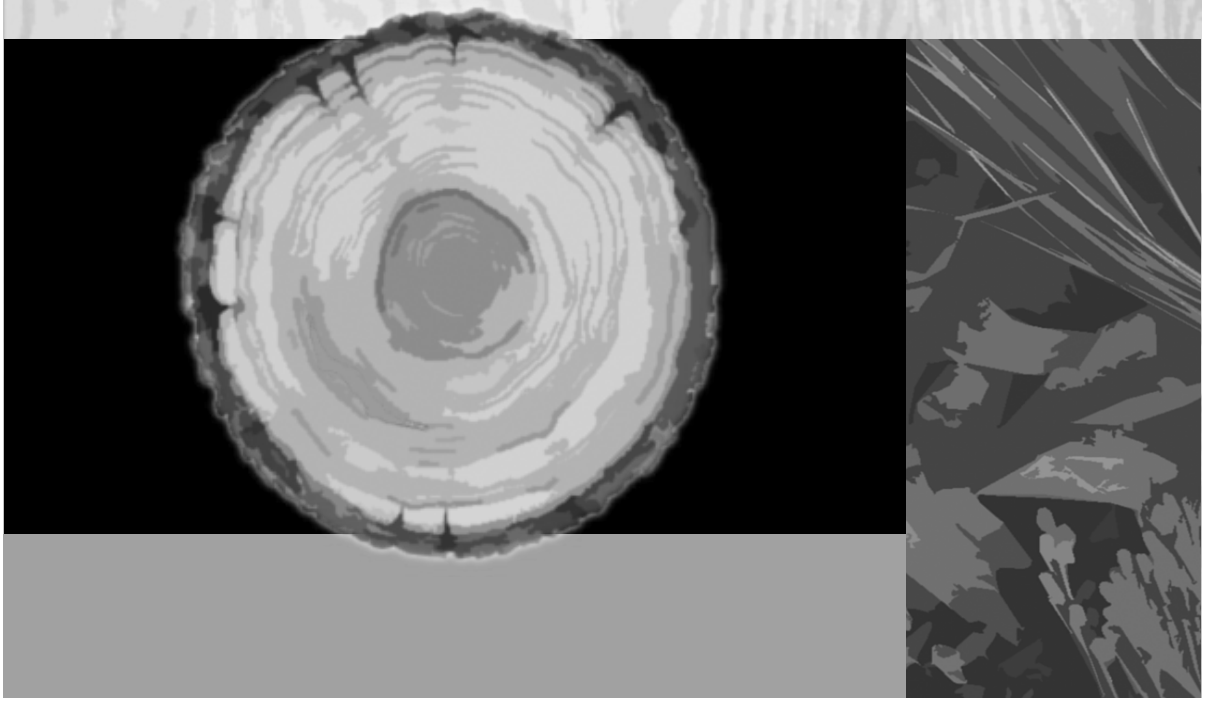
Progress Report for FY 2005

Center for Wood Utilization Research

at Oregon State University



Corvallis, OR 97331 • (541) 737-4257 • USDA Special Grant

PROGRESS REPORT FOR
FISCAL YEAR 2005

CENTER FOR WOOD UTILIZATION RESEARCH

AT OREGON STATE UNIVERSITY

Thomas E. McLain, co-PI
Steven D. Tesch, co-PI

College of Forestry
119 Richardson Hall
Oregon State University
Corvallis, OR 97331 USA

541-737-4257
http://cof.oregonstate.edu
http://woodscience.oregonstate.edu/USDAspecialgrant.php

Contents

Center for Wood Utilization Research

Oregon State University

Progress Report FY 2005

USDA CSREES Special Grant

Executive Summary

The USDA Special Grant for Wood Utilization Research (WUR) is focused on developing the science, technology, management approaches, and business practices that

- enhance the domestic and global competitiveness of the broad US wood products industry,
- maintain or expand sustainable and environmental acceptable forest operations and product manufacturing, and/or
- lead to more efficient use of renewable wood-based materials for the benefit of Americans.

Wood utilization research is critical to national needs because the US is the world's largest consumer of wood products and the largest importer. In Oregon especially, the global competitiveness of our domestic industry is of strategic importance to provide jobs, especially in rural areas; reduce dependence on nonrenewable materials; and sustain economic incentives for landowners to maintain private and public forests. The vast majority of US wood-products manufacturers are small- to medium-sized businesses. With the WUR Special Grant, Oregon State University is part of a larger national program to address critical wood utilization research needs that vary across the US and by discipline. Our principal focus is on the utilization of western species and the economic health of the Pacific Northwest industry. This report summarizes grant activities for FY2005.

Eleven active projects were supported by the USDA Special Grant to Oregon State University in 2005. Project research *generated 51 publications*, including *33 in peer-reviewed scientific journals,* and *6 graduate student theses*. Technology transfer continued at a high level of activity, with research results conveyed through *nearly 70 activities to scientists and practitioners* in industry, academe, and government agencies, as well as to policy- and decision-makers and the public.

Activities this year focused on important knowledge needs to extend the availability and utilization of domestic wood resources, improve our basic understanding of how wood is formed and responds to stress in advanced manufacturing techniques, and offer potential to enhance industry competitiveness through increased productivity and value recovery. Several studies have improved the scientific basis for understanding and mitigating the impacts of timber harvesting activities on soil and water resources, thereby improving the knowledge base for rational forest management regulations that influence timber supply.

Research and development activities in wood science and manufacturing seek to develop new understandings of biodegradation of composite materials in service, improve the performance of wood-frame structures in earthquakes, reduce hazardous air emissions, and provide better product yields from available wood supplies. Key research results on the life cycle environmental costs of material selection are now being implemented into national standards and practices that inform consumers, architects, and public policymakers. Pioneering research on wood residue chemistry, adhesion in wood-plastic composites and adaptive control in mechanical bucking may offer new economic development opportunities.

This Special Grant has enabled the University to leverage funding from the State of Oregon, industry, and other sources to develop intellectual capacity and provide operating funds for faculty

and students. Support for graduate students is especially critical in the face of a looming shortage of well-trained scientists, engineers, managers, and teachers in the field. The WUR Special Grant directly contributes to national and international research leadership in the cost-effective and environmentally sustainable use of wood.

Highlights of projects completed this year include the following.

- A study of how decay affects the strength of wood products in service revealed effective methods of nondestructively measuring potential for reduction in capacity and assessed the potential for fungal degradation to reduce the ability of nailed connections to resist seismic forces when employed in shear walls. This work aids in maintaining confidence in using wood in light frame-structures.

- Research documenting the amount of sediment generated from older road systems constructed before modern design and construction practices showed that currently accepted predictive models are inadequate. Results will improve landowners' ability to estimate environmental affects from harvesting operations, as well as the scientific basis for regulating harvesting activities during inclement weather.

- A study to quantify effects of deterioration on performance of light-frame wood buildings showed that such buildings framed in a reasonable manner and not having widespread deterioration will meet or exceed the lateral resistance performance of similarly constructed new buildings and should have similar seismic and wind performance.

- Evaluation of the system behavior of three-dimensional wood truss assemblies found that system design procedure could be used to assess system behavior of truss assemblies and may improve the conventional truss design method.

- A GIS-based framework was developed to improve forecasting of logging production. An annual crew-scheduling model was developed to apply these production estimates to the problem of allocation of units and crews to meet the customer demand. When the work is fully developed, forest industry firms will be better able to integrate their logging and milling operations and increase efficiency through an optimized primary forest supply chain.

- Research on applications of synthetic rope technology in timber harvesting operations demonstrated likely benefits in logging productivity and in worker ergonomics, including projections for substantial reductions in lost time accidents and insurance claims.

- Findings of a project to improve wood utilization and reduce energy use through effective lumber drying contribute to lowering costs, thus making domestic wood more competitive with imported wood and other materials.

- Studies on innovation in the forest sector have resulted in a new industry-endorsed initiative, the Oregon Wood Innovation Center, which will enhance global competitiveness of wood products manufacturers through innovation in products, processes, and business systems.

- A method developed to study patterns and mechanisms of radial water movement makes it possible to measure axial and radial pressure gradients *in situ*. The method will be useful to estimate water flux, which is used in studies of productivity and climate change. The information gained in this study will enhance understanding of drought tolerance.

- Development of a decision support system has the potential to provide forest managers with a methodology to evaluate post-wildfire timber salvage options to achieve economic value and environmental risk goals.

- Research on logging equipment productivity and capabilities will further the use of innovative technology and harvest planning approaches that are economically, environmentally, and socially sustainable to achieve diverse land management objectives.
- Cost and effectiveness analysis of three smart-sensor systems demonstrated their applicability in measuring external log characteristics and internal wood properties, and in tracking logs from forest to mill. The research also demonstrated the advantages of combining sensor technology with spatial models of stem characteristics to improve the performance of the sensor systems.
- Research quantifying the downstream environmental effects of timber harvesting adjacent to perennial non-fishbearing streams will inform policy decisions concerning forest practice rules for riparian areas along such streams. In the absence of such data on contemporary harvest practices, a precautionary approach to streamside protection could limit access to large acreages of productive forest in the Pacific Northwest.

One of the highlights of the OSU WUR Special Grant Program has been the attention paid to the dissemination of new information using a variety of outlets. This high level of technology transfer is reflected in the nearly 70 activities that targeted a variety of audiences, ranging from scientific conferences to workshops for landowners and manufacturers.

This report covers activities conducted under the following USDA/CSREES Special Grants:

02-34158-11903

03-34158-13892

04-34158-14679

05-34158-16380

Progress Reports

Improving Products and Processes to Enhance the Global Competitiveness of Oregon's Wood Products Industry

Softwood Grade Estimator for Inclusion in the CORY and SAW3D Simulation Programs

Charles C. Brunner, James W. Funck, James E. Reeb

Initiation Date: FY 04 Revised Completion Date: FY 07

Objectives: (1) to develop a lumber grade estimator for the softwood appearance grades found in the Western Wood Products Association (WWPA) rules for factory lumber; (2) to incorporate the estimator into the board-sawing simulator CORY and the log-sawing simulator SAW3D

The computer code for finding cutting areas of different softwood lumber appearance grades, e.g., No. 1 and No. 2 door, sash cuttings, etc., is in the final stages of development. Preliminary testing indicates that it is able to identify all the grade cuttings in our test boards. The preliminary code for determining board grade according to the WWPA rules for factory lumber has also been developed. Testing of the entire program will begin upon completion of these two components. Integration with SAW3D and CORY will start after program testing is completed.

Durability of Wood-Based Composites Employed in Building Envelopes

Jeffrey J. Morrell, Robert J. Leichti

Initiation Date: FY 04 Revised Completion Date: FY 07

Objectives: (1) to develop improved systems for assessing durability of water-resistant materials; (2) to assess the effects of various decay fungi on properties of wood-based composites; (3) to evaluate methods for nondestructive assessment of decay of wood-based composites

We examined several methods for enhancing the durability of wood-based materials. We also explored the effects of wetting and fungal exposure on OSB/Douglas-fir walls. Fungal growth was evident at the end of the 3-month test, but there was no evidence of advanced decay. These results differ from those of our accelerated tests on OSB/Douglas-fir test sections and illustrate the effects of larger scale on results. Moisture uptake was the primary source of changes in properties. After 1 year of wetting and fungal exposure, the systems had lost approximately 20% of their original capacity. Portions of the wall attacked by fungi were not always the areas of failure; moisture intrusion appeared to be more critical. We need to identify a simpler system that would allow us to test more assemblies. The large size of the present assembly increases the time to when decay occurs, presents storage problems, and limits our ability to adequate replicate tests.

We have begun follow-up tests on the effects of decay on connector assemblies, using additional fungi and material combinations. We have performed x-ray densitometry on OSB, plywood, and solid wood specimens that will be exposed to decay fungi and then assessed with NIR spectroscopy and other nondestructive methods. The goal is to develop correlations between these methods and losses in properties that can be related to connector failure. We are collaborating with researchers at the University of Tennessee to take advantage of their NIR capabilities. Our first tests assessed the ability of NIR to predict natural durability of a tropical hardwood. These tests took advantage of decay resistance and extractive content data we had already generated and allowed us to develop a better understanding of the potential for using NIR in decay prediction.

