COFE 2026 Annual Meeting — Missoula, Montana | August 2-5, 2026

16.5 Continuing Forestry Education Credits from the Society of American Foresters are available for this conference

Conference registration check in will be available from 3-5 PM at the Holiday Inn and from 6-9 PM at the Welcome Reception on UM Campus

*** *Denotes a student presentation***

Day 1: Sunday, August 2

Time	Event
4:00 - 5:30 PM	COFE Executive Committee Meeting — Forestry 206, UM Campus
6:00 - 9:00 PM	Welcome Reception — Taco Dinner Hosted by Headwaters Tech Hub, Davidson Honors College Patio, UM Campus

Day 2: Monday, August 3

8:30 - 10:00 AM — Plenary Session I

Time	Talk
8:30-8:40	**Welcome to COFE 2026** *Beth Dodson*
8:40-9:10	**Welcome to the University of Montana** *Libby Metcalf*
9:10-9:20	**Overview of Conference & Field Tour** *Beth Dodson*
9:20-9:40	**State of the Forestry and Wood Products Sectors in Montana** * *Carmen Murrill*
9:40-10:00	**Frictionless Forestry: Why Applied Research Struggles to Translate into Practice** *Steve Bick*

10:10 - 10:30 AM — Break (Hosted by BurnBot)

10:00 – 10:10 | Ian Moore Welcome, Sponsorship by BurnBot

10:30 AM - 12:00 PM — Plenary Session II: Overview of Conference Topics

Time	Talk
10:30-10:50	**Optimization and AI: What Actually Works and What Are the Trends in Forest Operations Planning and Engineering** *René Zamora-Cristales*
10:50-11:10	**Management of Forest Roads in the Province of Quebec: A Review of Challenges and Solutions** *Shuva Gautam*
11:10-11:30	**What Drives Feller-Buncher Productivity? A Meta-Analysis, Key Factors Identification, and a Predictive Model** *Rafael O. Brown, Mathew F. Smidt, Nathaniel M. Anderson*
11:30-11:50	**Everything Everywhere All at Once — Landscape-Scale Cross-Boundary Forest Operations** *Nathaniel Anderson*

12:00 – 1:30 PM — Harvest Lunch with Chicken & Salad Bar

1:30 - 3:00 PM — Concurrent Sessions

Time	A1: Interactions Between Wood Properties and Operations *Moderator - Joe Conrad*	A2: Forest Management Systems *Moderator - Ben Spong*

1:30 – 1:50	**Automated Deep Learning-Based Log Cross-Section Ring Characterization in Ponderosa Pine** * *Tzu-I Liao, Woodam Chung, Laurence Schimleck*	**Effects on Harvesting Costs and Landowner Revenues When Introducing Shelterwood Management** *Lars Eliasson, Anders Rowell*
1:50-2:10	**Occlusion Rate and Defect Core Determination in Pruned Loblolly for Clear Wood Production** * *Paityn Matecki, Daniel DeArmond*	**Timber Harvesting Challenges on Small Family Forests in Northern Minnesota, USA** *Charlie Blinn, William Sauerer*
2:10-2:30	**Relating Log Cross-Section Ring Attributes to Lumber Mechanical Properties for Effective On-Site Log Sorting** * *Tzu-I Liao, Woodam Chung, Michelle Jayawickrama, Lech Muszyński, Laurence Schimleck*	**Understanding Virginia's Family Woodland Owners Management Decisions** * *Emma D. Busteed, Scott M. Barrett, Jennifer Gagnon, Shane Furze*
2:30-2:50	**On-Site Prediction of Knot Characteristics from Harvester-Derived Stem Diameter Profiles** * *Taehyung Kim, Woodam Chung, Lucas Wells*	**An Evaluation of Pruning Time Across Thinning Treatments in a 15-Year-Old Loblolly Pine Plantation** *Daniel DeArmond, Kevin Boston, Segar Chhetri, Matthew Pelkki*
2:50-3:00	**Q&A with all presenters**	**Q&A with all presenters**

3:00 - 3:30 PM — Break

3:30 – 5:00 PM — Concurrent Sessions

Time	**B1: Volume Estimation** *Moderator - Han-Sup Han*	**B2: Steep Slope & Tethered Systems** *Moderator - Charlie Blinn*
3:30-3:50	**Developing Supply Curves for Woody Biomass in Northwestern California Based on Harvest and Transportation Costs** * *Jonathan Guczek, Hunter Harrill, Natascia Magagnotti, Raffaele Spinelli, Alan Tepley*	**Productivity Analysis of Single-Stem Helicopter Logging Operations in Coastal British Columbia** *Omar Mologni, Rosalia Jaffray, Quinn Kenny, Gregory Paradis, Dominik Roeser*
3:50-4:10	**From Stem Scan to Stand Estimate: A Smartphone-Based Timber Cruising Application** * *Heechan Jeong, Heesung Woo, Taejin Kim, Jiyeon Ryu*	**Production Studies of Steep Slope Harvesting Machines in Northern California** * *Bridger Paradis, Hunter Harrill, Jeffrey Kane, Han-Sup Han*
4:10-4:30	**ForestStruct3D: A Newly Developed AI-Based Tool for Forest LiDAR Analysis with an Embedded Tree Segmentation Model** * *Jiyeon Ryu et al, Heesung Woo, Taejin Kim, Heechan Jeong*	**Winch-Assist Harvesting in Appalachia: Balancing Soil Impacts and Logging Productivity** * *Dylan Lang, Ben Spong, Curt Hassler, Mathew Smidt*
4:30-4:50	**Calculating the Volume of Roundwood Piles Under Cranes Utilizing UAS in the Southern U. S.** * *Prakash Ojha, Marissa 'Jo' Daniel, Richard Cristan, Brian Via, Lana Narine*	**Productivity Analysis of Shotgun Cable Yarding** *Hunter Harrill*
4:50-5:00	**Q&A with all presenters**	**Q&A with all presenters**

Evening — Dinner on Own

Day 3: Tuesday, August 4

8:30 - 10:00 AM — Concurrent Sessions

Time	**C1: Slash Treatment & Site Preparation** *Moderator - Hunter Harrill*	**C2: Environmental Impacts & BMPs** *Moderator - Mark Vessar*
8:30-8:50	**Operational Efficiency and Ecological Effects of Forestry Mulching in Alabama** * *Hannah Mayo*	**Evaluating the Effectiveness of Georgia's Forestry Stream Crossing BMPs for Current and Future Conditions** * *Emma Merritt, M. Chad Bolding, Joseph L. Conrad IV, Timothy R. Miller, Brent S. Hawks*
8:50-9:10	**Analyzing the Productivity and Cost of Slash Management from a Cut-to-Length Harvesting System in a Southwestern Ponderosa Pine Forest** *Tucker Herbert, Rafael Brown, Jeffrey Halbrook, Nate Anderson, Han-Sup Han*	**Categorizing Rutting Following Thinning in Loblolly Pine Stands in the U.S. South** * *J. Tyler Patton, Joseph L. Conrad IV, Bronson P. Bullock, Stephen M. Kinane, Chad Bolding*

9:10-9:30	**Rethinking Slash Disposal: Productivity and Cost of Carbonizing Logging Residues in British Columbia** * *Adelin Nicorescu, Omar Mologni, Dominik Roeser*	**Evaluating Plantation Performance in Restoring Coal-Mined Lands through Soil Erosion and Ground Cover Analysis** * *Ashmita Bhandari, Manisha Parajuli*
9:30-9:50	**Operational Feasibility of Heavy-Lift Drone-Assisted Seedling Delivery for Steep-Slope Reforestation** *Taejin Kim, Heesung Woo, Heechan Jeong, Jiyeon Ryu, Jeong Ho Kim*	**Spatial Patterns of Residual Tree Damage Across Trail Designs and Harvest Intensities in Mechanized CTL Harvesting** *Bibek Bhandari, Shuva H. Gautam*
9:50-10:00	**Q&A with all presenters**	**Q&A with all presenters**

10:00 - 10:30 AM — Break

10:30 AM - 12:00 PM — Concurrent Sessions

Time	D1: Advanced Technologies *Moderator - Eric Labelle*	D2: Supply Chains *Moderator - Chad Bolding*
10:30-10:50	**Real-Time Implementation of Digital Forest Restoration Prescriptions Using Computer Vision and LiDAR Stem Maps** *Woodam Chung, Lucas Wells, Lingbo Dong, Heesung Woo*	**Assessment of the Harvesting Capacity for Conducting Forest Fuel Reduction Treatments in Idaho and Oregon** * *Jessie McCullough, M. Chad Bolding, Joseph L. Conrad IV, Mathew Smidt, Jaana Korhonen, Timothy R. Miller*

10:50-11:10	**Satellite Teleoperation for Resilient Remote Forestry Delimbing Operations in Canada** *Maxime Vaidis, Eric R. Labelle, Philippe Giguère*	**Advanced Supply Chain Engineering to Support Fuel Treatment and Forest Restoration** * *Jinghan Zhao, Jingxin Wang, Nate Anderson*
11:10-11:30	**Application of Advanced Technologies in Forestry: Opportunities, Operational Integration, and Practical Challenges** *Heesung Woo, Taejin Kim, Heechan Jeong, Jiyeon Ryu, Suhas V. Sumukh, Jacob A. Webb, Sun Eun Choi*	**Assessing Fine Particulate Matter Emissions and their Regulatory Revisions Impact Analysis on the Forest Industry of Alabama** * *Manisha Subedi, Marissa "Jo" Daniel, Richard Cristan, Lana Narine, Manisha Parajul*
11:30-11:50		**Innovation in Timber Harvesting in the U.S. South: The Opportunity for Cut-to-Length in Changing Timber Markets*** *Timothy R. Miller, M. Chad Bolding, Joseph L. Conrad IV | Pete Bettinger, Bruno K. da Silva, Raffaele Spinelli*
11:50-12:00	**Q&A with all presenters**	**Q&A with all presenters**

12:00 - 2:00 PM — Sandwich & Salad Lunch and COFE Business Meeting

2:00 - 3:30 PM — Concurrent Sessions

Time	E1: Ground-Based Harvesting Systems *Moderator - Nate Anderson*	E2: Improving Safety of Forest Operations *Moderator - Scott Barret*
2:00-2:20	**4D Simulation of Cut-To-Length Harvesting Using Discrete-Event Simulation and Building Information Modeling** * *Murat Ozmen, Woodam Chung*	**Further "Extensions" of Synthetic Rope Technology** *John Garland, Steve Pilkerton, John Sessions, David O'Neill, Mike Spear, Rob Keefe, Ryer Becker, Eloise Zimbelman, Hunter Harrill, Eric Parazoo, Michael Griffin*
2:20-2:40	**Evaluating the Productivity and Cost of Salvage Logging with Whole-Tree Harvesting Systems Following Hurricane Helene in South Georgia, USA** * *Onyinye P. Choko, Joseph L. Conrad IV, Puneet Dwivedi, Pete Bettinger, Chad Bolding, Bruno K. Da Silva*	**Use of the Android Team Awareness Kit (ATAK) to Increase Situational Awareness and Improve Logging Safety** *Robert F. Keefe, Eloise G. Zimbelman*
2:40-3:00	**SkidPC Online: A Web-Based Modernization of a Ground-Based Timber Harvesting Decision Support Tool** *Ben Spong*	**Reducing Injury Risk in Timber Felling: A Multi-Phase Evaluation of Exoskeletons** *Allen, Mina Salehi, Seobin Choi, Kiana Kia, Woodam Chung, Jeong Ho Kim*

3:00-3:20	**Long-Term Economic Impacts of Bladed Skid Trails Compared to Competing Systems in Appalachia** *M. Berry, R. Chewning, S.M. Barrett*	**Real-time Estimates of Logging Equipment Carbon Emissions in the Southeastern United States** *Abubakar Tahiru, Marissa "Jo" Daniel, Richard Cristan*
3:20-3:30	**Q&A with all presenters**	**Q&A with all presenters**

3:30 - 4:00 PM — Break

4:00 - 5:00 PM — Concurrent Sessions

Time	F1: Data Science to Improve Forest Operations *Moderator - Jeff Halbrook*	F2: Transportation *Moderator - Jo Daniel*
4:00-4:20	**IMU-Based Activity Recognition for Forestry Loaders: Toward Automated Detection** * *Adelin Nicorescu, Omar Mologni, Dominik Roeser*	**Development and Validation of GATES: A Tool to Estimate Log Truck Costs in the US South** *Jack Derochers, Joseph L. Conrad IV, M. Chad Bolding, Mathew Smidt, Bruno K. Da Silva*
4:20-4:40	**Optimization of Harvest Unit Layout for Tethered Cut-To-Length Thinning Operations** * *Murat Ozmen, Woodam Chung*	**Are Trees Heavier Today? Re-Evaluating 1974 Transportation Weight Limits in the Context of Modern Forest Allometry** *Mandira Pokharel, Marissa "Jo" Daniel, James Chappell, Abubakar Tahiru*

