NSF I/UCRC Center for Advanced Forestry Systems

2021 (Year 2) Phase III Progress Report

National Science Foundation

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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

CAFS Lead Site Director's Report

As Year 2 of the Center for Advanced Forestry Systems' (CAFS) Phase 3 wraps up, I am very excited to see the tremendous evolution and current momentum of the organization. Despite the challenges created by the ongoing global pandemic, CAFS membership remains strong with 84 members (59 Primary, 25 Secondary) and over $2.5M in total membership contributions. On the research front, CAFS has maintained a diverse portfolio of collaborative projects with a total of 18 ongoing efforts. This includes two new NSF Skills Training in Advanced Research & Technology (START) supplemental grants led by University of Maine and North Carolina State University that are linking CAFS sites with two-year technical colleges. This is ina ddition to an ongoing NSF INTERN project at the University of Idaho.

As highlighted in this annual report, substantial progress has been made by other ongoing or new research projects examining response to fertilization, regional variation in site productivity as well as maximum carrying capacity, and numerous remote sensing efforts looking at forest health, species composition, and leaf area index. Membership support of these projects continues to remain high, while there remains strong agreement on the CAFS Strategic Plan & Technology Roadmap that was developed at the start of Phase 3 in 2019.

Research on emerging technologies and remote sensing continue to be high priorities for CAFS members. A recent stakeholder technology needs assessment survey of CAFS members conducted during industry advisory board meeting in November found nearly 70% of participants (representing more than 30 million acres of privately owned land) already use remote sensing products in their decision-making, but over 50% indicated more accurate or higher resolution spatial products are needed due to the current incompleteness of the information. As Director of CAFS, I will continue to explore ways to leverage current member contributions and identify researchers who could help address membership research needs. Currently, CAFS has more than 50 faculty, students, research assistants, and post-docs conducting regional and national research across 7 university sites.

With growing interest in forests, significant efforts over the last year have focused on the potential recruitment of new members into CAFS. This has largely been done in concert with an existing partnership with the National Council for Air and Stream Improvement (NCASI) and their supporting members. Given the similarity of their missions, it is hoped that in future years CAFS and NCASI will release a joint request for proposals. For now, a joint meeting between the NCASI and CAFS membership is being planned for June 2022.

Through coordination with CAFS' NSF Program Officer, important changes to our bylaws were made with direct support by our membership. These changes have helped to better clarify our operating procedures, membership levels, and voting rights. This has slightly reduced our total membership contributions, but has provided more consistency across sites. I believe these types of changes are necessary as CAFS is nearing the halfway point of our Phase 3 awards and we need to think strategically about successful graduation as an IUCRC. As always, I will remain committed to this end goal and do appreciate all the support as well input we have received since the start. For now, I look forward to the start of Year 3 and all the exciting progress being made by the ongoing research.

Aaron Weiskittel
Director, Center for Advanced Forestry Systems
Director, Univeristy 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 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 hosted two remote IAB meetings in 2021 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.

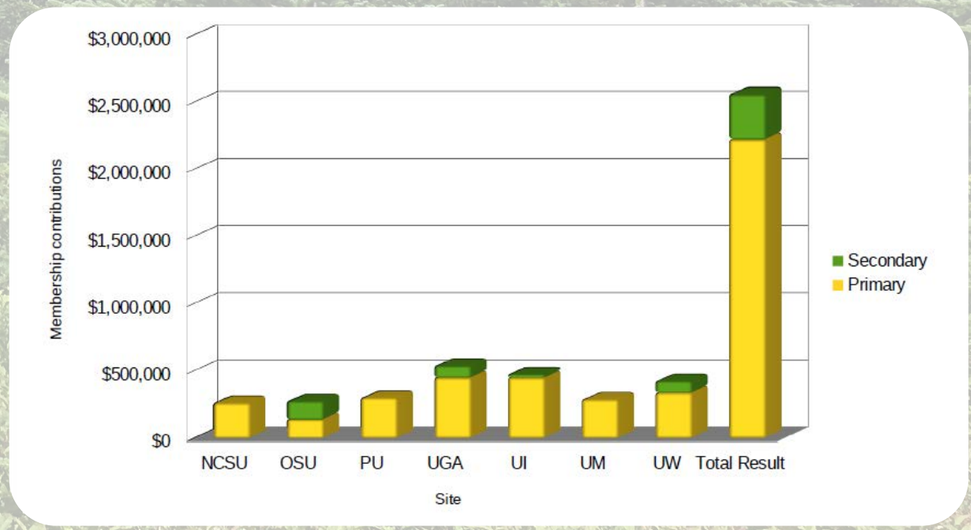
2021 Highlights

CAFS Researchers continued their research efforts as pandemic restrictions eased. Although IAB meetings still had to be conducted virtually, site directors and researchers pivoted to this "new normal" and continued to produce research published in refereed publications and to present virtually at a variety of scientific meetings.

CAFS Industry Members benefited from research on white pine blister rust and other tree fungi, regional growth models on the economics of late-rotation fertilization, variables that determine changes in taper allowing for the utilization of localized functions to further improve volume estimation, silvicultural recommendations for Douglas-fir plantations based on physiologic response, models that facilitate comparisons of silvicultural strategies to maximize observed site-index, and informed forest plantation management through more efficient and specific characterization of tree health using remote sensing data.