Environmental Management of Biobased Product Manufacture to Reduce Energy Use and Global Warming

James B. Wilson

Initiation Date: FY 05 Scheduled Completion Date: FY 07

Objectives: (1) to assess impacts of technology advancements in the wood products industry from the CORRIM

I (circa 1970) to CORRIM II (circa 2000) studies in terms of energy and material use efficiency; (2) to assess impacts of technology selection on the life-cycle inventory and life-cycle assessment of biobased composite panels; (3) to assess management opportunities for reducing energy use, global warming, and emissions to air, water, and land in the manufacture of biobased composite panels

The CORRIM I and II data on manufacturing practices for the production of OSB, plywood, and dimension softwood lumber were reviewed. The CORRIM II study contains detailed data on energy and material use efficiency, but the CORRIM I study lacked detail on the fuel type breakdown of total energy use. We are exploring ways to reconstruct the data from historical records of the industry.

To assess impacts of technology selection on life cycle inventory and life cycle assessment of the manufacture of bio-based composite panels, CORRIM II life cycle inventory models (LCI) for OSB, plywood, particleboard, and medium density fiberboard will be used. Because the models are based on weighted averages of surveyed data of the industry, it is necessary to go back to the original data and tie it to specific technology use for production.

Existing CORRIM LCI models for plywood and OSB are being updated with new data being collected for the resins used in these products. Models for particleboard and MDF are being developed based on the new resin data. The raw survey data for these products are being used to assess the impact of manufacturing technology on energy and material use and on emissions. The production data of individual manufacturing operations are being tied to the technology type used.

When all LCI models have been completed and updated, sensitivity studies of the CORRIM LCI models for the various biobased composites will be conducted in order to assess management opportunities for reducing energy use, global warming, and emissions.

Discovering New Knowledge for Future Opportunities and Benefits

Investigation of Interfacial Adhesion of Wood-Plastic Composites

Kaichang Li

Initiation Date: FY 04 Revised Completion Date: FY 07

Objective: to investigate (1) methods of enhancing the interfacial adhesion between wood and plastics in wood-plastic composites (WPCs) and (2) the adhesion mechanisms

Two compatibilizer systems are being developed: stearic anhydride-PAE (polyaminoamide-epichlorohydrin) resins and a stearic anhydride-PMDI (poly[methylene(polyphenyl isocyanate)]) system.The systems will be evaluated for their efficacy in enhancing interfacial adhesion between wood and plastics. Their compatibilization mechanisms systems will also be investigated.

We developed and characterized a commercially viable compatibilizer system: a combination of stearic acid and polymeric methylene diphenyl diisocyanate (PMDI). This system significantly improved the strength and stiffness of the resulting wood-polyethylene (PE) composites and is superior to maleic anhydride-grafted PE, one of the most effective compatibilizers in terms of enhancing the interfacial adhesion between wood and polyethylene. Stearic acid is readily available and inexpensive. PMDI is currently used as a wood adhesive. The PMDI-(stearic acid) system is thus cost-competitive to maleic anhydride-grafted PE.

Chemistry of Mill Residues for Increased and Improved Resource Recovery in Traditional Forest Products Operations

Joseph J. Karchesy

Initiation Date: FY 04 Revised Completion Date: FY 07

Objectives: (1) to identify potentially useful chemicals, extracts, or chemical-based materials from traditional mill residues of western sawmill, plywood, or wood composites operations; (2) to provide traditional forest products operations with a way to increase the value of their resources and help support the main mill operations

Materials being investigated initially are wood residues and residual foliage, and lignans, flavonoids, and other antioxidants and terpenoids with functionally useful reactivity, structures, or biological activity.

A process was developed to recover a blue essential oil from noble fir foliage. Two essential oils are produced: one amber and the second a deep blue. Blue essential oils from trees are rare and usually command a higher market value. The color in this case is due to the compound guiazulene, which may also make this oil suitable for pharmaceutical applications.

Natural products from Pacific Northwest forest resources and mill residues can offer alternatives to synthetic pesticides in control of both arthropods of public health concern and forest fungal pathogens. Tree heartwood extracts with high toxicity (low LC_{50}) in preliminary brine shrimp bioassays were good sources of bioactive compounds. The activities of isolated compounds, selected derivatives, extracts, and woody materials from Alaska yellow, incense, Port-Orford, and western red cedars and western juniper were compared against mosquitoes, ticks, and the fungus responsible for sudden oak death.

Heartwood from *Chamaecyparis nootkatensis* (yellow-cedar trees), its steam-distilled essential oil, and individual compounds were strong inhibitors of *P. ramorum* zoospore germination, sporangia germination, and hyphal growth. Nootkatin and carvacrol are the two most active compounds. Since yellow-cedar heartwood is abundant and can be readily processed into sawdust, it could be used to reduce spore dispersal in areas with sudden oak death. Further research may lead to development of spray formulations of the individual compounds for application to foliage.

Collaborative research conducted with the CDC under laboratory conditions indicates that extracts from Alaska yellow cedar are plausible alternatives to synthetic chemicals for protection against ticks and mosquitoes. Several of these compounds are currently registered with the FDA as ingestible and therefore are predictably safe for topical applications. Many of these compounds can be found in other plant species, most notably citrus fruits, which could provide a cheap and widely available source. Botanical repellents are now more widely accepted by the public, and these extracts could be formulated more efficiently to produce a commercial product.

Mechano-Sorptive Characteristics of Three Northwest Softwood Species in Compression Parallel to the Grain

Lech Muszyński

Initiation Date: FY 05 Scheduled Completion Date: FY 07

Objectives: (1) in the long term, to develop a foundation for a systematic database of clearly defined hygromechanical characteristics of commercial wood species that will be used to solve problems where wood is used in changing environmental conditions; (2) to determine the hygromechanical properties in compression parallel to the grain of three Northwest softwood species; (3) to examine potential correlations between the mechano-sorptive characteristics and other physical or mechanical properties of wood

Earlier projects revealed significant variability in the Poisson ratios (PR) in wood samples subjected to creep. The literature on the Poisson effect in continuous and cellular solids was reviewed. A simple mathematical model was developed for a parametric study on the significance and implications of the variability of the Poisson's effect for the accuracy of modeling long-term behavior of wood and wood-based composites. This study will include error assessment, as well as possible revision of constitutive models that would reflect this phenomenon. The calculations include isotropic and orthotropic materials subjected to various theoretical load configurations.

A loading fixture for axial creep experiments was designed and is expected to be fully operational by the end of March. Four specimens may be subjected to sustained axial loads (tension/compression) simultaneously.

Preliminary sorption tests were performed on the compression specimens of enhanced geometry ("ribbed" sections for optimum lateral stability and enhanced moisture exchange).

The plans for 2006 include arrival and training of a graduate student; building a dedicated small-scale humidity control system for the tests with cyclic humidity; fabrication of test specimens from fresh Douglas-fir, ponderosa pine and western hemlock logs; preliminary test series to determine optimal climate cycle duration; a substudy to examine the significance of stress level on mechano-sorptive compliance in compression; and a regular test series in compression and tension.

Enhancing Engineering Applications for Wood and Wood-Based Materials

Evaluation of Seismic Performance of Code-Prescribed, Wood-Frame Shear Walls

Rakesh Gupta; Collaborator, Thomas H. Miller

Initiation Date: FY 04 Revised Completion Date: FY 07

Objectives: To evaluate the performance of code-prescribed, wood-frame shear walls under monotonic, cyclic, and real earthquake loads, specifically (1) to estimate variability in the response of shear walls; (2) to evaluate the effect of anchorage; (3) to evaluate the effect of dead load; (4) to

compare the performance of shear walls between monotonic, cyclic, and dynamic loading conditions

This year, shear walls were tested under actual earthquake loads. All fully and partially anchored subduction zone earthquake tests in this project resulted in ultimate loading conditions and caused significant damage. These tests also caused large and high levels of cumulative drift ($\Delta_{cumulative}$) and total energy dissipation (E_{total}). This was not entirely true for fully and partially anchored walls tested with the SE03 strike-slip ground motion, because the $\Delta_{cumulative}$ and E_{total} levels indicate the loading conditions were less severe than in the subduction zone tests.

In general, partially anchored subduction zone earthquake tests exhibited failure modes of screw and nail edge breakout along the sill plate.

Fully and partially anchored walls exhibited different load paths. More fasteners are engaged in the fully anchored wall load path than in partially anchored walls, since the transfer of load from sheathing to end studs is more evenly distributed throughout the wall. As a result, fully anchored walls had damage more evenly distributed throughout the wall (rather than at the sill plate), favorable wall performance, and less wall uplift.

With respect to monotonic and cyclic tests from Phase I of this project, subduction zone earthquake tests of fully anchored walls had capacities (P_{max}) and energy dissipation (E) levels that were most similar to the cyclic, rather than the monotonic, tests. The monotonic and cyclic tests from Phase I of this project did not provide a good representation of subduction zone earthquake tests with respect to deflection at maximum load (Δ_{max}), initial wall stiffness (k_e), and wall ductility (μ). In partially anchored walls, subduction zone and strike-slip earthquake tests had P_{max}, Δ_{max}, k_e, and μ that were most similar to the cyclic tests; however, E levels were most similar to the monotonic tests. In partially anchored walls, monotonic tests resulted in greater P_{max}, and cyclic tests resulted in lower E when compared with the SE19 earthquake test. No other statistically significant differences were found.

The only walls to satisfy the FEMA 356 collapse-prevention interstory drift requirements were fully anchored and were tested with the SE13 ground motion. For fully anchored walls, the SE03 strike-slip earthquake test met the life safety interstory drift requirements; for partially anchored walls, it met the collapse prevention interstory drift requirements.

Earthquake tests causing high $\Delta_{cumulative}$, E, and E_{total} corresponded to fully and partially anchored walls meeting the FEMA 356 m-factor acceptance criteria. It is inconclusive whether m-factors from monotonic and cyclic tests are good representations for subduction zone and strike-slip earthquake tests for partially anchored walls. For fully anchored walls, m-factors from cyclic tests provided a conservative representation of those from subduction zone earthquake tests.

Extending the Timber Resource Through Improved Harvesting, Transportation, and Manufacturing

Adaptive Control of Bucking on Harvesters for Improved Wood Utilization

Glen E. Murphy

Initiation Date: FY 04 Revised Completion Date: FY 07

Objectives: (1) to assess how well a sample of forest industry production controllers can use new sources of stem information to adaptively control bucking on harvesters in pine stands and determine what decision rules they utilize; (2) to compare adaptive control by production controllers with existing adaptive control heuristics and to develop new heuristics, objective functions, and constraint penalty functions; (3) to investigate which data sources are important—sources that are spatially related, temporally related, or most similar—and determine what weighting factors should be applied to different data sources if combinations of data are used; (4) to determine how many stems are required in each new set of data to obtain acceptable results; (5) to determine the impact of harvester work methods and measurement accuracy on overall success and variability in adaptive control; (6) to establish an intensively measured 25-acre plot in McDonald-Dunn Forest where every tree is spatially located for testing adaptive control heuristics in a mature Douglas-fir stand

A 20-acre plot, named Extendo, was established in a mature (70+ years) Douglas-fir stand in the OSU College of Forestry's McDonald-Dunn Forest in 2004. In FY 04, every tree (>2700) was tagged, measured for DBH, and classified as hardwood or softwood. In FY 05, a surveying

team spatially located each tree. The site was mapped with LIDAR imagery in the winter of 2005. A scientist from Forest Research in New Zealand tested newly developed inventory tools and provided detailed stem descriptions of every tree in the Extendo plot in spring of 2005. Comparisons of stem measurements taken from LIDAR and ground assessments have begun.

Stem data from four *Pinus radiata* stands, one real and three artificially generated, were used to determine the effect of adaptively varying target proportions for given log types as the stands were being harvested on success in meeting market requirements. Varying the target proportions provided the best overall apportionment degree in only one of the four test stands. Stem data from one real-world and one artificially generated stand were used to determine how frequently bucking parameters should be adaptively controlled to obtain acceptable bucking solutions. Updating frequency was evaluated for every 4, 8, 16, 32, 64, 128, 256, and 512 stems. There were no significant differences in apportionment degree when examining update rates from 4 to 512 stems in both of the test stands. Stem data from one stand were used to determine whether adaptively controlling bucking on the basis of spatially close data meets market requirements better than using temporally close data. No difference was found.