4:40-5:00	**Machine learning-based forecasting of felling productivity in Western Canada** *Stephanie Bron, Omar Mologni, Dominik Roeser*	**Developing an Optimized Trucking Model to Improve Timber Transportation Efficiency, Cost, and Capacity in the US South*** *Bandana Subedi, Joseph L. Conrad IV, Miachel Chad Bolding, Pete Bettinger, Damon Hartley*
5:00-5:10	**Q&A with all presenters**	**Q&A with all presenters**

5:45 PM — Conference Dinner and Awards Banquet

National Museum of Forest Service History

Time	Event
5:45	Bus departs conference hotel
6:00 – 7:00	Cocktail hour and museum perusal
7:00-8:00	Dinner
8:00-8:30	Awards
8:45 PM	Bus departs, return to hotel by 9

Day 4: Wednesday, August 5

8:00 AM - 5:00 PM — Field Tour of Active Forest Operations, Featuring Public Lands Management

Location here

Time	Event
8:00	Bus departs conference hotel
8:00 - 5:00	details TBD
5:00	Bus returns to hotel by 5

Everything Everywhere All at Once: Landscape-scale, cross-boundary forest operations to address simultaneous wildfire and forest health crises in the wildland-urban interface

by Nathaniel Anderson | U.S. Forest Service, Rocky Mountain Research Station

Session P2 - Plenary

A major outbreak of mountain pine beetle (MPB; Dendroctonus ponderosae) appears to be accelerating in pine forests along the Front Range of central Colorado, USA, and is expected to result in widespread mortality of Ponderosa pine (Pinus ponderosa) and other species affected by ongoing drought. At the same time, foresters are fighting to implement thinning to reduce wildfire risk and protect homes and infrastructure in this mountainous, densely populated wildland-urban interface. This presentation will review three decades of relevant forest operations research from interior western North America to identify and adapt lessons learned to this challenging case. Models developed during previous outbreaks have documented increased likelihood of infestation, enhanced mortality or both as a result of higher stocking. Research suggests that stand density reductions through thinning across large areas can abate MPB-caused tree mortality, which is consistent with fuel treatment objectives to reduce wildfire intensity. However, the probability of individual tree attack within infested stands can be positively correlated with tree diameter, which may lessen the effectiveness of fuel treatments that emphasize removal of smaller diameter, sub-dominant trees. Following outbreak, a variety of studies have documented increased operational costs and decreased product value associated with delayed salvage harvesting. The authors present a decision matrix for forest operations on the Front Range that considers stand conditions, regulatory constraints, machine options and system configuration, logistics, infrastructure, and market demand. Benchmarks are set for expected net cost and investment needed to achieve results on non-commercial stands at various feasibility levels. Realizing the stated government goals of treating forests, ensuring effective wildfire response, and building resilient communities, including expanding forest industry, will only be achieved through aggressive and well-planned forest operations, which will be complicated by the difficult terrain, urban environment and limited log markets in the region.

Long-Term Economic Impacts of Bladed Skid Trails Compared to Competing Systems in Appalachia

by M. Berry | R. Chewning | S.M. Barrett | Virgina Tech

Session E1 - Ground-based harvesting systems

Bladed skid trails remain a widely used ground-based access system in Appalachian timber harvesting, yet their long-term economic implications relative to alternative systems, particularly emerging tethered harvesting and skyline yarding are not well quantified. This study evaluates the economic tradeoffs among these systems by integrating operational costs, site disturbance extent, and post-harvest value recovery. We compare conventional bladed skid trail systems, which incur upfront bulldozing and trail construction costs, with tethered systems that reduce ground disturbance but require higher capital investment, and skyline systems that induce yet higher costs while minimizing soil impacts. This study will analyze the economic implications of these harvesting systems in Appalachia when evaluated over longer time horizons of hardwood rotations (upwards of 100 years). Using a combination of cost accounting and stand-level spatial analysis, we quantify the proportion of area occupied by skid trails, bladed corridors, and yarding infrastructure, and assess how these footprints influence residual stand value and future management options. Emphasis is placed on the percentage of site occupied by bladed trails versus skyline corridors or tethered machine paths, and how this translates into opportunity costs, altered regeneration patterns, and constraints on future harvesting entries. It is thought that when incorporating the value of retained growing stock and site degradation, higher-impact systems may still be economically optimal but other systems may be more competitive or superior in particularly sensitive or high-value sites. These findings will provide a more comprehensive accounting framework for harvest system selection that integrates both immediate operational costs, ground disturbance and long-term land productivity.

Evaluating Plantation Performance in Restoring Coal-Mined Lands through Soil Erosion and Ground Cover Analysis

by Ashmita Bhandari | Dr. Manisha Parajuli | Graduate Student at Kentucky State University | Assistant Professor of Forestry, Kentucky State University

Session C2 - Environmental Impacts & BMPs

Mining activities cause severe land degradation through removal of topsoil, soil compaction, nutrient depletion, and accelerated erosion. Reforestation is being done to improve soil conditions and promote ecosystem restoration on degraded lands. This study examined the role of reforestation in limiting soil erosion and ground cover composition between abandoned and reclaimed mined lands in Eastern Kentucky. Soil erosion was estimated using the Revised Universal Soil Loss Equation (RUSLE) and ground cover analysis was performed by making circular plots with quadrants measuring 33 × 33 feet. Status of bare soil, invasive species, grass, planted trees, litter, rock fragments, and wooden debris were studied for ground cover analysis. The results showed that average annual soil loss was higher in abandoned sites (2.56 ton/ha/yr) than in plantation sites (2.07 ton/ha/yr), but the difference was not statistically significant. Correlation analysis showed that soil erosion was strongly and positively associated with bare soil in both abandoned ($r = 0.72$) and plantation sites ($r = 0.69$), meaning that exposed soil led to greater erosion risk. In plantation sites, planted trees showed moderately negative correlation with soil loss ($r = -0.63$), indicating reduced erosion with increased trees. Overall, the findings suggest that bare soil and planted tree species are useful indicators for evaluating reclamation status. This study provides practical information that can help mine landowners and land managers to monitor site conditions, identify vulnerable areas, and make better decisions about reclamation planning.

Key words: Abandoned coal-mine land, invasive species, reforestation, RUSLE, soil loss

Spatial patterns of residual tree damage across trail designs and harvest intensities in mechanized CTL harvesting

by Bibek Bhandari | Shuva H. Gautam | Université Laval

Session C2 - Environmental Impacts & BMPs

Residual tree damage during mechanized partial harvesting remains a critical concern for sustaining stand structure and productivity, as well as long-term value. While numerous studies have examined factors influencing such damage, the spatial relationship between residual tree damage and machine operating trail systems in cut-to-length (CTL) harvesting remains insufficiently understood. Improving this understanding is essential for optimizing trail design and minimizing stand disturbance.

This study evaluated how residual tree damage varies with distance to trails, trail design, and harvest intensity in mixed hardwood stands of southern Quebec, Canada. Three different trail systems; conventional trails (CT) at 20 m spacing, ghost trails (GT) and diagonal entries (DE), both at 30 m spacing were combined with two harvest intensities (27% and 40% by basal area), resulting in six treatments. Post-harvest tree-level spatial data were collected for 3,262 trees, including 983 damaged, from five perpendicular transects per treatment to quantify the distance from the center of the nearest trail, number of damages per tree, and vertical damage location.

Across all treatments, damaged trees were generally concentrated near trails, with highest frequency occurring within 0-6 m of the nearest trail. For damaged trees, distances to primary trails were generally lower at DE trails while CT showed higher median distances and greater variability. GT exhibited intermediate distances between the two. Vertical distribution patterns varied by harvest intensity. Damage was predominantly concentrated on lower and mid stems across all treatments. At 27% intensity, damage was concentrated in the 0.3-1.3 m stem section, with a clear upward shift toward the 1.3-5 m range at 40% intensity.

These findings highlight the role of trail design and harvest intensity in shaping both spatial and vertical damage patterns. These findings provide insights for improving harvesting practices and reducing residual stand damage.

Frictionless Forestry: Why Applied Research Struggles to Translate into Practice

by Steve Bick | Northeast Forests

Session P1 - Plenary

High-quality forestry research continues to advance analytical capability, yet many tools, models, and information products see limited use in day-to-day decision-making. This presentation examines that gap not as a failure of science, but as a challenge of translation.

Drawing on survey responses from Forest Business School alumni, agency staff, and practicing professionals, this work explores how decisions are actually made in the field and how research outputs are incorporated—or bypassed—under real-world constraints. Findings suggest that practitioners operate within iterative, time-constrained workflows shaped by prior experience, economic conditions, and institutional requirements. Within this context, tools that impose high data burdens, complex interfaces, or unclear outputs are often used selectively or set aside, regardless of their technical strength.

The results point to a consistent pattern: adoption is strongly influenced by friction. Systems that are durable, interpretable, and easy to integrate into existing workflows tend to persist, while those that require substantial effort to operate or maintain struggle to gain traction. Notably, respondents report increasing use of general-purpose tools, including artificial intelligence, to perform tasks that formal systems do not address efficiently.

Rather than calling for less research or reduced rigor, these findings highlight an opportunity to improve the operational impact of applied work. The presentation outlines practical considerations for aligning research outputs with field use, including designing for minimum viable data requirements, providing layered formats for communication, and planning for long-term usability. Increasing the accessibility and integration of research outputs may represent one of the most direct pathways to extending their practical and scholarly impact.

Timber Harvesting Challenges on Small Family Forests in Northern Minnesota, USA

by Charlie Blinn | William Sauerer | University of Minnesota

Session A2 - Forest management systems

One-third of forestland ownerships in Minnesota are comprised of privately-owned, family forests. The majority (65%) of those family forests are found on less than 8-hectare parcels and the owners of which commonly have alternative land stewardship objectives that differ from traditional forest management goals. Timber harvesting as a management objective is universally low in priority for small family forest owners, yet it is often still required to achieve many of the landowner's other stewardship objectives. A logging business owner makes various decisions based on economic factors when considering a timber sale purchase; but they may also consider other factors particular to their business characteristics. All these considerations become increasingly important as the size of a timber sale decreases and may become barriers to implementing a timber harvest on small family forests.

Northern Minnesota logging business owners were surveyed to collect individual business-specific data regarding factors affecting their decisions to purchase small-sized timber sales, barriers to harvesting timber on small tracts, and the general characteristics of their business. Results suggest that some logging businesses may be more readily adaptable to harvesting on small family forests. A logging business whose annual production was $\leq$3,625 cubic meters and used a chainsaw as a primary felling method was the most likely to purchase a timber sale of 725 cubic meters and less. While they generally target purchasing higher volume timber sales, larger producing businesses annually complete more of these small sales than the smaller logging businesses. The most important factor for a larger logging business' consideration to purchase a small timber sale is whether the sale is adjacent to another larger and available timber sale. If the family forest tract is not adjacent to another timber sale, the lowest volume producers appear to be the most likely to purchase the sale.

Machine learning–based forecasting of felling productivity in Western Canada

by Stephanie Bron | Omar Mologni | Dominik Roeser | University of British Columbia

Session F1 - Data science to improve forest operations

The integration of onboard computers (OBCs) into mechanized forest operations has enabled the automated collection of large operational datasets. A major initiative in this area is the Forest Machine Connectivity project in Western Canada, in which more than 650 forestry machines have been equipped with FPDat II OBCs. These machines span the full tree-to-truck supply chain, including felling, primary transport, processing, and loading, and have generated data from over 2,900 cutblocks and approximately 200,000 daily work logs, primarily under whole-tree harvesting systems typical of the region. Combined with spatial information from multiple sources, these records provide a foundation for fully automated, large-scale productivity analyses of logging operations. The objective of this study is to leverage this dataset to develop a machine-learning-based model for predicting felling productivity at the cutblock level using a digital elevation model, forest inventory, road network, and block boundaries as inputs. Because most existing studies have focused on explanatory rather than predictive modelling, this approach addresses a comparatively underexplored area and has the potential to support improved operational planning and decision-making. A data-cleaning protocol is first applied to retain only high-quality observations by excluding partially felled cutblocks, imprecise inventory data, and incomplete machine records. The resulting dataset is then divided into training, validation, and test subsets. Several machine learning algorithms, including gradient boosted machines and support vector machines, are evaluated against conventional approaches such as linear regression, and model performance is reported. A key strength of this study is the potential for the resulting models to be deployed operationally and updated as new production data become available. In this way, the modelling framework can function as an adaptive system rather than a static tool, learning from an expanding dataset to support more effective planning as operational conditions and practices evolve.

