**COOPERATIVE FORESTRY RESEARCH UNIT**

**PRE-PROPOSAL**

**PROJECT TITLE:** Secrets in the CTRN: Causal factors of thinning response and transfer to adaptive management regimes in Maine spruce-fir forests

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**ABSTRACT:**

Standdensity management through thinning is a common silvicultural method that has traditionally been utilized for production of commodity timber goods, regeneration, and quality improvement. Recently, there has been renewed interest in thinning regimes to mitigate forest health risks, enhance C sequestration and structural complexity, and control competing vegetation. While a rich volume of work from the Commercial Thinning Research Network (CTRN) has examined thinning practices under a variety of treatment timing and intensities, questions remain regarding the interactions of stem and stand response with site conditions (i.e., site productivity). To date, little is known about the edaphic, climatic, and physiologic mechanisms of the duration and magnitude of tree response to thinning in the Northeast region. Therefore, quantifying the site-specific limiting factors to growth is imperative to adaptative management strategies and effective silviculture. In other regions, tree ring stable isotopes have been used to reconstruct tree water use efficiency and disentangle the influential factors of silvicultural treatments, including thinning, and site conditions on stem growth response. However, most efforts have been limited to a single study area and un-replicated across a landscape or region. In parallel, advances in remote sensing derived estimates of water balance through potential evapotranspiration have been demonstrated to provide unbiased, high spatial resolution predictions of thinning treatment response, yet lack a descriptive biological mechanism. Therefore, this project aims to quantify the site and physiological causal mechanisms of operational thinning response through the integration of tree-ring stable isotopes (*δ*13C and *δ*18O) with high spatiotemporal resolution remote sensing estimates of evapotranspiration (20 meter at 1-month intervals) across the CTRN study sites in Maine. Findings from this work can offer insight to the site-limiting factors to site carrying capacity (e.g., Maximum Stand Density Index) and thinning response, be used to generate new, site-specific density management guidelines, and may serve as a framework for growth model calibration, and future planning.

**PROJECT OBJECTIVES:**

The overall objective of the proposed project is to assess site-specific factors of operational thinning response with new and emerging tools across mixed spruce-fir across Maine. Specific objectives include:

1. Quantify the causal mechanisms of long-term 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) and long-term CTRN 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 the CTRN sites
3. Simulate potential changes in thinning response and growth dynamics given alterations in future climate scenarios and seasonal water availability
4. 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
5. Develop regional spatiotemporal silvicultural thinning guidelines and geospatial tools of estimated treatment response to aid decision support in commercial forest operations

**BACKGROUND:**

Density management is a common regime in Maine owing in part to past episodic disturbances and forest and land use policies. A lot of questions remain, and there are new questions regarding other benefits in light of diseases (BBD) and new markets (e.g., terrestrial C sequestration and long-term storage)

[1] Creativity and innovation in forest management requires an understanding of site-physiologic dynamics integrated with new technology – need to reassess the past methods to date to ensure that they are aligned with site capacity

Pull from BEF here.

The importance of thinning in density management for traditional and evolving practices

Optimal silvicultural practices maintain stand density levels that balance individual tree growth, stem quality, and stand volume production. The goal is to maintain stocking levels that capture site resources and avert growth stagnation (Langsaetter 1941), the rate of which are ultimately dependent upon base site productivity, and species-specific development patterns (Pretzsch 2009). To date, the effect of site conditions has largely been represented by a proxy variable (i.e. site index), classification factor, or altogether omitted.

*Looming questions, - what are causal mechanisms behind the magnitiude and length of response.*

*Response diminishes as either 1. Limited water gets used up by residual trees and then underground competition limits growth, or*

*2. if water is adequate, then trees will continue to grow/expand crowns until light becomes limiting (aboveground competition)*

*Different ways to get at the water component.*

*[2] Forest productivity linked to water (Gholz et al.) but little is known about it*

While the NE doesn’t’ have drought, species performance and yields are ultimately dependent upon a niche within the terrestrial-atmospheric gradient of precipitation, temperature, and radiation inputs.

Forest vegetation productive capacity *reflect site water availability and seasonal variations in evapotranspiration*, which in turn reflect local physiographic and regional climatic patterns.

Site water availability (SWA) can be simplified as a direct function of precipitation, evapotranspirative demand, and soil water storage. While demonstrated as an explicit component of stand productivity (Scolforo et al. 2019), SWA can further serve as a robust indicator of seedling survival and early growth (Waghorn et al. 2015), genetic performance (Prevéy et al. 2018) and response to silvicultural treatments including competing weed control (Gonzalez-Benecke and Dinger 2018) and thinning (Ojeda et al. 2018) at local sites.

