Modified from "A Neural Network Approach to Generating Leaf Area Index Estimates Using the Sentinel-2 Satellite Record"

Rachel L. Cook (NCSU), Andrew Trlica (NCSU), Aaron Weiskittel (UM), Mark Kimsey (UI), Alicia Peduzzi (UGA)

This project seeks to expand the capability and accessibility of our ongoing modeling work in predicting timber plantation canopy leaf-area index (LAI) using freely available global-coverage satellite data. The project will use the LAI model to develop potential productivity and response maps in conjunction with soils and climate data; apply LAI tools to midrotation silvicultural decisions; assess operational level response to herbicide and/or variable rate fertilization; use canopy LAI to make Fertilizer Rate decisions (vs Random rate); assess response in canopy LAI due to changes in understory LAI; and use repeat LiDAR flights (and ground truth data) to assess individual tree height and volume response to treatments.

Annual Progress

- LAI and deciduous understory model improvements
- Field data collection: field measurements (diameter, height, hight to live crown, and understory metrics) completed
- Helicopter and aerial LiDAR acquisitions



Deciduous understory quantification (Loblolly), imagery based in EE like LAI

Future Plans

- Continue to collect data at field sites in NC (2 yr post-treatment and TX (3 yr post-treatment)
- Full analysis of field and RS data
- LAI and Deciduous Understory model improvements
- Integrate with soils and Site Index modeling

Member Company Benefits

- Accessibility to LAI canopy layers
- Operational scale results from mid-rotation fertilization vs herbicide across soils and geology
- Ability to assess return on investment for rates of fertilization and/or herbicide
- Determination of when/where LAI-based, variable rate fertilizer application can be beneficial

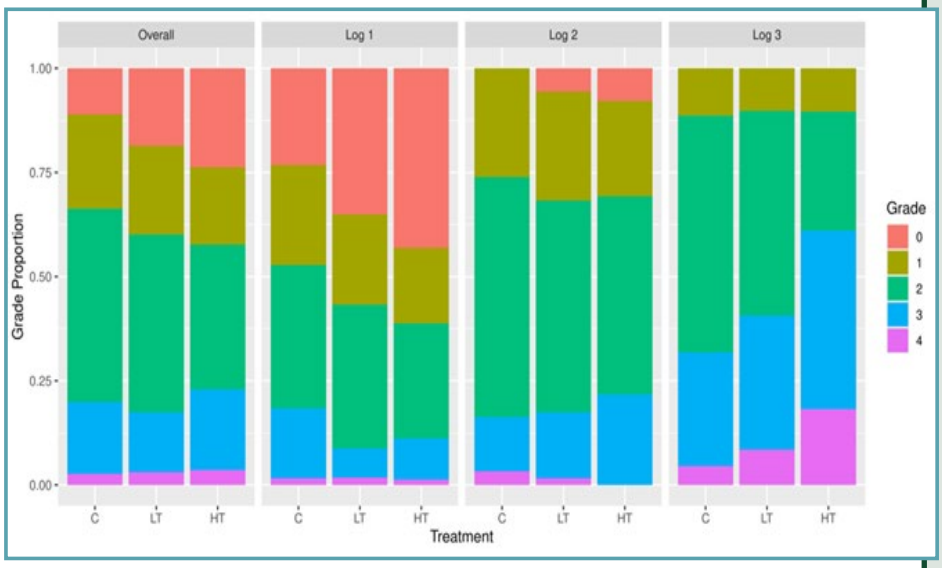
Quantifying Silvicultural Treatment Effect on Lumber Quantity and Quality in Loblolly Pine

Joe Dahlen, Anjila Lamichhane, & Bronson Bullock (UGA),
Corey Green (VT), Tom Eberhardt (USFS), Cristian Montes (Rayonier)

Even though over 18 billion board feet of southern pine lumber are produced each year from the U.S. south, information on silvicultural treatment impacts on lumber quantity and lumber is very limited. This is because forest through mill studies are difficult to conduct and thus rarely done. This study will investigate the impact of silvicultural treatment on the lumber quantity and quality from loblolly pine from the Forest Modeling Research Cooperative's Regionwide Intensively Managed (IMP) study.

Annual Progress

- 3 treatments: control, light thinning, heavy thinning with pruning in butt log; treatments applied when trees reach 40-46 ft
- 105 total trees, 35 treated (5 stands, 7 trees/plot)
- Destructive (via ASTM standards) and non-destructive testing: acoustic velocity, lumber imaging for knots (>88,000 images with 4 sides of each piece)



Future Plans

- Knot isolation and modeling
- Ring-by-ring specific gravity, ultrasonic velocity, extractives

Member Company Benefits

- Lumber quality and quantity information as a result of silviculture from a designed experiment
- Evaluation on the impacts of thinning regimes relative to no thinning

Quantifying Carbon Sequestration as a Function of Silvicultural Treatment in Loblolly Pine

Joe Dahlen, Tilak Neupane, Sameen Raut, Sameen Raut, Nawa Raj Pokhrel, & Dan Markewitz (UGA), Tom Eberhardt (USFS), Cristian Montes (Rayonier)

There is a growing interest in quantifying carbon sequestered from managed forests. Information is available on silvicultural treatment effects on stem volume for loblolly pine, however information is limited on the carbon sequestered as a function of silvicultural treatment. Trees from the Intensively Managed Plantation thinning trial will be sampled from 5 of the study sites. The stem volume will be measured, and disks collected at multiple height levels. The amount of carbon sequestered from each tree will be measured annually from the disks such that the total carbon found in the main bole can be quantified annually. The data from the individual trees will be scaled to the plot level.

Annual Progress

- Carbon averaged 46.8% on extractive free wood samples ; carbon averaged 71.6% on wood extractives
- Thousands of samples scanned
- Extractives model for loblolly pine: negative extractives predicted

Carbon in Wood+Extractives

Carbon	N	Mean (%)	SD	Min	Q1 (%)	Median (%)	Q3 (%)	Max
Measured	50	49.3	3.1	45.9	47.1	48.2	50.8	59.3
Predicted	546	47.8	1.4	46.7	47	47.3	48	57.5

Predicted Carbon from, 1) average wood carbon (46.8%)
2) Predicted NIR extractives via model (R^2 = 0.94)
Average carbon of extractives (71.6%)

- Extractives model with light gradient boosting machine: no negative predictions
- Lignin, cellulose, and carbon content: samples ground, lignin via CASA method, cellulose via Diglyme method + bleaching, carbon via CHNS analyzer (50 samples)

Future Plans

- Complete lignin measurements and cellulose measurements
- Expand chemistry measurements to include new stands
- Fit LGBM NIR models
- Predict ring level values and build models

Member Company Benefits

- Information on carbon stored as a function of silvicultural treatment in loblolly pine.
- Provide preliminary results on the use of a rapid field tool to estimate carbon stored at a stand level when combined with biometric information.

