**PROJECT ID:** (CAFS Central will fill in new project code)

**PROJECT TITLE:** Density Management Strategies for Enhancing Carbon Sequestration in U.S. Working Forests

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| **PROJECT DESCRIPTION:**  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 proposed 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.  Thinning is a common silvicultural method that is widely utilized for production of timber goods, stimulation of tree regeneration, and stand quality improvement. There has been renewed interest in density management to mitigate forest health risks and enhance C sequestration. While a rich volume of work has examined thinning practices under a variety of treatment timing and intensities (i.e., residual stocking), questions remain regarding the influence of site conditions (available water, light, nutrients) and competitive interactions on tree response. To date, little is known about the edaphic, climatic, and physiologic mechanisms of the duration and magnitude of tree response to thinning across the working forested regions of North America. Therefore, quantifying the site-specific limiting factors to growth is imperative to adaptative management strategies and appropriate silviculture. In emerging studies, tree ring stable isotopes and composite estimators of evapotranspiration rates and site productivity have been used to reconstruct tree water use efficiency and disentangle the influential factors of silvicultural treatments (e.g., thinning fertilization) and site conditions on stem growth response.  This project aims to leverage regional plot networks that have been previously established for density management research studies. The approach optimizes the allocation of sampling resources while minimizing time needed for completion of the project and expected deliverables. The overall goals of this work are to quantify the causal mechanisms of thinning response through the integration of tree-ring stable isotopes (*δ*13C and *δ*18O) with high spatiotemporal resolution remote sensing estimates of evapotranspiration and productivity estimators across working forests of the U.S. Findings from this work can offer insight to the limiting factors of site carrying capacity (e.g., Stand Density Index) and thinning response, leading to refined site-specific density guidelines, silvicultural planning, and forest C sequestration. |
| **HYPOTHESES and/or OBJECTIVES:**  The overall objective of the proposed project is to assess site-specific factors of operational thinning response with new and emerging tools in operational forestlands. Specific objectives include: **1**) Quantify the causal mechanisms of stem growth response (or lack of) to variations in thinning intensity, timing, and site variables through sampling and analysis of tree ring stable isotopes (*δ*13C and *δ*18O) with long-term datasets **2**) Link remote sensing composite estimates of productivity, (e.g., cumulative monthly timesteps of water availability) with thresholds of thinning response across the hydrologic gradient of sites and patterns in stable isotopes **3**) Test the accuracy, precision, and compatibility of tree and stand reconstruction through stem increment cores with field measurements to form a framework for future sampling efforts **4**) Develop site- and species-specific silvicultural thinning guidelines and geospatial tools of estimated treatment response to aid decision support in commercial forest operations. |
| **METHODS:**  This study will be established in two phases: [**1**] A pilot project in 2023-2024 at UMaine on the Commercial Thinning Research Network density management study; and [**2**] Expansion of the approach across forested regions of the U.S., including the Pacific Northwest (UW), Inland Empire (UI), and Southeastern (UGA, NCSU) in 2024-2027.  [**1**] The CTRN experimental sites cover a range of site quality, mean annual precipitation, and evapotranspiration, and was installed by the Cooperative Forestry Research Unit in 2000. In 6 of the remaining CTRN installations, 40 trees (1 per diameter distribution quintile) will be sampled and cored at each Control and lowest residual density thinning plot of both species (1 spruce and 1 fir), for a total of 240 sampled trees. 