Contemporary developments in data science and geoprocessing technology offer an attractive solution to estimating spatial trends in terrestrial productivity through the integration of climatic, physiographic, and edaphic remote sensing data and field measurements. Recent efforts to generate geocentric productivity estimates in commercial plantations of New Zealand (Watt et al. 2010) and Chile (Montes et al. 2016) at high resolution (100 m/328 ft) framework offer a potential solution.

There are different ways to get at the questions,

C and O isotopes

but so far no one has combined the two

[3] Treatments to reallocate resources sometimes work, sometimes they don’t - why can be answered through isotopes

Past and current work

Tying all of this together could provide a novel approach to thinning prioritization in mixed spruce-fir and advance our knowledge of the craft

Isotopes in other regions

Marshall et al., at sites with lower water, higher discrimination, and shorter response

At sites with adequate water, lower discrimination, and longer response

If we can tie in relationships with water, we can generate high resolution maps for management support and provide good baseline data for future forest managaemnet.

**APPROACH:**

This study will utilize fertilized and control tree-based plots in the SMC Type V Paired-tree projects across Oregon and Washington, USA and British Columbia, CAN. These sites cover the major physiographic sub-regions characteristic of the PNW across a range of plantation ages and site and stand conditions. The SMV Type V uses a paired-tree approach, with extensive soil chemistry, micrometeorological, and foliar nutrient data collected prior to treatment (Littke et al. 2014).

In a subset of twenty installations from the SMC Type V study, a total of 20 trees (1 per quintile) will be selected from each installation (10 control and 10 fertilized) for 400 trees total for collection of increment cores (Figure 1). Cores will be taken at breast height (1.3m) and processed for cross-dating at the UW. Stem rings will be measured for early/latewood two years prior to and six years after fertilization. Tree cores six years after fertilization will be split into earlywood and latewood and will be composited by year, treatment, and installation for measurement of δ 13 C and δ 18 O (at Northern Illinois University) to determine the relative impact of N addition to A/gs patterns, and explore these variables across ranges in site and stand conditions. These methods have been effectively utilized to assess physiologic response and intrinsic water use efficiency in conifer thinning studies (Warren et al. 2001; Powers et al. 2010) and fertilization treatments of Douglas-fir (Brooks and Coulombe 2009; Brooks and Mitchell 2011; Cornejo-Oviedo et al. 2017) in single site experimental units. Tree-ring derived growth rates and isotopic composition (i.e. Δδ13C) will be used in conjunction with micrometeorological data to assess the relative contribution of edaphic and stand conditions on physiological utilization of N. We anticipate using a variety of statistical methods for analysis and predicting response by site and stand conditions with linear and non-linear mixed models using the glmm (Knudson 2018) and nlme (Pinheiro and Bates 2018) packages in R statistical programming environment.

**ANTICIPATED BENEFITS TO CFRU MEMBERS:**

The project will leverage the CTRN, a unique, regional network of experimental thinning plots that spans the mixed spruce-fir forests of Maine.

that integrates traditional tree and plot measurements with remote sensing and micrometeorological variables. Findings from this work will be used to generate site-specific, predictive estimates of potential productivity of planted WS forests and natural regeneration that can be mapped with high resolution (e.g., 1/5 acre) across the region. These products can serve as decision support tools for multiple landowners seeking to strategically diversify their product portfolios (timber commodities, C, etc.) across their forestlands. These benefits directly support and align with the stated 5-year goals of the CFRU; Refining new tools for determining site productivity (Silviculture and Applied Research), and: Improving land base descriptions and modeling site productivity (Emerging Technologies and Modeling).

**APPROXIMATE LENGTH OF STUDY:**

Initial 2 years of study funded by CFRU, years 3-4 funded by Maine Agricultural and Forest Experiment Station.

**ESTIMATED AMOUNT REQUESTED FROM CFRU:**

For full support of 1 M.S. student, field sampling, faculty summer salary - $160,000 ($53,333 per year). Funding for an additional

**MATCHING FUNDS:**

Experimental sites, seedlings, planting, and treatment operations will be provided in-kind by JD Irving.Measurements and student support past year 3 of the project will be supported by funding provided by the Maine Agricultural and Forest Experiment Station.5 -year recurring measurements will be funded by availability.

**DELIVERABLES:**

Findings from this work will be disseminated to cooperators in the form of technical reports and raster geospatial tools. Site tours and technical transfer workshops will be used to demonstrate operational application and facilitate cooperator engagement with products. This project seeks to support a total of 2 M.S. students, each of which will generate original thesis works that can be submitted to peer-reviewed forestry journal articles. This project and associated products can be further used as a framework for additional investigation.