Project Highlights

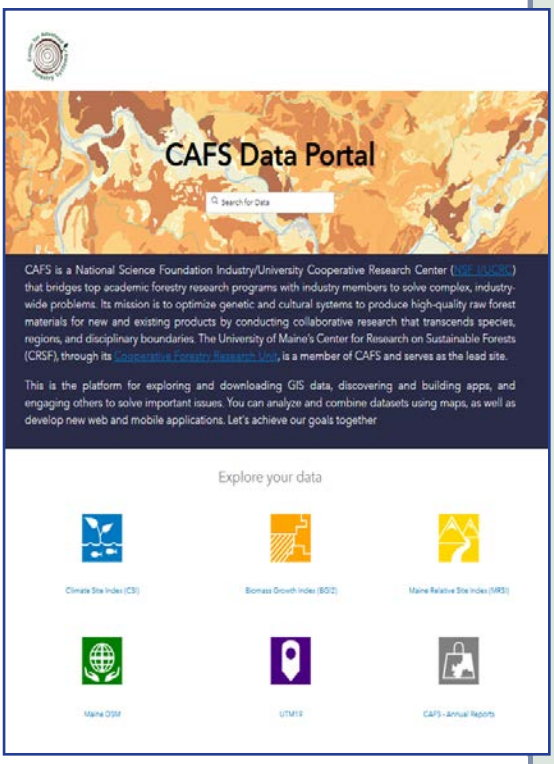
Center for Advanced Forestry Systems Interactive Mapping Platform (CAFS IMP)

Okan Pala and Adem Kurtipek (NCSU)

Our goal is to create a user-friendly internet mapping platform (CASF IMP). The interactive mapping platform will be used to visualize the data extent, location, format as well as data custodian's information for further communication. We are using ArcGIS Online (AGOL) platform for data sharing and collaboration. Through this platform, site coordinators and technicians can have direct access to their data through a password-controlled environment managed by AGOL. They will be able to access, visualize, download, and upload data. Moreover, the users will be able to update their data on the fly without having to download and upload the layers.

Annual Progress

- Discovery, implementation, and evaluation phases complete
- Training/Transfer phase ongoing
- Multiple raster and vector layers
- Technology choices: Experience Builder, WebApp Builder, Portal Front-end, ArcGIS



Data portal accessible to CAFS membership

Future Plans

- Explore more possible use cases
- Increased participation (more data sharing & portal usage)
- Implement new features on the WebApp (raster analysis, direct data export, additional functionality based on need)
- Implement secure folder sharing from the portal with industry partners
- Secure additional funding

Member Company Benefits

- CAFS IMP can be used to communicate and visualize the site data, increase collaboration among CAFS sites, and provide ease for data finding and updating, resulting in time and cost savings for member organizations

The Effects of Dominant Tree Height Definition on Loblolly Pine Growth and Yield Model Outputs in the Southeast U.S.

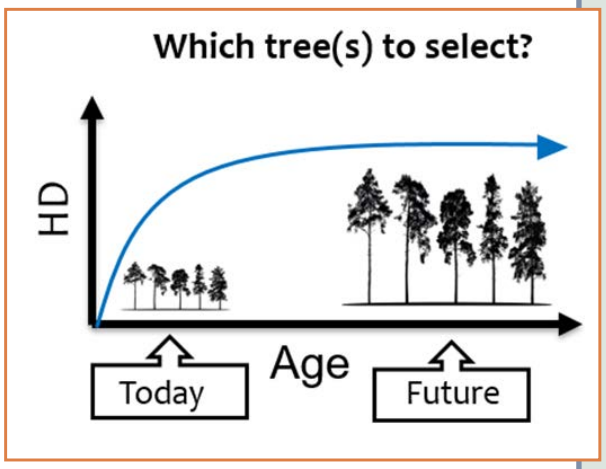
Bronson Bullock, Caddis Fulford, Cristian Montes (UGA), Rachel Cook (NSCU), Temesgen Hailemariam (OSU), Eric Turnblom (UW), Aaron Weiskittel (UMaine)

FINAL REPORT

The project examined the implications derived from different dominant tree height definition usages on growth and yield models; 19 definitions were evaluated. Statistical significances between different dominant height definitions and silvicultural treatments (e.g., thinning), stand conditions (e.g., density), and physiographic regions were highlighted.

Major Findings & Outputs

- Significant differences in Avg. Dom HT estimations and distributions and 'site index' on growth & yield model outputs
- Relational pattern between Avg. Dom HT and silvicultural treatment varied based on definition usage
- Ten-year projections (15-25 years) avg. differences in growth functions
- No significant differences in PMRC 1996 growth & yield system's performance



- Economic rotation age extended or reduced by a maximum one year based on definition usage
- Graduate student thesis; preparing peer-reviewed paper

Future Plans

- Whole-stand model v. individual-tree model; .5-acre plot size v. .1-acre plot size; pine v. hardwood species; even-aged v. uneven-aged stands

Member Company Benefits

- Help forest managers make more informed decisions on which definitions to employ
- Highlight potential influence on forest management and/or financial investment decisions as a result of the variability between different dominant tree height definitions
- Suggest new research directions that may include the examination of other important commercial tree species and growth & yield models

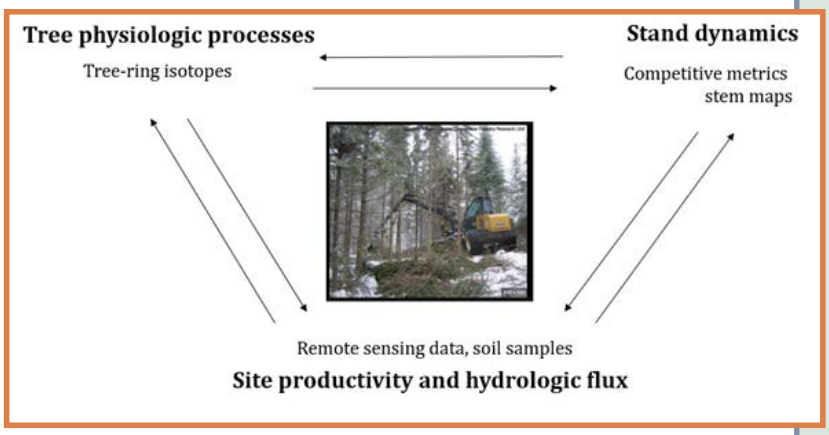
Density Management Strategies for Enhancing Carbon Sequestration in U.S. Working Forests

Mike Premer, Lila Beck (UMaine), Eric Turnblom (UW), Kim Littke (UW), Rachel Cook (NCSU), Mark Kimsey (UI), Bronson Bullock (UGA)

The role of forest ecosystems as a natural climate solution, specifically C sequestration and storage, has been widely recognized across the forested regions of North America. Working forests offer potential for C sequestration-oriented management as these settings are already intensively managed for commodity products, and, in turn, long-term C storage. This project aims to assess the role of silvicultural treatments, specifically stand density management, on terrestrial C sequestration and forest growth utilizing existing research networks and to synthesize these findings into management guidelines and basis of future research.