What drives feller-buncher productivity? A metanalysis, key factors identification, and a predictive model.

by Rafael O. Brown | Mathew F. Smidt | Nathaniel M. Anderson | Post Doctoral Researcher - ORISE, USDA Forest Service | USDA Forest Service, Southern Research Station | USDA Forest Service, Rocky Mountain Research Station

Session P2 - Plenary

Operations involving feller-bunchers are affected by numerous factors, including topography, soil conditions, climate, type of operation (e.g., clearcutting or thinning), stand characteristics (e.g., average volume, basal area, diameter, and stocking per hectare), operator experience, and equipment specifications. These variables lead to considerable variation in productivity, cycle time, and costs reported in forestry literature. Despite extensive research examining these factors across diverse conditions, challenges remain in directly comparing results and in developing universal feller-buncher models adaptable to different operational settings. This study performed a meta-analysis of 53 research articles from journals, technical reports, conference proceedings, and theses to identify key productivity factors and create a predictive model applicable across various scenarios. Data collected included productivity, cycle time, dendrometric variables, topography, stand characteristics, equipment details, and cutting head types, all standardized to comparable units of productivity (m^3•PMH-1). Generalized linear models were employed to assess the impact of independent variables on productivity.

The results show that swing-to-tree equipment outperforms drive-to-tree setups in productivity. Additionally, disc saw heads perform better than shear heads. No significant difference in productivity was observed between hardwood and softwood, although both outperform operations on mixed wood. Productivity tends to be lower in partial cuts than in clear-cutting. Slope has a limited effect, but the scant data on steep slopes indicate a need for further investigation. It is also possible that engine power variations confound slope effects.

The models developed demonstrated strong performance, validating their utility for estimating productivity and for planning and evaluating feller-buncher operations. Cross-validation showed a normalized RMSE of 0.44 and near-zero bias (0.31%), confirming model reliability. This comprehensive analysis improves understanding of the factors influencing productivity and provides a solid basis for future research to refine operational models, enhancing efficiency and effectiveness in forest harvesting activities.

Understanding Virginia’s Family Woodland Owners Management Decisions

by Emma D. Busteed | Scott M. Barrett | Jennifer Gagnon | Shane Furze | Virginia Tech

Session A2 - Forest management systems

Virginia’s forest land encompasses 16 million acres, of which 60% is owned by family woodland owners (VDOF, 2025). With Virginia’s forest industry generating $23 billion annually, the continued success of the forest supply chain depends heavily on family woodland owners making informed decisions and overcoming barriers to active management. In 2025, over 3,700 management plans were written by the Virginia Department of Forestry (VDOF), but a plan does not improve forestland unless it is implemented. Virginia Cooperative Extension’s Forest Landowner Education program provides Virginia’s family woodland owners with science-based information and resources to help them obtain and implement their management plans. Although the US Forest Service Forest Inventory and Analysis program surveys woodland owners every five years at the national level, it does not specifically address landowner needs related to Extension programming. No recent studies have surveyed Virginia’s family woodland owner population related to management behaviors and harvesting decisions; therefore, this research aims to understand family woodland owners’ motivations and decisions to harvest their timber. In partnership with the Virginia Department of Forestry and Virginia Cooperative Extension, those that have harvested timber on their land in the last 5 years will be surveyed through an online survey in spring and summer 2026. The survey will help us characterize family woodland owners, determine why they chose to harvest their forest, and understand how satisfied they are with the outcome. Results will provide insight into family woodland owners harvesting and management decisions, their needs for Extension programming, and give the Virginia Department of Forestry and the Virginia Cooperative Extension knowledge on how best to support them through educational, financial, and technical programs.

Reducing Injury Risk in Timber Felling: A Multi-Phase Evaluation of Exoskeletons

by Allen Chan | Mina Salehi | Seobin Choi | Kiana Kia | Woodam Chung | Jeong Ho Kim | Oregon State University | Oregon State University | Incheon National University | Oregon State University | Oregon State University | Texas A&M University

Session E2 - Improving safety of forest operations

Manual timber felling is physically demanding work characterized by awkward postures and high biomechanical loads which place workers at an elevated risk for musculoskeletal disorders (MSDs), particularly low back injuries. Passive exoskeletons have emerged as a promising intervention, but their practical effectiveness and adoption potential in forestry are underexplored. This study employed a three-phase approach to evaluate the feasibility, effectiveness, and real-world applicability of exoskeletons for manual timber felling. In the first phase, industry readiness and user perspectives were assessed through a stakeholder survey (N=22). Results indicated strong interest in exoskeleton adoption, with timber felling identified as a high-priority task. Most participants expressed willingness to use exoskeletons frequently, provided usability concerns are addressed. Field biomechanical assessments conducted alongside the survey revealed that trunk postures and spinal loads frequently exceeded recommended limits, confirming the need for effective ergonomic intervention. In the second phase, controlled laboratory experiments (N=20) quantified biomechanical effects under simulated timber felling conditions. Selected exoskeletons reduced low back muscle activity, demonstrating measurable potential to mitigate physical workload and informing device selection for field evaluation. In the third phase, field trials with professional loggers (N=9) assessed exoskeleton performance under operational conditions. Results showed reductions in muscle activity and perceived exertion, consistent with laboratory findings. Collectively, these findings suggest that there is promise for exoskeleton adoption in manual timber felling, though effectiveness depends on appropriately matching assistive torque capabilities to task demands and user characteristics. Future work should focus on optimizing device–task compatibility, addressing usability barriers, and developing implementation guidelines to support safe and scalable integration of exoskeleton technologies in forestry practice. By reducing physical demands and injury risk, exoskeletons may also serve as an enabling technology to modernize forestry work, helping address a diminishing and aging workforce by making the work safer and more attractive for younger generations.

Evaluating the Productivity and Cost of Salvage Logging with Whole-Tree Harvesting Systems Following Hurricane Helene in South Georgia, USA

by Onyinye P. Choko | Joe L. Conrad IV | Puneet Dwivedi | Pete Bettinger | Chad Bolding | Bruno K. Da Silva | Harley Langdale Jr. Center for Forest Business, Warnell School of Forestry and Natural Resources, University of Georgia | Harley Langdale Jr. Center for Forest Business, Warnell School of Forestry and Natural Resources, University of Georgia | Forestry and Environmental Conservation Department, Clemson University | Harley Langdale Jr. Center for Forest Business, Warnell School of Forestry and Natural Resources, University of Georgia | Harley Langdale Jr. Center for Forest Business, Warnell School of Forestry and Natural Resources, University of Georgia | Harley Langdale Jr. Center for Forest Business, Warnell School of Forestry and Natural Resources, University of Georgia

Session E1 - Ground-based harvesting systems

Salvage logging is common in the US South after major storms, but information on harvesting productivity and cost post hurricane damage remains limited. The goal of this study was to examine salvage logging productivity and cost after Hurricane Helene in South Georgia, USA. The specific objectives were to a) estimate machine productivity during salvage logging operations; b) determine the cost ($/tonne) of logging in the damaged stands; and c) compare productivity and cost outcomes between disturbed and undisturbed stands. We collected data from three pine plantation stands where trees were grouped by damage type, including undamaged trees, uprooted whole trees with stump, hang-up whole trees, uprooted and broken trees with separate butt and top, broken trees with a separate butt or top section, and uprooted whole trees without a stump. Machine productivity was measured using time studies of wheeled feller-bunchers, grapple skidders, and loaders. We recorded cycle times for felling, skidding, processing, and loading. Machine costs were estimated using the machine rate method to determine the hourly costs of owning and operating the machinery. Results indicate that delay-free productivity averaged 64.9 tonnes per productive machine hour (t pmh^{-1}) for feller-bunchers, 26.4 t pmh^{-1} for skidders, and 29.8 t pmh^{-1} for loaders. Productivity values were generally lower than those reported for logging operations in undisturbed stands in the study area, with feller-buncher, skidder, and loader productivity reduced by 21%, 3% and 19% respectively. Overall system productivity ranged from 16.5 to 17.7 tonnes per scheduled machines hour across the three sites. The average cut-and-haul cost was \$30.9 t^{-1}, representing a 24% increase compared to operations in undisturbed stands. These results highlight the need for developing policies that support efficient, cost-effective salvage logging and enhance post-disturbance timber recovery.

Real-Time Implementation of Digital Forest Restoration Prescriptions Using Computer Vision and LiDAR Stem Maps

by Woodam Chung | Lucas Wells | Lingbo Dong | Heesung Woo | Oregon State University | SilvxLabs |Northeast Forestry University | Oregon State University

Session D1 – Advanced technologies

Spatially explicit silvicultural prescriptions that incorporate individual tree locations and multi-scale spatial heterogeneity are increasingly recognized as essential for effective forest restoration in fire-prone landscapes. Current methods often rely on Designation by Prescription (DxP) to avoid the high costs of manual tree marking, but these can lack the spatial nuance required for complex restoration. This study introduces an integrated workflow that bridges this gap by automating both prescription generation and real-time field implementation without pre-marking. The workflow consists of two stages. In the first stage, a LiDAR-derived stem map is generated from UAV LiDAR data, and an automated algorithm selects cut and leave trees based on a spatially explicit silvicultural prescription, enabling digital treatment planning at the individual tree level prior to field implementation. In the second stage, a computer vision system loaded with the prescription-ready stem map captures and analyzes stereo images in real time to identify and measure trees in the field. A tree group matching algorithm spatially aligns detected trees on the stem map and relays cut and leave designations to the operator on the fly, guiding harvesting decisions. The system is currently being validated across multiple thinning units in Oregon using georeferenced backpack mobile LiDAR system data collected simultaneously along the same machine path, providing independent assessment of positioning accuracy and tree matching quality. This technology enables individual tree-level prescription and implementation without reliance on costly pre-marking or specialized field expertise. By accommodating diverse silvicultural goals and establishing a framework for further automation, this system advances the transition toward precision forestry at operational scales.

An Evaluation of Pruning Time Across Thinning Treatments in a 15-Year-Old Loblolly Pine Plantation

by Daniel DeArmond | Kevin Boston | Segar Chhetri | Matthew Pelkki | University of Arkansas at Monticello

Session A2 - Forest management systems

The current trend of diminishing pulpwood capacity in the US South shows no sign of abating. Thus, the standard silvicultural practice of high-density pine plantations with a thinning operation at approximately 15 years of age will likely need to be reassessed. In this context, the present research sought to evaluate the added-value cost of thinning and pruning in a 15-year-old loblolly pine plantation in southeastern Arkansas.

Our experiment occurred in a stand with approximately 800 trees per acre (TPA). Thinning reduced stand density to blocks with 160 and 240 TPA. Within each block, the best-form trees were pruned to an average height of 18 feet using a pole saw (Sentei) employing four laborers: three students and an arborist. Pruning time was measured in minutes and seconds. The objective was to determine the time required to prune a single tree. In total, three hundred trees were manually pruned using a 16-foot telescoping pruning saw in an established plantation. The plantation experienced natural seed after establishment, which created a highly dense and overstocked stand at approximately 800 TPA. So, prior to pruning, two different precommercial thinning treatments were applied, one at 160 TPA and the other at 240 TPA, as well as an unthinned pruning treatment of 120 superior future crop trees to be used as a control.

The average time for thinning a single tree was approximately three minutes. Furthermore, results demonstrated similar times for thinned/clean forest floor (M = 2.91, SD = 1.81), thinned/slash on forest floor (M = 2.55, SD = 1.45), and unthinned control (M = 2.96, SD = 2.64). In this study, 93% of pruned trees had no living branches, which were easier to remove than live branches. These results will be used to monitor the subsequent clear wood formation to determine the cost effectiveness of pruning.