FY22 Budget

$2.5M in contributions across 7 sites and 84 primary and secondary IAB members



Phase 3 Technology 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					

Phase 3 Milestone Timeline

Milestone	Fiscal Year				
	18-19	19-20	20-21	21-22	22-23
Apply for & secure NSF Phase III funding					
Approve bylaws, strategic plan, & technology roadmap					
Initiate research projects identified on technology roadmap					
Revise and refine bylaws, strategic plan, & technology roadmap					
Secure additional partners including industry, academia, and non-profit sectors.					
Integrate center research and education activities that effectively train and benefit undergraduate and graduate students					
Survey, document, and prioritize industry member research needs					
Plan and host biannual meetings					
Annually report progress, outcomes, and finances					

2021 IAB Attendance Summary

	June IAB Meeting				November IAB Meeting			
	N of Member Firms Attending	N of Member Representatives Attending	N of Students Attending	N of Faculty Attending	N of Member Firms Attending	N of Member Representatives Attending	N of Students Attending	N of Faculty Attending
University of Maine	9	15	3	3	4	6	3	1
University of Idaho	8	9	0	4	7	9	3	1
University of Washington	16	27	0	4	7	12	-	3
NC State University	2	2	4	1	4	11	1	1
Oregon State University	15	25	3	5	6	12	5	2
Purdue University	4	4	6	5	2	5	2	5
University of Georgia	18	25	2	2	5	14	-	3
TOTAL:	72	107	18	24	35	69	14	16

Ongoing Projects

Lead Site	PI	Title	Status for 2021-22
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
UGA*	Montes 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/ Cross	20.82 Stand response to thinning: Enhancing response prediction through modeling	Continuing
UW	Cross/ Turnblom	20.83 Using predictive analytics to decompose site index	Continuing
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
OSU*	Mainwaring	21.86 Stem form of nitrogen fertilized Douglas-fir trees	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
UI	Kimsey et al.	21.90 Improving forest sample estimation through UAS canopy structure stratification	Continuing
NCSU	Cook et al.	21.91 NCSU START	Continuing
UM	Weiskittel et al.	21.91 UMaine START	Continuing

**Indicates multi-site projects*

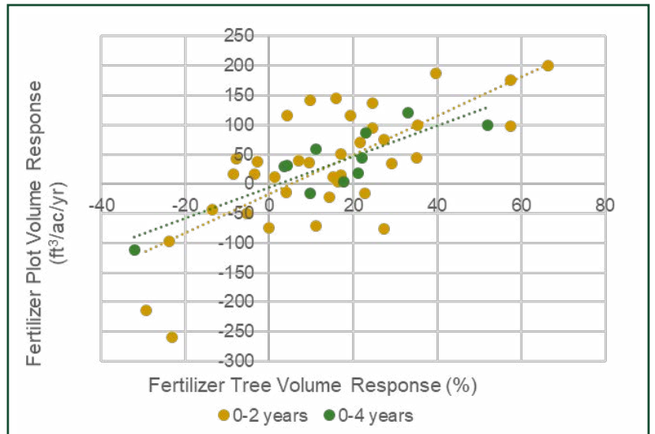
Stand and Tree Responses to Late-Rotation Fertilization

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. This study will provide a much-needed examination of the economics involved with late-rotation fertilization.

Year Five Progress

- All installations measured for two-year response; 11/34 measured for four-year response
- Tree volume response is positively related to plot response
  - Variability is related to difference in mortality after fertilization
  - Mortality in fertilized plots tended to be smaller trees
- Responsive installations have higher elevation and forest floor and soil C:N ratio
  - Lower site index, foliar N, and PRS nitrate and aluminum
  - Best response on installations with high PRS Ca and K



Future Plans

- Remaining 22 installations will be measured for four-year response in Fall 2021 and 2022
- Four installations destroyed by fire or windstorms
- New installations will be established in Spring 2022
- Spring 2022: Prepare manuscript describing relationships between PRS nutrient adsorption, soil and site productivity, and 4-year fertilizer response

Assessing & Mapping Regional Variation in Site Productivity

Cristian Montes (UGA), Rachel Cook (NCSU), Aaron Weiskittel (UM), Mark Coleman (UI), Doug Jacobs (Purdue), Mark Kimsey (UI), Erik Turnblom (UW), Carlos Gonzalez (OSU)

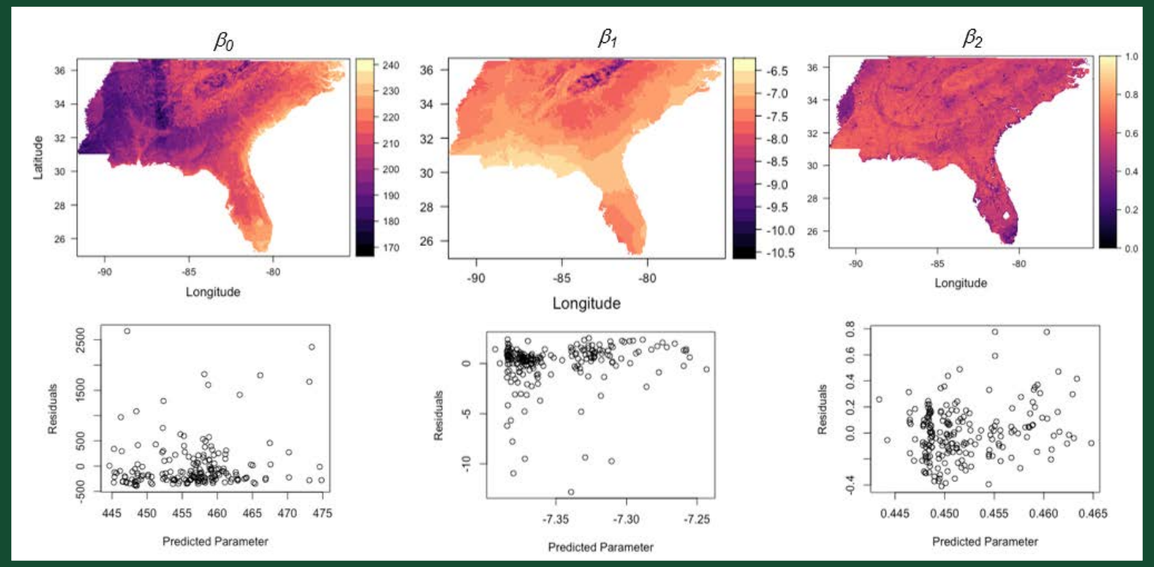
This project features cross-site collaboration and sharing of remotely sensed and empirical field data for spatial modeling of potential site productivity. Theobjective is to develop a consistent and biologically-meaningful metric of potential site productivity that can be related to a combination of 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 Two Progress

- Several maps with auxiliary variables available.
- Site Index interpolation using generalized additive models and machine learning methods.
- Results show strong climatic effects.
- Uncertainty in stand projections determined and modeled as well, showing uneven uncertainty values across the southeast U.S.