In 2005 the FASTBUCK optimal bucking software was expanded with batch processing capability and the inclusion of two new stem characteristics–sweep and wood density. Test versions of these changes are included in three separate programs. In 2006, the expanded FASTBUCK capabilities will be merged into a single program. Stem assessments gathered from the Extendo plot will be converted to a format that can be used by FASTBUCK. A test of adaptively controlling bucking in a Douglas-fir stand will be carried out. Log market prices and specifications will be assembled for the test.

Increasing the Efficiency of Timber Harvesting Plans and the Log Supply Chain Through Improved Inventory Analysis Techniques

Kevin D. Boston, Glen E. Murphy, Jeffery D. Hamann

Initiation Date: FY 05 Scheduled Completion Date: FY 07

Objectives: (1) to quantify the risk and uncertainty contained in operational forest plans; (2) to apply spatial statistics to operational inventory data with the goal of reducing the uncertainty in the volume and value estimates; (3) to design sampling methods that best implement advanced inventory techniques and allow the industry to adopt this technology rapidly

Study area one, known as Extendo, has been fully inventoried and stem mapped. The second study area, known as B&M, has had the boundary surveyed and approximately 50% of the stems mapped. The development of sampling schemes will be completed by fall 06.

Science to Support Environmentally Responsible Wood Procurement

Development of Methodologies to Evaluate the Impact of Construction Practices, Materials, and Road Use on the Economic and Environmental Performance of Aggregate Forest Roads in the Oregon Coast Range

Kevin D. Boston, Marvin R. Pyles

Initiation Date: FY 04 Revised Completion Date: FY 07

Objectives: (1) to implement the current aggregate road design methodologies from rural roads to determine their suitability for forest roads; (2) to test the potential for improved environmental performance by comparing the laboratory measures of subgrade and surface strength compacted at current field density and moisture conditions with properties at optimal density conditions; (3) to determine the changes in road shape based on road use and road strength

Field data have been collected and all but one road have been resurveyed. The remaining road will be resurveyed after operations are completed in winter 2006. An MS student is completing fifteen point compaction curves with the CBR machine.

The Design of Forest Roads to Minimize the Delivery of Fine Sediment While Transporting Logs During Wet Weather

Arne E. Skaugset III, Elizabeth M. Toman

Initiation Date: FY 04 Revised Completion Date: FY 07

Objectives: (1) to develop and test designs for aggregate pavement structures for low-volume forest roads that will

minimize the generation of fine sediment from the road surface during active use in wet weather; (2) to investigate the relative role that aggregate quality (geology of the surface aggregate) plays in the generation of sediment from road surfaces during active use in wet weather; (3) to perform a benefit/cost analysis of the different design alternatives comparing the cost of the installed pavement aggregate surface with the savings in sediment from the road surface; (4) to investigate the opportunity to use the road installations to investigate management strategies for roads during periods of wet weather; (5) to use the data generated to verify, or perhaps modify, the coefficients used to predict the impacts of traffic on sediment yield used in SEDMODL and other models that predict the effects of traffic on the generation of sediment from low volume, aggregate-surfaced roads

During the past year, progress was made in three areas.

(1) We developed a method to design the aggregate pavement, specifically aggregate depth, of low-volume roads with the goal of minimizing sediment production during wet-weather hauling.

(2) We investigated the 'opportunity costs' due to reduced revenue or increased costs associated with using traffic management as a strategy to minimize sediment production from roads during wet weather hauling. The method that was developed for the design of aggregate surfaces resulted in much thicker aggregate depths than previous methods, making these roads much more expensive to build and maintain. An alternative strategy to minimize sediment yield during wet-weather log transport is to manage truck traffic and not allow log trucks to operate during wet weather. The decreased availability of hauling days in the winter should represent lost revenue and be an opportunity cost that could help defray the cost of more expensive roads.

    To evaluate the opportunity costs that reduced hauling during wet weather, a hypothetical project was carried out. The regulatory restrictions in the California Forest Practices Rules were applied to the Oregon State University College of Forestry Research Forests. Four scenarios were simulated. Opportunity costs were between about 2 and 18% of total net revenue.

(3) One replication of the field research study to test the design method developed in this project against other standard designs was installed; Green Diamond Resources Company in northern California agreed to host this replication. Data will be collected this winter. At least two other cooperators (Port Blakely and the Oregon Department of Forestry) have volunteered to participate.

The activities for the coming year include finding hosts for a maximum of two more replications. We then will locate the field sites, construct the roads, collect the data when logging occurs, and analyze the data.

Termination Reports for Completed Projects

Assessing the Chemical-Mechanical Relations in Nailed Light-Frame Connections Subjected to Fungal Biodeterioration

Robert J. Leichti, Scott M. Kent

Initiation Date: FY 03 Completion Date: FY 06

Objectives: to determine changes in physical, mechanical, and chemical properties of aspen oriented-strand-board (OSB) sheathing after exposure to *Postia placenta* (brown rot) under ideal growth conditions for up to 30 weeks, specifically evaluating (1) the feasibility of using near-infrared (NIR) spectroscopy to predict the level of decay damage in terms of dowel-bearing strength, changes in specific gravity, and solubility in an aqueous solution of sodium hydroxide; (2) the spatial density distribution of sound and decayed OSB as determined with x-ray densitometry

The variability of the test results in each incubation time group was relatively high, a combination of the inherent variability of the material and that associated with the rate of fungal growth. This finding implies that prediction of time-to-failure due to fungal deterioration involves considerable uncertainty.

Two statistical models were developed to relate dowel-bearing strength to specific gravity. The first model used gross specific gravity of the OSB sample; the second used a zone of averaged specific gravity, determined with an x-ray densitometer, under the nail during the dowel-bearing test, averaged for a distance of half the nail diameter. A linear relationship fitted to the data gave coefficients of determination of 0.64 for the gross specific gravity and 0.81 for the averaged x-ray specific gravity. The slopes of the two models were not statistically distinguishable, but the unexplained variance was smaller for the second. This finding indicates that the dowel-bearing strength was affected by the local density of the material directly under the nail during the dowel-bearing test. Because the unexplained variation was only moderately reduced, factors not addressed or measured in this experiment likely also affected the outcome.

The NIR spectra between 1300 and 2400 nm were used to create models for specific gravity, shear strength, dowel bearing strength, and NaOH solubility. The prediction for specific gravity had the highest coefficient of determination, 0.90; the others ranged between 0.84 and 0.85. The NIR system used is portable with a self-contained light source, which would enable *in-situ* evaluation of the sheathing in buildings.

The probability of nonductile failure increased as bending yield strength increased. Also, the peak capacity of the walls increased as bending yield strength increased up to 100 ksi. Nails with bending yield strength greater than 100 ksi did not enhance cyclic wall performance.

Results of decayed single nail tests were used to estimate cyclic wall performance over time. Wall system performance remained unaffected until a large percentage of the nails were severely decayed.

The Effect of Road Connectivity on Fine Sediment Delivery to Streams

Arne E. Skaugset III

Initiation Date: FY 02 Completion Date: FY 05

Objectives: (1) to determine (a) a technically feasible, cost-effective method to measure the amount of fine sediment generated by individual road segments; (b) road and site characteristics that affect the amount of fine sediment generated by individual road segments; (c) the amount and timing of sediment from connected road segments relative to the sediment load carried in the live stream where the road segment(s) are connected; (2) to model sediment production from individual road segments; (3) to compare the amount of fine sediment generated from connected road segments with the total basin sediment yield

This research was conducted in the Oak Creek Watershed of the McDonald/Dunn Research Forest, Oregon State University. The sediment load for various periods was measured during the 2003 water year. The only parameter describing the characteristics of the hillslope and the road that the culvert drained that showed a significant relationship with

sediment load was total discharge through the culvert. In general, the amount of sediment that the road produced was a function of the total amount of runoff. This factor outweighed all other road and hillslope characteristics.

The road and hillslope characteristics associated with the road segments studied were used as input variables for two models used to predict sediment yield from the road segments: WEPP:Road and SEDMODL2. Neither model predicted the measured sediment yield from the road segments well. More importantly, neither could predict the relative rank of the road segments with respect to sediment yield. While the models are not expected to predict the actual sediment volumes well, it is generally thought that they should be able to predict the relative rank of the road segments.

Instrumentation was installed and data were collected on a single small watershed in Oak Creek with a road running through it. Data were collected during the 2004 water year on the runoff and sediment yield from the roads, from the watersheds above the road, and from the total watershed. Analysis of the data describing the hydrology of the watershed is being completed; robust treatment of the sediment data awaits the completion of that task. Work is continuing on the sediment yield of Oak Creek and a watershed scale assessment of the sediment yield from the roads in the watersheds.

The housing boom in the United States after World War II left a legacy of timber harvesting on federal and private ownership with an accompanying legacy of forest roads. There is concern about the impact of this 'legacy road system' on the hydrology and sediment regimes of roaded watersheds. The results of this project indicate that currently accepted models overestimate real sediment production and, more importantly, do not assign the correct relative risk to the road segments. They also show that the single best predictor of sediment yield from roads is total runoff. The methods developed should improve the collection of discharge and sediment data from road segments. The results from this research should be valuable to landowners interested in more accurately estimating the impact of their legacy road systems on runoff and sediment.

Engineering Durability in Wood Structural Systems

Robert J. Leichti, David V. Rosowsky

Initiation Date: FY 03 Completion Date: FY 06

Objective: to quantify selected effects of in-service deterioration on the performance of conventional wood frame and light commercial structures

The first part of this project investigated the vulnerability of the existing housing resource to potential hazard loadings. The basic design premise that connection details in light-frame construction do not change in capacity or energy dissipation characteristics is not necessarily true, even if the connections have degraded. The general condition of connections, such as nailed and metal-plate connection, in existing structures was not known.

Permission to remove selected connections and subassemblies from buildings to be demolished was obtained from local building departments for laboratory testing in lateral loading. Connection and subassembly removal from light frame buildings constructed from 1900 to 1970 occurred from early summer 2004 to late fall 2004. Wall units with plaster-lath construction were relathed and replastered in the laboratory. A set of wall plank-sheathed and lath-and-plaster units was tested according to a monotonic load protocol, and a set of lath-and-plaster walls was tested with a fully reversed cyclic protocol. The capacity of plaster-lath wall systems depended on the attachment of the lath to the studs.

Nail bending yield strength did not change with age; values met current design expectations. The wood embedment strength was statistically similar to the current design value for Douglas Fir-Larch. Yield mode IV was the most prevalent yield mode and matched the calculated yield mode. The mean capacity exceeded the calculated design capacity by a factor of about 3, in keeping with modern performance requirements. Capacity of plank-sheathed walls was approximately 2.2× the FEM 356 specified values. In plaster-and-lath walls, the interior surface played a significant role in lateral force resistance.

Light-frame wood buildings built between 1900–1970 may have many variations in framing. Those that are framed in a reasonable manner and that do not exhibit fungal decay or other widespread deterioration will meet or exceed the lateral resistance performance of new buildings of similar construction. The seismic and wind performance of older buildings should be not substantially less than newer buildings.

Evaluation of System Behavior of Three-Dimensional Wood Truss Assemblies

Rakesh Gupta

Initiation Date: FY 03 Completion Date: FY 06

Objectives: to provide a practical approach to analyzing three-dimensional light-frame wood truss assemblies by using commercially available structural analysis computer

programs, specifically (1) to determine (a) a suitable design analog for a single truss, (b) a practical way to model two-way action of sheathing and composite action, and (c) a suitable and practical joint model for assembly modeling; and (2) to investigate boundary condition (truss-to-wall connections) models to be employed in the assembly model

The premise of this research was that some 'system effects' are not included in truss assembly design using conventional design procedure (CDP) and that a 3-D structural analysis program can be used to analyze and design whole-truss assemblies (i.e., system design procedure, SDP) and include system effects directly.

SDP is a simple, yet comprehensive, integrated analysis and design approach to solving a rather complex problem. The basic approach is to analyze actual truss assemblies with 3-D structural analysis software. If 3-D assembly models are used to derive system factors for a 2-D analysis of a single truss, the same 3-D model of the assembly could be used to analyze and design the entire assembly without the system factors. The use of system factors is appropriate when designing a single truss but may not be needed if the whole assembly is analyzed and designed as a system.