Development and validation of GATES: a tool to estimate log truck costs in the US South

by Jack Derochers | Joseph L. Conrad IV | M. Chad Bolding | Mathew Smidt | Bruno K. Da Silva | University of Georgia | University of Georgia | University of Georgia | US Forest Service | University of Georgia

Session F2 - Transportation

In the US South, log trucks are critical to the forest products supply chain, connecting harvested raw materials with receiving mills. Log truck owners (LTOs) face challenges to profitability and cost estimation due to volatile fuel, insurance, and labor costs. The objective of this research was to provide a new, Excel based cost estimation tool for log truck costs in the US South to LTOs in the region. This tool is GATES, the University of Georgia Trucking Cost Estimation System. The default inputs and assumptions for GATES were collected from interviews collected with LTOs in the US South (Derochers et al. In Review). Cost estimates were validated using data from four case studies, together providing information for 42 unique haul routes and over 3,600 individual loads. Profitability of case studies was explored, comparing estimated costs to published minimum haul rates. We also assessed whether GATES produced significantly different errors, either under or overestimating compared to actual costs, based on haul distance. GATES produces estimates of costs for one truck operating one haul route using default inputs and cost information provided by the user. To ensure accuracy of estimates, GATES was validated using interviews with LTOs in the US South. When compared to actual costs, estimates underestimated actual costs by an average of 3% when using advanced inputs, and 9% with simplified inputs. A significant difference ($p < 0.001$) was found in the errors of short hauls compared to long (100+ km) hauls. Profitability was extremely challenging at minimum haul rates; only 19 percent of routes were profitable at market haul rates and GATES estimated costs. This tool is useful for users across the supply chain who are interested in log truck costs. Effects from changing input costs will become clearer with GATES, providing better information for LTO financial decision making.

Effects on harvesting costs and landowner revenues when introducing shelterwood management

by Lars Eliasson | Anders Rowell | Skogforsk, The forestry research institute of Sweden | Skogforsk, The forestry research institute of Sweden

Session A2 - Forest management systems

The interest for alternative forest management methods has increased during the last decade, due to changing goals of the landowners, certification schemes and public opinion. These include shelterwoods, which currently are used where natural regeneration is preferred or where seedlings need protection from frosts. The main drawbacks are longer regeneration periods, risk for storm damage and the need for a succession of logging operations to establish, thin and remove the shelterwood.

In 2024, Uppsala University Foundations Management of Estates and Funds decided to establish a large-scale trial to evaluate economic and ecological effects of using pine shelterwoods. Twelve blocks were established and harvesting and forwarding were made between November 2024 and May 2025.

Due to targeted shelterwood density about 50% of the volume was harvested and harvested trees were on average 10% smaller than in the clearcut plots. Although the distance between strip roads increased to compensate for the reduction in harvested volume per ha the harvester had to drive 48% longer per harvested tree. This increased time used for both harvester- and boom-movements. Harvester productivity in shelterwood cuts were 15-18% lower than in clear cuts, and forwarder productivity was reduced by 11 per cent due to reduced wood concentration and a larger need to co-load assortments.

The shelterwood treatment had 13-17% higher direct harvesting cost, but as relocation costs remain constant per site the total cost increase per cubic meter is higher. As trees harvested are smaller, the wood value per cubic meter of the harvested trees will also be smaller. This leads to lower revenue for the landowner, but with prospect of future revenues in about ten years. Then wood value will be higher as shelterwood trees are large, and if natural regeneration is successful money needs not to be spent on replanting, but harvesting costs will be high.

Further "Extensions" of Synthetic Rope Technology

by John Garland | Steve Pilkerton | John Sessions | David O\'Neill | Mike Spear | Rob Keefe | Ryer Becker |Eloise Zimbelman | Hunter Harrill | Eric Parazoo | Michael Griffin | OSU Prof Emeritus, PNASH, U. W. |OSU Student Logging Crew | OSU Distinguished Professor | Gannet Nets Inc | Gannet Nets Inc | Univ of Idaho | Univ of Idaho | Univ of Idaho | Cal Poly Humboldt | Lone Rock Resources

Session E2 - Improving safety of forest operations

Presentation describes the trial of synthetic rope skyline extensions to replace steel wire rope saving thousands of pounds of skyline weight. Two skyline extensions of two thousand and fifteen hundred feet of 12-strand UHMW rope with a UHMW 32 Carrier Cover, 30mm core, and a diameter of 36mm, with a breaking strength of 181,881 pounds were tested. Data were collected on tensions and loads, and observations made on operational and environmental benefits. In another trial, a multi-point skyline anchoring system using small diameter trees and synthetic blocks, ropes, and connectors was tested. Data from three load cells were collected on the ultra low friction and ultra light connectors. All rigging could be delivered by drone. The system addresses the lack of adequate anchors for harvesting small diameter timber. These trials show potential benefits of new synthetic rope and lighter rigging for skyline logging operations and the need for further research.

Management of Forest Roads in the Province of Quebec: A Review of Challenges and Solutions

by Shuva Gautam | Université Laval

Session P2 - Plenary

The forest products industry plays a vital role in the socioeconomic development of many communities in the province of Quebec, Canada. This industry is supported by an extensive forest road network totaling approximately 485,000 kilometers. Once road sections are constructed to provide access for forestry operations, it is used by multiple stakeholders, including indigenous communities, hunters, fishers, and ecotourism operators, thereby contributing to rural economic development. However, the management and maintenance of such an extensive road network require significant financial commitment. As a result, a large proportion of forest roads are abandoned, particularly when alternative users lack the resources required to contribute to their maintenance. The abandonment of forest roads can lead to considerable environmental impacts, which are expected to be exacerbated by climate change. This study reviews the key challenges associated with forest road management in Quebec and introduces a hierarchical planning framework to support decision-making across different temporal and spatial scales. The proposed framework aims to enhance long-term sustainability and reduce environmental impacts.

Developing Supply Curves for Woody Biomass in Northwestern California Based on Harvest and Transportation Costs

by Jonathan Guczek | Hunter Harrill | Natascia Magagnotti | Raffaele Spinelli | Alan Tepley | Cal Poly Humboldt | Cal Poly Humboldt | CNR IBE | CNR IBE | Cal Poly Humboldt

Session B1 - Volume Estimation

Mechanized forest treatments, including thinning operations in response to wildfire, have created an increase in non-merchantable biomass, material that is left onsite and typically disposed of through open-air burning due to a lack of available markets. Quantifying the cost of harvesting and transporting this material is a critical part of creating mechanisms to mobilize harvesting residues and residuals (i.e., non-merchantable species) as a commodity. The focus of this project is to assess biomass availability in California at various cost ranges. Literature related to biomass mobilization in California was reviewed to establish a baseline for harvest costs. Forest treatments within the last five years were compiled from state and federal databases and defined by polygons within a shapefile in GIS. Each treatment was assigned the most likely harvest system that included ground-based, cut-to-length, and cable methods. Machine and productivity rates based on existing literature were applied to a spreadsheet cost model. Project partners developed additional model inputs, including distance to roadside, stand volume, and average piece size, by applying the Forest Vegetation Simulator (FVS) to assess stand conditions within treatment polygons. Current biomass purchasing locations were designated as mobilization hubs that allowed for assessment of supply curves on a regional basis. Transportation costs were estimated through network analysis programming; locations were designated based on current biomass purchasing facilities, with all treatments within a 60-mile radius accounting for that region's supply curve. The assessment of approximately 19,000 treatment polygons with the harvest cost model yielded a set of biomass supply curves for both high quality chips and hog fuel in Northwest California.

Productivity Analysis of Shotgun Cable Yarding

by Hunter Harrill | Cal Poly Humboldt

Session B2 - Steep Slope & Tethered Systems

Five cable logging crews in Washington state USA were visited for the purpose of the study. While each crew operated a different yarder, they all utilized either a standing skyline or live skyline system in the shotgun configuration. A detailed time study was performed at each site, recording the total cycle time and individual components (e.g. Outhaul, Hook, Inhaul, Unhook) of the cycle. Variables affecting the cycle or component times were also recorded, like: yarding distance, pieces/cycle (including number of stems, logs & tops), suspension type, carriage type, etc. The number of delays, duration and type was also recorded at each site to determine the utilization rate for each yarder. From the data collected estimates of the average cycle time and productivity (tons/Productive Machine Hour (PMH)) were calculated. General linear statistical models were developed to predict the cycle time and productivity of each crew and as a population. The observed utilization rate of crews ranged from 67-98%. The average cycle time ranged from approximately 2-11 minutes, while most averaged under four minutes and were dependent on carriage type (i.e. choker or grapple). Results indicated a wide range of productivity (approx. 18-100 tons/PMH) between the crews, which was due to a variety of factors including average payload, yarding distance, and site-specific challenges. However, results were comparable with similar studies of modern cable yarding systems in other regions.

Analyzing the productivity and cost of slash management from a cut-to-length harvesting system in a Southwestern ponderosa pine forest

by Tucker Herbert | Rafael Brown | Jeffrey Halbrook | Nate Anderson | Han-Sup Han | Ecological Restoration Institute | USDA Forest Service | USDA Forest Service | USDA Forest Service | Ecological Restoration Institute

Session C1 - Slash treatment and site preparation

In Southwestern ponderosa pine (*Pinus ponderosa*) forests across northern Arizona, conventional whole-tree (WT) harvesting operations generate large quantities of slash that accumulate at landings, requiring subsequent removal or disposal through open pile burning (OPB) or chipping. While OPB is a relatively inexpensive and widely used method, it can contribute to smoke emissions, increase the risk of fire escape, alter soil properties, and is often limited by weather conditions. This study evaluates an alternative approach to slash management for mechanical thinning treatments using a cut-to-length (CTL) harvesting system on the Coconino National Forest near Flagstaff, AZ. A field-based time-and-motion study was conducted to quantify system productivity, stump-to-truck costs, and wood utilization associated with CTL thinning operations incorporating in-woods mastication or broadcast chipping of residual slash. Machine-level data were collected for harvesters, forwarders, and slash treatment equipment to assess productive machine hours, treatment rates, and cost per unit area and volume. This integrated approach to slash management has the potential to reduce the need for OPB, minimize residual biomass accumulation, and support progress toward ecological restoration objectives. Field data collection was completed in March and April 2026, and preliminary results will be presented. Study outcomes aim to inform future management strategies for fuel reduction thinning treatments and forest restoration projects across the Southwest.

From Stem Scan to Stand Estimate: A Smartphone-Based Timber Cruising Application

by Heechan Jeong | Heesung Woo | Taejin Kim | Jiyeon Ryu | Department of Forest Engineering, Resources, and Management (FERM), College of Forestry, Oregon State University

Session B1 - Volume Estimation

Timber cruising remains essential for stand-level planning and harvesting decisions, but conventional field inventory is labor-intensive and often relies on manual measurements. Furthermore, data collection in the field is susceptible to random errors arising from individual judgment and operator-dependent decisions, which may affect measurement consistency and overall inventory reliability. Recently, sensor-equipped smartphones have created new opportunities for tree measurement; however, most existing applications focus primarily on individual tree attributes rather than the broader workflow needed for operational timber cruising. This study presents the development and evaluation of a smartphone-based timber cruising workflow that integrates sensor-based tree measurement with automated inventory summaries. The proposed application is designed to support plot navigation, tapeless fixed-area plot establishment with boundary visualization, diameter at breast height (DBH) estimation, and tree height estimation. Using these inputs together with local volume equations, the app automatically calculates plot- and stand-level metrics such as trees per acre, basal area, quadratic mean diameter, and volume. The system is intended for offline field use and allows users to review and edit measurements during data collection. The workflow will be evaluated under field conditions by comparing smartphone-derived inventory results with conventional cruise data collected using standard forestry instruments. Performance will be assessed at both tree and plot levels, with emphasis on measurement accuracy, agreement in stand-level metrics, volume estimation, and field efficiency. This work presents a practical approach for digital timber cruising by combining smartphone-based sensing capabilities with conventional cruising workflows to improve data management efficiency.