Future Plans

- Include soil maps, at the regional scale.
- Include steady state LAI map as one of the predictors.



Interpolated local parameters that allow for better characterization of the site.

Project Highlights

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

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

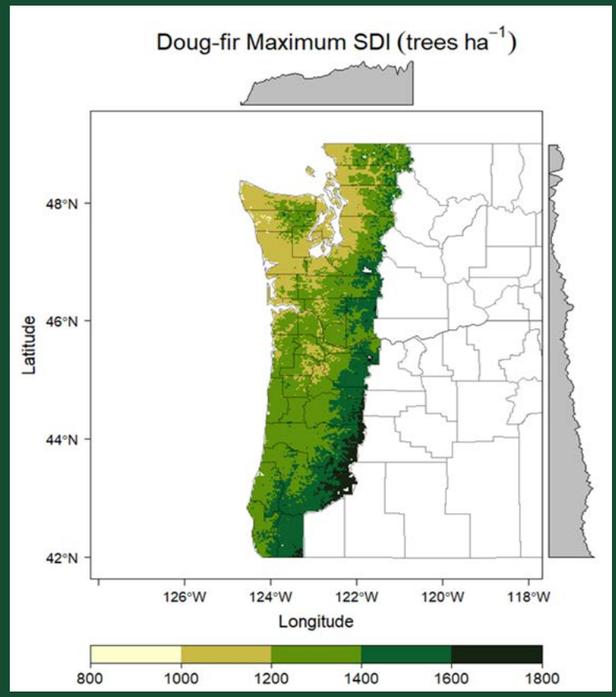
Maximum site carrying capacity determines the number of individuals of a certain size per unit of area that a defined stand can support and maintain. The objective of this research project is to 1) synthesize a nationwide forest measurements database from publicly available data and from CAFS members,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

Year Two Progress

- Data Collection
  - Northeast Region
    - Comprehensive site/inventory data provided by Weiskittel
    - Inventory records provided by Hancock Forest Management
  - Southeast Region
    - Inventory plot records provided by: Hancock Forest Management and PotlatchDeltic
  - Enhanced soil parent material database provided by Rachel Cook (FPC)
  - All Regions
    - Nearing CUI agreement between UI and FIA to obtain all unfuzzed FIA coordinates across the US
- Database draft

Future Plans

- Final version of draft database
- 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), Andrei Toca (Purdue)

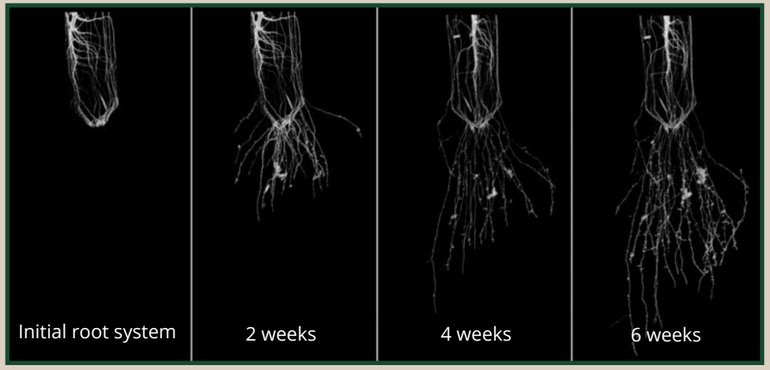
Multi-institution project to examine drought-related physiological parameters (e.g., stem and root hydraulics, resistance to cavitation) and root morphological traits of various genotypes of western larch, black walnut, and coastal Douglas-fir from diverse maternal tree climates across each species'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

Year Two Progress

- Nondestructive analysis of simulated post-planting root development and architecture using 3D imaging based on X-ray computed tomography (CT)
- Outplanting across multiple forest systems relevant to CAFS members
- Field performance measurements
  - Pre-dawn and mid-day water potential
  - Growth (height, diameter and biomass)
  - Root development
  - Nutrient analysis
  - Vigor/Damage (browsing, drought, heat)
  - Survival

Future Plans

- Laboratory analysis: root scanning, leaf area, biomass
- Digital analysis: root growth dynamics, root branching, lateral root angle, rooting depth
- Field performance measurements: scanning of root systems excavatd in the field; leaf nutrient analysis
- Manuscript preparation: nursery, hydraulics, outplanting



3D root segmentation of one-year old Douglas-fir seedlings using an X-ray computed tomography root scanner.

Project Highlights

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)

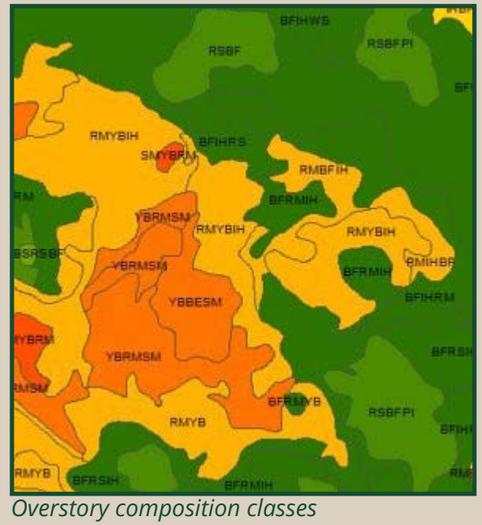
For the past several decades, machine learning (ML) algorithms have been adopted and refined to improve forest map accuracy. However, several decades of data and algorithm development in satellite remote sensing have not yielded robust solutions for eliminating systematic map error. This research specifically 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 Two Progress

- Sentinel-2 image processing across Maine
  - 132 Sentinel-2 images processed over Maine to-date
  - Roughly 6-8 clear-view acquisitions at any location, collected throughout the growing season
- Large-area LiDAR processing
  - Computation of 10 m gridded metrics from USGS QL2 LiDAR
  - Parallel processing on the UMaine computing cluster
  - 2018 acquisition just about complete; remainder queued for processing
- Software development to support map validation
  - Our maps of species abundance, overstory composition, and forest types are derived from multiple individual ML models
  - Validation and accuracy assessment is technically challenging
  - Code nearly complete to support multiple validation strategies

Future Plans

- Complete data processing over Maine
- Complete map validation software
- Iteratively implement and evaluate strategies for species, forest type, and biomass mapping.
- Transition toward data processing for study areas in the NW, SE, and Upper Midwest.