Annual Progress

- All 6 CTRN sites have been core sampled; 3 of 6 are cross-dated and ready for isotope analysis
- Isotope cores being processed
- Annual and cumulative Water Deficit/Surplus (Index) raster layers generated for Maine (1990-2020) at 1/5-acre resolution and available for user download



Three-pronged project approach

Future Plans

- Finish isotope processing
- Isotope samples to Columbia Univ for analysis
- Extend to the Pacific Northwest, increment borers sent to UW; extend to sites in southeast

Member Company Benefits

- Silvicultural guidelines and geospatial tools of treatment priority and response
- Leveraging long-term, cooperative dataset with emerging technologies
- Quantifying C sequestration and tools for C-based management
- Improve silvicultural recommendations for density management for major conifer species across the U.S.

Site-Stand Dynamics and Pine Beetle Mortality in Ponderosa Pine Ecosystems: Implications for Density Management

Mark Kimsey Jr., Haley Anderson, Steve Cook, Ann Abbott (UI)

The goal of this project is to develop a companion ponderosa pine SDImax model that is sensitive to stressors that precipitate western pine beetle (WPB, MPB) mortality outbreaks. These stressors may or may not coincide with traditional density management thresholds that are associated with density dependent related mortality. It is critical to develop a more granular understanding of which site and stand variable combinations contribute to pine beetle outbreaks across spatial and temporal scales. Spatially and temporally explicit models that identify at risk pine ecosystems will enable targeted and timely treatment prescriptions for creating resilient forests.

Annual Progress

- Data acquisition complete: aerial survey data, abiotic stand information, dryness index, stand data
- Synthesis of information and preliminary analysis underway: summarizing existing knowledge base, sorting data, spatial data analysis, simple logistic regressions of abiotic data

Future Plans

- User friendly tool that provides effective density management recommendations for ponderosa pine stands flexible to climate, species composition, site type, and method of measurement at the stand-scale for reduced susceptibility of western and mountain pine beetle epidemics across their respective ranges
- Draft dissertation: review of existing knowledge, model development for current climatic conditions, model development for future climatic conditions

Member Company Benefits

- Potential time and cost savings by reducing large-scale mortality from pine beetle epidemics
- More resilient forest stands
- Density threshold modifiers for existing SDImax models that incorporate pine beetle epidemic risk factors

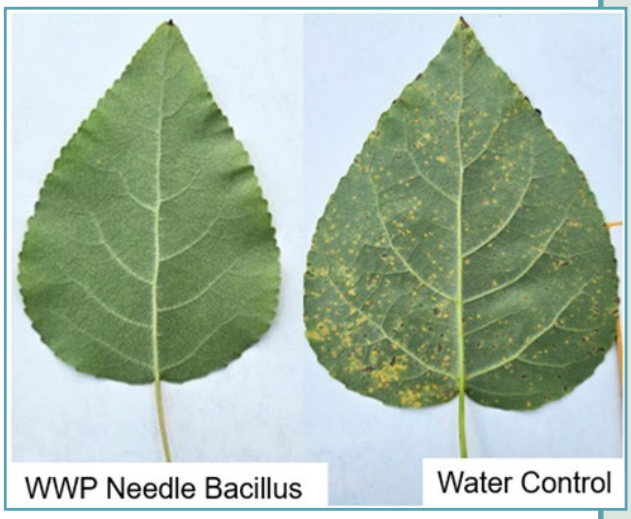
Enhancing Resistance to Fungal Pathogens in Commercial Tree Species

George Newcombe and Abby Ferson-Mitchell (UI)

During a CAFS-NSF funded internship in 2022, endophytic treatments were tested on susceptible seed of three tree species: western white pine (WWP), Port-Orford-cedar (POC), and Hawaiian koa, all commercially valuable species and of concern for restoration efforts due to devastation caused by pathogens. In this study, we will retest the repeatability of the significant findings, and expand the project by including commercially planted 'resistant' varieties (e.g., WWP Bingham F2 lot). WWP Bingham F2 lot has demonstrated between 70-80% survival in some stands and about 33% or less in other stands due to white pine blister rust. Study objectives are to enhance survival of commercial susceptible and 'resistant' varieties of seedlings against virulent strains of devastating pathogens.

Annual Progress

- WWP 2022-2024 trial: needle Bacillus and seed Bacillus significantly reduced needle lesion severity on a susceptible seed lot
- WWP 2023-2024 trial: needle Bacillus significantly reduced needle lesion severity on susceptible and 'resistant' seed lots
- POC: inoculate with pathogen, testing 3 factors: bacterial treatment v. water control; susceptible seed v. resistant seed sources; homogenization risk with inoculation method
- WWP: disease severity scoring: bacterial treatment v. water control; susceptible seed v. resistant seed sources; high spore density v. low spore density



Future Plans

- Koa seed acquisition and testing
- POC: repeat inoculate with pathogen trial
- Continue monitoring mortality on WWP and POC
- Run analysis and draft manuscripts

Member Company Benefits

- Reducing the cost and effort for reforestation following a failed plantation
- Enhance survival of out-planted resistant varieties in areas impacted by low-medium-high pathogen loads
- Increase survival of 'susceptible' families that lack genes for resistance but have other desirable genetic traits that improve hardiness and yield

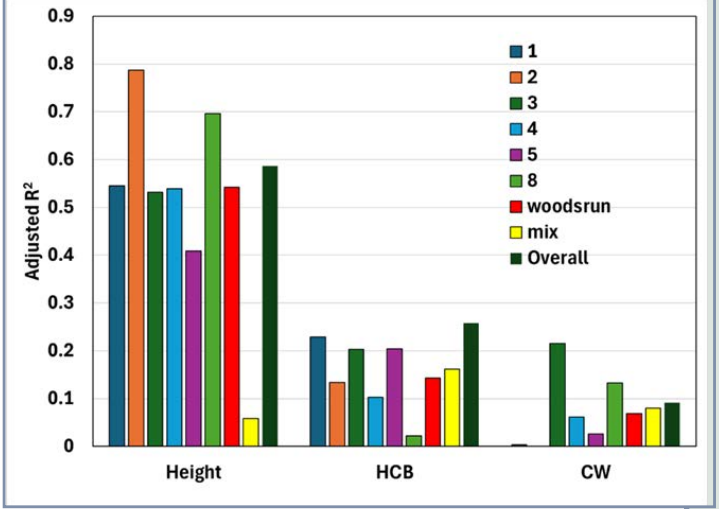
Determination of Crown Morphological Traits Using Laser Scanning in Douglas-fir and Loblolly Pine Genetics Trials

Doug Mainwaring, Sukhyun Joo (OSU), Rachel Cook (NCSU), David Carter (VT)

Intensive sampling of genetically selected trees has identified specific heritable crown attributes associated with enhanced individual tree growth, including short branch lengths, high leaf area density per unit crown length, and narrow crowns. The objective is to collect laser-scanned data from pure-family plantations to develop an algorithm for identifying specific crown characteristics associated with enhanced growth, and to apply these protocols within progeny test trials to identify candidate families for additional ground-based measurements.