In the first study, a commercially available three-dimensional structural analysis program, ETABS®, was used to investigate the system behavior of wood truss assemblies. Single trusses (Fink and parallel chord) and nine-truss Fink roof truss assemblies were modeled. Predicted deflections, member internal forces, truss strengths, and load-sharing of four nine-truss roof systems agreed well with experimental results from the literature. The study demonstrated the feasibility of using 3-D structural analysis software for investigating truss-assembly system behavior and concluded that truss system design may be improved by including system behavior directly, rather than using system modification factors to design single trusses.

In the second study, an actual MPC wood-truss assembly was analyzed as a system to investigate some of the behavioral issues that may arise in an actual complex roof-truss assembly used in the US. The designs of all of its trusses were obtained from a truss-plate manufacturer (TPM), which had designed the assembly with CDP. The assembly was also analyzed as a system using SDP with a commercially available structural analysis computer program, SAP2000. The assembly consisted of fourteen different types of trusses plus two gable end trusses, 54 trusses total. The 3-D SAP2000 model consisted of the sheathing beam model from the first study, no composite action, no vertical walls or foundation, and pin-pin boundary condition for all trusses. The combined stress indices (CSI) of individual trusses from CDP were compared with the CSI obtained from SDP. With SDP, the CSI for one member of a truss increased over 1.0 (indicating failure) in the assembly, demonstrating that using SDP to redesign the member to bring CSI below 1.0 will increase safety. The truss with the maximum CSI value of 0.99 based on CDP had CSI of only 0.62 based on SDP. The CSI values for most other trusses decreased by as much as 43%, indicating that using SDP might reduce truss-fabrication costs. Most individual trusses inside the assembly actually carried lower load than those outside the assembly because stiffer trusses attract a lot of load. The predictions of maximum CSI and its location using SDP differed from those based on CDP. The study concluded that a computer program capable of analyzing 3-D structures can be a practical tool to design MPC truss assemblies.

The effect of variability of modulus of elasticity (MOE) on load distribution in subassemblies was also investigated in two truss types. In general, a truss with higher MOE should attract more load in the assembly. We did not, however, find any trends to show that trusses with higher average MOE values attracted more loads, demonstrating that variability in MOE values may be only one source of system effects. Our study showed that this effect is generally very small or not present. In actual truss assemblies, other effects related to geometry and configuration affect system behavior much more than does variation in MOE.

The study demonstrated that various 'system'-related issues that may strongly influence the behavior of an assembly are not considered in CDP. Boundary conditions in truss assemblies (i.e., gable-end trusses) significantly affect load distribution. Member forces of the trusses near gable-end trusses are much different when analyzed with SDP than with CDP.

In the third study, three actual 3-D assemblies—T-shaped, L-shaped, and complex—were analyzed with SDP. The assemblies were laid out and designed with TPM software; the program uses CDP for designing assemblies. SAP2000 was then used to model and analyze 3-D truss assemblies (i.e., SDP). Three system effects observed by SDP in all three assemblies are not accounted for by CDP: reduced applied load effect, deflection compatibility, and stiff-truss effect. The maximum CSI for most trusses in all three assemblies was reduced by 6%–60% because of 'system effects.' Thus, SDP can help to improve the analysis of truss assemblies by directly including 'system effects' not accounted for by CDP.

These studies demonstrate changes in individual truss behavior resulting from system effects related to the geometry and configuration of the assemblies. SDP can be used to consider these system effects directly. It can also provide a fuller description of truss behavior in the assembly than can CDP. Software used by TPMs already can lay out complete 3-D assembly geometry and could easily be extended from current 2-D truss analysis to 3-D assembly analysis and design. System behavior of truss assemblies may improve the conventional truss design method by (a) including system behavior directly, (b) increasing safety through improved analysis, and (c) reducing construction through lower grade and size of truss members.

Improving the Planning, Scheduling, and Tracking of the Primary Forest Supply Chain

Kevin D. Boston

Initiation Date: FY 03 Completion Date: FY 06

Objectives: (1) to develop a framework for implementation of a supply chain management system for forest operations to improve profits and customer service by developing new planning, scheduling, and reporting tools to align harvest and distribution capacity to best meet customer demands; (2) to develop new production forecasting tools that will support improved supply chain management

Research focused on the components of the primary forest products supply chain. An overview of the elements in the primary supply chain was completed and has demonstrated the ability to reduce the production variability along the supply chain. The framework developed for this pilot project will allow efficient execution of other research problems within the supply chain format.

The research developed the framework for the primary forest supply chain that will allow firms to better analyze how they plan their operations and to begin to optimize their supply chain based on an improved estimate of logging production. They will be able to integrate their logging and milling operations to gain a further efficiency from an optimized supply chain.

Improving Primary Production with New Technologies: Synthetic Rope Applications

John J. Garland, Stephen J. Pilkerton

Initiation Date: FY 04 Completion Date: FY 06

Objectives: (1) to assess the technologies and potential gains from using synthetic rope to replace wire rope in rigging applications for cable harvesting; (2) to develop and test suitable end connectors for synthetic rope and develop synthetic rope chokers to replace wire rope in harvesting operations; (3) to develop and test harvest systems for synthetic rope in applications to harvest small underutilized material and biomass materials and for small-scale forest harvest operations; (4) to assess synthetic rope for running line applications for skylines, haulback, and mainlines: operating techniques and wear/damage assessments; (5) to develop a validated planning approach to replace wire rope with synthetic rope in cable logging applications by adding synthetic rope to LOGGERPC (OSU Forest Engineering Software) or as a stand-alone computer application

Two research cooperators continue to use synthetic rope for skyline extensions on cable yarders. Indications are positive for application viability, economic benefit, and productivity enhancements. Two additional cooperators use synthetic rope for rigging intermediate supports and tail trees for improved access, environmental performance, and yarding productivity with cable yarding activities. There is a positive reaction from all cooperators with respect to rigging uses. Additional logging contractors are implementing lift tree rigging with synthetic rope. Rope manufacturers are establishing distributor networks in the Pacific Northwest and advertising in trade journals.

One synthetic choker design has been successfully implemented. This design is most effective with small-scale winching applications and is typically fabricated by users themselves. Other choker designs have not been successful in commercial applications. End connector terminations using Applied Fiber technologies (patent pending) were largely successful. Product engineers with the developer stated that 30 days of OSU research cooperation saved them six months of development time.

One woodland owner used synthetic rope and synthetic chokers to harvest small timber. His observations and our time studies confirm efficiencies using both the synthetic winch line and chokers. Continuing use demonstrates system durability.

Our trials with synthetic rope as a mainline demonstrated effectiveness, but also carriage damage. Evaluation of differences between steel and synthetic mainline is continuing. Further research on used mainline helped determine that 50% to 75% of the strength remained, depending on distance from the point of wear and damage.

Laboratory research on tension/stretch relationships shows that new synthetic rope elongates to remove construc-

tional stretch while being "conditioned" (stretched to at least 50% of ultimate strength). Buried eye splices stretch about 17% during conditioning. There is a generally linear relationship with stretch and tension in the "working range" (10%–50% ult.) for 3/8" rope tested. We have not been able to test larger sizes. For the rope tested, the linear relationship may not hold beyond the 50% ultimate level. We have data to quantify tension deflection relationships for short rope lengths, but not for spans typically used in cable operations.

Payload assessments and comparisons used a computer model adapted for steel cable payload analysis for synthetic rope. The model compares well with direct solution results comparing steel and synthetic rope with equal elevation endpoints reported earlier. When model results are applied to typical uphill cable operations at differing elevations, the payload difference results from an 8% deflection increase from 46% to 72% for 5/8" and from 14% to 25% for 1" skyline sizes of steel and synthetic. The potential efficiency gains for synthetic rope are greater for the smaller diameter skylines used for harvesting small material, underutilized material, and biomass on steep slopes.

Further research is needed to develop an empirical approach for synthetic rope to be used in cable yarding payload analysis programs like LOGGERPC (OSU Forest Engineering Software). Material properties of synthetic rope in tension differ substantially from the estimated properties conventionally assumed for steel wire rope. We have further hypotheses to test with the data collected.

Replacing wire rope with synthetic in cable harvesting and for winches on logging tractors offers ergonomic benefits to workers. The efficiency gained when synthetic rope is used in rigging, especially for skyline extensions and tail/intermediate support trees, compensates for higher costs of synthetic over wire rope. Landowners and those working with biomass and underutilized material gain because the rope is easier to handle and increases payloads over wire ropes. We can estimate how the rope will perform with computer models but need to verify the results. New synthetic rope chokers were tested but need further development. The logging industry is adopting synthetic rope, as shown by increased distributors and marketing efforts of the rope manufacturers. Further research on synthetic rope will bring further benefits to the logging industry.

This research has applications for conducting environmentally sensitive harvesting operations on both gentle and steep slope terrain and soils. Cable systems are used on gentle terrain when ground-based systems would generate unacceptable impacts or are seasonally limited. Current harvests of underutilized small-diameter trees are primarily on gentle ground in order to minimize delivered raw material costs to value-added processing or energy production facilities. The timbered western and Intermountain regions of the US, however, are primarily mountainous. This research will position the industry to address recovery of the timber resource more economically, with improved worker ergonomics, and in an environmentally sensitive manner.

Improved Utilization of Wood and Reduced Energy Use During Lumber Processing Through Effective Drying

Michael R. Milota

Initiation Date: FY 03 Completion Date: FY 06

Objectives: (1) to develop methods to make the model adapt to new process information; (2) to investigate methods to reduce energy consumption in lumber drying by modifying drying schedules and wood handling at the sawmill and planer; (3) to reduce moisture content (MC) variability of dried lumber and increase lumber quality by optimal lumber processing

A model developed earlier in the project, using the Excel spreadsheet program, was further modified and presented to an industry audience at a workshop for kiln operator training. We also used the model to investigate fan reversal time, with particular emphasis on the first interval, and demonstrated that moisture variability can be reduced with careful selection of the reversal intervals. Fewer fan reversals reduced energy use, and the appropriate number of fan reversals improved lumber quality.

Energy consumption by dry kilns would be greatly increased by emission control devices such as regenerative thermal oxidizers. By affecting the venting, these devices also affect the drying schedule and lumber quality. We measured total hydrocarbon, methanol, and formaldehyde emissions and developed relationships for how these vary with initial MC and drying schedule for western hemlock, the most commonly dried species in the western US. In most cases, emission levels could be reduced to meet pending regulations by using a lower operating temperature, rather than adding emission control devices. We also investigated the effect of wood handling and storage on emissions. Storage time affected MC, which in turn affected emissions. Other variables, such as season, did not significantly impact the results. We also measured emissions from Douglas-fir, ponderosa pine, lodgepole pine, white fir,

and red alder. This information will be useful for mills in predicting emission levels, complying with federal and state regulations, and maintaining a clean environment.

As an alternative to regenerative thermal oxidizers, we investigated how well pollutants from wood could be absorbed into ionic liquids. Twelve ionic liquids were tested bench-scale. A two-column device was constructed to continuously absorb pollutants from exhaust gas and regenerate the ionic liquid. Recoveries of pollutants ranged from 80 to 99%. This equipment would reduce energy use at the kiln compared to regenerative thermal oxidizers.

Information on the emissions produced and the materials and energy consumed during lumber production were collected by survey. Results indicated that lumber drying is responsible for as much as 85% of the energy required to process logs into lumber and most of the airborne emissions. The information guides mills in comparing their energy use to industry norms.

The findings of this project will contribute to making domestic wood more competitive with imported wood and with other materials.

Innovation and New Product Development in the Global Forest Sector

Eric N. Hansen

Initiation Date: FY 03 Completion Date: FY 06

Objectives: (1) to develop a valid and reliable measure of innovation in the forest sector; (2) to assess current practices in innovation and new product development in the US forest sector; (3) to determine the roles of market orientation and innovation in US forest sector firm performance; (4) to develop case examples of successful new product introductions in the US forest sector; (5) to assess current practices in innovation and new product development in Finland; (6) to assess current practices in innovation and new product development in the Chinese furniture industry

A five-dimension measure of innovativeness was developed based on the propensity of firms both to create and to adopt innovations. This measure differs from much of the literature that relies on adoption only. Analysis is ongoing to refine the measure. Further data collection and refinement are planned.

Industry managers see three forms of innovation—product, process, and business systems. A cross-sectoral study shed light on the state-of-the-art in the industry. The industry tends to rely most heavily on process innovation. Overall, it does not use a structured approach to new product development, which may be a significant weakness in its fight to maintain competitiveness.