2 increment cores will be taken at breast height and processed for cross-dating and measurements at the Forest Ecology Laboratory at UMaine. Cores will be measured for radial growth 10 years prior to treatment and 20 years post- thinning. Tree tissue samples of *δ*13C and *δ*18O will be composited by tree and at set time intervals -immediately pre-harvest, and 4-8-12-16 years after treatment - for a total of 5 samples of stable isotopes per tree. Samples will be prepared at UMaine and processed at the Stable Isotope Laboratory at Columbia University. Estimates of evapotranspiration and potential productivity at each treatment plot will be generated with geoprocessing software to estimate incoming radiation and combined with publicly available monthly climate records. SWA estimates will be conducted at a monthly time step from 1998 to 2020 to test the influence of average and cumulative SWA since treatment on radial growth response and stable isotope discrimination. For this analysis, we will estimate monthly evapotranspiration from January 2000 to December 2022 to align with the duration of the CTRN study, and test potential interactions between productivity estimators, *δ*13C and *δ*18O, and diameter growth increment. Response to competition will be quantified using 20 Competition Indices (CI) that are most common in the literature. The work will support the development of an original MSc thesis that will be submitted as two separate peer-reviewed journal articles.  [**2**] There are several notable long-term density management studies across the regions of CAFS membership. For this component of the project, each cooperating region will conduct field measurements and destructively sample tree ring cores like the process outlined above but tailored to the measurement cycles and any unique characteristics to the study design. The specific plot networks of interest are: (*i*) Type I Series at the Stand Management Cooperative (UW); (*ii*) Region Wide 19 at the Forest Productivity Cooperative (NCSU); (*iii*) Culture x Density at the Plantation Management Research Cooperative (UGA); and (*iv*) Paired Plot Density Management (PPDM) network at the Intermountain Forestry Cooperative (UI). Raw samples will be sent to the UMaine Forest Management Laboratory for in-house measurement of ring-widths and pre-processing for isotope lab submission. Data will be shared among collaborators and used as the basis of an original thesis work by a graduate student at UMaine that will be submitted as two peer-reviewed journal articles. A variety of statistical tests will be used for analysis and predictive modeling, including, but not limited to; (non-)linear mixed models (NLMM), generalized additive models (GAM), randomForest regression, Cubist regression, and regression-kriging, to generate spatially explicit estimates of variables of interest and decision support tools (e.g., site specific relative density targets) with associated ranges of uncertainty. |
| **PROJECT TIMELINE:**  Summer 2023 Core 2 **CTRN (UMaine)** sites with plot measurements.  Fall 2023 Sample preparation and processing.  Spring 2024 Analysis and reporting.  Summer 2024 Core 4 **CTRN** (**UMaine**) sites with plot measurements.  Core6 **RW-19** (**NCSU**) sites,6 **Type I** (**UW**) sites.  Fall 2024 - Spring 2025 Sample preparation and processing.  Summer 2025 Core 6 **C x D sites** (UGA), 6 **PPDM** (**UI**), 1 MSc thesis (CTRN)  Fall 2025 – Fall 2026 Sample preparation and processing/ report generation.  Spring 2027 – Summer 2027 Workshops, manuscript generation, 1MSc thesis (All Sites) |
| **EXPECTED DELIVERABLES – ONE YEAR:**  6 CTRN sites in Maine will be sampled during the first year to work out the sampling protocol, perform field measurements, collect tree-ring samples, and pre-processing. Tree cores will be sent to Columbia University for processing of *δ*13C and *δ*18O isotopes. Field data and remote sensing-based estimates of productivity will be integrated with isotope results for analysis. By end of summer 2024, 6 RW-19 and 6 Type I Sites measured, and cores collected. |
| **EXPECTED DELIVERABLES – LONG-TERM:**  1) A final report that uses the integrated findings from across cooperating regions into a cohesive document for C-oriented management guidelines in U.S. working forests  2) Integration of cross-regional cooperative datasets for analysis and collaborative extension  3) Four publications submitted to peer-reviewed journals that reflect each project objective.  4) Partial support for 2 MSc students with original thesis works |
| **POTENTIAL MEMBER COMPANY BENEFITS:**  Synthesize the quantification and assessment of observed correlations between stand structure, edaphic variables, and thinning physiologic response into regional silvicultural recommendations for working forests. Improve silvicultural recommendations for density management for major conifer species across the U.S. |
| **NEXT YEAR’S PROJECT BUDGET – NSF/CAFS PORTION:**  Student tuition support $28,869 (CAFS UMaine) |
| **NEXT YEAR’S PROJECT BUDGET - OTHER SOURCES, INCLUDING SITE-SPECIFIC:**  Student tuition support $28,869 (CAFS UMaine)  Field sampling and processing costs - $11,500 (CAFS NCSU); $11,500 (CAFS UW) |
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