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**TITLE: Physiologic Response to Commercial Fertilization Programs in Pacific Northwest Forest Plantations**

**LOCATION:** Oregon and Washington USA; British Columbia CDN

**DATE:** 24 July 2018

**PROJECT OBJECTIVES**

The overall objective of the proposed project is to assess forest ecophysiology patterns in operational nutrition programs across the Pacific Northwest region. Specific objectives include:

1. Investigate causal mechanisms between edaphic variables and physiological processes across the leaf, tree, and stand scales under variations in fertilization timing and stand/site conditions
2. Provide empirical data to inform silvicultural treatment response in Growth and Yield (G&Y) prediction and projection systems and regional resource management support under current conditions and variations in future climate
3. Develop regional spatiotemporal silvicultural nutrition guidelines for commercial forest operations

**JUSTIFICATION**

**Linkage to the Center for Advanced Forestry Systems (CAFS) research plan**

Sustainable growth and productivity in the forest industry has been identified as a priority subject area in the National Science Foundation Industry/University Cooperative Research Centers (I/UCRC) program. This proposed project aims 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.

**Significance/Impact of Management Issue**

Forest productivity is commonly limited by site nutrient availability, and deficiencies can result in extended rotations, forest health issues, and ultimately, unrealized volume gain. The forest products industry of Oregon and Washington contributes a combined $50 billion to the annual regional economy, and 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. These processes have direct influences on terrestrial C sequestration and commodity volume and value. Therefore, additional information and site/stand conditions and quantifying causal mechanisms are needed for treatment deployment and matching silvicultural practices to site specific nutrient cycling rates and inherent productivity.

**Cost/Economic Efficiency**

This project aims to leverage existing regional research plot networks that have been established for biogeochemical assessment of nutrient management regimes (Project ID 16.69). The utility of an existing study network offers a considerable benefit in allocation of sampling resources and time needed for completion of project and outlined deliverables. Therefore, amending this proposed sampling program to current efforts is disproportionate to the anticipated products and benefits to regional and adaptive forest management.

**DESCRIPTION**

**Background**

Working forests have long been intensively managed for supply of timber commodity products, yet are increasingly recognized for their role as terrestrial C stocks and potential in emerging markets. As such, advances in precision and site specific silviculture can aid in establishing links between treatment factors and responses that extend to land use strategy, planning, and policy. Forest development and yield is constrained by inherent soil productivity, nutrient cycling rates, and local hydrologic processes (Assman 1970, Fisher and Binkley 2002, Landsberg and Sands 2010). In commercial plantations, nutrient additions through fertilization has been common practice to enhance productivity (Clutter et al. 1983, Binkley 1986). Nutrition programs vary by region across North America due to differences in geologic history, soil formation processes and characteristics, as well as major forest cover types and silvics.

In the Pacific Northwest, it is generally recognized that plant-available N is the primary limiting element to growth of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco.), while P+K can be equally important in some conditions (Steinbrenner 1968). As such, the majority of traditional nutrient management research in the region has primarily been limited to N applications, and early work in cooperative nutrition research assessed the response of second growth forests to mid-rotation (35-55 yr.) N applications and reported a range in results across stand density and dosage levels (Miller et al. 1979, Strand and DeBell 1979, Li et al. 2005). Growth response to N fertilization ranged from 0-12% and 20-35% in un-thinned and thinned stands, respectively, yet conclusive findings are confounded by comparisons across contrasting sites and insufficient power to detect treatment differences (Farnum 1979; Li et al. 2005). Recent efforts to prioritize fertilization programs by physiographic sub regions of the PNW have identified edaphic factors that are highly correlated with fertilizer response, including parent material and topographic features (Littke et al. 2014), and can greatly aid in management efforts in regional plantations. Yet, this work further highlights the importance of pre-treatment stand condition in the magnitude of response, which may be further attributed to causal mechanisms between nutrient uptake and utilization in physiological processes across the leaf, tree, and stand scales.

In general, greater stand density indirectly shifts leaf N and H20 utilization from CO2 fixation (C*f*) to light absorption (chlorophyll synthesis- *chl*) through shading effects and reductions in photosynthetically active radiation (PAR) (Hinckley et al. 1979, Brix 1983, Ripullone et al. 2004). Although N amendments at canopy closure can increase photosynthetic capacity through gains in water use efficiency (photosynthesis [*A*]/ stomatal conductance [g*s*]), the degree of response is limited by intensified light competition (and greater *chl*:*Cf*), and foliar deficiency of the stand compared with the site maximum at canopy closure (Brix 1983, Running and Coughlan 1988; Gholz et al. 1990). In contrast, N applications in stands of low density (either early in development or after thinning) have been observed to result in a dynamic response of increased photosynthetic rate in the short-term (2-3 years) shifting to gains in leaf area, stem growth, and long-term stand yields (Strand and DeBell 1979, Brix 1983, Brooks and Mitchell 2011; Cornejo-Oviedo et al. 2017). Therefore, auxiliary data provided by measurements of physiologic processes can aid in interpreting tree and stand response to intermediate treatments, and further provide a framework for spatiotemporal prioritization of management practices.