Findings of the study suggest that more market-oriented companies are also more innovative. The strongest connections, however, were between a competitor orientation and innovativeness. A formal new product development process was positively correlated to innovativeness and market orientation. High- and medium-innovative mills were consistently different (e.g., more market oriented, more structured NPD process) from low-innovative mills.

Results suggest that Chinese furniture firms are pursuing innovation with equal focuses on product, process, and business systems. Incremental innovation is pursued more than radical innovation. A responsive market orientation has been adopted by the industry. Innovation is significantly correlated with competitiveness and company size, suggesting that large firms are likely to become innovation leaders. The industry is known for its heavy export orientation, but no relation was found between a firm's export orientation and innovation. Innovation and profitability were not correlated, suggesting that the industry's traditional low-cost/low-profit approach still profoundly influences its innovativeness.

Through an enhanced understanding of the multi-dimensionality of innovativeness, industry managers may shift their focus beyond process innovation. Recognizing and implementing other forms of innovation promises increased competitiveness for the industry. Studies on innovation in the forest sector have resulted in a new industry-endorsed initiative in Oregon, the Oregon Wood Innovation Center. The mission of the Center is to enhance global competitiveness of Oregon's wood products manufacturers through innovation in products, processes, and business systems.

Patterns and Mechanisms of Radial Water Movement in Live Sapwood

Barbara L. Gartner

Initiation Date: FY 03 Completion Date: FY 06

Objectives: (1) to categorize tree species on the extent to which their live wood permits radial water movement; (2) to characterize which anatomical features are associated with radial water transport; (3) to characterize the physi-

ological and growth strategies associated with the low vs. high resistance to radial water transport, to enable predictions beyond this dataset

One of the most important outcomes was the demonstration of a method of estimating axial tension gradients in the sapwood at different depths. Unless there is resistanceless flow in the radial direction, in periods of transpiration the tension gradient in the outside of the sapwood has to be higher than that in the inside of the sapwood. We demonstrated the magnitude of this effect in four hardwood and two coniferous species.

In two of the hardwood species (*Alnus rubra* and *Arbutus menziesii)*, the axial tension gradient was about the same at all radial locations, implying there is little resistance to radial flow. In both *Populus* spp. and *Acer macrophyllum*, the axial tension gradient increased from the outer two positions to a peak about 4.5 cm inward from the bark, and then declined again toward the heartwood/sapwood border. This implies that there was an increasing resistance for radial water movement throughout the outer half of the sapwood, and so radial flow was likely to be little, but that radial flow would be larger again in the innermost sapwood. In the softwood *Pseudotsuga menziesii*, axial tension gradients were 44%–50% higher in the outer sapwood than in the inner sapwood. In the four hardwoods studied, the sap flow, conductivity, and moisture content trends often were not monotonic, indicating that these species have much patchier water transport than expected. In *Pinus ponderosa*, the outer part of the sapwood (representing 40% of the sapwood volume) contributed up to 60% of the overall stored water. Much of the rest came from inner sapwood and needed to be transported radially to be used. The tension gradient tends to be about 100 times higher in the longitudinal than the radial direction, suggesting that flow is about 100 times higher longitudinally than radially. Conductivity and sap flow were higher in outer sapwood than in inner in all species studied.

In softwoods, the needles are attached at a range of depths. We used 16 species, mostly available at a nearby commercial nursery that provided a common-garden setting. Species fell into three categories in terms of the growth rings that needles of a given age were pulling water through. In four species, the foliage stayed attached to the wood made the same year; in eight species, it did not; in four species, the pattern was too variable to categorize. The longevity of a needle connection appeared more related to the tree's radial growth rate than to needle age in the species on which we concentrated.

Without the method we developed, measuring axial and radial pressure gradients in situ is impossible. The method will be useful to estimate water flux, information used by modelers of productivity and climate change. The methods will also help physiologists understand water movement and water storage in trees more accurately. This is essential to understanding the mechanisms of drought tolerance, which is increasingly important with climate change and the ever-increasing use of more marginal lands for plantations.

The knowledge that species vary in radial resistance to water movement suggests different paths in different species. This information could eventually be useful to wood scientists when trying to categorize species that will dry quickly and suggesting cutting patterns for different wood types.

The demonstration that needles do not necessarily pull dye directly through the older sapwood demonstrates that the sapflux profiles often reported (higher sap flow 1 cm inside the cambium) is not caused by a peak of foliage attachments there. This information will help people better interpret radial patterns of sapflow, which is important for understanding behavior during drought.

Planning for Fire-Killed Timber Salvage Considering Economic Values and Environmental Risks

John Sessions

Initiation Date: FY 03 Completion Date: FY 06

Objectives: to develop a decision support system to be used to assist managers in evaluating economic values and environmental risks associated with timber salvage in fire-prone forests

A methodology was developed to estimate stand value as a function of time since fire-kill, logging system, and distance from road. A forest growth-and-yield model simulator linked with a search algorithm to identify optimal management regimes (SLOMO) has been modified to incorporate snag dynamics for SW Oregon forests. With this model, dead trees, down wood, and fuel loads can be tracked over time following implementation of a salvage policy. The goal of evaluating alternative timber salvage policies as a function of economic and environmental values has not been completed.

This work has the potential to provide managers with a methodology to assist them in weighing timber salvage alternatives. Legislation has been introduced into Congress

to accelerate decision making by federal forest managers after wildfire. The ability to project the consequences of alternative courses of action is an important element in decisionmaking. The decision model being developed under this project potentially will provide an estimate of the costs of implementing alternative salvage prescriptions in terms of logging costs and the resulting forest structure of live and dead trees and down wood.

Pushing the Limits: Production Economics and Impacts of Alternative Silvicultural Systems in the 21st Century

Loren D. Kellogg, Glen E. Murphy, Stephen H. Schoenholtz, Paul W. Adams, Kevin D. Boston

Initiation Date: FY 02 Completion Date: FY 05

Objectives: (1) to determine the influence of four levels of intervention on production economics and tree damage in western Oregon stands and to identify how such interventions could be managed under a multiple-entry scenario; (2) to determine how newly developed slash-bundling technology could be best integrated with "conventional" harvesting systems to remove small trees in high-fire-risk and unhealthy stands in eastern Oregon and to assess the impacts of this technology on site sustainability; (3) to extend the operating season of eastern Oregon harvesting systems by developing economically viable and environmentally acceptable protocols and procedures for operating harvesting systems in winter and to compare the impact on soil disturbance of an extended and a conventional season; (4) to assess the effect on production economics of different levels of market complexity for a cut-to-length, mechanized harvesting system operating in a western and an eastern Oregon stand; (5) to identify the long-term impacts on site productivity of soil disturbance caused by harvesting

The most problematic issues concerning forest fuel reduction in central and eastern Oregon were assessed through field visits. These visits, research experience, and the literature indicate that forest managers need information to support decisions about forest fuels treatments and equipment selection for silvicultural treatments. Three areas of mechanical fuel-reduction systems needing study are (1) conventional/commercial systems (feller-buncher/grapple skidder combinations); (2) unconventional/commercial systems (mobile in-woods chippers, and cable systems); and (3) noncommercial systems (masticating and mulching technologies for vegetation composition change only). Production and cost studies were designed to gather this information. A comprehensive study investigated both commercial and noncommercial approaches to mechanical forest fuel reduction, including (1) soil disturbance, (2) system productivity, (3) owning and operating costs, (4) system effectiveness within the fuels reduction treatment, and (5) treatment effectiveness for altering future wildfire behavior. Study sites and cooperators were identified in southwest Oregon (Boise Cascade Corp) and central Oregon (Confederated Tribes of the Warm Springs Reservation). Pretreatment measurements were completed on soils and vegetation, productivity studies were conducted, and posttreatment measurements were completed on all study sites. Size and number of standing trees, shrub percent cover, downed fuel composition, and visual classification and compaction of soils were recorded before and after treatments. Machine productivity was determined with shift-level studies, activity sampling, detailed time and motion studies, and video photography.

The southwest Oregon study analyzed a conventional ground-based harvesting system (tracked, swing-boom feller-buncher and two rubber-tired grapple-skidders) in a forest-fuels reduction thinning of a 20-acre mixed-conifer stand on gentle terrain. The central Oregon study comprised two study sites: a 40-acre mixed-conifer high-elevation stand and an 80-acre ponderosa pine low-elevation stand. At each site, two machine configurations were studied: (1) flexible track drive-to-tree skidding machine equipped with a masticating head; and (2) an excavator based swing-boom machine equipped with a rotary disk mulching head.

Future fire behavior in the treated stands will be predicted with the Fire and Fuels Extension (FFE) to the Forest Vegetation Simulator (FVS). The difference between pre- and posttreatment standing tree characteristics, percent shrub cover, and downed woody fuel composition will determine the silvicultural treatment effectiveness for the machines and systems studied. Posttreatment stands will be grown into the future with FVS to allow establishment of long-term strategies for reducing hazardous fuels and creating more fire-resilient landscapes.

Production studies were also conducted on slash bundling systems in Finland as the basis for determining production rates for three levels of treatment (bundle and leave at stump, bundle and remove to roadside, bundle and transport to an energy plant) for five representative stand types in the western US. Slash was limited to trees less than 10 cm DBH and the limbs and tops of larger trees removed in

a conventional thinning operation. These simulated production rates were combined with constructed hourly costs to determine unit costs on a green tonne and a per-hectare basis. Per-hectare costs ranged from $250 for "bundle and leave" to $1090 for "bundle and transport." Costs depended on forest type.

In central and eastern Oregon, development of economically viable and environmentally acceptable protocols and procedures for harvesting in winter is an important issue. A study was designed to compare operational issues and soil disturbance with harvesting operations conducted over snow versus during drier summer conditions. A new method was designed for assessing soil compaction impacts correlated with equipment passes. Skidding distance (equipment passes) is measured at the outer end of the skid trail to the point of observation as a means of comparing skid trails of varying lengths. Other new procedures for measuring machine production were completed with the multi-dat technology developed by the Forest Engineering Institute of Canada (FERIC) and manufactured by GENEQ Inc. of Montreal, Canada. Shift-level equipment utilization and delays were easily captured with this technology. The information identifies places where contractors can make changes that will help increase production and lower harvesting cost.

The effect of market complexity was evaluated for five species/market combinations in North America and New Zealand. The trend in the industry is to increase the number of log sorts to maximize value by producing products that meet very explicit specifications of log buyers. The results suggest that theoretical value recovery increases sharply by adding a few log-sorts but then flattens as the total log-sorts increase above five. The effect of the number of log-sorts on piece size and number of pieces handled, which affect production and costs, was inconsistent between species/market combinations.

Three studies were completed to help identify long-term impacts on site productivity of various levels of soil disturbance caused by harvesting operations. Soil disturbance sites and trees first measured by OSU researchers in the 1970s either could not be located or the trees had been felled, so long-term impacts on site productivity could not be assessed. A suitable trial was located in New Zealand. The effect of harvest-related soil disturbance on the productivity, log product yields, and economic potential of second-rotation *Pinus radiata* growing on clay loam was assessed in this long-term trial 21 years after planting and the results projected to the expected harvest age of 28 years. Relative to the controls, individual tree volumes at 21 years were 10% lower in the plots where the litter had been removed and the topsoil had been compacted and up to 43% lower in the plots where the topsoil had been removed and the subsoil compacted. The degree of compaction did not affect individual tree volume in the plots where litter had been removed but did have a significant effect where the topsoil had been removed. Per-tree economic potential was reduced more (up to 61% loss) than was individual tree volume, largely due to changes in log product yield distribution. Projecting tree growth to the end of the rotation indicated that the impacts of soil disturbance on tree growth, economic potential, and log product yields are likely to be similar to those at age 21.

A second site-productivity study included modeling road sediments reaching streams over 20 years under two scenarios for a 4900-ha forest in the foothills of the Oregon Coast Range. In the "clustered" scenario, all harvesting took place in the northern half of the forest. In the "dispersed" scenario, the same level of harvesting activity was allocated to the full forest. Three spatial modeling packages were used: SPECTRUM, to schedule the harvest settings over 150 years; NETWORK 2000, to determine which roads would be used during the first 20 years of harvest and how many truck loads would be transported over them; and SEDMODL2, to determine the road sediment yields likely to reach a stream. Concentrating the forest harvesting activity on half of the forest reduced total road sediment yields by 36% compared with dispersed harvesting. Fewer roads would generate sediment under the "clustered" scenario, but traffic intensities on these roads would be greater, partially negating the sediment yield savings.