Overstory composition classes

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, 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 Two Progress

- Quantifying tree foliar chemical and physiological responses to abiotic and biotic stress using hyperspectral data
- 29 foliar biochemical traits were analyzed using high-performance liquid chromatography (HPLC) for trait retrievals (determination of the ability of hyperspectral data to estimate leaf functional traits)
- Four stress combinations: fungal infection+soil quality; fungal infection+drought; nutrient deficiency+drought; nutrient deficiency+salt deposition
- Assessed the reliability of hyperspectral information to scale from leaf, to tree, to stand, to landscape-level measurements

Future Plans

- Predict other biochemical leaf traits under abiotic and biotic stressors.

Leaf starch and condensed tannins

- Determine physiological and chemical differences among stress treatments.
- Prepare a research paper for publication.

Project Highlights

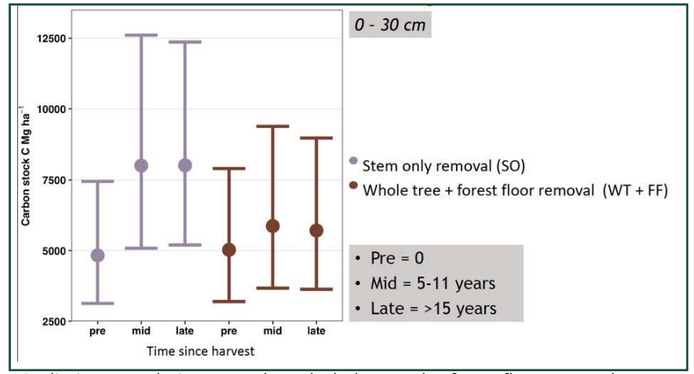
Resilience of Soil Organic Matter to Harvesting: A Global Study of Long-term Soil Productivity Experiments

Jeff Hatten (OSU), Stephanie Winters (OSU), Kate Heckman (USFS), Deb Dumroese (USFS),
Scott Holub (WY), Loretta Garrett (Scion, NZ), 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 Two Progress

- Ongoing 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).
- Using carbon-14 dating for soil organic matter across three of the sites to analyze carbon pools



Preliminary analysis stem-only and whole tree plus forest floor removal.

Preliminary analysis on 2 sites with stem-only removal shows a modest increase

Preliminary analysis on whole tree sites shows weak decrease

Future Plans

- Continue measure radiocarbon on other sites and soils
- Density fractionation to determine which portion of the soil (particulate or mineral associated) carbon pool is being affected
- XRD and selective dissolution to determine the role of mineralogy in setting up a soil's resilience
- Biomarkers to determine sources (roots, shoots, microbial, etc.)

2021 CAFS Phase 3 Progress Report

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)

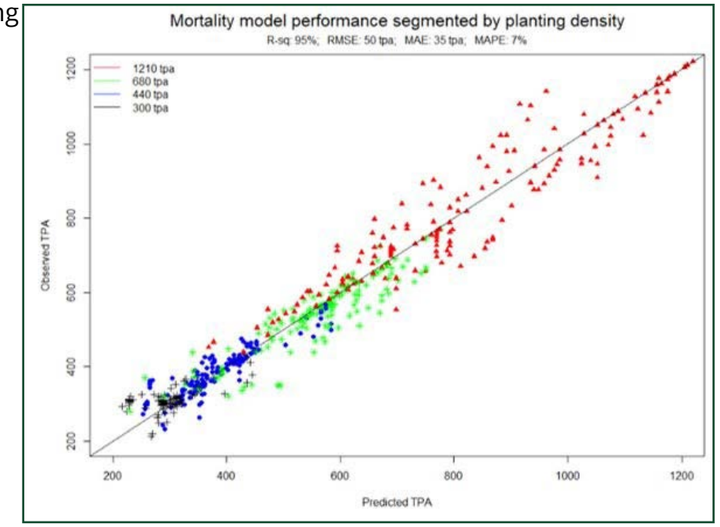
Forecasting yield is a primary objective of forest managers, who often use more than one tool for making predictions; stand level models are used for longer-term planning, while individual level models are often used for closer-to-harvest forecasts when needed. With this project we propose to build on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

- Incorporating pre-commercial thinning effects
- Eigenanalayis of the climate NA data across 25 of the type 3 sites contirbuting data to our mortality modeling
- Sources of variation in the current data set include frost-free period, mean annual precipitation, beginning and end of the frost-free period
- Some of the historic data is spotty, had to fit second order response using most important predictors from the Eigenanalysis

Future Plans

- Further updates on PYC modeling
- Benchmark fitted model with treatment augmentations (jackknifing, cross-validation) against independent data set
- Expand technology to other commerical use types



Project Highlights

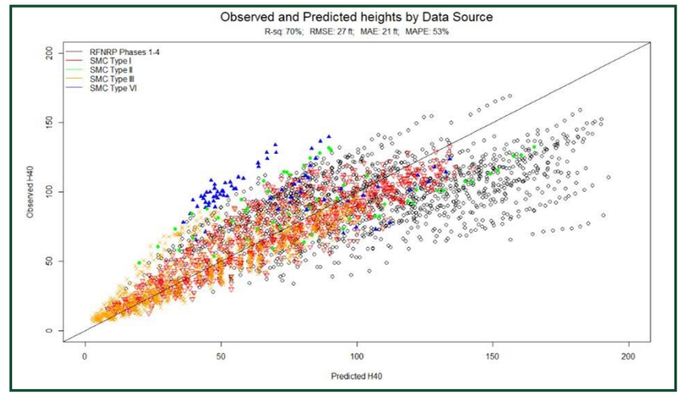
Using Predictive Analytics to Decompose Site Index

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 Two Progress

- Identified the modified-Weibull as the preferable model for height over age
- Compared the behavior of the parameters relative to the asymptote and then each other, finding the shape parameter of the modified Weibull to be the most independent variable of the height over age curve



- Shape parameter driven by temperatures, less so by precipitation and standard attributes

Future Plans

- Observed relationship between rate and shape parameters indicate a uniqueness and independence to shape. Relationship is robust across age, location, spacing, and natural vs. planted. The largest shape values are fitted on the older, dense stands.
- Include soil data attributes in RHS predictor set for both rate and shape. Shape in particular is a number that exists "in the wild" and is likely a complex function of many variables and their interactions.
- Exploration of machine-learning techniques to relate (rate, shape) to various static, periodic, and dynamic predictors.
- Online tool for mapping of base layers (predictors) and facilitating site index predictions in development through partnership with Precision Forestry Cooperative at University of Washington.

