**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, tree 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., 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 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 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. 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 regional spatiotemporal silvicultural thinning guidelines and geospatial tools of estimated treatment response to aid decision support in commercial forest operations

**BACKGROUND:**

Silvicultural thinning is common in the mixed spruce-fir (*P. rubens* and *A. balsamea*) forests of Maine, owing in part to past episodic pest disturbances and land use policies. Traditional stocking targets were established to balance individual tree growth and quality, species dominance, stand volume, and commodity production, while minimizing mortality loss. There has been widespread and renewed interest in thinning to enhance C sequestration rates and wildlife habitat, decrease abiotic disturbance associated mortality (e.g., wind, fire), and mitigate susceptibility to pests, across a variety of landownerships and associated goals. However, questions remain regarding the transferability of stocking guidelines and compatibility with local growing conditions, stand and site response capacity, and long-term objectives. Therefore, a mechanistic understanding of forest growth processes, site dynamics, and response to treatments could improve and support precision silvicultural prescriptions.

It is generally recognized that organic productive capacity and species composition reflect site-specific seasonal variation in precipitation and radiation (site water availability - SWA), attributed to local topography and regional climatic patterns. In forest stands, the onset of tree competition can result in limitation of either water or sunlight through belowground root interactions or aboveground shading effects. Thinning can temporarily alleviate competition and increase growth and C sequestration until the residual trees re-occupy stand growing space. The duration and magnitude of thinning response is dependent upon residual density and SWA. However, it can be difficult to discern the relative impact of limiting factors (water, sunlight) on reduced growth with traditional measurements. The use of tree ring stable isotopes (*δ*13C and *δ*18O) offers a promising solution to identify the limiting factors to tree growth through a temporally referenced composite variable of water use efficiency (*wue* - C assimilated: water lost) (Marshall et al. 2022). This approach has been demonstrated to detect physiologic response and *wue* 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, and recently, regional paired-tree nutrition networks in the Pacific Northwest (Premer et al. 2018). To date, this approach has not been utilized in silvicultural trials of the Northeast region but could be especially useful in a setting with a long-term, replicated silvicultural trial like the CTRN to identify limiting factors to response. In parallel, remote sensing and geoprocessing technology have been utilized to develop high resolution (e.g. 1/5 acre) estimates of SWA in other regions in the form of a water deficit/surplus index as geospatial raster products (Montes et al. 2016; Premer 2020). While computationally intensive, this method utilizes user-defined cumulative monthly time steps to generate simple composite variables of locally calibrated SWA estimators. These tools have been successfully demonstrated as robust predictor variables in studies estimating site index of *Pinus taeda* (Koirala et al. 2021) in the SE, and response to thinning in *Pinus radiata* in Chile (Ojeda et al. 2018), and other applications in Douglas fir plantations across Washington and Oregon. While the NE region is not susceptible to drought or water deficit, excess water can decrease site quality, and optimal SWA for any given tree species varies with functional traits. Given the coupling of tree growth, leaf area, and SWA, this method may provide a framework to map potential thinning response and hydrologic based estimates of productivity in spruce-fir forests. The overall objective is to integrate CTRN plot records with stable ring tree isotopes and high spatiotemporal resolution estimates of evapotranspiration to generate site-specific potential of C sequestration and residual stem growth of spruce-fir stands given variations in thinning regimes and SWA.

**APPROACH:**

This study will utilize trees in thinned and control plots in the CTRN projects across Maine. These sites cover a range of site quality (SI50 = 43-79 ft.), and mean annual precipitation (40-51 in.), and evapotranspiration (5-8 in. water surplus). In a subset of 10 of the remaining 15 CTRN installations, 40 trees (1 per diameter distribution quintile) will be sampled and cored at each Control and 0.3 RD thinning plot of both species (1 red spruce and 1 balsam fir), for a total of 400 tree increment cores. 2 tree 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 of the year 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 Northern Illinois University or the Climate Change Institute at the UMaine. Estimates of evapotranspiration and SWA 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 1990 to 2020 to test the difference of average and cumulative SWA since treatment on radial growth response and stable isotope discrimination. A variety of open-source software will be used for data processing, analytical approaches will use numerous parametric and nonparametric statistical tests.

**ANTICIPATED BENEFITS TO CFRU MEMBERS:**

The project will leverage the CTRN, a unique long-term regional network of experimental thinning plots that spans the mixed spruce-fir forests of Maine. Results can provide previously unavailable information on limiting factors to stand growth response to management that can be directly transferred to application. Findings from this work can be used to update thinning guidelines and generate geospatial decision support tools in spruce-fir systems that are physiologically based and calibrated at a local, site level (e.g., 1/5 acre).

**APPROXIMATE LENGTH OF STUDY:**

Study duration will be approximately 2 years from startup to completion (2023-2025), with possibility of extension through the Center for Advanced Forestry Systems.

**ESTIMATED AMOUNT REQUESTED FROM CFRU:**

For 1 year of MS student support, 1 summer of field sampling, field equipment, faculty summer salary, and processing costs - $78,733

**MATCHING FUNDS:**

Year 2 of MS student support (~$35k) will be sought by the Center for Advanced Forestry Systems. Computing equipment (~3k) will be provided by funding from the Maine Agricultural and Forest Experimental Station.

**DELIVERABLES:**

Findings from this work will be disseminated to cooperators in the form of technical reports and raster geospatial tools. Site tours (2) and technical transfer workshops (2) will be used to demonstrate operational application and facilitate cooperator engagement with products. This project seeks to directly support a M.S. student, with cost-sharing to support a second M.S. student. Both students will work with faculty guidance to complete the project along and 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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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).

a total of 10 trees per species (red spruce and balsam fir)

Control, medium, heavy

10 each?

Tree cores six years at the 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.

What are we really trying to do: form site-specific, geospatial estimates of potential C13 discrimination/uptake, which in turn could offer a new framework for C sequestration management across various forest types (under what sites and conditions are trees starting to sequester less C as indicated by a gradual reduction in discrimination due to stomatal closure).

**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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Warren, C.R., McGrath, J.F., and M.A. Adams. 20

fine resolution remote sensing data (100 m), and geoprocessing applications to estimate a water deficit index (WDI) through integration of reference evapotranspiration and site water holding capacity (Montes et al. 2016).

offer an attractive solution to estimating spatial trends in terrestrial productivity through the integration of climatic, topographic, and meterological data. 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.

This approach offers a promising solution

Recent work

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.

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.

is constrained at any given site by incoming precipitation and radiation,

*reflect site water availability and seasonal variations in evapotranspiration*, which in turn reflect local physiographic and regional climatic patterns

and species-specific traits to utilize these resources to capture CO2 for maintenance and growth. In forested stands,.

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

radiation and water to

new and emerging tools can be employed to quantify the mechanistic processes of forest productivity.

quantifying and mapping of the key processes of tree and forest growth would support

all of which vary with growing conditions and site capacity.

Stocking guidelines, including specifications for thinning intensity and timing, are generally

ilvicultural practices such as thinning and soil scarification can directly manipulate site resource availability such as light interception and seedbed

Under traditional silvicultural regimes, stocking guidelines aimed to

for commodity production,

The goal is to maintain stocking levels that capture site resources and

However,

ultimately dependent upon base site productivity and species-specific development patterns.

As management goals have shifted to include a s

To date, the effect of site conditions has largely been represented by a proxy variable (i.e. site index), classification factor, or altogether omitted.

In the spruce-fir forests of the region,

the rate of which is

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

*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.

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

Shown to vary across a precipitation gradient….

WD estimates and mapping of other variables…

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