Use of the Android Team Awareness Kit (ATAK) to Increase Situational Awareness and Improve Logging Safety

by Robert F. Keefe | Eloise G. Zimbelman | University of Idaho

Session E2 - Improving safety of forest operations

Originally developed by the US Air Force Research Lab (AFRL) in 2010, the Android Team Awareness Kit has since been adopted broadly by the US Department of Defense for tactical military operations. ATAK provided integration of GIS mapping and real-time location sharing through multiple types of networking. For example, radio-based sharing of individual or equipment GNSS locations for aircraft, ships, and personnel could be integrated with Wi-Fi communication and cellular networking seamlessly. Chat communications, breadcrumb options for monitoring other personnel, and the capability to share a common operating picture substantially increased Situational Awareness for warfighters in complex environments with many moving parts. As of the early 2020s, ATAK has now transitioned from military-only to public safety uses, and now civilian use. The Android version, Civ-TAK, is now available on the Google Play store and can be installed and used without special permissions that were required in earlier versions. ATAK is of interest for logging safety applications because the inter-operator functionality in combat conditions is very similar to what happens in operational forestry. On active logging operations, a team of remote workers in heavy equipment, often intermingled with ground workers, interact with quick movements in and out of sight at varying distances from one another to complete a mission. Historically, the complexity and rapid pace of logging, coupled with limited visibility and awareness, has resulted in frequent accidents. ATAK has considerable potential to help reduce jobsite fatalities and injuries. We provide an overview of ATAK tools that are useful for increased Situational Awareness in logging, including monitoring of equipment movements, sharing of jobsite hazards among the crew, and integration of georeferenced PDF maps. We further describe training being provided in 2026 for loggers in the Pacific Northwest to learn ATAK use for improved safety, including integration with smartwatches and other devices.

On-Site Prediction of Knot Characteristics from Harvester-Derived Stem Diameter Profiles in Cut-to-Length Operations

by Taehyung Kim | Woodam Chung | Lucas Wells | Oregon State University | Oregon State University |Silvx Labs

Session A1 - Interactions between wood properties and operations

Knots are one of the primary determinants of log grading and the structural strength of wood products. However, log sorting at timber harvesting sites in the Pacific Northwest relies almost exclusively on diameter and length while knot information is simply unavailable during processing and bucking. This study demonstrates that stem diameter profiles captured by harvester heads through the StanForD system can be used to predict knot characteristics on site, without additional sensors or equipment. Ten Douglas-fir trees were sampled during commercial Cut-To-Length (CTL) thinning operations at two sites in western Oregon. StanForD stem diameter profiles were extracted from the harvester, and actual knot size and longitudinal position were recorded through manual measurement for knots exceeding 1 cm diameter at the knot base. Three methods of identifying potential knot locations from consecutive stem diameter changes in StanForD data were developed and compared: (1) segments where stem diameter increases; (2) segments where stem diameter increases or remains unchanged; and (3) segments where local stem diameter change deviates from the tree-level average by more than 1 cm. Method 3 yielded the strongest predictive performance. Maximum magnitude of diameter change and horizontal segment length together were correlated with maximum knot size ($R^2 = 0.54$) and knot count ($R^2 = 0.66$), demonstrating that localized harvester-measured diameter variations reflect underlying knot characteristics. These results indicate that StanForD diameter profiles, already generated as a byproduct of standard CTL harvesting, contain a detectable knot signal, suggesting practical potential for on-site knot estimation. Incorporating knot predictions into current diameter- and length-based sorting rules could improve in-woods sorting decisions and reduce downstream grading requirements, offering an opportunity to enhance timber supply chain efficiency.

Operational Feasibility of Heavy-Lift Drone–Assisted Seedling Delivery for Steep-Slope Reforestation

by Taejin Kim | Heesung Woo | Heechan Jeong | Jiyeon Ryu | Jeong Ho Kim | Oregon State University |Oregon State University | Oregon State University | Oregon State University | Texas A&M University

Session C1 - Slash treatment and site preparation

Reforestation on steep terrain often requires workers to manually carry seedling boxes under physically demanding and operationally inefficient conditions. A heavy-lift drone has the potential to reduce this transport burden, but the field feasibility of UAV-assisted seedling delivery in operational forest settings remains insufficiently understood. This study presents a preliminary field evaluation of a heavy-lift drone–based seedling delivery concept at an experimental forest site in Oregon, with emphasis on operational feasibility, early failure modes, and engineering implications for system refinement.

Pre-tests were conducted in a stepwise manner, beginning with basic flight and payload checks, followed by forest delivery trials using surrogate payloads, and then seedling box delivery tests representing the intended operational task. Rather than estimating final productivity effects, this preliminary study examined whether the delivery concept could function under field conditions and what constraints emerged during operation.

The pre-tests confirmed basic operational feasibility, but also revealed several critical bottlenecks. Steep slopes made stable drop-off difficult, and identifying exact drop locations from the air was more challenging than expected. Prolonged hovering for payload positioning increased system stress and reduced operational margin. In addition, slope-related interference affected hook release reliability, and cumulative operational stress contributed to mechanical breakdown. These findings indicate that delivery precision, hover burden, and release stability are the primary engineering constraints that must be addressed before full-scale evaluation. The results also provide the basis for a subsequent comparative field study of manual versus UAV-assisted seedling transport, focused on productivity and worker workload.

Winch-Assist Harvesting in Appalachia: Balancing Soil Impacts and Logging Productivity

by Dylan Lang | Ben Spong | Curt Hassler | Mathew Smidt | West Virginia University | West Virginia University | West Virginia University | USFS

Session B2 - Steep Slope & Tethered Systems

Conventional timber harvesting in central Appalachia often relies on ground-based felling and skidding using bladed skid trails across steep slopes, resulting in high costs and significant soil disturbance. Alternative systems such as helicopter logging can reduce soil impacts but are limited by cost, contractor availability, and carbon emissions. Winch-assist harvesting presents a promising middle ground—improving access to steep terrain while potentially minimizing soil disturbance.

Existing studies of winch-assist systems largely focus on softwood forests in the western U.S. and New Zealand, leaving a gap in understanding for Appalachian hardwood conditions. This research evaluates both soil impacts and operational productivity of winch-assist logging systems across multiple sites in central Appalachia. Soil disturbance was assessed using adapted classification methods from previous studies to compare winch-assist and conventional operations.

Additionally, a time study was conducted to assess winch-assist systems in these conditions. A new hybrid time study methodology was used to assess the productivity of felling, yarding/skidding, processing, and loading. Results are then compared to conventional methods to further inform management decisions.

Results show that winch-assist operations do not increase soil disturbance compared to conventional methods and can reduce the need for constructed skid roads. These findings highlight the potential for winch-assist harvesting to improve safety, efficiency, and environmental sustainability in steep terrain operations across the Appalachian region.

Automated Deep Learning-Based Log Cross-Section Ring Characterization in Ponderosa Pine

by Tzu-I Liao | Woodam Chung | Laurence Schimleck | Oregon State University

Session A1 - Interactions between wood properties and operations

Accurate measurement of log cross-section ring attributes, such as earlywood-latewood (EW-LW) ratio and ring width, is important for wood quality assessment, but manual and semi-automated approaches remain labor-intensive and difficult to scale. This study develops an automated deep learning-based workflow for log cross-section characterization from high-resolution images of ponderosa pine, providing a scalable upstream input for log sorting and value recovery applications. The method uses a U-Net model to detect EW-LW boundaries, followed by post-processing to refine predicted boundaries, establish pith-centered radial structure, and derive growth ring attributes. Model development is based on expert-annotated lumber end images, while the resulting workflow is intended to support ring characterization relevant to log cross-section-based quality assessment. The dataset consists of 31 sanded ponderosa pine log cross sections and associated lumber end images used to support model development and evaluation. Model performance is evaluated primarily using computer vision metrics, while densitometer-derived log cross-section measurements provide supporting physical validation. Rather than focusing only on boundary detection, the main contribution of this work is an ring characterization workflow that transforms predicted intra-ring boundaries into quantified growth ring attributes. These attributes may serve as direct inputs to statistical models linking log cross-section growth ring attributes to lumber mechanical properties. By providing a repeatable, scalable in-woods method for log cross-section characterization, this work advances automated log quality assessment and contributes a foundational component to decision-support tools for forest operations and wood supply chain optimization.

Relating Log Cross-Section Ring Attributes to Lumber Mechanical Properties for Effective On-Site Log Sorting

by Tzu-I Liao | Woodam Chung | Michelle Jayawickrama | Lech Muszyński | Laurence Schimleck | Oregon State University

Session A1 - Interactions between wood properties and operations

The forest products industry lacks reliable non-destructive methods to estimate downstream lumber performance from logs prior to processing them into products, limiting opportunities for value-optimized wood supply chains. log cross-section ring attributes, such as earlywood-latewood ratio and ring width, and lumber mechanical properties in ponderosa pine to support image-based in-woods log sorting for improved value recovery. The dataset includes 31 log discs and corresponding cross-section images, 160 associated lumber samples, and 320 lumber end images. Log cross-section ring attributes are extracted using an automated image-processing workflow, while board-end-level attributes are quantified from densitometer-based measurements. Lumber bending strength and dynamic elastic modulus are determined using standard methods. In addition, lumber radial positions within the source log cross section are identified. Statistical modeling is used to quantify the relationships between log cross-section attributes and lumber properties. Preliminary results suggest that cross-section ring attributes explain meaningful variation in lumber mechanical properties and that lumber position within the log provides additional predictive value. By linking internal log structure to downstream product performance, this work supports the development of practical in-woods log sorting with the potential to improve value recovery, optimize wood supply chain decisions, and diversify downstream wood product arrays.

Occlusion Rate and Defect Core Determination in Pruned Loblolly for Clear Wood Production

by Paityn Matecki | Daniel DeArmond | Graduate Student, University of Arkansas at Monticello | Assistant Professor of Forest Procurement/Marketing, University of Arkansas at Monticello

Session A1 - Interactions between wood properties and operations

In the US South, loblolly plantations are abundant. So, how can landowners add value to their plantations in a saturated market? A potential option is silvicultural treatment such as artificial pruning to increase the amount of knot-free clear wood formation. In this endeavor, a long-term loblolly pruning experiment was established in southeastern, Arkansas. A randomized block design was implemented, which was composed of four blocks containing four one-acre subblocks. Each subblock was assigned a treatment: pre-commercial thin (PCT) to 160 trees per acre (TPA), PCT to 240 TPA, pruning only of 120 crop TPA/no PCT and a control with no PCT or pruning. The objective was to determine the feasibility of mid-rotation pruning and the subsequent increases in clear wood production. The study was conducted in a 15-year-old loblolly plantation that was pruned after the PCT. Trees were manually pruned to a height of 18 feet with Sentei telescoping pole saws by four laborers in the winter of 2025-26. In total, 120 trees were randomly selected from the PCT and pruned only treatments. Annual measurements will be taken at the stump height (1’), diameter at breast height (4.5’) and the bole height (17.5’) to determine the defect core. Occlusion rates will be determined by measuring the pruning wounds in the uppermost whorl below the bole height. Area of the unoccluded pruning wound will be measured in the vertical and horizontal position biannually. Once the pruning wounds have fully occluded and the defect core determined, clear wood formation can be modeled.

Operational Efficiency and Ecological Effects of Forestry Mulching in Alabama

by Hannah Mayo | Auburn University

Session C1 - Slash treatment and site preparation

Forestry Mulching is increasingly recognized as a sustainable management practice that reduces wildfire risk, improves soil health, and changes habitat structure. However, its economic feasibility and ecological impacts remain understudied. This research addresses these gaps through three components: (1) an operational time-motion study, (2) an ecological assessment on forest structure and ladder fuels, and (3) a wildlife study on the short-term effects of mulching on forest-dwelling reptiles. The first component is an operational time motion study designed to quantify mulcher productivity across pine and hardwood stands. A detailed study of each mulching phase will be conducted to establish baseline productivity metrics. The data from the time study will be paired with a cost analysis to identify the costs of fuel, labor, and machine depreciation. The second component evaluates short-term ecological responses to mulching. Habitat features such as duff and litter depth, ladder fuel presence, and basal area will be compared pre- and post- mulch treatment. The third component compares snake presence before and after mulching treatments in hardwood and pine forests. Using drift fence arrays with traps and cameras, snake presence will be recorded before and after the mulch treatment. Together, these studies provide three perspectives on mulching as a forest and habitat management tool. Findings from this research will inform landowners, forest managers, and wildlife biologists by identifying both the operational and ecological implications of forestry mulching, making it a sustainable and biodiversity-enhancing tool for modern land management.