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 Two Progress

- 21 installations cored, dated, and measured for earlywood and latewood growth
  - Response was greatest in the first 4 years, but continued up to 10 years
  - Responding installations had higher elevation & forest floor C:N ratio and lower NO3 and Al
  - Temporary responders grew more earlywood or latewood shortly after fertilization, but grew the same as controls after 2 years
  - Some non-responders grew significantly less ring area in fertilized trees
- 15 installations split into earlywood and latewood for -1 - 6 years after fertilization
- One responding installation analyzed for C and O isotopes from wood and alpha cellulose
  - Wood ratios are highly correlated with alpha cellulose ratios
- Fertilization decreased D13C and increased water use efficiency especially in earlywood
  - Greater photosynthetic assimilation
  - Hot and dry spring in 2015 lowered stomatal conductance and increased water use efficiency
- Increasing effect of fertilization on d18O in latewood is likely due to increasing leaf area over time
  - Late summer drought reduced stomatal conductance

Future Plans

- Analyze remaining 20 installations for C and O isotopes
- Core 9 installations in Spring 2021
  - Measure tree rings and analyze C and O isotopes in 2022
- Publish peer-reviewed publications from the results of this study

Project Highlights

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. The 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. A species comparison study was installed in 1996 by Starker Forests in Central Oregon. Nine native and non-native conifer species were planted in three sites along a water deficit gradient from the western Coast Range to the Willamette Valley of western Oregon.

Year Two Progress

- Install measurement plots and tag trees
- Install weather stations and litterfall traps
- Initial Inventory (DBH, HT) and tree selection (10 per plot)
- Understory Vegetation Survey and Biomass sampling

Future Plans

- Continue bimonthly measuring LAI and Light Interception with LAI-2200c and Ceptometer
- Continue bi-monthly dendrobands and LAI measurement, as well as litter collection
- Ongoing wood coring, foliar sampling, forest floor and soil samples
- Peer-reviewed publications and presentations to broad audiences
- Data collected will be used to calibrate and validate the model 3-PG, allowing addressing the effects of climate change in productivity and deployment distribution for all nine species

DF	Douglas-fir
GF	Grand fir
GS	Giant sequoia
POC	Port Orford cedar
PP	Ponderosa pine (Willamette Valley)
SSP	Sitka spruce
WH	Western hemlock
WRC	Western red cedar
WWP	Western white pine (Blister Rust Resistant)

Stem Form of Nitrogen-fertilized Douglas-fir Trees

Doug Mainwaring (OSU), Kim Littke (UW), Eric Turnblom (UW),
Aaron Weiskittel (UM), Sukhyun Joo (OSU), Carlos Gonzalez (OSU)

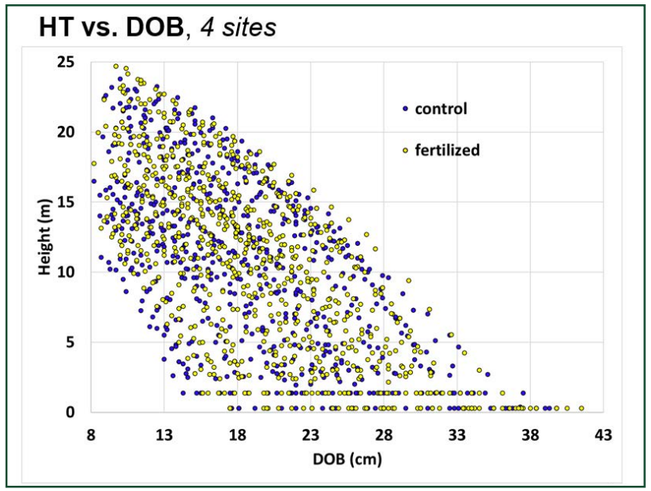
Current estimates of the positive Douglas-fir volume response to nitrogen fertilization are based entirely on measurable responses of diameter at breast height and total height despite the fact that log volumes are based on top-of-log scaling diameters. A recent analysis of stem form from a sample of Douglas-fir growing in operational stands shown to respond to nitrogen fertilization found that fertilization was a significant explanatory factor in describing the larger upper stem diameters within fertilized stands, all else being equal. The Stand Management Cooperative at the University of Washington currently has a large regional experiment studying the response of late rotation aged stands to nitrogen fertilization. Being the closest simulation of actual operational N fertilization to date, these sites provide an ideal setting to test for the upper stem response to N fertilization. Being able to estimate a more comprehensive and precise volume response to fertilization would improve the ability to assess where fertilization would be appropriate, as well as the financial benefit gained by treatment. This study would involve measurement of upper stem diameters four years following treatment, with an anticipated second measurement 4-6 years later, at time of final harvest.