Annual Progress

- Laser scanning of 3 family plantations; point cloud processing by FPC partners to explore correlations between laster-scanned and measured crown variables
- Tested algorithm of estimation of crown traits from laser scan data
- Poor correlation between scan-derived and measured tree variables
- Produced a version of growth & yield model (CIPSANON) that enables differentiation of family level SI and crown width type; accurately predicts DBH increment of narrow crowded trees



Among matched trees, there was poor correlation between scan-derived and measured variables

Future Plans

- Capture the environmental component of crown width with crown profile measurements across the Douglas-fir region
- Manuscript for peer-reviewed journal
- Dataset of measurements from field sites
- Final models describing adjustment of G&Y equations to account for crown traits

Member Company Benefits

- Ability to test for the benefits of growing Douglas-fir in ideotype plantings.
- An algorithm for aerial detection of crown traits within progeny tests, realized gain trials, and plantations.

The Interplay Between Sampling Design and Small Area Estimation to Improve Forestland Inventory

Temesgen Hailemariam (OSU), Aaron Weiskittel, Mike Premer (UM), Rachel Cook (NCSU), Phil Radtke, Corey Green (VT)

One of the challenges often faced in forestland inventory/valuation is estimating gross and net merchantable volume for smaller areas of interest consisting of delineated stands within a larger forested population or ownership. Project objectives: (1) examine variable selection methods for developing small-area estimation models that link inventory plots and remotely sensed data for timberland inventory; (2) examine the performance of selected sampling designs and sample sizes for applying SAE models; (3) Examine the use of small-area estimators to either reduce sample size when precision is given or improve precision when the sample size is fixed; and (4) explore methods to allocate sample size to subpopulation, including optimal allocation of samples in small domains.

Annual Progress

- Acquired Carbon Project Data collected by Green Diamond Resources Company (GDRC) in Klamath county
- Individual inventory plot, stand and polygon-level summaries
- Sentinel data, including mean reflectance values from selected Sentinel-2 bands and other derived variables

Future Plans

- Review of the literature on variable selection for estimating stand volume and site index from climate, terrain, and remotely sensed data
- Complete initial variable selection methods and comparisons on pilot project
- Protocols that aid in linking remotely sensed data and ground data/attributes
- Translate some of the theories in small-area estimation to practices.

Member Company Benefits

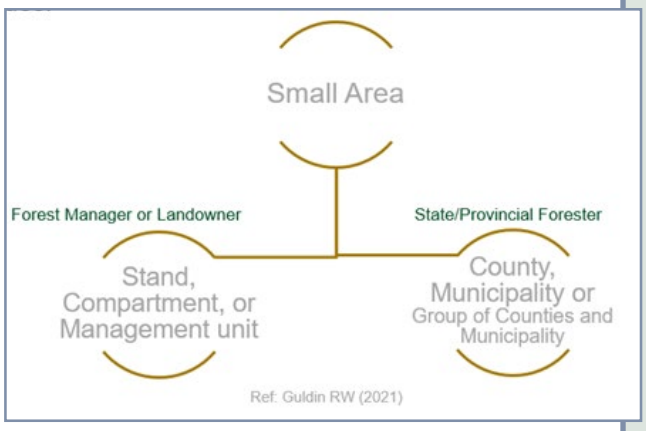
- Greater understanding in borrowing strength from linking freely available remotely sensed and ground data to improve the estimation of selected stand variables and to reduce the costs of data acquisition or establishing ground plots
- Identify protocols to operationalize small area estimation methods and developing cost-effective variable selection algorithms solutions for improved stand- and ownership-level estimation

2024 Project Starts

Robust Small-Area Estimation Strategies for Developing Accurate Stand-level Diameter Distributions

Jaslam Poolakkal, Mark Kimsey (UI), David Affleck (UMontana), Paul Parker (UC Santa Cruz), Nathaniel Naumann (PotlatchDeltic)

This study will focus on diverse and complex mixed conifer forests of the Pacific Northwest and Rocky Mountains, and across more uniform southern pine forests of the Southeast US. The project will leverage forest tree-level databases developed through the national CAFS SDImax project, with additional sourced industry inventory data. Auxiliary data from the national CAFS SDImax database (climate, topography, geology, soil) will be augmented with remote sensing data from 3D NAIP, Sentinel, and where available, free 3DEP LiDAR. This dataset will enable us to provide reliable, spatially explicit estimates of stand-level diameter distributions.



Annual Progress

- Initiated discussions with industry members regarding data availability and project data requirements
- Tested algorithm of estimation of crown traits from laser scan data
- A consortium of industry and public partners, including USDA-NRCS, is being assembled to enhance DSM acquisition in target project areas
- Reviewing recent research papers published in SAE to align methodologies with the latest advancements

Future Plans

- Comprehensive literature review
- Compile forest inventory data from industry, public land management, and research plots across northwest, Rocky Mountains, southeastern US
- Data preprocessing and conduct exploratory data analyis for model development

Member Company Benefits

- ML-based SAE models can demonstrate the ability to develop robust estimates of stand characteristics in areas with limited or no sample data; SAE characterization of the diameter distribution of forest stands managed for timber production provides improved tree lists for growth and yield modeling and carbon estimation

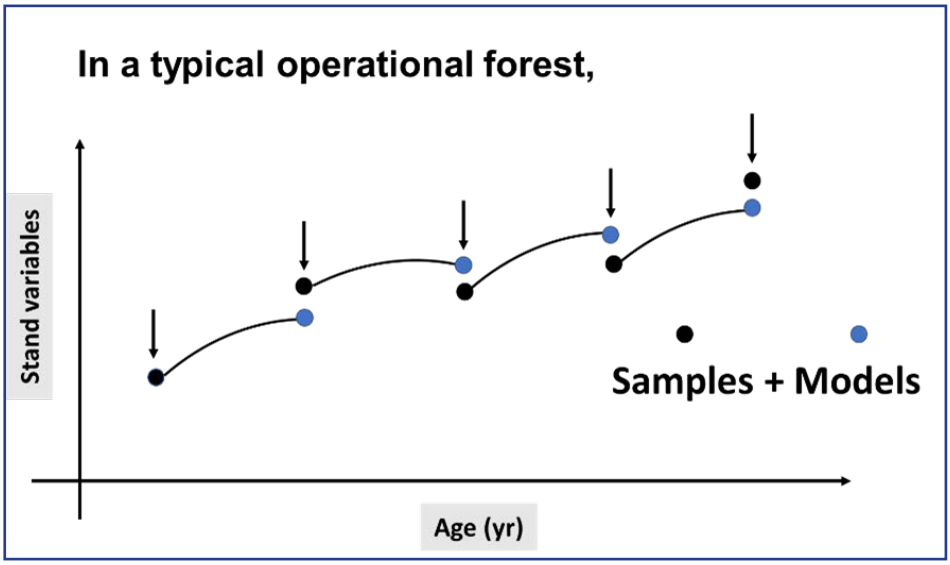
Integrating SAE Methods with Stand-level Forest Inventory and Growth Projection for Southern Pine Plantations