Assessment of the Harvesting Capacity for Conducting Forest Fuel Reduction Treatments in Idaho and Oregon

by Jessie McCullough | M. Chad Bolding | Joseph L. Conrad IV. | Mathew Smidt | Jaana Korhonen |Timothy R. Miller | University of Georgia | University of Georgia | University of Georgia | Southern Research Station, USDA Forest Service | University of Georgia | University of Georgia

Session D2 – Supply chains

Due to increasingly disastrous wildfire activity in the western US, the USDA Forest Service implemented a 10-year wildfire crisis plan in 2022. To reduce fuel loads and lessen the threat of disastrous wildfires, fuel reduction treatments are being conducted in Idaho and Oregon by logging and forestry contractors. The objectives of this study are to 1) evaluate woody biomass harvesting capacity in the states of Idaho and Oregon, 2) document barriers and identify best practices to effectively conduct fuel reduction treatments, and 3) identify opportunities to support the establishment and retention of logging industry capacity. A logging and forestry contractor business owners survey was conducted in each state to better understand harvesting capacity and cost of fuel reduction treatments. These surveys were distributed through both standard mail and email in cooperation with logging and forestry professional organizations. The surveys used the same or similar questions for both states and were distributed to 277 businesses in Idaho and 634 businesses in Oregon. Forty-three responses were received from Idaho, and 118 were received from Oregon, yielding adjusted response rates of 15% and 19%, respectively. Preliminary analysis from Idaho indicates that owners are aging with the average age of owners being 57 years old. Around 35% of owners did not expect to continue their business within the next 5 years with most indicating they planned to retire. Of the owners who plan to remain in business, 55% reported their business was to maintain the same production level. With only 25% of businesses participating in woody biomass harvesting, there is a lack of harvesting capacity of woody biomass. Due to high rates of anticipated attrition among business owners, there is a potential for fuel reduction capacity to be below requisite levels to fulfill demand for fuel reduction treatments.

Evaluating the Effectiveness of Georgia's Forestry Stream Crossing Best Management Practices for Current and Future Conditions

by Emma Merritt | M. Chad Bolding | Joseph L. Conrad, IV | Timothy R. Miller | Brent S. Hawks | University of Georgia | University of Georgia | University of Georgia | University of Georgia | Weyerhaeuser Company

Session C2 - Environmental impacts & BMP

Georgia's forestry Best Management Practices (BMPs) for water quality are critical for minimizing environmental impacts from forest operations. Changes in rainfall intensity, land use patterns, and hydrologic dynamics have raised concerns among landowners and forestry professionals regarding culvert sizing recommendations. These guidelines, developed in 1981, may need to be updated to reflect changing conditions. Improper sizing or installation of culverts can lead to crossing failure, sedimentation, and downstream impacts. The goals of this project are to evaluate the efficacy of Georgia's water quality BMP guidelines for culvert crossings and to develop updated, operationally feasible recommendations to ensure continued protection of water quality. To address these goals, crossings will be assessed throughout Georgia's Piedmont (n = 200) and Coastal Plain (n = 200) regions to determine whether current BMP guidelines adequately account for present and projected conditions. An in-field assessment of 400 culverts will use established BMP audit and aquatic organism passage methods to evaluate installation, sizing, and implementation under observed conditions. This work directly supports a prioritization process for crossing replacement based on economic and ecological criteria, as several of these crossings were installed before widespread adoption of BMPs. Preliminary results from the Georgia Piedmont (n = 72) found an average BMP score of 78%. Only 15% of assessed culvert crossings met current BMP sizing guidelines; 68% had design, construction, or maintenance issues that could disrupt aquatic organism movement, and 62% of crossings failed to meet fill standards or lacked proper stabilization. We expect to see lower scoring stream crossings in the Piedmont compared to the Coastal Plain because of the erosive history of the region, steeper topography, and frequent changes in landowner since BMPs were established. Findings from this study will inform recommendations aimed at improving BMP effectiveness and ensuring long-term sustainability of forest operations and water quality protection.

Innovation in Timber Harvesting in the U.S. South: The Opportunity for Cut-to-Length in Changing Timber Markets

by Timothy R. Miller | M. Chad Bolding | Joseph L. Conrad IV | Pete Bettinger | Bruno K. da Silva | Raffaele Spinelli | University of Georgia, Harley Langdale Jr. Center for Forest Business | University of Georgia, Harley Langdale Jr. Center for Forest Business | University of Georgia, Harley Langdale Jr. Center for Forest Business | University of Georgia, Harley Langdale Jr. Center for Forest Business |University of Georgia, Harley Langdale Jr. Center for Forest Business | CNR Institute of Bioeconomy, Italian National Research Council

Session D2 – Supply chains

The forest industry in the U.S. South has undergone a significant structural market shift since 2022. During this period, 11 pulp mills have closed, representing an approximately 7.4 million tonne reduction in pulp production capacity and a 22.7 million tonne reduction in regional wood demand. These closures have constrained markets for low-value fiber, creating greater importance on high-grade value recovery for forest managers. While international research indicates that cut-to-length (CTL) harvesting systems can be highly effective at maximizing value recovery, limited recent research exists evaluating its capabilities and limitations in planted pine systems typical of the U.S. South. This study aims to evaluate CTL system performance across a range of stand conditions in the U.S. South. Our specific objectives were to 1) evaluate the productivity and cost of CTL harvest systems across a variety of harvesting conditions, 2) identify the stand characteristics best suited for CTL integration, and 3) quantify the value recovery potential for landowners and managers relative to conventional whole-tree systems. We identified four loblolly pine (*Pinus taeda* L.) harvest sites within the lower Coastal Plain physiographic region of Florida, USA. Data were collected from regeneration harvests of small-diameter, marginal sawtimber stands and large-diameter sawtimber stands, as well as second thinning operations. We conducted elemental time studies on Ponsse Ergo harvesters and Ponsse Elephant King forwarders across the three primary CTL functions: felling-processing, forwarding, and loading. These data were supplemented with onboard machine data to quantify fuel consumption and carbon emissions on a per tonne basis across each harvest area. This research provides a technical baseline for CTL performance within silvicultural systems typical of the U.S. South. Furthermore, this study aims to help stakeholders implement data-driven harvesting system selection to improve value recovery under evolving market conditions.

Productivity analysis of single-stem helicopter logging operations in coastal British Columbia

by Omar Mologni | Rosalia Jaffray | Quinn Kenny | Gregory Paradis | Dominik Roeser | The University of British Columbiia

Session B2 - Steep Slope & Tethered Systems

Single-stem helicopter logging (SSH) is a selective harvesting system used to recover high quality stems in stands where terrain, access limitations, stand structure, or value-recovery objectives constrain the use of conventional methods. SSH relies on ground crews to pre-condition selected stems through delimbing, topping, and jigging, after which stems are snapped from the stump and extracted by helicopter using a horizontal grapple on a 61 m (200 ft) longline. Although SSH is gaining operational traction, there is limited quantitative information available to guide planning, productivity expectations, and cost forecasting. This study evaluated the productivity and time-element structure of snap-and-fly SSH operations under real operational conditions. Field observations were collected in February–March 2025 at the Malcolm Knapp Research Forest (Maple Ridge, BC, Canada), documenting approximately 31 hours of helicopter activity across three cutblocks in second-growth coastal forest totaling 17 ha (43 acres). Operations were conducted in two phases using a Kaman K-Max K-1200 for smaller stems and a Sikorsky S-61N for larger stems. The dataset includes 791 turns derived from synchronized video, GNSS flight tracking, payload measurements, and mapped stem locations. Turn-level performance was analyzed using a time-element framework consisting of fly empty, hook-up and breakout, fly loaded, and unhook phases. The analysis characterizes cycle composition, quantifies turn-level variability, and identifies operational factors influencing performance, providing benchmarks to support planning, evaluation, and decision-making in selective helicopter logging systems.

State of the Forestry and Wood Products Sectors in Montana

by Carmen Murrill | University of Montana

Session P1 - Plenary

Forest managers and the wood products industry throughout the Intermountain West are experiencing unprecedented challenges. Climate change impacts abound: wildfires in rural and urban areas alike can be catastrophic, drought is an ever-present threat, and all but one National Forest in-state has greater tree mortality than growth. Montana faces socio-political trials as well: timber jobs along with public lands employment decline, litigation stalls necessary forest management, and the market for wood product building materials is only becoming more competitive.

At this crucial ecologic and economic juncture, there is also a hunger for innovative solutions. Several of the forest collaboratives I attend have seen increased participation and a diversifying of voices in the room; a clear indicator of the abundance of stakeholders who see themselves as having a role in guiding forest management. Thankfully, many foresters and timber industry leaders have dedicated their careers to not only tracking the challenges, but looking forward towards modernizing this nuanced public service and livelihood. I have and continue to benefit from the public engagement these folks facilitate so that we may evolve.

We need look no further than our relationship with forests past and present to see that we have a collective need. Sustainable forest management in Montana is not only possible, it is beneficial for all. Federal public lands constitute a huge portion of the total western U.S. landmass (30% of Montana's acreage, though for some counties it is over 80%). Much of this is in close proximity to cities and towns, and much is merchantable timber land. This presents a unique opportunity for shared responsibility and ownership in how the forest industry evolves. We all depend upon the health of our communities, we all have a role in finding solutions for how our future takes shape.

IMU-based activity recognition for forestry loaders: toward automated detection

by Adelin Nicorescu | Omar Mologni | Dominik Roeser | The University of British Columbia

Session F1 - Data science to improve forest operations

Accurate activity recognition is essential for understanding machine utilization and improving productivity in forestry operations. Conventional time studies, while valuable, are often labor-intensive, costly, and limited in duration and scale. In contrast, remotely collected sensor data offer a promising alternative for continuous, objective, and scalable monitoring of machine activities under real operating conditions. This study investigates the use of inertial measurement unit (IMU) sensors to distinguish among key loader activities, with the broader goal of supporting more efficient and automated productivity assessment. Three IMU sensors were installed on a loader: one on the cab, one on the boom, and one on the stick. These placements were selected to capture both whole-machine motion and the movement of the loader's working elements. Data will be collected across a range of loader operating activities representative of typical forestry work. The sensor signals will be analyzed to identify characteristic motion patterns associated with each activity and to assess the value of combining measurements from multiple sensor locations for activity classification. The expected outcome is the development of a practical framework for recognizing loader activities from remotely collected motion data, reducing the need for time-consuming and expensive manual time studies. Improved activity recognition could enable more detailed and continuous productivity monitoring, better estimates of machine utilization, and a clearer understanding of operational performance. In the long term, these findings may help researchers and practitioners develop scalable digital monitoring systems that support operational planning, benchmarking, and management decisions in forestry and other equipment-intensive industries.

Rethinking slash disposal: productivity and cost of carbonizing logging residues in British Columbia

by Adelin Nicorescu | Omar Mologni | Dominik Roeser | The University of British Columbia

Session C1 - Slash treatment and site preparation

In British Columbia (BC), tree-length harvesting systems generate large volumes of residual biomass in the form of slash piles, which can conflict with reforestation, access, and wildfire risk reduction objectives and therefore require removal. Disposal is increasingly challenging due to shrinking burning windows driven by air quality regulations and changing climatic conditions. Slash-pile burning (SPB) remains a widely used method for logging residue disposal in BC; however, as the province seeks more efficient biomass management approaches, understanding the productivity and cost implications of alternative technologies is essential. The carbonizer offer a promising option by enabling on-site carbonization of logging residues while producing biochar as a potential value-added product. This study evaluates the productivity and cost performance of the Tigercat Carbonizer 6040 in forestry operations across the Lower Mainland of BC. Field data were collected from multiple sites representing a range of biomass types and operational conditions. Measurements included machine productivity, biomass input rates, biochar yield, and machine fuel and water consumption. Data collection methods combined direct in-field observations, on-board computer systems for remote productivity tracking, drone-based photogrammetry for biomass volume estimation, and laboratory analysis of biochar samples. By analyzing operational efficiency and associated costs, this research aims to provide forestry stakeholders with practical insights into the economic feasibility of integrating carbonizing technologies into existing biomass management systems. The findings are intended to support decision-making regarding equipment deployment, operational planning, and supply chain integration in BC's forestry sector.

Calculating the Volume of Roundwood Piles Under Cranes Utilizing Unmanned Aerial System (UAS) in the Southern United States

by Prakash Ojha | Marissa 'Jo' Daniel | Richard Cristan | Brian Via | Lana Narine | College of Forestry, Wildlife and Environment, Auburn University

Session B1 - Volume Estimation

Accurate estimation of roundwood pile volume is important for efficient resource management, financial accounting, and supply chain logistics. Traditionally, ocular estimation is done due to its simplicity, cost-effectiveness, and time efficiency. Still, it is prone to human errors, which result in inconsistent results, as well as require a highly trained and experienced person. There is a need for a repeatable, data-driven regression model that becomes an alternative to the ocular estimation method. With the recent advancements in remote sensing technologies, unmanned aerial systems (UAS) have become a revolutionary tool that has been utilized in the volume estimation of forest biomass. However, their application in forest industries to estimate the volume of roundwood piles for regression modeling has not been explored.