Year One Progress

- Field sites located based on potential N response, fertilized 8-10 years prior to final harvest
- Samples sites chosen based on positive response, dominant height
- Sampled site ages: 30-40 years
- Field work completed height and DOB measurements at five installations

Future Plans

- Statistical analysis of measurements
- Report with final models describing stem form, accounting for the effect of fertilization
- Public presentation of findings at CAFS Annual Meeting and regional Coop meetings
- Draft manuscript for peer-reviewed journal



Project Highlights

A Neural Network Approach to Generating Leaf Area Index Estimates Using the Sentinel-2 Satellite Record and LiDAR

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

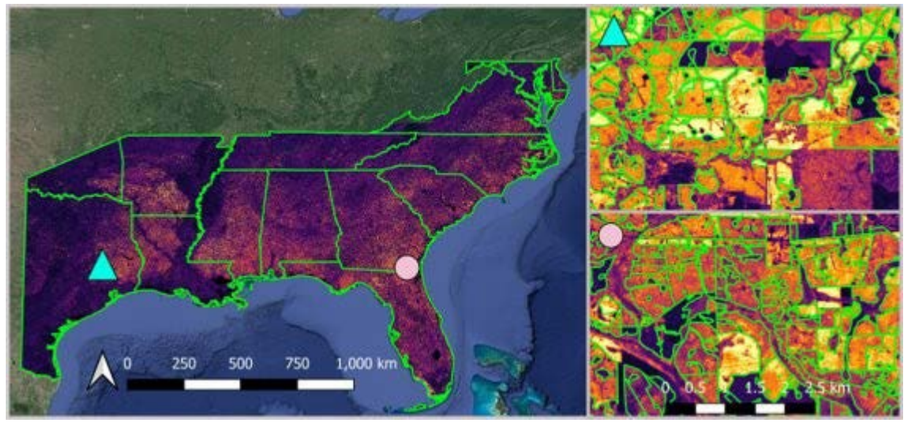
This project seeks to expand the capability and accessibility of our ongoing modeling work in predicting timber plantation canopy leaf-area index (LAI) using freely available global-coverage satellite data. Leveraging the work completed to date, we seek funding to 1) expand the species range covered by the model, 2) develop a user friendly interface so the results can be accessed and used by the non-specialist, 3) build capacity to predict and map deciduous understory presence, and finally 4) to build a national-scale site potential productivity baseline map for future silvicultural response modeling.

Year One Progress

- "Global" + machine learning calibrated to Loblolly pine canopy LAI
- Built a more sophisticated neural net model (predicts more accuratley when using large amounts of lidar training data).
- Using time difference between winter and spring to reveal where decidious understory is underneath the canopy
- Looking at ground data

Future Plans

- Produce accessible tools/databases for canopy and understory mapping across variety of forest types and regions
- Build web-based interface making it possbile to drop in a shape file and date range to produce mapping



Software works through Google Earth Engine -- project is building the algorithm

Data + computing power already exists in the cloud

Input date+time to produce maps on demand

Scalable for large areas, time series

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

Joe Dahlen (UGA), Cristian Montes (UGA), Bronson Bullock (UGA), Corey Green (VT), Harold Burkhardt (VT), Tom Eberhardt (USFS)

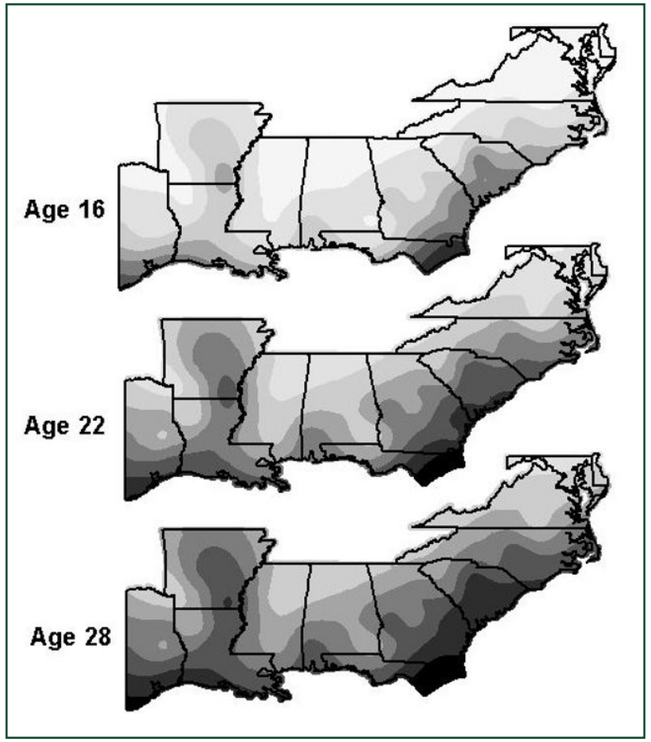
Even though over 18 billion board feet of southern pine lumber are produced each year from the U.S. south, information on silvicultural treatment impacts on lumber quantity and lumber is very limited. This is because forest through mill studies are difficult to conduct and thus rarely done. This study 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. The study has 3 treatments, a control treatment with no thinning or pruning, a light thinning treatment where 1/3 of the trees have been removed, and a heavy thinning treatment where 2/3 of the trees were removed and the first log was pruned.

Year One Progress

- Lumber sawn at mill and 1,200 pieces arrived in Athens in June
- Analysis of log acoustic velocity
- Regional effects on velocity

Future Plans

- Measure volume, grade and mechanical properties of lumber to determine silvicultural treatment effects
- Lumber testing



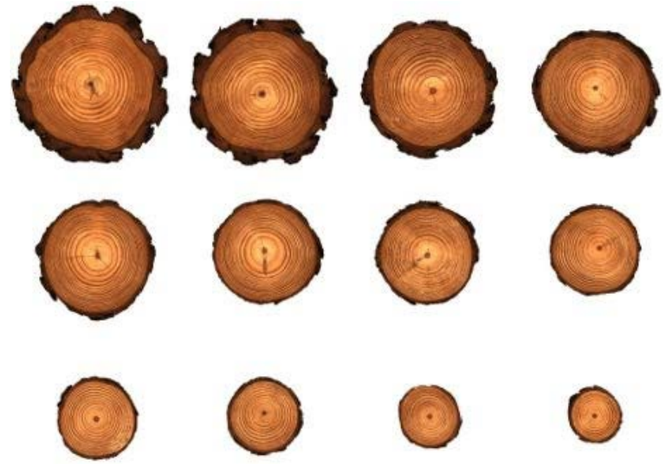
Specific gravity variations from differing regions at different ages.

Project Highlights

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

Joe Dahlen (UGA), Cristian Montes (UGA), Bronson Bullock (UGA), Dan Markewitz (UGA), Tom Eberhardt (USFS)

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. This study will investigate carbon sequestered in the main bole of loblolly pine from the CAPPS study which has 4 treatments: control, herbicide, fertilizer, and herbicide plus fertilizer. The study will be harvested as part of an AFRI grant, and thus this provides an opportunity to sample this study at a final harvest.