Sheng-I Yang, Bronson Bullock (UGA), Phil Radtke, Corey Green (VT)

The aim of this project is to examine the possible impacts of future climate change on the growth and resulting yield of loblolly pine via simulating reduced rainfall using throughfall exclusion troughs to carry a portion of the water off of each plot into a buffer area. We will also evaluate how loblolly pine will respond under reduced moisture conditions when there is a mid-rotation thinning treatment applied. The resulting impacts on wood quality and related wood properties will be evaluated using disks sampled destructively from trees on the treatment plots during the thinning operations.

Annual Progress

- Graduate student recruiting
- Data compilation plans: discuss with multiple industry partners and establish data sharing MOUs
- Data received from several industry partners for SAE work



Future Plans

- Recruit another graduate student
- Conduct preliminary analyses with previously collected data
- Request additional data from other industry partners

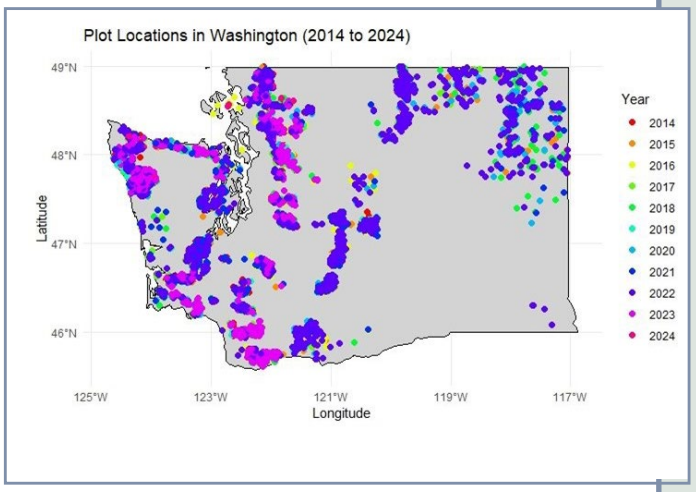
Member Company Benefits

- Insight into the impacts of reduced moisture in loblolly pine plantations both pre- and post-thinning

Using Small Area Estimation and 3D-NAIP/Sentinel-derived Variables for Multivariate Prediction of Stand Attribute

Sukhyun Joo, Tamesgen Hailemariam (OSU), Bryce Frank, Jacob Strunk (USDA FIA), Dale Hogg (Green DIamond), Nathaniel Naumann (PotlatchDeltic), Cristian Montes (Rayonier), Phil Radtke (VT), Rachel Cook (NCSU), Ethan Hughes (Washinton DNR)

The Forest Inventory and Analysis (FIA) program by the USDA Forest Service offers reliable forest inventory data at both national and regional levels. However, when estimating at fine spatial resolution, such as geographic units, industrial land ownerships, or county levels, the accuracy decreases due to increased sampling errors caused by limited sample sizes. The primary objective of this research is to provide current stand- and tree-level attributes across various spatial resolutions (e.g., state, county, specific stand, management unit, pixel) to create detailed multivariate models integrating FIA, 3D-NAIP, and Sentinel data with climate and non-FIA private industry data.



Annual Progress

- PhD student recruitment
- Data acquisition: Washington DNR ground and remotely sensed (DAP and LiDAR point clouds) inventory data

Future Plans

- Secure the Materials Transfer Agreement (MTA) for accessing confidential FIA plot locations
- Model development: Compare the performance of univariate and multivariate models begin with Washington and Oregon regions
- Continue integrating FIA data, private industry cruise/stand exam data, and remotely sensed data (3D-NAIP/Sentinel) for multivariate model development

Member Company Benefits

- Enhanced accuracy in forest inventory estimates, leading to more informed management
- Cost savings through reduced need for extensive ground-based sampling to estimate stand attributes, such as gross and net merchantable volume
- protocols that leverage remotely sensed data and additional information to enhance the precision of predicting key stand attributes (e.g., trees per acre, basal area, volume estimates), thereby reducing uncertainty in these predictions

The Effect of Silvicultural Treatment on Douglas-fir Stem Form

Doug Mainwaring, Sukhyun Joo, Carlos Gonzalez, Temesgen Hailemariam (OSU), Eric Turnblom, Jason Cross, Kim Littke (UW), Mark Kimsey (UI)

Volume estimates of projected tree lists are based on existing taper equations which do not currently account for any changes in stem form that may result from silvicultural treatments. Proper assessment of the short- or long-term volume or financial yield of such treatments require that any benefits derived from associated changes in stem form be accounted for. We propose taper measurements of rotation-aged trees from thinned stands, and mid-rotation-aged trees from stands representing contrasts in early vegetation control, pre-commercial thinning, or genetic selection to test for silvicultural effects on stem form using a combination of felled tree, climbed tree, and SLAM LiDAR measurements.

Annual Progress

- Tree sampling and SLAM LiDAR scanning will be distributed across Oregon and Washington

Future Plans

- Construct taper modifier equations to adjust a conventional taper prediction to account for any significant treatment effect
- Collect SLAM LiDAR data on standing trees subject to felled or climbed upper stem diameter measurements
- Validate the remotely collected data and/or calibrate it to correct for any bias

Member Company Benefits

- Improved volume/yield estimates within treated stands, and additional information on mid-rotation-aged stands to improve the timing of potential mid-rotation thinning treatments
- Model adjusting stem form predictions for sites responsive to silvicultural treatment
- Improved assessment of yield/financial benefit of specific treatments

Throughfall Reduction Impacts on Loblolly Pine Plantations Pre- and Post-Thinning

Bronson Bullock, Joe Dahlen, Stephen Kinane (UGA), Tom Eberhardt (USFS FPL)

This project aims to examine the possible impacts climate change will have on the productivity of loblolly pine plantations given that loblolly pine is the most important commercial species in the U.S. South. Changes in precipitation are widely documented as a result of a changing climate. Here we will examine the possible impacts of future climate change on the growth and resulting yield of loblolly pine via simulating reduced rainfall using throughfall exclusion troughs to carry a portion of the water off of each plot into a buffer area. We will also evaluate how loblolly pine will respond under reduced moisture conditions when there is a mid-rotation thinning treatment applied. The resulting impacts on wood quality and related wood properties will be evaluated using disks sampled destructively from trees on the treatment plots during the thinning operations.