A third study assessed effects of contemporary harvesting operations on soil disturbance, decomposition, and nutrient availability as indicators of potential impacts on long-term soil productivity on two sites in western Oregon and western Washington under intensive management of Douglas-fir (*Pseudotsuga menziesii*). Bimonthly *in situ* measurements of net nitrogen mineralization and decomposition on (1) skid trails with visual evidence of compaction and mineral soils exposure; (2) skid trails containing logging debris; (3) low-disturbance areas between skid trails with low levels of logging debris; (4) low-disturbance areas between skid trails with high levels of logging debris; and (5) areas immediately adjacent to small slash piles on the two sites were completed for a 2-year post-harvest period. At each site, replicated experiments were established to compare (1) bole-only harvesting; (2) whole-tree harvesting; and (3) bole-only harvesting with creation of small debris piles on subsequent

soil and stand productivity. Logging debris was greater with bole-only harvesting, and overall treatment effects on Douglas-fir needle decomposition and soil nitrogen mineralization were limited at both study sites.

This research impacts wood utilization in the Pacific Northwest by identifying new forest harvesting technology and operational practices that improve production and lower harvesting costs. Better understanding of the capability and limitations of new equipment and operational practices allows forest managers to move forward with needed forest silviculture treatments to reduce the risk of catastrophic wildfire while utilizing small trees and biomass for new value-added wood products, energy production, and biofuels. Favorable economics for these operations helps offset the costs of silviculture treatments to improve forest health. A better understanding of potential impacts from harvesting operations on long-term soil productivity furthers the use of appropriate technology and harvest planning approaches that are sustainable economically, environmentally, and socially.

Smart Sensor System Technology for Improved Wood Utilization

Glen E. Murphy

Initiation Date: FY 02 Completion Date: FY 05

Objectives: (1) to review current developments in sensor system technologies that mimic human senses and identify at least seven applications that could be expected to improve wood utilization; (2) to assess the costs and effectiveness of at least three promising sensor technologies; (3) to determine how at least two of these technologies could best be linked with a memory function (smart sensors) to reduce waste, meet market needs for niche products, increase value recovery, or control costs; (4) to develop methods and protocols for at least one smart sensor technology and establish linkages with equipment manufacturers and suppliers

Three technologies—laser scanning, electronic nose and near infrared sensors—were initially identified for more detailed examination. A laser scanning system developed in New Zealand for automatically measuring taper, sweep, and branch size in standing trees was identified, but negotiations with a New Zealand company to trial the equipment were unsuccessful. The use of touch sensors was evaluated as an alternative technology. Trials on aroma tagging and electronic nose technology were completed in New Zealand in the summer of 2002. The trials spanned forest products from logs through green lumber, kiln-dried lumber, and paper. Four approaches to scanning on a mechanized harvester head were evaluated in economic terms. These approaches incorporate aspects of the "smart" component of smart sensor systems. In FY 03 the analyses were expanded to include Douglas fir and ponderosa pine.

In FY 03, more than 400 Douglas-fir wood discs were collected from 120 trees and 17 locations around Oregon. The wood discs were subsampled to provide material for assessing basic density, spiral grain, and possibly extractives content. Chainsaw wood chips were also collected from all 400 discs. Preliminary analysis of 100 of the chip samples indicated that near-infrared (NIR) technology could be used to accurately predict basic density, but not spiral grain. In FY05, NIR measurements were also completed on 50 dried chainsaw wood chip samples and 50 dried and ground chain sawwood chip samples. Analyses indicated that basic density could be successfully predicted for all three sample types. Extractives content of samples from the 400+ disks were to have been measured in collaboration with researchers from the University of Idaho. In FY 04 we were informed that the work was unlikely to be started until late 2005 or possibly 2006. Work on extractives content was, therefore, not completed in time for inclusion in this project.

The spatial variation of spiral grain and wood density in Douglas-fir was analyzed for all wood disks. Spiral grain was not related to height within the tree, aspect, or elevation. Wood density was weakly related to height within a tree, but not to elevation or aspect.

Field data were collected on the length and diameter measurement accuracy of two mechanized harvesting systems using conventional measurement technology in ponderosa pine stands in eastern Oregon. These measurements served as benchmarks for comparing new sensing technology. Field work on value recovery and measurement accuracy of a mechanized harvesting system was also undertaken in radiata pine stands in New Zealand. The effects of measurement errors on value recovery were determined for harvesters working in three species of pine. The data sets used in the analysis came from eastern Oregon, the southeastern USA, and New Zealand. Current diameter sensing systems measure overbark diameters and have to predict underbark diameters, since logs are sold based on underbark specifications. The effects on value recovery of six different approaches to bark thickness predictions were evaluated for use on mechanized harvesters/processors working in radiata and ponderosa pine and Douglas fir.

Five adaptive control approaches to optimal bucking were evaluated using a computer program (*FASTBUCK*) written

in FY02 for optimally bucking a single stand of trees to meet order book constraints. This will allow more detailed testing of various smart sensor system approaches and adaptive control of bucking. An algorithm was developed for optimally bucking stems into logs based on both internal and external quality features. The incorporation of internal properties into bucking algorithms is novel. The algorithm was implemented in Visual C++ and tested on a data set of over 3700 pine trees. Log prices of Douglas-fir were estimated through an economic analysis of the effects of wood density on lumber recovery and pulp yield.

In collaboration with Australian foresters, the potential ability of mechanized harvesters to "harvest information", as well as wood, and so improve wood utilization was investigated—effectively an extension of the "smart" in smart sensor technology.

Incorporation of smart sensor systems in mechanized harvesters offers step change solutions for improving wood utilization. Obtaining consistent, reliable measurements under harsh operating environments is one challenge faced by users of sensor technology. This research demonstrated that contact sensor systems can be used to measure external log properties, near infra-red sensor systems can be used to measure internal wood properties, and aroma tagging and electronic nose systems can be used to track logs from forest to mill. It also demonstrated that sensor systems could be made "smarter" by combining them with spatial models of stem characteristics, such as bark thickness and density gradients. In some cases, the gains in value are likely to exceed the additional costs associated with using this technology.

Quantifying the Cumulative Effects of Timber Harvesting Adjacent to Perennial Non-Fishbearing Streams on Water Quality

Arne E. Skaugset III

Initiation Date: FY 03 Completion Date: FY 06

Objectives: (1) to determine the on-site effects of harvesting adjacent to perennial, non-fishbearing streams on stream temperature and accelerated erosion; (2) to determine the cumulative effects of harvesting adjacent to several perennial, non-fishbearing streams on stream temperature and accelerated erosion off-site in fishbearing streams; (3) to identify and quantify the hydrologic processes and the magnitude of the processes responsible for propagating stream temperature and sediment effects downstream

Stream temperature data have been collected for four summers. The maximum stream temperature, occurring on July 27, 2003, was 19.1˚C at the mouth of Hinkle Creek and 17.7˚C and 17.1˚C at the mouths of the North and South Forks of Hinkle Creek, respectively. All other maximum stream temperatures ranged from 12.5˚C to 17.5˚C. The pattern is identical in other years on the day of the maximum daily stream temperature, although the values are lower.

The average distance from the end of fish use to the drainage divide in the Hinkle Creek study watersheds is approximately 1,700 m, ranging from 1,300 m to 2,000 m. A range in maximum daily stream temperature of about 6˚C was calculated; this was not expected for locations in the 'headwaters' of a fully shaded forested watershed. Calibration relationships between the control and treatment watersheds were developed. The control watershed (North Fork Hinkle Creek) and the treatment watershed (South Fork Hinkle Creek) showed a linear relationship in stream temperature. These relationships have been established for all four of the treatment 'headwater' watersheds in conjunction with a control watershed.

Precipitation and streamflow data were collected for the winters of the 2004 and 2005 water years for the Hinkle Creek study watersheds. Precipitation was measured at a single micrometeorological station at the approximate centroid of the two study watersheds. Streamflow was measured at the mouths of the North and South Forks of Hinkle Creek and at the six study 'headwater' watersheds. The total annual precipitation for the 2005 WY was 1,232 mm (48.5 inches).

Two parameters describing streamflow can potentially affect fish and will be investigated for treatment effects resulting from forest management: the magnitude of instantaneous peak flows from the selected storms and the volume of quick flow or storm flow generated by each storm. The values of these parameters are derived from the annual hydrographs and calibration equations are developed.

Sediment yield could be affected by forest practices and could affect fisheries. The parameter of interest is total storm sediment yield or the sediment yield transported by the quickflow or storm flow of a storm. Calibration equations can be developed with simple linear regression for storm sediment yield also. These relationships were developed for the four treatment 'headwater' watersheds. Similar relationships for the North and South Forks of Hinkle Creek await development.

In summary, the calibration period for the study watersheds is complete and calibration relationships have been devel-

oped from four summers of maximum daily stream temperature data for the large fish-bearing watersheds and for the treatment non-fishbearing 'headwater' watersheds. Calibration relationships for peak flows, storm quick-flow, and storm sediment yield were developed for the two winters of flow data. Treatments or timber harvest is taking place this year. The next step is to collect posttreatment data and use the calibration relationships to evaluate whether there was a treatment effect and, if so, how large it was.

The annual harvest on private, industrial forestland in Oregon is a little less than 4 billion board feet a year. The value of the solid wood products industry to Oregon is approximately $11 billion a year, and it employs approximately 80,000 workers directly. If the forest practices rules regarding the protection of perennial, non-fishbearing streams are changed and these changes are similar to the forest practice rules in the state of Washington, roughly 10% of the commercial forestland base for private industrial landowners would be removed. This could translate into a loss of 8,000 jobs in the forestry sector and $1.1 billion a year to the Oregon economy. The results from this research are intended to help inform policy changes regarding perennial, non-fishbearing streams. The research may show that more rigorous forest practice rules are needed to protect fisheries, and the investment from foregone gain on 10% of the commercial forest land base is a sound investment. Conversely, it may show that the potential environmental effects from harvesting adjacent to perennial, non-fishbearing streams are minor, and a major increase in forest practice protection is unwarranted. More likely, the result will be between these extremes. Either way, the value of this research is that the policy process will be informed by research results.

Publications, Theses, and Technology Transfer Activities and Presentations

Publications

Acuna, M, and GE Murphy. 2005. Optimally matching wood to markets: understanding spatial variation of wood density and spiral grain in Douglas-fir, pp. 100–113 in *Soil, Water and Timber Management: Forest Engineering Solutions in Response to Forest Regulation,* P Matzka and L Kellogg, comps. Proceedings of the 2005 Council on Forest Engineering Conference, July 11–14, Fortuna, CA.

Bettinger, P, D Graetz, and J Sessions. 2005. A density-dependent stand-level optimization approach for deriving management prescriptions for interior northwest (USA) landscapes. *Forest Ecology and Management* 217: 171–186.

Bolding, MC, LD Kellogg, and CT Davis. 2005. Soil disturbance from an integrated mechanical forest fuel reduction operation in southwest Oregon, pp. 266–277 in *Proceedings, 28th Annual Council on Forest Engineering Meeting*, July 11–14, Fortuna, CA. 10 p.

Boston, K. 2005. The desired future state of primary forested supply chain, pp. 39–46 in *The Role of Forests for Coming Generations*. K. Naito, ed. Japanese Society of Forest Planning Press, Utsunomiya.

Boston, K. 2005. The role of ICT in forest business. L. Hetemäki and S. Nilsson, eds. IUFRO Task Force on ICT and Forestry Sector. *IUFRO World Series* 18: 64–75.

Boston K, and A Bord. 2005. The variability of construction practices and material properties found on forest roads in Oregon, pp. 290–301 in *Soil, Water and Timber Management: Forest Engineering Solutions in Response to Forest Regulation,* P Matzka and L Kellogg, comps. Proceedings of the 2005 Council on Forest Engineering Conference, July 11–14, Fortuna, CA.

Carey, P, and GE Murphy. 2005. Mechanised versus motor-manual log-making in two Chilean *Pinus radiata* stands. *New Zealand Journal of Forestry Science* 35(1): 25–34.

Conradie, IP, WD Greene, JF Cox, and GE Murphy. 2005. Applying the thinking process of the theory of constraints: An exploratory research methodology to evaluate the lack of use of cut-to-length harvesting systems in the Southeastern United States. *Journal of Forest Products Business Research* Volume 2(1): pp. n.a. (online journal)

Crespell, P, C Knowles, and E Hansen. 2005. Innovation Pays Off. Timber Processing. March.