Year One Progress

- Plot level information on the biometric data
- Determining what sampling will be done

Future Plans

- Dan Markewitz leveraging PINEMAP, growing CAPPS – Soil health in managed forests
- CAPPS study will be harvested and replanted
- Working with Dan Markewitz on logistics to sample trees
- Carbon stored in the main bole as a function of silviculture treatment.
- Preliminary results on a field tool to estimate stored at a stand level when combined with tree biometric information.

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INTERN: Improving Forest Sample Estimation Through UAS Canopy Structure Stratification

Mark Kimsey, Logan Wimme (UI)

Evaluate the use of UAS to improve traditional stand inventories through photogrammetric stratification of imagery derived canopy height models to increase accuracy and reduce cost of traditional inventories.

Year One Progress

- Aerial imagery collected for six sites
- Drone flights completed
- Canopy stratification completed
- Stratified plots generated
- Stratified cruises completed
- Traditional cruises completed
- Point clouds generated to create canopy height models

Future Plans

- Obtain volume estimates from DNR (traditional)
- Compare volume estimates (traditional vs stratified)
- Conduct cost analysis
- Assess effectiveness of UAS stratification approach

Project Highlights

Supplemental Grants Awarded Fall 2021
START: Skills Training in Advanced Research & Technology

NC State University & Montgomery Community College Summer Internship Program

Rachel Cook and Andrew Trlica, NC State University
Dylan Hurley, Montgomery Community College

Partnership with Montgomery Community College offering paid internships/field experience with CAFS member company and CAFS research experience at NC State. Focus on GIS and remote sensing and on the ground experiences. Three $3k internships for 2022 and 2023. Goal is to create pipeline to the NC State forestry program that might lead to graduate school studies or employment with CAFS industry members.

MONTGOMERY COMMUNITY COLLEGE

University of Maine & University of Maine at Fort Kent

Aaron Weiskittel and Nicole Rogers, University of Maine
Neil Thompson and Ned Rubert-Nason, University of Maine Fort Kent

Partnership with University of Maine Fort Kent's 2-year technical college to support a two-year project on spruce budworm that will use high-resolution UAVs and foliar traits to detect early defoliation or trees that are susceptible to it. Internships will encompass lab sampling and field work.

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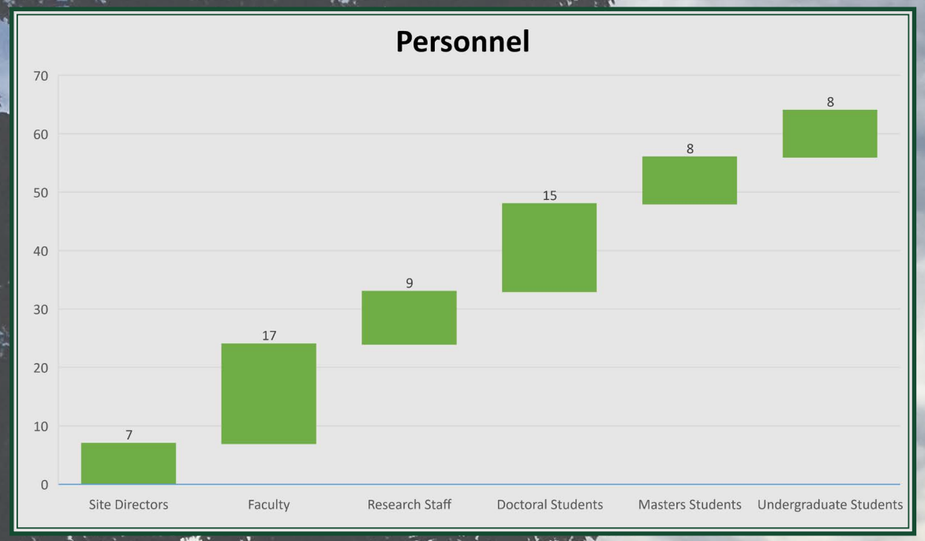
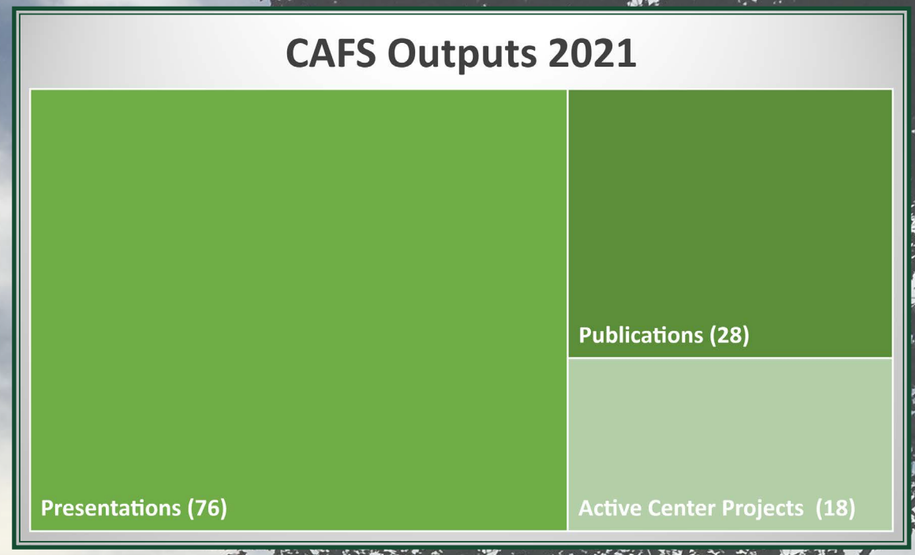
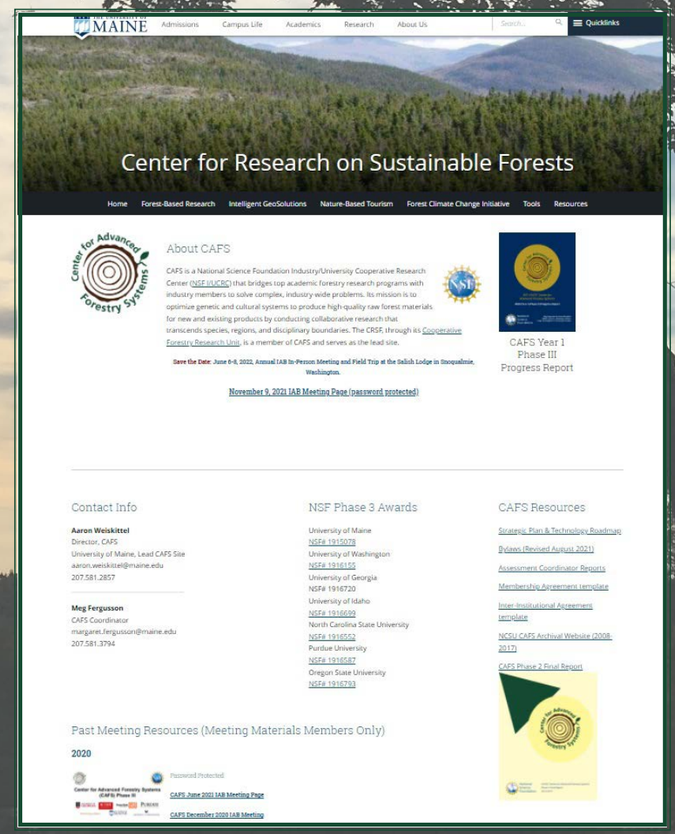