This study aims to evaluate and estimate the volume of roundwood piles using UAS under cranes in mills, compare the results of the UAS-based method with the ocular method, and develop a regression model based on pile characteristics. The study sites will be selected in different forest mills across the southern United States, as this region is the nation's powerhouse for roundwood production. UAS imagery will be collected and processed using Pix4DMatic, generating orthomosaics and digital surface models. Key parameters, such as pile height, footprint area, perimeter, and slope, will be extracted and used in regression analysis. The UAS-based estimates will be validated against ocular estimates using statistical metrics such as RMSE and R^2.

The expected outcomes include an efficient, repeatable, and accurate method for estimating roundwood volume, as well as species-specific regression equations. This study will provide a decision support tool for making informed financial decisions and planning inventory. This study will lay the ground for future integration with advanced tools such as machine learning, deep learning, and artificial learning.

Optimization of Harvest Unit Layout for Tethered Cut-To-Length Thinning Operations

by Murat Ozmen | Woodam Chung | Oregon State University

Session F1 - Data science to improve forest operations

Tethered Cut-To-Length (CTL) logging systems have seen rapid adoption for their potential to improve productivity on steep slopes, reduce soil disturbance, and enhance worker safety. However, realizing this potential depends directly on harvest unit layout planning that requires distinct treatment from conventional operations given the additional constraints imposed by steep terrain. This study introduces a two-stage layout-generation approach designed for tethered CTL thinning operations. The approach utilizes high-resolution LiDAR-derived digital terrain models (DTMs) and tree-level inventory data to systematically evaluate layout alternatives. In the first stage, a feasibility analysis generates candidate anchor locations and harvester travel corridors by enforcing operational and safety constraints, such as maximum slope limits and allowable cable lengths. In the second stage, a genetic algorithm (GA) optimizes the selection of primary and side-washing corridors, minimizing total corridor length while maximizing coverage of pre-marked cut trees through a penalty-based objective function that discourages corridor overlaps, improper anchor spacing, and redundant cut-tree coverage. The approach was evaluated through a sensitivity analysis across two harvest units with contrasting terrain conditions under maximum downhill longitudinal-slope limits of 45%, 55%, 65%, 75%, and 85%. In the steeper unit (Case 1), relaxing the slope limit increased access to target cut trees, reducing the number of uncovered cut trees by 73%. In the moderately sloped unit (Case 2), coverage gains diminished as the slope limit increased, plateaued at 75% and 85% limits with near-complete stand coverage. Under this regime, the optimization produced layouts at the 85% maximum slope limit that maintained the same high coverage but further reduced the total required corridor length. The resulting georeferenced layouts and summary indicators can support planners in evaluating coverage–corridor length trade-offs for tethered CTL thinning under steep-slope conditions.

4D Simulation of Cut-To-Length Harvesting Using Discrete-Event Simulation and Building Information Modeling

by Murat Ozmen | Woodam Chung | Oregon State University | Oregon State University

Session E1 - Ground-based harvesting systems

Effective planning of Cut-To-Length (CTL) harvesting operations requires tools capable of representing complex machine interactions, spatial constraints, and time-dependent workflows before field execution. This study addresses that need by combining discrete-event simulation (DES), which models time-based operational events, and Building Information Modeling (BIM), which links 3D model elements to time-based schedules, into an integrated virtual harvesting framework, while adapting the 4D simulation paradigm established in construction to forest engineering. The DES component models CTL harvesting operations at the tree and log level through a high-resolution temporal event schedule, allowing concurrent harvester and forwarder activities to be evaluated under spatial and operational rules. Based on a predefined harvest layout, the model defines harvester-forwarder interactions, examines corridor priorities, and identifies efficient workflow alternatives. Key performance outputs include total operation time, machine utilization, delay times, and bottlenecks across varied machine combinations and workflow scenarios. The BIM component links this event schedule to georeferenced digital model elements, creating a 4D simulation environment that animates the time-based progression of harvesting operations. This virtual harvesting environment allows planners to review operational sequences, anticipate machine conflicts, and identify implementation issues prior to field execution. The integrated framework of DES and BIM supports both quantitative performance evaluation and visual verification of modeled workflows, offering a transferable approach for 4D simulation of timber harvesting operations.

Production Studies of Steep Slope Harvesting Machines in Northern California

by Bridger Paradis | Hunter Harrill | Jeffrey Kane | Han-Sup Han | Cal Poly Humboldt | Cal Poly Humboldt | Cal Poly Humboldt | Northern Arizona University

Session B2 - Steep Slope & Tethered Systems

The 2023 US Forest Service Wildfire Crisis Strategy identified several high-risk landscapes where fuel reduction treatments should be prioritized, including the Klamath and Trinity National Forests. While the agency plans to increase the annual acreage of these treatments, topographic challenges often limit areas that can be treated and require consideration of different approaches. Mechanized operations are more costly, but the pace and scale of these operations could outweigh their expenses. Tethered felling and an extraction using modern small-scale unguyed yarders have been identified as viable options. Both these machines are capable of operating on significantly steeper slopes in comparison to standard ground-based operations. Justification for the use of these machines includes: reduced labor, increased mobility, shoveling capabilities for the feller, and decreased set-up time for the yarder.

Two separate time-based studies were used to analyze the productivity of each machine. The studies occurred at four locations for the tethered felling machine and three locations for the yarder. More than 60 days of shift-level analysis and a week of detailed time study data were recorded. Results of the study showed a cycle time of just under five minutes for the felling machine when felling and shoveling, and a 2.5 minute cycle time for the yarder. Productivity for the felling machine was approximately 9.4 mbf/hr, and around 3 mbf/hour for the yarder. Cost per acre, as well as cost per unit of volume (mbf/hr) estimates, were also derived. For example, the felling machine costs around $32/mbf and $1,860/ac. The aim is for fuels managers to be able to use these estimates to aid in planning future fuel reduction projects. Thus, incentivizing the use of tethered machinery and small-scale yarders as a viable mechanized alternative to improve the pace and scale of field reduction treatments.

Categorizing Rutting Following Thinning in Loblolly Pine (Pinus taeda) Stands in the US South

by J. Tyler Patton | Dr. Joseph L. Conrad IV | Dr. Bronson P. Bullock | Dr. Stephen M. Kinane | Dr. Chad Bolding | Warnell School of Forestry and Natural Resources

Session C2 - Environmental Impacts & BMPs

Rutting is a negative consequence that can occur from conducting forest operations under wet soil conditions. Previous studies have linked rutting to an increase in bulk density and a decrease in stand productivity. This study aims to assess the extent and severity of rutting along skid trails in loblolly pine (*Pinus taeda*) stands in the southeastern US following thinning during wet soil conditions. For this project, ruts were classified into three depth categories: no/minor ruts (<7.5 cm), moderate ruts (7.5–29.9 cm), and deep ruts (≥30 cm). Study sites consisted of loblolly pine plantations in the southeastern US with deep ruts resulting from thinning operations performed 3–5 years before the study. The skid trails were mapped and rut depths recorded, then were spatially analyzed to determine the percentage and length of ruts within each category. Preliminary analysis indicates that for the sites containing deep ruts, an average of 6% of skid trail length was heavily rutted, 6% was moderately rutted, and 88% experience no/minor rutting. The average uninterrupted length for each category was 37 m for deep ruts, 25 m for moderate ruts, and 114 m for no/minor ruts. While deep ruts are a large concern for landowners, preliminary results indicate that heavy ruts typically make up a small percentage of the stands in which they are found. These results will be used to aid future studies evaluating the impact of different rut depths on residual tree growth.

Are Trees Heavier Today? Re-evaluating 1974 Transportation Weight Limits in the Context of Modern Forest Allometry

by Mandira Pokharel | Marissa Jo Daniel | James Chappell | Abubakar Tahiru | Auburn University | Auburn University | Alabama Forestry Commission | Auburn University

Session F2 - Transportation

Forest operations and transportation policies have historically relied on static weight-based assumptions created after weighing trees in the 1970s, yet modern silviculture and genetics may have fundamentally altered the geometry of commercial timber. This study investigated temporal shifts in merchantable bole weight and height in the southern United States to determine if these historical assumptions require recalibration. We analyzed USDA Forest Service Forest Inventory and Analysis (FIA) data for loblolly pine (*Pinus taeda*), sweetgum (*Liquidambar styraciflua*), and yellow-poplar (*Liriodendron tulipifera*) in Georgia (1997–2023), Alabama (2000–2023), and Mississippi (2009–2023). Using weighted least squares regression, we modeled temporal changes in bole weight and height while controlling for diameter, age, and site productivity. Results indicate a consistent, statistically significant increase in bole weight across all states, with annual growth rates ranging from 0.51% to 1.29%. This trend is mechanistically driven by simultaneous increases in tree height within fixed diameter classes. Notably, loblolly pine exhibited a "plantation effect," where weight accumulation was significantly faster in planted stands compared to natural stands, a disparity absent in hardwood species. Our results show that the modern forest inventory is allometrically distinct, being taller and heavier for a given diameter than historical stocks. This shift implies that static transportation limits may be increasingly misaligned with the biological reality of the current forest.

ForestStruct3D: A Newly Developed AI-Based Tool for Forest LiDAR Analysis with an Embedded Tree Segmentation Model

by Jiyeon Ryu | Heesung Woo | Taejin Kim | Heechan Jeong | Department of Forest Engineering, Resources, and Management (FERM), College of Forestry, Oregon State University

Session B1 - Volume estimation

Accurate individual tree information is critical for forest inventory and management planning, but efficiently extracting such information in structurally complex stands remains challenging. Mobile laser scanning (MLS) provides a practical means of capturing detailed under-canopy forest structure, which aerial platforms often characterize incompletely. However, most existing pre-trained segmentation models were developed from datasets with limited representation of under-canopy complexity, and their semantic schemes often lack separate classes for understory vegetation and dead branches. Consequently, these components are often misclassified as ground or crown, limiting the accuracy of tree-level structural estimates.

To address this issue, we adapted ForestFormer3D using MLS data collected from 35 structurally distinct stands in western Oregon. The semantic scheme was expanded from three to five classes by explicitly adding understory vegetation and dead branch classes, improving representation of forest structural complexity. The adapted model achieved mean IoU values of 0.77 and 0.73 for semantic segmentation and the highest individual tree segmentation F1-scores (0.88 and 0.77) among five baseline models. The model also achieved precisions of 0.99 and 0.82, which are particularly important for minimizing segmentation errors that can lead to overestimation of tree counts in stand-level inventories.

Based on this segmentation model, we are developing ForestStruct3D, an integrated software tool that automates the extraction and visualization of tree-level structural attributes from segmented point clouds, including DBH, height, crown dimensions, understory density, and dead branch distribution, within a single processing pipeline. The tool is expected to provide a scalable and reproducible framework for structure-informed forest inventory in complex stands.

SkidPC Online: A Web-Based Modernization of a Ground-Based Timber Harvesting Decision Support Tool

by Ben Spong | West Virginia University

Session E1 - Ground-based harvesting systems

SkidPC began with the development of rubber-tired skidder models by Olsen and Gibbons (1983) and tracked vehicle algorithms by Gleason (1986). These models were integrated into a unified DOS-based program by Balcom in 1987. This foundation was significantly expanded at Oregon State University with the release of **SkidPC 2000** (Spong, 2001), which introduced forwarder and clambunk skidder modules, a rut depth estimation model based on Wronski and Humphreys (1994), and a Windows-native VB6 interface. However, while SkidPC 2000 has been available now for over two decades, the aging VB6 platform eventually limited its accessibility and compatibility with modern computing environments.

This paper presents SkidPC Online, a comprehensive modernization developed at West Virginia University using Python and FastAPI. All core terramechanics models remain preserved, including the Freitag-based traction equations and the Wronski and Humphreys rut depth model, alongside several new extensions. Multi-segment road analysis allows independent slope, soil cone index, and segment length across a full extraction corridor. An integrated elevation proxy enables slope inputs derived from public digital elevation data.

A notable new capability is tire chains support for the rubber-tired skidder. The implementation modifies the K_1 asymptotic friction coefficient of the Freitag traction equation as a function of soil cone index, applies a smooth logistic slip-gate function consistent with Cudzik et al. (2018), and enforces a mandatory rolling resistance penalty per Stoilov (2007). The model helps predicts neutral or negative net chain effects at low wheel slip while capturing traction benefits on soft soils.

Additional improvements include an automatic maximum payload search that identifies the largest feasible turn weight when conditions preclude the user-specified load, and plain-language error diagnostics. Accessible via any web browser without installation, SkidPC Online preserves four decades of analytical development while substantially expanding reach for operations planners, researchers, and educators.