Davis, CT, LD Kellogg, and MC Bolding. 2005. Measuring machine productivity with a multi-dat data logger: A demonstration on three forest machines. pp. 156-168 in *Soil, Water and Timber Management: Forest Engineering Solutions in Response to Forest Regulation,* P Matzka and L Kellogg, comps. Proceedings of the 2005 Council on Forest Engineering Conference, July 11–14, Fortuna, CA.

Domec, J-C, ML Pruyn and BL Gartner. 2005. Axial and radial profiles in conductivities, water storage and native embolism in trunks of young and old-growth ponderosa pine trees. *Plant, Cell and Environment* 28: 1103–1113.

Garland, JJ, and SJ Pilkerton. 2005. Use of synthetic rope as a skidder winchline for designated skid trails. pp. 187-194 in *Soil, Water and Timber Management: Forest Engineering Solutions in Response to Forest Regulation,* P Matzka and L Kellogg, comps. Proceedings of the 2005 Council on Forest Engineering Conference, July 11–14, Fortuna, CA.

Gartner, BL 2005. Assessing wood characteristics and wood quality in intensively management plantations. *Journal of Forestry* 103: 75–77.

Geng, Y, K Li, and J Simonsen. 2005. A combination of poly(diphenylmethane diisocyanate) and stearic anhydride as a novel compatibilizer for wood-polyethylene composites. *Journal of Adhesion Science and Technology* 19: 987–1001.

Geng, Y, K Li, and J Simonsen. 2005. A commercially viable compatibilizer system for wood-polyethylene composites. *Journal of Adhesion Science and Technology* 19: 1363–1373.

Grotta, AT, BL Gartner, SR Radosevich, and M Huso. 2005. Influence of red alder competition on cambial phenology

and latewood formation in Douglas-fir. *IAWA Journal* 26(3): 309–324.

Gupta, R, TH Miller and D-R Dung. 2004. Practical solutions to wood truss assembly design problems. *Practice Periodical on Structural Design and Construction* 9(1): 54–60.

Hansen, E. 2005. Innovation & NPD in the Oregon and Alaska Forest Products Sectors, pp. 32–36 in *Proceedings, Linking Healthy Forests and Communities: Successful Strategies and Future Directions*, October 19–21, Anchorage, AK. General Technical Report PNW-GTR-631, USDA Forest Service, Pacific Northwest Research Station, Portland, OR.

Hetemäki, L, A Baudin and K Boston. 2005. Historical uses of ICT in forestry sector. L. Hetemäki and S. Nilsson, eds. IUFRO Task Force on ICT and Forestry Sector. *IUFRO World Series* 18: 8–23.

Hovgaard, A, E Hansen and J Roos. 2005. Innovation in the forest products industry: An analysis of companies in Alaska and Oregon. General Technical Report PNW-GTR-629, USDA Forest Service, Pacific Northwest Research Station, Portland, OR.

Kelsey, RG, PE Hennon, M Huso, and JJ Karchesy. 2005. Changes in heartwood chemistry of dead yellow-cedar trees that remain standing for 80 years or more in Southeast Alaska. *Journal of Chemical Ecology* 31: 2653–2670.

Kent, SM, RJ Leichti, DV Rosowsky, and JJ Morrell. 2005. Effects of decay on the cyclic properties of nailed connections. *Journal of Materials in Civil Engineering* 17: 579–585.

Kiser, J, D Solmie, L Kellogg, and MG Wing. 2005. Efficiencies of traditional and digital measurement technologies for forest operations. *Western Journal of Applied Forestry* 20: 138–143.

Leichti, R, JJ Morrell, and D Rosowsky. 2005. Effect of decay on wall system behavior. *Wood Design Focus* 15(1): 3–7.

Milota, MR, CD West, and ID Hartley. 2005. Gate-to-gate life cycle inventory for softwood lumber production. *Wood and Fiber Science* 37(5): 47–57.

Murphy, GE. 2005. Controlling value recovery along the forest-to-mill supply chain. Paper presented at XXII IUFRO World Congress, August 8–13, Brisbane, Australia. *The International Forestry Review* 7(5): 130.

Murphy, GE, H Marshall, and I Conradie. 2003. Market complexity and its effect on variables that gauge the economics of harvesting production. *New Zealand Journal of Forestry Science* 33: 281–292.

Murphy, GE, H Marshall, and T Evanson. 2005. Production speed effects on log-making error rates and value recovery for a mechanized processing operation in Radiata pine. *Southern African Forestry Journal* 204: 23–35.

Murphy, GE, and M Wing. 2005. Road sediment yields from dispersed versus clustered forest harvesting activity: a case study. *International Journal of Forest Engineering* 16(2): 65–72.

Panella, NA, MC Dolan, JK Karchesy, Y Xiong, J Peralta-Cruz, M Khasawneh, JA Montenieri, and GO Maupin. 2005. Use of novel compounds for pest control: Insecticidal and acaricidal activity of essential oil components from heartwood of Alaska yellow cedar (*Chamaecyparis nootkatensis*). *Journal of Medical Entomology* 42: 352–358.

Perez-Garcia, J, B Lippke, D Briggs, J Wilson, J. Bowyer, and J Meil. 2005. The environmental performance of renewable building materials in the context of residential construction. *Wood Fiber Science* 37(5): 3–17.

Pilkerton, SJ, and JJ Garland. 2005. Laboratory and field trials of synthetic rope for skyline applications in cable yarding, pp. 195-208 in *Soil, Water and Timber Management: Forest Engineering Solutions in Response to Forest Regulation*, P Matzka and L Kellogg, comps. Proceedings of the 2005 Council on Forest Engineering Conference, July 11–14, Fortuna, CA.

Pruyn, ML, ME Harmon, and BL Gartner. 2005. Storage versus substrate limitation to bole respiratory potential in two coniferous tree species of contrasting sapwood width. *Journal of Experimental Botany* 56: 2637–2649.

Puettmann, ME, and JB Wilson. 2005. Gate-to-gate life-cycle inventory of glued-laminated timbers production. *Wood Fiber Science* 37(5): 99–113.

Puettmann, ME, and JB Wilson. 2005. Life-cycle analysis of wood products: Cradle-to-gate LCI of residential building materials. *Wood Fiber Science* 37(5): 18–29.

Saputra, H, J Simonsen, and K. Li. 2004. Effect of extractives on the flexural properties of wood/plastic composites. *Composite Interfaces* 11: 515–524.

Scott, RJ, RJ Leichti, and TH Miller. 2005. An experimental investigation of foundation details and base shear capacity for log buildings. *Forest Products Journal* 55(4): 38–45.

Scott, RJ, RJ Leichti, and TH Miller. 2005. Finite-element modeling of log wall lateral force resistance. Forest Products Journal 55(9): 48–54.

Seaders, P, R Gupta, and TH Miller. 2003. Performance of code-prescribed shear walls under monotonic and cyclic

tests. Abstract. in Biographies and Abstracts, Forest Products Society, 57th Annual Meeting, June 22–25, Bellevue, WA.

Seaders, P, R Gupta, and TH Miller. 2003. Performance of wood shear walls under actual earthquake. Abstract. in Proc. of the 55th Annual Meeting, February 5–8, Earthquake Engineering Research Institute, Portland, OR.

Sessions, J, P Bettinger, R Buckman, M Newton, and J Hamann. 2004. Hastening the return of complex forests following fire: The consequences of delay. *Journal of Forestry* 102(3): 38–45.

Sessions, J, P Bettinger, and GE Murphy. 2005. Heuristic approaches in forest planning, in *Handbook on Operations Research in Natural Resources,* Andres Weintraub, ed. Springer-Kluwer Publishers.

Simmons, AN, and AE Skaugset. 2005. The influence of roads on the hydrology of a forested watershed, pp. 229–235 in *Soil, Water and Timber Management: Forest Engineering Solutions in Response to Forest Regulation,* P Matzka and L Kellogg, comps. Proceedings of the 2005 Council on Forest Engineering Conference, July 11–14, Fortuna, CA

Skaugset, A. 2005. Watersheds Research Cooperative 2004–2005 Annual Report. Department of Forest Engineering, Oregon State Univ., Corvallis.

Toman, EM, AE Skaugset, and GE Murphy. 2005. The opportunities to haul timber during wet weather with forest road improvements, pp. 335–342 in *Soil, Water and Timber Management: Forest Engineering Solutions in Response to Forest Regulation,* P Matzka and L Kellogg, comps. Proceedings of the 2005 Council on Forest Engineering Conference, July 11–14, Fortuna, CA.

Wagner, E, and E Hansen. 2005. Innovation in large versus small companies: insights from the U.S. wood products industry. *Management Decision* 43: 837–850.

Wilson, JB. 2005. Documenting the environmental performance of wood building materials. Editorial. *Wood Fiber Science* 37(5): 1–2.

Wilson, JB, and ER Dancer. 2005. Gate-to-gate life-cycle inventory of I-joist production. *Wood Fiber Science* 37(5): 85–98.

Wilson, JB, and ER Dancer. 2005. Gate-to-gate life-cycle inventory of laminated veneer lumber production. *Wood Fiber Science* 37(5): 114–127.

Wilson, JB, and ET Sakimoto. 2005. Gate-to-gate life-cycle inventory of softwood plywood production. *Wood Fiber Science* 37(5): 58–73.

Wing, MG, and LD Kellogg. 2004. Locating and mobile mapping techniques for forestry applications. *Geographic Information Sciences* 10(2): 75–182.

Zhang, C, K Li, and J Simonsen. 2004. Improvement of interfacial adhesion between wood and polypropylene in wood-polypropylene composites. *Journal of Adhesion Science and Technology* 18(14): 1603–1612.

Theses

Anderson, EN. 2005. *The effects of nail bending-yield stress and biological deterioration on the cyclic performance of shearwalls*. MS thesis. Department of Wood Science, Oregon State University, Corvallis.

Bohle, KT. 2005. *Forecasting harvesting production rates using GIS*. MF thesis. Department of Forest Engineering, Oregon State University, Corvallis.

Fallas-Cedeno, L. 2005. *Water movement in the stem xylem in relation to xylem specific conductivity in four hardwood species*. MS thesis. Departments of Wood Science and Engineering and Forest Science, Oregon State University, Corvallis.

Renninger, H. 2005. *Effects of release from suppression on hydraulic architecture, photosynthetic capacity and functional wood characteristics in Douglas-fir and western hemlock*. MS thesis. Departments of Wood Science and Engineering and Forest Science, Oregon State University, Corvallis.

Wang, F. 2005. *Henry's Law constants for pollutants from the wood industry in room temperature ionic liquids*. MS thesis. Oregon State University. Corvallis.

White, KB. 2005. *The performance of wood frame shear walls under earthquake loads*. MS Thesis. Oregon State University, Corvallis.

Technology Transfer Activities And Presentations

Acuna, M, and GE Murphy. 2005. Optimally matching wood to markets: understanding spatial variation of wood density and spiral grain in Douglas-fir, 28th Annual Council on Forest Engineering Meeting, July 11-14, Fortuna, CA.

Bae, YS, J Kim, Y Ham, and J Karchesy. 2005. A New Phenylpropanoid Derivative of Catechin from the Needles of *Taxus cuspidata*. Abstracts, 60th Northwest Regional Meeting of the American Chemical Society, June 15–18, Fairbanks, AK.

Barragan-Huerta, B, Hernandez de Jesus, M, J Karchesy and J Peralta-Cruz. 2005. Isolation and Antioxidant Activity of (S)-4-Methoxydalbergione, a Natural Product from the Campinceran Tree (*Dalbergia congestiflora*). Abstracts, 60th Northwest Regional Meeting of the American Chemical Society, June 15–18, Fairbanks, AK.

Bohle, K, and K, Boston. 2005. Forecasting harvesting production rates using GIS: A case study, Canadian Operations Research Society. Halifax, Nova Scotia, Canada.

Bolding, MC. 2005. Soil disturbance from an integrated mechanical forest fuel reduction operation in southwest Oregon, 28th Annual Council on Forest Engineering Meeting, July 11–14, Fortuna, CA.

Boston, K. 2005. 3rd Iberian American Symposium on Forest Management and Economics and 11th Symposium on Systems Analysis, September 18–21, Ubatuba, Sao Paulo, Brazil.