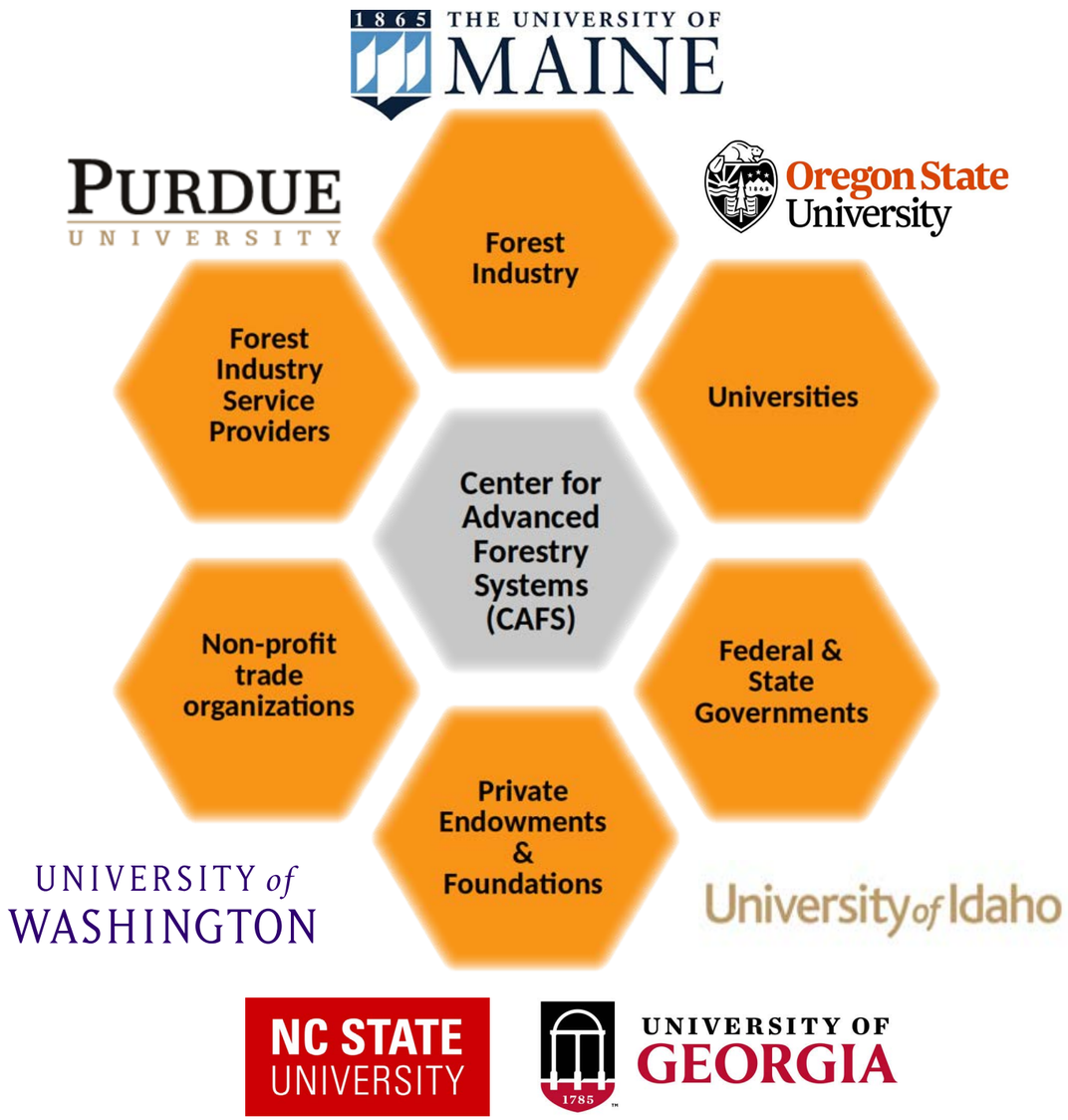
Results of informal poll on technology needs and issues from the November IAB meeting.

Top information-related (i.e., data) challenges	Most important technological needs	Type of technologies organization currently uses	Primary issues facing forest landowners
Incompleteness of information	Better decision-support tools	GIS	Incomplete information
Complexity of information	More accurate or higher-resolution information (data)	Growth and yield models	Incentives for active management
Cost of information	Improved linkage of available decision-support tools	Inventory systems	Demands for ecosystem services (e.g. carbon, biodiversity)
Access to information	Easier access to information (data)	Relational Databases other than GIS	Restrictive policies
Lack of representativeness or relevance of available information		Remote Sensing	Lack of markets
		Field-ready smartphones or tablets	

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



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.



Center for Advanced Forestry Systems