Annual Progress

- Leverage the previous Pine Integrated Network: Education, Mitigation, and Adaption (PINEMAP) project which was established to evaluate the effects of climate, soils, and management approaches on carbon sequestration rates
- Study site is located in the Georgia Piedmont and was established in 2011 (planted 2006) in which 4 reps with four treatments were imposed: (1) control, (2) fertilizer, (3) throughfall exclusion via troughs carrying water offsite, (4) fertilization x throughfall exclusion combined treatment
- Thinning design currently being developed
- Initial findings presented at SOMENS/NEMO meeting in November

Future Plans

- Continue working on details of planning thinning operation
- Evaluate differences in height-diameter models between different treatments over time
- Model different thinning scenarios to look at outcome prior to operational thinning on the research plots

Member Company Benefits

- The findings of this work will provide insight into the impacts of reduced moisture in loblolly pine plantations both pre- and post-thining

NSF Supplemental Funding Programs

CAFS sites have successfully applied for supplemental funding from NSF to help advance the readiness of the STEM workforce to acquire core professional competencies and skills that will support careers in any sector of the U.S. economy. Details of these projects are provided in the following pages.

START
Skills Training in Advanced Research & Technology

Funding supports students, faculty and faculty/student teams from 2-year institutions of higher education in gaining experience working on state-of-the-art, industrially driven IUCRC research projects at IUCRC sites. The program benefits may include alumni and peer support; paid, credit-based internships; and forest research experiences at CAFS university sites.

NSF START: University of Maine & University of Maine at Fort Kent

Aaron Weiskittel and Nicole Rogers (UM)

Ned Rubert-Nason and Neil Thompson, University of Maine Fort Kent

Aaron Weiskittel and Nicole Rogers, University of Maine

Partnership with University of Maine Fort Kent's 2-year technical college to support a two-year project working toward a better understanding of commercial tree responses to stress. Working with faculty from UM and UMFK, internships will encompass lab sampling and field work, including using hyperspectral imaging to assess tree health, determining the effects of microclimate on forest health and regeneration, and estimation of wood moisture content. CAFS has funded three student interns, and indirectly supported 10+ undergraduates since 2021. CAFS sponsored travel by 2 UMFK faculty to attend the 2023 CAFS IAB meeting in Louisville, KY; and 1 UMFK faculty and 1 UMFK student to attend the 2024 CAFS IAB meeting in Madison, WI.

Current progress

- Hyperspectral tree health assessment: All field data collected and lab analyses complete for Populus and Picea; preliminary predictive models built and presented at the 2024 Ecological Society of America conference; manuscript in preparation for *Canadian Journal of Forest Research*
- Environmental change effects on forest health & regeneration: Monitoring long-term climate variables at 3 locations in Aroostook Co. Maine; newly-sponsored projects exploring effects of biochar soil amendment on tree growth and carbon storage (MEIF), land management on forest soil microbiomes (NSF E-CORE: OIA-2412131), and land management on tree growth/health (NSF E-RISE: OIA-2416915)
- Wood moisture content: predictive algorithm developed for SCiO handheld NIR spectrometer; manuscript in revision for *Wood & Fiber Science*
- *Transferable skills:* Communication, innovation, critical thinking, and leadership

Future Plans

- Optimize predictive models, share computer code for predicting tree health from hyperspectral images
- Continue climate data collection and study of biochar soil amendment impacts on tree growth and carbon storage
- Investigate causes of cedar decline.
- Finalize publications

NSF START: University of Maine

Kellyanna Merrill, Jonathan Little, Casn

Aaron Weiskittel, Kacey Legaard

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Background

The Spruce Budworm (SBW) of North America goes through harmful cyclical population booms that threaten northeastern forests due to its diet of red, black, and white spruce trees as well as balsam fir. We understand the SBW prefers mature host trees, which is why the prevailing theory of the SBW cyclical population boom occurs about every 40-60 years. What we need to examine further is what other environmental factors lend themselves to the thriving of SBW in specific areas, so we can target those areas for preventative/mitigation efforts.

Research Question

What correlations can we see in our existing environmental data wi
the presence of the northeastern spruce budworm? Does incoming
solar radiation (insolation), relative elevation, tree canopy height, o
host species ground coverage show any correlating pattern with the
presence of the SBW?

Methodology

The primary tools for this project were ArcGIS Pro and Excel. First a buffer zone of 250 meters around each of our SBW sample sites was created and a new shapefile out of that (see maps 1, 2, and 3). This shapefile was used as the basis for the extracted zonal statistics for the following environmental data parameters: relative elevation, insolation, tree canopy height, host species, and the host species balsam fir.

The primary statistical zonal value focused on was mean terrain values within that 250 meter SBW buffer. Each table was exported into an Excel spreadsheet and the data normalized. Within the SBW dataset, erroneous -1 values were extracted, along with the same values from the corresponding terrain data.

Next the environmental parameters were quartered up from highest to lowest to visualize them in the histogram. The accompanying moth data that fell within each of those quarters was calculated for the means of SBW, as seen in figure 2.

However, the quartile charts are very simplified portrayals of large datasets, so for each environmental parameter we included a scatter plot. The scatter plots show the means of each moth count point on the Y axis and the relevant environmental data on the X axis. First we did this with just the most recent moth data from 2023, and then we did this same process but with the mean value of each site's moth count from 2014-2023.

The accompanying maps are made with ArcGIS Pro for visual aid.

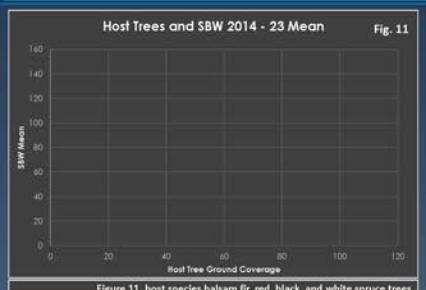


Figure 11. host species balsam fir, red, black, and white spruce trees.

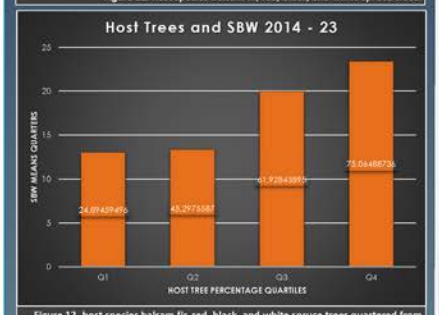


Figure 12. host species balsam fir, red, black, and white spruce trees quartered from lowest percentage to highest.