Developing an optimized trucking model to improve timber transportation efficiency, cost, and capacity in the US South

by Bandana Subedi | Joseph L. Conrad IV | Miachel Chad Bolding | Pete Bettinger | Damon Hartley |Graduate Research Assistant, University of Georgia | Associate Professor, Forest Operations, University of Georgia | Associate Dean for Research, Professor and Langdale Endowed Chair, Forest Business, University of Georgia | Professor, Landscape Planning and Harvest Scheduling and Hargreaves Distinguished Professor in Forest Management, University of Georgia | Senior Research Scientist, Idaho National Laboratory

Session F2 - Transportation

The wood supply chain in the US is a complex network of forest owners, logging contractors, transportation providers, and mills. The transportation component can account for 30–50% of the delivered timber cost and is a common operational bottleneck in the wood supply chain. Unfortunately, trucking efficiency is hindered by few backhaul opportunities (with trucks averaging only 48% loaded miles), increasing haul distances caused by Gross Vehicle Weight (GVW) limit disparities between state and federal highways, combined with weight-restricted bridges, and recent mill closures. These regulatory and operational hurdles often result in increased fuel consumption and costs. This study will develop an optimized trucking model to quantify timber transportation efficiency impacts associated with potential operational, infrastructure, and regulatory changes. We will integrate spatial data on harvest sites from Forest Inventory and Analysis, public road network, and mill locations from the FORISK's North American Mill Capacity Database. The study will employ location-allocation analysis to create a baseline scenario without constraints for wood baskets in the US South. Then, mixed integer linear programming will be employed to model scenarios and simulate interactions between harvest sites, log trucks, and mills, in addition to different combinations of operational and regulatory constraints. The study will evaluate the effects of specific interventions such as shared trucking fleets, reduced turn times at harvest sites and mills, upgrades to weight-restricted bridges, and interstate weight parity. Scenarios will be analyzed to estimate the benefits and costs of each combination of factors. Ultimately, the optimized model will be used to assess the costs and benefits of strategies designed to improve timber transportation efficiency. This research will assist log truck owners, logging business owners, mills, and policymakers to identify opportunities to improve the efficiency and competitiveness of the southern wood supply chain.

Assessing Fine Particulate Matter Emissions and their Regulatory Revisions Impact Analysis on the Forest Industry of Alabama

by Manisha Subedi | Dr. Marissa "Jo" Daniel | Dr. Richard Cristan | Dr. Lana Narine | Dr. Manisha Parajuli | College of Forestry, Wildlife and Environment, Auburn University

Session D2 – Supply chains

The recently revised primary annual fine particulate matter (PM2.5) standard from 12.0 µg/m³ to 9.0 µg/m³ by the U.S. EPA is expected to present challenges for Alabama's forest industry. This study aims to understand awareness and understanding, perceptions, and the potential impacts of new PM2.5 standards. Altogether 73 forest industries located in Alabama, including sawmills (59), pulp and paper mills (5), pellets mills (3), and oriented strand board (OSB) mills (3), were mail surveyed, of which 26.02 % of the total response rate was obtained. The findings revealed that facilities are aware of the new PM2.5 standards, made by environmental consultants and industry associations, and are involved in calculating annual PM2.5 emissions using EPA-based methods. Awareness doesn't vary significantly by mill type, ownership, scale, or years of operation. Facilities are strongly concerned, moderately prepared, and have moderate technical capacity to respond to the impact of new standards. Overall, they perceive that the new standards' negative consequences outweigh their environmental benefits, such as better public health and air quality. Financial impacts, such as higher costs, reduced investment, reduced revenue or profit, and operational impacts such as changes in operational methods and delays, are the most highly ranked impacts, followed by equipment and infrastructure, regulatory and administrative, workforce, and environmental benefits. Facilities reported on the cost associated with permits and emission control technologies are the current and future economic and financial burden. Operational modifications are not currently considered but are expected to cause challenges in the future. Facilities have developed cost management and adaptation strategies and are seeking further technical support to respond to new PM2.5 standards. The findings will support informed PM2.5 standards policy decision-making for forestry and environmental stakeholders, which makes Alabama better and balanced in terms of economic growth, healthier communities, and overall environmental quality, particularly in rural areas.

Real-time Estimates of Logging Equipment Carbon Emissions in the Southeastern United States

by Abubakar Tahiru | Marissa "Jo" Daniel | Richard Cristan | Auburn University

Session E2 - Improving safety of forest operations

Whole tree harvesting using mechanized equipment is widely practiced in Southeastern U.S. forestry, yet limited field data exist on exhaust emissions under real-world conditions. This study addressed this gap by measuring carbon dioxide (CO_2) and carbon monoxide (CO) emissions from active logging machinery using Portable Emissions Measurement Systems (PEMS). Emissions were evaluated across factors including Diesel Exhaust Fluid (DEF) usage, machine type, engine power group, activity type, grapple size, and transmission type. DEF-equipped machines emitted 16.93 g/kWh less CO_2 ($p < 0.001$) and 0.108 g/kWh less CO ($p < 0.001$) on average than non-DEF machines. Among equipment types, feller bunchers recorded the highest CO_2 emissions (345.18 g/kWh), followed by skidders (304.63 g/kWh), with loaders emitting the least (221.50 g/kWh). Regression analysis confirmed that loaders emitted 116.98 g/kWh less CO_2 ($p < 0.001$) than feller bunchers, while skidders emitted 56.20 g/kWh less ($p < 0.001$). Loaders also maintained the lowest average CO emissions (0.115 g/kWh), compared to 0.008 g/kWh and 0.002 g/kWh for feller bunchers and skidders, respectively. CO_2 emissions were highest during loaded skidding and lowest during idle. Mid-powered machines (165–184 kW) exhibited the highest CO_2 output, while higher-powered units (185–203 kW) were more carbon efficient ($p < 0.001$). Transmission type also influenced emissions skidders equipped with hydrostatic drives emitted less CO_2 than those using continuously variable transmissions ($p < 0.01$). These results demonstrate the effectiveness of Tier 4 standards in reducing emissions and underscore the influence of equipment characteristics and operational factors on carbon outputs during logging.

Satellite Teleoperation for Resilient Remote Forestry Delimbing Operations in Canada

by Maxime Vaidis | Eric R. Labelle | Philippe Giguère | Université Laval

Session D1 – Advanced technologies

Remote full-tree forestry operations in Canada depend on delimbing tasks that are repetitive, precision-critical, and physically demanding. These operations are often conducted far from urban centers and mills, where companies face persistent shortages of qualified operators and significant logistical costs associated with transporting crews to harvesting sites. In many Canadian forest regions, cellular connectivity is unavailable or unreliable, limiting the applicability of conventional teleoperation solutions based on LTE or 5G networks.

This work presents the development of a satellite-based teleoperation system for forestry delimbers intended for remote full-tree operations in Canada. The goal is to allow an operator located in an operations center near a mill or service hub to control the machine in real time, reducing travel, improving working conditions, and increasing workforce flexibility. The approach may also help retain experienced operators who prefer not to work full-time in remote forest environments.

The main technical challenge is maintaining safe and responsive machine control despite the latency and bandwidth constraints of satellite communication. To address this, the system combines optimized video and sensor streaming, adaptive bitrate management, edge processing, and prioritization of critical control data. Safety functions are designed to ensure predictable machine behavior during communication degradation or temporary link interruption. A key operational objective is to keep total data use below 4 TB per month while preserving sufficient situational awareness for teleoperation.

Initial validation are conducted on a Caterpillar delimber equipped with the system at a controlled private site in Canada, where tests assessed sensor integration, communication robustness, control stability, latency, and bandwidth use. Operational trials in active Canadian forest conditions are planned for summer 2026. This project supports the feasibility of reliable and economically viable satellite teleoperation for heavy forestry equipment in remote Canadian environments.

Application of Advanced Technologies in Forestry: Opportunities, Operational Integration, and Practical Challenges

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Session D1- Advanced technologies

Advanced technologies are expanding opportunities to improve forest operations, inventory, forest health monitoring, reforestation, and worker safety under complex field conditions. However, many emerging tools are still difficult to apply consistently in operational forestry because of limitations related to cost, portability, sensing performance, data quality, model reliability, and field deployment constraints. This presentation introduces an integrated forestry technology framework designed to address practical forestry applications through five research areas: field-centered deployable solutions, vision- and LiDAR-based forest perception, AI-based real-time mapping systems, robotic applications, and ground-penetrating radar (GPR) applications. Representative examples include UAV-based seedball delivery, heavy-lift drone systems for seedling transport and planting in remote or steep terrain, smartphone LiDAR for slash pile volume estimation, AI-based disease detection and forest health assessment, low-cost handheld LiDAR and SLAM for accessible 3D forest mapping, and robotic platforms for navigation, hazard detection, and safety support in wildfire environments. The presentation also covers GPR-based applications for underground infrastructure analysis, forest road stability assessment, root-zone investigation, and automated subsurface structure mapping using both ground and aerial platforms. These examples demonstrate the potential of advanced forestry technologies to reduce labor demands, improve measurement consistency, expand access to precision data, and support safer and more efficient operations. At the same time, this work shares the practical limitations and implementation challenges of each technology in real forestry settings. The overall goal is to support next-generation forest engineering by integrating sensing, AI, robotics, and subsurface detection into scalable, field-ready systems for measurement, monitoring, decision support, and autonomous or semi-autonomous operations.

Optimization and AI: What Actually Works and What Are the Trends in Forest Operations Planning and Engineering

by René Zamora-Cristales | Department of Forest Engineering Resources and Management, Oregon State University

Session P2 - Plenary

Artificial intelligence (AI) is transforming value chains across industries, yet its concrete applications in forest operations remain emerging and fragmented. In remote sensing, machine learning models have improved feature detection in satellite imagery, enhancing tree recognition, species classification, and attribute estimation. Precision forestry leverages AI-assisted technologies to increase the cost-effectiveness of machine-dependent operations such as harvesting, forwarding, and road planning. AI is also refining landscape-level fire spread models, improving preparedness and response capacity for risk mitigation. Optimization stands to benefit significantly from AI integration. Machine learning can generate improved growth and yield predictions that feed into harvest scheduling models, leading to better long-term planning outcomes. AI-driven route optimization can reduce transportation costs and environmental impact by identifying efficient log-truck routing under dynamic conditions. In silviculture, AI-enhanced decision support systems can optimize planting density, thinning regimes, and species selection by learning from large operational datasets. Computer vision combined with optimization has shown promise in automated log bucking, maximizing value recovery at the stump. However, significant questions persist regarding the integration of AI with optimization and simulation frameworks, particularly given the spatial and temporal variability inherent in forest environments. Model transferability across regions and forest types remains a challenge, as does the availability of high-quality training data. Additional uncertainty surrounds AI's potential impact on the labor market in forest operations. This presentation provides a comprehensive review of current trends, practical challenges, and priority research areas aimed at equipping the next generation of foresters. We address the nuances of applying AI to ground-level operations, seeking to demystify its role and offer a balanced assessment of both its promise and limitations.

Advanced Supply Chain Engineering to Support Fuel Treatment and Forest Restoration

by Jinghan Zhao | Jingxin Wang | Nate Anderson | North Carolina State University | North Carolina State University | U.S. Forest Service

Session D2 – Supply chains

To mitigate wildfire risk in the western United States, forest fuel treatments such as mechanical thinning and prescribed burning have been widely implemented in fire-prone areas. While these treatments play a critical role in reducing wildfire hazards, they also present both opportunities and challenges. A substantial amount of biomass generated from fuel treatments offers new opportunities for bioenergy development. However, without effective downstream utilization, the resulting residues may lead to issues related to piling, transportation, and secondary combustion. Existing forest biomass supply chain studies have primarily focused on logging residues and sawmill residues, with limited attention paid to biomass derived from fuel treatments as a feedstock source. Moreover, spatially explicit assessments of biomass availability aligned with priority investment landscapes remain scarce. This study aims to develop a novel biomass supply chain framework that incorporates fuel treatment products into upstream biomass supply and to evaluate their supply potential and system costs under different utilization scenarios. The proposed framework integrates multiple methodological approaches, including forest management simulations based on the FVS-BioSum model, GIS-based spatial suitability analysis, and a comparative application of mathematical programming and machine learning techniques for supply chain optimization. The results are expected to provide quantitative decision support for the Wildfire Crisis Strategy and regional bioeconomy development. This study contributes to the coordinated advancement of sustainable forest management and the energy transition.