Boston K, and A Bord. 2005. The variability of construction practices and material properties found on forest roads in Oregon, 28th Annual Meeting of the Council on Forest Engineering, July 11–14, Fortuna, CA.

Boston, K, and J Hamann. 2005. Future of the Forestry Supply Chain. International Perspectives on Forestry 2(September):12–13, World Forestry Center, Portland, OR.

Cao, X, and E Hansen. 2005. Innovation in China's Furniture Industry. Forest Business Solutions Research Brief. Wood Science and Engineering. Oregon State University. 2 p.

Carroll, CT, RJ Leichti, and DV Rosowsky. 2005. The performance of existing residential construction shearwalls under lateral forces – a look at materials and assemblies, in Biographies and Abstracts, Forest Products Society International Meeting, June 20, Quebec City, Canada. Forest Products Society, Madison, WI.

Clark, R, E Zink, K Grant, and J Karchesy. 2005. A Study of the Volatile Constituents of Noble Fir Needle Oil. Abstracts, 60th Northwest Regional Meeting of the American Chemical Society, June 15–18, Fairbanks, AK.

Crespell, P, C Knowles and E Hansen. 2005. Innovation in the North American Softwood Sawmilling Industry. Poster Presentation, 22nd IUFRO World Congress, August 8–13, Brisbane, Australia.

Davis, CT. 2005. Measuring machine productivity with a multi-dat data logger: A demonstration on three forest machines, 28th Annual Council on Forest Engineering Meeting, July 11–14, Fortuna, CA.

Dietrich, G, JC Dolan, J Piesman, RJ Eisen, and J Karchesy. 2005. Repellent activity of fractioned compounds of Alaska yellow cedar essential oil against nymphal *Ixodes scapularis,* International Conference on Diseases in Nature Communicable to Man (INCDNCM), 60th Annual Meeting, August 7–9, Calgary, Alberta, Canada.

Dolan, MC, NA Panella, E Dietrich, B Gabrielle, J Karchesy and GO Maupin. 2005. Arthropod control compositions comprising eremophilane sesquiterpene and dialkylphenol. U.S. Pat. Appl. Publ. (2005). 36 p., Cont.-in-part of U.S. Ser. No. 450,024.

Domec J-C, FC Meinzer, BL Gartner, and J Housset. 2005. Dynamic variation in xylem conductivity: mechanisms and consequences for water movement through sapwood, p. 238 in Abstracts of the 17th International Botanical Congress, Vienna, Austria.

Dunham, SM, LM Ganio, and BL Gartner. 2005. Hierarchical analysis of structural and functional tradeoffs in hydraulic properties of Douglas-fir xylem. Proceedings, Annual Meeting of the Ecological Society of America. On CD.

Garland, J. 2005. Application of Synthetic Rope in Logging. CD compilation of publications/theses/presentations. Available from Forest Engineering Department Oregon State University, Corvallis.

Garland, J. 2005. Human factors and synthetic rope. Synthetic Rope in Logging: Applications, Research & Developments Conference, December 3, Corvallis, OR.

Garland, J. 2005. Logger Panel Presentation, Synthetic Rope Users, Associated Oregon Loggers Annual Safety Conference, November 5, Bend, OR.

Garland, J. 2005. Research on end connectors. Synthetic Rope in Logging: Applications, Research & Developments Conference, December 30, Corvallis, OR.

Garland, J. 2005. Summary of prior OSU Research, Synthetic Rope in Logging: Applications, Research & Developments Conference, December 2, Corvallis, OR.

Garland, J. 2005. Synthetic Rope Applications, Western Regional COFE Meeting, April 22, Redding, CA.

Garland, J. 2005. Vendor Display, Oregon Logging Conference, February 20–22, Eugene, OR. Samson Paper Technologies.

Garland, J. 2005. Synthetic Rope in Logging, New Zealand Contractors Association Meeting, August 16, Rotorua, NZ.

Garland, J, and S Pilkerton. 2005. Synthetic Rope in Logging: Applications, Research & Developments Conference, December 2–3, Corvallis, OR.

Garland, J, and S Pilkerton. 2005. Woodland Owner Winching with Synthetic Rope, April 1, Scio, OR.

Hamann, J, and K Boston. 2005. The use of spatial statistics to improve the performance of forestry supply chains, IUFRO Conference on Sustainable Forestry in Theory and Practice, April, Edinburgh, Scotland, UK.

Hansen, E. 2005. Innovation Evolution in the NA Structural Panel Industry. Forest Business Solutions Research Brief. Wood Science and Engineering. Oregon State University.

Hansen, E. 2005. Worked with Drs. Ewald Rametsteiner and Anssi Niskanen to successfully deliver a parallel main session at the IUFRO World Congress in Brisbane, Australia. Innovation and entrepreneurship—rural economic development & industry.

Hansen, E. 2005. Innovation in the Forest Industry, Laval University Summer School, June 16–17, Quebec City, Canada.

Hansen, E, E Rametsteiner, S Korhonen and S Shook. 2005. Current state-of-knowledge: Innovation research in the global forest sector, 22nd IUFRO World Congress, August 8–13, Brisbane, Australia.

Karchesy, J. 2005. Natural Products and Our Forest Resources: A Heritage for Future Discovery. Invited Seminar: Division of Molecular Cell and Developmental Biology, April 25, University of Texas at Austin.

Kellogg. LD. 2005. Mechanical forest fuel reduction and measuring machine productivity with a multi-dat data logger, Western Region Council on Forest Engineering Conference, November 18–19, Grants Pass, OR.

Kelsey, RG, PE Hennon, M Huso, DK Manter, and J Karchesy. 2005. Heartwood Chemistry of Standing Dead Yellow-Cedar in Southeast Alaska and the Sporicidal Activity of Heartwood toward *Phytophthora ramorum* (Sudden Oak Death). Abstracts, 60th Northwest Regional Meeting of the American Chemical Society, June 15–18, Fairbanks, AK.

Knowles, C, P Crespell, and E Hansen. 2005. Innovation in the North American Sawmilling Industry. Forest Business Solutions Research Brief. Wood Science and Engineering. Oregon State University. 2 p.

Knowles, C, and E Hansen. 2005. Measuring Innovativeness in the Forest Products Industry, Forest Products Society 59th Annual Meeting, June 18–22, Quebec City, Canada.

Knowles, C, and E, Hansen. 2005. Measuring Innovativeness in the Forest Products Industry, 22nd IUFRO World Congress, August 8–13, Brisbane, Australia.

Knowles, C, and E Hansen. 2005. Measuring Innovativeness in the North American Forest Products Industry and Overview of Wood Science and Engineering at OSU. Presented at the University of Melbourne, August 17.

Knowles, C, and E Hansen. 2005. Measuring Innovativeness in the North American Forest Products Industry and Overview of Wood Science and Engineering at OSU. Presented at Lincoln University, August 29.

Lowers, J, and S Pilkerton. 2005. Small woodland winching applications and synthetic chokers, Synthetic Rope in Logging: Applications, Research & Developments Conference, December 3, Corvallis, OR.

Manter, DK, RG Kelsey, and J. Karchesy. 2005. The Sporicidal Activity of *Chamaecyparis nootkatensis* heartwood and constituents toward *Phytophthora ramorum* in culture, Pacific Chem 2005 Conference, Natural Products in Agriculture and Forestry: Structure, Function, and Utilization, December 15–20, Honolulu, HI.

Meehan, NA, SH Schoenholtz, and TB Harrington. 2005. Post-harvest woody debris manipulation in western Oregon and Washington: Early responses of needle litter decomposition. Paper presented to Forest, Range and Wildland Soils Division, American Society of Agronomy Annual Meeting, November, Salt Lake City, UT.

Meinzer, F, B Bond, R Brooks, J-C Domec, B Gartner, J Warren, and D Woodruff. 2005. Trees and water: Coping with being large, pp. 56–57 in Proceedings, Annual Meeting of the Northwest Scientific Association, Corvallis, OR.

Milota, MR. 2005. Effects of drying temperature and initial moisture content on total hydrocarbon and HAP emissions from western hemlock lumber, pp. D13-D20 in National Council for Air and Stream Improvement, West Coast Regional Meeting, September 28–29, Portland, OR.

Milota, MR. 2005. Hazardous air pollutants: What they mean to a sawmill, pp. 85–89 in Proceedings of the Western Dry Kiln Association, May 3–4, Portland, OR.

Milota, MR. 2005. Model use at Oregon State University Lumber Drying Workshop, December.

Milota, MR, and K Li. 2004. Preliminary Work on VOC and HAP Recovery Using Ionic Liquids. in 2004 Paper Summit,

Spring Technical and International Environmental Conference, May 3–6, Atlanta, GA. (Electronic proceedings).

Milota, MR. 2004. Drying hemlock in a research kiln, pp. 24–26 in Proceedings of the Western Dry Kiln Association, May 3–4, Portland, OR.

Murphy, GE. 2005. Enhancing Oregon's global competitiveness through forest engineering. Lematta Professorship Seminar, April, Corvallis, OR.

Murphy, GE. 2005. Maximizing wood value capture at harvest. Oregon Forest Industries, Council Annual Conference, October, Corvallis, OR.

Murphy, GE. 2005. Production speed effects on log-making error rates and value recovery, Forest Products Society Conference, June, Quebec City, Canada.

Murphy, GE, and HD Marshall. 2005. Advanced harvesting technology in the forestry supply chain: Its impact on production economics, World Forestry Center Board of Directors Meeting, May.

Muszyński, L. 2005: Empirical Data for Modeling: Methodological Aspects in Experimentation Involving Hygro-mechanical Characteristics of Wood, 11th Polish Drying Symposium, September 13–16, Poznań, Poland.

Pilkerton, S. 2005. Field trial applications: suggestions for success, Synthetic Rope in Logging: Applications, Research & Developments Conference, December 3, Corvallis, OR.

Pilkerton, S. 2005. Laboratory results of stretch and loading, Synthetic Rope in Logging: Applications, Research & Developments Conference, December 3, Corvallis, OR.

Pilkerton, S. 2005. Synthetic rope properties and use guidelines, Synthetic Rope in Logging: Applications, Research & Developments Conference, December 2, Corvallis, OR.

Pilkerton, S. 2005. Woodard Tree Day, June 11, Cottage Grove, OR.

Renninger, H, B. Gartner, and R Meinzer. 2005. Douglas-fir vs. western hemlock: Is hydraulic architecture a constraint on release from suppression? Proceedings, Annual Meeting of the Ecological Society of America. On CD.

Royer, TA, and AE Skaugset. 2005. Scaling up hydrologic and water quality impacts from individual road segments to a small watershed, 28th Annual Meeting of the Council on Forest Engineering, July 11–14, Fortuna, CA.

Royer, TA and AE Skaugset. 2005. Scaling up hydrologic and water quality impacts from individual road segments to a small watershed. Department of Forest Engineering Seminar, Winter Quarter.

Simmons, AN and AE Skaugset. 2005. The influence of roads on the hydrology of a forested watershed, 28th Annual Meeting of the Council on Forest Engineering, July 11–14, Fortuna, CA.

Toman, E. 2005. Characterizing subgrade behavior under heavy-traffic loads on unbound aggregate roads during wet weather. Project Report for Jerry Yamamura. CE 574, Engineering Properties of Soils.

Toman, EM. 2005. The opportunities to haul timber during wet weather with forest road improvements. 28th Annual Meeting of the Council on Forest Engineering, July 11–14, Fortuna, CA.

Wilson, J. 2005. Determining the Cost of Drying Lumber: the Role Energy Plays in This Cost. How to Dry Lumber for Quality and Profit, December 2005, Corvallis, OR.

Wilson, J. 2005. Energy Use in Plywood Manufacturing: A Big Target for Cost Savings. Plywood Manufacturing, June 05, Corvallis, OR.

Wilson, J. 2005. Leadership in Energy & Environmental Design (LEED) Update. Wood Moulding and Millwork Association, Summer Board Meeting, August 18, Vail, CO.

Wilson, J. 2005. Wood as a Green Building Material: Life Cycle Assessment of Wood Use in Residential Construction. NAHB Green Building Conference, March 15, Atlanta, GA.

Wimer. J. 2005. Use and abuse of synthetic rope, Synthetic Rope in Logging: Applications, Research & Developments Conference, December 3, Corvallis, OR.