Host trees: The balsam fir, black, white, and red spruce raster layers were normalized into a single raster showing ground-coverage percentage. The host species make up the primary diet of the SBW and therefor show the clearest correlation of a rise in SBW when there is a rise in host trees.

Figure 1. *Incoming Solar Radiation (insolation) on X axis and 2023 moth counts/site.*

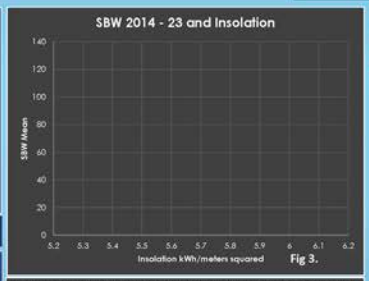
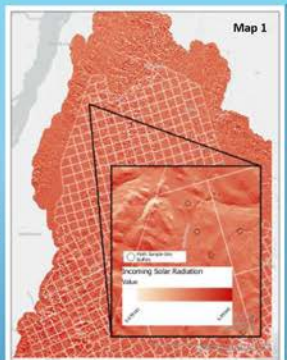


Figure 3. Shows the same parameters as fig. 1 but uses 2014-2023 means per site instead of just 2023 to see longer-term relationships.

Figure 2. *The insolation values organized lowest to highest, and grouped into respective quarters*

Figure 4. *Mean quartiles insolation, moth counts for 2014 – 2023 averaged within the quartiles*

Results: Insolation: SBW 2014 – 2023, and SBW Exclusively 2023



Map 1. *Insolation raster layer focusing on an area of township T18 R13 Wels*

Insolation: The insolation data is harder to see a clear pattern, and it may just be that incoming solar radiation in this region of Maine does not play a significant role in SBW populations. The **test statistic** was **1.371** for the distribution of the SBW 2014 – 2023 means along the insolation X axis.

e & Monroe Community College

mir Brown, Monroe Community College
d, Erin Simons-Legaard, UMaine

rth Eastern Spruce Budworm

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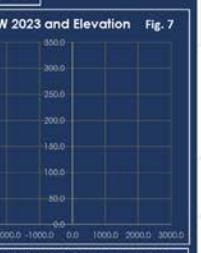
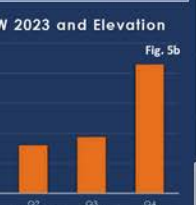
ber, 2024

Elevation Results

Elevation: Elevations were another example of where it was necessary to look at all available years of SBW population means averaged out rather than just the most recent year. In figure 5b showing 2023, there is a SBW spike in the fourth quartile where the previous three quartiles trend downward as elevation gets steeper. In figure 6 you can see the trend stays consistent, where SBW populations dip when elevation rises.





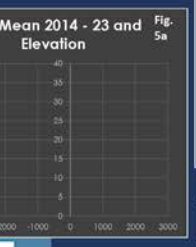


Figure 6. *Elevation grouped into heights in CM, from Q1 lowest to Q4 highest, showing preference for lower elevation terrain over 10 years*

Figure 5a is SBW mean for 2014 – 23 over elevation to show the overall trends of SBW appearances

Tree Canopy: SBW 2014 – 23 Means and SBW 2023 Alone

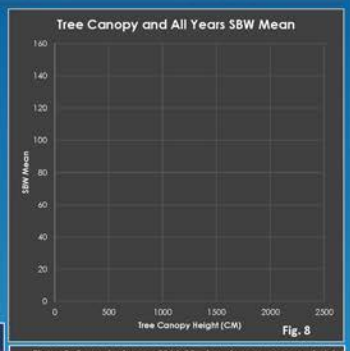


Figure 8. *Spruce budworm, 2014-23, plotted over tree canopy height*

Figure 7. *Spruce budworm, 2023, plotted over tree canopy height*

Figure 9. *SBW, 2023 moth counts over tree canopy height quartered by height from shortest to tallest*

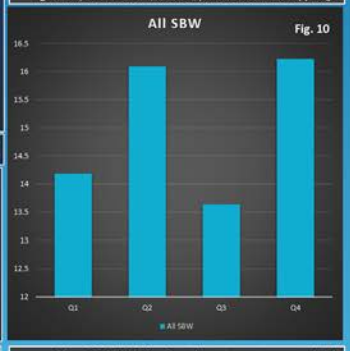


Figure 10. *SBW, 2014 - 23 moth counts over tree canopy height quartered by height, note that graph starts at 12*

Canopy height: The 2023 SBW means divided over canopy height quartiles shows a steep drop-off in SBW means/site at Q4 (mean SBW went from 18 to 9). Next we expanded the scope of the data to get the means of 2014-23 SBW so that we could see if this drop-off is consistent across all SBW data. As we see in figure 10, Q4 has the highest mean value of SBW for all years, which is consistent with what we understand about tree maturity correlating with higher SBW populations. It does appear as though Q3 also has a steep drop off in the "All SBW" means chart, but the difference between Q3 and Q4 is only about 2.5 SBW, it's just that the graph begins at 12. The **test statistic** for the canopy height quarters and the SBW 2014 – 23 is **0.00679**, which indicates a very unlikely chance that these results happened erroneously.

Future Work

- Explore SBW data using other measures of center than just mean, such as median and standard deviation.
  - It would also be useful to see the ranges of SBW within the environment quartiles.
- Evaluate larvae (L2) data to see how this compares with moth count.
- Continued evaluation of forest health and extent of defoliation with remote sensing and GIS tools
  - NDVI analysis and spectral signatures.
- Studying and implementing mitigation efforts with for SBW population control that do not harm other aspects of Maine's ecosystem
- Cooperation with Quebec forestry departments and land management.

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Casmir Brown, *GIS and Geography Student Mentor*

