**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 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**

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| 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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