As mentioned, there has been noteworthy progress in identifying edaphic factors correlated to tree and stand response to fertilization across the PNW, and ongoing work by the Stand Management Cooperative (SMC) at the University of Washington (UW) continues to expand upon a robust regional plot network. We propose to leverage subsets of the existing plot network and utilize retrospective dendrochronological techniques to assess physiologic patterns of tree and stand response to past nutrition amendments. The objectives of this work are to (*i*) utilizing tree and stand physiologic measurements in conjunction with edaphic variables to advance regional site-specific precision silviculture, and (*ii*) provide baseline ecophysiological reference data for forest management planning in unknown future growing conditions.

**Methods**

This study will utilize fertilized and control plots in the SMC Type I and V projects for a total of 48 plots across Oregon and Washington, USA and British Columbia, CDN. These sites expand across major physiographic sub regions characteristic of the PNW, and while each has been designed with their own sampling system and objectives, they provide a long-term record of fertilization response across a range of plantation ages, and site and stand conditions. The SMC Type I plot network was established between 1986-1994 in juvenile *Psueotsuga menziesii* stands using a response by unit area (stand-level) approach, and provide long-term records of growth response, however lack detailed edaphic data at the time of treatment. In contrast, the SMV type V uses a paired-tree approach, with extensive soil chemistry, micrometeorological, and foliar nutrient data collected prior to and following treatment.

In a subset of pre-determined plots (SMC I – 18; SMC IV – 30) a total of 10 trees will be selected from each quintile (2 per quintile – 480 trees total) of the diameter distribution for collection of increment cores. Cores will be taken perpendicularly and at breast height (1.3m) and processed for cross-dating at the UW. Stem rings ± 7 years of fertilization date will be measured and separated by early/latewood for measurement of δ13Cand δ18O (at the UW IsoLab) to determine the relative impact of N addition to *A*/*gs* patterns, and explore these variables across ranges in site and stand conditions. These methods have been effectively utilized to assess physiologic response and intrinsic water use efficiency (*wuei*) in conifer thinning studies (Warren et al. 2001, Powers et al. 2010) and fertilization treatments of Douglas-fir (Brooks and Mitchell 2011, Oviedo et al. 2017) in single site experimental units. Tree-ring derived growth rates and isotopic composition (i.e. Δδ13C) will be used in conjunction with micrometeorological data to assess the relative contribution of edaphic and stand conditions on physiological utilization of N. We anticipate using a variety of statistical methods for analysis and predicting response by site and stand conditions with linear and non-linear mixed models using the *glmm* (Knudson 2018) and *nlme* (Pinheiro and Bates 2018) packages in R statistical programming environment.

**Products**: Project deliverables will include 1) synthesizing the quantification and assessment of observed correlations between stand structure, edaphic variables and N fertilization physiologic response into regional silvicultural recommendations for Douglas-fir plantations; 2) A report that uses the Northern Institute of Applied Climate Science adaptive silviculture and Climate Change Response frameworks for alternative treatment simulations under variations in future climate; and 3) Three publications submitted to high-impact peer reviewed journals that reflect each project objective.

**Schedule of Activities:** The proposed project is expected to last for two years commencing in September 2019 and ending in December 2021. Key project phases and their respective starting dates (mm/yyyy) are listed below:

09/2019 – Identify plot subsets for field data collection through auxiliary data and finalize sampling protocol

01/2020 – Data collection SMC Type I and V

06/2020 – Sample processing

01/2021 – Data collection SMC V

06/2021 – Sample processing

09/2021 – Submit final reports and journal manuscripts, present findings at a conference

12/2021 – Project completion

**PROPOSED BUDGET**

|  |  |  |
| --- | --- | --- |
| Budget item: | Justification | Cost |
| Graduate Student (MSc) | 12 months per year. Responsible for analyzing data, laboratory processing, writing reports and journal articles. | $42,000 |
| SMC Field Crew | 48 installations – estimated 1 day per tree core collection - Responsible for field sampling | $52,400 |
| Contract Services  (IsoLab- UW): | Isotopic analyses – a large number needed to determine physiologic processes to treatment over time across the region | $67,200 |
| UW Overhead (40%) |  | $64,640 |
| **Total** |  | $226,240 |

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