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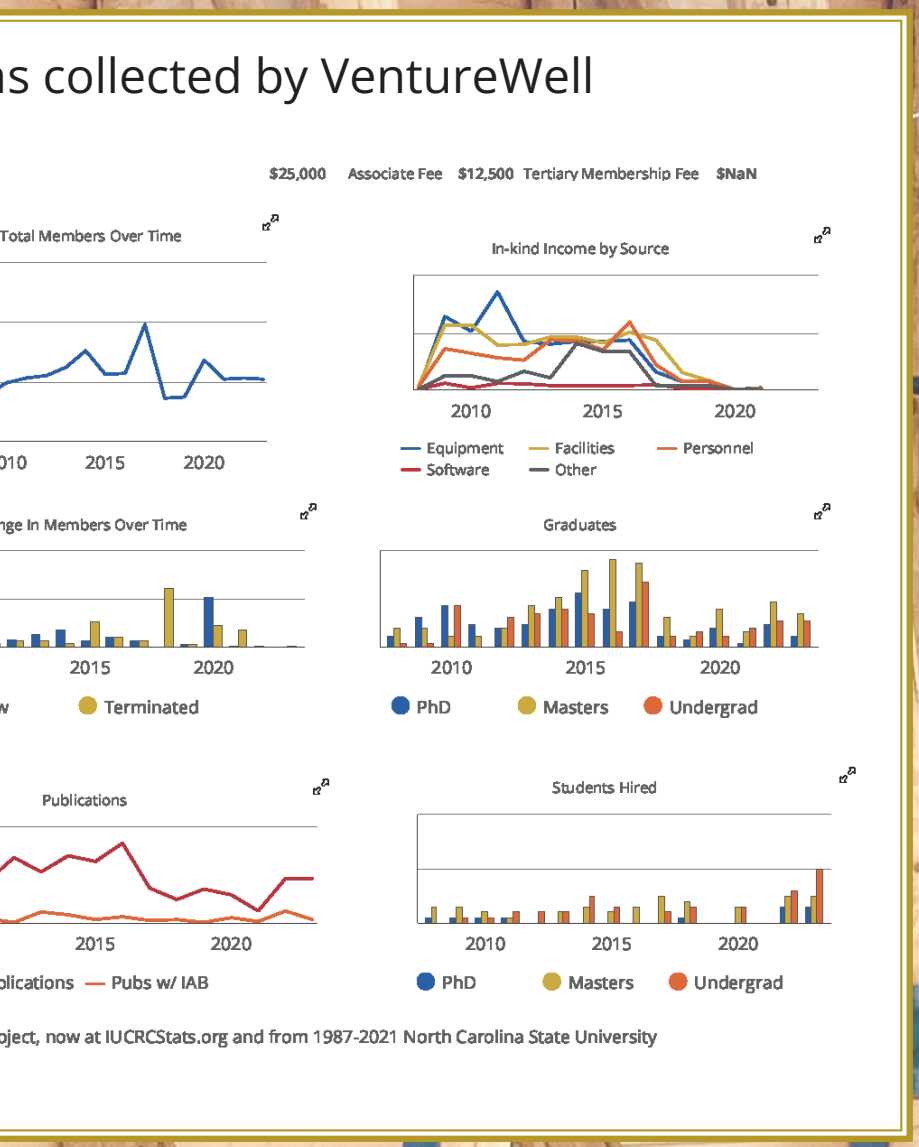
References & Data Sources

All maps are projected in USA Contiguous Albers Equal Area Conic USGS.
Cooperative Forestry Research Unit. (2016). Coming Spruce Budworm Outbreak. University of Maine.

crsf.umaine.edu/forest-research/cafs/

The CAFS Website provides public-facing resources about the program, the strategic plan and technology roadmap, bylo and assessment coordinator reports. In addition, password-protected meeting pages provide a vital resource for indu members and researchers to access project updates and internal advisory board materials. The website will continue provide important updates to the CAFS programming as it transitions from an NSF IUCRC at the end of 2025.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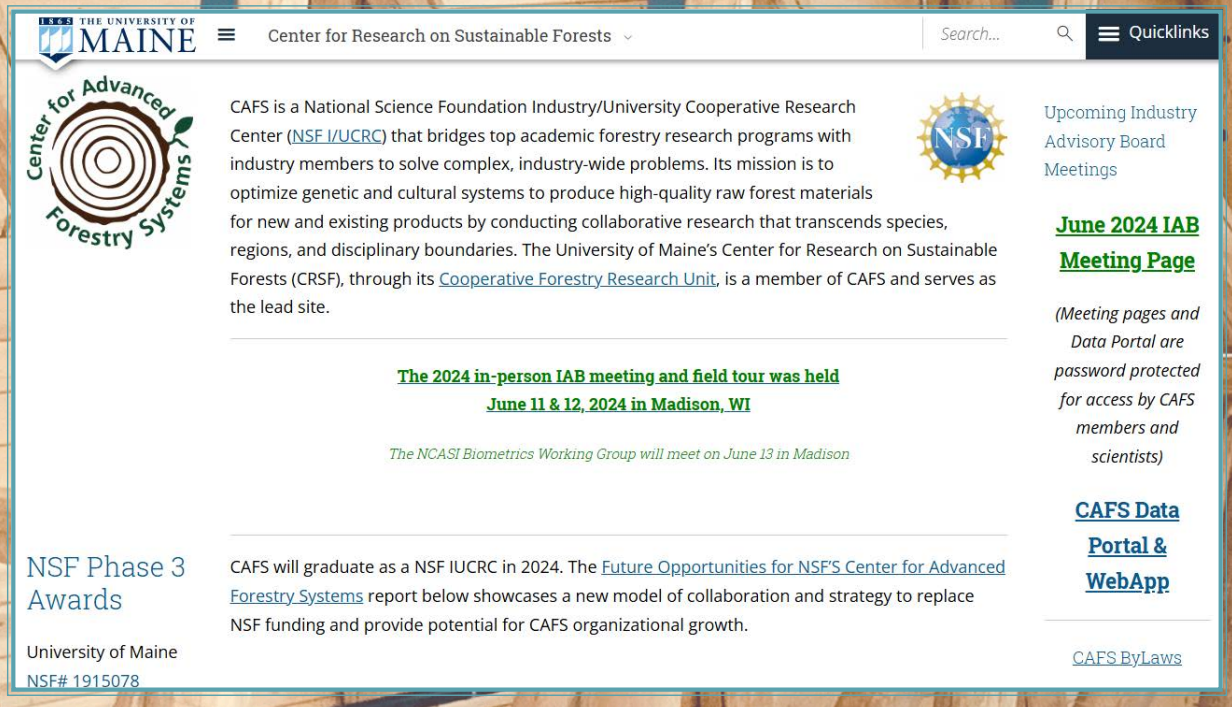
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CAFS is a National Science Foundation Industry/University Cooperative Research Center (NSF I/UCRC) that bridges top academic forestry research programs with industry members to solve complex, industry-wide problems. Its mission is to optimize genetic and cultural systems to produce high-quality raw forest materials for new and existing products by conducting collaborative research that transcends species, regions, and disciplinary boundaries. The University of Maine's Center for Research on Sustainable Forests (CRSF), through its Cooperative Forestry Research Unit, is a member of CAFS and serves as the lead site.
NSF
The 2024 in-person IAB meeting and field tour was held June 11 & 12, 2024 in Madison, WI
The NCASI Biometrics Working Group will meet on June 13 in Madison
NSF Phase 3 Awards
University of Maine
NSF# 1915078
CAFS will graduate as a NSF IUCRC in 2024. The Future Opportunities for NSF'S Center for Advanced Forestry Systems report below showcases a new model of collaboration and strategy to replace NSF funding and provide potential for CAFS organizational growth.
Upcoming Industry Advisory Board Meetings
June 2024 IAB Meeting Page
(Meeting pages and Data Portal are password protected for access by CAFS members and scientists)
CAFS Data Portal & WebApp
CAFS ByLaws

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.


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